

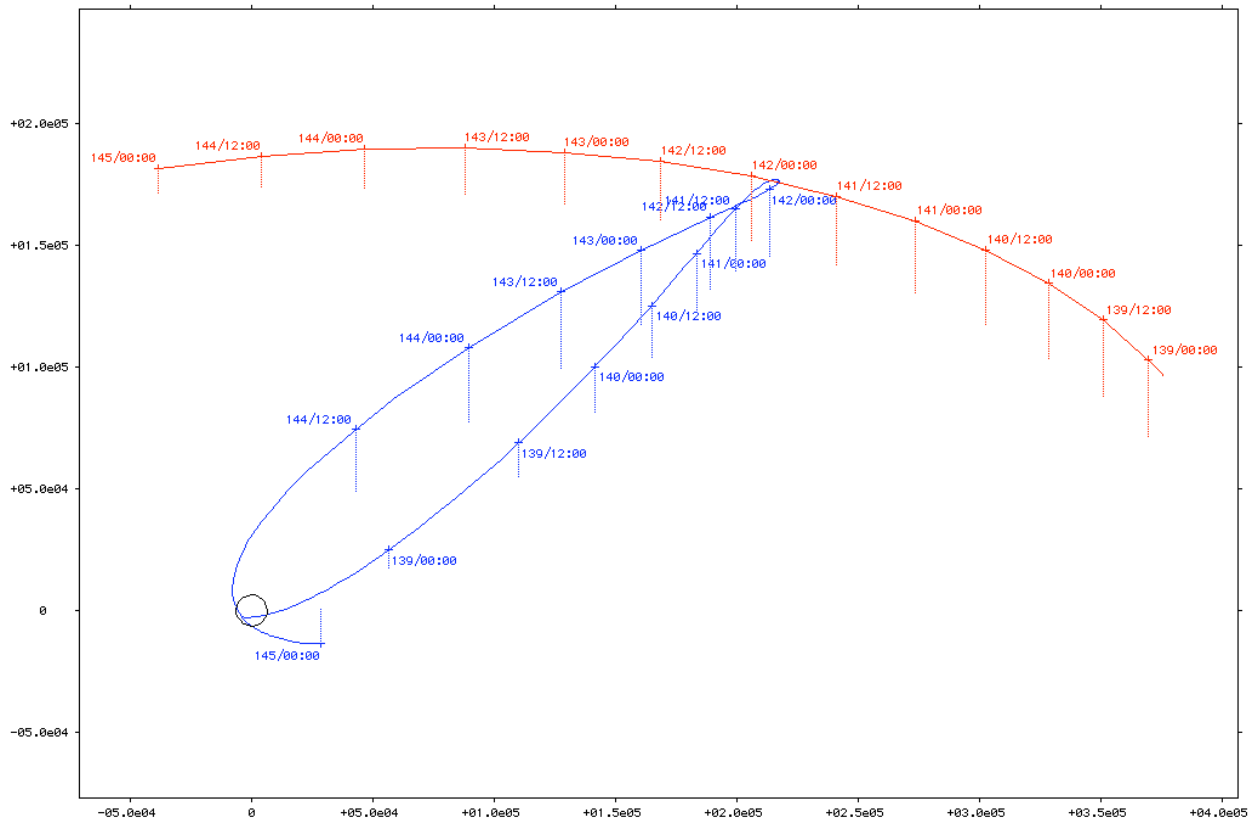
# Flight Dynamics Officer (FDO)

## Console Handbook

### Volume 3

#### On-Orbit Trajectory Operations

**VERIFY CORRECT VERSION IN “PCN HISTORY” BEFORE USE**



National Aeronautics and  
Space Administration

**Lyndon B. Johnson Space Center**  
Houston, Texas

*About the cover diagram:*

An Apollo 10 free-return trajectory reconstruction by WeavEncke ([blue](#)), together with the Moon's orbit ([red](#)), are plotted with respect to the Earth (black). Time ticks are in GMT year 1969 ddd/hh:mm format, and accompanying dotted lines are projections onto the ecliptic plane of epoch J2000.0. Axis units are in km. Initial conditions are inferred from trans-lunar tracking local batch solution MADX232 at epoch 140/13:39:00.7 GMT.

# FDO Console Handbook Volume 3 Rev A

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## FDO Console Handbook Volume 3 PCN History

<u>PCN #</u>	<u>Date</u>	<u>Change Summary</u>
90-1	2-16-90	Rewrite uplink procedures; update CG Shift table
90-2	6-7-90	Correct Section 3.8 pagination error
90-3	11-29-90	Add Section 3.9.4; rewrite Section 3.6
91-1	5-24-91	Rewrite uplink procedures; add OTREL documentation
92-1	1-17-92	Rewrite Sections 3.1 and 3.11; add Appendices 3.A and 3.B
92-2	4-20-92	Rewrite Section 3.5; modify Section 3.11 & Appendix 3.A
93-1	3-18-93	Rewrite Section 3.6; modify Appendices 3.A and 3.B; add Appendix C
93-2	8-19-93	Update Sections 3.5 and 3.6; update Appendix 3.A
94-1	3-16-94	Rewrite Section 3.12; modify Sections 3.5 and 3.6; modify Appendices 3.A and 3.C; replace Appendix 3.B; add Appendix 3.D
94-2	4-5-94	Update page 6-62 CAUTION paragraph
94-3	4-13-94	Rewrite Section 3.3; modify Sections 3.5 and 3.6; modify Appendix 3.A
94-4	8-10-94	Modify Section 3.3; modify Appendix 3.A
95-1	5-16-95	Modify Table 3.6.11.2-4 after OV-102/5 ROMS pod swap
96-1	3-15-96	Modify Section 3.11
96-2	5-3-96	Rewrite Section 3.4; modify Section 3.6; modify Appendix 3.A; add Appendices 3.E and 3.F
96-3	6-3-96	Rewrite Section 3.2; modify Sections 3.3 and 3.6; modify Appendix 3.A; add Appendix 3.G
96-4	7-10-96	Modify Section 3.11; modify Appendix 3.A; modify Appendix 3.C; add Appendix 3.H
96-5	11-4-96	Modify Sections 3.3, 3.6, and 3.12; modify Appendices 3.A and 3.C; add Appendix 3.I
96-6	12-18-96	Modify Sections 3.7 and 3.12; modify Appendix 3.I
97-1	9-19-97	Modify Sections 3.3, 3.5, 3.6, and 3.12; modify Appendices 3.A and 3.I; add Appendices 3.J and 3.K
97-2	11-14-97	Modify Section 3.7.6; modify Appendix 3.J
98-1	1-20-98	Modify Sections 3.3, 3.4, 3.6, and 3.12; modify Appendix 3.A; add Appendices 3.L and 3.M
98-2	6-1-98	Rewrite Section 3.6; modify Appendices 3.A and 3.I
98-3	10-25-98	Modify Sections 3.2, 3.5, 3.6, 3.7.6, and 3.12; modify Appendix 3.A
99-1	7-13-99	Rewrite Section 3.8; modify Section 3.1 and Appendix 3.A
99-2	11-16-99	Modify Sections 3.2, 3.3, 3.8, 3.11, and 3.12; modify Appendices 3.A, 3.I, and 3.J
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02-2	3-27-02	Modify Sections 3.6 and 3.12
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## FDO Console Handbook Volume 3 PCN History

<u>PCN #</u>	<u>Date</u>	<u>Change Summary</u>
Rev A.....	11-1-03 .....	Rewrite of all sections and appendices for TrS compatibility; retire Appendices 3.E, 3.H, and 3.K; add Volume 3a FOUO Annex
05-1 .....	3-15-05 .....	Rewrite all sections (except 3.1 and 3.8) and modify Appendix 3.A for STS-114 RTF-mandatory CRs; migrate additional Section 3.11 FOUO material to Volume 3a
05-2 .....	4-14-05 .....	Modify Sections 3.2, 3.4, 3.10, and 3.11
05-3 .....	6-15-05 .....	Modify Sections 3.2, 3.7, 3.10, 3.11, 3.12, and Appendix 3.A
05-4 .....	10-18-05 .....	Modify Sections 3.3, 3.7, 3.9, 3.10, 3.11, and 3.12
06-1 .....	3-3-06.....	Revive Appendices 3.E, 3.H, and 3.K; modify Sections 3.4, 3.5, 3.7, 3.9, 3.10, 3.11, and 3.12; modify Appendices 3.A and 3.I.
06-2 .....	8-25-06 .....	Modify Sections 3.5, 3.10, 3.11, and 3.12; modify Appendix 3.I.
07-1 .....	3-1-07.....	Add Appendix 3.N; modify Sections 3.6, 3.9, 3.10, 3.11, and 3.12; modify Appendices 3.A, 3.E, and 3.K.
07-2 .....	5-15-07 .....	Modify Sections 3.1, 3.3, and 3.10.

**PCN History Concludes On This Page**

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## FDO Console Handbook Section 3.1: Orbit Introduction

### 3.1 Introduction

This Volume 3 of the *Flight Dynamics Officer Console Handbook* explains duties and responsibilities of the orbit Flight Dynamics Officer (FDO), the Trajectory Officer (TRAJ), and some support positions. Console operating procedures and trajectory processors are related with enough background for trainees, while leaving essential information easily accessible to experienced personnel.

Where appropriate, certain paragraphs in this volume begin with an underlined notice conveying the level of criticality associated with the topic under discussion. Paragraphs commencing with "NOTE:" contain informative topics contributing to efficient console operations but which otherwise have no impact to data integrity or mission success/safety. In paragraphs beginning with "CAUTION:", topics governing data integrity are discussed, but compromising these data will not immediately impact mission success/safety. Topics directly affecting mission success/safety are discussed in paragraphs commencing with a "WARNING:" notice.

Throughout this volume, reference is made to DYNAMICS (sometimes abbreviated as "DYN" or "DY"), TAO, and NAVIGATION (sometimes abbreviated as "NAV") personnel. Beginning with STS-121/ULF1.1 in 2006, these three flight control disciplines were merged into NAV during routine orbit trajectory operations (TAO remains a distinct discipline only during critical day-of-rendezvous operations). Consequently, "DYNAMICS", "DYN", "DY", or "TAO" should be interpreted as "another NAV" whenever encountered in a Volume 3 orbit context except when mission-critical TAO duties are referenced.

NOTE: although only one NAV typically communicates with FDO and TRAJ via the NAV SUPPORT loop during routine orbit operations, multiple personnel are actually assigned to this discipline on any shift. If heavy workload is encountered, parallel communications with NAV personnel dedicated to specific tasks can be coordinated on the SDP DYN loop. During critical operations, TAO communications are also conducted via SDP DYN.

This handbook is unique in that many procedures and techniques, much background information, and even rules of thumb, are formally documented. This will enable Flight Dynamics personnel to achieve higher levels of proficiency more quickly than before. In addition, the base of knowledge common to all trajectory personnel will be elevated.

Some unclassified Volume 3 information, to which United States Strategic Command (USSTRATCOM) capabilities are sensitive, have been migrated into a "For Operational Use Only" (FOUO) annex called Volume 3a. Access to Volume 3a is restricted to FDO Console personnel and their technical management. Specific references to FOUO material in Volume 3a are confined to Section 3.11, USSTRATCOM.

Proposed changes and additions to this volume are submitted and tracked through a Change Request (CR) process (see Appendix 3.J). Status of any CR may be obtained from a spreadsheet at the following location on the JSC-MOD-FS3 server.

S:\Divisions\DM\Private\DM32\DOCS\FDOCHB\CRstat.xls

## **FDO Console Handbook Section 3.1: Orbit Introduction**

**Section 3.1 Concludes On This Page**

## FDO Console Handbook Section 3.2: Simulation Initialization

### 3.2 Simulation (Sim) Initialization

Most generic and flight-specific flight control team training is performed in a mode called integrated simulation. A sim is termed "integrated" when both the Mission Control Center (MCC) and the Shuttle Mission Simulator (SMS)<sup>1</sup> are coordinated to experience the same flow of real time events. Certain sims, such as those during Planning shifts with the crew asleep, can be run in MCC stand-alone mode. Others can be run in SMS stand-alone mode to provide supplemental flight crew training or cockpit procedures validation. Some flight-specific sims involve participants at facilities remote from JSC and are called Joint Integrated Simulations (JISs). Still another integrated sim configuration is the combined or dual sim in which both the Shuttle and International Space Station (ISS) flight control teams (FCTs) participate. In this case, simulated events between the SMS and Shuttle FCT are routed in parallel with those flowing between the ISS FCT and Space Station Training Facility (SSTF). This section will specifically address integrated sim initialization. MCC stand-alone sim initialization only requires a subset of the topics covered here. Any additional effort pertaining to JIS initialization tends to be flight-specific in nature and is beyond the scope of this FDO Console Handbook volume.

**NOTE:** some of the material presented in this section is also applicable to MCC initialization during a real mission. Section 3.2.4.1 documents actions required to recover from a Trajectory Server (TrS) turnaround and is equally pertinent to missions and sims.

**NOTE:** this section also contains general workstation problem reporting procedures. These include the process whereby anomaly reports (ARs) are produced and submitted.

Prior to start of an orbit sim, FDO must perform a variety of trajectory data reconfiguration tasks essential to sim integrity and fidelity throughout the MCC and SMS. The orbit sim initialization ops concept calls for picking up a mission's timeline at some intermediate point as though all previous countdown, ascent, and orbit events had already transpired. Depending on sim training objectives, previous events may have been nominal or dispersed to varying degrees. The Simulation Supervisor (SIM SUP) and affected FCT disciplines typically brief all anomalous initial conditions immediately before the sim begins.

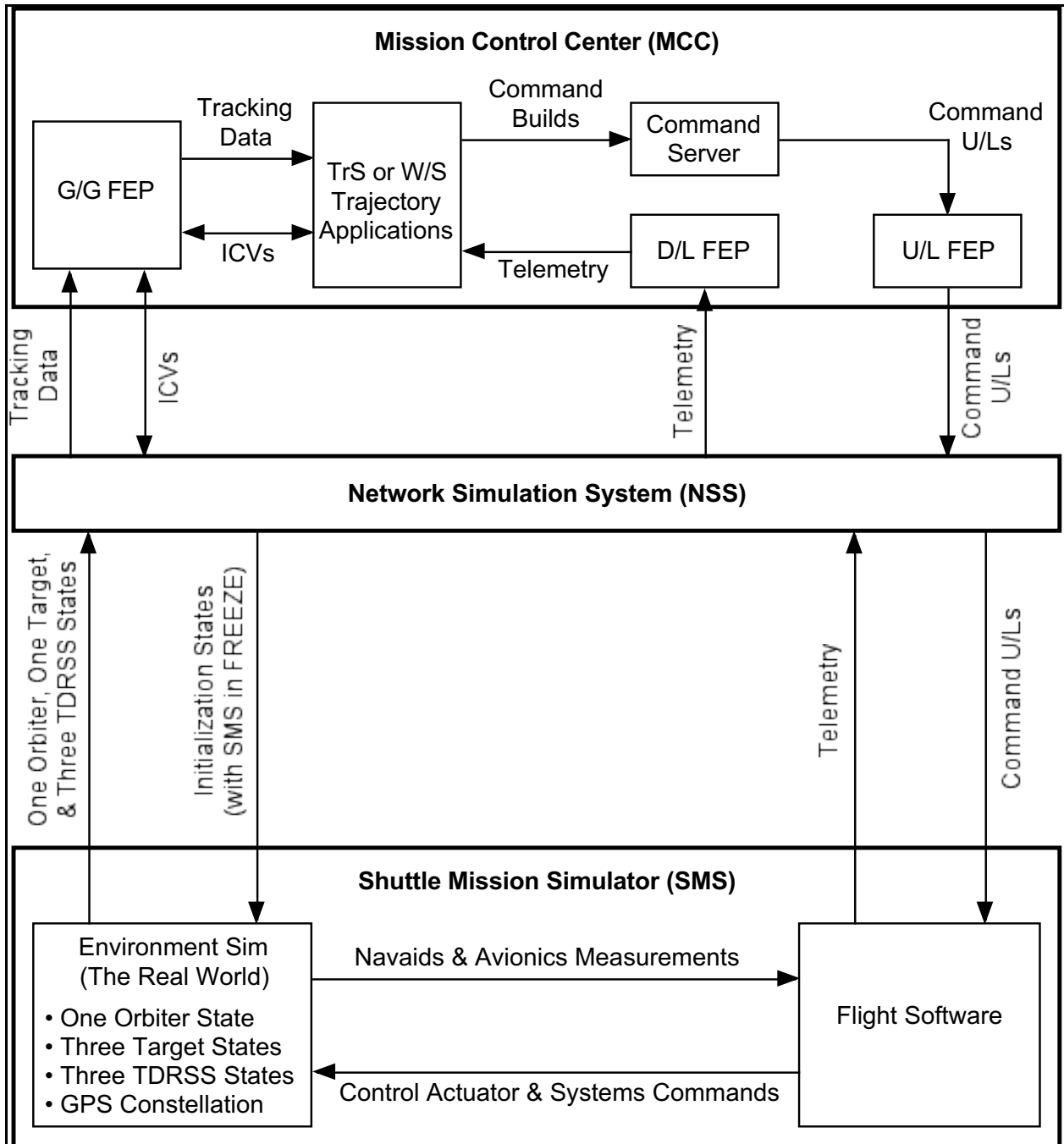
#### 3.2.1 Sim Architecture

To effectively manage sim initialization processes, FDOs must understand the MCC/SMS as a system, together with associated data interfaces. This understanding is also required to correctly evaluate ground and onboard navigation performance, to troubleshoot MCC/SMS trajectory anomalies, and to recover from an MCC or SMS system crash. Figure 3.2.1-1 introduces elements of MCC/SMS system architecture.

---

<sup>1</sup> Building 5/35 locales in which the SMS operates are collectively called the Shuttle Mission Training Facility (SMTF). Because SMS locale is essentially transparent to FDO operations, SMTF will be referenced only infrequently herein. Training Division personnel will refer to SMTF as the Shuttle counterpart of the Space Station Training Facility (SSTF).

## FDO Console Handbook Section 3.2: Simulation Initialization



**Figure 3.2.1-1: Integrated Sim Architecture and Data Interfaces**

During an integrated sim, MCC's Ground-to-Ground Front-End Processor (G/G FEP), Downlink Front-End Processor (D/L FEP), and Uplink Front-End Processor (U/L FEP) exchange data with the "outside world" just as they would during a real mission. The only difference is these data are routed via the NSS during a sim in lieu of the NASA Communications (NASCOM) network's support during a real mission. In fact, there is only one data interface shown in Figure 3.2.1-1 without a real mission analog. FDO depends heavily on initialization states shipped from NSS to the SMS Environment for integrated sim trajectory coordination, but no such interface exists during a mission. Because of time

## FDO Console Handbook Section 3.2: Simulation Initialization

homogeneity requirements, initialization states can be shipped to the Environment only when SMS is in FREEZE mode (the flow of real time events is "on hold").

Other than minor reformatting and network acquisition logic, telemetry and command U/Ls flow freely between FEPs and Flight Software with comparatively little NSS involvement. At SIM SUP direction, these data can even be "forced" through the NSS during simulated loss of signal (LOS) periods. In contrast, the NSS plays a substantial role in converting non-time-homogeneous state vectors received from the SMS Environment into correlated tracking data shipped to the G/G FEP. Per the sim script, NSS operators can add noise or sensor bias effects to the output tracking data. Although it may be possible to track multiple target satellites simultaneously during a real mission, the NSS can only provide simulated tracking data for one of the three SMS Environment target trajectories at any point in time. It is possible to select different targets for tracking during the course of a simulation, however.

Because the NSS functions much like a tracking station would during a real mission, it can exchange Inter-Center Vectors (ICVs) with the G/G FEP. An ICV from the NSS can be built from any SMS Environment state vector. Environment-driven ICVs can be generated at the NSS with the SMS in FREEZE or RUN. Consequently, they can be used to verify MCC/SMS trajectory coordination independent of tracking data at any time during an integrated sim or before the sim even starts.

**CAUTION:** use of ICVs to status the SMS Environment following sim start may compromise training objectives. This action should only be taken with concurrence from the appropriate Training Division personnel, usually GNC Monitor or Rendezvous Monitor. Typically, direct SMS Environment status is sought only when tracking or other sim trajectory data are suspect or degraded in some way not under Training Division control.

The SMS Environment uses a reconfigured real world Global Positioning System (GPS) almanac to simulate satellite motion for the entire catalog. Although this almanac may be several years old with respect to the sim timeframe, its fidelity is more than adequate for training purposes. An error model degrades simulated GPS receiver accuracy in an attempt to mimic real world performance achieved by Shuttle avionics.

SMS Flight Software consists of production PASS and BFS code running on actual GPC hardware. Flight Software "sees" the Real World through a real time feedback loop running at 25 hz with the Environment Sim. To appreciate what this loop accomplishes, consider a routine Universal Pointing maneuver about to reach its target attitude. True attitude and body axis rates integrated by the Environment's Equations of Motion (EOM) are passed to the IMU model, where realistic measurement errors are introduced. The IMU measurements are then fed through simulated avionics data channels to Flight Software. A current attitude within the targeted deadband is detected, and RCS jet firing commands are issued to null rates reported by the IMUs. Commands traverse other simulated avionics data channels back to the Environment's RCS model, where corresponding forces and moments are computed. These are fed to EOM and integrated, closing the feedback loop.

### 3.2.2 Sim Reconfiguration

Coordination of an integrated sim trajectory between the MCC and SMS typically starts with computer software loads built at each facility. Although a distinction is made between generic and flight-specific loads or sims, any load's pedigree is ultimately traceable to some flight-specific data baseline. Overlays are applied to the load's data baseline until the desired sim configuration is achieved. This process often concludes with manual entries and

## FDO Console Handbook Section 3.2: Simulation Initialization

inter-facility data exchanges within minutes of sim start. Additional sim reconfiguration information can be found in the *Lead FDO Handbook*.

**NOTE:** in the following discussion, references to TrS also apply to TSA by default. In cases where TSA differs from TrS, TSA-specific references will be made.

A component of any MCC TrS load is a dataset consisting of flight-independent quantities (such as conversion factors and physical constants) merged with dummy flight-specific inputs (such as a payload bay door open time and an ATL) insuring a fully operational system. In lieu of other sim-specific data, this load-specific baseline is used to bring up the TrS "cold". In parallel with the MCC load build, a flight-specific Flight Design cycle publishes standard trajectory products pertinent to the sim. These products are collected by trajectory disciplines including FDO and reformatted or reprocessed as necessary. Immediately prior to sim start, Flight-Design-dependent data are fed into TrS via manual or electronic processes to overlay the load-specific baseline. The overlaid data are then captured in a checkpoint, usually among the last MCC actions before moding SMS to RUN. Subsequent sims utilizing the same TrS load and Flight Design cycle may be able to invoke an archived checkpoint to significantly reduce pre-sim data overlay actions.

Concurrent with MCC's products, analogous Flight Design data are integrated with various software baselines to produce an SMS load. Each SMS load is delivered with a limited number of "reset points". After a "reset", the SMS is in FREEZE at a specific SGMT and MET with its Environment Sim and Flight Software synchronized and ready for RUN. Although reset points can support integrated sims, they are usually of little direct use to specific training objectives. Typically, Training Division will only use a reset point as the data baseline in a "fly-to" process targeting the desired sim configuration. When this is achieved, the SMS is moded to FREEZE at the proper SGMT/MET and a datastore point is cut and archived. Reset points actually begin their existence as datastore points before an offline quality assurance process converts them. There is no functional difference between a reset and a "return to datastore" on the SMS other than the specific data values configured. Because fly-to procedures are often complex and manual, datastores are usually produced during dedicated SMS stand-alone sessions days in advance of an integrated sim. Following a return to datastore (or reset), SMS memory can be overlaid in FREEZE immediately prior to an integrated sim start. Initialization state vectors can be received from the MCC via the NSS or from local mass storage archives, and an SMS processor called Delta Reset can be invoked to automatically alter entire blocks of memory from archived data.

FDO routinely plays a key part in Training Division's datastore generation process. Suppose a datastore at 1/23:45 MET is required to start an integrated sim. Because some of the associated fly-to process will be performed with the SMS in RUN, Orbiter and target state vectors with which to initialize the SMS Environment will be needed at some point before then. The SMS cannot propagate backward in time, so a liberal estimate of RUN duration is essential to producing a datastore at 1/23:45 MET. Estimating about 40 minutes of RUN time will be necessary, Training Division rounds time conservatively and requests vectors from FDO at 1/23:00 MET. During the fly-to process, here's what happens to FDO's data.

- 1) Reset SMS to a delivered point at 0/01:00 MET.
- 2) Command a STEP AHEAD, targeting FREEZE at 1/23:00 MET.
- 3) Apply FDO's state vectors to the Environment Sim's Orbiter and target state vectors.

## FDO Console Handbook Section 3.2: Simulation Initialization

- 4) Mode to RUN, uplink Environment Orbiter and target state vectors as required, then fly-to the attitude and Orbiter/payload systems configurations required for sim start.
- 5) Mode to FREEZE at 1/23:45 MET, initialize all Environment Sim TDRS state vectors to generic TDR coordinates, and apply Systems Division-supplied consumable quantities to the Environment Sim.

NOTE: to integrate SMS with MCC in real time, NSS requires SMS be moded to RUN at an even GMT minute. When moded to RUN for an integrated sim, SMS must also be within a few ms of an even SGMT minute. In support of these integration requirements, SMS has dedicated "GMT RUN" and "SGMT FREEZE" moding controls to perform the required actions automatically. A GMT RUN will mode SMS to RUN on the first even GMT minute after it's invoked. An SGMT FREEZE will mode SMS to FREEZE on the first even SGMT minute after it's invoked, but it rarely achieves its goal exactly. This is because the FREEZE command must first be issued to Flight Software, allowing for a variable delayed response received before passing the targeted even minute. Only when the Flight Software freeze is confirmed can the rest of SMS actually be frozen. This process typically yields integrated datastore SGMTs with seconds fields like 59.92 or 59.96 (always an even multiple of 0.04 sec due to the 25-hz Flight Software feedback loop). State vector transfers to the SMS Environment must therefore be tagged with the precise SGMT FREEZE epoch to minimize initial downtrack deviations with MCC.

- 6) Capture and archive the integrated sim datastore.

CAUTION: the fly-to process outlined above didn't involve any burn executions, even though burns may have existed in the timeline between 1/23:00 and 1/23:45 MET. Unless corresponding burn PADs are requested by Training Division, FDO should *coast* the Orbiter state backward from 1/23:45 MET, deleting any burns encountered in the nominal trajectory profile. By deleting burns, FDO eliminates the burden of burn execution from Training Division's fly-to timeline. Thanks to closure, the coasted trajectory insures reasonable MCC/SMS Orbiter trajectory coordination independent of burn execution, even if MCC initialization state vectors are never transferred to the Environment Sim.

NOTE: because a TDRS trajectory is essentially geostationary, a time-invariant TDR state vector is used to initialize both the Environment Sim and MCC (reference NASA-JSC letter DM4-93-75). For each TDRS station longitude to be simulated, a single generic TDR state is documented by Orbit FDOs to be used by the Simulation Community at any sim start time. Consequently, FDO should never need to supply Training Division a TDRS state vector unless it initializes a trajectory at a new station longitude. As of October 2000, TDR geostationary states reflecting GSFC's recently abandoned inclination stationkeeping strategy had been coordinated with the Simulation Community at longitudes 174° W, 171° W, 150° W, 49° W, 47° W, 41° W, and 85° E. Of these satellites, the one at 49° W is rarely used by the Shuttle program. It should normally be excluded from sim processing, particularly by PSAT.

## FDO Console Handbook Section 3.2: Simulation Initialization

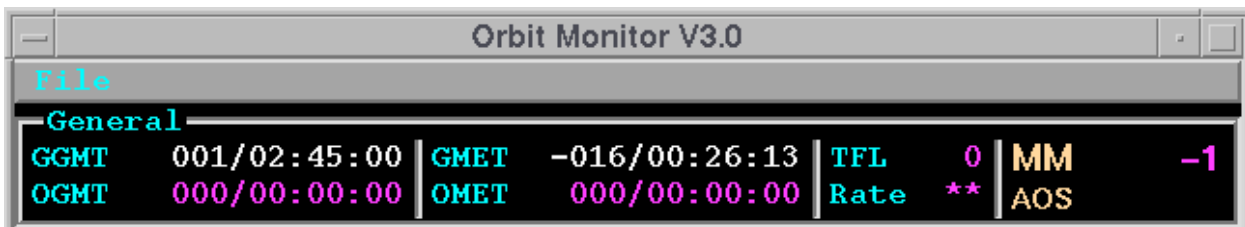
### 3.2.3 Sim Start

In this section, "sim start" is defined to be the period from FDO's console arrival time until FD and SIM SUP pronounce the sim is "GO for normal ops". Typically, FDO arrives on console about an hour in local time prior to the scheduled sim start. If all goes well, SMS is moded to RUN by the scheduled sim start, and normal ops will begin 5 to 10 min later.

At arrival time, FDO will normally find TrS clear for inputs following restoration of the load's data baseline or a previously archived checkpoint. In either case, DYNAMICS will also have generated TrS inputs according to the Sim Initialization Checklist by the time FDO arrives. This checklist can be downloaded from the FDO Home Page. The assigned FDO fills it out and submits it to the DYNAMICS Console at least two hrs before sim start and typically a day or so in advance. If a current TrS SGMT is displayed prior to sim start, it will probably equate to an early January date in the sim year skewed weeks or months before the scheduled sim start SGMT. This laggard timekeeping insures events that may happen to transpire or "execute" before sim start are well in the past with respect to the sim's timeline. Although TrS can step ahead or back in SGMT virtually instantaneously, stepping back in time cannot reset an executed event. Although it may be easy to cope with some inadvertently executed events such as burns, an executed launch event cannot be reset without restoring the load's data baseline or an existing checkpoint. Because such actions may incur substantial sim start delays, early January timekeeping is used to eliminate the possibility of stepping *back* to sim start. After the SMS is moded to RUN, TAO will verify successful integration with MCC, then step TrS ahead to the SMS SGMT.

**NOTE:** both commands and telemetry will normally flow between the MCC and SMS shortly after SMS modes to RUN, even before TrS is stepped ahead. Other real time processes, notably the 2-D DEMOS "world map" application, will not synchronize with the sim until TrS is stepped ahead.

**CAUTION:** because current TrS time lags the sim's by many days prior to step ahead, any current-time-dependent TrS displays will be invalid before then. For example, the Orbit Monitor's General GGMT and GMET displays are well before the sim time frame prior to TrS step ahead (see Figure 3.2.3-1).



The screenshot shows a window titled "Orbit Monitor V3.0" with a menu bar containing "File". Below the menu bar is a "General" section with a table of time-related data. The table has two rows and four columns. The first row shows GGMT (001/02:45:00), GMET (-016/00:26:13), TFL (0), and MM (-1). The second row shows OGMT (000/00:00:00), OMET (000/00:00:00), Rate (\*\*), and AOS.

General							
GGMT	001/02:45:00	GMET	-016/00:26:13	TFL	0	MM	-1
OGMT	000/00:00:00	OMET	000/00:00:00	Rate	**	AOS	

Figure 3.2.3-1: Orbit Monitor Time Skews Prior to Sim Start

The following generic checklist illustrates a typical sim start sequence of events. In scanning this sequence, be aware that the chronology of events is not necessarily optimum with respect to a particular sim. For example, one day it may be more efficient to perform state vector exchanges with the SMS before taking a TrS checkpoint, while the next day it may be more efficient to do so afterward. Steps in the checklist essential to FDO's "GO for normal ops" call are accompanied by a sequence number which is appended by an asterisk "\*\*".

**CAUTION:** asterisked mandatory events in the following procedure comprise the bare minimum FDO readiness for sim start. In this context, any data integrity checks capable of



## FDO Console Handbook Section 3.2: Simulation Initialization

postponement beyond sim start are considered optional, and the SMS Environment and Flight Software are assumed acceptably configured. Under extreme conditions, sim start can even occur with unconfigured MCC ephemerides. Any MCC ephemeris can be anchored off an ICV gathered from the SMS Environment, again assuming this source is properly configured. Under these conditions, FDO will be able to do little more than monitor Flight Software navigation status initially following sim start, and the pre-sim checkpoint should be supplemented with another once postponed sim start procedures are completed.

**NOTE:** a shorthand ephemeris naming convention is used in the following steps and throughout this volume in which the ephemeris number "n" is prefixed as detailed below.

"En",  $\leq 1 \leq 10$ , denotes a TrS-resident ephemeris

"Mn",  $\leq 1 \leq 10$ , denotes a TrS-resident ephemeris mirror in the TSA Global database

"Gn",  $\leq 1 \leq 8$ , denotes a TSA-TUPable ephemeris in the TSA Global database

"Ln",  $\leq 1 \leq 8$ , denotes a TSA-TUPable ephemeris in the TSA Local database

"R" denotes the prime entry ephemeris EDS mirror in the TSA Global database

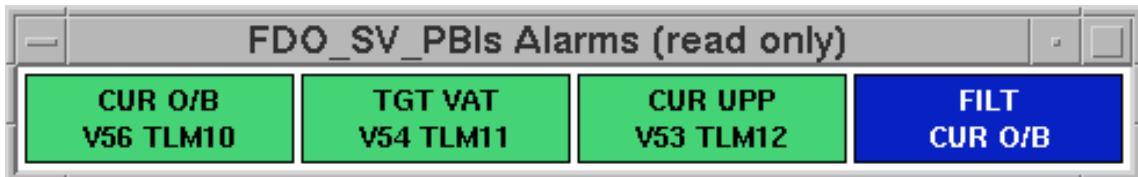
**NOTE:** a TDRS-specific TSA-TUPable ephemeris naming convention of the form "aLLLb" is also used throughout this volume as detailed below.

"a" is any uppercase letter (A through Z), with T used by default unless ambiguities would otherwise arise due to simultaneous use of co-stationed satellites

"LLL" is an unsigned integer value with leading zeros corresponding to longitude of the ascending node (LAN) magnitude

"a" is either "E" or "W" to place LAN in the correct geographic hemisphere

- 1\*) Initiate workstation logon with userid, password, and activity inputs.
- 2\*) Signon to DVIS and verify TrS status is "up and clear" with DYNAMICS.
- 3\*) Configure State Vector PBIs as illustrated by Figure 3.2.3-2.



**Figure 3.2.3-2: State Vector PBIs Configured for Orbit Sims**

**CAUTION:** the Figure 3.2.3-3 PBIs are critical to ONAV assessments, particularly during rendezvous. When these PBIs are properly configured, close or iconify their window. This action prevents inadvertent mouse clicks from selecting undesired ONAV state vectors from the telemetry stream.

- 4) Initialize Local TSA with an "Initialize Local Trajectory(P80)" menu selection, then invoke Orbit FDO and MOC Processors 1/2 DDDs.
- 5) Verify Orbiter and Target ephemeris anchors in Checkout Monitor.
- 6) Check GNAV TRAJ INIT's JACCHIA VALUES (see Figure 3.2.3-3) versus F10 and KP in the FDO Data Book's Payload Data section. In lieu of NAV, DYNAMICS can update these values. Verify with Trench Monitor these values are present in the SMS Environment. Coordinate F10 and KP

## FDO Console Handbook Section 3.2: Simulation Initialization

values in TSA Solar Flux tables by bracketing the sim time frame with Data Book values.

**CAUTION:** changes to Jacchia values may critically influence trajectory modeling. Insure any such changes are performed and TUPed into the pertinent ephemerides before initiating state vector transfers to the SMS Environment.

```
TRAJINT:(TRAJINT): GNAV TRAJ INIT
114                                GNAV TRAJ INIT                                C
GMT: 001:02:51:17                  MET: -16:00:19:56

LIFTOFF
017:03:11:13.000

P80 INIT DATE                      MISSION TIMES TABLE
2003 01 01                          YEAR    2003

BASE JULIAN DATE                   JACCHIA VALUES
2452639.5                           F10.7   131.00
OGMT                               KP       2.95
000:00:09:28S                     ET - UTC CONSTANT
SUN/MOON TABLE                    64.18
2002 12 24                          UT1 - UTC
2004 02 05                          0.00000

ONBOARD RNP
YEAR 2003      GPS/GMT TIME ADJUST      0.0  secs
DAY 30        LEAP SEC.CORRECTION 13    secs
              GPS OFFSET DAYS 8396    days

 XMIT           Hide  Undo  Quit
```

Figure 3.2.3-3: GNAV TRAJ INIT

**NOTE:** TSA Solar Flux tables support linear interpolations at ~90-day intervals within the table. Prior to the table, the first two table values are extrapolated. After the table, the last two table values are extrapolated. See Figure 3.2.3-4.

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Jacchia Solar Flux Update v5.0.4								
GLOBAL		SSP		JACCHIA TABLE				CURRENT
YEAR	DAY	F10.7	Kp	YEAR	DAY	F10.7	Kp	
1998	62	104.70	2.39	2003	62	160.50	2.92	
1998	153	115.50	2.65	2003	153	131.00	2.95	
1998	245	127.78	2.78	2003	245	131.00	2.95	
1998	336	132.64	2.68	2003	336	131.00	2.95	
1999	62	145.50	2.57	2004	62	101.10	3.21	
1999	153	152.30	2.64	2004	153	97.80	3.19	
1999	245	158.15	2.72	2004	245	93.25	3.21	
1999	336	172.45	2.76	2004	336	89.87	3.14	
2000	62	176.70	3.03	2005	62	86.60	3.04	
2000	153	178.90	2.95	2005	153	83.60	3.02	
2000	245	177.85	2.87	2005	245	80.77	2.99	
2000	336	173.53	2.94	2005	336	78.07	3.01	
2001	62	166.90	2.78	2006	62	75.70	3.05	
2001	153	164.90	2.78	2006	153	73.60	3.00	
2001	245	159.65	2.81	2006	245	71.88	2.96	
2001	336	155.23	2.84	2006	336	70.59	2.93	
2002	62	148.20	2.93	2007	62	69.90	2.90	
2002	153	142.10	3.00	2007	153	69.90	2.73	
2002	245	136.35	3.01	2007	245	71.02	2.54	
2002	336	160.50	2.92	2007	336	72.72	2.38	

HELP (F1) EXECUTE (F2) SAVE MENU (F3) EXIT MENU (F4) OVR (F5) HARDCOPY (F5)

Figure 3.2.3-4: TSA Solar Flux Table

NOTE: during a real mission, it may also be necessary to coordinate a non-zero UT1-UTC value in GNAV TRAJ INIT with TSA's System display (see Figure 3.2.3-5). This empirical value is based on GMT day and impacts J2K state vector precision.

sys\_dsp

---

File

---

LOCAL

Reference Time:

UT1 - UTC Time:

---

MSG:

SAVE
QUIT

Figure 3.2.3-5: TSA System Display

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- 7) Check CARGO BAY DOOR STATUS (see Figure 3.2.3-6) for an **OPEN** entry at 0/01:30 MET.

CBDS:(CBDS):						
114	CARGO BAY DOOR STATUS				A	
	used	status	used	status		
EPH1	X		EPH6			
EPH2	X		EPH7	X		
EPH3			EPH8	X		
EPH4			EPH9	X	TUP reqd	
EPH5	X		EPH10	X	TUP reqd	
OPTION	██████████		TIME	██████████		
	GMT	STATUS		MET		
	017:03:11:13.00	CLOS		000:00:00:00.00		
	017:04:41:13.00	OPEN		000:01:30:00.00		

Figure 3.2.3-6: CBDS Initialized for Orbit Sims

- 8) Verify no unexpected entries in ephemeris WGL tables.
- 9) Check ATTITUDE TIMELINE (ATL; see Figure 3.2.3-7) and VENT TIMELINE (see Figure 3.2.3-8).

**NOTE:** POINTING will nominally supply real ATL data for TrS incorporation through DYNAMICS prior to sim start.

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**ATL:(ATL):**

114 **ATTITUDE TIMELINE** A

Time of 1st Entry 017:00:00:00 Display Threshold 017:00:01:00

NO.	COMMENT	TIME		MODE	MATRIX	EIGEN AXIS	RATE	ATTITUDE		
		GMT/MET						ROLL	PITCH	YAW
1	0815RNDZ	017:00:00:00		LVLH		P		0.00	0.00	0.00
		000:03:11:13				Y				
2	OMS-2	017:03:41:13		IH	MIR602			356.00	134.00	293.00
		000:00:30:00								
3	-ZLV +YVV	017:04:31:04		LVLH				0.00	180.00	90.00
		000:01:19:51								
4	OMS3	017:06:11:20		IH	MIR602			246.00	227.00	358.00
		000:03:00:07								
5	LVLH Hold	017:06:26:13		LVLH				179.67	7.18	359.79
		000:03:15:00								
6	NC-1	017:07:01:30		IH	MIR602			114.00	46.00	4.00
		000:03:50:17								
7	-ZLV -XVV	017:07:26:12		LVLH				-0.00	180.00	0.00
		000:04:14:59								
8	NC-2	017:20:41:11		IH	MIR602			118.00	36.00	22.00
		000:17:29:58								
9	-ZLV -XVV	017:21:11:10		LVLH				-0.00	180.00	0.00
		000:17:59:57								
10	-ZLV -XVV	018:00:21:13		LVLH				-0.00	180.00	0.00
		000:21:10:00								
11	NC-3	018:04:21:12		IH	MIR602			121.00	31.00	27.00
		001:01:09:59								
12	-ZLV -XVV	018:04:51:13		LVLH				0.00	180.00	0.00
		001:01:40:00								
13	-ZLV +YVV	018:16:38:43		LVLH				0.00	180.00	90.00
		001:13:27:30								
14	LVLH Hold	018:19:06:13		LVLH				0.00	180.00	90.00
		001:15:55:00								
15	NC-4	018:19:44:25		IH	MIR602			303.00	30.00	24.00
		001:16:33:12								

Quit

Figure 3.2.3-7: ATL Example As Initialized for Orbit Sims

**VTL:(VTL): Vent Timeline**

114 **Vent Timeline** B

GMT: 001:03:01:50 MET: -16:00:09:23

OPTION:  DELTA:

ENTRY	ACT	VENT	START GMT	END GMT
1		APU1	300:00:00:00.000	300:01:00:00.000

Figure 3.2.3-8: VTL Example As Initialized for Orbit Sims

- 10) TUP ephemerides and verify resulting Trajectory Profile Status (TPS) weights, drag profiles, integrator options, STDN options, anchor vector IDs, orbit counters, and time spans.
- 11) Alert DYNAMICS that state vectors can be fetched from TrS ephemerides for transfer to the SMS.
- 12) Check each TSA TDRSS ephemeris. Use Checkout Monitor to verify start vector longitude corresponds to ephemeris name, then use TPS Tier 1 to

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check start/stop times span the sim and M2. After checks are complete, inform INCO that TDRSS Antenna Management state vector commands can be built.

**CAUTION:** with regard to TDRSS ephemeris initialization, recall the difference between state vector *propagation* and state vector *rotation*. To coordinate TDRSS ephemerides with the SMS Environment, it's essential TrS anchors are rotated at epochs within a few seconds of the actual SMS sim start datastore. If the datastore shifts to an SGMT minute different from that scheduled, new TDRSS ephemerides should be built from anchors rotated to that epoch.

**NOTE:** only TSA TDRSS ephemerides are of direct concern to FDO/TRAJ. A parallel set of TrS-resident TDRSS ephemerides supports orbit determination through the Orbiter-to-TDRSS S-band return link. The health of these ephemerides is NAV's responsibility and outside this handbook's scope.

- 13\*) Bring up the AutoMC UIF and insure the following PSAT configurations are specified. The M3 configuration assumes an ISS rendezvous is in progress. Nominally, no M3 acquisitions are required post-docking/grapple.
- M1: STDN=ON Nets=A/B/C/D/P/S/T(eph)
  - M2: STDN=OFF Nets=B/C/D/P/S/T(eph)
  - M3: STDN=ON Nets=C/R/S/T(eph)
  - R: STDN=ON Nets=E/N/S/T(eph)
- Start AutoMC VAT and ephemeris mirrors as required. When mirroring status is GOOD, inform DFE that acquisitions data are current (this should be done by sim start -20 min).

**NOTE:** disable M2 mirroring after sim start planning is complete. Further E2 TUPs during the sim aren't required unless a significant long-term impact to this planning is encountered and it cannot be covered by E1/M1.

- 14\*) Start DV Sensor.
- 15) Start Command Manager and build state vector command loads as required, fetching ~5 min after scheduled sim start.
- 16) If day-of-rendezvous, develop and transfer burn plans with MARS, create PET and DOCK clocks, check RMM ILOADs, and verify preliminary PADs/nominal TIGs Flight Note are distributed to crew/FD/CAPCOM/FAO/PROP/GNC/RENDEZVOUS. Also verify 1-rev-late TIGs Flight Note is prepared.
- 17) Check mass properties versus the "Orbit" baseline in the FDO Data Book's Mass Properties section. Verify the ECT configuration in TrS and TSA.
- 18) Request runway/lakebed status and WX sheet from GNC Monitor, input winds to QuAC as required, then annotate and distribute WX sheet to FD and CAPCOM.
- 19) Determine next PLS (> 4 hours after sim start) from FDO Data Book's ConUS DOPS section.
- 20) Check DEORBIT CONSTRAINTS TABLE (DCT; see Figures 3.2.3-9a through c) parameters in Columns 1 through 6.

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GLOBAL	SSP	DEORBIT CONSTRAINTS TABLE		CURRENT
DEORBIT	COL 1	DEORBIT	COL 2	
TDOOR (1)	02:40 (HH:MM)	TDOOR (1)	02:40 (HH:MM)	
THR-PR/BU (2)	OBP / (3) OL	THR-PR/BU (2)	OL / (3) OL	
TRIMS (4)	SYSP	TRIMS (4)	SYSP	
PROPUSAGE (5)	IPLANE	PROPUSAGE (5)	IPLANE	
GUIDMODE (6)	PEG4	GUIDMODE (6)	PEG4	
TVROLL (7)	180	TVROLL (7)	180	
C1 (8) 0	C2 (9) 0	C1 (8) 0	C2 (9) 0	
REI (10) 0	TFF (11) 09:00	REI (10) 0	TFF (11) 09:00	
POSTBURN		POSTBURN		
	MM303		MM303	
DT (12)	02:00	DT (12)	02:00	
ALPHA (14)	40.0	ALPHA (14)	40.0	
BETA (16)	0	BETA (16)	0	
PHI (18)	0	PHI (18)	0	
ENTRY		ENTRY		
NCYCLE (20)	8	D23C (21)	28.6	
ELEVON SCHEDULE		(22)	-3	
ATMOS (23)	AT5	ATMOS (23)	AT5	
VR (24)	0	VR (24)	0	
			APPR	
PLSID (25)	EDW22	(26)	OVHD	
RLSID (27)	EDW04	(28)	OVHD	

**Figure 3.2.3-9a: Example DCT Configuration In Columns 1 & 2**

GLOBAL	SSP	DEORBIT CONSTRAINTS TABLE		CURRENT
DEORBIT	COL 3	DEORBIT	COL 4	
TDOOR (1)	02:40 (HH:MM)	TDOOR (1)	02:40 (HH:MM)	
THR-PR/BU (2)	OBP / (3) OL	THR-PR/BU (2)	OBP / (3) OL	
TRIMS (4)	SYSP	TRIMS (4)	SYSP	
PROPUSAGE (5)	IPLANE	PROPUSAGE (5)	IPLANE	
GUIDMODE (6)	PEG4	GUIDMODE (6)	PEG4	
TVROLL (7)	180	TVROLL (7)	180	
C1 (8) 0	C2 (9) 0	C1 (8) 0	C2 (9) 0	
REI (10) 0	TFF (11) 09:00	REI (10) 0	TFF (11) 09:00	
POSTBURN		POSTBURN		
	MM303		MM303	
DT (12)	02:00	DT (12)	02:00	
ALPHA (14)	40.0	ALPHA (14)	40.0	
BETA (16)	0	BETA (16)	0	
PHI (18)	0	PHI (18)	0	
ENTRY		ENTRY		
NCYCLE (20)	8	D23C (21)	28.6	
ELEVON SCHEDULE		(22)	-3	
ATMOS (23)	AT5	ATMOS (23)	AT5	
VR (24)	0	VR (24)	0	
			APPR	
PLSID (25)	EDW22	(26)	OVHD	
RLSID (27)	EDW04	(28)	OVHD	

**Figure 3.2.3-9b: Example DCT Configuration In Columns 3 & 4**

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GLOBAL	SSP	DEORBIT CONSTRAINTS TABLE				CURRENT
		COL 5		COL 6		
DEORBIT				DEORBIT		
TDOOR (1)	02:40 (HH:MM)			TDOOR (1)	02:40 (HH:MM)	
THR-PR/BU	(2) OL / (3) OL			THR-PR/BU	(2) OBP / (3) OL	
TRIMS (4)	SYSP			TRIMS (4)	SYSP	
PROPUSAGE (5)	IPLANE			PROPUSAGE (5)	IPLANE	
GUIDMODE (6)	PEG4			GUIDMODE (6)	PEG4	
TVROLL (7)	180			TVROLL (7)	180	
C1 (8) 0	C2 (9) 0			C1 (8) 0	C2 (9) 0	
REI (10) 0	TFF (11) 09:00			REI (10) 0	TFF (11) 09:00	
POSTBURN				POSTBURN		
	MM303	MM304			MM303	MM304
DT (12)	02:00	(13) 05:00			DT (12)	02:00 (13) 05:00
ALPHA (14)	40.0	(15) 40.0			ALPHA (14)	40.0 (15) 40.0
BETA (16)	0	(17) 0			BETA (16)	0 (17) 0
PHI (18)	0	(19) 0			PHI (18)	0 (19) -90
ENTRY				ENTRY		
NCYCLE (20)	8	D23C (21)	28.6	NCYCLE (20)	8	D23C (21) 28.6
ELEVON SCHEDULE		(22)	-3	ELEVON SCHEDULE		(22) -3
ATMOS (23)	AT5			ATMOS (23)	AT5	
VR (24)	0			VR (24)	0	
		APPR				APPR
PLSID (25)	KSC15	(26) OVHD			PLSID (25)	KSC15 (26) OVHD
RLSID (27)	KSC33	(28) OVHD			RLSID (27)	KSC33 (28) OVHD

**Figure 3.2.3-9c: Example DCT Configuration In Columns 5 & 6**

- 21) Obtain current SMS state vector transfer status from NAV. If all has gone well, the following actions will have been verified.
  - a) Orbiter and target (if required) states have been incorporated into the SMS Environment.
  - b) NSS has collected Orbiter, target (if required), and TDRSS state vectors from the SMS Environment and transferred them as ICVs to MCC, where they now reside in VAT slots.
  - c) NAV has performed a Vector Compare run for the Orbiter and any target vehicle(s), obtaining acceptably small deviations between MCC and SMS (SMS TDRSS states are verified by NAV in the TDRSS VECTOR DETAILS display). Each run typically places the vehicle's TrS ephemeris vector at sim start in the Base and the corresponding vector received from the SMS Environment in Column 1.

Figure 3.2.3-10 provides an acceptable sim start MCC/SMS Vector Compare example for an ISS target.



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VC1:(VC1): VECTOR COMPARE				
114	Vector Compare 1			C
GMT:001:02:53:18		MET:-16:00:17:55		
LINK/EPH: P3	INTEG:	REF: M50	UNITS: FS	
OPTION: TIME	VALUE: 018:17:41:59.800	THRESH TIME: 018:17:41:59.800		
OUTPUT GMT: 018:17:41:59.800	OUTPUT MET: 001:14:30:46.800			
TIME NAME	018:17:41:59.800	018:17:11:13	EPH	EPH
	MISC 007 EPHE3	ISS 026 EPHE3		
X	-17351489.501	2.144		
Y	-6690685.696	2.640		
Z	12042670.604	-2.683		
$\dot{X}$	-2018.2775591	0.001016		
$\dot{Y}$	-20659.4750656	0.000095		
$\dot{Z}$	-14316.9061680	0.002160		
A	22173378.8	-10		
E	0.0016945053	-0.00000016		
I	51.637564	-0.0000		
w	74.880826	-0.0082		
$\lambda^{an}$	14.433615	0.0000		
u	61.639772	0.0082		
U	22155482	-4		
V	0	-1		
W	-0	-2		
$\dot{U}$	37.570	0.000		
$\dot{V}$	25216.260	-0.001		
$\dot{W}$	-0.000	0.002		
$\phi$	32.817108	-0.00000		
$\lambda$	178.478420	-0.00001		
H <sub>o</sub>	205.7611	-0.0006		
H <sub>a</sub>	210.7999	-0.0022		
H <sub>p</sub>	198.8769	-0.0012		
VECTORS: ██████████ ██████████ ██████████ ██████████				
STOP AT: ████████ OF ██████████ THRESH TIME: ██████████				
LINK/EPH: ████████ INTEG: ████████ REF: ████████ UNITS: ████████				
<input type="checkbox"/> Xmit		<input type="checkbox"/> Undo		
		<input type="checkbox"/> Quit		

**Figure 3.2.3-10: An Acceptable Sim Start SMS Transfer VC**

- 22) Request a "GO for checkpoint" from TRAJ and MPSR controllers making TrS or TSA Global inputs. When all are GO, request TrS and Global checkpoints from TAO.
- 23) Brief FD on state vector transfer status.
- 24\*) Monitor sim initial conditions briefings, SMS mode to RUN, and TrS step ahead proceedings. Support as required.
- 25) Verify forward link with INCO, then uplink required command loads per standard procedures. A typical Orbiter onboard state vector deviation from E1 prior to uplink appears in Figure 3.2.3-11.

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RNDZ_STAT:(RNDZ_STAT): ONAV ORBITAL S			
114 / 104		Rendezvous ONAV Status	
OGMT 018:17:43:34	OMET 001:14:32:21	OI 185	GN 22 SM 24
RGMT 018:17:43:35	SVT 018:17:43:34.349		
MGMT 018:17:43:31	STATE VECTOR	TIME TAGS 0 T	
	GND-PFS 10	GND-TGT 11	ONBD REL
U	-39634	30171841	-28959783
V	-1004297	20649799	-21040831
W	914	37541	-35670
UD	1044.0	-23490.8	23842.5
VD	31.6	34312.5	-33154.6
WD	1.7	-27.6	27.6
		TUDS 018:17:28:34.8	
		TUDT 018:17:14:58.0	
		T_ST 000:00:00:00.0	
		T_C 000:00:00:00.0	
		T_RR 000:00:00:00.0	
		T_E 18:17:43:21.87	

Figure 3.2.3-11: Typical Onboard/MCC SV Deviation Before Uplink

When uplink procedures are concluded and acceptable Orbiter/Ground navigation is verified, FDO is GO for normal ops. Once sim start current quantities are confirmed to be available from PROP, EECOM, EGIL, and MMACS, TRAJ performs a current Orbiter mass properties cycle (see Section 3.6.7.2), and sim start procedures are complete.

### 3.2.4 Sim Recovery

This section addresses two distinctly different sim recovery scenarios. The first deals with MCC recovery procedures, while the second is concerned with SMS recovery. Because the former scenario can occur during a real mission, corresponding MCC recovery procedures have applicability beyond sims. Still other recovery scenarios, arising from data mis-coordination prior to sim start, are discussed at the end of this section.

#### 3.2.4.1 MCC Recovery

With the centralized MCC trajectory capabilities prevailing at this writing, FDO-specific recovery efforts following a power failure or computer anomaly tend to center on TrS (reference Flight Control Operations Handbook [FCOH] SOP 11.4). Although certain useful datasets such as DOPS can be threatened by workstation failures, their recovery tends to be straightforward. The workstation is rebooted, data are retrieved from workstation mass storage or TSA Global, and the compromised datasets are regenerated. Typically, workstation recovery is complete within 30 min without posing any significant impact to other flight controllers. Due to its centralized function, however, TrS recovery can involve protracted data outages throughout MCC and can require complex efforts coordinated among multiple flight control disciplines. An overview of TrS-based trajectory processors and interfaces appears in Figure 3.2.4.1-1. Many Figure 3.2.4.1-1 elements have external interfaces omitted in the interest of clarity. For example, Global VATs have a TVETS interface through the CMC Dropbox to USSTRATCOM, POINTING has a workstation interface enabling TrS ATL updates, and Global TDRSS ephemerides interface with INCO Antenna Management state vector command builds.

Other centralized facilities, such as the High Availability (HA) server on which the TSA Global database resides, support multiple disciplines. Recovery procedures for these facilities appear in FCOH SOP 17.12.



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Time and flight controller energy necessary to recover from a TrS failure are strongly dependent on available hardware and data archive configurations after the failure. The following failure scenario list progresses in order of increasing effort required to recover.

NOTE: in this scenario, TSA restoration isn't required because the outage is confined to TrS. Likewise, mirrored TrS ephemeris and VAT data may be OK if AutoMC didn't detect a source change and mirror corrupted data. If an ephemeris mirror has been corrupted, it should be deleted via TSA TPS Tier 0 until a good source TrS ephemeris can be mirrored. A corrupted VAT mirror can be deleted via TVETS.

NOTE: the TrS VAT mirror in TSA Global is 2-way. Assuming the mirror hasn't been corrupted, it's advisable to Copy-and-Paste the entire TrS VAT mirror into a Local VAT prior to TrS recovery. This preserves the mirror's original contents when the restored VAT is mirrored to Global after TrS recovery. The Local VAT can then be copied-and-pasted back into the Global mirror and the TrS VAT itself without manual state vector data entry.

- 1) A "hot" backup server is online, completely synchronized with the prime TrS, and unaffected by the prime's failure. In this ideal "select-over" case, the backup becomes the new prime TrS and recovery is momentary. The only impact is loss of redundancy in the event of another TrS failure. If the backup is out-of-synch or somehow also affected by the prime TrS failure to some degree, its usefulness quickly degenerates to the point where other recovery options are more reliable.
- 2) A TrS checkpoint unaffected by the failure was archived at an epoch in the recent past. After a TrS is brought online, the checkpoint data are restored and any subsequent updates required are manually overlaid. Ideally, a static standby server is pre-configured to be online in about 5 min. Otherwise, a new server must be requested from FSM. If a pristine TrS is available and manual overlays are minimal, this recovery process can be completed in half an hour. Should a checkpoint's integrity be suspect or if it requires excessive manual overlays, its usefulness quickly degenerates to the point where other recovery options are more reliable.

CAUTION: to preclude the possibility of checkpoint restore and AutoMC collisions in TSA Global, disable all AutoMC mirroring during a checkpoint restore.

- 3) A pristine server is available for "coldstart" turnaround. Following coldstart, all data necessary to attain the pre-failure TrS configuration are overlaid via manual or group MED input. This recovery process may require 2 hours or more to complete and is summarized in the following procedure.
  - a) Immediately alert FD, then verify the DYNAMICS Console will be manned by 2 controllers ASAP. If possible, have DFE transfer any data required by the NASCOM network prior to TrS termination.
  - b) If possible, verify ONAV health and uplink state vectors as required, then obtain hardcopies of the following TrS displays prior to termination.
    - TRAJ PROF STATUS for ephemeris configurations

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- CHECKOUT MONITOR for each important VAT state and all ephemeris anchors (see the preceding NOTE regarding mirrored VAT preservation)
  - EPHn WGL TABLE for all existing WGLs
  - VTL/VIT for all existing vents
  - DMT NO. n for each existing burn
  - GNAV TRAJ INIT for Jacchia values
- c) If possible, verify POINTING has good workstation-resident ATL data prior to TrS termination.
- d) Verify NAV is GO for TrS termination, verify all AutoMC mirroring is disabled, then give TAO a GO to terminate the prime TrS and initiate backup coldstart.
- e) During TrS termination and coldstart, continue to monitor DVIS loops, status FD, and make FDO Log entries. Maintain TSA Global trajectories and datasets as required in lieu of TrS.
- f) Following coldstart, activate AutoVAT mirroring and restore any slots preserved in Local. Next, rebuild TrS ephemerides and activate AutoEph mirroring as required.
- g) Restore burn modeling data to TrS ephemerides as required.
- h) Verify NAV and POINTING have restored their data to TrS. ReTUP ephemerides as necessary. Inform DFE when new acquisition data are generated.
- i) Verify ONAV health and uplink state vectors as required.

As an aid to MCC data recovery, the following paths are provided.

TSA Global = /users/trjcom/ASA01/<flight\_id>\_<activity\_type>/Global/

TSA Local = /mcc/rw\_local/<user position>/TSA<ver>/

Mission Data Archive = /users/fdo/Data/<flight\_id>/

PMP Baseline Data = /users/trj/Database/<flight\_id>/PMP<ver>/<sup>2</sup>

### 3.2.4.2 SMS Recovery

When the SMS is lost during an integrated sim, FDO's primary concern in recovering the sim is avoiding a TrS turnaround. Whereas a TrS turnaround requires at least 30 min, the SMS recovery procedure is comparatively rapid in theory and involves little flight control

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<sup>2</sup> At the Database level in this directory tree, reconfiguration files are applicable to multiple flights and processors in addition to PMP.

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team effort. Since time required to troubleshoot an SMS problem is rarely known accurately, SIM SUP and FD usually adopt a recovery strategy assuming the SMS will be back online in well under the time required to perform a TrS turnaround at any point.

Any procedural streamlining attributable to SMS recovery is largely due to an SMS function called Safestore. With Safestore active, sim-critical data such as state vectors and consumable quantities are archived to mass storage at an interval typically set at a few minutes. Thus, the recovering SMS performs a return to the original sim start datastore, then steps ahead in time to the last valid Safestore archive. After this archive is restored, an additional SMS step ahead is performed to a pre-designated even-SGMT-minute in the future with respect to current MCC SGMT. This epoch becomes the new sim start time, and the SMS remains there in FREEZE until a GO for sim start is received from SIM SUP. To support SIM SUP's call, NAV/DYN should perform the usual pre-sim Orbiter and (if applicable) target state vector transfers and checks with the SMS Environment. If the Safestore data are corrupted or a Safestore archive is unavailable, MCC state vectors must be transferred to the SMS Environment prior to the new sim start.

**CAUTION:** significant differences between TDRSS state vector rotation and propagation arise over sim time intervals of only a few minutes. Consequently, an SMS recovery at any time other than the original sim start requires state vectors from MCC TDRSS ephemerides be transferred to SMS Environment at the recovery SGMT. If this transfer isn't performed, NAV's batch chain will be broken following SMS recovery. In addition, COMMAND may have to replan TDRSS SHOs and INCO may lose TDRSS forward/return links if original sim start TDRSS trajectories aren't preserved in the SMS Environment.

To guard against a TrS turnaround, FDO should have TAO place TrS in FREEZE and obtain a TrS/Global checkpoint ASAP following loss of the SMS. Unlike former MOC limitations, TrS processing is unrestricted in FREEZE, and it's possible to step backward as well as forward in time to synchronize with the recovered SMS. With TrS in FREEZE during SMS recovery, inadvertent event executions are prevented. An executed event such as a burn cannot be "unexecuted", even if TrS steps backward in time.

**NOTE:** NSS outages pose an interruption to command, telemetry, voice communications, and tracking. Because NSS can be re-integrated "on the fly" with both MCC and SMS running, however, FDO generally plays no active role in associated recovery procedures.

### 3.2.4.3 Data Mis-Coordination at Sim Start

As is evident from Section 3.2.2, an intense amount of inter-facility coordination is necessary to produce a properly integrated sim. Human error occasionally leads to mis-coordinated data between the MCC and SMS. When an error is discovered late in the data reconfiguration process, FDO may be called on to rectify the situation during sim start preparations. The following mis-coordination examples are accompanied by suggested FDO-initiated recovery strategies.

- 1) The GMTLO at MCC differs from that at SMS. This scenario will probably be accompanied by mismatches in sim start SGMT and MET as well. Because an SMS datastore's GMTLO and SGMT cannot be easily altered, it's usually the best course of action for the MCC to match the SMS. Have DYNAMICS alter the TrS GMTLO with a D65 MED input. If SMS trajectories are acceptable for the sim, anchor MCC ephemerides using state vectors transferred from the

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SMS Environment. Otherwise, rotate MCC anchors to the new GMTLO with TSA and transfer the new sim start states to the SMS Environment.

NOTE: TSA's Vector Rotate processor can only interface with the Local VAT.

- 2) An SMS rendezvous datastore is corrupted. The only recourse is to use an SMS reset at a given SGMT and MET. Although the GMTLO may not change in this scenario, it's necessary for FDO to preserve the original sim start's relative motion and Ti lighting conditions. First, note the relative state at sim start to be preserved. Next, input the old sim start's target TDR state at the new sim start SGMT. This "vector rotation" will roughly preserve communications and tracking acquisitions during rendezvous. Now TUP a target ephemeris off the rotated state and use lighting constraints to fix the new Ti SGMT. This will impose a new sim start SGMT which must be *after* the SMS reset's SGMT. Inform SIM SUP of this new time (rounded to the even SGMT minute) so the SMS can perform a STEP AHEAD to it. Finally, offset the Orbiter state as required from the new sim start target state. In lieu of a dedicated offset capability, the desired relative state can be achieved for the Orbiter by developing a mock deploy-retrieve rendezvous plan. This plan ends with the same target-relative position constraints applicable to the original sim and references the new target ephemeris. After new sim start Orbiter and target states are transferred to the SMS Environment, the revised sim is ready to commence.
- 3) Unacceptable residuals are obtained when MCC and SMS Environment sim start TDRSS state vectors are compared. Typically, this condition arises when either facility isn't using the published generic TDR states rotated to the sim start time. If the SMS states are otherwise acceptable for the sim, the quickest recovery results from adopting them as MCC TDRSS ephemeris anchors. In this case, INCO should be notified of TDRSS ephemeris changes possibly invalidating Antenna Management command loads. Otherwise, acceptable MCC sim start TDRSS states should be verified by FDO, then transferred to the SMS Environment.

### 3.2.5 Workstation Anomaly Procedures

This section supplements FCOH SOP 17.2. When a workstation problem occurs, perform the following steps.

- 1) If the problem isn't known to originate with a DM application, immediately contact Workstation Software Support (WSS) on the WSS CALL loop. If you are in a time-critical situation and your workstation is down, notify Ground Controller (GC) and move to your backup workstation while WSS works the problem. *WSS should take a look at the problem and try to figure out where the problem is. If the problem is with the system, WSS will contact the appropriate support personnel to fix the problem. If the problem is with a user application, WSS will contact your Group Administrator (GA).*
- 2) If you believe the problem is with a DM application, call your GA. *WSS should call your GA in this case, however, sometimes it is quicker for you to take this step. The GA on-call list is on console.*

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- 3) Write an Anomaly Report (AR) documenting the problem. For TrS-related ARs, pass the number to GC. Use the web-based DRTS WEB Quick Entry page at URL <http://usa10.unitedspacealliance.com/tx/drts/>. *An AR is required for each problem encountered, even if you believe the problem has already been reported (one AR per sim or mission is adequate). TOCSS personnel will track and help resolve the problem if required. If time doesn't permit the AR to be written immediately, it must be submitted before you depart MCC following your shift.*

Procedures FDO performs to submit an AR appear in DM-SW-01, *DM GAF FDD User Involvement In the Formal MCC Software Life Cycle*. Consult the "AR Process" section of this document for specifics. A DM-SW-01 copy can be downloaded from URL <http://mod.jsc.nasa.gov/dm/division/documents/DM-SW-01.doc>, and a download link is provided on the FDO home page. Following AR submission, the originator receives an e-mailed confirmation from DRTS personnel after processing is complete. It may be advisable to forward this notification to other affected colleagues.

### 3.2.6 Simulator Combination

During a dual simulation, the ISS trajectory can potentially be computed by either the SMS or SSTF. The prevailing ISS trajectory source will drive Orbiter cockpit visual cues, rendezvous sensor acquisitions, and ISS tracking data simulated by NSS. When the two simulators combine, two software inhibits are enabled by default such that the SMS Environment's ISS trajectory prevails for all users except those internal to SSTF. One inhibit resides in each simulator, and both must be manually disabled for the SSTF's ISS trajectory to prevail.

When the Orbiter and ISS are undocked during dual sims, removing the inhibits to use SSTF's ISS trajectory produces unacceptably noisy relative motion between the two vehicles. This "relmo noise" is thought to arise from timing inconsistencies between SSTF ISS trajectory data differenced with SMS Orbiter trajectory data. It consists of relative position jumps amounting to thousands of feet in magnitude at irregular time intervals.

On the other hand, the SSTF requires ISS trajectory data to drive internal systems simulations, most notably the Control Moment Gyros (CMGs). Unfortunately, SMS Environment ISS trajectory data are inaccessible from SSTF.

Consequently, the prevailing ISS trajectory data source during a dual sim is heavily dependent on the phase of flight. When the Orbiter and ISS are undocked, SMS data prevail except within SSTF. During mated simulations, inhibits are removed once the two simulators combine and SSTF data prevail thereafter. In a dual rendezvous sim, inhibits are removed shortly after hard dock to support attitude control handover from the Orbiter to CMGs. Because the two simulators have been in RUN for hours between a rendezvous sim's start time and docking, a large mated vehicle trajectory jump will generally occur when SSTF data first replace those from SMS. Although NAV will need to reinitialize mated tracking at this point, perturbations and modeling discontinuities dictate similar action in a real mission.

Due to facilities scheduling or an SSTF outage, it may be necessary to combine SSTF with SMS more than a few minutes after sim start. In such cases, TOPO and FDO will be notified by the Sim Team of the estimated time until simulator combination. In addition, the Sim Team will disclose to TOPO and FDO their intent to inhibit or enable SSTF as the ISS



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trajectory data source. Similar notification will be made whenever the Sim Team changes SSTF's status as ISS trajectory data source, such as after Shuttle docking.

After simulator combination, it may be advisable for NAV to request an ISS Environment state vector from NSS with the Sim Team's permission. If unexpected deviations between the Environment and MCC's ISS ephemeris are reported by NAV, corrective action may be necessary. For example, an inadvertent SSTF update to the ISS trajectory during a dual rendezvous sim was cause for moding to FREEZE while the ISS Environment state vector was corrected from MCC's ephemeris.

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**Section 3.2 Concludes On This Page**

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## 3.3 Ephemeris Maintenance

Orbit trajectories are modeled using data sets called ephemerides. An ephemeris contains chronologically ordered state vectors generated in accord with tracking/telemetry, burn targeting, mass properties, attitude/vent time line (ATL/VTL), and executive information defining a trajectory. This section relates elements and procedures governing basic ephemeris creation and maintenance.

Current FDO operations encompass somewhat redundant sets of software on different platforms. An Ephemeris Ops Concept has been developed, detailing which software suite is to be used at what time for product generation and real-time calls. Accordingly, Section 3.3.1 discusses ephemeris operations on Trajectory Server (TrS). Section 3.3.2 documents TrS ephemeris mirroring using AutoMC. Section 3.3.3 presents TSA-based ephemeris operations. Section 3.3.4 highlights state vector processing.

### 3.3.1 TrS Trajectory Profile Status (TPS)

TrS Trajectory Profile Status (TPS) displays are used to track the configuration of up to 20 ephemerides. Ephemerides 1 through 10 are called "vehicle ephemerides" in TrS because they model trajectories associated with the Orbiter and other spacecraft, such as deployed payloads or rendezvous targets. During a Shuttle mission, FDO products are typically generated using these ephemerides (or mirrored copies) as their trajectory source. In a separate TPS display are ten additional geosynchronous satellite ephemerides. These are referred to as "TDRSS ephemerides" because they are typically assigned to elements of the Tracking and Data Relay Satellite System (TDRSS).

NOTE: Ground Navigation (NAV) is the only discipline currently using TrS TDRSS ephemerides. These ephemerides are unique in that they're the only ones in MCC capable of modeling solar radiation pressure (SRP). TDRSS-based orbit determination requires SRP modeling to effectively utilize GSFC-supplied TDRSS state vectors. Because all related operations are specific to NAV, TrS-resident TDRSS ephemerides and the associated TPS display are generally beyond the scope of this handbook. Consequently, unqualified ephemeris or TPS references throughout this handbook should be associated with vehicle ephemerides.

To properly model a trajectory, FDO supplies an ephemeris with physical and dynamics characteristics, together with an initial or "anchor" state vector. This defining information is displayed on the TPS (see Figure 3.3.1-1). There are actually 2 TPS formats available in TrS. Figure 3.3.1-1 illustrates the "FDO TPS" format, which lists all 10 vehicle ephemerides vertically. The other format is "TPS", which displays vehicle ephemerides in 2 columns of 5 rows each. Both TPS formats provide the same data content.

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```

114                FDO TPS                C
Ephemeris E4 is not initialized

MET 001:15:57:02.61 E1 Cur ORB 27
GMT 018:19:08:15.61 PriOrbEph= E1
GMTR 017:03:11:13.00 PriTgtEph= E3

"NC4NPC2"
EPH E1 PROFILE GOOD SRP 0.0000
TUP NUMBER 20 KCON 1.0000
NUMBER MNVRS 5 KVAR 1.0000
WTS INIT CURRENT AREA 5166.00
VEH 247019.0 245563.6 INT GR OPT VAM
OMS 24267.0 22811.6 STDN OPT YES
RCS 4592.0 4592.0
EPHB VEH WT 247019.0
AVID ORB 026 ORBB 26
GMTV 018:17:11:13.00 TORB 018:17:11:13.00
EPHL 48.00
EPHE 018:17:11:13.00 METB 001:14:00:00.00
EPHE 020:17:11:13.00 METE 003:14:00:00.00

"NNNPC2"
EPH E2 PROFILE GOOD SRP 0.0000
TUP NUMBER 10 KCON 1.0000
NUMBER MNVRS 4 KVAR 1.0000
WTS INIT CURRENT AREA 5166.00
VEH 247019.0 245560.3 INT GR OPT VAM
OMS 24267.0 22808.3 STDN OPT NO
RCS 4592.0 4592.0
EPHB VEH WT 247019.0
AVID ORB 026 ORBB 26
GMTV 018:17:11:13.00 TORB 018:17:11:13.00
EPHL 240.00
EPHE 018:17:11:13.00 METB 001:14:00:00.00
EPHE 028:17:11:13.00 METE 011:14:00:00.00

Prime Target
EPH E3 PROFILE GOOD SRP 0.0000
TUP NUMBER 1 KCON 1.1750
NUMBER MNVRS 0 KVAR 1.0000
WTS INIT CURRENT AREA 7806.00
VEH 371564.6 371564.6 INT GR OPT DM
OMS 24267.0 24267.0 STDN OPT YES
RCS 4592.0 4592.0
EPHB VEH WT 371564.6
AVID ISS 026 ORBB 26
GMTV 018:17:11:13.00 TORB 018:17:11:13.00
EPHL 48.00
EPHE 018:17:11:13.00 METB 001:14:00:00.00
EPHE 020:17:11:13.00 METE 003:14:00:00.00

Planning Target
EPH E4 PROFILE BAD SRP 0.0000
TUP NUMBER 0 KCON 1.0000
NUMBER MNVRS 0 KVAR 1.0000
WTS INIT CURRENT AREA 1208.48
VEH 256236.6 256236.6 INT GR OPT DM

```

Figure 3.3.1-1: TrS FDO TPS

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### 3.3.1.1 TrS Orbit Prediction Theory and Integrator Constants

Orbit prediction software generating ephemerides adopts a theory of orbit motion modeled by integrating the following accelerations.

- 1) Earth gravity acceleration is computed from a truncated infinite series expansion of Legendre polynomials. This recursive algorithm accesses a database of harmonic coefficients arranged in lower-triangular-matrix form. An element of the database is termed  $J_{n,m}$ , where the row  $n$  is the harmonic's degree and the column  $m$  is its order. When  $m=0$ , the coefficient's effect is symmetric about a parallel of latitude, and it's termed a zonal harmonic. When  $n = m$  for a matrix diagonal coefficient, its influence is symmetric about a great circle of longitude. This is a sectorial harmonic. No latitude or longitude symmetry is associated with the action of coefficients having  $n \neq m$ , and they're termed tesseral harmonics. Orbit prediction software is configured with a Goddard Earth Model 10 (GEM10) database truncated to seventh degree and order.

NOTE: the TrS gravity model has computation singularities at near-polar locations. The near-Earth space susceptible to these singularities and consequences arising from their encounter are unknown.

- 2) Lunisolar gravity acceleration is computed from Newton's Law of Universal Gravitation using Sun and Moon positions from Jet Propulsion Laboratory Development Ephemeris 118 (JPL DE 118) in TrS.
- 3) Atmospheric drag acceleration is computed from atmospheric density estimates provided by the Jacchia-Lineberry model (see JSC 18507, Internal Note 82-FM-52). Drag is disabled at altitudes greater than 378 nm (700 km). Below 67 nm (125 km; 410105 ft), the model is switched to the 1962 Standard Atmosphere. This acceleration doesn't apply to TrS TDRSS ephemerides, regardless of altitude.
- 4) Translation burn accelerations are computed according to Mission Planning Table (MPT) data associated with a vehicle ephemeris. This acceleration doesn't apply to TrS TDRSS ephemerides.
- 5) Body-fixed and UVW-fixed vent accelerations are optionally computed according to the Vent Timeline (VTL). This acceleration doesn't apply to TrS TDRSS ephemerides.
- 6) SRP acceleration is computed only for TrS TDRSS ephemerides. Satellite-specific radiation pressure characteristics accompany TDRSS state vectors received from GSFC. Using the S81 MED, NAV specifies these characteristics to TrS. They may be monitored on the TDRS VAT display (see Figure 3.3.1.1-1). Raw SRP data received from GSFC appear in the left TDRS VAT column, while TDRSS ephemeris profile details are in the right column. Reflectance values range from 1.0 (perfect absorber) to 2.0 (perfect reflector). Note that a reflectance value of zero effectively disables radiation pressure modeling. This modeling is also disabled at altitudes less than 17000 nm (31484 km).

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112 Intercenter TDRS VAT					B				
GMT: 192:22:44:07					MET: 00:16:02:49				
<b>TDRS 1</b> T047W002 192:22:44:00.720 0.00000 0.0000 0.000000 T047W001 192:21:40:59.760 0.00000 0.0000 0.000000					<b>TDRS 6</b> T049W001 192:21:40:59.760 0.00000 0.0000 0.000000				
<b>TDRS 2</b> T171W002 192:21:55:20.680 0.00000 0.0000 0.000000 T171W001 192:21:40:59.760 0.00000 0.0000 0.000000					<b>TDRS 7</b> MASS(KG) AREA(M <sup>2</sup> ) REFLECT				
<b>TDRS 3</b> T085E001 192:21:40:59.760 0.00000 0.0000 0.000000					<b>TDRS 8</b> MASS(KG) AREA(M <sup>2</sup> ) REFLECT				
<b>TDRS 4</b> T041W001 192:21:40:59.760 0.00000 0.0000 0.000000					<b>TDRS 9</b> MASS(KG) AREA(M <sup>2</sup> ) REFLECT				
<b>TDRS 5</b> T174W001 192:21:40:59.760 0.00000 0.0000 0.000000					<b>TDRS 10</b> MASS(KG) AREA(M <sup>2</sup> ) REFLECT				
<input type="checkbox"/> XMIT					<input type="checkbox"/> Quit				

Figure 3.3.1.1-1: TDRS VAT

Integrator constants reflect characteristics influencing accelerations integrated to produce a vehicle ephemeris. Therefore, they don't apply to TDRSS ephemerides in TrS. Values for the constants appear at the upper-right-hand corner in each vehicle ephemeris box displayed by TPS. The degree to which integrator constants effect an ephemeris depends on vehicle weights, which appear in the **VEH** line of each **WTS** table displayed by TPS.

- 1) **KCON** and **KVAR** are multipliers for constant-area and variable-area drag, respectively. They are independent of the coefficient of drag (CD). Collectively known as "K-factors", KCONs and KVARs are used to scale the modeled drag acceleration acting on a vehicle. A KCON value only applies when an ephemeris integration option of D (constant-area drag) is in effect, and a KVAR value only applies when an option of A (variable area drag) is in effect. NAV

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may advise FDO on a K-factor change based on empirical analysis of tracking data. Systematic orbit energy trends NAV cannot model in the VTL may also be approximated by an appropriate K-factor. Values from 0 to 99.9999 are accepted.

- 2) **AREA** is the effective average vehicle surface area encountering the flux of atmospheric particles, expressed in square feet. Because AREA is a constant for a given ephemeris, it's only applicable when an integration option of D is in effect. Values from 0 to 9999.99 are accepted.
- 3) **INTGR OPT** stands for integration options. These codes determine which of the physical and dynamics characteristics apply to an ephemeris. Individual options are defined as follows.
  - a) **V** invokes vent forces from the current VTL configuration whenever the ephemeris is updated.
  - b) **A** invokes attitude-dependent atmospheric drag according to the current ATL and Cargo Bay Door Status Table (CBDST) configurations whenever the ephemeris is updated.
  - c) **D** invokes constant-area atmospheric drag, as specified by the pertinent KCON and AREA, whenever an ephemeris is updated. A constant  $C_D$  value of 2 is associated with the D option.
  - d) **M** models the effects of translation burns residing in the ephemeris-specific MPT whenever an update occurs.

**NOTE:** valid integration options are as follows.

TrS Processor	MED	Supported Integration Options
Profile Update	M51	A, AM, D, DM, M, VA, VAM, VD, VDM, VM
Vector Compare	S44	D, M, DM, A, AM, VD, VM, VDM, VA, VAM
Vector Integrate	S85	VAM, VA, AM, A, DM, D
Checkout Monitor	U02	VAM, VA, AM, A, DM, D

The Jacchia-Lineberry atmosphere model is critically dependent on measurements of solar flux (F10.7) in units of Janskys\*  $10^4$  and geomagnetic index (KP) in dimensionless units. Jacchia values in use by TrS, together with other trajectory initialization parameters, may be viewed on GNAV TRAJ INIT (see Figure 3.3.1-2). Once initialized by NAV prior to launch, these Jacchia values usually remain fixed for the entire mission. Typical deviations in F10.7 and KP experienced during a mission can be handled effectively by updates to KCON, KVAR, or AREA values. Only in extreme cases, such as the period following a violent solar flare, will NAV need to update Jacchia values during a mission.

**CAUTION:** NAV computes operational Jacchia values differently from those in use by TOPO. Values computed for F10 and KP by NAV are an average of actual values extending over the previous 90 and 360 days, respectively. In contrast, TOPO uses MSFC 50% (best guess) predictions at 90-day intervals in a table which is linearly interpolated. These inconsistencies are permissible as long as corresponding KCON, AREA, and WEIGHT values are developed and used consistently with each atmosphere

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configuration. Under no circumstances should a drag profile be blindly adopted for use with an inconsistent atmosphere.

112	GNAV TRAJ INIT		C
GMT: 192:22:49:44			MET: 00:16:08:26
LIFTOFF			
192:06:41:18.000			
P80 INIT DATE	MISSION TIMES TABLE		
2002 07 01	YEAR	2002	
BASE JULIAN DATE	JACCHIA VALUES		
2452274.5	F10.7	203.00	
OGMT	KP	2.27	
192:22:49:47	ET - UTC CONSTANT		
SUN/MOON TABLE		64.18	
2002 06 23	UT1 - UTC		
2003 08 05		0.00000	
ONBOARD RNP			
YEAR 2002	GPS/GMT TIME ADJUST	0.0	secs
DAY 225	LEAP SEC.CORRECTION	13	secs
	GPS OFFSET DAYS	8031	days
<input checked="" type="checkbox"/> XMIT	<input checked="" type="checkbox"/> Hide	<input type="checkbox"/> Undo	<input type="checkbox"/> Quit

Figure 3.3.1-2: Ground NAV Trajectory Initialization Display

### 3.3.1.2 Ephemeris Weights

In each TPS vehicle ephemeris display area, a dedicated weights section is divided into initial (INIT) and current (CURRENT) columns. Each column contains three entries: the total vehicle weight (VEH), the Orbital Maneuvering System (OMS) propellant weight, and the Reaction Control System (RCS) propellant weight (see Figure 3.3.1-1).

**CAUTION:** special care is often required when specifying weights to an ephemeris modeling target or payload vehicle burns. In this application, payload ejections usually qualify as burns. Because the Engine Characteristics Table (ECT) frequently cannot accept sufficiently low flow rates, a substitute Orbiter thruster must be used in place of the operating mechanism. In such cases, target/payload burns may result in negative weights and ephemeris failure if the real vehicle INIT weight is input. An effective workaround is to



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amplify both the AREA and INIT weight such that their ratio is preserved to correctly model drag. This technique may also entail corresponding amplification of OMS/RCS weights in the ephemeris. If a sufficiently large INIT weight is selected, its depletion due to Orbiter thruster flow rate during a burn will be negligible. As a general rule, an INIT weight of 5000 lbs is usually sufficient.

The INIT weight column of TPS reflects VEH, OMS, and RCS weights applicable to the ephemeris start time. The CURRENT column displays these weights at the current time. As weight changes occur in real time, the CURRENT and INIT weights will differ. These changes are driven by entries in the Weight Gain/Loss Table (WGL) or MPT associated with an ephemeris. For more information on WGLs and MPTs, consult Sections 3.3.1.7.1.2 and 3.7.1.1, respectively.

The DYNAMICS controller initializes vehicle weight (VEH) using the M51 MED, causing the initial value to appear in TPS's INIT column. If the ephemeris WGL table contains weight changes due to deploys or retrieves, or the ephemeris MPT contains translation burns depleting propellant weights, the CURRENT column values will change in real time with the weight changes.

**CAUTION:** if burns prior to the EPHB epoch reside in an MPT, any change to the corresponding INIT weight will generally result in an unintended CURRENT weight. This is a permanent TrS limitation (reference AR 019409 closure). Before making an INIT weight change, verify all burns prior to EPHB are deleted and converted to WGLs as appropriate.

Another weight, the Ephemeris Begin Vehicle Weight (EPHB VEH WT), is displayed below the RCS weight row. The EPHB VEH WT and INIT weight will not agree if weight changes have occurred in the WGL Table or the MPT before the current state vector update. As anchor vector time changes, the EPHB VEH WT will change to reflect weight deltas from these ephemeris-specific tables applied to the INIT weight.

DYNAMICS initializes OMS weight using the M49 MED. When the TIG of an OMS burn in the MPT passes, the ephemeris CURRENT weight will decrement by an amount equal to the weight of propellant used for the burn. The INIT weight will not change. The RCS INIT weight is also initialized using the M49 MED, and RCS CURRENT weight changes as any RCS burns in the MPT are executed.

Approximately once each shift, PROP issues copies of the OMS/RCS Consumables Status form to FCR operators. At the FDO Console, this form's OMS and RCS Usable Propellant Remaining TOTAL weights are used to update OMS and RCS weights in vehicle ephemerides. With these inputs, Orbiter propellant remaining is accurately tracked by CURRENT OMS and RCS weights as burns are executed and confirmed. These weights are converted to equivalent remaining  $\Delta v$  for display on an appropriate MPT and DMT. Consequently, OMS and RCS weights do not directly influence an ephemeris trajectory, as does total vehicle weight, and no ephemeris TUP is necessary when they are modified. Consumables Status weights may also be input to vehicle ephemerides modeling targets unless large burns, which would result in a negative propellant weight, are to be modeled. From the Figure 3.3.1.2-1 example, respective values of 9441 and 5293 would be input to the OMS INIT and RCS INIT weights of an ephemeris.

**NOTE:** since the mid-1990s, OMS/RCS Consumables updates to ephemeris weights have ceased to be performed as standard procedure. This capability is retained in TrS, however, and is documented here should a need for it develop in the future.

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OMS/RCS Consumables Status		May 17 18:51:48 1994		
STS-65 ORBIT 4		Vehicle Weight: 247048 lbs		
Current MET: 000:09:35:17				
SUMMARY				
RCS Propellant (lbs/%)	LEFT	RIGHT	FORWARD	TOTAL
Usable Propellant Remaining	1967/ 89	1971/ 90	1355/ 62	5293/ 80
Delta Mission Completion R/L	557/ 25	420/ 19	788/ 36	
Delta Deorbit Redline	1098/ 50	1102/ 50	1234/ 56	
OMS Propellant (lbs/%)				
Usable Propellant Remaining	4699/ 36	4741/ 37		9441/ 36
Delta Mission Completion R/L	343/ 3	313/ 2		
Delta Deorbit Redline	790/ 6	859/ 7		
Interconnect Usage	59/ 0	0/ 0		59/ 0
Delta V (fps)				
OMS Delta V Available (2 OME)	= 391.4 fps			
ICNCT Delta V Available ( 4+X )	= 322.5 fps			
Weather extension days above redlines: Aft 22.1 Fwd 28.1				

**Figure 3.3.1.2-1: OMS/RCS Consumables Status Form**

### 3.3.1.3 The "Anchor Vector"

An anchor vector is the state vector with which an ephemeris is initialized. Both the anchor vector identifier and its GMT appear on TPS to the right of the "AVID" and "GMTV" identifiers, respectively (see Figure 3.3.1-1). To anchor a TrS ephemeris, DYNAMICS uses the P16 MED.

Whenever an ephemeris is anchored on a new vector, FDO should monitor the change in AVID on TPS to verify the correct state is in use. If other ephemerides are "chained" off the newly reanchored trajectory, their anchors must be updated from this trajectory to retain a correctly chained relationship.

By default, DYNAMICS will start an ephemeris at the anchor vector's epoch. However, FDO can specify an independent ephemeris "static start" in GMT or MET. The static start can always be later than the anchor epoch, but it can only be earlier if a maneuver doesn't

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exist in the MPT between the anchor and static start epochs. This restriction is imposed by PFNI's inability to integrate backward through a burn arc.

**CAUTION:** the GMTV field in TrS TPS only displays the anchor vector GMT when the ephemeris starts at the anchor vector time. Strictly speaking, the GMTV field is redundant with the corresponding EPHB field and always reflects ephemeris start GMT.

Any TrS vector ID is constrained to the format 6 alpha-numeric characters, followed by 3 numeric characters, and the AVID is no exception. When supplied by NAV, the AVID's alpha characters relate the tracking data source, such as "EST " or "ASC ". If a target vehicle is being tracked, NAV's vector ID alpha field will have a "T" as its fourth character. The numeric field supplied by NAV is the orbit number at the start of the data source's tracking arc. Under this convention, AVID "ASCT066" signifies an ephemeris is anchored off Ascension Island's target vehicle tracking which began on Orbit 66.

### 3.3.1.4 The Orbit Counter

An ephemeris orbit counter is a tally of ascending node crossings with respect to Earth's true equator. Although the count has an arbitrary origin, it's usually defined as "1" at launch. Orbit counters must be verified for correctness because ephemeris trajectory events (such as burn TIGs and site acquisitions) are tagged with orbit numbers for correlation with other data sets (such as DOPS tables and tracking timelines).

On TPS, orbit counts associated with each vehicle ephemeris are managed and verified using readouts adjacent to the "ORBB" and "TORB" fields (see Figure 3.3.1-1). ORBB must be set to the orbit count at the ephemeris start time. Unlike the MOC, TORB in TrS is fixed to the ephemeris start time.

**CAUTION:** in many cases, a new anchor epoch does not lie in the time span of an existing ephemeris. When re-anchored, such an ephemeris will generally not have a correct ORBB value. These cases often arise for planning ephemerides anchored at future epochs when the anchor is shifted earlier. Whenever in doubt of an orbit count pedigree, verify the suspect ORBB against an ephemeris with a good orbit count, against current DOPS Nodal Data output, or against a valid Flight Plan or Execute Package.

**CAUTION:** static starting a mirrored TrS ephemeris too close to an ascending node may precipitate skewed orbit counts in its mirror. If a Checkout Monitor at ephemeris start indicates northbound motion at a latitude magnitude  $< 0.1^\circ$ , consideration should be given to starting the TrS source ephemeris one minute earlier or later to achieve reliable mirrored orbit counts.

### 3.3.1.5 Ephemeris Begin, End, and Length

TPS displays both begin and end times for all ephemerides. These times appear in GMT and MET. Length for each ephemeris is displayed in hours. Corresponding TPS labels are as follows (see Figure 3.3.1-1).

- 1) EPHL: ephemeris length in hours
- 2) EPHB: ephemeris begin time in GMT

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- 3) EPHE: ephemeris end time in GMT
- 4) METB: ephemeris begin time in MET
- 5) METE: ephemeris end time in MET

In TrS, ephemerides can be up to 20 days (480 hrs) long. DYNAMICS uses the M00 MED to input ephemeris length.

**CAUTION:** the GMTV field in TrS TPS always reads the same epoch as the EPHB field, even when the ephemeris begins at a time differing from that of the anchor vector.

### 3.3.1.6 STDN Options

Each vehicle ephemeris has a "STDN OPT" entry on TPS. Although this "YES/NO" switch governs automated acquisitions processing by TrS, acquisitions data residing on TrS are only generated by NAV for their exclusive use and are beyond this handbook's scope. Acquisitions data used by FDO and the Shuttle FCT are generated using TSA PSAT operating on TrS mirrors and other ephemerides residing in TSA Global. See Section 3.4 regarding acquisitions data generation details.

### 3.3.1.7 Trajectory Update (TUP) Procedures

Trajectory updates (TUPs) occur for many reasons falling into two principal categories: event planning and unmodeled perturbations. Planned events include burns, attitude maneuvers, payload deploys or retrieves, payload bay door openings or closings, and TDRSS scheduling. Examples of unmodeled perturbations are executed burn residuals, translations from attitude maneuvers or deadbanding, and atmospheric density variations arising from solar flares or geomagnetic storms. Except for burns (see Section 3.7), all TUPs can be handled with the same MEDs used to initialize an ephemeris. TUPs for planning purposes require minimal internal coordination and are executed as directed by FDO. TUPs for perturbations require evaluation and coordination between FDO, NAV, DFE, and DYNAMICS.

#### 3.3.1.7.1 TUPs for Planning Purposes

This section relates typical ephemeris TUP procedures required to track evolution of trajectory event planning.

##### 3.3.1.7.1.1 ATL and VTL Updates

Whenever POINTING begins an ATL update, the "ATTITUDE TIMELINE" DDD is illuminated. This signals FDO that any ephemerides with the "A" integrator option may no longer be valid. Because the ATL also drives body-fixed vents in the VTL, ephemerides with the "V" integrator option may be affected too. The following actions should be taken.

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**CAUTION:** perturbations due to ATL or VTL changes may be appreciable, particularly in the context of precision burn targeting iterations over long trajectory arcs. It may be desirable to postpone such iterations until the ATL and VTL are stable. Optionally, targeting can be done in an ephemeris with neither A nor V integrator options. Such an ephemeris is decoupled from ATL and VTL influences.

- 1) POINTING will contact FDO with a request to update the TrS ATL. After determining the update's scope and verifying NAV is GO, FDO authorizes POINTING to proceed. When finished, POINTING notifies FDO the ATL is updated.
- 2) Decide which ephemerides are affected by the update. If attitude-dependent drag or vents aren't important to ephemeris integrity, a dedicated TUP to incorporate ATL update effects isn't necessary. For example, ATL changes at current time will have noise-level effects in an AM ephemeris modeling the next day's deorbit burn from a 250 nm circular orbit.
- 3) After POINTING has completed the update, request NAV verify VTL agreement with the new ATL. When NAV initiates a VTL update, the "VENT TIMELINE" DDD will illuminate.
- 4) Following any VTL updates by NAV, have DYNAMICS TUP the ATL and VTL changes into the affected ephemerides. Remember any ephemeris chained off an affected ephemeris must also be TUPed to preserve the chained relationship. Verify each TUP via TPS's "TUP NUMBER" field (see Figure 3.3.1-1), which will increment following the TUP. During each TUP, the corresponding "EPHEMERIS x UPDATE" DDD will illuminate.

**NOTE:** neither the "ATTITUDE TIMELINE" nor the "VENT TIMELINE" DDD will extinguish until E1 has been TUPed.

**CAUTION:** there is only one ATL and one VTL in TrS. This limitation may cause conflicts between multiple TrS ephemerides, particularly if they model differing vehicles or trajectory options. Any ephemeris with the "A" integration option is ATL-dependent. Any ephemeris with the "V" integration option is VTL-dependent. If the VTL contains body-fixed vents, a "V" ephemeris may implicitly depend on the ATL even if it has no "A" option.

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Status of the current ATL can be monitored on the ATTITUDE TIMELINE display. This multi-page display relates each orientation planned or executed by the Orbiter, together with the MET/GMT at which this attitude is achieved (commonly called the "in-attitude time"). An M50-to-body (MODE = IH) or LVLH-to-body (MODE = LVLH) pitch-yaw-roll Euler sequence accompanies each attitude and is displayed in roll-pitch-yaw order. Ephemerides assume each ATL entry reflects a period of either inertial or LVLH attitude hold for purposes of integrating drag or body-fixed vent accelerations. Consequently, rotation about a special eigen-axis (MODE = ROTR) has no effect on ephemerides. Some ATL MED capabilities are directly available to FDO via interactive SAMMI widgets. See Appendix 3.L for operational procedures and considerations relating to interactive ATL features. An ATL example appears in Figure 3.3.1.7.1.1-1.

112		ATTITUDE TIMELINE							A	
		Time of 1st Entry 192:00:00:00			Display Threshold 192:00:01:00			Reset to Launch		
NO.	COMMENT	TIME GMT/MET	MODE	MATRIX	EIGEN AXIS	RATE	ATTITUDE			
							ROLL	PITCH	YAW	
1	FREE0416	192:00:00:00	LVLH		P		0.00	0.00	0.00	
		000:06:41:18			Y					
2	OMS-2	192:07:19:18	IH	MIR603			78.06	132.12	11.71	
		000:00:38:00								
3	-ZLV -YVY	192:07:55:26	LVLH				0.00	180.00	270.00	
		000:01:14:08								
4	NC 1	192:10:13:59	IH	MIR603			78.60	131.91	11.67	
		000:03:32:41								
5	-ZLV -XVY	192:10:33:40	LVLH				0.00	180.00	-0.00	
		000:03:52:22								
6	Phantom R F	192:22:10:12	LVLH				10.36	322.48	14.77	
		000:15:28:54								
7	Phantom R F	192:22:15:12	LVLH				9.42	345.48	14.81	
		000:15:33:54								
8	Phantom R F	192:22:20:12	LVLH				8.24	8.89	14.85	
		000:15:38:54								
9	Phantom R F	192:22:25:12	LVLH				6.88	32.01	14.90	
		000:15:43:54								
10	Phantom R F	192:22:30:12	LVLH				5.46	54.25	14.93	
		000:15:48:54								
11	Phantom R F	192:22:35:12	LVLH				4.10	75.29	14.96	
		000:15:53:54								
12	Phantom R F	192:22:40:12	LVLH				2.84	95.09	14.98	
		000:15:58:54								
13	NC 2 OMS	192:22:55:05	IH	MIR603			99.00	307.00	17.00	
		000:16:13:47								
14	-ZLV -XVY	192:23:21:16	LVLH				-0.00	180.00	-0.00	
		000:16:39:58								
15	Phantom deploy	193:00:21:18	IH	MIR603			314.00	312.00	339.00	
		000:17:40:00								

Quit

Figure 3.3.1.7.1.1-1: ATL Display

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Status of the current VTL can be monitored on the VENT TIMELINE display. This multi-page display supports storage of up to 200 vents covering the period from orbit insertion to a post-deorbit geodetic altitude of 300000 ft, where vehicle ephemerides are terminated. Figure 3.3.1.7.1.1-2 illustrates a typical VTL configuration.

**112**
Vent Timeline
**A**

GMT: 192:22:51:20
MET: 00:16:10:02

OPTION: ██████████      DELTA: ████████████████████

██████████      ██████████      ████████████████████      ████████████████████

ENTRY	ACT	VENT	START GMT	END GMT

▲  
▼

XMIT
 Delete Range ████████████████████
 Undo

Threshold ████████████████████
 Quit

Figure 3.3.1.7.1.1-2: VTL Display

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Each vent in the VTL references the Vent Initialization Table (VIT) to obtain its force components in the Orbiter body frame or UVW. Using the vent acronym appearing in the VIT's VENT column, the corresponding Orbiter body force or UVW components may be obtained on the VIT display. An example of the VIT appears as Figure 3.3.1.7.1.1-3.

112		Vent Initialization Table			A
GMT:192:22:51:48					MET: 00:16:10:30
OPTION		0.000	0.000	0.000	
VENT	FORCE-X/U	FORCE-Y/V	FORCE-Z/W	TYPE	
AOA1	0.000	0.000	2.710	BODY	
AOA2	0.000	0.000	5.420	BODY	
AOA3	0.000	0.000	8.130	BODY	
APU1	0.000	0.000	3.450	BODY	
APU2	0.000	0.000	3.450	BODY	
APU3	0.000	0.000	3.450	BODY	
DOD1	0.000	0.000	2.670	BODY	
DOD2	0.000	0.000	5.340	BODY	
DOD3	0.000	0.000	8.010	BODY	
DOP1	0.000	0.000	4.100	BODY	
DOP2	0.000	0.000	8.200	BODY	
DOP3	0.000	0.000	12.300	BODY	
H2O1	0.000	0.000	0.650	BODY	
H2O2	0.000	0.000	0.650	BODY	
H2O3	0.000	0.000	0.650	BODY	
HLE	0.080	1.120	0.600	BODY	

XMIT
 Undo

Quit

Figure 3.3.1.7.1.1-3: VIT Display

### 3.3.1.7.1.2 Vehicle Weight Updates

As new vehicle weight computations are made in response to consumables usage or payload configuration changes (see Section 3.6), corresponding Weight Gain/Loss (WGL) table inputs track the vehicle's total weight history as a series of discrete weight changes. With this history, forces due to aero drag, vents, and engine thrust can be accurately converted to accelerations for numeric integration. A WGL table is dedicated to each



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vehicle ephemeris for this purpose, and an example WGL table display appears in Figure 3.3.1.7.1.2-1. In TrS, WGL table displays WGL1 thru WGL10 correspond to E1-10.

Ephemeris E10 Weight Gain/Loss Timeline D

GMT 018:19:12:46.63      INIT WEIGHT 371564.6      CUR WEIGHT 370564.6

MET	GMT	DELTA WT	TOTAL WT
██████████	██████████	██████████	██████████

Update EPH  E10       TUP       CLEAR

SET	MET	GMT	DELTA WT	TOTAL WT
1	001:00:00:00.00	018:03:11:13.00	*	-1000.0      370564.6

DELETE
  MET
  DELTA
  TOTAL

ADD/MOD

 MET       GMT

UNDO
  QUIT

**Figure 3.3.1.7.1.2-1: WGL Table Display**

Up to 75 WGLs can be input to a table. Propellant weight loss due to a burn is not normally input to a WGL table because it's automatically modeled by PFNI once a burn is placed in the ephemeris MPT. In fact, any WGL specified during the time span of a burn will be ignored by the ephemeris.

WGLs also support mated reboost modeling. Reboost thrust profiles simulated by Charles Stark Draper Labs (CSDL) personnel are obtained prelaunch as an effective time-invariant force on the mated Orbiter/ISS "stack". NAV infers UVW components from this force in the VIT/VTL to model reboost in TrS ephemerides. During mated ops, dedicated Orbiter and ISS ephemerides, each with the corresponding undocked weight, are continuously maintained to address sudden termination of mated ops and subsequent

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relative motion assessments. Consequently, for the reboost vent force to model properly in an Orbiter "V" ephemeris, a WGL up to stack weight is applied about 10 min prior to reboost initiation. Likewise, another WGL back down to Orbiter-only weight is applied to this ephemeris about 10 min after reboost termination. The second WGL may also account for expected propellant consumption during reboost.

**NOTE:** based on reboost tracking, NAV may refine a CSDL force obtained prelaunch in a process akin to conventional burn confirmation (see Section 3.7.2.11.5). This empirical performance value may also be used on subsequent missions if the reboost method and stack mass properties are unchanged.

**CAUTION:** because the ISS ephemeris has no "V" integration option, no mated reboost modeling is performed therein. Care should be taken to purge acquisitions data from the ISS ephemeris after docking, restoring PSAT output only after the mission's final mated reboost is complete. See Section 3.4.3.3.

An input to a WGL table is specified to DYNAMICS as a weight change or as a total weight, together with the time (MET or GMT) of the change and the ephemeris to which it applies. After a WGL table input has been made to an ephemeris, the "EPHx-WGL UPDATE" DDD is illuminated until a TUP to this ephemeris is completed. Depending on input options, an ephemeris may or may not be immediately TUPed when the WGL entry is made. If the ephemeris is not TUPed, an "EPHEMERIS BAD" message appears on the corresponding WGL table display. When a TUP is completed, the message becomes "EPHEMERIS GOOD". A similar status message appears on TPS (see Figure 3.3.1-1). In its "BAD" state, an ephemeris status reminds FDO that a weight change has yet to be incorporated.

**CAUTION:** although WGL tables are displayed with both DELTA WT and TOTAL WT values, only the former are actually preserved during subsequent WGL updates. For example, suppose WGL Set 25 was input as TOTAL WT = 230000 lbm at next PLS deorbit TIG (> 4 hrs in the future). At the time this input was made, Set 24 had current TOTAL WT = 232000 lbm such that Set 25's DELTA WT = -2000 lbm. Now suppose TRAJ gets end-of-shift current mass properties and inserts a current time TOTAL WT WGL = 231000 lbm as the new Set 25. Because *only* DELTA WTs are preserved, the new Set 26's TOTAL WT shifts to 231000 - 2000 = 229000 lbm. To preserve the deorbit TIG prediction, Set 26 would have to be re-input as a 230000 lbm TOTAL WT WGL after the current weight input was performed.

### 3.3.1.7.1.3 Integrator Constants Updates

Sometimes FDO finds it necessary to change vehicle ephemeris integrator constants. The M51 MED is used by DYNAMICS in response to FDO requests to support changes in initial weight, integration options, and drag characteristics (area and K-factor). New constants may be required when initializing an ephemeris to model a spacecraft deployment or when updating a drag profile due to detected changes in solar flux. Changes can be verified on TPS (see Figure 3.3.1-1).

The M51 MED has a TUP option. If integrator constants are changed without an ephemeris TUP, the corresponding profile status will read "BAD". This reminds FDO these changes were not incorporated into the ephemeris. Any TUP to this ephemeris will result in a "GOOD" status.

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### **3.3.1.7.1.4 Ephemeris Length Updates**

Typically, 48-hour ephemerides are adequate for most trajectory applications. Ephemerides modeling complex trajectory operations, deploys, or day of rendezvous activities may be more abbreviated to expedite iterative TUPs. Long ephemeris lengths may be required, sometimes with multiple ephemerides chained end-to-end, but E2 can typically cover duration requirements < 20 days. The M00 MED is used by DYNAMICS to change ephemeris length, followed by the P16 MED to TUP, usually with the original anchor vector. If the ephemeris is not TUPed, its profile status (see Figure 3.3.1-1) remains "GOOD". This is technically correct, since altering ephemeris length does not render the existing trajectory invalid. On TPS, the new length appears next to the "EPHL" label, but the ephemeris still retains its original length until a TUP is performed.

### **3.3.1.7.1.5 Cargo Bay Door Status Table (CBDST) Updates**

Attitude-dependent drag modeling may reflect either fully open or fully closed cargo bay doors. Ephemerides with "A" integration options must therefore be TUPed after the Cargo Bay Door Status Table (CBDST) is updated. On FDO request, DYNAMICS will update this table with the P41 MED. Up to 10 open or closed entries can be made to the CBDST in either MET or GMT. The "CBDS-T/L UPDATE" DDD becomes illuminated after this MED is transmitted. Only after a subsequent E1 TUP is the DDD extinguished.

The CBDST is displayed with the Cargo Door Status display (see Figure 3.3.1.7.1.5-1). In addition to displaying times associated with each open (OPEN) or closed (CLOS) status, current vehicle ephemeris integration options are indicated. An "X" appears next to any vehicle ephemeris referencing the CBDST.

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```

112          CARGO BAY DOOR STATUS          A

      used  status      used  status
EPH1 X      |          | EPH6      | TUP reqd
EPH2 X      |          | EPH7 X    |
EPH3        |          | EPH8 X    | TUP reqd
EPH4        |          | EPH9 X    | TUP reqd
EPH5 X      | TUP reqd | EPH10 X  | TUP reqd

OPTION █████ TIME █████

      GMT          STATUS          MET
* 192:06:41:18.00 CLOS 000:00:00:00.00
* 192:08:11:18.00 OPEN 000:01:30:00.00

 ADD           UNDO
 DELETE        QUIT
    
```

**Figure 3.3.1.7.1.5-1: Cargo Door Status Display**

Normally, the CBDST contains three entries. The first is a CLOS at some time prior to launch. This insures the doors are closed at the start of any Orbiter ephemeris integration. The next entry reflects initial on orbit door opening, normally about 0/01:30 MET. The final entry is CLOS about 2 hours and 45 minutes before the deorbit burn. Additional entries can be made to account for temporary door closings during the flight, particularly in response to deorbit wave-offs.

### 3.3.1.7.2 TUPs for Unmodeled Perturbations

The effects of perturbations become apparent as tracking data of the Orbiter or target vehicles is processed by NAV. When these effects degrade ephemeris integrity beyond limits which are predefined or in accord with NAV's engineering judgment (see Section 3.5), the ephemeris should be updated with a new anchor vector created from the tracking data. Depending on tracking coverage and the cause of ephemeris degradation, time required for NAV to obtain an effective update may range from minutes to many hours. The following procedure serves as a guideline to TUPing either an Orbiter or target ephemeris.

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- 1) Using the Vector Compare display with output at current time, NAV shows FDO deltas between the latest tracking vector (commonly called the "current solution"), an Orbiter/target ephemeris vector, and an onboard Orbiter/target vector.
- 2) If the errors violate Flight Rule A4-101 or NAV's engineering judgment and NAV is satisfied with the latest tracking vector, FDO requests NAV (using the S85 MED) move the current solution to a standard Vector Administration Table (VAT) slot. Slot 39 (V39) is reserved for the Orbiter, while V38 is for a target.
- 3) Using the S44 MED (Vector Compare), NAV confirms the move to V38/V39. All zeros should be displayed on Vector Compare. Following this confirmation, NAV notifies both FDO and DYNAMICS the move has been made.
- 4) After move notification, FDO requests DYNAMICS TUP the desired ephemerides using V38/V39 as anchor. The appropriate "EPH x UPDATE" DDD will indicate a TUP in progress.
- 5) Using TPS, FDO verifies the TUP. The corresponding AVID and EPHB (see Figure 3.3.1-1) should be identical to the vector stored in V38/V39.
- 6) FDO requests NAV perform a Vector Compare between the TUPed ephemeris and V38/V39. The comparison should contain small deltas, indicating a good TUP.

### 3.3.1.8 TrS Vehicle Ephemeris Allocations

There are 10 vehicle ephemerides in TrS. Exact ephemeris use changes between Ascent, Orbit, and Entry phases. During Orbit, general ephemeris allocations are as follows.

<b>Ephemeris</b>	<b>Allocation</b>
E1	Short Term SSP
E2	Long Term SSP
E3	Prime ISS (or target vehicle)
E4	Contingency (Debris)
E5	ORB Onboard SV
E6	TGT Onboard SV
E7	MARS Rndz Planning
E8	Profile Rndz Breakout Planning
E9	Early COLA Assessment
E10	OA Planning

E1 thru E6 are considered "Golden" in that a command load can be built from them, a Flight-Critical call can be made from them, or products for customers external to DM can be generated from them. More information documenting previously approved standard ephemeris operations can be found in the *Flight Dynamics Operational Plan*, JSC-29853.

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### 3.3.2 TDRSS Ephemeris Updates

With FDO coordination, NAV and DYNAMICS maintain two parallel sets of TDRSS ephemerides.

- A) A set of TrS TDRS ephemerides is maintained to support NAV's orbit determination through these satellites. Because this tracking function is highly sensitive to radial velocity between the Orbiter and a TDRS, MCC-unique solar radiation pressure modeling capability in TrS TDRS ephemerides is required.
- B) A set of TSA TDRS ephemerides is maintained to support DFE/COMMAND TDRSS scheduling activities and INCO uplinks optimizing Orbiter communications and command capabilities with onboard antenna selection and pointing.

NOTE: as more and more TDRSS users compete for limited tracking and communications resources, updates to TDRSS scheduling are becoming increasingly frequent during Shuttle missions. Particularly during Shuttle crew sleep or other periods of low priority use, TDRSS support may be dedicated to other users. Although this can result in an extended LOS, it may be possible to schedule other TDRSS elements, such as TDRS-Z, to partially offset loss of communications or tracking coverage.

Periodic updates to TrS and TSA TDRSS ephemerides are required during the course of a mission. A set of six TDRSS vectors, spaced at 24-hour intervals, is received by NAV each Monday, Wednesday, and Friday from GSFC. These states serve as TDRSS ephemeris anchors because JSC is not capable of processing Bilateral Ranging Transponder System (BRTS) data, the system used for TDRSS orbit determination. The following procedure is recommended for TUPing TDRSS ephemerides.

- 1) Using the S85 MED, NAV will move new TDRSS vectors to the appropriate VAT slots.
- 2) After moves are complete, NAV will request permission from FDO to update the appropriate TDRSS ephemerides.
- 3) With FDO authorization, NAV works with DYNAMICS to TUP the appropriate TrS and TSA TDRSS ephemerides.
- 4) Using Vector Compare, NAV confirms TrS-based TDRSS ephemerides are updated, then notifies FDO the task is complete.
- 5) Using TSA Checkout Monitor and TPS Tier 1, TRAJ verifies TSA TDRSS ephemerides have expected initial longitudes, start times in the recent past, and 10-day durations.

### 3.3.3 Trajectory Mirroring with AutoMOC

Trajectory mirroring software, collectively referred to as "AutoMOC", is split into 3 function-specific components. All AutoMOC components are under FDO's direct control.

- 1) **AutoUIF:** dedicated graphic user interface with cyclic status updates
- 2) **AutoEph:** TrS E1-10 mirroring to TSA SSP Global M1-10

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### 3) **AutoVAT**: two-way VAT mirroring between TrS and TSA SSP Global

An AutoUIF illustration appears in Figure 3.3.3-1. AutoUIF shows status for all 10 ephemeris mirrors and the VAT mirror.

File Help					
EphM1	EphM2	EphM3	EphM4	EphM5	AUTOVAT
WST152 GOOD INCN 16 16 white-fcr10 N 2 MPT 2	ORB149 GOOD GOOD 11 11 white-fcr10 V 0 MPT 0	ORB149 GOOD GOOD 35 35 white-fcr10 N 1 MPT 1	ORB149 GOOD GOOD 28 28 white-fcr10 N 1 MPT 1	ORB149 GOOD GOOD 2 2 white-fcr10 N 1 MPT 1	VAT Mirror white-fcr10
EphM6	EphM7	EphM8	EphM9	EphM10	
TVT021 BAD GOOD 0 4 N 0 MPT 0	EST027 BAD GOOD 0 31 N 0 MPT 7	ORB025 BAD GOOD 0 4 N 0 MPT 0	GOOD NONE 2 -1 N 0 MPT 0	GOOD NONE 4 -1 N 0 MPT 0	
General Status Message:					

**Figure 3.3.3-1: AutoUIF Appearance**

Each pane or block comprising AutoUIF's interactive region corresponds to an AutoEph or AutoVAT mirror and is independently colored to convey general red/yellow/green/blue status. A pane also displays detailed mirroring information. Below the ephemeris and anchor ID fields, each AutoEph block displays ephemeris status and TUP count for the TrS source on the left and the TSA mirror on the right. Section 3.3.4 provides definitions for ephemeris status indications. Displayed beneath the ephemeris status and TUP count is the controlling workstation supporting the mirroring workload, together with a Y/N indicator of STDN options ON/OFF (see Section 3.4.2.2). If a block display is red, mirroring is disabled. Mirrored MPT information is displayed at the bottom of each block. Each block is colored to provide a general health indication. Red coloration indicates mirroring is disabled. Yellow coloration indicates mirroring is enabled, but the mirror is not synchronized with its TrS source. A yellow condition typically arises during an update, particularly one requiring extensive acquisition computations with STDN options On. Blue coloration indicates ephemeris files could not be read. Green coloration indicates all updates are complete.

**CAUTION:** to avoid excessive workstation loading and inconsistent acquisitions in an AutoEph mirror, toggle STDN options OFF in all active mirrors prior to performing TSA TDRSS ephemeris TUPs. The only exception to this action would be a STDN options ON primary ephemeris known to be free of any TDRSS secondary ephemeris subscriptions undergoing TUP.

A mirror is enabled or disabled with a right-click in the corresponding AutoUIF block's title string. This invokes the AutoUIF pop-up menu as illustrated in Figure 3.3.3-2. Note Start/Stop menu items in the Figure 3.3.3-2 example are disabled. This is because M3 is currently being mirrored by the WFCR-10 workstation, while AutoUIF is being displayed elsewhere. Only the workstation currently mirroring a MOC ephemeris has capability to stop mirroring that ephemeris. The pop-up menu's PSAT and AcqMon items will invoke

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corresponding user interfaces in a context corresponding to the pertinent TrS ephemeris mirror.

File		Help		EphM1		EphM2		EphM3		EphM4		EphM5		AUTOVAT	
		ORB088		EST032		HST026		LE1		VAT Mirror		white-fcr10			
		GOOD GOOD		BAD GOOD		BAD INCN		GOOD NONE		VAT Mirror		white-fcr10			
		3 3		0 37		0 1		0 0		white-fcr10		white-fcr10			
		white-fcr10 Y		N		N		N		white-fcr10		white-fcr10			
		0 MPT 0		0 MPT 0		0 MPT 0		0 MPT 0		white-fcr10		white-fcr10			
		EphM6		EphM7		EphM9		EphM10		white-fcr10		white-fcr10			
		GOOD NONE		GOOD NONE		GOOD NONE		GOOD NONE		white-fcr10		white-fcr10			
		0 -1		0 -1		0 -1		0 0		white-fcr10		white-fcr10			
		N		N		N		N		white-fcr10		white-fcr10			
		0 MPT 0		0 MPT 0		0 MPT 0		0 MPT 0		white-fcr10		white-fcr10			
		Start		Stop		TPS		Nodal Display		MPT		PSAT		ACQMON	
		0 MPT 0		0 MPT 0		0 MPT 0		0 MPT 0		0 MPT 0		0 MPT 0		0 MPT 0	
		General Status Message:													

Figure 3.3.3-2: AutoUIF Pop-Up Menu Mirror Controls

### 3.3.4 TSA Trajectory Profile Status

There are 16 vehicle ephemerides in TSA, with 8 being in Local and 8 in Global. TSA ephemerides are typically used during pre-mission planning. All of the products delivered by Lead FDO prior to launch will also use a TSA ephemeris as their trajectory source. The differences between TSA and TrS ephemerides are detailed in this section.



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Both ephemeris maintenance and post-processing functions are facilitated in TSA by an interactive, 2-tiered Trajectory Profile Status (TPS) capability. The TPS performs cyclic updates every 5 sec or so. High-level status for all ephemerides is provided by the TPS Tier 0 display. An example appears in Figure 3.3.4-1.

SSP GLOBAL TPS DISPLAY						
File	Edit	Entry	Details	View: ^ Local ^ ISS	SSP	00:05
ID	STAT	T#	Updated	Comments		
Eph1	T GOOD	4	036/07:18	Case A: 160 nm @ 28.5 deg		
Eph2	NONE		000/00:00			
Eph3	T GOOD	45	036/07:29	ISS MRO 4 (EST 112)		
Eph4	NONE		000/00:00			
Eph5	NONE		000/00:00			
Eph6	T GOOD	3	026/03:17	WLP 109: AUTOMOC Eph# 1		
Eph7	NONE		000/00:00			
Eph8	GOOD	26	021/18:46	WST 029: AUTOMOC Eph# 1		
EphM1	GOOD	26	021/18:46	WST 029: AUTOMOC Eph# 1		
EphM2	GOOD	23	021/22:49	FLT 015: AUTOMOC Eph# 2		
EphM3	INCN	4	021/21:46	ASC 059: AUTOMOC Eph# 3		
EphM4	INCN	4	021/23:27	TVT 015: AUTOMOC Eph# 4		
A023E	T GOOD	1	111/00:58	TDRS 047 Vector		
EphR	GOOD	1	028/03:06	AutoMOC: Entry to KSC33/64		
KSC000STIN00	T GOOD	4	028/04:03	Case A: 160 nm @ 28.5 deg		
T041W	T GOOD	4	022/02:01	TE 041		
T047W	T GOOD	32	022/02:01	TDRS 047 Vector		
T049W	NONE		000/00:00			
T171W	T GOOD	16	022/02:03	T171W		
T174W	T GOOD	4	022/01:55	TW 174		
T275W	T GOOD	14	022/01:59	TDRS 275		

Detailed display launched.

Figure 3.3.4-1: TPS Tier 0

Radio buttons are provided to "View" only those ephemerides associated with the TSA database segment selected (Local, ISS Global, or SSP Global). A timer appears to the right of these radio buttons, indicating min:sec since the last cyclic Tier 0 update. Each ephemeris-specific record in Tier 0's table contains the following information.

**ID:** the name by which an ephemeris "Location" is referenced in the TSA database. Vehicle ephemerides are Eph1-8, and TrS ephemerides mirrored by AutoEph are EphM1-4 in this figure although there are 10 possible TrS ephemeris mirrors. The prime entry ephemeris is EphR. It may be mirrored from TrS whenever an EDS run is performed with the "make prime" output flag enabled. Case-specific EDS output may also be promoted to a Global entry ephemeris via copy/paste. A case-specific ID is of the form "SSSoooAPCHrr", where SSS = landing site ID, ooo = deorbit TIG orbit number, APCH = "STIN" (straight-in approach) or "OVHD" (overhead approach), and rr = targeted runway. Each TDRSS ephemeris has an ID of the form "AnnnB", where A = any alphabetic character (typically "T" is used unless another letter is required to avoid duplication), nnn = mean nadir longitude, and B = longitude direction ("E" or "W" of the Prime Meridian).

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**NOTE:** FDO, NAV, and DYNAMICS can create any subdirectory permitted by UNIX in an Ephem directory, and TPS Tier 0 will display it. For this directory to be processed by TSA, however, it must conform to the foregoing ID naming conventions. In the case of a TDRSS ephemeris, the ID must also appear in the pertinent Vector Routing File (VRF) maintained by NAV or DYNAMICS in the `Global/Vectors/` directory.

**NOTE:** the TSA SCT still maintains a perfectly geostationary TDRSS constellation of "tall mountains" in its "T" site group.

**TUPability:** a "T" follows the ID field only if the ephemeris is TUPable by TSA's Ephemeris Update menu. This column will be blank for empty ephemeris directories, unTUPable TrS mirrors, and promoted EDS ephemerides.

**STDN:** an asterisk follows the TUPability column only if the ephemeris will automatically be post-processed by PSAT after an update occurs. An asterisked Tier 0 ephemeris is therefore equivalent to a STDN-enabled ephemeris. Because PSAT can operate on any ephemeris residing in TSA's database, both TUPable and unTUPable ephemerides may be STDN-enabled.

**STAT:** indicates the current status of an ephemeris update or of PSAT post-processing as follows.

**GOOD** all updates and post-processing are complete. Acquisition data, if present, are consistent with all pertinent ephemeris trajectories.

**BAD** an update has suffered a non-recoverable error. Neither the ephemeris trajectory nor its acquisitions should be used.

**NONE** no update has occurred since the ephemeris was created or deleted. The ephemeris is empty.

**BUSY** an update from a TSA-external source (AUTOEph or EDS) is in progress.

**TUP** an update by TSA's Ephemeris Update is in progress.

**TUP2** A secondary ephemeris has been updated during the TUP of a primary ephemeris.

**PSAT** acquisition post-processing by PSAT is in progress.

**INCN** PSAT data are present which predate the last ephemeris update. Associated acquisition data may be inconsistent with the ephemeris trajectory and should not be used.

**INC2** PSAT data are present which predate a relevant secondary TDRSS ephemeris update (a secondary ephemeris TUP occurred during a PSAT run on this primary ephemeris). The PSAT menu has previously established subscription links between this primary ephemeris and one or more TDRSS secondaries. Any TDRSS acquisitions may be inconsistent with recent TDRSS ephemeris updates and should not be used.

**T#:** tallies the number of updates since the ephemeris was created or deleted.

**Updated:** displays elapsed time in days/hrs:min since the last update.

**Comments:** displays the comment string entered to the TSA Ephemeris Update menu if the ephemeris is TUPable. In the case of unTUPable ephemerides, the comment is supplied by AutoEph or EDS.

The TPS Tier 0 table is interactive. Left-click in an ephemeris record to select it, and Tier 0 will indicate your action by setting the record's background coloration to white. You may now invoke Tier 0 Edit menu items (see Figure 3.3.4-2) to Cut/Copy/Paste/Delete an

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ephemeris, including its associated PSAT acquisition data. An ephemeris Paste operation offers two mutually exclusive options: Insert or Replace. If you select Insert, you must specify a new ephemeris directory name to receive the Paste data. A Replace first purges all data from the ephemeris selected in Tier 0, then stores all data captured from the ephemeris selected when a Cut or Copy was previously performed.

SSP GLOBAL TPS DISPLAY								
File	Edit	Entry	Details	View:	Local	ISS	SSP	00:02
ID	Select All		dated					Comments
Eph1	Deselect All		2/06:18	Anchor				Ephemeris
Eph2			2/05:57	Mnvr				Ephemeris
Eph3	Cut	Ctrl-X	0/00:00					
Eph4	Copy	Ctrl-C	2/06:03	Mnvr				Ephemeris
Eph5			8/05:23	Mnvr				Ephemeris
Eph6	Paste	Ctrl-V	0/00:00					
Eph7			0/00:53	WS				001 Sim Start Orbiter
Eph8	Delete		0/00:02	WS				001: AUTOMOC Eph# 1
EphM1		*GOOD	4 000/00:02	WS				001: AUTOMOC Eph# 1
EphM2		BAD	4 000/00:16	WS				001: AUTOMOC Eph# 2
EphM3		INCN	1 000/01:06	WS				001: AUTOMOC Eph# 3
EphM4		INCN	2 000/00:16	WS				001: AUTOMOC Eph# 4
A023E		NONE	000/00:00					
EDW2020VHD22		GOOD	2 008/06:13	EPS				Entry:Tue Dec 5 10:00:52 2000
EDW2030VHD22		GOOD	2 008/06:55	EPS				Entry:Tue Dec 5 09:18:06 2000
EphR		T BAD	0 000/00:00					Default values
KSC000STIN00		NONE	000/00:00					
KSC154STIN15		GOOD	5 008/03:07	EPS				Entry:Tue Dec 5 13:06:46 2000
KSC2010VHD15		GOOD	3 008/06:22	EPS				Entry:Tue Dec 5 09:51:22 2000
NOR2020VHD17		NONE	000/00:00					
S041W		T GOOD	1 042/00:17	T041				from SMS ENV
T041W		T GOOD	5 000/00:03	TDRS				SPARE 041 (V43)
T047W		T GOOD	81 000/01:22	TDRS				047 Vector
T049W		T GOOD	2 000/01:00	T049W				= TDRS-1A (8302602)
T171W		T GOOD	66 000/00:29	T171W				
T174W		T GOOD	5 000/00:32	Case I:				T174W @ 2.2 deg
T275W		T GOOD	3 000/01:13	T275W				= TDRS-3C (8809102)

Figure 3.3.4-2: TPS Tier 0 Edit Menu

**CAUTION:** any Delete or Paste operation targeting a TSA Global ephemeris should only be performed by FDO or at FDO's explicit direction.

**CAUTION:** subscription links may exist between a primary ephemeris being deleted or pasted and other TDRSS secondary ephemerides supporting PSAT acquisition computations. Whereas TPS Tier 0 insures these links are modified accordingly following a Delete or Paste, the Xdir utility isn't link-savvy. Consequently, Xdir should no longer be used to delete or copy ephemerides except to archive destinations outside the TSA database. Following an Xdir restore to the TSA database, the state of any archived links should promptly be checked and updated as necessary via the PSAT menu.

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**CAUTION:** when a Global ephemeris is copied to a Local ephemeris using TPS Tier 0, any subscriptions to TDRSS secondary ephemerides will be dissolved in the Local copy. If these subscriptions are to be preserved in Local, they must be manually reactivated using the PSAT menu.

**CAUTION:** TPS Tier 0 will generally preserve the Cut or Copied PSAT configuration after Pasting into another ephemeris. The only exception is a Paste into EphR. In that case, whatever previous PSAT configuration existed in EphR is preserved.

With a TPS Tier 0 ephemeris record selected, right-click anywhere in the Tier 0 window and select the "Start..." item to invoke the context menu. This menu accesses TSA functions in a context consistent with the selected ephemeris. Interaction with TSA DNAV nested menus is thereby minimized. Options associated with Tier 0's context menu are illustrated in Figure 3.3.4-3.

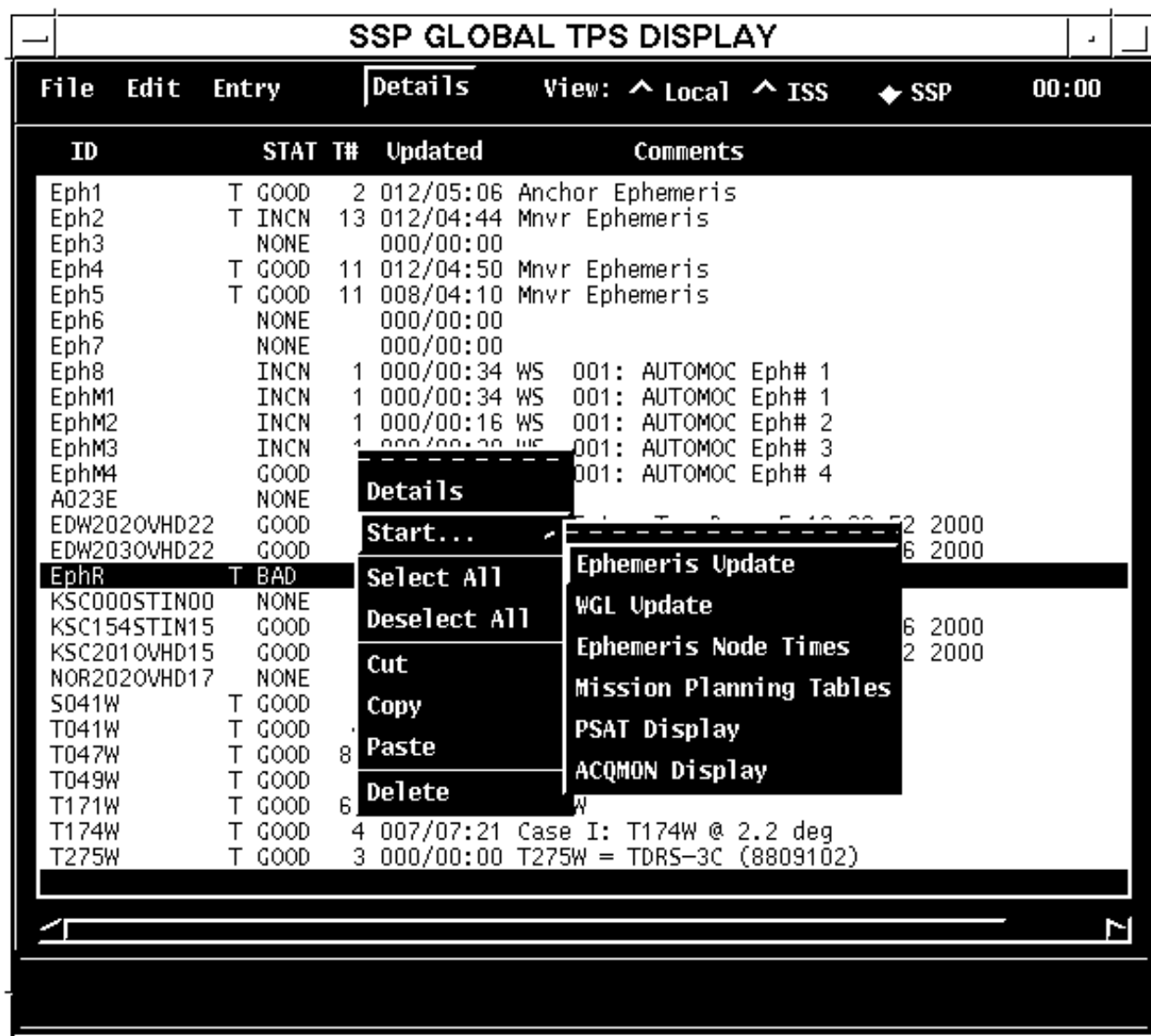


Figure 3.3.4-3: TPS Tier 0 Context Menu

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A final interactive TPS Tier 0 capability permits Tier 1 to be invoked for any selected ephemeris. After a Tier 0 left-click selects an ephemeris, its Tier 1 display may be invoked in either of two ways. You may either left-click Tier 0's Details button, or you may select the Details item from Tier 0's context menu (see Figure 3.3.4-3). A TPS Tier 1 example appears in Figure 3.3.4-4.

```
SSP GLOBAL
File                                00:05
EPHEM ID: Eph1                      STAT: GOOD TUP #: 4
NUM MNVRS: 0                        KVAR: 1.000
INITWT: 230000.0                    KCON: 1.000
EPHBWT: 230000.0                    AREA: 0.00
END WT: 230000.0                    INT OPT: DM
AVID: L V1                          G: 267:16:00:00.000
COMMENT: Case A: 160 nm @ 28.5 deg
LENGTH: 120.000 ORB/DDY/DORB: 70/ 5/ 8
GMTR: 2000:263:06:18:00.000          STDN: N
EPHB G: 267:16:00:00.000 M: 004:09:42:00.000
EPHE G: 272:16:00:00.000 M: 009:09:42:00.000
```

Figure 3.3.4-4: TPS Tier 1

The major Tier 1 interactive feature of interest is a context menu akin to Tier 0's (see Figure 3.3.3-3). It's invoked with a right-click anywhere in the Tier 1 window.

**CAUTION:** unlike TrS TPS, the Tier 1 anchor vector GMT display (the GMT epoch displayed to the right of AVID) *always* indicates precisely that. For a given anchor, this Tier 1 display will remain unchanged regardless of the ephemeris static start time.

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Some features of the TSA Ephemeris Update menu are worthy of note. An example of this menu's configuration appears in Figure 3.3.4-5 for a TDRS ephemeris. DYNAMICS is responsible for TSA TDRSS ephemeris TUPs (see Section 3.3.2 for TDRSS ephemeris update procedures).

TUPABLE		FDO EPHEMERIS UPDATE				CURRENT		
SYSTEM	VEHICLE	LOCATION						
EPHEMERIS	T047W	SSP	T047W	STATUS	GOOD	TUP	32	
				NUMBER OF MNVRS		0		
EPH COMMENT TDRS 047 Vector								
WEIGHTS	INIT WT	EPHB WT	CUR WT	KCON	1,000			
VEHICLE	3968.8	0.0	0.0	KVAR	1,000			
OMS	N/A	N/A	N/A	AREA	430.56			
RCS	N/A	N/A	N/A	INT OPTS	D (A,D,VA,VAM,AM,DM)			
SYSTEM		VEHICLE	LOCATION	STDN OPT	N (Y,N)			
ANCHOR SOURCE	M	ISS	V18	GMTR	G 2001:018:11:14:08,000			
ANCHOR VECTOR TIME	M 001:12:29:52,000			TRANSFER WTS?	N (Y,N)			
STATIC START TIME	M 001:12:29:52,000			EPHB ORB DAY	2	NO.	1	
STOP TIME	D 002:00:00:00,000			EPHB ORB NO.	2			
EPHB	2001:019:23:44:00,000			METB	001:12:29:52,000			
EPHE	2001:021:23:44:00,000			METE	003:12:29:52,000			
HELP	EXECUTE	SAVE MENU	EXIT MENU	OVR	FETCH EPH	EDIT WGL	DISPLAY MPT	DISPLAY VAT
F1	F2	F3	F4		F6	F7	F8	F9

Figure 3.3.4-5: Ephemeris Update Menu

Figure 3.3.4-5 illustrates how each TDRS is implemented as a unique SYSTEM in the TSA database akin to TSA's Local and Global SYSTEMs. As such, each TDRS SYSTEM enjoys a dedicated VAT. Unlike Local and Global, however, a TDRS SYSTEM has but one ephemeris LOCATION. Moreover, this ephemeris LOCATION has the same name as its SYSTEM. Because a TDRS ephemeris LOCATION is effectively redundant with its SYSTEM, the Ephemeris Update menu will accept an "E" or "e" for LOCATION once SYSTEM is specified. To minimize interacting with Ephemeris Update menu SYSTEM/VEHICLE/LOCATION fields, invoke the menu using a TPS Tier 0 or Tier 1 context menu. These fields at the top of the menu will be filled in by contextual access, leaving only SYSTEM/VEHICLE/LOCATION for the anchor vector to be specified.

**CAUTION:** like all menus with a TOAST heritage, Ephemeris Update requires you press the return key to register any input. Consequently, only use enter, tab, and arrow keys to *navigate* among fields in this menu. Always use the return key to *register* an input, or unintended results (including aborted TUPs) may be obtained when the menu is executed or saved.

### 3.3.4.1 TSA Orbit Prediction Theory and Integrator Constants

The following accelerations are modeled during TSA orbit prediction and ephemeris generation.

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- 1) Earth gravity acceleration uses the same GEM10 coefficients, truncated to seventh degree and order, as does the TrS model. Unlike the TrS model, TSA uses Pines' recursion method and suffers no singularities near the geographic poles.
- 2) Lunisolar gravity acceleration uses lower fidelity analytic Sun/Moon ephemerides, as opposed to JPL DE 118 positions in TrS. Although the TSA model is inadequate for precision prediction near the Moon and in interplanetary space, it does satisfy LEO and GEO requirements. Moreover, the analytic TSA approach does not require Sun/Moon ephemeris file reconfiguration when prediction outside the original calendar year is desired. This is necessary in TrS.
- 3) The 1962 Standard Atmosphere table provides densities supporting ballistic atmospheric drag acceleration modeling below 125 km (67 nm; 410105 ft). The Jacchia-Lineberry density model is used from 125 to 2500 km (1350 nm).
- 4) Propulsive accelerations are computed with PFNI according to the MPT and ECT.

NOTE: TSA doesn't model propulsive vent or solar radiation pressure accelerations. The latter perturbation is significant to TDRSS-based orbit determination and is only modeled by TrS TDRSS ephemerides dedicated to that function. TSA TDRSS ephemerides support acquisitions and Orbiter antenna management functions not requiring the level of fidelity provided by solar radiation pressure modeling. Their prediction theory is identical to any other TUPable TSA ephemeris.

Ephemeris-specific constants in TSA govern ballistic aerodynamic acceleration modeling as follows. These are specified on the Ephemeris Update menu (see Figure 3.3.4-5). TPS Tier 1 (see Figure 3.3.4-4) displays values for these constants.

- 1) **KCON** is a dimensionless constant-area drag scale factor. Inclusive limits are a -999.999 minimum and a +999.999 maximum. Because  $KCON < 0$  is supported, a crude posigrade acceleration can be approximated akin to a TrS +V vent.
- 2) **AREA** is the effective average vehicle surface area in  $\text{ft}^2$  encountering the flux of atmospheric particles. Inclusive limits are a minimum of -99999.99 and a maximum of +9999.99.
- 3) **INTGR OPT** are limited to **D** (constant-area drag acceleration) and **M** (maneuver accelerations). The only combinations supported in TSA are D and DM.

NOTE: the TSA Ephemeris Update menu displays A, VA, VAM, and AM integrator options, but these are not implemented. An error message will appear at the bottom of the menu if these unsupported options are specified.

Solar flux ( $F_{10.7}$  in Jansky\*  $10^4$ ) and geomagnetic index (dimensionless  $K_p$ ) values are used in TSA Jacchia-Lineberry atmospheric density modeling. They are input in the Jacchia Table (see Figure 3.3.4-6). Values in the table are applicable to a day of year. Whenever TSA predicts at times between days in the table, the  $F_{10.7}$  and  $K_p$  are linearly interpolated between adjacent bracketing values. To replicate constant values used in TrS, specify the TrS  $F_{10}$  and  $K_p$  from GNAV TRAJ INIT (see Figure 3.3.1-2) repetitively in the TSA table such that the period of interest is bracketed and interpolation operates on a function of time with zero slope.

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**CAUTION:** although the time period covered by TSA's Jacchia Table is reconfigurable, it may occasionally be necessary to predict trajectories before or after this interval. In such cases, TSA will linearly *extrapolate* the nearest two table entries to obtain F10 and  $K_p$  values used in prediction. It may therefore be desirable to enter identical F10 and  $K_p$  values for the first or last two Jacchia Table lines when predicting before or after the table, respectively.

LOCAL		JACCHIA TABLE				CURRENT	
YEAR	DAY	F10.7	$K_p$	YEAR	DAY	F10.7	$K_p$
1998	62	104.70	2.39	2003	62	131.00	2.95
1998	153	115.50	2.65	2003	153	131.00	2.95
1998	245	127.78	2.78	2003	245	131.00	2.95
1998	336	132.64	2.68	2003	336	131.00	2.95
1999	62	145.50	2.57	2004	62	101.10	3.21
1999	153	152.30	2.64	2004	153	97.80	3.19
1999	245	158.15	2.72	2004	245	93.25	3.21
1999	336	172.45	2.76	2004	336	89.87	3.14
2000	62	176.70	3.03	2005	62	86.60	3.04
2000	153	178.90	2.95	2005	153	83.60	3.02
2000	245	177.85	2.87	2005	245	80.77	2.99
2000	336	173.53	2.94	2005	336	78.07	3.01
2001	62	166.90	2.78	2006	62	75.70	3.05
2001	153	164.90	2.78	2006	153	73.60	3.00
2001	245	159.65	2.81	2006	245	71.88	2.96
2001	336	155.23	2.84	2006	336	70.59	2.93
2002	62	148.20	2.93	2007	62	69.90	2.90
2002	153	142.10	3.00	2007	153	69.90	2.73
2002	245	136.35	3.01	2007	245	71.02	2.54
2002	336	131.00	2.95	2007	336	72.72	2.38

HELP	EXECUTE	SAVE MENU	EXIT MENU	OVR	HARDCOPY			
F1	F2	F3	F4		F5	F6	F7	F8

**Figure 3.3.4-6: TSA Jacchia Table**

### 3.3.4.2 Ephemeris Weights

TSA does not keep track of OMS and RCS weight. There are 3 weights displayed in a TPS Tier 1 ephemeris-specific window (see Figure 3.3.4-4): INIT WT, EPHB WT, and END WT. The INIT WT is the weight entered in the Ephemeris Update menu (see Figure 3.3.4-5). EPHB WT is the weight at the start time of the ephemeris. The INIT WT and EPHB WT will usually be the same as the value entered in the EPHEMERIS UPDATE window. The EPHB WT can be different than the INIT WT if there is a WGL between anchor vector time and ephemeris static start time. The END WT reflects all WGLs between anchor vector time and ephemeris end time. In contrast to TrS, a TSA WGL "remembers" if it was specified as a total or delta weight. Thus, a total weight WGL will prevail in TSA even if other delta weights are subsequently inserted prior to it. In addition, TSA automatically maintains any weight loss from a maneuver as a dedicated line item in the corresponding ephemeris WGL table.



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### 3.3.4.3 Anchor Vector

Unlike TrS, the TSA TPS Tier 1 anchor vector time (see field to the right of AVID in Figure 3.3.4-4) is displayed as a value independent from the ephemeris start time. Thus, a static start time differing from that of the anchor epoch may be directly verified on TPS Tier 1.

### 3.3.4.4 Orbit Counters

A TSA ephemeris maintains 3 orbit count parameters as follows (see Figure 3.3.4-4). Only the first of these counters is duplicated in TrS.

- 1) **ORB** is the mission orbit count. It's initialized to 1 at launch and is never reset.
- 2) **DDY** has no operational use. It's a count of the number of times daily orbit (DORB) has been recycled to 1.
- 3) **DORB** is the daily orbit count. It recycles to 1 on the first ascending node west of 20° East longitude. At ISS altitudes, the count reaches 15 (~70% of days) or 16 (~30% of days) before recycling. The probability of reaching DORB = 16 on a given day increases at lower altitudes.

### 3.3.4.5 Ephemeris Length

TSA ephemeris length is limited to 180 days, 9 times greater than the TrS limit.

### 3.3.4.6 STDN Options

The Ephemeris Update menu (see Figure 3.3.4-5) permits STDN OPT to be toggled Y (YES) or N (NO). This function is also provided on the PSAT menu (see Section 3.4.2.2). When Y is specified, PSAT will automatically compute acquisitions for the entire ephemeris duration following each time this ephemeris is TUPed. Which acquisitions are computed can only be specified through the PSAT menu.

### 3.3.4.7 Trajectory Update (TUP) Procedures

Standard TSA TDRSS ephemeris TUP procedures are documented in Section 3.3.2. Any other TSA TUPs to G1-8 or L1-8 will probably be performed by FDO or TRAJ using the Ephemeris Update menu (see Figure 3.3.4-5). Because these ephemerides are essentially limited to DM integrator options, there are no external ATL, VTL, or CBDS dependencies to consider. Only the pertinent Jacchia Table, ECT, and MPT are relevant. The following Ephemeris Update menu behavior is noteworthy.

- 1) Several menu fields (notably EPH COMMENT and INIT WT) are dependent on the specified ANCHOR SOURCE field. However, these fields will only update to reflect the source if they're blanked before return is pressed from the ANCHOR SOURCE field and a valid anchor vector is fetched.

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- 2) Orbit number fields reflect the specified STATIC START TIME. If the specified ANCHOR SOURCE is a VAT slot, orbit number fields are guesses based on this anchor state vector's current orbit period. It may be necessary to verify and correct these guesses manually. Although TrS mission orbit count is limited to 999 or less, TSA can maintain counts through 9999.
- 3) Unlike TrS, TSA ephemeris duration need not be specified explicitly. Duration can be inferred from STATIC START TIME and a STOP TIME provided in GMT or MET. Using the "D" (DELTA) input mode, STOP TIME can also be specified as an ephemeris duration.

### 3.3.5 State Vector Processing

This section documents tracking data analysis computations supervised by NAV, together with commonly used utility software to manipulate state vectors.

#### 3.3.5.1 Orbit Determination and Differential Correction

The process of obtaining orbit elements or state vectors from sensor observations is called orbit determination. At the FDO Console, this process is nearly transparent. Procedures associated with differential correction of these elements are more visible to FDO, however.

Orbit determination uses radar tracking data to determine best-estimate state vectors. In theory, an orbit is completely determined if 6 independent time-tagged observations are available. An example of a complete observation set would be azimuth, elevation, range, and the time derivatives of each. On the other hand, knowledge of the orbit can be accurately refined using less data than is required for complete orbit determination. This process is called differential correction. For example, differential correction could be performed if six or more time-tagged range rates were available. The tracking data and parameters NAV actually uses for differential correction include the following sources.

- 1) TDRSS: Doppler data are received from the Orbiter's S-Band transponder. Range data can also be received from targets, such as HST, equipped with a TDRSS-compatible transponder.
- 2) Ground Space Flight Tracking and Data Network (GSTDN): X-angle, Y-angle, range, and S-Band transponder Doppler data are received. Note that a complete orbit determination is possible from these data.
- 3) C-band Radars: range, azimuth, and elevation are obtained without accompanying rates.
- 4) Remote Tracking Sites (RTS): azimuth, elevation, and Doppler data from the S-Band transponder are received. These sites have yielded tracking solutions of mixed quality in the past and are no longer used for orbit determination.

Differential correction (DC) is necessary because unpredictable forces, such as atmospheric drag and attitude maneuvers, perturb the orbit. Although we do mathematically model some perturbing forces such as those due to gravity, the models are never perfect. As a result, the actual orbit gradually deviates from that predicted.

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The DC processor computes sensor observations based on the current state vector, then compares them to the actual observations. Differences between the values of actual and predicted parameters, called residuals, are statistically analyzed, and the results are used to update the state vector.

After DC software integrates a vector to the beginning of a sensor pass, it predicts the values of certain tracking parameters (azimuth, elevation, etc.) throughout the pass. When actual radar data are received, they are collected in "batches", and actual tracking parameters are compared to those computed. The DC program computes and averages residuals, then determines the associated standard deviations (sigmas). If necessary, NAV may manually edit out obviously anomalous data to obtain a "clean" DC solution.

These solutions are obtained for subsequent acceptable sensor passes using a technique called "batch-to-batch" processing. NAV evaluates the data quality, decides whether or not the pass should be used, and determines the weighting factor each pass is allowed to have on the combined solution. As more sensor data are gathered and incorporated, the square root of the sum of the squares (RSS) of the residuals becomes smaller and smaller. At this point, a curve fit through the actual data is nearly identical to a prediction that becomes the DC solution. The increased accuracy of this solution is reflected by changes to a covariance matrix, which contains history data used as a weighting factor in DC calculations.

Conceptually, the covariance matrix mathematically describes a series of error ellipses defining a tube along the vehicle's actual trajectory over time. Immediately after orbit insertion, before any radar data have been processed, the tube's cross-section is large because of trajectory dispersions during ascent. When NAV processes the first batch solutions and performs a DC, the cross-section shrinks. Eventually, the cross-section becomes very small, closely circumscribing the actual flight path. During orbit operations, as subsequent tracking data are processed, the imaginary tube alternately swells and shrinks about the actual trajectory. Swelling occurs during periods of limited or degraded tracking coverage, and following maneuvers or unanticipated orbit perturbations. One of several available covariance modes is selected by NAV to begin DC processing. The following modes may be selected by PBI or by MED entry.

- 1) SS1: no a-priori covariance matrix exists. This option assumes current processing is not constrained by any past observation history.
- 2) SS2 and SS3: these modes employ predetermined, canned covariance matrices and are rarely used. SS2 constrains the orbit plane to that of the a-priori state vector but allows in-plane orbit elements to change. SS3 constrains vent components to specified axes during long arc superbatches DC processing to solve for perturbations caused by venting.
- 3) SS4: this is the default covariance mode used for normal batch-to-batch processing. It uses the covariance matrix associated with the input anchor vector. This PBI executes the DC process knowing there is uncertainty in the state vector and previous data have been processed.
- 4) K-GAMMA: this mode opens up the covariance matrix and allows the current batch of tracking data more freedom to correct the input state vector. In other words, K-GAMMA downweights the covariance matrix, allowing the current batch to more strongly influence a solution. This option might be selected following an orbit burn or attitude maneuver, when trajectory dispersions are expected to be larger than usual.

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Since the quality of solutions output by the DC processor is directly related to tracking data quality, great care must be taken to insure bad data are not included in DC processing. If tracking data fall within the ignition and cutoff times of a burn defined in the MPT, they are automatically discarded. This is because DC processing assumes free-fall coasting flight. Any translations during a tracking pass may cause similar problems. Both pre-flight and in real time, care should be taken to avoid scheduling burns or attitude maneuvers, vents, or water dumps during a critical tracking arc.

Once a DC solution is complete, a new covariance matrix and state vector are computed. The covariance and state are then integrated to the next tracking station's batch acquisition time, and the DC process is ready to be invoked once again.

### 3.3.5.2 State Vector Comparison Processor

With MED inputs from NAV, the vector comparison process provides time-homogeneous elements for up to four state vectors. Up to three element sets may then be subtracted from the designated "base" set to infer trends among the original states. This process involves two steps. First, all vectors to be compared are integrated to a specified "output" epoch. Next, the integrated, time-homogeneous states are passed to the Vector Elements Calculator (VEC). The VEC in turn computes quantities referenced by Vector Comparison (VC) Display 1/2. There are actually 4 VCs, but only 1 and 2 are accessible to FDO.

The VC displays a base vector and up to three comparison vectors. The left-most column contains absolute (as opposed to differenced) elements of the base vector as integrated to the output epoch. The other columns show differences between base vector elements and those of the comparison vectors as integrated to the same output epoch. These differences are obtained in the sense "base minus column". Under this "fly-to" convention, a differenced element may be thought of as "what you'd have to add onto the corresponding absolute column element to obtain the corresponding base value".

Both GMT and MET of the output epoch are displayed near the top left of VC. These fields have "OUTPUT GMT" and "OUTPUT MET" labels, respectively. Each element set displayed by VC is headed by the corresponding state's GMT epoch prior to integration, followed by a vector ID and the ephemeris or DC link from which integration parameters are obtained. Figure 3.3.5.2-1 illustrates the Vector Comparison Display. Section 9.2.1 explains each VC field of in detail.

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<b>112</b>		Vector Compare 1			C
GMT: 192:22:53:08		MET: 00:16:11:50			
LINK/EPH: S1		INTEG: VAM	REF: M50	UNITS: FS	
OPTION: TIME		VALUE: 192:21:55:14.000			
		THRESH TIME: 192:21:55:14.000			
OUTPUT GMT: 192:21:55:14.000		OUTPUT MET: 000:15:13:56.000			
<b>TIME</b>	192:21:55:14.000	192:21:11:18	192:22:51:09.		
<b>NAME</b>	BS10 029 EPHE1	ORBITR001 EPHE1	FLTI 000 EPHE1	EPH	
X	13822510.714	-11.117	353.170		
Y	199949.322	-1503.051	-624.882		
Z	16923438.097	-407.334	-166.707		
$\dot{X}$	-3393.7880681	1.041878	0.115069		
$\dot{Y}$	25040.4680909	0.481494	-0.012836		
$\dot{Z}$	2232.5164213	1.216259	0.315128		
A	21829892.3	89	176		
E	0.0075038146	0.00000347	0.00001784		
I	51.555642	-0.0000	-0.0007		
w	181.312721	-0.1574	-0.0505		
$\lambda^{an}$	6.387944	-0.0008	0.0002		
v	261.861106	0.1536	0.0485		
U	21851877	-336	89		
V	0	-1521	-678		
W	0	-7	-274		
$\dot{U}$	-188.633	1.605	0.317		
$\dot{V}$	25367.132	0.455	0.002		
$\dot{W}$	-0.000	-0.111	0.111		
$\phi$	51.226531	-0.00060	-0.00097		
$\lambda$	103.065223	-0.00627	-0.00263		
Ho	159.4174	-0.0555	0.0144		
Ha	177.7195	0.0330	0.0947		
Hp	124.2428	-0.0037	-0.0371		
VECTORS: ██████████ ██████████ ██████████ ██████████					
STOP AT: ████████ OF ██████████ THRESH TIME: ██████████					
LINK/EPH: ████████ INTEG: ████████ REF: ████████ UNITS: ████████					
<input type="checkbox"/> Xmit				<input type="checkbox"/> Undo	
				<input type="checkbox"/> Quit	

**Figure 3.3.5.2-1: State Vector Comparison 1**

**NOTE:** VC uses the same Ha/Hp algorithm as that supporting Checkout Monitor. In TrS, certain limitations apply to this algorithm, while more sophisticated Ha/Hp computations exist in TSA. See Section 3.3.5.4 for details.

State Vector Comparison is the primary FDO/NAV state vector evaluation tool. Displayed UVW differences are heavily used in this application because state vector accuracy degradation trends are easily perceived in this system. In evaluating any state vector, FDO should consult with NAV about data quality, pass geometry, and other factors influencing tracking solution accuracy. Only then can an ephemeris update be made with confidence.

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### 3.3.5.3 The Checkout Monitor Processor

Checkout Monitor (C/O) is one of FDO's most extensively used processors. Following input, typically by DYNAMICS at FDO direction, it generates orbit elements displays and other trajectory data at a specified stop condition. Using C/O displays, FDO monitors virtually every aspect of the orbit from liftoff to landing. These displays also supply trajectory data to payload and other external users.

A state vector from the VAT, an ephemeris, or from a DC link can be fetched by C/O and propagated forward or backward to any valid point in time for output. In TrS, additional integration stop options can be specified such that output occurs after a specified threshold time when a given inertial flight path angle, altitude, latitude, or longitude is reached. A subset of these capabilities are directly available to FDO via interactive SAMMI widgets on C/O. See Appendix L of this volume for operational procedures and considerations relating to interactive C/O features.

There are 10 independent C/O displays supported by TrS. Each is capable of presenting Cartesian elements in Mean-of-1950 (M50), Runway, True-of-Date Rotating (TDR), and Mean of 2000 (J2K) coordinate systems. The different C/O displays are allocated as follows.

C/O No.	Owner(s)
1 & 2	FDO/TRAJ
3 & 4	NAV/DYNAMICS/TAO
5 & 6	Entry Support
7 & 8	MARS
9 & 10	Profile Support/External Customers

The default M50 C/O configuration is illustrated in Figure 3.3.5.3-1. Section 9.2.1 explains the content of all C/O displays in detail.

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Checkout Monitor 1		B
GMT 192:22:57:09.007		MET 000:16:15:51.007
EPH [REDACTED] STOP OPTION [REDACTED] STOP VALUE [REDACTED]		<input type="checkbox"/> UNDO
VECTOR [REDACTED] THRESHOLD [REDACTED]		<input type="checkbox"/> XMIT
INT OPT [REDACTED] LINK [REDACTED]		
GMT192:21:46:00.00	HA 178.897	STOP OPTION TIM
MET000:15:04:42.00	METHA000:16:22:15	ALT, RAD
ORB 11	HP 124.097	FPA
VID EV01	METHP000:15:37:03	MVI, MVE
		LONG
		LAT
M50 State Vector	V <sub>I</sub> 25264.9575	THRESH GMT 192:21:46:00
	V <sub>REL</sub> 24285.5718	MET 000:15:04:42
	γ -0.341686	REFDAY 7/ 1/2002
POSITION (FT)	ψ <sub>REL</sub> 46.9932	LO 192:06:41:18.000
X 12832188.3	ψ <sub>TEI</sub> 49.0315	EPH E1 GOOD TUP 6
Y -12781487.6	φ <sub>c</sub> 34:36:15N	VEH WEIGHT 252740.0
Z 12400165.7	φ <sub>c</sub> 34.604090	KV 1.000 KC 1.000
	φ <sub>u</sub> 34:46:32N	AREA 2751.00
VELOCITY (FPS)	φ <sub>d</sub> 34.775564	INT MED EPH VAM
VX 6827.883411	λ 59:31:02E	SRP 0.000
VY 20225.092853	λ 59.517299	
VZ 13514.573821	h <sub>s</sub> 168.55138	KEPLERIAN ELEMENTS
	h <sub>o</sub> 172.28077	A 3595.7562
POSITION (M)	h <sub>o</sub> 1046797.87	E 0.007563
X 3911251.01	R 3612.47950	IM50 51.29031
Y -3895797.41	T <sub>an</sub> 000:16:23:00	ITEI 51.57459
Z 3779570.51	λ <sub>an</sub> 6:23:18E	WP <sub>M50</sub> 174.67456
VELOCITY (MPS)	BETA ANG 19.949	WP <sub>TEI</sub> 174.75215
VX 2081.138864	PERIOD 001:30:08	RAAN <sub>M50</sub> 281.83557
VY 6164.608302	RA <sub>M50</sub> 315.1134	N 231.70869
VZ 4119.242101	DEC <sub>M50</sub> 34.3976	M 232.39126

**Figure 3.3.5.3-1: MSK 2300 M50 C/O Monitor**

**NOTE:** in TrS, C/O Ha/Hp computations utilize an algorithm with appreciable limitations (see JSC-118286, *CCS Trajectory Operations Design Specification*, routine ELFAAP documentation). Although this method accounts for earth's excess equatorial mass (also known as "J<sub>2</sub> effects"), it's only strictly valid for a near-circular orbit. If an orbit perturbed only by J<sub>2</sub> is sampled throughout its period, this algorithm will yield different Ha/Hp values. These osculations increase with increasing eccentricity. For example, an orbit with H<sub>a</sub> = 300 nm and H<sub>p</sub> = 100 nm will produce peak-to-valley osculations amounting to about 2.5 nm over a period. As eccentricity increases beyond 1.0, an invalid negative Hp value is computed, while a reasonably accurate value for H<sub>p</sub> is instead computed for H<sub>a</sub>. In TSA, C/O H<sub>a</sub>/H<sub>p</sub> computations utilize a more sophisticated algorithm (see STS 83-0002G, *Level C FSSR Guidance Ascent/RTLS*, ORB ALT TIME TSK documentation). For the H<sub>a</sub> = 300 nm and H<sub>p</sub>=100 nm case, peak-to-valley osculations amounting to little more than 0.1

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nm are obtained. At high eccentricities, reasonable values for both  $H_a$  (if defined) and  $H_p$  are computed in the workstation by ignoring  $J_2$  effects.

**NOTE:** in TrS, C/O orbit period computations utilize Kepler's Third Law, in which the square of the period is proportional to the cube of the semi-major axis. Since the osculating (Keplerian, instantaneous, conic, or 2-body) semi-major axis is used for this calculation, the period also osculates by up to 10 sec peak-to-valley during a typical Shuttle orbit. The TrS C/O orbit period is therefore neither equivalent to the anomalistic period (perigee-to-perigee), nor equivalent to the nodal period (ascending-node-to-ascending-node). In TSA, C/O orbit period computations are more sophisticated. A nodal period is calculated inclusive of  $J_2$  effects, reducing osculations over a typical Shuttle orbit to less than 1 sec.

Figure 3.3.5.3-2 supplies equivalent reference frame nomenclature for systems with which FDO commonly exchanges trajectory data.

<b>TrS</b>	Mean Equator & Equinox of Besselian Epoch 1950.0 (M50)	Runway (RWY)	Greenwich True-of-Date Rotating (TDR)	Mean Equator & Equinox of Julian Epoch 2000.0 (J2K)	Greenwich True-of-Epoch Inertial (TEI)	
<b>TSA</b>	M50		TDR	J2K		
<b>IPS</b>	Aries Mean Equator & Equinox of 1950 (M50)		Earth-Fixed Equatorial of Epoch (EFE)	Aries Mean Equator & Equinox of 2000 (J2000)	True Equator & Greenwich Meridian of Epoch (TEG) <sup>1</sup>	True Equator & Equinox of Epoch (TEE)
<b>SMS</b>	M50	Runway	Geographic			Aries True-of-Date (TOD)
<b>USSTRATCOM</b>	Geocentric Inertial Cartesian Equator of 1950 <sup>2</sup>		Geocentric Rotating Cartesian Equator of Date <sup>3</sup>			Geocentric Inertial Cartesian Equator of Date (TEME)

**Figure 3.3.5.3-2: A Reference Frame "Rosetta Stone"**

Figure 3.3.5.3-3 defines each of the reference frames cross-referenced above. Since all frames are right-handed Cartesian in nature, definition of their respective Y-axes has been omitted.

<sup>1</sup>Because of epoch differences, TEI and TEG are generally not equivalent. See Figure 3.3.5.3-3 for TEI and TEG epoch definitions.

<sup>2</sup> USSTRATCOM's equivalent of M50 is flawed and should not be used. Vector magnitudes do not agree with those of other USSTRATCOM-supported Cartesian frames following internal transformation.

<sup>3</sup>This is the preferred frame for USSTRATCOM state vector transfer.



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	<b>M50</b>	<b>Runway</b>	<b>TDR</b>	<b>J2K</b>	<b>TEI</b>	<b>TEE</b>
Epoch	Year 1949 at 365/22:09:18 GMT, or Julian ephemeris date 2433282.4234	Inferred from TDR or Geographic	Z-Axis inertially fixed at 00:00 GMT of launch date <sup>4</sup>	Year 2000 at approx. 001/11:59 GMT, or Julian ephemeris date 2451545	31 Dec 00:00 GMT of year prior to state vector epoch <sup>5</sup>	00:00 GMT of launch date <sup>6</sup>
X - Y Plane	Mean equator of epoch	Origin local horizontal	True equator of epoch	Mean equator of epoch	True equator of epoch	True equator of epoch
X - Axis	Mean Vernal equinox of epoch	Runway C/L in rollout direction	0° latitude; 0° longitude	Mean Vernal equinox of epoch	0° latitude; 0° longitude at epoch	True Vernal equinox of epoch <sup>7</sup>
Z - Axis	Mean north rotational pole of epoch	Origin geodetic nadir	True north rotational pole of epoch	Mean north rotational pole of epoch	True north rotational pole of epoch	True north rotational pole of epoch
Origin	Geocenter	Targeted runway C/L and threshold	Geocenter	Geocenter	Geocenter	Geocenter

**Figure 3.3.5.3-3: A Reference Frame "Dictionary"**

### 3.3.5.4 Apsis Height Computation Methods

Earth's non-spherical mass distribution causes noticeable perturbations in a spacecraft's orbit, especially at low eccentricities and altitudes. When an orbit is described using traditional Keplerian orbit elements, these perturbations cause the elements to osculate or vary with time. Vectors taken from different parts of the orbit may produce very different values for Keplerian elements because a homogeneous spherical central body does *not* produce the gravity field through which the vehicle flies. The strongest perturbative effects are caused by excess equatorial mass, as related by the second-degree zonal gravity harmonic  $J_2$ . To achieve consistent element values over time, Trajectory Operations software tools calculate apsis heights with methods designed to account for  $J_2$  effects and produce time-invariant results. The degree to which consistency is achieved is indicated by minimal "osculation amplitude" as apsis heights are computed from osculating state vectors sampled around a  $J_2$ -perturbed orbit. Osculation amplitudes and pedigrees for some commonly encountered methods are presented in the following subsections.

**NOTE:** *height* (typically denoted by "H") is distinct from *altitude* (typically denoted by "h"). Even though it may account for  $J_2$  gravitational perturbations, height is referenced to a spherical Earth radius, typically one at the equator. Altitude is usually referenced normal to an ellipsoid approximating global sea level.

<sup>4</sup>This epoch applies to the workstation's TDR implementation. In TrS, TDR's Z-axis is inertially fixed at 00:00, 06:00, 12:00, or 18:00 GMT of the current day according to state vector GMT proximity.

<sup>5</sup>TEG epoch can be manually specified. Flight Design procedures set the TEG epoch to 00:00 GMT of the launch day. As a consequence, TEG X and Y axes are generally displaced significantly by Earth rotation from those of TEI. The TEG Z-axis is only slightly displaced from that of TEI by precession and nutation, however.

<sup>6</sup>TEME epoch coincides with state vector GMT.

<sup>7</sup>TEME's X-axis is the Mean Vernal equinox of epoch.

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### 3.3.5.4.1 TrS

Apsis height computations in TrS Checkout Monitor and DMT are only accurate for highly circular orbits. Even at low eccentricities, osculation amplitudes of several miles may be encountered. These apsis heights reference a mean or invariant orbit, as opposed to the actual osculating trajectory. The TrS Checkout/DMT method of calculating  $H_a$  and  $H_p$  is by far inferior to any of the other methods described here. The algorithm used for TSA's Maneuver Eval Table (MET) is different. It exhibits osculation amplitudes of only a few tenths of a nm around a typical Shuttle orbit, and these invariant values are corrected to the osculating trajectory.

### 3.3.5.4.2 Flight Design Planning and Analysis (FDPA)

This tool is used by TOPOs for long-range planning and analysis. Boeing/Robert Gottlieb developed the apsis height computation method used in FDPA. It calculates invariant elements using the mean motion and references these elements to a mean orbit. Inherent to this method is the assumption of a highly circular orbit. As a consequence, accuracy and stability of the elements produced by this method swiftly degrade with increasing eccentricity (see Figure 3.3.5.4.2-1). FDPA exhibits slightly lower osculation amplitudes than does TSA only up to an eccentricity of approximately 0.005. At typical Shuttle orbit heights, this "break even" eccentricity corresponds to a  $H_a - H_p = \sim 35$  nm.

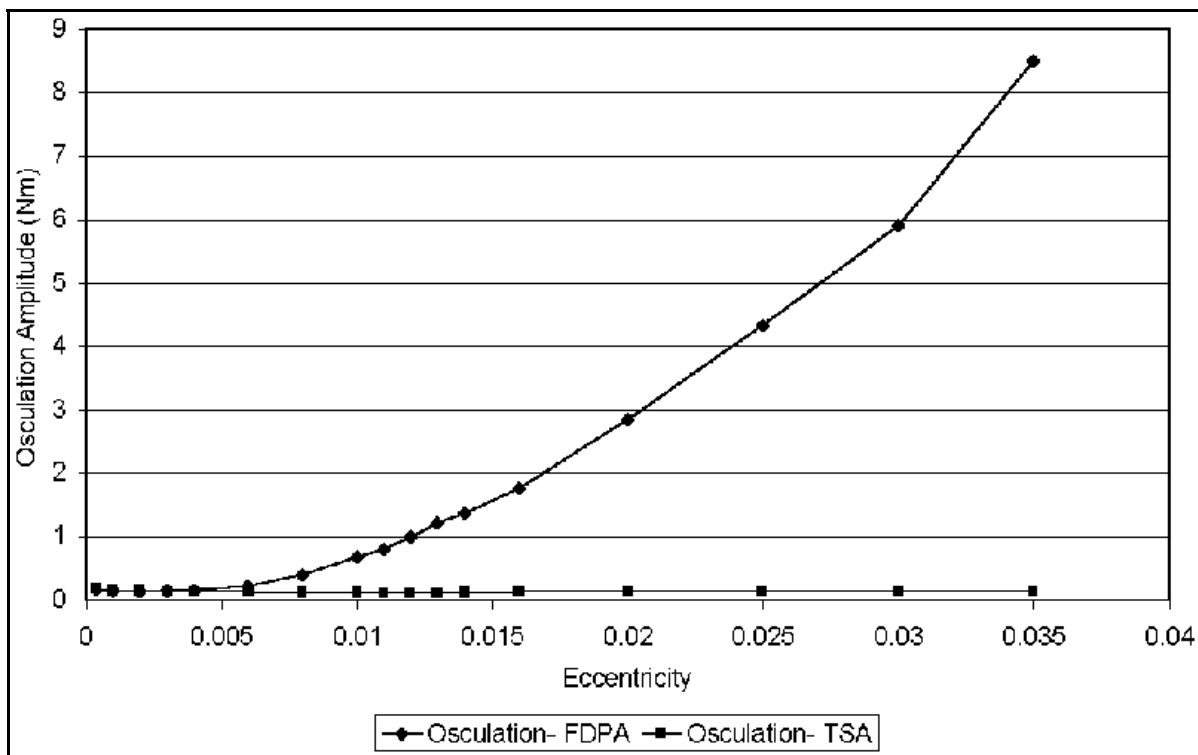


Figure 3.3.5.4.2-1: FDPA & TSA/TOAST  $H_a/H_p$  Osculation Amplitudes

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### 3.3.5.4.3 TSA

Both FDO and TOPO use TSA in real time operations. This tool employs multiple apsis height computation methods producing accurate  $H_a$  and  $H_p$  values at all possible eccentricities. At low and intermediate eccentricities, TSA calculates invariant elements using a mean trajectory. A correction factor is then applied to reference the true osculating trajectory. This method exhibits appreciable osculation amplitudes at extremely low eccentricities due to  $J_3$  and higher order terms. However, the osculations quickly damp out at moderate eccentricities. For eccentricities approaching 1 and beyond, computation reverts to Keplerian values assuming unperturbed conic motion. The major strength of this method is its capability to handle all eccentricities. Except for extremely circular orbits ( $H_a - H_p < 1\text{nm}$ ), this is the best tool for apsis height determination.

NOTE: TSA Checkout Monitor's rightmost column includes output from the MCC-M apsis height computation described in Section 3.3.5.4.4.

### 3.3.5.4.4 MCC-Moscow (MCC-M) Ballistics

On ISS flights, trajectory coordination with MCC-M Ballistics through TOPO is frequently required. Ballistics uses a different method to calculate apsis heights. This method references a true osculating trajectory like TSA. Its major strength is that it achieves smaller osculation amplitudes in highly circular orbits than does TSA, and it also achieves smaller osculation amplitudes in more eccentric orbits than does FDPA. As eccentricity increases to moderate values beyond the Shuttle's nominal flight envelope, osculation amplitudes associated with the Ballistics method exceed TSA's. When eccentricity approaches 1, the Ballistics method becomes invalid.

## 3.3.6 External Ephemeris Interfaces

In addition to NASCOM interfaces with TrS ephemerides E1-10 enabled by the Ground-to-Ground FEP, other external interfaces support TrS ephemeris mirrors and G1-8. Posting procedures mirroring an ephemeris to FTW for web-based access by external trajectory customers is documented in Section 3.11.8. A subset of these procedures generates an `Events.txt` file accessed by GC's 2D DEMOS application to annotate MCC's World Map display with discrete events. In addition, 2D DEMOS can poll state vectors resident in a TrS mirror or Global ephemeris to plot a ground track. The following subsections document these 2D DEMOS trajectory interfaces, together with noteworthy World Map display features.

### 3.3.6.1 Ephemeris Interfaces With 2D DEMOS

The 2-Dimensional Distributed Earth Modeling System (2D DEMOS) user interface operated by GC permits any of 10 possible TrS ephemeris mirrors or 8 possible Global TSA ephemerides to be accessed for ground track plotting on MCC's World Map display. Up to 4 ephemeris ground tracks may be plotted simultaneously.

NOTE: trajectory data sources other than ephemerides may also be accessed by 2D DEMOS. These sources include state vectors internal to 2D DEMOS as well as those from a telemetry stream. An AEG orbit predictor is then used in 2D DEMOS to coast the

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state vector and generate ground track points for plotting on the World Map. When an ephemeris source is used, however, ground track plotting is confined to interpolating and mapping ephemeris points in "connect the dots" fashion. Only with an ephemeris source will the effects of future maneuvers be reflected by the mapped ground track.

**CAUTION:** because of permanent AEG limitations, selecting a telemetry source state vector with sufficiently high eccentricity may lead to a 2D DEMOS crash. Even LEO-to-GEO transfer orbits may precipitate AEG-generated crashes. For high-eccentricity trajectories, only use an ephemeris source with 2D DEMOS.

An example of the World Map display appears in Figure 3.3.6.1-1. Noteworthy display features are listed below with reference to this example.

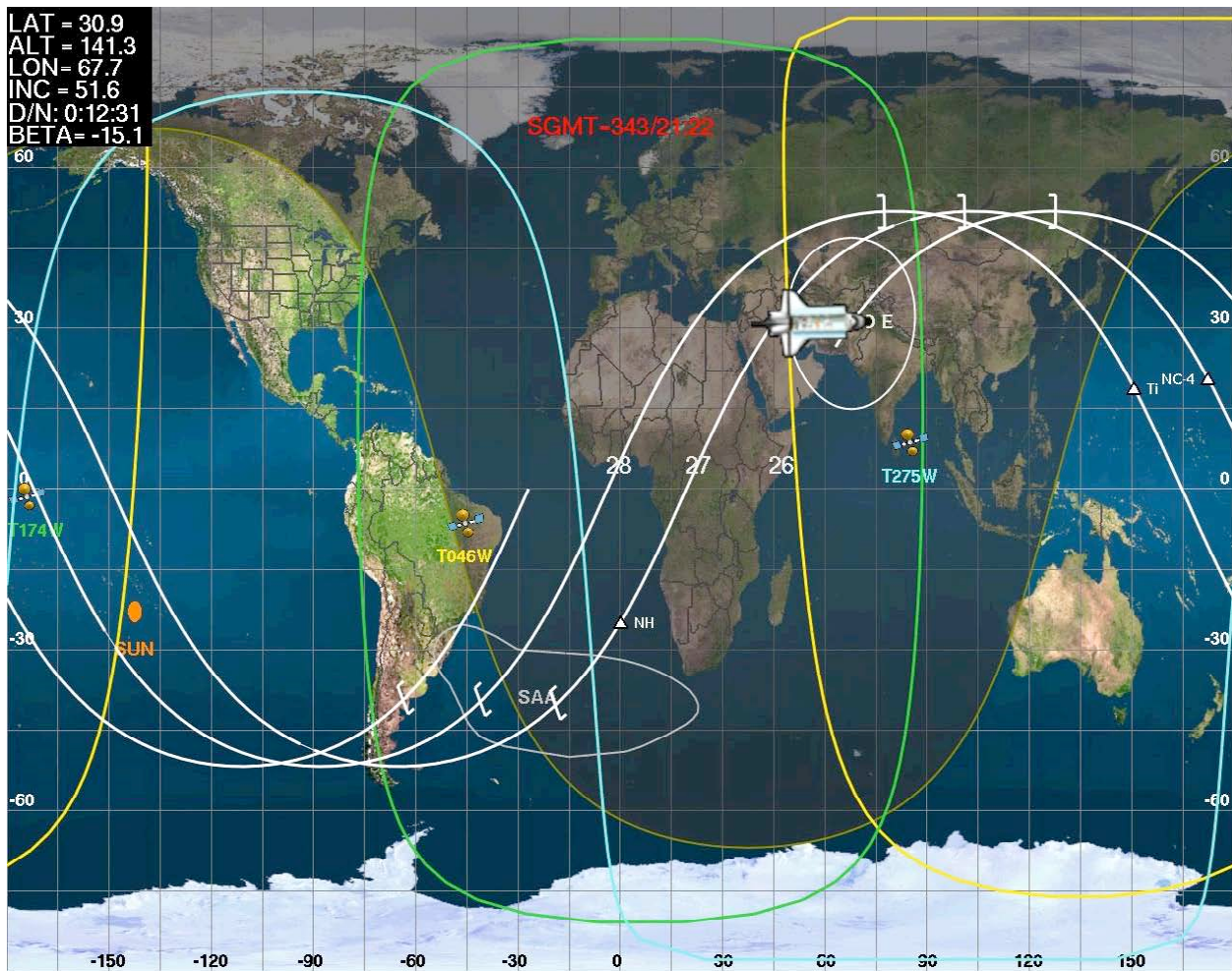


Figure 3.3.6.1-1: 2D DEMOS Display Example

- 1) Current GMT (simulated or real) is indicated with red digitals, and current trajectory parameters are indicated with white-on-black digitals in this example. Current nadir location on Earth's surface for each plotted ephemeris is indicated with a vehicle-specific "spotter" (in this example, a Shuttle Orbiter over Pakistan). The oval circumscribing the spotter is the region of Earth's surface currently visible from the vehicle's location.
- 2) Light and dark World Map shading indicates current day and night regions on Earth's surface. These regions are separated with a yellow terminator line. In this case, it's

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afternoon to evening at ConUS longitudes. The Sun's current nadir location on Earth's surface is indicated with an orange disk labeled "SUN" in the South Pacific. Longitude at this nadir corresponds to local solar noon on Earth.

NOTE: allowing for eastward Earth rotation under the Sun's nadir location, orbit solar noon can be estimated as a ground track point with minimal great circle arc length to this nadir. In the example, Orbit 26 noon is over the South Pacific with the solar nadir southwest of the ground track (the Sun's nadir longitude will be closer to 150° W because of eastward Earth rotation over the next half orbit from current time to orbit noon). The arc length is then equal to the Sun's beta angle magnitude. With the Sun south of the ground track, a direction opposite the example orbit's angular momentum vector, beta is negative. Since Earth's excess equatorial mass precesses the orbit plane westward with respect to the Sun in inertial space, beta magnitude in the example will be decreasing until beta becomes positive in a few days. This graphic beta visualization supplements the World Map's digital beta display.

- 3) Orbit sunrise and sunset are indicated by square brackets "enclosing" orbit night. Thus, a "[" denotes sunset, and a "]" denotes sunrise. Earthbound observers near a bracket have good viewing geometry for the associated satellite. Orbit precession due to Earth's excess equatorial mass causes the brackets to shift in the direction of orbit motion over many orbits. To differentiate between multiple ephemeris plots, corresponding brackets and ground track points are plotted in the same color.
- 4) A mission event is indicated with a triangle and accompanying label plotted on the corresponding ground track at the time it occurs. To differentiate between multiple ephemeris plots, corresponding mission events and ground track points are plotted in the same color. Example mission events are labeled "NH", "NC-4", and "Ti". Because FDO can provide mission events in association with an ephemeris accessed by 2D DEMOS, further details on this interface are provided later in this section.
- 5) Ground tracks are plotted with a "pen" whose width is regulated by TDRSS SHOs. The wider pen indicates some form of TDRSS communications link has been scheduled for the vehicle corresponding to the accessed ephemeris. A thinner pen indicates no communications link with TDRSS has been scheduled.

NOTE: it's possible to access multiple SHOs files through the 2D DEMOS user interface. With this capability, scheduled communications associated with Shuttle and ISS can be independently displayed on the World Map when each vehicle's ephemeris is being accessed by 2D DEMOS. This also opens up the possibility that the wrong SHOs file could be associated with an accessed ephemeris.

- 6) Geosynchronous TDRSS Earth nadir locations are indicated with TDRSS spotters for all relevant satellites. These locations are mapped by 2D DEMOS using two possible trajectory sources. Generally, a TSA Global TDRSS ephemeris is accessed by 2D DEMOS to account for north/south motion at inclinations approaching 10° or more. If a TDRSS ephemeris is unavailable, a fixed "equatorial tall mountain" longitude can be specified to the 2D DEMOS user interface as an approximation. In the example, satellites labeled "T174W", "T046W", and "T275W" are being plotted on the World Map. The color used to draw a satellite's label also corresponds to that used in plotting the satellite's communication footprint. In the example, a green line encloses all nadir locations at which communication with the T174W satellite isn't possible due to Earth occultation. Since none of the satellites in the example is exactly above Earth's equator, all are accessing TSA Global TDRSS ephemerides.

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CAUTION: all communications footprints (those for TDRSS and ground sites) are strictly correct only for current time and the primary ground track. The primary ground track is typically indicated on the World Map in white.

### 3.3.6.2 Mission Event Generation Supporting World Map Display

Beginning with STS-116/12A.1, FDO has the capability to display time-tagged discrete events on the MCC World Map. This function is facilitated by a new 2D DEMOS interface using the `Events.txt` file in an ephemeris directory being accessed by 2D DEMOS to plot a World Map ground track. Similar mission events generation capability is provided to GC and FAO through an application accessed through GC's Master DNAV.

NOTE: events specified by GC and FAO aren't associated with a specific ephemeris but rather with a specific 2D DEMOS vehicle. These events will generally be displayed with their vehicle's ground track plot regardless of the corresponding trajectory source.

CAUTION: by default, all events within the time interval spanned by the ground track will be plotted on the World Map. Be aware these will generally be broadcast worldwide over NASA Select. Selected FDO-generated events can be suppressed by manually deleting them from `Events.txt`. Any event can also be individually suppressed by requesting GC do so via the 2D DEMOS user interface. Event suppression by GC will be lifted if the event's time tag changes. The event would then reappear on the World Map if the corresponding ground track point is plotted.

To generate mission events for World Map display, follow FTW posting procedures from Section 3.11.8.1.3 as far as MPTGEN processing. Once an `Events.txt` update is complete, further FTW posting operations aren't necessary for World Map display purposes. Mission events are the analog equivalent of digital wall clocks. Consequently, FDO should alert the Flight Control Team of significant mission events changes as FD Loop traffic permits.

NOTE: except at 2D DEMOS initialization, mission events are plotted independently from other World Map display content. Thus, from 4 to 5 min may elapse between an `Events.txt` update and the corresponding World Map mission event update, even if the corresponding ephemeris is TUPed or its mirror is toggled OFF/ON.

### 3.3.6.3 World Map Display Dumps

Any World Map display operating in MCC can be accessed and dumped using a Netscape-based utility invoked from GC's Master DNAV. The dump is saved to a high resolution JPEG file whose location is user-specified. This file can be post-processed per Appendix 3.H procedures to paste into Flight Note and other documentation. Cyclic dumps from every instance of 2D DEMOS running in MCC can also be found in the `/users/gc/2DDemos/Screen_Snap/ OPS` directory tree.

## Section 3.3 Concludes On This Page

## **FDO Console Handbook Section 3.4: Acquisitions**

### **3.4 Acquisitions**

This section documents a set of related processing and display functions used by FDO to post-process ephemerides. In general, these functions determine when the Orbiter has "acquired" line-of-sight to other objects unobstructed by the Earth. Consequently, these capabilities are collectively called "acquisitions".

Accurate acquisitions data are typically of high importance. The Ops Support Team (OST), particularly the DFE and COMMAND disciplines, uses acquisitions data to schedule tracking and communications support to the Orbiter. Both NAV and ONAV issue requests for ground-based navigation support using acquisitions data. Disciplines such as RENDEZVOUS, FAO, and EVA employ both communications and lighting acquisitions data to develop crew activity timelines. Finally, USSTRATCOM uses acquisitions data to restrict radar facility operations during periods of close Orbiter proximity. See Section 3.11.4 for radar restrictions details.

Two sets of acquisitions functions exist in the MCC with very nearly identical capabilities. The first set is hosted on the Trajectory Server (TrS) and used exclusively by NAV with the exception of the Remote Site Entry display and its TrS-based Station Characteristics Table (SCT) interface. These specific capabilities are documented in Section 3.4.1. All other TrS-based acquisitions capabilities are beyond FDO Console Handbook scope.

The second set of acquisitions functions, hosted on workstations, consists primarily of the Predicted Site Acquisition Table (PSAT) processor, the Acquisitions Monitor (AcqMon) PSAT output "viewer", and TSA's SCT. Output from PSAT can be shared by FDO with the entire Flight Control Team, including ISS disciplines if a joint activity is being supported. Because PSAT is workstation-based, it operates on TrS ephemerides using AutoEph mirrors. It can also process TSA-TUPable ephemerides, as well as entry ephemerides from the Entry Design System (EDS). Workstation-based acquisitions are thoroughly documented in Section 3.4.2.

Standard acquisition procedures and configurations have developed and evolved as mature TSA capabilities were delivered in 2001 and TrS became operational in 2002. These operations are documented in Section 3.4.3.

#### **3.4.1 TrS Acquisitions Capabilities**

As mentioned previously, the majority of TrS acquisitions functions are used exclusively by NAV and lie outside the scope of the FDO Console Handbook. A TrS-unique acquisition capability called Remote Site Entry is utilized by FDO, however. With Remote Site Entry, azimuth, elevation, and range from a specified earthbound location to any TrS ephemeris trajectory, including the prime entry trajectory, can be displayed. This section describes data, procedures, and displays associated with Remote Site Entry.

##### **3.4.1.1 TrS Station Characteristics Table**

Prior to each mission, NAV verifies station characteristics parameters corresponding to all launch, orbit, and landing C-band and S-band tracking stations scheduled for mission support. Following publication as Flight Design product NAVG-23, these data are incorporated into the TrS Station Characteristics Table (SCT). Parameters include station geodetic location, terrain masking, refraction multipliers, data weight multipliers, and other



## FDO Console Handbook Section 3.4: Acquisitions

station-specific data. The SCT data are accessed and used by multiple TrS acquisition processors, including Remote Site Entry, to compute AOS/LOS times or line-of-sight geometry. In addition, NAV uses SCT data to process Orbiter and target tracking data (see Section 3.3.2).

**NOTE:** on a flight-specific basis, FDO may require additional sites in the TrS SCT. These sites are typically elements of foreign partner or payload customer tracking networks. Flight-specific SCT updates are performed by NAV, and they can be made during a mission if necessary. The SCT is usually configured with a number of "spare" slots intended to be filled with site data manually or from mass storage media. It's therefore possible to operate acquisition processors with unanticipated or special-purpose ground-based sites, such as Earth observation targets of opportunity or sensors subject to RADAR restrictions (see Section 3.11.4).

A list of station IDs residing in the TrS SCT, along with corresponding geodetic locations, can be viewed in the SCT Summary display (see Figure 3.4.1.1-1).

107		Station Characteristics Summary				A	
GMT: 159:06:59:56		GMTR: 143:14:25:00				MET: 15:16:34:56	
SCT NUMBER	STATION ID	STATION CONTACT	GEODETTIC LONGITUDE	GEODETTIC LATITUDE	ALTITUDE (M)	ALTITUDE (F)	
1	ANTC 91	P N	-61.792458	17.143772	-33.100000	-108.595801	
2	ASCC 70	P N	-14.402467	-7.906589	23.650000	77.591864	
3	ASTC 10		-14.401183	-7.972531	109.520000	359.317585	
4	BDQC 1		-64.653356	32.348067	-35.250000	-115.649606	
5	CMTC 3	E	-80.563344	28.517142	-51.946700	-170.428806	
6	CNOC 8		-80.575453	28.492989	-50.000000	-164.041995	
7	CNVC 65	E	-80.576472	28.481764	-49.570000	-162.631234	
8	FDRC 39	P N	-117.911550	34.960636	750.590000	2462.565617	
9	EFFC 42		-117.931417	34.970458	774.310000	2540.387139	
10	FRCC 43	P N	-117.911503	34.960781	750.570000	2462.500000	
11	FRFC 9		-117.911847	34.957753	750.440000	2462.073491	
12	HOLC 61		-106.099322	32.901406	1207.790000	3962.565617	
13	JDIC 22	E	-80.108358	26.982942	-39.453000	-129.438976	
14	KMAC 92		167.481992	9.398703	26.220000	86.023622	
15	KMLC 2		167.481992	9.398703	26.220000	86.023622	
16	KMRC 69	P N	167.481992	9.398703	26.220000	86.023622	
17	KMTC 74		167.718369	8.719500	27.910000	91.568241	
18	KPTC 68	P N	-158.266572	21.572094	284.580000	933.661417	
19	MLAC 71	P N E	-80.664361	28.424858	-52.430000	-172.014436	
20	MLMC 67	E	-80.682767	28.626092	-53.030000	-173.982940	
21	MTLC 14		-110.788800	32.441719	2754.320000	9036.482940	
22	PATC 21	E	-80.599250	28.226550	-48.880000	-160.367454	
23	PMFC 18		-119.154875	34.123011	-60.060000	-197.047244	
24	PMPC 24		-119.153906	34.122647	-60.590000	-198.786089	
25	PMSC 54		-119.152939	34.122239	-60.580000	-198.753281	

Update Contacts   
  Get Site   
  Undo   
  Quit

**Figure 3.4.1.1-1: TrS SCT Summary Display**

In its **STATION CONTACT** column, SCT Summary indicates which sites are to be processed by TrS for output to which NAV display. Those sites accompanied by **P** will be processed for NAV's Predicted Site Acquisition Table (PSAT) display, those with **N** will be processed for NAV's Next Station Contacts (NSC) display, and those with **E** will be processed by NAV's Entry PSAT (EPSAT) display. Any site residing in the TrS SCT is available for Remote Site Entry processing.



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### 3.4.1.2 Remote Site Entry Display

For a selected TrS SCT site, the Remote Site Entry display generates azimuth (in deg east of true north), elevation (in degrees above the geodetic horizontal plane), and slant range to a vehicle at regular time intervals following a specified start epoch. A total of 40 az-el-range data sets, beginning with that corresponding to the start epoch, are time-tagged and displayed in tabular fashion.

Remote Site Entry is a NAV-owned display. Inputs are very intuitive to anyone familiar with SAMMI interactive field conventions (see Appendix 3.L). Although NAV can operate Remote Site Entry per FDO requests, the display's interactive fields are enabled for FDO use as well. If it's preferable for FDO to operate Remote Site Entry autonomously, NAV must be polled for authorization beforehand.

When Remote Site Entry is first invoked following TrS initialization, it assumes the configuration illustrated by Figure 3.4.1.2-1.

<b>107</b>	<b>Remote Site Entry</b>			<b>A</b>
GMT: 159:06:52:31		MET: 015:16:27:31		
<b>Site ID</b>	<b>EPH</b>	<b>Start Time</b>	<b>A Time</b>	
L/L TO 46 CHAR Format Translator - OFF VCT Slot 2				
<b>Sample</b>	<b>Site GMT Time</b>	<b>Azimuth</b>	<b>Elevation</b>	<b>Range (ER)</b>
<b>Upcoming Acquisition</b>	<b>EPSAT AOS</b>			
	<b>LOS</b>			
<input type="checkbox"/> XMIT	EPH <input type="checkbox"/>	Site <input type="checkbox"/>	Units <b>ER</b>	<input type="checkbox"/> Undo
	Time <input type="checkbox"/>	DT <input type="checkbox"/>	Seconds	<input type="checkbox"/> Quit
Groundtrack Digitals table is not initialized				

**Figure 3.4.1.2-1: Remote Site Entry Configuration Following TrS Initialization**

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Perform the following procedure to generate a Remote Site Entry display. Note that any existing inputs may be reused if appropriate for subsequent output, and uppercase or lowercase alphabetic input is acceptable.

- 1) Right-click the EPH field and select ephemeris E1-10 or Entry as appropriate from the resulting pop-up menu.
- 2) Type the site ID in the Site field as it appears in the TrS SCT Summary display. An optional right-click in this field will invoke a nested pop-up menu from which any C-band site may be selected.
- 3) Right-click the Units field and select ER (Earth radii), FT (feet), IN (inches), KM (kilometers), M (meters), NM (nautical miles), or YD (yards) units to associate with displayed slant range values.
- 4) Type the display start epoch in the Time field using ddd:hh:mm:ss format. Leading zeros are optional, as are exact-zero subfields delimited by colons. The value will be interpreted as a GMT epoch unless a "P" or "p" prefix is supplied to denote an MET epoch. The start epoch must lie within the corresponding ephemeris time span.
- 5) Type the tabular display time interval in the DT field.
- 6) Click XMIT. Advisory Services will log a U20 transmission with EPH, Time, and DT field inputs, followed by a U50 transmission with Site and Units field inputs. Remote Site Entry should subsequently assume a configuration similar to that illustrated by Figure 3.4.1.2-2.

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107	Remote Site Entry			A
GMT: 159:07:24:00				MET: 015:16:59:00
Site ID STLS	EPH E2	Start Time 159:07:40:00	A Time 00:00:30.00	
L/L TO 46 CHAR Format Translator - OFF VCT Slot 2				
Sample	Site MET Time	Azimuth	Elevation	Range (NM)
1	015:17:15:00	245.929	-2.735	1175.56418461
2	015:17:15:30	246.380	-1.023	1061.04875447
3	015:17:16:00	246.928	0.872	946.52771533
4	015:17:16:30	247.613	3.025	832.15275236
5	015:17:17:00	248.502	5.557	718.15149902
6	015:17:17:30	249.717	8.678	604.89801207
7	015:17:18:00	251.494	12.780	493.07703506
8	015:17:18:30	254.377	18.664	384.11981582
9	015:17:19:00	259.909	28.145	281.56129966
10	015:17:19:30	274.485	45.079	195.92488398
11	015:17:20:00	334.260	63.006	157.86762055
12	015:17:20:30	32.499	44.658	197.22509203
13	015:17:21:00	46.694	27.901	283.36659893
14	015:17:21:30	52.139	18.515	386.09794876
15	015:17:22:00	54.995	12.676	495.12109650
16	015:17:22:30	56.766	8.598	606.96633593
17	015:17:23:00	57.984	5.491	720.22402434
18	015:17:23:30	58.883	2.968	834.21793576
19	015:17:24:00	59.582	0.821	948.57789577
20	015:17:24:30	60.146	-1.070	1063.07826673
Upcoming Acquisition		EPSAT AOS LOS		
<input checked="" type="checkbox"/> XMIT	EPH E2	Site STLS	Units NM	<input type="checkbox"/> Undo
	Time p15:17:15:	DT 30	Seconds	<input type="checkbox"/> Quit

**Figure 3.4.1.2-2: Remote Site Entry Configuration Following Processing**

### 3.4.2 TSA Acquisitions Capabilities

Beginning with OI-28 and STS-98/5A in early CY 2001, a majority of acquisitions capabilities were migrated from the MOC to workstation-based software under TSA. This migration enabled the following ops concepts.

- 1) Routine FDO access to acquisitions generation and inter-disciplinary viewing capabilities without advance facilities scheduling
- 2) Consolidated acquisition generation and viewing, each in a respective application, regardless of acquisition type or trajectory data source
- 3) Text-based acquisition data sharing and export

All TSA acquisitions are computed by a Predicted Site Acquisitions Table (PSAT) processor. This output includes four types of acquisitions.

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- A) Ground: a line-of-sight satisfying elevation and/or terrain masking conditions exists between a primary ephemeris trajectory and one of multiple possible earthbound sites.
- B) TDRSS: a line-of-sight unobstructed by Earth exists between a primary ephemeris trajectory and one of multiple possible secondary ephemeris trajectories. In lieu of secondary ephemerides, geostationary locations may be specified in the TSA SCT.
- C) SR/SS: a line-of-sight unobstructed by Earth exists between a primary ephemeris trajectory and the Sun.
- D) MR/MS: a line-of-sight unobstructed by Earth exists between a primary ephemeris trajectory and the Moon.

**NOTE:** as an alternative to ephemeris-based primary trajectory input, PSAT can infer a coasted primary trajectory using vectors specified from a VAT. Because VAT-based PSAT processing is currently not associated with the FDO acquisition ops concept, it's beyond the scope of this handbook.

The following subsections detail functions associated with TSA acquisitions software.

### 3.4.2.1 TSA Station Characteristics Table

The TSA Station Characteristics Table (SCT) is a database of earthbound and geostationary site locations, together with other site-specific data facilitating PSAT processing. A FDO administrator configures an SCT for generic or flight-specific TSA baselines. Using the "Create SCT" (CRTSCT) application, the administrator merges data from Flight Design products NAVO-16B (TACANs) and NAVG-23 (C-band and S-band ground sites) with a manually maintained SCT containing FDO-required sites not otherwise available. The SCT administrator provides the merged SCT to TOCSS as the generic baseline using the GA/DYNAMICS Initialization Pad available at `S:\Divisions\DM\Shared\FDDNav\`. Any Lead FDO to whom the generic SCT is applicable may then elect to modify it further, creating an SCT for submission to TOCSS in association with that specific flight.

Whenever Local TSA is initialized in an OPS activity, one of two possible SCTs may result. If no flight-specific SCT has been installed by TOCSS for the flight associated with the OPS activity, the generic baseline will reside in Local. However, if a flight-specific SCT exists for the activity, it will supersede the generic configuration.

The SCT configuration residing in Global is generally restored from a checkpoint. Since Global is used for sims and flights, the assigned Lead FDO is responsible for that SCT's pedigree. During a mission, Global SCT updates may be performed as necessary by any FDO/TRAJ, in coordination with the Lead FDO and other shifts, using appropriate FDO Log and Handover entries. Note that such updates can only be routed to the Local SCT configuration using manual copies facilitated by Xdir.

**CAUTION:** prior to the pre-launch ARD Confidence Run, a TSA Global database is an unstable repository for SCT and other acquisitions data. Various checkpoints are regularly restored to Global during sims in the post-FRR timeframe. Pre-launch, archive SCT and acquisitions data intended for Global use in your home directory for safekeeping. SCT data reside in the `System/SCT.data` file (terrain masking data associated with some of the

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SCT's ground sites are found in site-specific files within the `System/AZEL_DATA/` directory), while acquisitions data are stored in multiple files within the `Ephem` subdirectory corresponding to the specified primary ephemeris.

**CAUTION:** there is no capability to explicitly designate whether PSAT uses the Local or Global SCT. The SCT referenced by a specific PSAT run is inferred to be the TSA database segment where output acquisitions data are routed. Output is in turn associated with the specified primary ephemeris directory. Thus, if a primary ephemeris in Global is specified to PSAT for processing, the Global SCT will be referenced for that specific run. All TrS ephemeris mirrors and EDS entry ephemerides initially reside in Global.

The TSA SCT display lists up to 400 sites. The list begins with ground sites and ends with geostationary sites fixed at equatorial locations 19323 nm in altitude. Within these two sets, sites are listed in alphanumeric order according to SITE ID. The end of a typical SCT display list appears in Figure 3.4.2.1-1. In this example, note site MLMC is available for interactive modification via fields immediately above the display's function keys.

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SCT – Station Characteristics Table v5.0.4							
GLOBAL	SSP	FDO STATION CHARACTERISTICS TABLE (SCT)				CURRENT	# OF RECS 195/400
SITE ID	MASK	GEODETTIC LATITUDE	LONGITUDE	FISCHER ELLIPSOID ALT (FT)	MIN ELEV ANG(DG)	MAX SLANT RNG(NMI)	SITE GROUP
UYT23	N	47:37:38.0N	052:44:53.6W	368	0.0	0.0	N
VDBC	Y	34:39:57.1N	239:25:07.1E	202	0.0	0.0	CEP
VDHC	Y	34:45:29.7N	239:22:22.4E	10	0.0	0.0	CE
VDMC	Y	34:34:59.1N	239:26:20.0E	1984	0.0	0.0	CE
VDSC	Y	34:34:57.9N	239:26:18.7E	1974	0.0	0.0	CE
VDT5	Y	34:33:56.3N	239:29:56.7E	1952	0.0	0.0	
VLA	N	34:02:24.0N	107:22:12.0W	6969	10.0	0.0	B
VMTG	Y	34:34:59.1N	239:26:20.0E	1984	0.0	0.0	
VTSS	Y	34:49:32.3N	239:29:40.9E	793	0.0	0.0	S
WAPS	Y	37:55:30.2N	284:31:24.9E	-75	0.0	0.0	
WHSB	N	32:30:00.0N	106:36:36.0W	2341	5.0	0.0	A
WHSC	Y	32:21:28.7N	253:37:48.1E	3858	0.0	0.0	E
WLIC	Y	37:50:28.8N	284:30:53.8E	-152	0.0	0.0	C
WLMC	Y	37:51:23.4N	284:29:19.2E	-173	0.0	0.0	C
WLPC	N	37:55:48.0N	075:28:48.0W	-104	5.0	0.0	A
WLPC	Y	37:51:36.9N	284:29:26.7E	-143	0.0	0.0	C
WLPS	Y	37:55:38.5N	284:31:30.2E	-133	0.0	0.0	S
WLRC	Y	37:56:38.7N	284:32:08.9E	-119	0.0	0.0	C
WSMC	Y	32:21:37.7N	253:37:34.1E	3850	0.0	0.0	
WSSC	Y	33:48:49.7N	253:20:27.0E	4839	0.0	0.0	E
YJT78	N	48:34:56.9N	058:40:09.0W	1063	0.0	0.0	N
YOK85	N	35:44:56.2N	139:21:00.9E	466	0.0	0.0	N
YQX74	N	48:53:59.0N	054:32:05.4W	493	0.0	0.0	N
ZZA64	N	41:40:37.5N	001:03:30.6W	920	0.0	0.0	N
ZZA77	N	41:39:28.3N	001:01:51.1W	941	0.0	0.0	N
T041W			041:00:00.0W				T
T047W			047:00:00.0W				T
T049W			049:00:00.0W				
T171W			171:00:00.0W				T
T174W			174:00:00.0W				T
T275W			275:00:00.0W				T

ID WLMC MASKING Y(Y,N) LATITUDE 28:37:33.930N D(C,D) LONGITUDE 279:19:02.040E  
 ALTITUDE -173.982 F(S,F) MIN ELEV ANGLE 0.0000 MAX SLANT RANGE 0.000000  
 SITE GROUP EC

HELP  
F1

EXECUTE  
F2

EXIT MENU  
F3

OVR ▲ ACCEPT  
F4

DELETED ENTRY  
F5

PRINT SCT  
F6

FETCH DATA  
F7

F8

**Figure 3.4.2.1-1: Typical TSA SCT Display**

In the SCT display, a given site's MASK column indicates whether or not terrain masking data are significant to PSAT acquisition processing for this site. Terrain masking data may be thought of as the site horizon's elevation as a function of true azimuth. Both natural topography and man-made obstructions may be included. Site location is displayed in the GEODETTIC LATITUDE, LONGITUDE, and FISCHER ELLIPSOID ALT columns. A site-specific acquisition elevation threshold is displayed in the MIN ELEV ANG column. Generally, a site with nonzero MIN ELEV has MASK = N to disable terrain masking. In cases where MASK = Y, acquisition occurs when the primary trajectory exceeds both the terrain masking elevation and the MIN ELEV threshold at a given azimuth. The MAX SLANT RNG column is not currently significant to PSAT processing.

Arguably the most important SCT column displays SITE GROUP memberships. If a site has no group memberships, PSAT will not process it. Groupless sites are common in a typical SCT. They may serve as downmodes during certain contingencies, or they may

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become relevant only when mission-specific objectives are to be attempted. Up to 9 simultaneous group memberships are permissible for a single site. The current Acquisitions Ops Concept assigns groups to sites according to the following conventions.

SCT Group	Assignment Support Criteria
A	RESERVED
B	SIMPLEX payload objectives
C	General C-band tracking operations
D	ROCSAT or other communications interference assessments
E	Entry-specific C-band and S-band operations
N	TACAN co-channel interference assessments
P	General payload operations or Earth Obs prediction accuracy checks
R	Contingency Russian commanding at MIN EL = 7°
S	S-band communications supplementing TDRSS
T	Geostationary sites only
U	Future requirements

**Figure 3.4.2.1-2: TSA SCT Group Assignment Conventions**

During a mission, it may be necessary to modify or add a site in the SCT. This task is nominally performed by NAV, but it can also be performed by FDO or TRAJ in coordination with NAV. It entails the following actions.

- 1) If a site is to be modified, type its ID in the corresponding interactive field above the F1 button, then click the F8 button. Baseline data specific to this site will be fetched into adjacent interactive SCT fields for subsequent editing. If a new site is to be input, simply enter data to the interactive fields, an F8 fetch being optional.

**NOTE:** geostationary sites are distinguished from earthbound sites by a dedicated ID format = aNNNb. In this convention, a = [A, B, ..., Z], NNN = a three-digit integer corresponding to nadir longitude (use leading zeros as required near the Prime Meridian), and b = [E, W] corresponding to nadir longitude direction from the Prime Meridian. Unless multiple satellites located at the same geostationary longitude would otherwise create an ID ambiguity, a = T is customary.

**NOTE:** earthbound site IDs may be up to 6 upper-case characters in length using virtually any alphanumeric sequence. Be aware the ID string will become the filename of any associated terrain masking data. Consequently, these IDs should generally be confined to the character set [A, B, ..., Z, 0, 1, ..., 9].

**CAUTION:** software associated with other disciplines may not be capable of accessing TDRSS acquisition data for geostationary IDs not commencing with T. Likewise, Ground acquisitions to be associated with MCC wall clock displays may require earthbound site IDs end in a particular alphabetic character. Particularly if a new site's acquisitions are to be processed by an application other than AcqMon, check with the requesting discipline (typically GC, DFE, COMMAND, or INCO) to insure a compatible ID is used.

**NOTE:** the interactive SITE GROUP field will accept up to 10 characters for group assignments to a site, but only the leftmost 9 characters are significant. Virtually any

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SITE GROUP string less than 9 characters in length can be stored in the SCT, but a diagnostic will appear indicating characters not in the set [A, B, C, D, E, N, P, R, S, T, U] will not be significant. A geostationary site can only be assigned membership in the T group, and a ground site's membership in the T group is not significant to PSAT processing.

- 2) When interactive fields are properly configured, an F5 click modifies the SCT display accordingly. Note the SCT status field in the window's upper-right corner now reads MODIFIED. Steps 1 and 2 may be repeated for multiple site modifications or additions as required.
- 3) The displayed SCT configuration is saved to the corresponding SCT.data file in Local or Global when F2 is clicked. Only then will a MODIFIED SCT status become CURRENT, indicating PSAT can access the updated SCT configuration.

Occasionally, it may be necessary to add or modify terrain masking data associated with an earthbound SCT site. During console operations, this is nominally a NAV task, but FDO or TRAJ may also perform it in coordination with NAV. To access the terrain masking editor, first click the up/down arrow adjacent to the SCT's F5 button as required to display an F5 button labelled EDIT AZ/EL. The editor is invoked by clicking EDIT AZ/EL. Its appearance is illustrated by the Figure 3.4.2.1-3 example.

LOCAL	FDO STATION CHARACTERISTICS TABLE (SCT)				CURRENT
	AZIMUTH/ELEVATION EDIT				# OF PAIRS 42 /400
ID	ANTC	Y	MASKING Y(Y,N)	AZIMUTH T(M,T)	AZ BIAS 0.
AZ/ELEV	AZ/ELEV	AZ/ELEV	AZ/ELEV	AZ/ELEV	AZ/ELEV
0.0000/0.000	71.000/1.200	72.000/0.000	113.00/0.600	113.50/0.000	
130.00/0.200	145.00/0.400	165.00/0.500	172.00/0.700	185.00/1.000	
187.00/1.400	195.00/1.100	199.00/1.500	202.00/5.000	202.50/1.800	
204.00/1.400	207.00/1.700	212.00/2.200	213.00/1.700	217.00/1.400	
219.00/0.900	222.00/1.200	223.00/4.300	223.50/1.300	227.00/1.500	
230.00/2.000	234.00/2.500	237.00/2.900	250.00/2.500	254.00/2.000	
255.00/1.800	265.00/2.000	282.00/1.600	286.00/1.300	290.00/1.100	
293.00/1.300	298.00/1.000	300.00/0.700	305.00/0.400	308.00/0.200	
320.00/0.000	360.00/0.000	-----/-----	-----/-----	-----/-----	

EXECUTE	SAVE MENU	EXIT MENU	DVR		PRINT	FETCH DATA	
f1	f2	f3	f4	f5	f6	f7	f8

**Figure 3.4.2.1-3: Typical Terrain Masking Editor Appearance**

The editor supports specification of up to 400 azimuth/elevation points describing a ground site's horizon. Baseline editor terrain masking data, if they exist, will initially default to those of the site fetched into the SCT display's interactive ID field. To obtain any other site's baseline, type the corresponding string into the editor's ID field, then click F8. After the masking data are input or modified as required, the editor saves them to a file named per the ID field when F2 is clicked. The masking file will reside in Local or Global per the parent SCT display's origin, and a field in the upper-left corner of the editor window indicates this destination. All masking files are stored in the `System/AZEL_DATA/` directory.



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**CAUTION:** virtually any string up to 6 characters in length can be input to the editor's ID field, and it will become the associated data's file name. Consequently, insure the ID field matches the intended ground site ID and that both adhere to UNIX file name conventions. A masking data file not corresponding to an SCT ground site ID cannot be processed by PSAT.

**CAUTION:** the terrain masking editor will accept AZ/ELEV pairs in any sequence, but it will reorder them according to increasing azimuth as you type. Before clicking F2 to store the edited data, insure the first pair has AZ = 0.0, the last pair has AZ = 360.0°, and ELEV values for both pairs match. This condition insures any primary trajectory azimuth with respect to the ground site can be interpolated. Acquisitions with compromised integrity may result from processing a ground site whose masking data don't satisfy the "closure" condition.

**NOTE:** the AZIMUTH and AZ BIAS fields at the top of the terrain masking editor window imply AZ data may be entered with respect to local magnetic north at the ground site. These fields are inoperative. Even if AZIMUTH = M and AZ BIAS ≠ 0, entered AZ data will be interpreted and stored with respect to true north.

**NOTE:** valid ELEV data may lie between -90° and +90° inclusive. At these extremes, it's possible to specify a transparent Earth or opaque sky over any azimuth range.

### 3.4.2.2 TSA PSAT

The PSAT application is critically certified to generate ground, TDRSS, Sun, and Moon acquisitions associated with any primary trajectory in the TSA database. In addition to ephemerides, PSAT retains a capability to define a primary trajectory using discrete vectors stored in a single VAT. Because output from PSAT VAT processing is restricted to TSA Local's `PSAT_UDE` directory tree, this section will limit its scope to ephemeris-based PSAT primary trajectory processing. Should specific circumstances require input from a VAT, see the latest PSAT user's guide for processing details.

Coincident with its initial critical certification, PSAT's TOAST Era menu has been abandoned in favor of an X-Windows-based GUI. Unlike its predecessor, the new menu is capable of independently maintaining multiple, ephemeris-specific baselines which function as PSAT macros. Consequently, ephemeris context is significant not only to the new menu's output destination, but also to its default configuration. These defaults are polled when AutoMOC, Ephemeris Update, or EDS executes PSAT for ephemeris mirrors with STDN options enabled. A PSAT menu illustration appears in Figure 3.4.2.2-1.

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File Edit View Acquisition Help																																			
FDO Acquisition Menu : PSAT			<b>Current</b>																																
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Ephemeris Data																																			
STDN: <input checked="" type="checkbox"/> On <input type="checkbox"/> Off																																			
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EPHB GMT:	2002(Dec07)341/10:52:15.000	EPHB MET:	013/10:02:28.015																																
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**Figure 3.4.2.2-1: Typical PSAT Menu Appearance**

Primary ephemeris context in the PSAT menu may be established manually or automatically. With a menu that's already invoked, establish context by interacting with its topmost Vehicle/System/Location pop-up menus. These pop-ups are automatically configured for you if the PSAT menu is invoked using TPS Tier 0, TPS Tier 1, or the AutoMOC UIF. Immediately after primary ephemeris context is established, the PSAT menu will assume the configuration it last saved or executed in association with this ephemeris. This is indicated by a reverse-green "Current" field in the menu's upper-right corner. If another user or AutoMOC changes the primary-ephemeris-specific PSAT

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configuration to which the menu has context, the field reads reverse-yellow "Modified". A Modified PSAT menu status can be returned to Current in several ways.

- 1) Click the Modified field. This will alter your PSAT menu to reflect changes to the ephemeris-specific database since the menu was last in a Current condition.
- 2) Click the Save button. This will alter the ephemeris-specific database to reflect your menu's current configuration.
- 3) Click the Execute button. This performs the same database update as a Save, then generates PSAT acquisitions accordingly.

Once Vehicle/System/Location pop-up menus establish context to a primary ephemeris, the box immediately below them provides status information pertaining to that ephemeris. The primary ephemeris directory will receive all PSAT output, and its trajectory is relevant to all acquisitions computed in this menu context. None of the fields in the primary ephemeris status box are interactive.

Fields below the primary ephemeris status box govern PSAT processing options in this context. When primary ephemeris context is established, these fields assume default values typically requiring minimal interaction. The following paragraphs relate essential features associated with these fields.

**NOTE:** many of the ensuing PSAT menu fields, such as drag profile and comment, are similar to corresponding ephemeris status data, but they're stored in an independent TSA database element dedicated to each PSAT menu's context. Only when the dedicated element has been erased are ephemeris status values used to populate PSAT menu defaults. Consequently, changes to ephemeris status may not be reflected in the menu's default values. These defaults may be synchronized with the primary ephemeris status by selecting "Refresh With EPH" from PSAT's Edit pull-down menu.

**STDN:** associated On/Off radio buttons enable/disable "STDN options". Named after a similar function in the retired MOC, acquisitions for a primary ephemeris with STDN options On will be recomputed per its PSAT menu baseline immediately after each TUP. This is also the case for mirrored TrS ephemerides with STDN options On. A similar STDN options control is available on TSA's Ephemeris Update menu.

**Start/Stop:** associated multi-field entries and pop-up menus permit you to process a selected segment of time spanned by the primary ephemeris. Input may be made in M(I)ET or GMT.

**NOTE:** to minimize PSAT baseline configuration maintenance associated with a STDN options On primary ephemeris, Start/Stop values are overridden when PSAT is executed automatically. Under STDN options processing, PSAT will generate acquisitions for the entire primary ephemeris time span. Only when "Execute" is clicked on the PSAT menu will associated Start/Stop times be significant.

**Area/KCON/Weight:** these fields aren't interactive or significant when the PSAT menu's context is a primary ephemeris. Associated values initially default to the primary's current drag profile. They only become interactive when context is a TSA VAT.

**Orbit** fields: these initial orbit count values default to corresponding values in the primary ephemeris directory's `EPH.ORB` file. If this file doesn't exist, as is the case prior to

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ephemeris initialization in NONE status, all 3 initial orbit counts default to zero on the PSAT menu. Inputs to these fields have no significance whatever unless the PSAT menu's "Execute" button is clicked. They're completely ignored in favor of `EPH.ORB` values if PSAT processes automatically after a primary ephemeris with STDN options On is updated. Even if "Execute" is clicked, initial orbit counts on the PSAT menu may have no operational significance. In this case, PSAT's orbit count computations are stored in the primary ephemeris directory's `orbit.acq` file. No other application directly interfaces with `orbit.acq` orbit counts.

At this point, it's natural to wonder why PSAT menu orbit fields are interactive in a primary ephemeris context. The operational reason is to provide a daily orbit "guess" override capability in association with mirrored ephemerides. Because TrS doesn't maintain daily orbit counts, this guess may be incorrect. To override an incorrect guess, perform the following actions.

**NOTE:** an AutoMOC daily orbit count guess is only performed if the EPHB epoch doesn't lie within an existing `EPH.ORB`'s time span. Thus, an incorrect guess is most likely to arise at ephemeris initialization or when a planning ephemeris is set back to current time. Should an ephemeris be updated to track a totally new trajectory, an incorrect guess may also arise.

- 1) Disable mirroring for the errant AutoMOC ephemeris with incorrect daily orbit count. This action is optional if interrupted mirroring is undesirable. Its intent is to prevent an unexpected TrS TUP from introducing error in the `EPH.ORB` update.
- 2) Invoke a PSAT menu with context such that the primary ephemeris is the errant AutoMOC mirror.
- 3) Edit the PSAT menu's Daily Orbit Number field to reflect the correct value at primary ephemeris begin time (EPHB).
- 4) On the PSAT menu, click the Update EPH.ORB field's "Yes" radio button.
- 5) Click the PSAT menu's "Execute" button. When PSAT's processing completes, its `orbit.acq` data will also populate the primary ephemeris directory's `EPH.ORB` file. As long as the primary's anchor time during future updates remains within its pre-update time span, `EPH.ORB`'s orbit counts will be correct.
- 6) Click the Update EPH.ORB field's "No" radio button, then click the PSAT menu's "Save" button.

**CAUTION:** the foregoing step is essential to preserve orbit count integrity in mirrored ephemerides. Subsequent ephemeris TUPs will generally be at EPHB times later than those corresponding to the daily orbit value input to the PSAT menu. If the Update EPH.ORB option remains Yes, this same value will continue to override `EPH.ORB`, ultimately making it incorrect again.

- 7) If AutoMOC mirroring was suspended during the `EPH.ORB` update, it may be resumed at this time.

**NOTE:** TPS Tier 1 daily orbit count will not update following this procedure. To obtain an update for a mirrored ephemeris, TUP the source ephemeris. For a TSA-TUPable

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ephemeris, supply the correct initial daily orbit to the Ephemeris Update menu and perform a TUP to trigger the desired Tier 1 update.

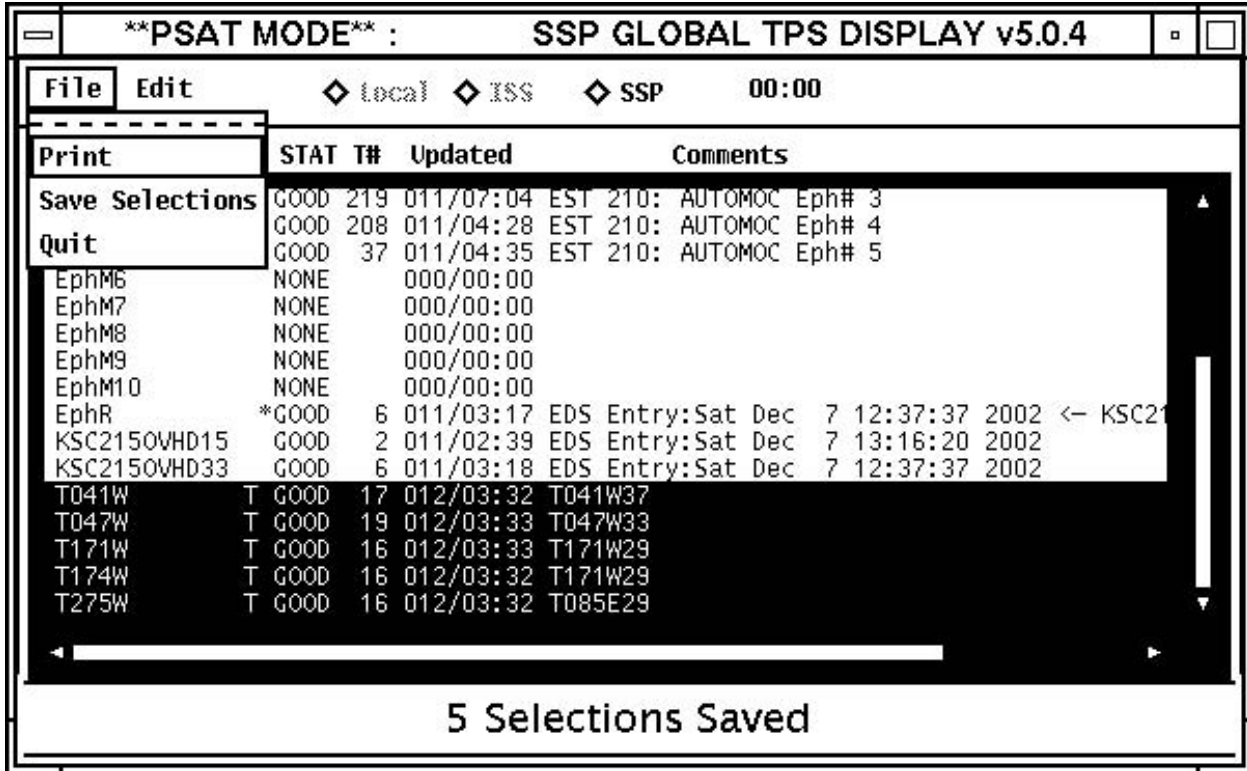
**Net** fields: the Yes/No radio button pairs govern whether or not PSAT processes SCT ground sites to generate acquisitions in the primary ephemeris directory. Only those sites with SCT membership in Yes nets will be processed. Nets are assigned to ground and geostationary sites by the TSA SCT menu, where they're termed site "Groups". See Section 3.4.2.1 for net assignment conventions and procedures.

The "T" (TDRSS) Net requires additional discussion. As with other nets, Yes/No radio buttons control whether or not any TDRSS acquisitions will be processed. If "Yes" is selected, you must also specify a TDRSS trajectory source using SCT/EPH radio buttons. An SCT TDRS trajectory is perfectly geostationary at an equatorial longitude stored in the TSA SCT. Because of its geostationary nature, an SCT TDRS trajectory is also called a "tall mountain". Under the "EPH" option, a TDRS trajectory is defined by a dedicated TSA Global secondary ephemeris. A primary ephemeris may be subscribed or "wired" to any number of TDRSS secondaries if the PSAT menu's EPH option is selected. Subscription links between a primary and its secondaries are initiated and terminated using the following procedure. These steps may be carried out by FDO or TRAJ.

- 1) Click the "EPHEM" button on the primary's PSAT menu, invoking the Secondary Ephemeris Selection (SES) dialog window (see Figure 3.4.2.2-2).

**NOTE:** an SES dialog is nearly identical in appearance to a TPS Tier 0 display. Its title bar contains a "\*\*\*PSAT MODE\*\*" string as a means of distinguishing its function. Behavior of an SES dialog is also distinct from a Tier 0 display. Because an SES is a PSAT menu modal dialog window, PSAT menu interactions and updates are inhibited when its SES is invoked. The only ephemerides significant to SES function reside in Global, so Local database access is inhibited. Finally, an SES is only required to select ephemerides. Consequently, Edit menu capabilities to Cut/Copy/Paste/Delete an ephemeris are disabled.

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**Figure 3.4.2.2-2: Secondary Ephemeris Selection (SES) Dialog Appearance**

- 2) In the SES dialog, click TDRSS ephemeris records as required to select or deselect them as secondaries. Selected records will appear reverse-field white.

**NOTE:** a T049W ephemeris may be built during sims, but this satellite is rarely used in the real world. Unless a scenario explicitly calls for its use, T049W may be omitted from PSAT processing.

- 3) Select "Save Selections" from the SES dialog's File menu. Verify the number of secondaries selected is confirmed as saved at the bottom of the SES window.
- 4) Quit the SES.

**CAUTION:** if a primary ephemeris with STDN options On is subscribed to a secondary ephemeris, a complete PSAT run will be triggered in the primary when the secondary is TUPed. In the case of TDRSS secondary ephemerides, multiple subscriptions routinely exist in one or more primaries. During a wholesale update to all TDRSS ephemerides, it's therefore advisable to temporarily set STDN options Off in all primaries and avoid multiple PSAT runs in each case.

**CAUTION:** on occasion, it may be necessary to delete a TDRSS ephemeris using TPS Tier 0. This action will dissolve any subscription links from primary ephemerides. After the TDRSS ephemeris is recreated, insure primary ephemeris links are established by executing the foregoing procedure.

**NOTE:** a Local primary ephemeris can be subscribed to Global secondary ephemerides. If the Local primary has STDN options On, TDRSS acquisitions will automatically be recomputed in EPH mode when the primary is TUPed. New TDRSS acquisitions will *not*

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be computed automatically if a secondary is TUPed, however. Thus, INC2 status can never apply to a Local primary ephemeris.

**NOTE:** when an entry ephemeris is promoted to the prime entry ephemeris `EphR` directory, the prime's PSAT menu configuration is not altered.

**CAUTION:** when a Global ephemeris is copied to a Local ephemeris using TPS Tier 0, any subscriptions to TDRSS secondary ephemerides will be dissolved in the Local copy. If these subscriptions are to be preserved in Local, they must be manually reactivated using the PSAT menu. This is a permanent limitation.

**CAUTION:** when an ephemeris is copied using TPS Tier 0, the copied PSAT menu configuration will generally not preserve the original. If the copied ephemeris PSAT menu configuration is significant, it must be reset manually. Except in the case of a promotion to `EphR`, Tier 0 copies will preserve PSAT menu configurations after AR 011160 is cleared.

**NOTE:** when processing TDRSS acquisitions in EPH mode, PSAT will compute only those AOS/LOS events in the time period covered by both the primary and pertinent secondary ephemerides. A PSAT Log window diagnostic will be issued if a secondary doesn't completely overlap the primary ephemeris time span.

**CAUTION:** initial TDRSS acquisitions may be in error if a primary ephemeris begins at 001/00:00:00 GMT. When computing January 1 GMT TDRSS acquisitions, insure the primary ephemeris starts no earlier than 001/00:00:01 GMT.

**NOTE:** a non-TDRS Global ephemeris can be selected as a secondary for PSAT processing. During a rendezvous, selecting M3 as a secondary to an M1 primary would generate times when a line-of-sight unobstructed by the Earth exists between a chaser and target.

**Comment:** this interactive field is, by default, the primary ephemeris comment string to which the PSAT menu has context. In lieu of a comment string in the primary ephemeris `EPH.DATA` file, the Comment field will drive AcqMon displays associated with this primary when PSAT completes processing. Consequently, any modification to the default string may create an undesirable inconsistency between the primary ephemeris TPS Tier 0 comment and that displayed by AcqMon. This field's chief purpose is to provide a comment associated with PSAT output to TSA Local's `PSAT_UDE` directory tree.

**Output Destination:** if the PSAT menu has a primary ephemeris context, you may route output to the primary's directory by default or to TSA Local's `PSAT_UDE` directory tree. Should the "Local PSAT\_UDE" radio button be selected, you may specify any valid subdirectory name, whether or not it already exists, and it will receive output in the `PSAT_UDE` tree. The pre-programmed default subdirectory name is `GENERIC`.

**Minimum Elevation:** this elevation threshold is applied to all ground site acquisition computations and guarantees elevation will exceed this value throughout any AOS. Elevation computed by PSAT at AOS/LOS is the greater of this threshold and either of two site-specific values. If terrain masking is enabled for the site (either through the generic PSAT menu option or a site-specific SCT toggle), the terrain masking elevation at the AOS/LOS azimuth is significant. If the site's terrain masking is disabled, its SCT-resident `MIN ELEV ANGLE` is significant.

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**Integration Time Step:** this 120-sec default time step does NOT control any integration or trajectory prediction process as its label implies. Rather, it regulates the time interval PSAT uses to step through a primary or secondary trajectory in search of acquisitions. Because PSAT's critical certification was achieved using a 120-sec step, changes to it aren't generally advisable. The default time step for an entry primary ephemeris is automatically set to 30 sec to insure accuracy at the high angular rates observed by ground sites during this phase of flight.

**CAUTION:** Integration Time Step values < 120 sec are *required* to confirm or refine high elevation acquisition AOS, LOS, or MaxEI events. To address these cases, invoke "The 30/30 Rule". If an acquisition event is expected at an elevation > 30°, manually set the Integration Time Step to 30 sec. The smaller step permits more accurate interpolation of non-linearities in the elevation-versus-time function as 90° is approached. In marginal cases, where a minimum elevation acquisition threshold > 30° is barely exceeded, the 120 sec default Integration Time Step value may fail to detect any acquisition at all.

**Acquisition Events:** these Yes/No radio button pairs enable/disable various PSAT processing options. Their purpose is generally self-evident. To maintain PSAT's certification pedigree, both Oblate Earth and Atmospheric Refraction options should be left in their default "No" condition. Use of the "Update EPH.ORB" option is covered in the PSAT menu's **Orbit** fields discussion.

**CAUTION:** if the PSAT menu has context in a blank ephemeris directory with NONE status, the Update EPH.ORB option will default to Yes. This is generally an undesirable state for this option. The update should be "Yes" only during the single PSAT run to correct an errant AutoMOC daily orbit guess. Leaving this option in a Yes state for a STDN options Yes ephemeris context can result in the same initial orbit counts being applied regardless of EPHB variations.

**NOTE:** if PSAT menu Start/Stop and Nets are configured such that no Ground or TDRSS acquisitions are computed, an "Error promoting files" Log window message will appear. Even if Sunrise/Set or Moonrise/Set acquisitions are enabled on the menu, none will be computed until at least one Ground or TDRSS acquisition is computed.

### 3.4.2.3 Acquisition Monitor (AcqMon)

With AcqMon, users throughout the Shuttle and ISS Flight Control Teams (FCTs) are able to independently access available acquisitions data, display them according to multiple content and format options, then output these displays to a printer or text file. In this capacity, AcqMon functions as the "viewer" companion to PSAT's acquisition data generation capability. It's possible to invoke AcqMon with various initial defaults through the Master FDO or TSA DNAVs, Tier 0 TPS, Tier 1 TPS, AutoUIF, or a PSAT menu. Shuttle FCOH SOP 5.8 documents AcqMon usage by the FCT. The following subsections detail AcqMon's multiple display modes and the means by which they're controlled.

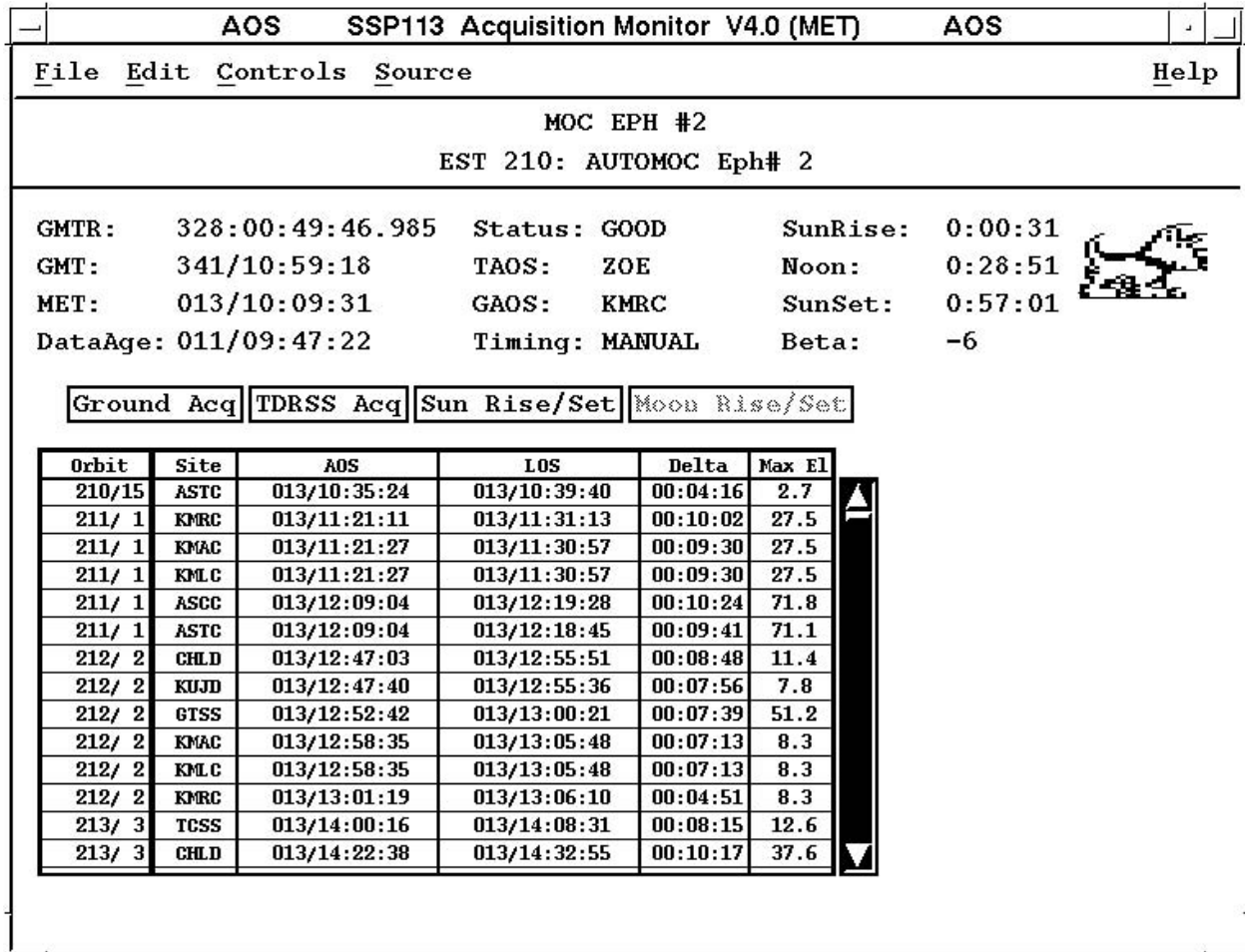
#### 3.4.2.3.1 AcqMon Ground Acquisitions and General Functions

The Ground acquisitions display mode is typically selected by default when AcqMon is invoked. If another mode is in effect, simply click AcqMon's "Ground Acq" button, and



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acquisitions between the selected primary ephemeris and ground sites will be displayed per the Figure 3.4.2.3.1-1 example.



**Figure 3.4.2.3.1-1: AcqMon Running In Ground Mode**

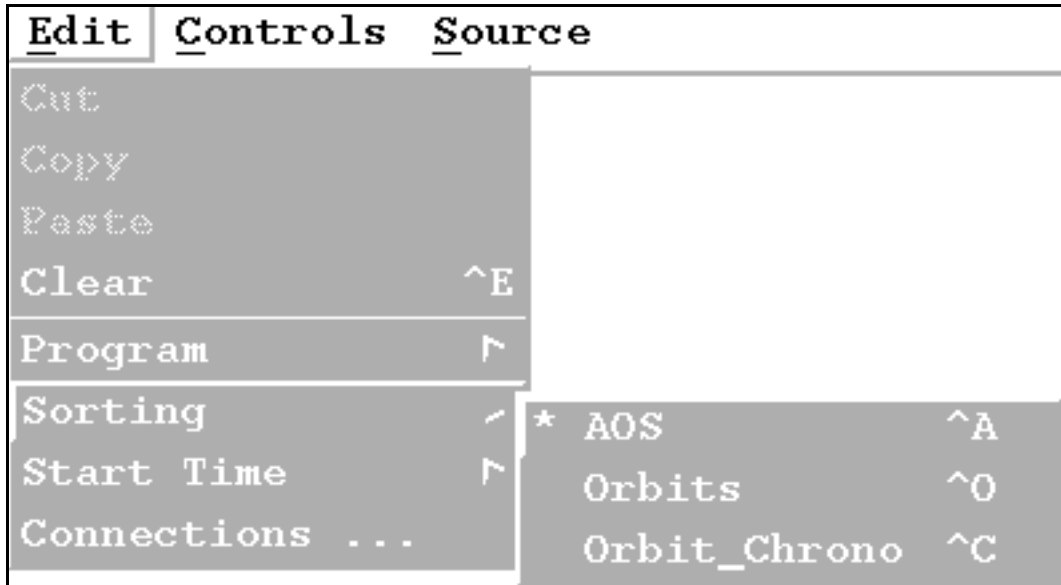
Located in the title bar at the top of AcqMon's window frame are two status indicators. The first status, acquisition sorting mode, is output in two mirrored fields flanking the title bar string. In the Figure 3.4.2.3.1-1 example, the sorting mode is set to its AOS default. Sorting options can be selected via AcqMon's "Edit" pulldown menu (see Figure 3.4.2.3.1-2), and they govern event sequencing in AcqMon's tabular display as follows.

**AOS:** a displayed orbit count will correspond to the AOS or rise event on the same line, but other events on this line will not fall on the associated orbit if an intervening ascending node occurs after the AOS or rise event. A left-to-right event chronology is maintained for each displayed line.

**ORBITS:** a displayed orbit count will correspond to all events on the same line. Left-to-right chronology will not be maintained for a line unless the AOS or rise event is the first to follow an ascending node.

**ORBIT\_CHRONO:** a displayed orbit count will correspond to all events on the same line. If necessary, left-to-right chronology will be maintained by utilizing two lines to display events during one orbit.

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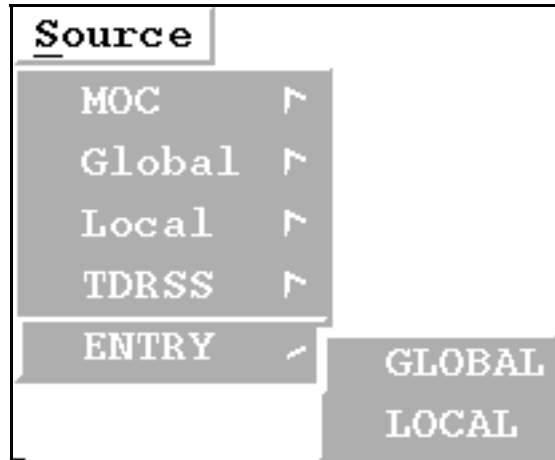
**Figure 3.4.2.3.1-2: Acquisition Sorting Option Selection**

Sorting option selection has deeper implications when acquisition events are more widely spread over an orbit than in Ground display mode. These implications are illustrated for Sun Rise/Set display mode in Section 3.4.2.3.3.

The second status indicator, enclosed by parenthesis in AcqMon's title bar string, provides the time scale applicable to events in the tabular display. In the Figure 3.4.3.2.1-1 example, "(MET)" indicates Ground AOS and LOS events are displayed in MET. Time scale options are selectable via AcqMon's "Controls" menu. In addition to the MET option, GMT events may be displayed in day-of-year or calendar date format. As a final alternative, the time interval from each AOS or LOS event to current time is dynamically displayed with the DT option. When operating in DT mode, AcqMon timers update once every 10 sec.

Immediately below AcqMon's pulldown menus is a rectangular region identifying the primary ephemeris source associated with displayed acquisitions data. In the Figure 3.4.2.3.1-1 example, "MOC EPH #2" indicates this primary ephemeris is the TrS Ephemeris 2 mirror (M2). This string is followed by whatever comment has been associated with the primary ephemeris. The primary ephemeris whose acquisitions are displayed can be selected using AcqMon's nested "Source" menu as illustrated by Figure 3.4.2.3.1-3. Items listed in the "MOC" submenu correspond to TrS ephemeris mirrors, while those listed in association with the "ENTRY" submenu originate from EDS processing. All other Source submenus reference TSA-TUPable ephemerides.

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**Figure 3.4.2.3.1-3: AcqMon's Nested Source Menus**

**NOTE:** during joint operations with ISS, it may be desirable to access acquisitions data stored by TOPO in ISS Global. This can be accomplished by selecting Program : ISS from AcqMon's "Edit" pulldown menu. In the "Source" menu, "Global" will then reflect TOPO's primary ephemerides. You can verify AcqMon's Program status in its title bar immediately to the left of the "Acquisition Monitor" substring. In the Figure 3.4.2.3.1-1 example, the "SSP113" title bar substring would change to the appropriate ISS substring following an Edit : Program : ISS menu item selection.

Below the primary ephemeris source identification strings are digital displays grouped into three columns. These displays are reviewed in the following subparagraphs.

**GMTR:** GMTLO associated with Timing Services through ROSS by default or specified in association with the primary ephemeris through the Connect dialog (see Figure 3.4.2.3.1-5).

**GMT and MET:** "current" time as defined by AcqMon. Default AcqMon current time is provided by Timing Services through ROSS. Current GMT/MET governs which acquisition AcqMon will select to be the first in its tabular display. Current AcqMon time also drives AOS/LOS timers when AcqMon functions in DT display mode. If the default first tabulated acquisition isn't acceptable, a new "no earlier than" display GMT threshold can be manually specified via the dialog window invoked by AcqMon's Edit : Start Time : User Start... pulldown menu item (see Figure 3.4.2.3.1-4). Manual overrides to current time may also be specified through the Connect dialog (see Figure 3.4.2.3.1-5).

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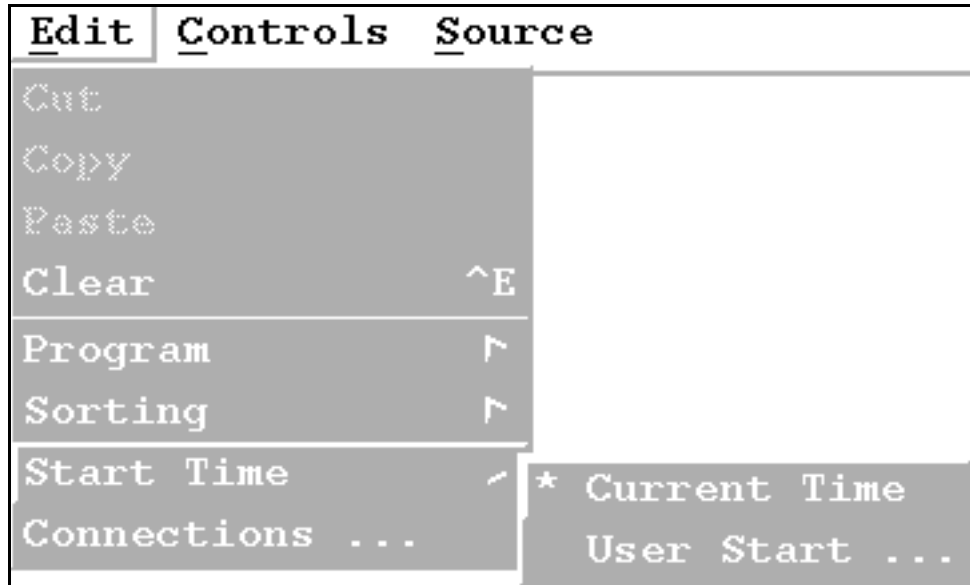


Figure 3.4.2.3.1-4: AcqMon Menu Items Controlling Display Start Time

**NOTE:** a display buffer of finite length stores data associated with AcqMon's tabular display. Particularly in the case of a long or old ephemeris, acquisitions of interest may lie before or after the buffer's time span. To access these acquisitions, select the Edit : Start Time : User Start... AcqMon menu item and specify a "no earlier than" display threshold GMT.

**CAUTION:** AcqMon current time defaults to a ROSS data stream driven by a Timing Services clock. Prior to sim start or before launch, this clock may not be correctly configured or even operational. In such instances, AcqMon current time may be manually set to a specified epoch by selecting the Edit : Connections... menu item. This action invokes the Connect dialog window (see Figure 3.4.2.3.1-5). In this window, click "Manual". Default SGMT and SGMTLO epochs from the primary ephemeris are then available for editing. After "OK" is clicked, AcqMon current time will begin counting up from the specified SGMT.

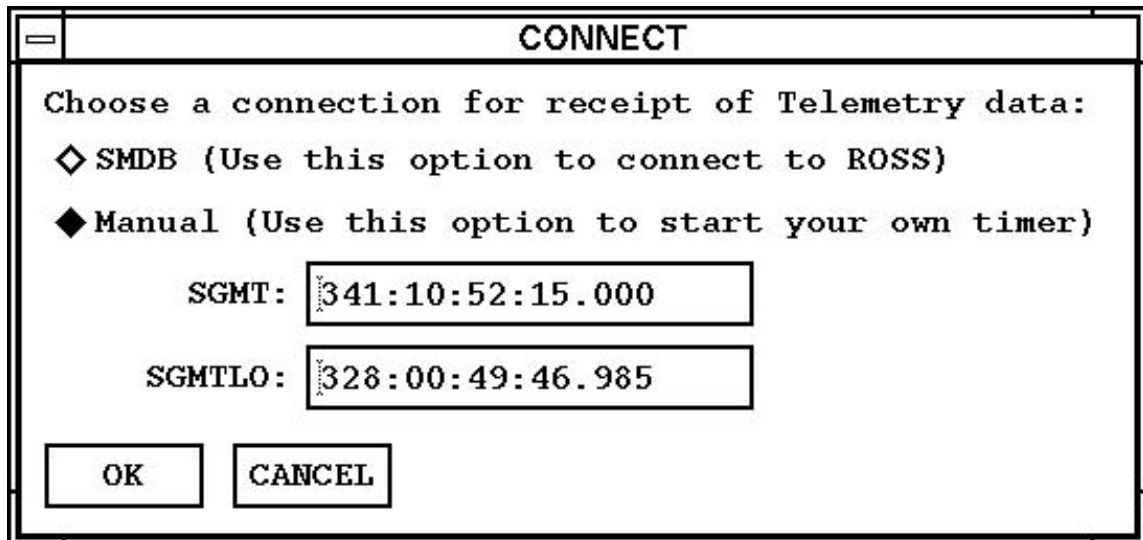


Figure 3.4.2.3.1-5: AcqMon's Connections Dialog Window

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**CAUTION:** even with "Manual" selected beforehand in the Connect dialog, any subsequent change in primary ephemeris via the "Source" menu will trigger AcqMon's return to its default ROSS timing data source.

**DataAge:** time elapsed since the primary ephemeris, selected via AcqMon's "Source" menu, was last updated.

**Status:** status associated with the primary ephemeris selected via AcqMon's "Source" menu. Users will not routinely question AcqMon validity if Status is "GOOD" and DataAge is reasonable. Typically, user validity questions arise when Status is "INCN". This means the primary ephemeris trajectory has been updated, but associated acquisition data have not been updated accordingly or the data haven't been purged altogether. To purge acquisitions data from an ephemeris, delete and regenerate the ephemeris without running PSAT. Otherwise, simply rerun PSAT to transition a primary ephemeris status from INCN to GOOD. To automate PSAT runs maintaining GOOD status, use the PSAT or Ephemeris Update menus to specify STDN status On for this primary ephemeris (see Figure 3.4.2.2-1's PSAT menu illustration).

**TAOS:** primary ephemeris TDRSS acquisition status at AcqMon current time.

**GAOS:** site ID pertaining to the upcoming or current primary ephemeris ground acquisition.

**Timing:** timing source (MANUAL or ROSS) from which AcqMon current time is inferred. This source is selected with the Connect dialog window (see Figure 3.4.2.3.1-5).

**SunRise:** countdown from AcqMon current time to the next primary ephemeris sunrise.

**Noon:** countdown from AcqMon current time to the next primary ephemeris solar noon.

**Sunset:** countdown from AcqMon current time to the next primary ephemeris sunset.

**Beta:** primary ephemeris solar beta angle corresponding to the nearest orbit midnight epoch. See Section 3.4.2.3.3 for detailed  $\beta$  information.

In Ground display mode, AcqMon's table contains the following data.

**Orbit:** primary ephemeris cumulative orbit count, followed by the daily orbit count. In the default AOS Sorting mode, these counts will apply exclusively to the corresponding AOS time if an ascending node exists between AOS and LOS. Although most Ground acquisitions are less than 10 min in duration for typical primary ephemerides, this condition can occur for some tropical sites such as Ascension or Kwajalein. If the orbit count at LOS is significant, select the "Orbits" or "Orbit\_Chrono" item in AcqMon's Edit : Sorting pulldown menu (see Figure 3.4.2.3.1-2).

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**Site:** the ground site ID to which each acquisition applies. The TSA SCT (Local or Global, corresponding to the primary ephemeris AcqMon references) supplies the displayed string.

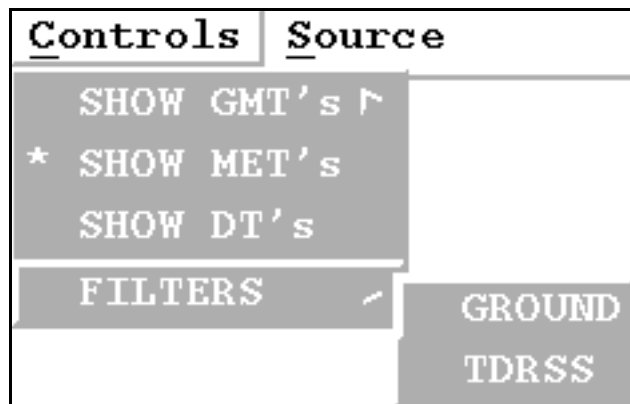
**AOS:** time at which the primary ephemeris trajectory's elevation above the ground site's local horizontal plane first satisfies the minimum constraint processed by PSAT.

**LOS:** time at which the primary ephemeris trajectory's elevation above the ground site's local horizontal plane last satisfies the minimum constraint processed by PSAT.

**Delta:** time interval from AOS to LOS.

**Max El:** the primary ephemeris trajectory's maximum elevation in deg above the ground site's local horizontal plane.

Ground site acquisition data processed by PSAT in association with a given primary ephemeris may be voluminous, even over short time intervals. An individual AcqMon user may only be interested in a small subset of these data. If this interest is consistent with TSA SCT Net or Group assignments (see Figure 3.4.2.1-2), the GROUND FILTER dialog may be used to exclude primary ephemeris acquisition subsets from AcqMon's tabular display. This dialog is invoked from AcqMon pulldown menu path Controls : FILTERS : GROUND as illustrated by Figure 3.4.2.3.1-6.



**Figure 3.4.2.3.1-6: Access to Acquisition Display Filtering Controls**

The GROUND FILTER dialog lists all 10 Nets to which ground sites may be assigned in the TSA SCT (see Figure 3.4.2.3.1-7). Membership in at least one Net is required for site acquisitions to be processed by PSAT, and a single site may have simultaneous membership in as many as 9 Nets. However, PSAT processing typically excludes some Nets. Those Nets PSAT actually processes in connection with the primary ephemeris referenced by AcqMon are accompanied by asterisks in the GROUND FILTER "Avail" column. By default, each processed Net is initially selected for display. If you click "Select" column check boxes, acquisitions specific to each processed Net may be excluded from AcqMon display. In the Figure 3.4.2.3.1-7 example, P Net acquisitions will be excluded from display after "OK" is clicked.

**NOTE:** if a new primary ephemeris is selected with AcqMon's "Source" menu, previous GROUND FILTER dialog input will be preserved.

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GROUND FILTER		
NET	Avail	Select
A		<input type="checkbox"/>
B	*	<input checked="" type="checkbox"/>
C	*	<input checked="" type="checkbox"/>
D	*	<input checked="" type="checkbox"/>
E		<input type="checkbox"/>
N		<input type="checkbox"/>
P	*	<input type="checkbox"/>
R		<input type="checkbox"/>
S	*	<input checked="" type="checkbox"/>
U		<input type="checkbox"/>

OK CANCEL

Figure 3.4.2.3.1-7: GROUND FILTER Dialog

### 3.4.2.3.2 AcqMon TDRSS Acquisitions

The TDRSS acquisitions display mode is selected by clicking AcqMon's "TDRSS Acq" button. Acquisitions between the selected primary ephemeris and associated secondary ephemerides will be displayed per the Figure 3.4.2.3.2-1 example.


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AOS
AOS
SSP113 Acquisition Monitor V4.0 (MET)

File Edit Controls Source
Help

MOC EPH #2

EST 210: AUTOMOC Eph# 2

GMTR: 328:00:49:46.985	Status: GOOD	SunRise: 1:32:06	
GMT: 341/11:00:08	TAOS: ZOE	Noon: 0:28:01	
MET: 013/10:10:21	GAOS: KMRC	SunSet: 0:56:11	
DataAge: 011/09:48:12	Timing: MANUAL	Beta: -6	

Ground Acq	TDRSS Acq	Sun Rise/Set	Moon Rise/Set
------------	-----------	--------------	---------------

Orbit	Sat	AOS	LOS	Delta
210/15	T174W	013/10:02:28	013/10:22:02	00:19:34
210/15	T171W	013/10:02:28	013/10:21:56	00:19:28
210/15	T047W	013/10:02:28	013/11:00:48	00:58:20
210/15	T041W	013/10:04:09	013/11:02:21	00:58:12
210/15	T275W	013/10:29:42	013/11:32:51	01:03:09
211/ 1	T174W	013/11:04:08	013/11:57:57	00:53:49
211/ 1	T171W	013/11:04:24	013/11:58:42	00:54:18
211/ 1	T047W	013/11:42:18	013/12:37:53	00:55:35
211/ 1	T041W	013/11:43:53	013/12:38:49	00:54:56
211/ 1	T275W	013/12:13:18	013/13:16:09	01:02:51
212/ 2	T174W	013/12:40:00	013/13:34:44	00:54:44
212/ 2	T171W	013/12:41:06	013/13:36:25	00:55:19
212/ 2	T047W	013/13:19:51	013/14:13:54	00:54:03
212/ 2	T041W	013/13:20:48	013/14:14:37	00:53:49

**Figure 3.4.2.3.2-1: AcqMon Running In TDRSS Mode**

In TDRSS display mode, AcqMon's table contains the following data.

**Orbit:** primary ephemeris cumulative orbit count, followed by the daily orbit count. In the default AOS Sorting mode, these counts will apply exclusively to the corresponding AOS time if an ascending node exists between AOS and LOS. If the orbit count at LOS is significant, select the "Orbits" or "Orbit\_Chrono" item in AcqMon's Edit : Sorting pulldown menu (see Figure 3.4.2.3.1-2).

**Sat:** the TDRS ID to which each acquisition applies. For a geostationary site, the TSA SCT (Local or Global, corresponding to the primary ephemeris referenced by AcqMon) supplies the displayed string. For a TDRS ephemeris, the displayed ID corresponds to the Global secondary ephemeris to which the primary is subscribed.

**AOS:** time at which the primary ephemeris trajectory first has a line-of-site to this TDRS unobstructed by the Earth.

**LOS:** time at which the primary ephemeris trajectory last has a line-of-site to this TDRS unobstructed by the Earth.

**Delta:** time interval from AOS to LOS.



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As in Ground display mode, AcqMon users can be overwhelmed by a myriad of displayed TDRSS acquisitions when only a subset is of interest. The TDRSS display mode is supported by an AcqMon acquisitions filtering function akin to that associated with the Ground display mode. The main difference between these two functions is Ground acquisition displays are filtered according to Net, while TDRSS acquisition displays are filtered according to individual satellite IDs. Use the AcqMon pulldown menu path Controls : FILTERS : TDRSS, as illustrated by Figure 3.4.2.3.1-6, to access the TDRSS FILTER dialog. This dialog lists all TDRSS secondary ephemerides or TSA SCT geostationary sites for which PSAT has computed acquisitions in association with the AcqMon primary ephemeris. In the Figure 3.4.2.3.2-2 example, AcqMon will no longer display T275W acquisitions after "OK" is clicked.

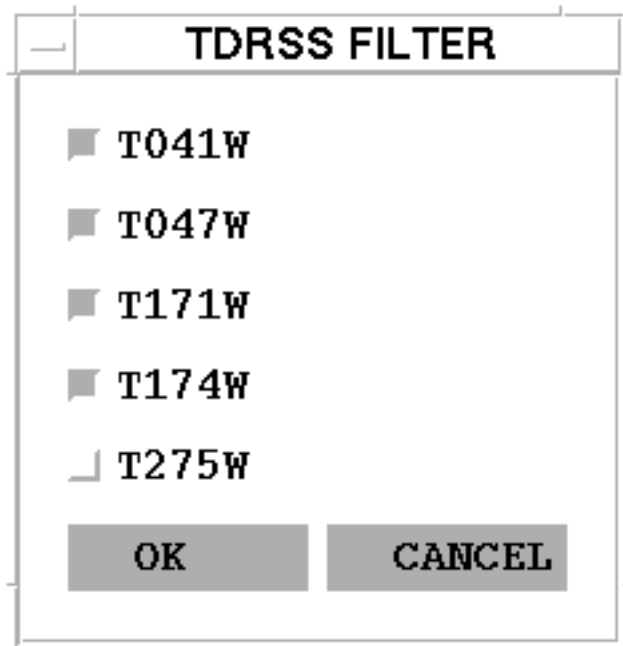


Figure 3.4.2.3.2-2: TDRSS FILTER Dialog

**NOTE:** if a new primary ephemeris is selected with AcqMon's "Source" menu, previous TDRSS FILTER dialog input will generally not be preserved. All TDRSS acquisitions associated with the new primary will be displayed until additional TDRSS FILTER dialog inputs are made to AcqMon.

### 3.4.2.3.3 AcqMon Sun Acquisitions

The Sun acquisitions display mode is selected by clicking AcqMon's "Sun Rise/Set" button. Acquisitions between the selected primary ephemeris and the Sun will be displayed per the Figure 3.4.2.3.3-1 example.

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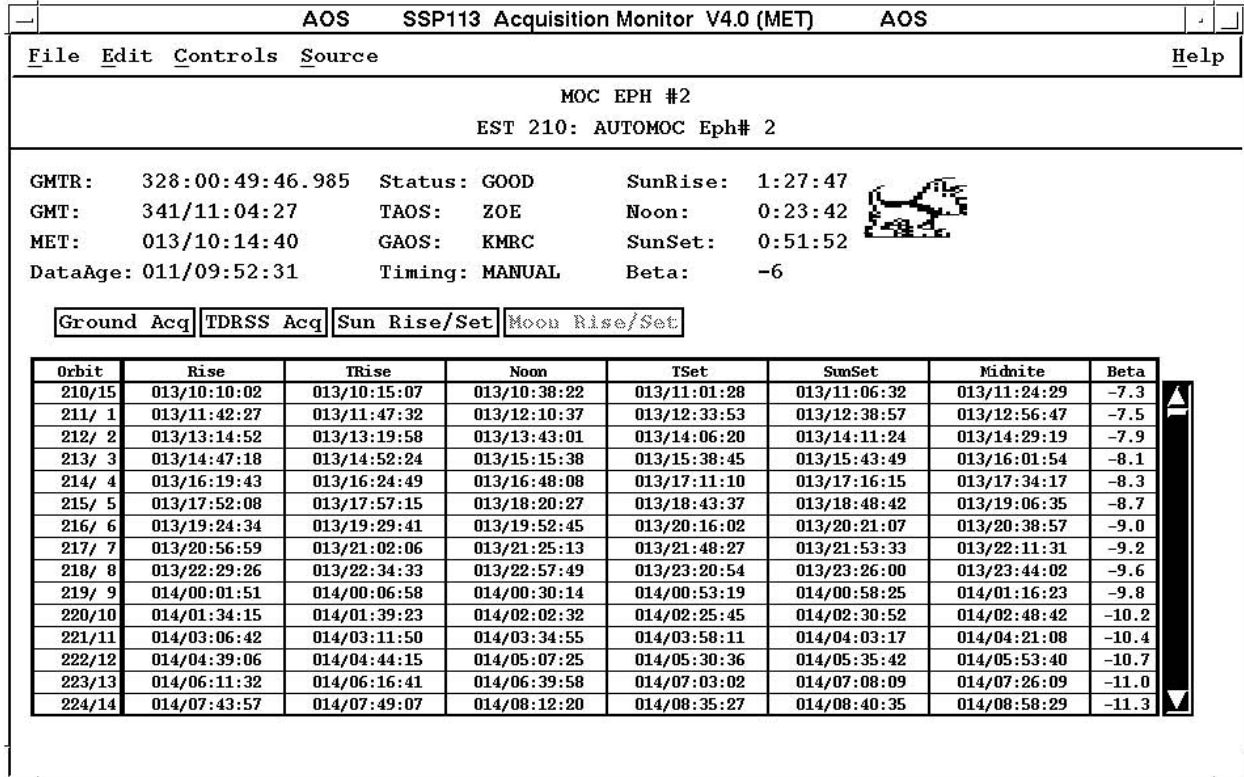


Figure 3.4.2.3.3-1: AcqMon Running In Sun Mode (AOS Sorting)

Figure 3.4.2.3.3-2 illustrates events in AcqMon's Sun Mode table.

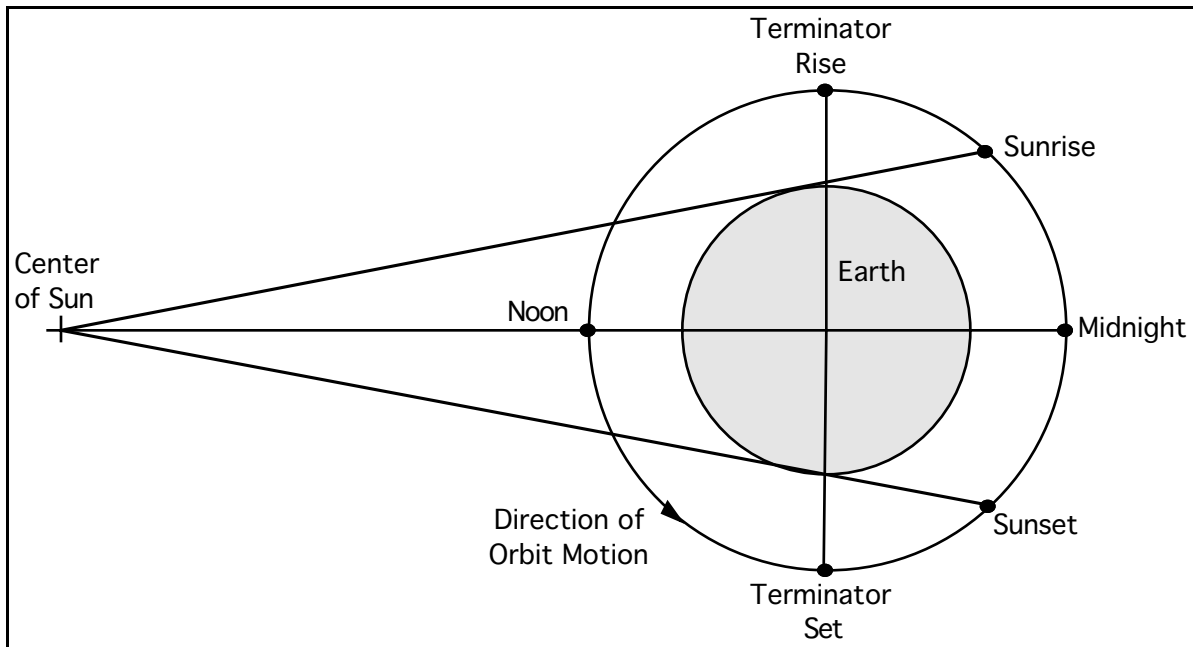


Figure 3.4.2.3.3-2: Sun Acquisition Events Geometry

**NOTE:** Figure 3.4.2.3.3-2 presents a somewhat idealized geometry in that the Sun's center lies in the orbit plane ( $\beta = 0$ ). As the sunlight's angle of incidence on the orbit plane increases ( $\beta$  increases in magnitude), the time between sunrise and sunset decreases for a

## FDO Console Handbook Section 3.4: Acquisitions


given orbit height until these events no longer exist and the primary ephemeris never enters Earth's shadow. These continuously lit "high  $\beta$ " orbits still possess terminator rise/set, noon, and midnight events, however. Only for two degenerate cases, where the Sun shines exactly along the orbit's angular momentum vector, do all lighting events become undefined. Neglecting solar parallax,  $\beta$  is defined using the Sun's geocentric position unit vector  $\mathbf{S}$  and the primary ephemeris angular momentum unit vector  $\mathbf{H}$ .

$$\beta \equiv 90^\circ - \arccos \{ \mathbf{S} \cdot \mathbf{H} \}$$

Thus,  $\beta$  is defined with a sign convention such that it's positive only when the Sun lies "north" of a posigrade orbit's plane. More generally,  $\beta$  is positive only when the Sun lies in the geocentric hemisphere whose pole coincides with the orbit's angular momentum vector.

The following paragraphs explain AcqMon's Sun table in more detail.

**Orbit:** primary ephemeris cumulative orbit count, followed by the daily orbit count. In the default AOS Sorting mode, these counts will apply only to the corresponding Rise time and subsequent events until an ascending node is encountered. If an ascending node exists anywhere between the Rise and Midnite events, Orbit values will be incorrect for events after the node. Should the orbit count at a non-Rise event be significant, select the "Orbits" or "Orbit\_Chrono" item in AcqMon's Edit : Sorting pulldown menu (see Figure 3.4.2.3.1-2). Detailed sorting mode definitions appear in Section 3.4.2.3.1. As an illustration of the influence these sorting modes have on AcqMon's Sun table for ascending nodes between noon and terminator set, reference Figures 3.4.2.3.3-1, -3, and -4. Each of these examples references the same Sun acquisition events with a different sorting mode.

ORBITS    SSP113 Acquisition Monitor V4.0 (MET)    ORBITS							
File Edit Controls Source							Help
MOC EPH #2							
EST 210: AUTOMOC Eph# 2							
GMTR:	328:00:49:46.985	Status: GOOD	SunRise:	1:25:36			
GMT:	341/11:06:38	TAOS: ZOE	Noon:	0:21:31			
MET:	013/10:16:51	GAOS: KMRC	SunSet:	0:49:41			
DataAge:	011/09:54:42	Timing: MANUAL	Beta:	0			
<input type="checkbox"/> Ground Acq <input type="checkbox"/> TDRSS Acq <input checked="" type="checkbox"/> Sun Rise/Set <input type="checkbox"/> Moon Rise/Set							
Orbit	Rise	TRise	Noon	TSet	SunSet	Midnite	Beta
210/15	013/10:10:02	013/10:15:07	013/10:38:22				0.0
211/ 1	013/11:42:27	013/11:47:32	013/12:10:37	013/11:01:28	013/11:06:32	013/11:24:29	-7.3
212/ 2	013/13:14:52	013/13:19:58	013/13:43:01	013/12:33:53	013/12:38:57	013/12:56:47	-7.5
213/ 3	013/14:47:18	013/14:52:24	013/15:15:38	013/14:06:20	013/14:11:24	013/14:29:19	-7.9
214/ 4	013/16:19:43	013/16:24:49	013/16:48:08	013/15:38:45	013/15:43:49	013/16:01:54	-8.1
215/ 5	013/17:52:08	013/17:57:15	013/18:20:27	013/17:11:10	013/17:16:15	013/17:34:17	-8.3
216/ 6	013/19:24:34	013/19:29:41	013/19:52:45	013/18:43:37	013/18:48:42	013/19:06:35	-8.7
217/ 7	013/20:56:59	013/21:02:06	013/21:25:13	013/20:16:02	013/20:21:07	013/20:38:57	-9.0
218/ 8	013/22:29:26	013/22:34:33	013/22:57:49	013/21:48:27	013/21:53:33	013/22:11:31	-9.2
219/ 9	014/00:01:51	014/00:06:58	014/00:30:14	013/23:20:54	013/23:26:00	013/23:44:02	-9.6
220/10	014/01:34:15	014/01:39:23	014/02:02:32	014/00:53:19	014/00:58:25	014/01:16:23	-9.8
221/11	014/03:06:42	014/03:11:50	014/03:34:55	014/02:25:45	014/02:30:52	014/02:48:42	-10.2
222/12	014/04:39:06	014/04:44:15	014/05:07:25	014/03:58:11	014/04:03:17	014/04:21:08	-10.4
223/13	014/06:11:32	014/06:16:41	014/06:39:58	014/05:30:36	014/05:35:42	014/05:53:40	-10.7
224/14	014/07:43:57	014/07:49:07	014/08:12:20	014/07:03:02	014/07:08:09	014/07:26:09	-11.0

**Figure 3.4.2.3.3-3: AcqMon Running In Sun Mode (Orbits Sorting)**


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ORBIT\_CHRONO
SSP113 Acquisition Monitor V4.0 (MET)
ORBIT\_CHRONO

File Edit Controls Source
Help

MOC Eph #2

EST 210: AUTOMOC Eph# 2

GMTR: 328:00:49:46.985	Status: GOOD	SunRise: 1:23:27	
GMT: 341/11:08:47	TAOS: ZOE	Noon: 0:19:22	
MET: 013/10:19:00	GAOS: KMRC	SunSet: 0:47:32	
DataAge: 011/09:56:51	Timing: MANUAL	Beta: 0	

Ground Acq
TDRSS Acq
Sun Rise/Set
Moon Rise/Set

Orbit	Rise	TRise	Noon	TSet	SunSet	Midnite	Beta
210/15	013/10:10:02	013/10:15:07	013/10:38:22				0.0
211/ 1				013/11:01:28	013/11:06:32	013/11:24:29	-7.3
211/ 1	013/11:42:27	013/11:47:32	013/12:10:37				-7.3
212/ 2				013/12:33:53	013/12:38:57	013/12:56:47	-7.5
212/ 2	013/13:14:52	013/13:19:58	013/13:43:01				-7.5
213/ 3				013/14:06:20	013/14:11:24	013/14:29:19	-7.9
213/ 3	013/14:47:18	013/14:52:24	013/15:15:38				-7.9
214/ 4				013/15:38:45	013/15:43:49	013/16:01:54	-8.1
214/ 4	013/16:19:43	013/16:24:49	013/16:48:08				-8.1
215/ 5				013/17:11:10	013/17:16:15	013/17:34:17	-8.3
215/ 5	013/17:52:08	013/17:57:15	013/18:20:27				-8.3
216/ 6				013/18:43:37	013/18:48:42	013/19:06:35	-8.7
216/ 6	013/19:24:34	013/19:29:41	013/19:52:45				-8.7
217/ 7				013/20:16:02	013/20:21:07	013/20:38:57	-9.0
217/ 7	013/20:56:59	013/21:02:06	013/21:25:13				-9.0

**Figure 3.4.2.3.3-4: AcqMon Running In Sun Mode (Orbit\_Chrono Sorting)**

**Rise:** time at which the Sun's center first appears above Earth's limb as viewed from the primary ephemeris trajectory. When  $\beta$  is large in magnitude, this event tends to become ill-defined in time because the Sun's apparent motion with respect to Earth's limb is at a shallow angle.

**TRise:** time at which the primary ephemeris trajectory nadir is also a point on Earth's sunrise terminator. It's more accurate to call this event "sunrise terminator crossing" as opposed to "terminator rise". The geocentric angle between the primary ephemeris trajectory and the Sun is also  $90^\circ$  at this time.

**Noon:** time at which the geocentric angle between the primary ephemeris trajectory and the Sun is at a minimum. If  $\beta = 0$  at this time, the Sun would be at the primary trajectory ephemeris position's zenith.

**TSet:** time at which the primary ephemeris trajectory nadir is also a point on Earth's sunset terminator. It's more accurate to call this event "sunset terminator crossing" as opposed to "terminator set". The geocentric angle between the primary ephemeris trajectory and the Sun is also  $90^\circ$  at this time.

**SunSet:** time at which the Sun's center last appears above Earth's limb as viewed from the primary ephemeris trajectory. When  $\beta$  is large in magnitude, this event tends to become ill-defined in time because the Sun's apparent motion with respect to Earth's limb is at a shallow angle.

**Midnite:** time at which the geocentric angle between the primary ephemeris trajectory and the Sun is at a maximum. If  $\beta = 0$  at this time, the Sun would be at the primary trajectory ephemeris position's nadir.

## FDO Console Handbook Section 3.4: Acquisitions

**Beta:**  $\beta$  in deg at the corresponding SunSet event. If a SunSet event doesn't exist for a given display line,  $\beta$  will correspond to that line's Midnite event. If a neither a SunSet nor a Midnite event exists for a particular line due to the primary ephemeris time span or the AcqMon sorting mode in effect, a zero  $\beta$  will be displayed by default.

### 3.4.2.3.4 AcqMon Moon Acquisitions

The Moon acquisitions display mode is selected by clicking AcqMon's "Moon Rise/Set" button. Acquisitions between the selected primary ephemeris and the Moon will be displayed per the Figure 3.4.2.3.4-1 example.

AOS
SSP113 Acquisition Monitor V4.0 (MET)
AOS

File
Edit
Controls
Source
Help

MOC EPH #2

EST 210: AUTOMOC Eph# 2

---

GMTR: 328:00:49:46.985

GMT: 341/11:12:08

MET: 013/10:22:21

DataAge: 000/00:00:45

Status: GOOD

TAOS: ZOE

GAOS: KMRC

Timing: MANUAL

SunRise: 1:20:06

Noon: 0:16:01

SunSet: 0:44:11

Beta: -6

Ground Acq

TDRSS Acq

Sun Rise/Set

Moon Rise/Set

Orbit	Rise	Noon	Set	MidNite
210/15	013/10:14:29	013/10:44:23	013/11:14:19	013/11:30:40
211/ 1	013/11:46:59	013/12:16:59	013/12:47:04	013/13:03:18
212/ 2	013/13:19:29	013/13:49:38	013/14:19:49	013/14:35:58
213/ 3	013/14:52:00	013/15:22:01	013/15:52:32	013/16:08:26
214/ 4	013/16:24:29	013/16:54:53	013/17:25:19	013/17:41:10
215/ 5	013/17:57:00	013/18:27:31	013/18:58:06	013/19:13:50
216/ 6	013/19:29:30	013/20:00:10	013/20:30:55	013/20:46:29
217/ 7	013/21:02:01	013/21:32:49	013/22:03:44	013/22:19:09
218/ 8	013/22:34:31	013/23:05:11	013/23:36:30	013/23:51:47
219/ 9	014/00:07:01	014/00:38:09	014/01:09:22	014/01:24:28
220/10	014/01:39:32	014/02:10:49	014/02:42:14	014/02:57:10
221/11	014/03:12:03	014/03:43:32	014/04:15:07	014/04:29:52
222/12	014/04:44:34	014/05:16:16	014/05:48:02	014/06:02:25
223/13	014/06:17:05	014/06:48:43	014/07:20:54	014/07:35:18
224/14	014/07:49:36	014/08:21:39	014/08:53:50	014/09:08:01

Figure 3.4.2.3.4-1: AcqMon Running In Moon Mode

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Figure 3.4.2.3.3-2 illustrates events in AcqMon's Moon Mode table. Although terminator events and a  $\beta$  angle for the Moon could be computed as they are for the Sun, no requirements for this capability currently exist. Consequently, data in AcqMon's Moon table are limited to the following parameters.

**Orbit:** primary ephemeris cumulative orbit count, followed by the daily orbit count. In the default AOS Sorting mode, these counts will apply only to the corresponding Rise time and subsequent events until an ascending node is encountered. If an ascending node exists anywhere between the Rise and Midnite events, Orbit values will be incorrect for events after the node. Should the orbit count at a non-Rise event be significant, select the "Orbits" or "Orbit\_Chrono" item in AcqMon's Edit : Sorting pulldown menu (see Figure 3.4.2.3.1-2). Detailed sorting mode definitions appear in Section 3.4.2.3.1. As an illustration of the influence these sorting modes have on AcqMon's Sun table for ascending nodes between noon and terminator set, reference Figures 3.4.2.3.3-1, -3, and -4. Each of these examples references the same Sun acquisition events with a different sorting mode.

**Rise:** time at which the Moon's center first appears above Earth's limb as viewed from the primary ephemeris trajectory.

**Noon:** time at which the geocentric angle between the primary ephemeris trajectory and the Moon is at a minimum.

**Set:** time at which the Moon's center last appears above Earth's limb as viewed from the primary ephemeris trajectory.

**MidNite:** time at which the geocentric angle between the primary ephemeris trajectory and the Moon is at a maximum.

### 3.4.2.4 Acquisition Wall Clocks Interfaces

Circa 2004, the Timing Services interface with Trajectory Acquisitions data was migrated from tracking MOC/TrS-generated events through GDR. The new interface uses TSA PSAT-generated acquisitions specific to an ephemeris directory in the TSA Global database selected by GC to be M1-10, G1-8, or R. From the specified ephemeris, Timing Services builds up to 4 sets of wall clocks. Each set can contain a US ground site AOS/LOS clock, a Russian ground site AOS/LOS clock, a SR/SS clock, and a TDRSS AOS/LOS clock.

**NOTE:** a TDRSS wall clock driven by PSAT data will only reflect acquisitions due to Earth blockage. No TDRSS scheduling constraints are reflected. Consequently, these clocks are usually driven by TDRSS SHOs data provided to GC by COMMAND.

**CAUTION:** Timing Services does not cyclically poll its selected source ephemeris for changes to acquisition data. Consequently, any significant change to trajectory modeling affecting acquisition wall clocks should be promptly communicated by FDO to GC. In these cases, GC will manually trigger Timing Services to rebuild clocks from the new acquisitions data.

## FDO Console Handbook Section 3.4: Acquisitions

### 3.4.3 Standard Acquisition Operations

This section summarizes standard procedures and configurations under which acquisition capabilities are applied during mission operations. With these capabilities, numerous other acquisition operations are possible. As such, this information should be regarded as a starting point from which other procedures and configurations can be developed as specific needs require.

**NOTE:** by default, insure all PSAT menu configurations use the following settings.

Min EI = 0  
Integ Time Step = 120 sec  
Terrain Masking = Y  
SRSS = Y  
MRMS = N  
Oblate Earth = N,  
Atm Refraction = N  
Update EPH.ORB = N

**NOTE:** procedures documented in the following subsections contain actions supporting trajectory operations other than those directly relating to acquisitions. The intent is to provide comprehensive procedures relating to these multiple systems such that only one FDO Console Handbook reference is required as each occasion arises.

#### 3.4.3.1 Pre-Launch Operations

**CAUTION:** approximately one day prior to the first in a series of launch attempts, TAO will initialize TrS and TSA Global from the flight-specific baseline. This initialization is necessary to insure any residual simulation data are purged and all late-breaking Init Pads from ARD Support are present prior to the ARD Confidence Run. If the Lead FDO has populated TSA Global with any pre-launch data, they will probably be purged by the initialization. These data may be archived by the Lead FDO as necessary before initialization, then restored to Global after initialization is complete.

**NOTE:** immediately prior to commencing TSA Global initialization for flight XXX, TAO will obtain a TSA Global checkpoint named "XXX Mission Pre-Restore". Contact a GA to restore selected segments of this checkpoint to Global if initialization has inadvertently purged them.

**NOTE:** in the pre-launch timeframe, AcqMon users may experience data access difficulties due to Timing Services configurations. In these cases, users must invoke the Connect dialog window by selecting AcqMon's Edit : Connections... menu item. In this window, click "Manual", then "OK", and AcqMon will define current time such that it counts up from ephemeris start.

##### 3.4.3.1.1 L -1 Day

- 1) Approximately 1 hour prior to initially scheduled Ascent Team activities, TAO initializes TrS and TSA Global databases from the flight-specific baseline.
- 2) Ascent FDO activates TrS Ephemeris 2/3 (E2/3) AutoEph mirrors (M2/3), together with the AutoVAT mirror. M3 activation is only required if a ground-up rendezvous is planned.

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- 3) Lead FDO configures TSA Global Ephemeris 1 (G1) to contain a "womb-to-tomb" nominal Orbiter trajectory through EOM+2 for a 1-day-late launch attempt. If a rendezvous is planned, G3 is configured as the target from launch/deploy through docking/grapple. PSAT is executed for these ephemerides as follows.

NOTE: the following G3/M3 PSAT configurations assume an ISS rendezvous is planned. Other targets may not require R Net processing, or they may need additional Net acquisitions.

G1:

STDN = OFF  
Nets = B/C/D/P/S/T(SCT)

G3:

STDN = OFF  
Nets = C/R/S/T(SCT)

NOTE: Master DNAV AcqMon accesses M1 by default if TrS is active. Users can select G1 acquisitions using AcqMon's "Source" menu. Pre-launch G1 duration and acquisition frequency will typically fill AcqMon's display buffer. If an acquisition outside this buffer is of interest, users can specify the buffer's start GMT by selecting Edit : Start Time : User Start... from AcqMon's menu bar.

- 4) Ascent FDO and FDO Support configure E2/M2 as an Orbiter "best plan" ephemeris through EOM+3. E3/M3 is configured as the target through docking/grapple if required. PSAT data for these ephemerides are manually generated with a menu Execute using the following configurations.

M2:

STDN = OFF  
Nets = B/C/D/P/S/T(SCT)

M3:

STDN = OFF  
Nets = C/R/S/T(SCT)

- 5) Lead FDO ensures the TSA SSP Global SCT, ECT, LST, and Jacchia data sets are configured correctly (coordinate changes to flight-specific TSA baseline with GA if necessary). NAV, LSO, and the Co-Lead FDO may be utilized in this effort. Verify minimum elevation for each Russian ground site in the SCT is 7°. This is the threshold required for contingency ISS Russian Segment commanding.
- 6) Lead FDO verifies TSA SSP Global GMTLO in Systems Display.
- 7) Ascent FDO requests users hold all inputs, then a TrS/Global checkpoint is taken.

### 3.4.3.1.2 Pre-Launch Planning Shift

- 1) NAV obtains latest TDRS state vectors from GSFC and routes them to TrS VAT slots 21 through 25.



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- 2) FDO activates AutoEph mirrors M2/3, together with the AutoVAT mirror. M3 activation is only required if a ground-up rendezvous is planned. FDO then verifies correct GMTLO in TSA SSP Global Systems Display.
- 3) FDO contacts INCO to determine which TDRSS ephemerides are required for command builds and acquisitions.
- 4) TRAJ assures PSAT STDN = OFF in all ephemerides. DYN is then given a GO to generate TSA TDRSS ephemerides using NAV's vectors per FDO's input.
- 5) FDO updates E3/M3 and E2/M2 as required, insuring the latter covers EOM+3 ConUS deorbit TIGs and models all nominal burns/reboots.

NOTE: it may be advisable to disable M2 mirroring until E2 updates are complete.

- 6) TRAJ verifies each TDRSS ephemeris has the proper anchor and duration. If an ISS rendezvous is planned, TOPO is notified SSP TDRSS ephemerides are configured.
- 7) TRAJ configures TSA PSAT menus as follows.

NOTE: because some ephemeris mirrors are empty at this point, their respective PSAT menus can only be "saved". Menus for M2, and possibly M3, correspond to active TrS ephemerides and can be "executed".

M1:

STDN = ON  
Nets = A/B/C/D/P/S/T(EPH)

M2:

STDN = OFF  
Nets = B/C/D/P/S/T(EPH)

M3:

STDN = ON  
Nets = C/R/S/T(EPH)

M4:

STDN = OFF  
Nets = B/C/D/P/S/T(EPH)

R:

STDN = ON  
Nets = E/N/S/T(eph)

- 8) When TDRSS and M2/3 configuration checks are complete, FDO informs GC, INCO, and COMMAND the associated data are ready. The E2/M2 mirror should be deactivated at this time.

NOTE: Master DNAV AcqMon accesses M1 by default. Users can select M2 acquisitions using AcqMon's "Source" menu. Pre-launch M2 duration and acquisition frequency will typically fill AcqMon's display buffer. If an acquisition outside this buffer is of interest, users can specify the buffer's start GMT by selecting Edit : Start Time : User Start... from AcqMon's menu bar.

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### 3.4.3.2 Ascent Operations

After any workstation reboot, FDO, TRAJ, or FDO Support verify M1, M3 (if required), M4, and VAT mirrors are active.

An automatic PSAT run will occur in M1 as soon as E1 is updated post-MECO. A PSAT run for M3 will have been generated during the pre-launch shift or during any subsequent TUPs, so no special actions are required for generating target acquisitions in the ascent/PI timeframe. Users can access mirrored TrS acquisitions data via AcqMon as previously described. During Ascent's PI handover, the Orbit 2 TRAJ should verify PSAT is configured as desired in each ephemeris (see Section 3.4.3.3) and that required TrS mirrors are active. The TSA SSP Global GMTLO will automatically update to the actual liftoff time as long as the VAT mirror was active at launch.

On a best-effort basis, FDO Support will update the FDO Trajectory Web (FTW) server to reflect E1/M1 rendezvous re-planning conducted post-OMS-2 if actual GMTLO differs more than ~10 sec from that planned. See Section 3.11.8.1.3 for FTW update procedures. In addition to possible Space Object Identification (SOI) activity planning, an update under these circumstances supports RTS network scheduling changes due to the GMTLO shift.

NOTE: paper simulations with RTS scheduling personnel at Schriever AFB have demonstrated Orbit 1 *Reef* (Diego Garcia or DGSS) az-el dispersions amounting to degrees in magnitude arise when planned GMTLO slips from inplane time in a Wrap = 0 pane to planar close in the Wrap = 1 pane on a two-pane launch day. It may not be possible to retain RTS support in this worst case, but every effort to recover from appreciable launch dispersions should be made after OMS-2.

### 3.4.3.3 Orbit Operations

The following actions establish a standard configuration for orbit acquisition operations.

- 1) Configure TrS ephemeris and VAT mirrors as required. At a minimum, M1 and the VAT should be active.

NOTE: although E2 should always reflect trajectory planning and acquisitions through EOM+2, it's often advisable to disable active M2 mirroring until acquisitions require an update. In addition to minimizing mirroring loads on a workstation, this prevents M2 status from becoming INCN after an inadvertent or trivial TUP.

NOTE: during a rendezvous, M3 mirroring should be active. After docking/grapple, however, M3 acquisitions data should be purged until undocking/deploy is imminent with no future reboosts scheduled. This eliminates any need to model reboosts or other vents in E3 when only one VTL exists. An M3 acquisitions purge can be easily accomplished by 3 actions. Suspend M3 mirroring, delete M3 using TPS Tier 0, then resume M3 mirroring.

- 2) Configure TSA PSAT menus as follows.

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M1:  
STDN = ON  
Nets = A/B/C/D/P/S/T(EPH)

M2:  
STDN = OFF  
Nets = B/C/D/P/S/T(EPH)

M3:  
STDN = ON  
Nets = C/R/S/T(EPH)

Entry Ephemerides:  
STDN = ON  
Nets = E/N/S/T(EPH)

CAUTION: because M1 data are promoted to the FTW server for OSA and FDO SUPPORT access, its length is required to cover ISS docking prior to mated operations. Post-docking, M1 length must be at least 96 hrs, and RTS planning may dictate additional duration.

- 3) Run the "Orbit D64" TrS group MED. This reconfigures TrS ECT MZH thrust and flow rate from MEP values to -X values with nose/tail attitude control.
- 4) Update DCT Columns 2 and 5 thrusters to OL/OL.
- 5) Update DCT Columns 3 and 6 initial C1/C2 values to zeros.

CAUTION: to avoid excessive workstation loading, do not turn on more than 5 ephemeris mirrors at a time.

The following actions are taken to update TSA TDRSS ephemerides on a daily basis:

- 1) NAV receives and checks TDRSS vectors from GSFC, places them in TrS VAT slots, gets a "GO" from FDO to update TrS TDRSS ephemerides, and requests TSA ephemeris TUPs from DYN.
- 2) DYN requests TRAJ verify STDN options are OFF in all SSP Global ephemerides. When TRAJ confirms this condition, DYN generates desired TDRSS ephemerides using NAV's vectors. An 10-day time span will be utilized by default.
- 3) After DYN completes all updates, FDO or TRAJ verifies each TSA TDRSS ephemeris has a correct anchor and duration, then TRAJ turns STDN options ON as before.
- 4) FDO notifies INCO and TOPO of the TDRS ephemeris updates.

NOTE: generally, STDN ephemeris TUPs aren't required immediately after TDRSS ephemeris TUPs. Daily GSFC updates aren't usually significant to TDRSS acquisitions unless a TDRSS maneuver is included.

The former TRACK controller's call sign is now DFE. Incoming calls from DFE to FDO will occur on the SDP DYN 1 loop. Communication will then commence on the TRAJ Coord 1 loop. FDO or TRAJ inform DFE of any new long-term acquisition data whenever significant changes are made to M2.

## **FDO Console Handbook Section 3.4: Acquisitions**

NOTE: any TrS or Global SCT update should be coordinated between FDO and NAV. Keep DFE and other users apprised of pertinent SCT changes.

NOTE: the Remote Site Entry display is available for FDO/TRAJ execution after obtaining a "GO" from NAV.

### **3.4.3.4 Entry Operations**

Generally, deorbit prep acquisition operations are identical to orbit acquisition operations. AcqMon will be the primary source of acquisitions data for the prime entry ephemeris (E<sub>phR</sub>). Users can access E<sub>phR</sub> acquisitions by selecting "R" from AcqMon's Source : Entry : Global menu path (see Figure 3.4.2.3.1-3). TrS EPSAT provides another source of E<sub>phR</sub> entry acquisitions. Entry ephemeris PSAT settings presented in Section 3.4.3.3 include "N" Net acquisitions to assess TACAN co-channel interference and "E" Net acquisitions to plan high speed C-band tracking or S-band communications support. The RADAR processor accesses case-specific entry ephemerides as necessary to compute all entry RADAR acquisitions.

NOTE: during entry, acquisitions data prior to EI will be based on the prime Orbiter ephemeris mirror, M1. From EI through landing, acquisitions information will be based on E<sub>phR</sub> with a PSAT step size of 30 sec.

**Section 3.4 Concludes On This Page**

## FDO Console Handbook Section 3.5: Orbiter Navigation

### 3.5 Orbiter Navigation

The principle function of the Space Shuttle Orbiter's Navigation System, hereafter called Orbiter Navigation, is to provide an estimate of the Orbiter's state vector to Guidance as well as to Universal Pointing software. Normally, the Orbiter's state vector is expressed in Cartesian coordinates of the Aries Mean-of-1950 system (M50) (described in Section 7.2.1.1 of *MCC Level B & C Requirements for Shuttle Operations, Vol. II: Trajectory Related Information Processing Software*) and consists of six elements (3 position; 3 velocity) plus time.

#### 3.5.1 Orbiter Navigation Data Sources

Five primary sources of information are available to Orbiter Navigation.

- 1) Gravity model acceleration computations
- 2) Inertial Measurement Unit (IMU) sensed accelerations
- 3) Atmospheric drag model acceleration computations
- 4) External sensor data
- 5) Unmodeled Vehicle Acceleration Compensation

##### 3.5.1.1 The Gravity Model

The simplest gravity model assumes the Earth is a perfect sphere of uniformly distributed mass. Unfortunately, the Earth is asymmetric in shape with variations in its density. This departure from uniform spherical symmetry causes an acceleration of an orbiting body that is generally not directed precisely at Earth's center. Accounting for this perturbed acceleration greatly increases state vector propagation accuracy.

The Orbiter's gravity potential model utilizes an infinite series expansion of Legendre polynomials called Pines method. This recursive algorithm accesses a database of harmonic coefficients arranged in lower-triangular-matrix form. An element of the database is termed  $J_{n,m}$ , where the row  $n$  is the harmonic's degree and the column  $m$  is its order. When  $m=0$ , the coefficient's effect is symmetric about a parallel of latitude, and it's termed a zonal harmonic. When  $n = m$  for a matrix diagonal coefficient, its influence is symmetric about a great circle of longitude, and it's termed a sectorial harmonic. No latitude or longitude symmetry is associated with the action of coefficients having  $n \neq m$ , and they are termed tesseral harmonics. The onboard model is configured with a Goddard Earth Model 9 (GEM9) database truncated to fourth degree and order.

##### 3.5.1.2 Inertial Measurement Units (IMUs)

Consisting of gimballed rate gyros and accelerometers mounted on a precisely positioned platform called the nav base, an IMU provides Orbiter Navigation with an inertial "fixed platform". This concept of a stable inertial IMU reference is idealized because IMUs do drift, and realignments using star sightings are required about once every day or so for the Hains IMUs (these realignments occurred more frequently with the old KT-70 IMUs). The IMUs sense velocity changes ( $\Delta V$ s) caused by translational maneuvers that exceed a certain threshold. They also determine the Orbiter's inertial attitude.

## FDO Console Handbook Section 3.5: Orbiter Navigation

An early version of Orbiter Navigation software picked up "false"  $\Delta V$ s whenever an attitude maneuver occurred. This happened because the IMUs are located about sixty feet from the Orbiter's center of gravity (CG), and this moment arm caused them to sense a translational acceleration every time a rotation occurred. Although the Orbiter was not really translating, the IMUs were. Orbiter Navigation has since been modified to subtract out most of this moment arm effect.

In order to filter out noise and false readings of perturbations, a minimum sensed delta-V threshold was included in the software. Although this eliminates all the false readings, it does sometimes prevent real perturbations from being recorded. One example is attitude control jet firings. Since the attitude control jets are not located symmetrically about the Orbiter, it is possible for attitude maneuvers to perturb the vehicle's trajectory. Sometimes these small  $\Delta V$ s are large enough to be picked up by the IMUs. At other times they are not. In addition, other trajectory perturbing events, such as water dumps, attitude hold jet firings, and fuel cell (FC) purges, may also be too small to be sensed by the IMUs. These unsensed accelerations cause a gradual degradation in the accuracy of the onboard state vector. Periodically a ground tracking solution is uplinked to correct the Orbiter Navigation system. This is done about once or twice per day, depending upon the number and magnitude of the perturbations (state vector updates are discussed further in Section 3.5.6).

### 3.5.1.3 The Drag Model

There is a tenuous atmosphere even at orbital altitudes, and this imparts drag accelerations to orbiting bodies that cannot be sensed by the IMUs. Consequently, Orbiter Navigation software contains a drag model. Drag computations are based on atmospheric density from a Babb-Mueller model, which is dependent on flight-specific I-LOADS. There are a total of 11 occurrences that cover the F10 range of 50 – 270 in 20 unit segments. The occurrence that is the closest to the expected solar flux for a given flight is selected as the Babb-Mueller I-LOAD for that flight. The occurrences are good for all altitudes.

Each occurrence contains a set of 4 coefficients and a switch altitude (141.78 nm.). Two of these coefficients are used for all altitudes. One or the other of the remaining two coefficients is used depending on whether the orbit is above or below the switch altitude. If solar flux is misjudged preflight or the altitude is significantly different from 142 nm, the Babb-Mueller density will be in error during the mission. The expected error from the Jacchia atmosphere is  $\leq 5\%$  for altitudes within 50 nm of the switch altitude and  $\leq 20\%$  for altitudes about 70 nm from the switch altitude (for altitudes closer to the extremes of 70 and 215 nm).

The Orbiter Navigation drag acceleration is also attitude-dependent. Vehicle orientation as determined by the IMUs permits a frontal area to be computed which proportionally scales Orbiter drag. The onboard drag model can be modified by uplinking a multiplier called the K-factor (DSM 400xx). Nominally, K-factor = 1.0. Ground Nav flight controllers will recommend changes to the K-factor when they observe systematic trends in onboard state vector accuracy that can be corrected by updating the drag model. The new drag acceleration is simply the old drag acceleration multiplied by the K-factor.

**CAUTION:** no modification of the Orbiter K-factor from its unity value has ever been performed operationally. A DSM 400xx is used in connection with Day Of Rendezvous (DOR) operations, but it leaves the Orbiter's K-factor unchanged. Its purpose is to modify the target K-factor as required. See Section 3.10.1.9.2 for DOR 400xx operations.

## FDO Console Handbook Section 3.5: Orbiter Navigation

### 3.5.1.4 External Orbiter Navigation Sensors

For on-orbit operations, the external Orbiter Navigation sensors include the rendezvous radar (RR), the crew optical alignment sight (COAS), and two star trackers (STs). The STs and COAS are used to make star sightings for IMU alignments and to track rendezvous targets. The RR is used to acquire and track rendezvous targets. See Section 3.10.1.7 for more on external sensors.

### 3.5.1.5 Unmodeled Vehicle Acceleration Compensation

Both venting and uncoupled RCS attitude hold thrusting are not modeled by Orbiter Navigation. Additionally, these perturbations are almost always below IMU accelerometer sensitivity thresholds and therefore eventually lead to Orbiter Navigation state vector errors. However, it is possible to uplink a compensating body force vector (DSM 426xx), called a vent, which consists of a body-fixed force plus on/off times. Ground Nav flight controllers determine the vent and build the command with FDO's approval and QA.

### 3.5.2 State Vector Propagation and Prediction

In Orbiter Navigation, the "propagation" function or task entails numeric integration of both analytic models and sensor data over time to calculate an updated state vector and covariance matrix. Orbiter Navigation software uses a Cowell algorithm with a multi-step integrator called "Super G" to accomplish this task. Super G invokes a 4x4 gravity model to account for non-spherical symmetries in the Earth's gravitational field and an atmosphere model to drive drag acceleration calculations.

During Major Mode 201 (coasting flight), the crew can set a flag to incorporate or ignore IMU sensed accelerations using ITEM 5 on SPEC 33 (REL NAV). This ITEM sets (or resets) the Average G flag, "AVG G ON", to incorporate (or suppress) sensed accelerations that exceed a specified threshold. ITEM 5 is sometimes called the "Average G switch" and is accompanied by an asterisk on SPEC 33 only when set, that is, "ON". The default setting for Average G is "ON" (\*), and the display will be initialized with Average G "ON" each time MM 201 or 202 is entered.

NOTE: SPEC 33 ITEM 5 can only be changed in MM 201.

With the Average G switch set (ON), IMU sensed  $\Delta V$ s exceeding a threshold value of 0.06 fps during an RCS jet firing will be incorporated into the state vector. A second threshold test compares IMU sensed accelerations to an I-LOADED value of 1000  $\mu g$  (0.032 ft/sec<sup>2</sup>). This parameter shows up as DV\_THRESH on FDO's RNDZ/Prox Ops Proc display and has the value 3840 since one nav cycle is 3.84 seconds. If the Average G switch is set, accelerations exceeding this threshold are incorporated regardless of whether or not an RCS jet is firing. This acceleration threshold can be changed by crew entry on the IMU Alignment display (SPEC 21, ITEM 18). Although crew entries are preserved between OPS 2 and OPS 8 transitions, the 1000  $\mu g$  value will be reloaded from mass memory during other OPS transitions.

When the Average G switch is reset (toggled OFF), Orbiter Navigation will ignore IMU sensed  $\Delta V$ s regardless of their magnitude. This option would only be used in a contingency case, such as one in which multiple IMU failures had occurred and IMU

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redundancy management (RM) could not prevent bad data from being incorporated into the state vector. It should be noted that any transition to MM201 or MM202 resets the flag to "ON".

The Orbiter Navigation function or "prediction" task uses a Cowell algorithm that only integrates analytic models to update a state vector and covariance matrix. Sensor data are never incorporated. Rather than maintain the current state, which is the primary task of propagation, prediction seeks to rapidly move a state through time. A typical prediction task is to bring an uplinked state from its accompanying time tag to current time. It would be impractical for Orbiter Navigation to maintain sensor data histories to cover this interval for propagation (if the uplinked vector were in the past). Consequently, propagation takes over from prediction after the uplinked vector has been brought to current time. It should be noted that prediction uses the current Orbiter attitude for its drag acceleration computations because an onboard attitude timeline (ATL) doesn't exist. Thus, uplinked state vector time tags should be close to the expected time of uplink to minimize prediction errors.

### 3.5.3 Kalman Filtering

Kalman filtering is a method of estimating the Orbiter state vector by minimizing errors between the actual and propagated state vectors. It uses the equations of motion, an initial state vector, external sensor data, and statistical estimates of state vector and sensor accuracy to calculate the new vector and associated covariance matrix. Unlike a least squares filter which computes one vector for a batch of data, the Kalman filter computes a vector for each time observations were made. Thus, it is a sequential filter.

If perfect external sensors were available, their measurements could be incorporated into the propagation without adjustment. In other words, they could be taken at face value. Since a sensor's accuracy is limited, however, use of its measurements must be tempered by our knowledge of its limitations. Fortunately, sensor errors can be statistically modeled, and these models can be used to evaluate measurements. For more information on Kalman filtering, see KAL FIL-S 2102, *Kalman Filter Supplemental Workbook*. For information on sensor noise and bias, see the ONAV and RGPO Console Handbooks.

The onboard Kalman filter outputs the following parameters that can be used to evaluate sensor data and the relative health or accuracy of the onboard state vector:

- 1) The residual
- 2) The covariance matrix
- 3) The ratio
- 4) An estimate of sensor biases

The residual is the difference between Orbiter Navigation's prediction of a measurement and the actual measurement. It can be used during a ST or radar pass to detect a possible sensor problem (examples are a ST locking onto a star or a radar bias) and to evaluate whether marks should be incorporated into the filter. If the data are good, the residual also gives an indication of the error in the onboard state vector.

In general, a covariance matrix is an  $n \times n$  matrix representing the uncertainties in the filter's solved-for state, where  $n$  = the number of elements being determined. The onboard rendezvous filter has a  $13 \times 13$  covariance matrix (3-position, 3-velocity, 3-unmodeled acceleration, and 4-sensor components). This matrix represents the error in the relative state of the Orbiter-target system; it is not just the Orbiter uncertainty. The main diagonal



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contains statistical variances of the solved-for state components; the square root of these elements is the  $1\sigma$  uncertainty of that component. The off-diagonal elements represent cross-correlations (covariances) of the solved-for state errors; that is, the statistical relationships between the error in one element of the solution state and those in another.

A covariance matrix may be thought of as an error ellipse around the actual flight path. Before data have been processed, the error ellipse or tube around the trajectory is large. As good data are incorporated into the filter, the uncertainty in the state vector decreases and the error ellipse shrinks. On the other hand, lack of data or bad data increase the uncertainty in navigation knowledge, and the covariance or error ellipse becomes larger.

The ratio is the residual divided by the maximum permissible error in the state vector as determined by analysis. For the onboard nav filter, the ratio is the absolute value (magnitude) of the residual divided by 6 times the covariance. The ratio is used to edit bad data as sensor data must pass the residual edit test before they are incorporated into the filter. A value greater than or equal to 1.0 causes the measurement to be edited (rejected) by the filter. A large ratio may be caused by any of multiple possible factors. Depending on the probable cause, different actions may be taken. If the covariance is too small, it may be reinitialized to a larger value allowing sensor data to be used by the filter. If the onboard vector is suspected to have large dispersions, the crew may be asked to “force” data into the filter and override the automatic edit feature. A third option requires RGPO to request an uplink of new vectors (see *RGPO Console Handbook*, SOP 4.3 Navigation Anomalies).

Lastly, the filter computes a sensor bias for each measurement type. The biases are computed in the coordinate system of the sensor whose measurements are being processed. The biases are only accurate if range measurements are being incorporated into the filter. Action is required if the sensor bias does not converge to a set value. RGPO and ONAV are responsible for monitoring and controlling the onboard Kalman filter during rendezvous operations.

### 3.5.4 Downtrack Position and Pointing Error Prediction

Orbiter pointing accuracy is fairly insensitive to state vector errors. An inertial downtrack error of about 60 nm causes a  $1^\circ$  Local Vertical/Local Horizontal (LVLH) pitch error. Because the onboard vector is usually kept accurate to within 5-10 nm (and almost never permitted to exceed 15-20 nm), inertial pointing is generally not affected by vector accuracy. It is only for very attitude-sensitive payloads that extra steps must be taken to reduce onboard downtrack error. Attitude maneuvers and other perturbing activities should be minimized around their critical data-take periods. More frequent uplinks of ground vectors to the onboard nav system may be required during these times.

The Vector Comparison display is used to evaluate the health of both Ground Navigation and Orbiter Navigation state vectors. Current semi-major axis and downtrack errors ( $\Delta a$  and  $\Delta V$ , respectively) observed using Vector Comparison may be used to estimate downtrack error after N orbits using the following rule of thumb.

$$\text{Future Downtrack Error} = -10 \cdot \Delta a \cdot N + \Delta V$$

**CAUTION:** both SIGN ( $\Delta a$ ) and SIGN ( $\Delta V$ ) are critical to obtaining a good estimate with the above computation. It should also be noted this  $\Delta V$  is downtrack position in the UVW

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system; not delta-velocity magnitude. Context must clarify how the  $\Delta V$  symbol is being used.

Because the Orbiter's IMUs can sense translational  $\Delta V$ s associated with attitude maneuvers, it is often best not to uplink a ground vector shortly after an attitude maneuver has occurred since the ephemeris is anchored on a pre-maneuver vector. A better time to update the ground ephemeris and uplink a vector to Orbiter Navigation is after an orbit or two of tracking with low activity (no translation burns, attitude maneuvers, vents, water dumps, or jet hot fires). This uplink may be performed, even if the onboard state vector position error is small, to give Orbiter Navigation a vector with a small  $\Delta a$  so it will propagate well through future attitude maneuvers. Planned and actual attitude maneuver times appear in the ATTITUDE TIMELINE display, while planned or actual vent times appear in the Vent Timeline display. Check the Flight Plan to see if any perturbing events are planned during the time period of interest.

**NOTE:** water dumps are generally not modeled as vents because their translational effects have yet to be quantified.

### 3.5.5 Rendezvous Nav

Orbiter Navigation during rendezvous performs several functions in addition to those normally performed on orbit. A target state vector and an Orbiter/target covariance matrix are propagated, and external sensor data can be incorporated into the Orbiter state vector. These additional functions are collectively called Rendezvous Nav. Rendezvous Nav can only be enabled if a target state vector, having a time tag within 15 hrs of current time, has been uplinked (DSM 402xx). If the state vector is more than 15 hrs from current time, it fails the prediction routine max time test and cannot be integrated to current time. The crew enables Rendezvous Nav by executing an ITEM 1 on the REL NAV display (SPEC 33) in OPS 201.

Rendezvous Nav has two applications. More commonly, it's used during rendezvous missions, when external sensors are used to track the rendezvous target, to compute an accurate Orbiter/target relative state vector. Rendezvous Nav is also used following satellite deployments to place the Orbiter in a window protect attitude prior to an upper stage burn. To obtain window protect attitude, the crew makes Universal Pointing (the GNC MM201 principal function display) entries approximately as follows:

- 1) Select TGT ID (ITEM 8) = 1. This specifies the Orbiter will track the Orbiter-to-target line of sight (as computed by Rendezvous Nav) with the body pointing vector determined by Steps 2 and 3.
- 2) Select BODY VECT = 5. This permits pitch and yaw to be directly input by Step 3.
- 3) Enter pitch (P), yaw (Y), and omicron (OM) values specified by Pointing operators to ITEMS 15, 16, and 17, respectively. The resulting body pointing vector will be roughly +Z (P  $\sim 270^\circ$  and Y  $\sim 0^\circ$ ). Rotation about this vector is given by OM to the degree Orbiter/target relative motion will be out-of-plane during the upper stage burn.
- 4) Select DAP AUTO (panel C3), and TRK (ITEM 19).

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By keeping the Orbiter belly pointed roughly at the target, upper stage plume particles hit comparatively thick black tiles, and sensitive regions about the Orbiter windows and RCS jets are protected.

**WARNING:** whenever Universal Pointing (UNIV PTG) is tracking TGT ID = 1, Rendezvous Nav must be enabled. Under this condition, disabling Rendezvous Nav or transitioning out of OPS 2 will result in an inertially fixed target being tracked by the Orbiter body. Very large angular rates can potentially be commanded as a result (an inertially fixed target might move from ahead of the Orbiter to behind it in a few seconds). To avoid this outcome, crew action is required before disabling Rendezvous Nav or commanding a transition out of OPS 2. Execute an ITEM 21 (CNCL) from UNIV PTG or disengage DAP AUTO from Panel C3.

### 3.5.5.1 Target, Filtered, and Propagated State Vectors

Once the target state vector has been initialized by uplink from the ground, Rendezvous Nav is enabled via SPEC 33 (REL NAV). This creates a copy of the filter vector (FLTR) called PROP. The FILT and PROP vectors can reference either vehicle, Orbiter or target, depending on the FILTER FLAG's value. Once enabled, Rendezvous Nav begins propagating Orbiter and target vectors. Some relative state information is output to the REL NAV display (R, Rdot,  $\Theta$ , Y, and Ydot). The target vector is propagated using gravity and drag models only, as no IMU sensed accelerations are available for this vehicle. The Orbiter vectors are propagated using gravity, drag, and sensed accelerations.

**CAUTION:** before REL NAV is enabled, the downlisted target vector is not valid, as it is not being propagated. Performing a Vector Compare or running a rendezvous plan using this vector will produce erroneous results.

Use of external sensors to provide accurate relative state information is critical during rendezvous. Once sensor data is fed into the Kalman filter, differences between the predicted relative state and the measured relative state are used to update the FLTR state vector. Other than IMU accelerations, the PROP state does not reflect any external sensor measurements unless it is manually over-written by the FLTR vector via a FLTR to PROP transfer (usually sometime after a valid sensor pass). The FILTER FLAG I-LOAD (FLTR UPDATE Item 15, SPEC 33; not displayed on the ground) controls which vehicle (Orbiter or target) is associated with the FLTR and PROP state vectors. The FILTER FLAG is normally ON ("ORB") so as to associate FLTR and PROP states with the Orbiter. The naming convention for the Orbiter downlisted vector is FLTI (when onboard states are grabbed, it is stored in V56). In this case, FLTI is the same as FLTR. The PROP downlisted vector is PRTI, and it is stored in V55. The down listed target vector is TVTI, and it gets stored in V54.

**NOTE:** the FLTI vector always exists in OPS 2, even when REL NAV is not enabled. During OPS 1 and 3, the Orbiter TLM vector (UPP) is called GCBI and gets routed to V53. In OPS 2, the UPP Orbiter vector is also routed to V53.

If the FILTER FLAG is OFF ("TGT"), FLTR and PROP pertain to the target. In this case, TVTI (the current target vector, V54) is the target state updated by sensor data; that is, it is the output vector from the Kalman filter (FLTR). PROP (V55) is the propagated target vector. FLTI (V56) is the propagated Orbiter vector and serves as the reference trajectory for the filter. A FLTR to PROP transfer moves a filtered TGT vector (FLTR)-to-PROP. A PROP to FLTR transfer, on the other hand, moves a target PROP vector to the filtered

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TGT (FLTR). The target FLTR/PROP option is useful in special cases, such as Tether Satellite, where propagation models alone are inadequate to predict relative motion and must be supplemented with external sensor data.

Figures 3.5.5.1-1 through 3.5.5.1-3 summarize the meaning of onboard vectors and show how FDO PBIs control their flow into the VAT for the two different FILTER FLAG settings.

OPS	Naming Convention	TLM ID and VAT Slot	Meaning or Definition
2	PRTI	TLM 186, V55	PROP vector (ORB or TGT depending upon FILTER FLAG); only exists when REL NAV enabled
2	TVTI	TLM 11, V54	TGT vector (filtered if TGT FILTER FLAG); only valid and propagated when REL NAV enabled
2	FLTI	TLM 10, V56	Orbiter (filtered if ORB FILTER FLAG); always exists in OPS 2
1 & 3	GCBI	TLM 12, V53	Orbiter UPP vector

**Figure 3.5.5.1-1: Onboard Downlisted Vectors and Their Definitions**

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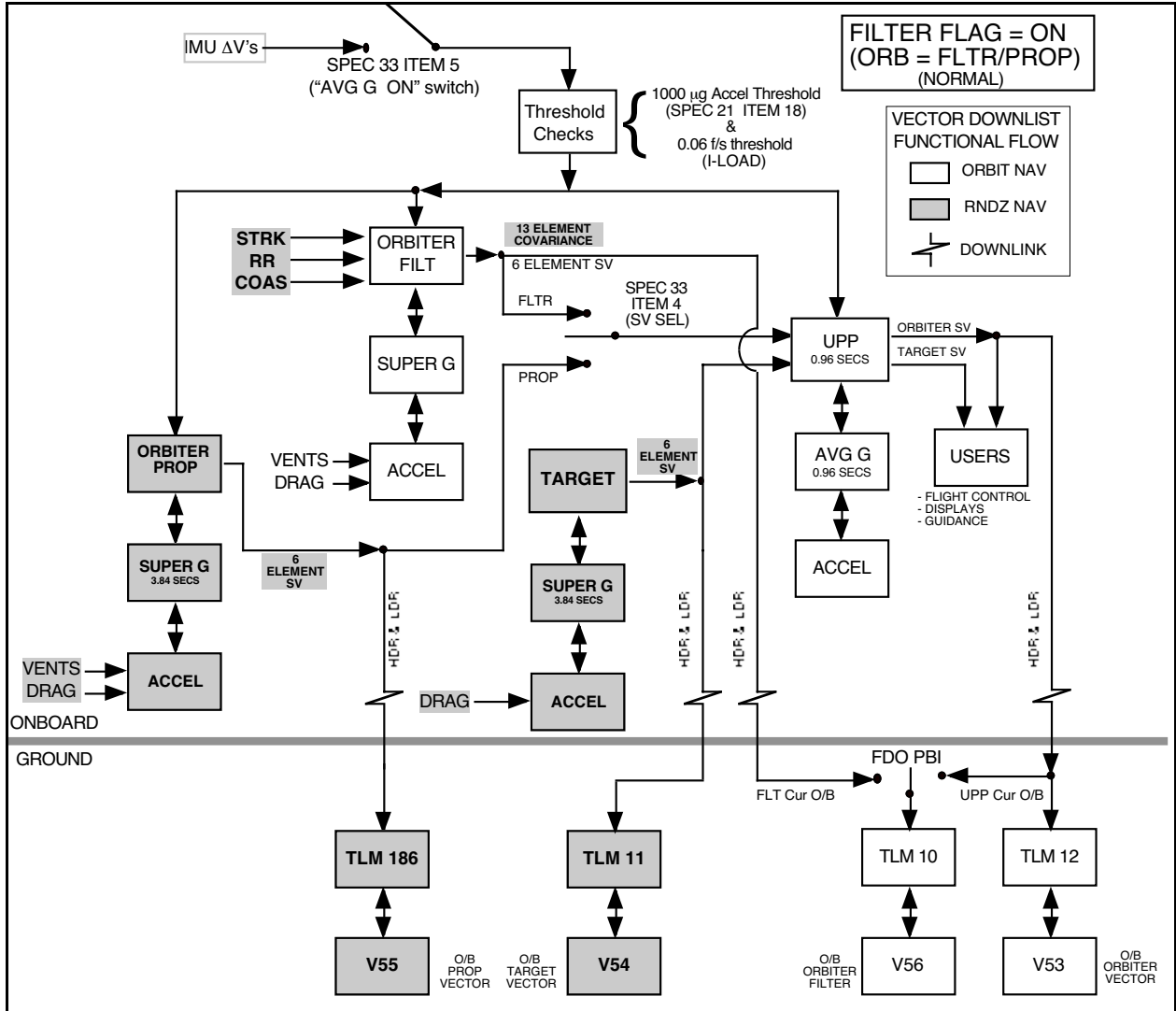
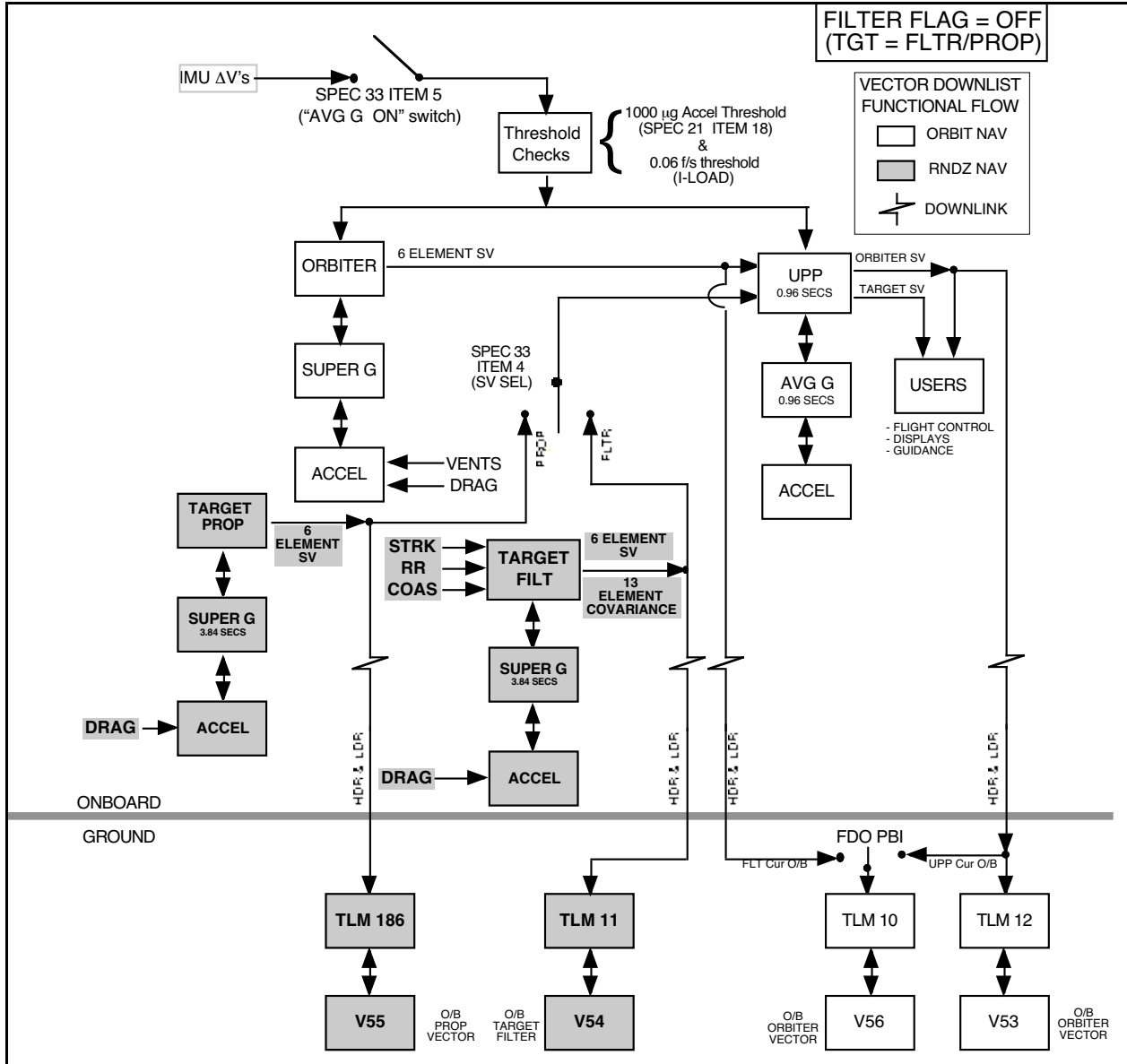


Figure 3.5.5.1-2: Orbiter Navigation Functional Flow With Filter Flag ON

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**Figure 3.5.5.1-3: Orbiter Navigation Functional Flow With Filter Flag Off**

Three external sensors (ST, COAS, RR) measure target position in terms of angles in their respective Orbiter body-referenced coordinate systems. The rendezvous radar sensor also measures Orbiter/target range and range rate. Since Orbiter and target state vectors are in the M50 system, sensor measurements must be transformed into M50 before incorporation into the state vector. The IMUs supply this transformation from body to M50 coordinates. Therefore, IMU attitude errors result in erroneous state vector updates since they are indistinguishable from real sensor measurements as far as the FLTR vector is concerned. This effect is more pronounced on the angle only sensors (ST, COAS). An IMU attitude error has little impact on RR data because the radar angles are weighted significantly less than both range and range rate measurements.

When the crew executes a FLTR to PROP transfer (SPEC 33 ITEM 8), PROP is overwritten by FLTR in order to maintain as accurate a PROP state as possible. This is done at the beginning of an external sensor pass after sensor acquisition verifies the data

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incorporated into FLTR during the previous sensor pass was good. If the crew determines FLTR has been contaminated by bad data, it can be overwritten with the uncorrupted PROP state with a PROP to FLTR transfer (SPEC 33 ITEM 9). This action is called a filter restart.

**CAUTION:** with Rendezvous Nav enabled in the ORB FILTER FLAG setting, Orbiter state vector uplinks to the vehicle are routed only to FLTR. Thus, the PROP vector will be based on an old FLTR vector. FLTR minus PROP on ground and onboard displays will show the difference between these vectors. To get the FLTR and PROP vectors back into sync again, have the crew perform a FLTR TO PROP transfer (SPEC 33 ITEM 8).

The PROP to FLTR transfer in the filter restart will also reinitialize the external sensor covariance matrix to I-LOADED values or to those last uplinked by RGPO. For rendezvous, initial covariance values are quite large because possible state vector errors are large. For Prox Ops or deploy, the initial covariance values are small because possible state vector errors are small. In either case, after sensor data have been incorporated, the covariance shrinks dramatically. The crew can reinitialize the covariance matrix by executing a COVAR REINIT (SPEC 33 ITEM 16). This is sometimes done to "open up" the covariance matrix if it has shrunk to the point of editing out good data.

**NOTE:** the current I-loaded Rendezvous state covariance matrix sigma values are 2000, 20000, 2000, 21, 2, 6 (UVW ft and fps). The current PROX OPS state covariance matrix sigma values are 1000, 1000, 1000, 1, 1, 1 (UVW ft and fps).

Post Ti, Rendezvous GPO uplinks the proximity operations (PROX OPS) covariance matrix. If a COVAR REINIT is required at this point in the rendezvous, this matrix will accelerate filter convergence and determination of sensor biases. Normally the filter is allowed to continue processing data through Ti so there is continuity between pre- and post-Ti solutions and covariance information. Performing a reinit results in the loss of sensor biases developed to that time.

The crew controls whether or not Rendezvous Nav incorporates sensor measurements into the FLTR state vector using the Auto-Inhibit-Force (AIF) switch and ITEM 3 (MEAS ENA) on SPEC 33. In the Auto mode, the Kalman filter will update FLTR with external sensor data only if the corresponding ratio is less than one. In the Inhibit mode, the ratio and residuals are output for display only, and FLTR is not updated. This mode is used at the beginning of a sensor pass to keep bad data from getting into the filter and to verify the acquisition of good data. In the Force mode, the edit criteria used in Auto are relaxed. If the ratio of the forced sensor "mark" (data point) is less than the ratio of the previous mark plus 0.2, then it is accepted for FLTR incorporation. The AIF switch reverts back to the mode it was in prior to Force selection on the following mark. For COAS measurements, all marks are forced one at a time. Therefore, the COAS is used only if all other external sensors have malfunctioned.

**NOTE:** during MM202, Rendezvous Nav is usually inhibited from incorporating measurements. While in MM202, measurements can be incorporated by selecting MEAS ENA (SPEC 33 ITEM 3). Upon return to MM201, this item is set to inhibit.

On the ground, the FLTR, PROP, and TVTI vectors are compared to ground navigation vectors. They can be further evaluated by generating residuals on incoming ground tracking data. The FLTR and TVTI vectors are periodically stored off in the TrS VAT in case onboard navigation becomes corrupted by erroneous sensor data or IMU malfunctions. The latest set of good vectors can be uplinked to restore onboard navigation health. See

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Section 3.10 for more information on procedures for storing these vectors during rendezvous.

One important point to be aware of operationally is the effect of OPS transitions on the various onboard state vectors. For some system failures, the GNC GPC may temporarily be placed in a major mode other than OPS 2 while on orbit. The effect this has on the vectors depends upon the OPS mode.

- 1) If PASS is moded to OPS 0, the target and PROP states will be lost. After 10 minutes in OPS 0, the FLTI state will be overwritten with a "default" equatorial vector, and a vector uplink will be required to recover.
- 2) If PASS is moded to OPS 8 or OPS 3, the target and PROP states will be lost. The PROP state will be reinitialized to the FLTI/FLTR state upon transition back to OPS 2 and re-enabling of REL NAV. A target vector must be uplinked before REL NAV can be enabled. The FLTI state remains valid during these transitions and is the default Orbiter state.

### 3.5.5.2 State Vector Transfers

An onboard state vector transfer overwrites one state vector with another. The four types of onboard state vector transfer are as follows.

- 1) FLTR to PROP (SPEC 33 ITEM 8)
- 2) PROP to FLTR (SPEC 33 ITEM 9)
- 3) Orbiter to target (SPEC 33 ITEM 10)
- 4) Target to Orbiter (SPEC 33 ITEM 11)

These transfers are possible only when Rendezvous Nav is enabled. Transfers 2, 3, and 4 also reinitialize the external sensor measurement covariance matrix. All four types of state vector transfer are mutually exclusive.

#### 3.5.5.2.1 FLTR to PROP Transfers

This operation overwrites the PROP vector with the FLTR vector. The crew performs a FLTR to PROP transfer at the beginning of each sensor acquisition period to provide a quality backup PROP state vector (i.e., save off the results of the previous good sensor pass) in case the FLTR state deteriorates due to bad sensor data. Deterioration of FLTR could occur, for example, if the star tracker locked onto a star instead of the target, if the selected IMU provided biased attitude data, or if the rendezvous radar locked onto orbital debris. A FLTR to PROP transfer is also required whenever an Orbiter vector is uplinked after REL NAV has been enabled.

#### 3.5.5.2.2 PROP to FLTR Transfers

A PROP to FLTR transfer overwrites the FLTR state vector with the PROP state vector. This is done if the FLTR vector goes bad as described in Section 3.5.5.2.1.



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### 3.5.5.2.3 Orbiter to Target Transfers

This transfer overwrites the target vector with the Orbiter vector. It can be used to provide a state vector for nonimpulsively deployed payloads, such as the RMS-deployed SPARTAN, or to reset REL NAV prior to undocking from ISS.

### 3.5.5.2.4 Target to Orbiter Transfers

This transfer can be used at the completion of a rendezvous when Rendezvous Nav's target state vector is much more accurate than its Orbiter vector because of the many translational and attitude maneuvers executed during the manual phase. This is a quick way to update the Orbiter vector. However, the MCC target state is usually more accurate than Rendezvous Nav's because the ground's atmosphere and geopotential models are of higher fidelity than the onboard models. In addition, a more recent tracking solution may be available than was used to initialize REL NAV. For these reasons, FDO will usually uplink what Ground Nav determines to be the best vector after rendezvous (either Orbiter or target) instead of having the crew perform the target to Orbiter transfer.

### 3.5.6 State Vector Updates/Command Load Uplinks

There are many reasons for maintaining an accurate onboard state vector. One of the most important is to protect for an emergency deorbit after a loss of communications inhibits Orbiter Navigation updates from the ground. Flight Rule (FR A4-154) sets the maximum allowable downtrack error at deorbit TIG to 20 nm. This is the largest downtrack error Entry Guidance can steer out between 130 Kft and TAEM interface using TACANs in the presence of three-sigma L/D variations and worst-case winds per an STS-1 analysis.

Since FR A4-154 specifies a 20 nm downtrack limit at deorbit TIG, while the TACAN study imposes the 20 nm downtrack error limit at 130 Kft, questions arise as to whether the flight rule is conservative enough. Orbiter navigation errors at deorbit would propagate for another 50 min by the time 130 Kft altitude is reached. To answer these questions, a Monte Carlo study has been performed during the summer of 2004. Four hundred Spacecraft Trajectory Analysis and Mission Planning Simulation (STAMPS) cycles were run for each of three deorbit nav cases (no initial nav error and  $\pm 20$  nm downtrack error at TIG -10 min with corresponding errors in other position and velocity components) for both an ascending and descending KSC entry.

This study shows Drag updating<sup>1</sup> removes 85% to 90% of the downtrack navigation error by the time TACAN acquisition altitude is achieved. Thus, navigation errors just prior to processing TACANs are not substantial (mean downtrack errors are 6-14 Kft). The study concludes that a  $\pm 20$  nm downtrack error at deorbit TIG does not violate any entry constraints and that drag updating will remove most of the error before TACANs are even acquired. Considering results of the two studies, it's apparent Entry Guidance could recover

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<sup>1</sup> Drag Updating is a process whereby air density values are derived from IMU-sensed drag accelerations. These densities are used in an onboard atmospheric model providing density as a function of altitude to compute an IMU-based altitude. This altitude is compared against NAV altitude computed from onboard-propagated position incorporating IMU acceleration data. Differences between these altitudes are used by the NAV filter to update the state vector. As new acceleration data are obtained, the process is repeated. Gradually the differences between the two altitudes decrease, as the NAV filter converges on a solution. Drag Updating begins when the onboard-sensed acceleration reaches 11 ft/s<sup>2</sup>.

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from downtrack errors larger than 20 nm. This maximum deorbit navigation error has not been determined.

In order to insure adequate state vector accuracy at deorbit TIG protecting the 20 nm flight rule limit, Orbiter Navigation state vector update criteria have been adopted for the Orbiter state based on an analysis presented by RSOC/Charles Barrett at On-Orbit Flight Techniques Panel #86 on June 10, 1988. The following two update criteria are evaluated with respect to an accurate Ground Nav solution, and either may be cause for an update. One should pay particular attention to these guidelines if there are Orbiter comm problems.

NOTE: the study presented at OFTP #86 assumes both of the following conditions are present. See rationale for FR A11-52.B, Loss of both Voice and Command, for more details.

- 1) Semi-major axis error greater than 1000 ft
- 2) Downtrack error predicted to be greater than 20000 ft in two orbits

CAUTION: along with high confidence in the current Ground Nav solution, the foregoing criteria assume an uplink would not jeopardize flight activities or planning in progress. There are occasions when FDO will not be able to honor these criteria with an immediate uplink, and judgment must be exercised in deciding when to update.

If neither Orbiter Navigation update criterion is exceeded, state vector accuracy should remain within the Deorbit TIG limit of 20 nm for up to 13 hours, assuming 1-sigma Orbiter Navigation uncertainties and  $H_p > 120$  nm. If  $105 \text{ nm} < H_p < 120 \text{ nm}$ , the time limit is 9 hrs. This is true even if the current Orbiter Navigation state vector is at an update criterion limit.

Assuming Orbiter Navigation is known to have an inferior state, the best Ground Nav state vector available should be uplinked before guided maneuvers and satellite deployments. The time tag of the uplinked vector should be as close as possible to the time the vector will actually be uplinked. This is because of slight differences in the predictor and propagator routines in Orbiter Navigation (see Section 3.5.2). The predictor moves an uplinked vector forward or backward in time from the vector time tag to the current Orbiter Navigation time. The propagator then integrates the vector forward in near real time. If a comparison were made between a vector predicted in time one direction and then propagated back in the other direction using Orbiter Navigation, the resulting vector will differ slightly from the original vector. This difference, called closure error, arises because the propagator uses current attitude to model drag throughout the integration interval, but the predictor freezes vehicle attitude at the beginning of the prediction interval. Also, as only the propagator is able to incorporate IMU sensed accelerations, a past history of accelerations is not maintained. Therefore, any vector predicted through periods of sensed accelerations would be in error. To minimize these predictor/propagator differences, the vector time tag should be close to the uplink execution time.

### 3.5.6.1 State Vector Command Load Uplink Procedures

Detailed state vector command build and uplink coordination procedures can be found in DM-CH-05, *Flight Dynamics Command Procedures*. On orbit, FDO is responsible for building Orbiter (DSM 401xx) and target (DSM 402xx) state vector command loads.

CAUTION: any state vector uplink is subject to failure, either through manual command load build procedures or a bad forward command link to the Orbiter. This failure may be

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insidious, or it may be detected and flagged by software validity tests. To avoid the problem of a bad forward link, the command shall be sent no later than 10 minutes before an LOS (FR A11-21, Critical Uplink Command Policy) and only after INCO reports solid lock-up following an AOS.

**CAUTION:** per the procedures described in the *Flight Dynamics Command Procedures* document, DM-CH-05, a state vector command load can be built either from E1-E4 or from TrS Checkout Monitor 1. If the Checkout Monitor method is used, care must be exercised to avoid an erroneous command load build and uplink. It is possible for human errors, LAN or software failures, or more probably a combination of these, to result in unintended Checkout Monitor 1 vector contents. Care must be taken to verify Checkout Monitor is configured as intended, or an erroneous state vector command load build, verification, and uplink will occur. Rigorous adherence to DM-CH-05 command load procedures will avoid the most likely causes of a bad command load uplink. The following caveats are also applicable to Checkout Monitor 1 used as a state vector command source.

- 1) The state vector command application does not dynamically poll Checkout Monitor 1 for a change in status. Selecting the CHECKOUT option prior to obtaining the intended Checkout Monitor 1 configuration will result in fetching an erroneous vector. This will not be automatically corrected if Checkout Monitor 1 is subsequently updated.
- 2) If a command load is built with the CHECKOUT option, the "RED" or "GREEN" compare status indicating command agreement with its data source will be of little value if Checkout Monitor 1 contains an unintended vector.
- 3) If DYNAMICS is updating the contents of Checkout Monitor 1, a verbal "update complete" confirmation will be made. If verbal confirmation is not received, request update status from DYNAMICS. FDO or TRAJ can also update Checkout Monitor 1 from an ephemeris source.
- 4) Prior to selecting the CHECKOUT option on the command application, subject Checkout Monitor 1 contents to common sense validity checks. For example, verify GMT, MET, Orb Count, VAT Slot or Ephemeris number, Apogee, Perigee, etc. match expectations. If some kind of LAN, software, or human error has placed an unintended vector in Checkout, a few seconds spent verifying the contents prior to building the command load will assist in avoiding an erroneous command uplink.

**CAUTION:** as noted in Section 3.5.1.1, Orbiter Navigation's gravity model is based on GEM9 coefficients truncated at fourth degree and fourth order. The TrS gravity model, however, is based on GEM10 coefficients truncated at seventh degree and seventh order. Immediately after a "perfect" uplink, comparisons between onboard and ground state vectors may diverge by up to 200 ft in semi-major axis. Over most regions of the Earth, such geopotential deviations amount to less than 50 ft. Should a near-worst-case deviation be obtained after an uplink supporting critical navigation operations, a follow-up uplink may be necessary. Regions of maximum geopotential deviation are typically traversed in less than 10 minutes of orbit motion.

**NOTE:** The DSM 403xx TDRSS State Vector commands are now built by INCO. This change in procedure began with OI-28/STS-98(5A) when onboard software was upgraded to process more than two TDRS vectors. The FDO/TRAJ supports this activity by having Dynamics build TSA TDRS ephemerides INCO uses to build the commands. FDO or TRAJ should always verify each TSA TDRS ephemeris is anchored at the correct longitude and has the correct duration after a Dynamics build (see Section 3.2.3).

**CAUTION:** if "East/West/Spare/Z" nomenclature is used to coordinate an ephemeris request from INCO, ambiguities can arise because multiple TDRSS elements may reside

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at similar longitudes. For example, "West" might refer to an element at either 171° or 174° west longitude. Because a mis-coordinated element may lead to loss of Orbiter communication, always use longitude-dependent nomenclature to coordinate which TDRSS element is required by INCO. For example, use "Z/+85" or "the +85 satellite" instead of "TDRS-Z" or "Z". As of May 2002, there are two satellites located at 171° W. The old one (#7) has been placed in storage mode while the new one (H) is now prime. Because the network will not use both of them at the same time, T171 W can be used as their designation, and FDO just needs to make sure the proper satellite vector (H or #7) is used to anchor this ephemeris.

**CAUTION:** some OPS workstations are Kerberos-inhibited. Any attempts to perform a Command Server login from these workstations will fail. No diagnostic regarding this condition is issued, the same negative response signature received from an erroneous password at login. In the Trajectory MPSR, all workstations with an "IPS MPSR" ID are Kerberos-inhibited.

**CAUTION:** prior to correcting a large state vector error via uplink, consider moding to DAP = FREE (or possibly DAP = INTL). This action may also be advisable prior to the equatorial state vector downmode 10 min after transition to OPS 0. In the FREE (or INTL) DAP mode, Universal Pointing cannot command large attitude maneuvers based on state vector changes. During rendezvous operations, RGPO will call for DAP = FREE before any Orbiter state vector uplink (see DM-CH-08, RGPO Console Handbook, Section 4.3, Navigation Anomalies).

### 3.5.6.2 Vent Command Load

Early in the Shuttle program, a phenomenon known as "energy growth" was observed. This term is purely relative, arising from the Shuttle orbit's tendency to decay less (or sometimes more) rapidly than expected. Only in extreme cases does the orbit period increase due to this effect (see Section 3.5.1.5, Unmodeled Vehicle Acceleration Compensation, for an introduction).

Uncoupled thrusting from the RCS causes energy growth or loss. When holding attitude, particularly with VRCS, jet firings impart net translational impulses. Torques on the Orbiter, particularly from unbalanced aerodynamic drag forces, eventually lead to RCS jet commands whenever a DAP dead band is reached. These commands result in systematic uncoupled thrusting when in LVLH attitude hold. Consider the following examples due to aerodynamic torque.

<u>Attitude</u>	<u>Net Torque</u>	<u>VRCS Impulse</u>
+YVV .....	Yaw Right.....	Posigrade
-YVV .....	Yaw Left.....	Posigrade
+ZVV .....	Pitch Down .....	Retrograde
-ZVV.....	Pitch Up.....	Posigrade

Normal trajectory integration techniques do not model energy growth. It causes both Orbiter Navigation and ground ephemerides to diverge from the actual trajectory.

Ground Navigation has developed a technique using vent models to compensate for this perturbation. By observing accumulated semi-major axis (energy) error over a long period of attitude hold at a given altitude, an average vent force can be computed to account for net jet firings. The restriction to this procedure is that the length of time in attitude hold must be

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sufficient to obtain a consistent average force. The TrS software includes both a UVW and Orbiter body vent capability. The UVW vent was not available in the old MOC (mainframe).

**CAUTION:** only one TrS VTL exists, and it is dependent on the single TrS ATL to provide inertial vent accelerations from body-fixed vents for integration in an ephemeris with the V integrator option. Therefore, a change to the ATL often requires a coordinated VTL update by Ground Nav. On the other hand, UVW-fixed vents require no ATL for correct integration into an ephemeris with the V option. All ephemerides with the V option are tied to the single VTL.

**NOTE:** Ground Nav can configure integration options in a data link independent of those in the corresponding ephemeris. This may provide greater flexibility in obtaining a vent solution. Conversely, it may contribute to invalid use of an otherwise correct solution.

The vent solution technique has worked well for ground ephemerides, minimizing anchor vector updates during long attitude hold periods. In 1991, during STS-40 Spacelab Life Sciences-1 mission, vent solutions were used with Orbiter Navigation for the first time. To accomplish this, Ground Nav computes a vent value compatible with the onboard trajectory software and builds the vent command DSM 426xx. FDO then coordinates the 426xx uplink with INCO. The uplinked vent force must be in Orbiter body coordinates. When restricted to a long attitude hold, vent uplinks have been successful in extending Orbiter Navigation's validity over longer time spans. Vent command procedures can be found in DM-CH-05, *Flight Dynamics Command Procedures*. Vents can also be used to model large perturbations that are not sensed by the IMUs, such as Tethered Satellite forces or vehicle reboosts (STS-98).

**NOTE:** ATL evolution may necessitate early termination of an onboard vent while it's in progress. This can be accomplished by uplinking a zero-magnitude vent with ON time in the recent past and OFF time in the near future.

**CAUTION:** vent uplinks attempting to model reboost accelerations are generally inadvisable. They rarely improve onboard trajectory modeling unless it's certain reboost propulsive accelerations can't be sensed by the IMUs. Typically, the uplinked vent force must also be scaled to reflect the difference between real world stack weight and onboard Orbiter-only weight.

### 3.5.6.3 K-Factor Command Load

This existing Orbiter Navigation capability (reference DSM 400xx documentation in Section 3.5.1.3) is used in connection with Day Of Rendezvous (DOR) operations, leaves the Orbiter's K-factor unchanged at unity, and only modifies the target K-factor as required. See Section 3.10.1.9.2 for DOR 400xx operations.

### 3.5.6.4 Crew Sleep Cycle State Vector (Sleep Vector) Uplink

For a loss of voice communications, FR A11-51 dictates the crew deorbit at the next Primary Landing Site (PLS) opportunity. If both voice and command are lost (FR 11-52.B), the crew must deorbit NLT the next PLS or sooner (ELS) if the quality of the onboard vector is unknown and it can't be updated via GPS or some alternate method (see Section 4.10.12.3, Voiced Delta State, in the Entry FDO Handbook for partial procedures).

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To avoid an ELS deorbit due to onboard state vector quality uncertainty if command and telemetry are lost during crew sleep, a "sleep vector" is uplinked. This uplink notifies the crew that a state vector, good through the next PLS, is now onboard. It is performed ASAP after crew sleep if the onboard vector violates navigation guidelines listed in Section 3.5.6.

A state vector tends to diverge very little during crew sleep because onboard activity is at a minimum. The best "sleep vector" is obtained if it is based on at least one orbit of tracking after pre-sleep activities and attitude maneuvers have ceased.

NOTE: The foregoing philosophy assumes the entire crew is asleep during crew sleep. It may become invalid during dual-shift crew operations, frequently planned during missions dedicated to Spacelab or Spacehab operations.

A sleep vector should yield less than 15 nm of accumulated downtrack error by the next PLS deorbit opportunity. By making 15 nm the criterion, as opposed to the 20 nm Flight Rule entry limit, a pad of 5 nm is allowed for dispersions likely to be introduced during deorbit prep activities (see Section 3.5.6). FDO applies the equation given in Section 3.5.4 to estimate future downtrack error, obtaining semi-major axis error from the VECTOR COMPARE display. Orbit Monitor may also be configured to display predicted downtrack error at the next PLS opportunity.

Detailed sleep vector uplink procedures are documented in DM-CH-05, *Flight Dynamics Command Procedures*. The state vector is uplinked along with a "dummy" zero  $\Delta V$  PEG 7 target set whose TIG is the next PLS deorbit TIG. During a complete loss of comm, the crew will consult the OPS 202 ORBIT MNVR EXEC display for TIG and PEG 7  $\Delta V$ s. If a sleep vector has been uplinked and the TIG is in the future, the crew will deorbit at that TIG. Otherwise, they will try to incorporate GPS into NAV and deorbit to the next PLS (preferably lit). If GPS is not usable, the crew will deorbit within 9 or 13 hours depending on orbit perigee. The landing site priority is lit ConUS, next ConUS, and next lit ELS. See also COMM SSR-1: Loss of All Voice Comm in the MAL book, Step 8 for the no command scenario.

FDO will continue to monitor the Orbiter Navigation state to insure downtrack error remains below 15 nm at the PLS TIG. If command capability exists, FDO will uplink a new vector if this limit is exceeded.

NOTE: lost command while communication remains functional is an MDF case.

### 3.5.7 On-Orbit $\Delta T$ Processor Applications

Radar range and Doppler observations were used extensively throughout the Apollo Program and Apollo/Soyuz Test Project to evaluate state vector downtrack position error. The  $\Delta T$  Processor (DTP) was developed to compute downtrack error and to derive a state vector time tag adjustment minimizing it. This processor was originally developed so Ground Nav and FDO could use it during STS entries. Flight Rule A4-201 governs use of the  $\Delta T$  update between a deorbit burn and Entry Interface. The DTP can be used on orbit if necessary, but this is not standard practice. It was used once as a final check of a vector prior to a satellite deployment and another time during STS-49 to verify INTELSAT had performed a burn as expected.

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The purpose of DTP is to rapidly compute a time tag correction to the onboard state vector reducing current downtrack position error. A one-second  $\Delta T$  corresponds to a 4.2 nm error, assuming relative velocity is 25000 fps. During a single tracking pass, FDO may use the DTP to evaluate Orbiter Navigation and Ground Nav state vectors, compute a time tag correction to the former, and voice the update to the crew. Inputs to the DTP include Orbiter Navigation's state vector together with range and Doppler (range rate) observations from a tracking station. The DTP can be run using data from C-Band radars or S-Band trackers. Only S-Band sensors provide both range and Doppler information to JSC so S-Band sites are preferred.

**CAUTION:** DTP processing is not possible with Doppler-only TDRSS tracking data.

The DTP uses an Encke prediction to build an ephemeris through the tracking pass. Next, a perturbed ephemeris is created, assuming the initial state vector's time tag is slipped by one second. These ephemerides are used throughout the pass to predict expected nominal and one-second-perturbed range and Doppler values corresponding to each frame of actual radar data. The predicted nominal and perturbed values are used to compute DTP partials (partial derivatives), which are explained below.

DTP partials are of two types: range partial and Doppler partial. The range partial is the downrange distance covered in one second by the unperturbed vehicle, divided by the difference in range between the perturbed and unperturbed trajectories. The Doppler partial is the downrange distance covered in one second, divided by the difference in range rate between the perturbed and unperturbed trajectories. Remember C-Band trackers do not provide Doppler data. Partial and  $\Delta T$ s for each frame of radar data are displayed on the DELTA T PROCESSING displays. Two  $\Delta T$ s are calculated for each frame of ground S-band radar data, one for each data type (Range, Doppler).

Range observations are most accurate for determining downrange error at low tracking elevations. For a given change in downrange, there is a larger change in range to the tracking site (slant range) at low elevations than at high elevations. Therefore, the first computed frames yield the best range solution. At maximum elevation, a very small change in slant range corresponds to a very large change in downrange distance. Therefore, at maximum elevation, the range partial becomes large rapidly and changes sign.

Doppler  $\Delta T$ s are most accurate at maximum elevation of the tracking pass. The Doppler partial becomes nearly constant near the point of closest approach (PCA). Therefore, if the Doppler solution is taken at or near PCA, the linear relationship is valid over a large band of downrange errors.

The initial low elevation range  $\Delta T$  is a good estimate and should agree with the maximum elevation Doppler  $\Delta T$ . For computational consistency, the Doppler  $\Delta T$  should be selected in the region where magnitude of the range partial increases and changes sign. If the range and Doppler solutions do not agree, the Doppler solution is generally considered to be more accurate because it is less susceptible to noise and bias errors. Obviously, if the DTP is run using C-Band data, this comparison cannot be made.

A  $\Delta T$  correction is manually incorporated into Orbiter Navigation using the HORIZONTAL SITUATION display, SPEC 50. The crew enters a voiced-up  $\Delta T$  into ITEM 18 and then loads it by executing ITEM 16. When Orbiter Navigation completes the update, ITEM 18's display field is automatically zeroed. This procedure can only be performed in OPS 3.

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Attempting to execute a non-zero ITEM 18 in OPS 1 or 6 will generate an "ILLEGAL ENTRY" message.

Upon receiving ITEMS 18 and 16, Orbiter Navigation fetches a current vector, adds the input  $\Delta T$  to it, and sends the resulting state vector to the Entry Precise Predictor (EPP). The EPP does not use IMU-sensed velocities; therefore it is valid only during unpowered flight. It integrates the input vector to a specified time (current time for  $\Delta T$  updates) and replaces the current Orbiter Navigation vector with the result.

Following  $\Delta T$  incorporation by PASS, the crew can apply corresponding corrections to an active BFS by first executing an ITEM 17 on BFS SPEC 50. This displays UVW  $\Delta s$  between PASS and BFS in ITEMS 10 through 15 ( $\Delta X$  displays the radial  $\Delta U$ ,  $\Delta Y$  displays the downtrack  $\Delta V$ , etc.). If the  $\Delta s$  are acceptable, an ITEM 16 EXEC from BFS SPEC 50 applies them.

A negative  $\Delta T$  indicates the vehicle is actually farther downrange than the onboard vector predicts. The vehicle is therefore high on energy at that time. Conversely, a positive  $\Delta T$  indicates the vehicle is actually behind its navigated position.

The DTP has definite limitations. It is designed to reduce the instantaneous downtrack position error only. If there is an error in knowledge of the orbit period (radial error), position error will continue to grow after the update. The range  $\Delta T$  relates a range to a downtrack position error. Therefore, the solution should be considered suspect if there is an out-of-plane or radial position error. Velocity errors do lead to position errors, but are not accounted for in the range solution. The Doppler solution relates range rate at the predicted point of closest approach to a downtrack position error. If a radial velocity error exists, the Doppler solution should be considered inaccurate. Out-of-plane and radial position errors are not sensed in the Doppler  $\Delta T$ . Ground Nav will use the residual plot of the pass to help determine if only a downtrack error is present.

### 3.5.8 Orbiter/Target Relative State (OTREL)

The TSA Orbiter/Target Relative (OTREL) application creates a new Orbiter and target state vector pair for uplink using the best ground tracking state available while preserving the current relative state from Rendezvous Nav.

During rendezvous or deployed operations when REL NAV (SPEC 33) is enabled, it may be necessary to update both the Orbiter and target onboard state vectors, especially during extended rendezvous operations. Consult Ground Nav to find out which ground state is better, the Orbiter or the target. In most cases the target state is known more accurately than that of the Orbiter. This case will be assumed here so the target state will be used as the base to create a new Orbiter state.

Rendezvous Nav provides an accurate relative state between the Orbiter and target. Radar, star trackers, and/or COAS may be used to update the state currently being processed via SPEC 33. Consult Rendezvous GPO to verify the relative state is good. The relative state can be applied to the ground target state with OTREL to create a new Orbiter state. This procedure assumes the relative state between Orbiter and target will not change appreciably (i.e., no Orbiter or target maneuvers) during its execution.



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- 1) Ask Ground Nav which solution, Orbiter or target, is better. Use the better state to create the other with OTREL. TUP the ephemeris, if necessary, to incorporate the latest Ground Nav solution. The following procedure assumes the target state is better than the Orbiter state.
- 2) Confirm a good relative onboard state with GPO.
- 3) "Grab" Orbiter and target states from the telemetry stream (V56 and V54, respectively). If the FLTR state has been corrupted, consult GPO about using the PROP vector, V55, instead of V56, or consider having the crew perform a PROP to FLTR transfer on SPEC 33 before grabbing onboard vectors.
- 4) Use TSA/Vector Edit or Checkout Monitor to store V54, V56, and a vector out of the target ephemeris at the desired time of uplink in Local VAT slots. Be sure correct weights and comments are associated with each vector before they are stored in the Local VAT. Perform a Vector Compare between the Orbiter and target vectors to determine the initial offsets. This step also QAs the vector stores. See the left half of Figure 3.5.8-1 for an example.
- 5) Use OTREL (TSA/Rendezvous Processors/"Orbiter/Target Relative") to create a final Orbiter state vector. Input TSA VAT slots corresponding to the onboard vectors (V54 and V56) as the INIT TARGET VECT and the INIT CHASER VECT, respectively (see Figure 3.5.8-2 for an example). The AREA and KCON for each vehicle are also required. Input the corresponding TSA VAT slot of the target state at desired uplink time as the FINAL TARGET VECT. Uplink time will default to that of the final target vector, but it can be changed if necessary. The FINAL CHASER VECTOR will be created when this display is EXECUTED. This vector should be stored in a Local TSA VAT slot with an appropriate comment. Check the INIT Relative State values against the previous vector compare results to verify they are reasonable. Get a hard copy of the OTREL output.

NOTE: because of the coordinate axis differences between LVLH and UVW, OTREL X, Y, and Z are UVW V, -W, and -U, respectively.

- 6) Use the TSA/Checkout Monitor to view the FINAL ORBITER VECTOR. Verify the orbit looks reasonable. Perform a Vector Compare between the final Orbiter and target vectors to verify the differences are as expected. Get a hard copy of both displays. See the right half of Figure 3.5.8-1 for example Vector Compare results.
- 7) Copy or Move the Final Orbiter Vector to a TrS VAT slot, and perform a Vector Compare to verify the move. Verify the vector time tag is correct. Have Dynamics anchor E5 and E6 on these final Orbiter and target vectors. Perform Vector Compares to confirm each ephemeris update.
- 8) As a final check, ask Ground Nav to compare E5 and E6. The deltas between the two ephemerides should be close to those output from OTREL. If they are not, recheck all vectors used in this procedure. If time is short, E3 could be used instead of E6. Otherwise, E6 provides a more complete QA of the entire process.
- 9) Build Orbiter and target state command loads (401xx and 402yy) for the same uplink time. The Orbiter state command load should be built from E5 by using

## FDO Console Handbook Section 3.5: Orbiter Navigation

TrS Checkout Monitor 1. The target state command load is built out of E6 (using TrS Checkout Monitor 1) or E3. Hardcopy the command loads. Refer to Section 3.5.6.1 for additional information on Orbiter and target state vector command loads.

**NOTE:** TrS Checkout Monitor 1 must be used as a command build data source in the foregoing step because COTM can only fetch ephemeris state vectors from E1-4.

**NOTE:** Vector labels used in the OTREL application are fixed. They assume a new Orbiter vector is being created from a ground target vector. In the event a ground Orbiter state is better, Orbiter vectors should be input to the INIT TARGET and FINAL TARGET slots referenced in Step 5. An onboard target vector is then entered in the INIT CHASER slot. The resulting output, or FINAL CHASER vector, will consequently be a new target state.

SYS	BASE VECTOR		COMPARE #1		BASE VECTOR		COMPARE #1		UNITS
	SSP	L	SSP	L	SSP	L	SSP	L	
LOC		V10		V11		V13		V12	
MET	001:17:43:00.0		001:17:43:00.0		001:17:45:00.0		001:17:45:00.0		
GMT	236:08:20:51.0		236:08:20:51.0		236:08:22:51.0		236:08:22:51.0		
COM	Orbiter for OT		Target for OTR		Final Orbiter		Final Target		
a	22215501.78		-20426.3043		22210113.93		-20453.0241		FT
e	0.001503		-0.000210		0.001651		-0.000280		
i	51.849626		0.000881		51.844210		0.000858		deg
zp	340.069679		329.651154		347.112465		333.438108		deg
RAAN	77.002642		0.001334		76.996213		0.001410		deg
h	238.972059		29.878302		239.712663		26.113676		deg
UVW									
U	22232676.72413		-35766.275230		22228566.91178		-37066.010489		FT
V	0.000000		-182564.504241		0.000000		-173845.442759		FT
W	0.000000		96.770689		0.000000		47.480897		FT
UDOT	-32.42174		194.49034		-35.90005		187.14913		FPS
VDOT	25152.54943		30.72516		25154.13842		32.06858		FPS
WDOT	0.00000		-0.59064		0.00000		-0.61248		FPS

**Figure 3.5.8-1: Juxtaposed Initial and Final Vector Offsets**

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```

                                ORBITER-TARGET RELATIVE STATE (OTREL)
-----
|                               SYS  LOC  COMMENT                               |
|                               (T,M) (V##)                               |
| INIT TARGET VECT  T    V11  Target for OTREL test                       |
|                               AREA 8939.3  KCON 1.0                       |
| INIT CHASER VECT  T    V10  Orbiter for OTREL test                       |
|                               AREA 1800.0  KCON 1.0                       |
| FINAL TARGET VECT T    V12  Final Target for OTREL test                 |
|-----
| LIFTOFF TIME (CHASER) G 2002:234:14:37:51.000                         |
| UPLINK TIME      (G,M) M 001:17:45:00.000                             |
|-----
| FINAL CHASER VAT SLOT T13 (NO,0,T##,M##)                             |
| COMMENT Final Orbiter for OTREL test                                  |
|-----

```

	INIT RELATIVE STATE	FINAL RELATIVE STATE
MET	001:17:43:00.000	001:17:45:00.000
LVLH		
X	-182265.3	-173550.9
Y	-100.9	-51.6
Z	37261.8	38422.2
XDOT	71.166328	73.958186
YDOT	0.590482	0.612835
ZDOT	10.885859	8.423633

**Figure 3.5.8-2 OTREL Menu Display**

### 3.5.9 Orbiter Navigation Support During Emergency Deorbit

During OPS 3 deorbit and entry phases, the Entry Guidance and Procedures Officer (GPO) and lead Onboard Ascent/Entry Navigator (ONAV-1) maintain Orbiter Navigation accuracy. In an emergency deorbit scenario, however, GPO and ONAV support may not be readily available. Orbit FDOs should therefore be conversant with OPS 3 Orbiter Navigation fundamentals as they relate to the Emergency Deorbit Checklist (Appendix 3.E) and Emergency Landing Site Uplink Notes (Section 3.9.7.3.4). These include building the following OPS 3 command loads, if required, in addition to DEORBIT TARGET PEG 4 (DSM 411xx, see Section 1.5.16 of the Flight Dynamics Command Procedures book) for both PASS and BFS uplink.

- 1) DEORBIT LANDING SITE (see Section 1.5.17, Flight Dynamics Command Procedures book): use DSM 412xx to uplink a new runway that is not in the onboard Landing Site Table (LST).
- 2) DEORBIT TACAN SITE (see Section 1.5.18, Flight Dynamics Command Procedures book): use DSM 413xx to uplink a primary and secondary TACAN station that is associated with the desired landing site's runway (see the Entry Checklist Flight Supplement for default TACAN configurations).

## **FDO Console Handbook Section 3.5: Orbiter Navigation**

WARNING: many pitfalls with potentially critical impact to Orbiter Navigation are associated with these uplinks. Co-channel interference between TACAN stations is but one example. Every effort should be made to obtain GPO consultation before an uplink is made.

If you have not been able to uplink a new state vector, GPS can be used to clean up the onboard state. See FR A4-203, Entry Navigation Update Philosophy, for the conditions that must be satisfied in order to use a GPS update. The FDO can work with GNC on this if GPO and ONAV are not available. Entry Pocket Checklist, Section 6 (GNC) contains GPS Incorporation procedures.

**Section 3.5 Concludes On This Page**

## **FDO Console Handbook Section 3.6: Orbit Mass Properties**

### **3.6 Orbit Mass Properties**

The FDO, Propulsion Officer (PROP), and Guidance, Navigation, and Control Officer (GNC) all require accurate mass properties information for use in their respective processors. During all flight phases, the Trajectory Officer (TRAJ) performs mass properties computations to obtain the current and/or predicted Orbiter weight, center of gravity (CG), moments and products of inertia, OMS engine trims, and ballast. This information is generally required prior to major maneuvers, deorbit planning, or at any time when mass property changes occur.

This section describes how to use mass properties displays, techniques, and rules of thumb in order to provide mass properties data on console. Use of supporting data, such as various Flight Design products, will also be addressed. A more detailed discussion of the ascent and entry mass properties procedures can be found in Volumes 4, and 5 of the FDO Console Handbook.

#### **3.6.1 Task Overview**

The orbit mass properties task is accomplished using the Paperless Mass Properties (PMP) workstation application and four TrS/TSA displays. Procedures entail configuring PMP displays to represent groups of payload masses, together with Orbiter consumables, using either telemetry data (for current values) or predicted data. These groups can be summarized as cargo, cryogenics, and non-propulsive consumables. Once mass property information for individual groups is determined, each is added together and combined with data for the inert Orbiter and propulsive consumables to determine the entire Orbiter mass properties. With total Orbiter mass properties available, further processing is necessary to generate engine trims for either orbit or deorbit maneuvers, total Orbiter mass properties at critical events from deorbit to landing, and ballast required (if any) to maintain Orbiter CG within flight rule limits. Current values of total Orbiter weight are then input by the FDO (via DYNAMICS) into ground ephemerides to improve their accuracy. Total Orbiter weight is also used by PROP to determine accurate  $\Delta V$  capability. Both Orbiter CG and inertia tensor data are important to GNC controllers, particularly in quasi-stable modes such as gravity gradient attitude control.

#### **3.6.2 Console Displays**

The PMP application and four TrS/TSA mass property displays are used during mass property operations (see Figure 3.6.2-1 for list of displays). The PMP application, and TrS/TSA mass property displays are called up from the Display Navigation (DNAV) "Mass Props" menu. Individual PMP displays are viewed using the PMP "Display" menu. Refer to the PMP User's Guide for more information.

## FDO Console Handbook Section 3.6: Orbit Mass Properties

PMP	Trajectory Server/TSA
Orbiter Buildup	Engine Char Table
Cargo Buildup	Ephemeris WGL Table
Non-prop Buildup	DMP Mass Props
Cryo Buildup	Entry Constraints Table
OMS Depletion	
CG Sum	
CG Box	
Landing Site	
Orbiter Buildup Inertia	
Cargo Buildup Inertia	
Non-prop Buildup Inertia	
Cryo Buildup Inertia	
CG Sum Inertia	

**Figure 3.6.2-1: Mass Property Displays**

### 3.6.3 Use of PROP Products

Several Flight Design products with the “PROP” prefix are used in support of FDO mass properties tasks. These are detailed in the following subsections.

#### 3.6.3.1 PROP-34 Data

Based on SODB amendment inputs, Flight Design produces the PROP-34 product. The Abbreviated Report (also known as sequential mass properties), MCC Data, and Orbiter Fluid Budget are contained in PROP-34. This document is the primary source of mass property data for FDO during each Flight Design cycle.

The PROP-34 MCC Data is the Flight Design product from which all data required for ascent, orbit, and entry PMP files can be obtained. The PROP-34 product includes mass property data at four points in the mission entitled as follows.

- 1) Liftoff
- 2) Payload Bay Door Open
- 3) Deorbit TIG (Nominal)
- 4) Landing (Post Landing)

Figures 3.6.3.1-1 through 3.6.3.1-5 illustrate the Liftoff section of the product. The format is the same for Payload Bay Door Open and Deorbit TIG. Lines prefixed with "L/O TO OMS-2" are still present in Payload Bay Door Open and Deorbit TIG sections of the product, but they're set to zero and are not used in PMP. The Landing format is basically the same, except it has no CG Sum since the entry has already been flown. The Performance AOA values are specified after the Landing section of the product under the heading "Other Data". If a performance AOA is declared, the Ascent Team will use these numbers. PROP-34 is formatted the same as PMP's Orbiter B/U, Cargo B/U, Non-Prop B/U, Cryo B/U, and CG Summary displays. Refer to Section 3.6.6 for details concerning use of PROP-34 to configure preflight PMP files.

The CG SUM data in PROP-34 contains 5 new lines (177 - 181) reflecting propulsive and non-propulsive consumables usage between liftoff and OMS-2. These had previously

## FDO Console Handbook Section 3.6: Orbit Mass Properties

been combined in a single L/O to OMS-2 bias entry. Separating this bias into prop and non-prop portions allows the ballast computation to be more accurate.

Line numbers in the PROP-34 MCC Data sections are consistent with line numbers in the PMP buildup and inertia tables. However, three of the five lines representing the L/O to OMS-2 quantities in PROP-34 are not tracked in the PMP CG SUM table. Therefore, line numbers on the CG SUM table are three less than their counterparts in the PROP-34 product.

The MISC PRESS & H2O change every day. Since FDO does not get these quantities on a daily basis, the Payload Bay Doors Open value is used on-orbit. If the Entry team desires a more accurate value prior to D/O, they may enter the Deorbit TIG MISC Press & H2O to eliminate this error.

PMP line 177 (L/O to OMS2 Prop) of the Ascent spreadsheet (Liftoff section of PROP-34) only covers AFT propellant used from L/O to OMS2 (line 180 in PROP-34). FRCS propellant used during that timeframe (line 177 in PROP-34) is not tracked in PMP, since we plan to dump it in line 182 (PMP Ascent spreadsheet). This propellant is roughly 150 lbm. This makes the trims computed using the Ascent Spreadsheet off by approximately  $0.02^\circ$  for a 250K lbm vehicle. When considering all uncertainties in the Ascent spreadsheet and the fact OMS Gimbals only use these as a starting point, this error is not viewed as operationally significant. This error does not affect the rest of the CG summary sheet since the FDUMP on line 182 accounts for this 150 lbm. If you cannot dump FRCS due to a systems problem, make sure PROP tells you how much propellant is remaining post-dump. Subtract this amount from the full dump and use this number in PMP. This will correctly account for the 150 lbm used during ascent.

PMP lines 186 and 187 (Ascent CG Sum) and 182 and 183 (Orbit/Entry CG Sum) account for OMS Slosh during entry. OMS Slosh is a result of going from a micro-g environment to a one-g environment. This reflects the OMS propellant moving from the AFT portion of the OMS tank to the FWD portion of the OMS tank. The first line removes the remaining post D/O OMS quantity from the AFT location, and the second line adds it back in at the FWD location. The formulation takes into account what tanks were depleted when OMS Depletion was run. The Ascent CG Sum page is shown in Figure 3.6.6.1-10, and the Orbit CG Sum page is shown in Figure 3.6.6.1-21.

**NOTE:** errors will be displayed in the OMS Slosh lines if current OMS quantities in the Orbiter Build Up are reduced and OMS Depletion is not re-run. A re-run avoids depleting more OMS than exists in the Orbiter Build Up.

**NOTE:** data shown in the following PROP-34 examples are for illustrative purposes only. These data do not match those displayed in Figures 3.6.6.1-1 through 22.

# FDO Console Handbook Section 3.6: Orbit Mass Properties

STS 107										
MCC TABLE										
**** LIFTOFF ****										
ITEMS	WT(LBM)	X(IN)	Y(IN)	Z(IN)	IXX(SF2)	IYY(SF2)	IZZ(SF2)	PXY(SF2)	PXZ(SF2)	PYZ(SF2)
1 INERT ORB	189261.0	1094.29	-1.19	368.33	874264.9	6688619.1	6969028.9	17518.3	134317.0	-1009.8
2 CARGO	35751.0	973.36	2.57	379.82	34115.5	391203.7	380253.6	-6.8	1430.5	193.9
3 NON PROP CONS	2914.4	1080.21	-5.56	382.19	4197.1	91961.5	91478.8	-1788.6	9812.9	56.9
4 CRYOGENICS	7429.4	1081.47	-8.65	354.41	11634.9	66887.6	67867.8	906.9	13828.5	645.3
5 OMS FU R	3260.6	1429.27	71.23	500.80	217.4	282.0	291.6	-1.9	4.7	8.4
6 OMS OX R	5410.0	1429.01	109.18	461.39	407.4	465.1	540.0	-8.6	9.5	-2.8
7 OMS FU L	3260.6	1429.27	-71.23	500.80	217.4	282.0	291.6	1.9	4.7	-8.4
8 OMS OX L	5410.0	1429.01	-109.18	461.39	407.4	465.1	540.0	8.6	9.5	2.8
9 RCS FU FWD	693.0	317.00	-24.00	365.00	-2.0	-4.3	-5.6	-2.5	-1.2	-0.8
10 RCS OX FWD	1116.0	317.00	24.00	364.99	-3.5	-7.8	-10.0	4.5	-2.2	1.4
11 RCS FU AFT R	856.0	1340.00	67.00	490.00	-4.5	-149.6	-153.7	-25.3	5.5	0.9
12 RCS OX AFT R	1356.0	1340.00	99.00	457.00	-7.1	-233.5	-226.5	-3.3	-40.0	-0.6
13 RCS FU AFT L	856.0	1340.00	-67.00	490.00	-4.5	-149.6	-153.7	25.3	5.5	-0.9
14 RCS OX AFT L	1356.0	1340.00	-99.00	457.00	-7.1	-233.5	-226.5	3.3	-40.0	0.6
15 OMS PROP MISC	158.8	1468.70	0.00	474.95	177.5	0.8	176.7	0.0	0.0	0.0
16 RCS UNUSABLE	912.0	960.62	1.96	431.01	1595.7	54929.0	55374.7	-248.0	5492.3	-25.3
17 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
18 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
19 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
20 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
21 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
22 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
23 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
24 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
25 TOTAL ORBITER	260000.8	1098.00	-0.78	378.85	1021429.6	8179663.0	8441822.7	12623.1	311827.4	710.2

**Figure 3.6.3.1-1: Typical PROP-34 Orbiter Build Up**

26 STATIC PAYLOAD	35561.0	975.30	2.10	379.50	33642.0	385588.0	374475.0	1303.0	2332.0	-23.0
27 RMS JET	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
28 KU JET	190.0	610.00	90.00	440.00	9.0	23.0	20.0	0.0	0.0	0.0
29 SPACEHAB - PAYLOAD	0.0	830.40	-19.80	417.10	13.0	11.0	15.0	0.0	0.0	0.0
30 STOWED URINE SAMPLES	0.0	650.00	0.00	389.50	0.0	0.0	0.0	0.0	0.0	0.0
31 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
32 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
33 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
34 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
35 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
36 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
37 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
38 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
39 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
40 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
41 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
42 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
43 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
44 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
45 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
46 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
47 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
48 DUMMY	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
49 TOT CARGO ORB SYS	35751.0	973.36	2.57	379.82	34115.5	391203.7	380253.6	-6.8	1430.5	193.9

DATA REFERENCE: FRRF107                      PREPARED BY: Charlotte Hannemann USH-433D  
 FLT. SOFTWARE: OI-29  
 ANALYSIS DATE: Fri Jan 31 07:02:04 2003

**Figure 3.6.3.1-2: Typical PROP-34 Cargo Build Up**



# FDO Console Handbook Section 3.6: Orbit Mass Properties

STS 107  
MCC TABLE

\*\*\*\* LIFTOFF \*\*\*\*

ITEMS	WT (LBM)	X (IN)	Y (IN)	Z (IN)	IXX (SF2)	IYY (SF2)	IZZ (SF2)	PXY (SF2)	PXZ (SF2)	PYZ (SF2)
51 GN2 SYS 1	157.3	976.63	-29.67	328.70	239.1	1511.1	1750.2	300.5	0.0	0.0
52 GN2 SYS 2	104.9	707.80	89.00	328.70	0.0	73.5	73.5	0.0	0.0	0.0
53 GN2 TK-5	0.0	791.00	85.00	318.00	0.0	0.0	0.0	0.0	0.0	0.0
54 NH3 TK-1	49.0	1350.00	66.00	442.00	0.0	0.0	0.0	0.0	0.0	0.0
55 NH3 TK-2	49.0	1370.00	67.00	443.00	0.0	0.0	0.0	0.0	0.0	0.0
56 APU N2H4 TK1	308.0	1400.00	-80.00	414.00	0.0	0.0	0.0	0.0	0.0	0.0
57 APU N2H4 TK2	308.0	1400.00	-85.00	381.00	0.0	0.0	0.0	0.0	0.0	0.0
58 APU N2H4 TK3	308.0	1400.00	80.00	414.00	0.0	0.0	0.0	0.0	0.0	0.0
59 HYD H2O TK-1	122.0	1373.00	0.00	481.00	0.0	0.0	0.0	0.0	0.0	0.0
60 HYD H2O TK-2	122.0	1393.00	0.00	483.00	0.0	0.0	0.0	0.0	0.0	0.0
61 HYD H2O TK-3	122.0	1353.00	0.00	479.00	0.0	0.0	0.0	0.0	0.0	0.0
62 POT H2O TK-A	55.7	518.00	0.00	294.00	0.0	0.0	0.0	0.0	0.0	0.0
63 POT H2O TK-B	165.0	534.00	0.00	293.00	0.0	0.0	0.0	0.0	0.0	0.0
64 POT H2O TK-C	157.0	545.00	0.90	313.00	0.0	0.0	0.0	0.0	0.0	0.0
65 POT H2O TK-D	157.0	528.00	0.00	311.00	0.0	0.0	0.0	0.0	0.0	0.0
66 POT H2O TK-E	0.0	470.00	-41.00	335.00	0.0	0.0	0.0	0.0	0.0	0.0
67 POT H2O TK-F	0.0	486.00	-41.00	335.00	0.0	0.0	0.0	0.0	0.0	0.0
68 WASTE H2O TK-1	20.0	512.00	0.00	310.00	0.0	0.0	0.0	0.0	0.0	0.0
69 MISC PRESS & H2O	709.5	979.87	-1.89	376.31	459.4	18742.0	18288.6	-42.4	16.5	19.7
100 (SUM LINES 51-69)	2914.4	1080.21	-5.56	382.19	4197.1	91961.5	91478.8	-1788.6	9812.9	56.9

DATA REFERENCE: FRRAF107      PREPARED BY: Charlotte Hannemann USH-433D  
 FLT. SOFTWARE: OI-29  
 ANALYSIS DATE: Fri Jan 31 07:02:04 2003

**Figure 3.6.3.1-3: Typical PROP-34 Non-Prop Build Up**

STS 107  
MCC TABLE

\*\*\*\* LIFTOFF \*\*\*\*

ITEMS	WT (LBM)	X (IN)	Y (IN)	Z (IN)	IXX (SF2)	IYY (SF2)	IZZ (SF2)	PXY (SF2)	PXZ (SF2)	PYZ (SF2)
101 CRYO O2 TK-1	673.8	778.50	-77.50	308.00	0.0	0.0	0.0	0.0	0.0	0.0
102 CRYO H2 TK-1	90.4	891.00	-76.00	306.10	0.0	0.0	0.0	0.0	0.0	0.0
103 CRYO O2 TK-2	673.8	721.50	77.50	308.00	0.0	0.0	0.0	0.0	0.0	0.0
104 CRYO H2 TK-2	90.4	835.00	76.00	307.60	0.0	0.0	0.0	0.0	0.0	0.0
105 CRYO O2 TK-3	673.8	1115.50	58.30	294.80	0.0	0.0	0.0	0.0	0.0	0.0
106 CRYO H2 TK-3	90.4	1009.80	-73.90	302.90	0.0	0.0	0.0	0.0	0.0	0.0
107 CRYO O2 TK-4	750.9	1065.20	-76.50	300.50	0.0	0.0	0.0	0.0	0.0	0.0
108 CRYO H2 TK-4	90.5	891.00	76.00	306.10	0.0	0.0	0.0	0.0	0.0	0.0
109 CRYO O2 TK-5	750.9	949.30	-70.00	306.20	0.0	0.0	0.0	0.0	0.0	0.0
110 CRYO H2 TK-5	90.5	949.30	69.00	302.80	0.0	0.0	0.0	0.0	0.0	0.0
111 CRYO O2 TK-6	777.9	1257.70	56.70	392.00	0.0	0.0	0.0	0.0	0.0	0.0
112 CRYO H2 TK-6	85.7	1262.50	28.50	350.00	0.0	0.0	0.0	0.0	0.0	0.0
113 CRYO O2 TK-7	777.9	1257.70	-56.70	392.00	0.0	0.0	0.0	0.0	0.0	0.0
114 CRYO H2 TK-7	85.7	1262.50	-28.50	350.00	0.0	0.0	0.0	0.0	0.0	0.0
115 CRYO O2 TK-8	777.9	1257.70	48.70	439.00	0.0	0.0	0.0	0.0	0.0	0.0
116 CRYO H2 TK-8	85.7	1262.50	0.00	399.40	0.0	0.0	0.0	0.0	0.0	0.0
117 CRYO O2 TK-9	777.9	1257.70	-48.70	439.00	0.0	0.0	0.0	0.0	0.0	0.0
118 CRYO H2 TK-9	85.7	1262.50	0.00	454.00	0.0	0.0	0.0	0.0	0.0	0.0
119 CRYO O2 TK-10	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
120 CRYO H2 TK-10	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
121 CRYO O2 TK-11	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
122 CRYO H2 TK-11	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
123 CRYO O2 TK-12	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
124 CRYO H2 TK-12	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
125 CRYO O2 TK-13	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
126 CRYO H2 TK-13	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
174 TOT CRYO	7429.4	1081.47	-8.65	354.41	11634.9	66887.6	67867.8	906.9	13828.5	645.3

DATA REFERENCE: FRRAF107      PREPARED BY: Charlotte Hannemann USH-433D  
 FLT. SOFTWARE: OI-29  
 ANALYSIS DATE: Fri Jan 31 07:02:04 2003

**Figure 3.6.3.1-4: Typical PROP-34 Cryogenics Build Up**

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STS 107										
MCC TABLE										
**** LIFTOFF ****										
ITEMS	WT (LBM)	X (IN)	Y (IN)	Z (IN)	IXX (SF2)	IYY (SF2)	IZZ (SF2)	PXY (SF2)	PXZ (SF2)	PYZ (SF2)
176 TOTAL ORBITER	260000.8	1098.00	-0.78	378.85	1021429.6	8179663.0	8441822.7	12623.1	311827.4	710.2
177 L/O TO OMS 2 FRCS PROP	-151.2	317.06	5.52	365.03	-17.8	0.0	-17.8	0.0	0.0	0.0
178 L/O TO OMS 2 ARCS PROP	-397.9	1339.99	-0.15	469.71	-689.2	-19.4	-664.4	0.1	0.3	-0.0
179 L/O TO OMS 2 OMS	-4000.0	1408.13	0.00	475.59	-8615.4	-475.2	-8197.6	0.0	-6.8	0.0
180 L/O TO OMS 2 AFT PROP	-4397.9	1401.96	-0.01	475.06	-9307.3	-860.0	-9224.8	-0.7	-37.8	-0.1
181 L/O TO OMS 2 NP	-268.4	1171.19	-15.31	350.94	-359.9	-5902.1	-5842.0	121.6	-701.9	12.1
182 OMS 2 TIG	255451.7	1093.23	-0.79	377.20	1003159.7	8061001.7	8323719.8	12557.8	283243.2	641.6
183 TVC WT POST D/O	243651.7	1076.77	-0.83	372.39	950801.3	7724662.2	7990317.2	11836.6	193125.6	430.9
184 DZEI	-210.5	1230.26	-9.78	401.35	-427.2	-3452.1	-3355.5	30.3	-557.5	-14.9
185 FDMP	-1573.2	317.00	5.54	365.00	-184.4	1.6	-183.1	-0.3	0.4	-0.1
186 FDMP ARCS USAGE	-33.0	1340.06	-0.10	469.63	-57.2	-0.1	-53.7	-0.1	0.2	-0.1
187 ENTRY INTERFACE	241835.0	1081.54	-0.87	372.40	949990.9	7522332.1	7787952.0	13580.2	190273.5	443.1
188 EI TO M3.5	-558.3	1347.15	-4.38	452.79	-961.2	-1110.1	-1677.9	48.9	-161.0	-44.4
189 AFT OMS CG	-1261.0	1456.84	0.00	475.33	-2332.0	-98.5	-2236.5	-0.0	-0.3	-0.0
190 FWD OMS CG	1261.0	1398.05	0.00	475.33	2332.0	332.1	2470.1	0.0	-20.4	0.0
191 TAEM INTERFACE	241276.7	1080.62	-0.86	372.22	948247.6	7501060.5	7766891.7	13728.0	185862.9	432.8
192 M3.5 TO LANDING	-117.1	1421.04	-7.10	439.18	-125.3	813.5	709.8	-18.5	151.2	-32.1
193 PRE-LANDING	241159.6	1080.45	-0.86	372.18	948007.9	7498830.2	7764670.0	13763.2	185437.7	411.3
194 GEAR UP	-7370.0	993.50	0.00	299.30	-25740.0	-118308.0	-143335.0	-9.0	2496.0	-0.0
195 GEAR DOWN	7370.0	1046.20	0.00	221.50	30580.0	128638.0	153848.0	10.0	-9199.0	-3.0
196 LANDING	241159.6	1082.07	-0.86	369.81	980222.5	7526238.5	7764886.7	13836.0	177063.3	302.4

DATA REFERENCE: FRRAF107                      PREPARED BY: Charlotte Hannemann USH-433D  
 FLT. SOFTWARE: OI-29  
 ANALYSIS DATE: Fri Jan 31 07:02:04 2003

**Figure 3.6.3.1-5: Typical PROP-34 CG-Sum Build Up**

The Abbreviated Report (see Figure 3.6.3.1-6) gives total vehicle mass property data for various mission events and ascent abort modes. The abort modes reflected in the Abbreviated Report are RTLS, TAL, and performance AOA cases. Other documented events are payload bay door opening, deploys, retrievals, maneuvers, payload bay door closing, a daily value, and events associated with deorbit and entry. The data are listed with an event number and title, along with post-event weight, Orbiter CG, and inertia tensor. These data are very useful for "quick look" reference when FDO is asked about Orbiter mass properties for some point in the mission profile. Consult the Abbreviated Report for the specified MET, or an event close to the desired time, and read the weight, CG, and inertia values listed in the report. Any known deviations from the report can be accounted for using techniques in Section 3.6.5.1 to provide a little more accuracy.

# FDO Console Handbook Section 3.6: Orbit Mass Properties

FLIGHT STS51		TABLE 5.1-5 ABBREVIATED REPORT					12-AUG-92	08:23:03		
WT (LB)	CENTER OF GRAVITY (IN)			MOMENTS OF INERTIA (SF2)			PRODUCTS OF INERTIA (SF2)			
	X	Y	Z	IXX	IYY	IZZ	PXY	PXZ	PYZ	
RTLS ET SEP 244668.2	ORBITER-RETURN TO LAUNCH SITE			POST ET SEP						
	1097.7	-0.9	374.6	920284.6	7476741.6	7757258.9	21918.1	192787.1	-575.2	
RTLS M=3 237786.2	ORBITER-RETURN TO LAUNCH SITE			M=3						
	1088.9	-1.0	373.7	902537.1	7317101.6	7601462.2	20333.4	175885.8	-87.7	
RTLS LAND 237639.2	ORBITER-RETURN TO LAUNCH SITE			LANDING						
	1090.4	-1.0	371.2	934707.5	7340320.5	7597160.5	20529.1	167773.7	-209.1	
TAL EI 240986.2	ORBITER-TRANS ATLANTIC ABORT			ENTRY INTERFACE						
	1093.4	-0.9	374.2	913717.1	7381936.0	7662949.4	20806.8	185286.0	-524.9	
TAL M=3 237232.2	ORBITER-TRANS ATLANTIC ABORT			MACH 3						
	1088.6	-1.0	373.5	900984.8	7289535.2	7573030.3	20519.1	172938.4	-71.6	
TAL LAND 237072.2	ORBITER-TRANS ATLANTIC ABORT			LANDING						
	1090.1	-1.0	371.1	933090.6	7312483.2	7568517.2	20698.0	164705.0	-196.8	
AOA PRDORB 240496.2	ORBITER-ABORT ONCE AROUND			PRE DEORBIT						
	1092.5	-1.0	374.9	914952.3	7379449.0	7660860.3	20789.8	195927.1	-3.5	
AOA EI 233973.2	ORBITER-ABORT ONCE AROUND			ENTRY INTERFACE						
	1093.4	-1.0	373.2	896956.4	7037372.8	7320170.5	22759.8	166083.7	-75.6	
AOA M=3 233123.2	ORBITER-ABORT ONCE AROUND			MACH 3						
	1092.3	-1.0	372.8	893225.9	7011666.0	7295573.1	22919.4	158997.0	-92.0	
AOA LAND 232955.2	ORBITER-ABORT ONCE AROUND			LANDING						
	1093.7	-1.0	370.3	925116.6	7034061.3	7290709.1	23133.5	151266.5	-213.4	
E-1 LOADED 4542996.2	SHUTTLE-PRE LAUNCH									
	1409.6	0.2	419.0	43798129.7	325359865.6	355567458.8	24048.1	8462729.3	17546.0	
E-1A LOADED 260080.2	ORBITER-PRE LAUNCH									
	1116.3	-0.8	380.0	980566.4	7854829.7	8133090.8	22799.3	286186.2	-363.7	
E-2 ST M EN 4537092.2	SHUTTLE-START MAIN ENGINES									
	1410.9	0.2	419.0	43797670.8	324138717.8	354346769.8	23842.0	8439656.4	17541.9	

**Figure 3.6.3.1-6: Abbreviated Report**

The Fluid Budget (see Figure 3.6.3.1-7) contains a consumables listing correlated with events in the Abbreviated Report. To determine nominal usage of a particular consumable such as cryogenics, look under the column listing this consumable and compute the difference in weight over the period of interest. This is helpful when trying to account for deviations in the usage profile.

**NOTE:** the fluid budget doesn't always give a tank-by-tank breakdown of a particular consumable. It only provides a total for all tanks. For example, CRYO LO2 is for all cryo tanks; not individual tanks.

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FLIGHT STS51		TABLE 5.1-4 ORBITER FLUID BUDGET (CONTINUED)											27-OCT-92		08:32:44		
EVENT (NUMBER)	MISC	OMS FU	OMS OX	RCS FWD	RCS AFT	POT H2O	WST H2O	HYD H2O	APU COOL	GN2	CRYO LO2	CRYO LH2	NH3	APU N2H4	TOTAL OMS	TOTAL NPC	
E-18	DAY 4	447.2	3587.0	5991.0	1777.0	4260.0	562.0	9.0	345.0	9.0	243.0	2122.0	245.0	98.0	798.0	9578.0	4878.2
E-19	DAY 5	447.2	3411.0	5782.0	1731.0	4260.0	562.0	9.0	345.0	9.0	237.0	1880.0	214.0	98.0	798.0	9113.0	4599.2
E-20	DAY 6	447.2	3378.0	5647.0	1690.0	4260.0	562.0	9.0	345.0	9.0	232.0	1636.0	185.0	98.0	798.0	9025.0	4321.2
E-21	ORFEUS	447.2	3309.0	5534.0	1343.0	3431.0	562.0	9.0	345.0	9.0	227.0	1393.0	156.0	98.0	798.0	8843.0	4044.2
E-22	DAY B	447.2	3309.0	5534.0	1307.0	3305.0	562.0	9.0	345.0	9.0	221.0	1149.0	126.0	98.0	784.0	8843.0	3750.2
E-23	PLBD C	431.2	3309.0	5534.0	1282.0	3225.0	518.0	94.0	345.0	9.0	216.0	986.0	97.0	98.0	784.0	8843.0	3498.2
E-24	DEORBI	431.2	3309.0	5534.0	1228.0	3070.0	432.0	96.0	345.0	9.0	216.0	872.0	92.0	98.0	784.0	8843.0	3375.2
E-24A	DEORB	431.2	603.0	1068.0	1228.0	3070.0	432.0	96.0	345.0	9.0	216.0	872.0	92.0	98.0	784.0	1671.0	3375.2
E-25	EI	369.2	603.0	1068.0	375.0	2912.0	417.0	96.0	318.0	9.0	216.0	866.0	92.0	98.0	853.0	1671.0	3134.2
E-25A	EI+3M	369.2	603.0	1068.0	375.0	2834.0	416.0	96.0	314.0	9.0	216.0	866.0	92.0	98.0	840.0	1671.0	3116.2
E-26	MACH 3	369.2	603.0	1068.0	375.0	2281.0	405.0	97.0	278.0	9.0	216.0	862.0	92.0	98.0	549.0	1671.0	2975.2
E-27	LANDIN	369.2	603.0	1068.0	375.0	2212.0	408.0	97.0	256.0	9.0	216.0	860.0	92.0	98.0	490.0	1671.0	2895.2
E-28	FERRY	439.2	603.0	1068.0	375.0	2212.0	428.0	107.0	233.0	9.0	216.0	100.0	34.0	98.0	270.0	1671.0	1934.2
***** NON-DEPLOYABLE CASES *****																	
E-29	EI	369.2	608.0	1076.0	375.0	3492.0	417.0	96.0	318.0	9.0	216.0	866.0	92.0	98.0	853.0	1684.0	3134.2
E-29A	EI +	369.2	608.0	1076.0	375.0	3414.0	416.0	96.0	314.0	9.0	216.0	866.0	92.0	98.0	840.0	1684.0	3116.2
E-30	MACH	369.2	608.0	1076.0	375.0	2881.0	405.0	97.0	278.0	9.0	216.0	862.0	92.0	98.0	549.0	1684.0	2975.2

Figure 3.6.3.1-7: Fluid Budget

## 3.6.3.2 OMS Ballast Baseline Quantity Worksheet

The OMS Ballast Baseline Quantity Worksheet (Figure 3.6.3.2-1) is obtained from the lead PROP Officer and includes the minimum OMS quantities, referred to as “ballast baseline qty”, for the left and right fuel and oxidizer tanks. These minimum quantities are equivalent to a 1-inch XCG uncertainty, an RCS entry dispersion OMS equivalent (calculated by taking the difference between a 2-sigma entry and a mean entry), the OMS dispersion, and tank-trapped propellant. Minimum quantities are usually less than 5% and are used in PMP’s ballast computations. They are entered in the PMP ballast dialog box along with ARCS and FRCS dump quantities and the XCG limit. If the OMS Ballast Baseline Worksheet is not available in the data book, the on-console PROP officer may have a copy. Default PMP values can also be used until the worksheet is available.

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STS: <input type="text" value="86"/>	CYCLE: <input type="text" value="FLT"/>	26-Aug-97
<b>OMS BALLAST BASELINE QUANTITY WORKSHEET</b>		
<b>INPUTS:</b>		
ORBITER NUMBER	<input type="text" value="104"/>	ORBITER WT AT TD <input type="text" value="215995"/>
	LEFT	RIGHT
	OX	FUEL
OMS LOADED GAGED QUANTITIES	<input type="text" value="80.71"/>	<input type="text" value="80.10"/>
	<input type="text" value="80.71"/>	<input type="text" value="80.10"/>
OMS LOADING UNCERTAINTY: "%" (FR 6-90)	<input type="text" value="40"/>	<input type="text" value="24"/>
	<input type="text" value="40"/>	<input type="text" value="24"/>
<b>CALCULATIONS:</b>		
OMS USABLE PROPELLANT	<input type="text" value="6501.2"/>	<input type="text" value="3921.7"/>
	<input type="text" value="6501.2"/>	<input type="text" value="3921.7"/>
OMS FLOWRATE DISPERSION: "%"	<input type="text" value="125.8"/>	<input type="text" value="76.2"/>
	<input type="text" value="125.8"/>	<input type="text" value="76.2"/>
OMS DISPERSIONS (RSS a & b)	<input type="text" value="132.0"/>	<input type="text" value="79.9"/>
	<input type="text" value="132.0"/>	<input type="text" value="79.9"/>
<b>ZERO USABLE = TANK TRAPPED + DISPERSIONS</b>		
	<input type="text" value="1067.8"/>	<input type="text" value="423.8"/>
<b>ONE INCH CG UNCERTAINTY = .00322 * ORBITER WEIGHT AT TOUCHDOWN</b>		
	<input type="text" value="695.5"/>	<input type="text" value="215995"/>
<b>OMS EQUIVALENT OF 3 SIGMA RCS ENTRY DISPERSIONS =</b>		
	<input type="text" value="620.5"/>	
<b>RSS QTY = (ONE INCH<sup>2</sup> + ENTRY DISP<sup>2</sup> + (a<sub>lox</sub><sup>2</sup> + a<sub>lf</sub><sup>2</sup> + a<sub>rox</sub><sup>2</sup> + a<sub>rf</sub><sup>2</sup>))<sup>0.5</sup></b>		
	<input type="text" value="955.0"/>	<input type="text" value="432.66"/>
<b>BASELINE QTY = ONE INCH CG + ENTRY DISP + ZERO USABLE - RSS QUANTITY</b>		
	<input type="text" value="1428.8"/>	<input type="text" value="955.0"/>
<b>FU RESIDUAL = (BASELINE QTY - TANK TRAPPED) * 2.65 * 2</b>		
	<input type="text" value="148.1"/>	<input type="text" value="1428.8"/>
<b>OX RESIDUAL = FU RESIDUAL * 1.65</b>		
	<input type="text" value="244.3"/>	<input type="text" value="148.1"/>
<b>OUTPUT</b>		
	LEFT	RIGHT
	OX	FUEL
RESIDUAL	<input type="text" value="244.3"/>	<input type="text" value="148.1"/>
	<input type="text" value="244.3"/>	<input type="text" value="148.1"/>
TANK TRAPPED	<input type="text" value="212.0"/>	<input type="text" value="110.0"/>
	<input type="text" value="212.0"/>	<input type="text" value="110.0"/>
BALLAST BASELINE QTY (LBS)	<input type="text" value="456.3"/>	<input type="text" value="258.1"/>
	<input type="text" value="456.3"/>	<input type="text" value="258.1"/>
BALLAST BASELINE QTY (%)	<input type="text" value="5.67"/>	<input type="text" value="5.28"/>
	<input type="text" value="5.67"/>	<input type="text" value="5.28"/>
		<b>FLIGHT DESIGN POUNDS</b>
		<input type="text" value="1582.8"/>
		$\Delta$ ARLS = 995.7 lbs

Figure 3.6.3.2-1: OMS Ballast Baseline Quantity Worksheet

## 3.6.4 Mass Property Related Flight Rules

When planning for deorbit and entry, care should be taken to assure Orbiter landing weight and CG limits are not exceeded. Flight Rule A4-159 documents inclination and flight phase dependent limits. Flight Rule A4-153 defines the contingency and nominal CG envelopes, including a 1 inch uncertainty for XCG and a 0.5 inch uncertainty for YCG. The contingency box represents the loss of control CG boundary for OMS tank fail cases. Vehicle control beyond the nominal CG envelope, yet within the contingency CG boundary, assumes all four yaw jets are available.

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**WARNING:** due to elevon saturation, there must be no ARCS jet failures during an entry with Orbiter CG in the contingency envelope. A jet failure under these conditions may result in loss of control.

CG boundaries as they exist today have evolved since prior to STS-1 and are a result of many analysis iterations performed by JSC, Rockwell International, and Boeing aerodynamics communities, as well as numerous Entry Flight Techniques discussions. The shape and dimensions of CG boundaries have changed many times as a function of assumptions made and Orbiter aerodynamic data collected from past flights. Boundaries are expected to expand as more is learned about Orbiter capabilities.

### **3.6.5 Manual Calculations and Reference Data**

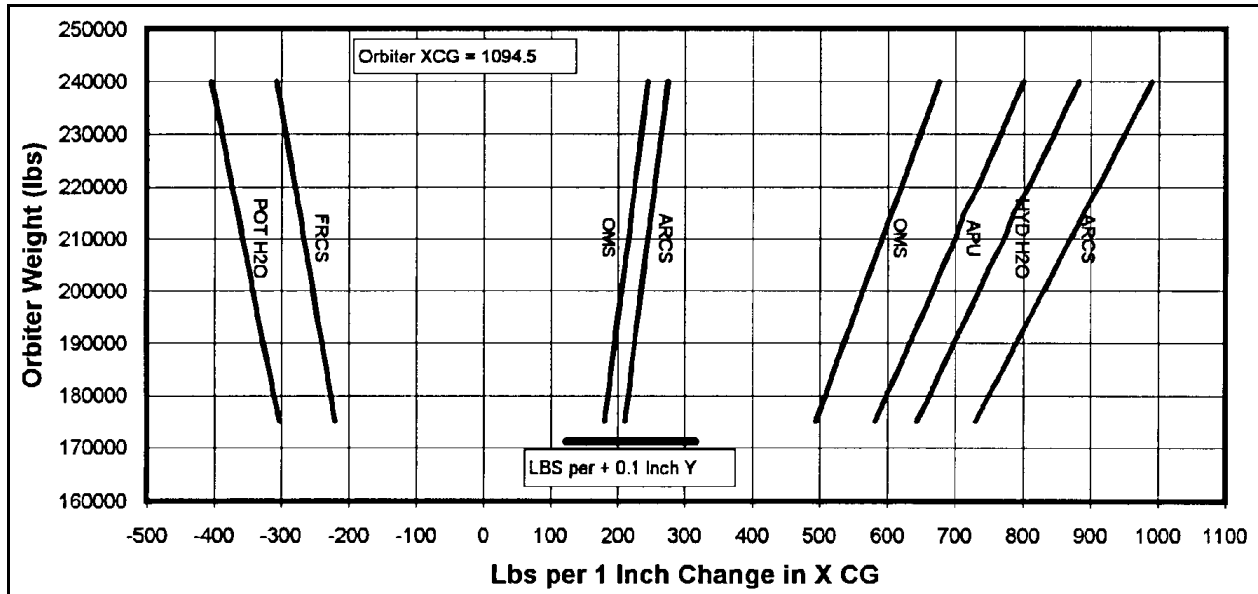
The following subsections explain how to provide information on Orbiter weight and CG status at any time in the mission profile without having to rely solely on a mass properties processor. Specifically, this section describes use of PROP-34's Abbreviated Report, reference data, trims calculations, and ways of quickly evaluating changes to mass properties.

#### **3.6.5.1 Back of the Envelope CGs**

This section explains how to quickly calculate Orbiter CGs using the Abbreviated Report and "rule of thumb" conversion numbers. Changes to total Orbiter CG caused by consumables usage are easily estimated in this way. The same methods may be applied both for nominal and off-nominal cases.

Figure 3.6.5.1-1 represents effects of consumables on the Orbiter CG. The abscissa is separated into data for XCG change and for YCG change. The ordinate represents Orbiter weight in pounds. To use the graph, locate the Orbiter weight and read across to the line of the desired consumable. Directly below, read the abscissa value to obtain the effect on the X and/or YCG change due to off-nominal usage. FDO can determine the change in total vehicle CG by dividing the amount of change in the consumable by the conversion number obtained from the graph. The resulting value is then added to the initial CG component to yield its final value. Note the XCG is in units of lbs/in, while the YCG is in units of lbs/0.1 in.

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**Figure 3.6.5.1-1: Effects of Consumables on Orbiter CG**

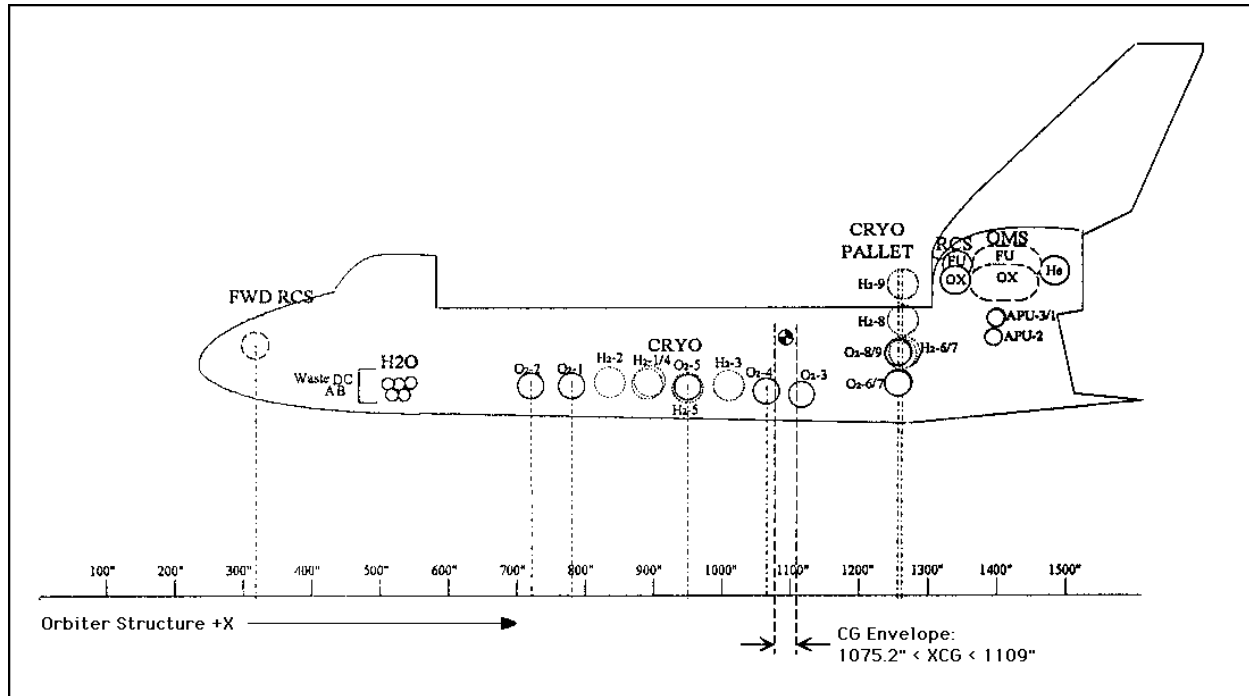
Figure 3.6.5.1-2 summarizes data acquired from the graph. Numbers are in lbs/in for XCGs and lbs/0.1 in for YCGs. To use the chart, locate the conversion number corresponding to the Orbiter weight and divide an off-nominal change in the consumable by this conversion number. The resulting value is the change in total Orbiter X and/or YCG. This number is then added to the planned CG to yield the final CG location. Note the distinct XCG shifts per unit-OMS-weight for use on orbit and during entry. The longitudinal CG during entry is less sensitive to OMS weight because aerodynamic forces cause propellants to settle forward in the OMS tanks and nearer the Orbiter CG. On orbit, values assume OMS propellant has settled aft due to ullage acceleration.

Weight (lbs)	XCG	XCG	XCG	XCG	XCG	XCG	XCG	YCG	YCG
	FRCS	OMS (ORB)	OMS (ENT)	ARCS	POT H2O	APU	HYD H2O	OMS	ARCS
240000	-307	676	805	990	-404	800	882	245	275
235000	-300	662	790	970	-396	783	863	240	270
230000	-293	648	775	950	-388	767	845	235	265
225000	-287	634	760	930	-381	750	827	230	260
220000	-280	620	745	910	-373	733	808	225	255
215000	-273	606	730	890	-365	713	786	220	250
210000	-267	592	715	870	-358	700	772	215	245
205000	-260	578	700	850	-350	683	753	210	240
200000	-253	564	685	830	-342	667	735	205	235
195000	-247	550	670	810	-335	650	717	200	230
190000	-240	536	655	790	-327	633	698	195	225
185000	-233	522	640	770	-319	616	680	190	220
180000	-227	508	625	750	-311	599	662	185	215
175000	-220	494	610	730	-303	582	644	180	210

**Figure 3.6.5.1-2: Effects of Consumables on Orbiter CG**

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Figure 3.6.5.1-3 illustrates the location of consumable tanks in the Orbiter structure frame's X-Z plane. Also included is the Orbiter's CG envelope.



**Figure 3.6.5.1-3: Orbiter Consumable Tanks**

Certain system problems, such as an OMS tank failure or FRCS retention/dump, can arise during an off-nominal situation and affect Orbiter mass properties. FDO will be expected to provide mass property updates reflecting the scenario. This can be done manually using the following procedure, along with the Abbreviated Report. The procedure reviews mass properties data sources and steps through associated calculations.

- 1) Use the Abbreviated Report to obtain the planned X and YCG components for the given case (TAL, RTLS, EOM).
- 2) When the "failed" amount of consumable is available, usually from PROP, EGIL, or EECOM, use the rules of thumb conversion numbers to find out how much the CG will change from the Abbreviated Report listing.
- 3) Add the change to the planned X and/or YCG in the Abbreviated Report. This will yield the final CG resulting from the consumable failure.

### EXAMPLE: TAL Case With Left OMS Tank Failed.

- 1) From the Abbreviated Report (FLT 26, CY 2), the weight and CG for nominal consumables usage to M3 are listed as:

Weight	XCG	YCG	ZCG
231006.9	1098.5	0.4	375.1.

- 2) PROP says 1500 lbs of OMS remain in the left tank. Looking at the rule of thumb conversion numbers for an Orbiter weight of 230000 lbs gives:
  - 2a) 775 lb/in of OMS for XCG change, and
  - 2b) 235 lb/0.1 in of OMS for YCG change.



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- 3) Using this information, we obtain the amount of CG change for the XCG and YCG as:
  - 3a)  $1500/775 = 1.9$  inches aft XCG change, and
  - 3b)  $1500/2350 = -0.63$  inch left YCG change (Left OMS is -Y).
- 4) Adding these resultant differences to the CGs from the Abbreviated Report yields:
  - 3c)  $X = 1098.5 + 1.9 = 1100.4$  inches at Mach 3 for TAL, and
  - 3d)  $Y = 0.4 - 0.63 = -0.23$  inches at Mach 3 for TAL.
- 5) Verify all resultant CGs are within the CG envelope (see All Flights Rule A4-153).

### 3.6.5.2 Unit and Prop Usage Conversions

The following miscellaneous information is useful for quick "back of the envelope" estimates during MCC operations.

#### Unit Conversions

- OMS:** 129.51 lbs/percent  
OX/FU Mixture Ratio = 1.66
- RCS:** 22.0 lbs/percent  
OX/FU Mixture Ratio = 1.6  
OX: 13.5 lbs/percent  
FU: 8.5 lbs/percent

#### OMS Remaining % Versus lbs

%	lbs
5 .....	1448
6 .....	1708
7 .....	1966
8 .....	2226
9 .....	2484
10.....	2744
11.....	3004
12.....	3262
13.....	3522
14.....	3780
15.....	4040
16.....	4298
17.....	4558
18.....	4816
19.....	5076
20.....	5336
21.....	5594
22.....	5854

NOTE: foregoing numbers include line-trapped quantities.

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### Propellant Usage Conversion (lbs/fps)

Orbiter Weight (lbs)	OMS	ARCS
180000.....	17.9.....	20.8
200000.....	19.8.....	23.1
220000.....	21.8.....	25.4
240000.....	23.8.....	27.7

### 3.6.5.3 Sample OMS Engine Data

Propellant mixture ratio for the OMS engines is typically 1.66 and will vary slightly with the specific engine being used, as shown in Figure 3.6.5.3-1 below. These data are valid as of December 11, 2002 and are for illustrative purposes only. The actual mixture ratio can be obtained from PROP, the official source of Figure 3.6.5.3-1 data. Current data can be found on PROP's web page: <http://mod.jsc.nasa.gov/df/df63/prop.htm> under the OMS Engine Assignments & Performance Table (.xls) header.

Vehicle	OMS Pod Number	Engine S/N	Thrust (lbf)	Total Flow Rate (lbm/sec)	I <sub>SP</sub> (sec)	Mixture Ratio Ox/Fu
OV-103	LP01	107	6082.0	19.34	314.5	1.649
	RP03	106	6120.0	19.29	317.3	1.661
OV-104	LP03	111	6087.0	19.33	314.9	1.641
	RP04	117	6116.0	19.35	316.1	1.673
OV-105	LP04	105	6093.0	19.25	316.5	1.652
	RP01	109	6070.0	19.23	315.7	1.649

Figure 3.6.5.3-1: OMS Engine Data

### 3.6.5.4 OMS Engine Trims

During a mission or simulation, FDO may be asked to provide OMS trims for some event. Sufficient time to obtain predicted consumable quantities, permitting the Orbiter CG to be accurately estimated (see Section 3.6.7.3), may not be available. Using the Abbreviated Report and a couple of equations, however, these values can be calculated quickly.

**CAUTION:** to best address Flight Software limitations, the single OMS pitch trim provided to DMT displays and Command applications is the *average* of LOMS pitch and ROMS pitch. It's therefore inadvisable to enter a parked OMS TVC trim into the ECT until that engine is to be burned. If only the parked engine is to be burned, its trims should be entered in the ECT for both engines. If the parked engine is to be burned with the other OMS, both sets of trims should be entered to the ECT such that averaged pitch trim drives burn attitude.

The first trim calculation step is to locate the desired event in the Abbreviated Report (or event closest to the desired MET) to obtain the corresponding weight and CG. Next, use these values in the following equations to calculate engine trims.

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$$M = \sqrt{(1518.0 - XCG)^2 + (492.0 - ZCG)^2} \text{ inches}$$

$$\text{Pitch} = 15.817 - \tan^{-1} \left[ \frac{492.0 - ZCG}{1518.0 - XCG} \right] \text{ deg}$$

$$\text{Left Yaw} = \tan^{-1} \left[ \frac{88.0 + YCG}{M} \right] - 6.5 \text{ deg}$$

$$\text{Right Yaw} = 6.5 - \tan^{-1} \left[ \frac{88.0 - YCG}{M} \right] \text{ deg}$$

Alternately, since GNC has software that also computes the required trims, FDO or TRAJ can simply look up the XCG, YCG, and ZCG in the abbreviated report for the event time desired (usually pre-deorbit) and give them to GNC.

Manually override TSA and TrS trims using PMP with the following steps.

- 1) Bring up PMP with current mass properties data.
- 2) Ensure you have run OMS Depletion so that current trim values are computed.
- 3) Bring up the Sync TSU Menu (under the Data pulldown).
- 4) Enter parked trim values (pitch and yaw) for the engine in question in the bottom of the Sync TSU Menu.

**NOTE:** for the engine that isn't parked, use PMP-generated values and ensure you have read the previous CAUTION paragraph in this section.

### 3.6.5.5 Ballast Requirement and Standard Ops

In some missions (typically with Spacelab payloads, or ISS rendezvous flights with large trusses), entry XCG is forward of the limit defined in All Flights Rule A4-153. Therefore, it becomes necessary to reserve some aft propellant (either RCS or OMS) as ballast in order to keep the XCG from moving too far forward during deorbit and entry. This propellant cannot be used for anything but ballast, and no  $\Delta V$  computations should be conducted using the ballast as available propellant.

To compute the amount of ballast needed, minimum amounts of aft propellant remaining post-deorbit must be assumed. This pushes the CG as far forward as possible so ballast will cover the worst-case propellant remaining situation. Note this does not include any FRCS limitations on dumps. If the FRCS cannot be dumped, ballast computations must consider this. The amount of minimum OMS propellant has been increasing for quite some time and can be obtained from the lead PROP for the particular flight. Minimum OMS quantities should not include line-tapped quantities as these are already accounted for in line 15 of the ORBITER BUILD-UP. The ARCS quantities should be the amount of ARCS to be used from deorbit to Mach 3. This value is 510 lbs, assuming no forward dump. To compute the amount of AFT RCS used to support a forward dump, multiply the amount of forward to be dumped by 0.020100595. This number is based on a curve fit of data

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provided by Shawn Holcomb/Prop Flight Design in December of 2002. The minimum ARCS quantity is therefore a summation of all ARCS propellant to be used. It is accounted for in the CG SUM display in two different lines (FDMP AFT USAGE and EI to M3). Consequently, there is no ARCS propellant left at Mach 3.

**NOTE:** TRAJ no longer needs to keep track of the ballasted EI to M3 CGs, as was done with the previous PMP versions. SLOSH is now modeled explicitly in the CG Sum Page. In older PMP versions, the EI to M3 line included a static slosh estimate.

In the early days of the Space Shuttle Program, minimum quantities were set to be 0.0 gauge. However, it was learned we were protecting ourselves from impossible situations, requiring more propellant be loaded pre-launch and reducing our ascent performance margin and orbit maneuver capability. Recently, a more realistic approach has been determined that requires less protection and thus less ballast.

The amount of ballast required is determined using PMP as described in Section 3.6.7.3. Cryogenic and non-prop consumable quantities are obtained for the deorbit opportunity of interest. Minimum OMS quantities, aft RCS to be used during entry, and the FRCS dump quantity are computed by PMP, but the user can overwrite these as well as the XCG limit. PMP calculates the Pre-Landing XCG assuming the OMS is depleted to minimum quantities, the entered amount of FRCS is dumped, and the entered ARCS is used during entry. If the XCG is too far forward, PMP iterates on the amount of ballast required (OMS or ARCS as selected by the user) so that the Pre-Landing XCG is at the limit.

### 3.6.5.5.1 Manual Ballast Calculation

A manual method to better understand ballast computations may also be performed using PMP but this is recommended only as an academic exercise. The ORBITER BUILD-UP can be configured with the minimum amount of aft propellant. This configuration will give the worst-case post-deorbit burn weight and CG. Run OMS Depletion with zero delta OMS. This will transfer Line 25 of the ORBITER BUILD-UP to the CG SUM page. The amount of ballast (if required) in the next iteration can be determined by observing the XCG at Pre-Landing. The difference between the obtained XCG and the CG limit is then multiplied by the conversion factor obtained in Figure 3.6.5.1-2 and added back in to the OMS OX and FU (lines 5-8). This procedure is enumerated in the steps below using data from Figure 3.6.5.5-1.

- 1) Obtain OMS minimum propellant quantities (From OMS Ballast Baseline Quantity Worksheet).

OMS OX (each side) = 473.0 lbs  
OMS FU (each side) = 268.2 lbs  
FRCS DUMP = 1705 lbs  
ARCS = 544.3 lbs

The ARCS quantity is computed as follows:  $510 \text{ lbs} + (\text{FRCS Dump}) * 0.020100595$ .

The FRCS dump is computed by finding the most constraining quantity (OX or FU) and then finding how much FRCS can be dumped. For example, if FU is the limiting quantity,  $\text{FRCS} = \text{FU} + \text{FU} * 1.6$ . If OX is the limiting quantity,

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FRCS = OX/1.6 + OX. In our example, OX is the limiting quantity (FU = 1049.5/1.6=655.94 which is less than 657.1 (FU actual). Since 1049.5 is the OX available from the FRCS, the FRCS dump = OX/1.6 + OX = 1049.5/1.6 + 1049.5 = 1705.4.

- 2) Configure the CARGO BUILD-UP, CRYOGENICS, and NON-PROP displays for the future deorbit attempt. If predicted values cannot be obtained, current values can be used.
- 3) Manually input the minimum OMS propellant quantities directly into lines 5-8 (473.0 for OX and 268.2 for FU).
- 4) Manually input the minimum ARCS propellant quantities. Some computations need to be performed here. An assumption must be made that ARCS is evenly divided into the left and right ARCS. With this assumption in mind, the total amount of left ARCS is 272.2 lbs/side (544.3 lbs/2 sides). With an oxidizer to fuel ratio of 1.6, the amount of ARCS fuel on each side is 104.7 lbs (272.2 lbs / (1 + 1.6)). Therefore, the amount of oxidizer on each side is 167.5 lbs (272.2-104.7).
- 5) No changes to predicted FRCS values are made. Figure 3.6.5.5-1 illustrates the ORBITER BUILD-UP display after all inputs are made. Line 25 now represents the worst case Orbiter weight and CG after the deorbit burn.

	ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN
1	INERT ORB (OP)	181947.0	1093.70	0.20	364.80
2	TOTAL CARGO	39513.0	984.72	-0.51	394.58
3	NON-PROP	6282.9	973.34	-2.20	387.47
4	CRYOGENICS	0.0	925.33	-14.34	303.66
5	OMS FU R	268.2	1455.43	72.71	501.95
6	OMS OX R	473.0	1455.16	110.90	462.40
7	OMS FU L	268.2	1455.43	-72.71	510.95
8	OMS OX L	473.0	1455.16	-110.90	462.40
9	RCS FU FWD	657.1	317.0	-24.00	365.00
10	RCS OX FWD	1049.5	317.0	24.00	365.00
11	RCS FU AFT R	104.7	1340.0	67.00	490.00
12	RCS OX AFT R	167.5	1340.0	99.00	457.00
13	RCS FU AFT L	104.7	1340.0	-67.00	490.00
14	RCS OX AFT L	167.5	1340.0	-99.00	457.00
15	OMS PROP MISC	153.0	1468.70	0.00	474.90
16	RCS UNUSABLE	912.0	960.60	2.00	431.00
17		0.0	0.00	0.00	0.00
18		0.0	0.00	0.00	0.00
19		0.0	0.00	0.00	0.00
20		0.0	0.00	0.00	0.00
25	<b>TOTAL ORBITER</b>	<b>232541.3</b>	<b>1068.84</b>	<b>0.06</b>	<b>371.77</b>

**Figure 3.6.5.5-1: Orbiter Build-Up During Ballast Computations**

- 6) Select OMS Depletion from the Process menu and use a  $\Delta$ OMS of 0 lbs. This will cause line 176 in the CG SUM display to be the same as line 25 (i.e. worst case post-burn weight and CG). Set FRCS Dump to value computed in step 1.
- 7) Insure the FRCS dump weight (line 178) reflects a full dump or whatever amount is coordinated with PROP.

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- 8) Verify CG SUM page has correct D/O to EI, EI to M3, and M3 to Landing data. (See Figure 3.6.5.5-2)

	ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN
176	TVC WT POST D/O	232541.3	1068.84	0.06	371.77
177	D/O to EI CONSUM	-247.2	1254.63	1.50	437.40
178	FRCS DUMP	-1705.0	317.00	5.50	365.00
179	FDUMP AFT USAGE	-34.3	1340.00	0.00	490.00
<b>180</b>	<b>ENTRY</b>	<b>237272.0</b>	<b>1080.90</b>	<b>-1.03</b>	<b>373.39</b>
	<b>INTERFACE</b>				
181	EI TO MACH 3	-475.8	1310.42	-4.60	450.30
182	AFT OMS CG	-1482.4	1455.26	-0.00	477.27
183	FWD OMS CG	1482.4	1384.81	-0.00	477.27
<b>184</b>	<b>TAEM INTERFACE</b>	<b>230079.1</b>	<b>1073.21</b>	<b>0.03</b>	<b>371.56</b>
185	M3 TO LANDING	-80.7	1386.79	-19.81	423.93
<b>186</b>	<b>PRE-LANDING</b>	<b>229998.4</b>	<b>1073.10</b>	<b>0.03</b>	<b>371.55</b>
187	GEAR UP	-7370.0	993.50	0.00	299.30
188	GEAR DOWN	7370.0	1046.20	0.00	221.50
<b>189</b>	<b>LANDING</b>	<b>229998.4</b>	<b>1074.49</b>	<b>0.03</b>	<b>369.05</b>
190	INERT ORB (GDN)	181947.0	1095.80	-0.10	365.30
191	INERT ORB (CL)	181947.0	1093.70	-0.10	368.50
192	INERT ORB (OP)	181947.0	1093.70	0.20	364.80
193					
194	OGD SLOPE SWPT	220000.0			
195					
196					
197					
198					
22	ENTRY INTERFACE	230554.8	1074.16	0.02	371.73
23	TAEM INTERFACE	230079.1	1073.21	0.03	371.56
24	LANDING	229998.4	1074.79	0.03	369.05

**Figure 3.6.5.5-2: CG Sum Display During First Ballast Iteration**

Note the XCG value of 1073.10 for Pre-Landing (line 186). The value is ahead of the 1075.2 inches forward limit. Therefore, ballast is required for this particular deorbit opportunity.

- 9) FDO needs to make an educated guess of the ballast requirements for the second time around. A good guess uses Figure 3.6.5.1-2 for an estimate of how much OMS or ARCS propellant changes the XCG by 1 inch. In this case, approximately 730 lbs of OMS ballast (215,000 lbs Orbiter) is required to move the XCG 1 inch. In the example, the XCG is located at 1073.10 inches (2.1 inches ahead of the forward CG limit). Therefore, a first guess at the total amount of OMS propellant required for ballast is 1533 lbs.
- 10) The iteration process now begins. Assuming the OMS propellant is equally distributed in both sides, the amount of OMS FU on each side is 288.2 lbs (1533/2/2.66), and the amount of OX on each side is 478.3 lbs (1533/2 – 288.2) in addition to the minimal quantities already there. Therefore, the new

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minimum OMS OX quantities are  $473 + 478.3 = 951.3$  lbs, and the new minimum OMS FU quantities are  $268.2 + 288.2 = 556.4$  lbs. Input these values back into the ORBITER BUILD-UP display.

- 11) Iterate on steps 6 through 9 to refine the estimate of OMS ballast requirements. Figure 3.6.5.5-3 shows how the iteration results converge.

OMS Ballast (lbs)	XCG at Pre-Landing
0.0	1073.10
1533	1075.21
1526	1075.20

**Figure 3.6.5.5-3: Ballast Convergence**

The final amount of ballast passed to PROP is therefore 1526 lbs. As stated earlier, no  $\Delta V$  can be achieved from this ballast. Further PROP TO FDO documents from PROP will relate the ballast, and  $\Delta V$ s will not include any of this propellant.

### 3.6.5.6 Typical CG SUM Display Usable Numbers

Usable numbers on the CG SUM display represent the net effect of various consumables used during a particular phase in the entry profile. The following usable numbers are collective data from previous flights provided for comparison purposes only. Each flight has its own unique differences from previous flights. The purpose here is to illustrate a range of values to expect for usable numbers. Any large deviation from these values should be coordinated with the Shuttle Data Office and/or the Flight Design Manager.

Deorbit to EI Usables				
Flight	Weight	XCG	YCG	ZCG
STS-111	-248.7	1251.60	-4.10	436.00
STS-113	-247.2	1254.63	1.50	437.40
STS-107	-261.0	1255.25	-9.56	431.25

EI to Mach 3 Usables				
Flight	Weight	XCG	YCG	ZCG
STS-111	-477.0	1308.90	-3.70	451.00
STS-113	-475.7	1310.42	-4.60	450.30
STS-107	-478.0	1309.22	-12.91	428.15

Mach 3 to Landing Usables				
Flight	Weight	XCG	YCG	ZCG
STS-111	-81.2	1396.00	-19.50	424.00
STS-113	-80.7	1386.79	-19.81	423.93
STS-107	-81.0	1395.75	-19.48	422.02

### 3.6.5.7 Miscellaneous Pressurants, GN2, and Trapped Propellant

Miscellaneous pressurants are tracked in the Non-Prop page on Line 69. This line is composed of the following items.

- 1) Cabin Air & Air Lock (A/L) Atmosphere

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- 2) Spacelab (S/L) Condensate Tank
- 3) S/L Nitrogen Tank
- 4) S/L Module and A/L Atmosphere
- 5) S/L Tunnel
- 6) APU Cool Water Tanks 1 & 2
- 7) Gas Generator Water Tank
- 8) Spacehab Module & Tunnel Atmosphere
- 9) Waster Water Tank 2
- 10) Emergency Oxygen Tank
- 11) Pressure
- 12) Helium Tank Mid
- 13) Helium Tank AFT
- 14) Inert MPS
- 15) Misc Fluids 172
- 16) OMS Pressurants
- 17) MISC Pressurants
- 18) RCS Total Helium

The Weights and CGs for these items can be found in Vol II of the SODB at URL [https://opo.jsc.nasa.gov/sodw/Main\\_public.cfm](https://opo.jsc.nasa.gov/sodw/Main_public.cfm). Example weights and CGs follow.

Cabin Air	185.00	504.90	0.00	382.20
S/L Cond	0.00	963.20	-5.50	332.30
S/L Nitro	0.00	893.90	46.90	449.20
S/L Module & Atm	0.00	1023.80	0.00	400.00
S/L Tunnel	0.00	773.40	0.00	376.00
APU Cool Water Tk1	0.00	1325.00	23.00	377.00
APU Cool Water Tk2	0.00	1325.00	23.00	403.00
Gas Gen H2O Tk	9.00	1316.00	17.30	389.00
S/H Module & Tunnel	25.00	638.20	0.00	370.00
Waste Water 2 Tk	0.00	528.00	0.00	311.00
Emergency O2 Tk	0.00	791.00	85.00	318.00
Pressure	0.00	0.00	0.00	0.00
He Tk Mid	162.00	1145.60	-7.90	305.80
He Tk Aft	47.00	1428.00	0.00	293.50
Inert MPS	0.00	0.00	0.00	0.00
Misc Fluids 172	0.00	0.00	0.00	0.00
OMS Pressurants	99.00	1486.00	0.00	462.00
Misc Pressurants	12.50	1151.00	-17.20	381.00
RCS Total He	24.00	1106.30	0.00	463.00
	563.50	997.27	-2.38	369.84

NOTE: He Tk Mid and He Tk Aft weight differences between PROP-34 and the SODB Vol II Table 4.4-5 are due to the time the quantities are snapped. The SODB time is at L-2 hrs and the PROP-34 L/O page time is L-2 sec.

The GN2 Sys 1 & 2 lines of the Non-Prop page actually represent a set of tanks. In PROP-34, GN2 Sys1 contains Tanks 1, 2, 5, and 6 and GN2 Sys 2 contains Tanks 3, 4, 7,



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and 8. The SODB simply has tanks numbered 1-4 in both systems (see SODB Volume II Figure 4.7-1).

Lastly, OMS trapped and RCS residuals/gauging tolerances are tracked on the Orbiter Build-Up page. Trapped OMS is tracked in Line 15, and unusable RCS is tracked in Line 16. The trapped OMS in Line 15 includes only propellant trapped outside the four OMS propellant tanks.

Values in PROP-34 come from SODB Volume II Section 4.1, tables 4.1-1 and 4.1-2, as follows.

OV-103 & Subs.

LOMS

	Wt	X	Y	Z
Fuel trapped outside tank	26.3	1468.7	-66.6	481.5
OX trapped outside tank	50.2	1468.7	-74.4	471.5
Total	76.50	1468.70	-71.72	474.94

ROMS

	Wt	X	Y	Z
	26.3	1468.7	66.6	481.5
	50.2	1468.7	74.4	471.5
Total	76.50	1468.70	71.72	474.94

Total L & R    153.00    1468.70    0.00    474.94

Unusable RCS in Line 16 includes the following quantities.

- 1) Left, Right, and Forward FU line and tank residuals
- 2) Left, Right, and Forward OX line and tank residuals
- 3) Left, Right, and Forward FU & OX gauging tolerance
- 4) Left, Right, and Forward OX vapors
- 5) Left and Right interconnect FU and OX residuals

Values in PROP-34 come from SODB Volume II Section 4.2, tables 4.2-1 and 4.2-2, as follows.

FRCS

	Wt	X	Y	Z
FU - lines	21.00	347.00	-5.00	374.00
FU - tank	84.00	317.00	-24.00	365.00
FU-Gaging Tolerance	34.00	317.00	-24.00	365.00
OX - lines	38.00	347.00	5.00	374.00
OX - Tanks	134.00	317.00	24.00	365.00
OX - Vapor	5.00	317.00	24.00	365.00
OX-Gaging Tolerance	50.00	317.00	24.00	365.00
Total	366.00	321.84	4.89	366.45

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LARCS

	Wt	X	Y	Z
FU - lines	35.00	1476.00	-90.00	485.00
FU - tank	33.00	1340.00	-67.00	490.00
FU-Gaging Tolerance	34.00	1340.00	-67.00	490.00
OX - lines	53.50	1476.00	-101.00	481.00
OX - Tanks	52.50	1340.00	-99.00	457.00
OX - Vapor	5.50	1340.00	-99.00	457.00
OX-Gaging Tolerance	50.00	1340.00	-99.00	457.00
	263.50	1385.68	-90.07	473.98

RARCS

	Wt	X	Y	Z
	35.00	1476.00	90.00	485.00
	33.00	1340.00	67.00	490.00
	34.00	1340.00	67.00	490.00
	53.50	1476.00	101.00	481.00
	52.50	1340.00	99.00	457.00
	5.50	1340.00	99.00	457.00
	50.00	1340.00	99.00	457.00
	263.50	1385.68	90.07	473.98

Interconnect

	Wt	X	Y	Z
A L FU	4.00	1469.00	-96.00	500.00
A R FU	4.00	1469.00	96.00	500.00
A L OX	5.50	1469.00	-109.00	488.00
A R OX	5.50	1469.00	109.00	488.00
Total	19.00	1469.00	0.00	493.00
RCS Total	912.00	960.48	1.96	431.23

### 3.6.6 Pre-Mission Procedures

The Co-Lead FDO is usually delegated all the pre-mission mass properties tasks for a particular flight. This section discusses procedures for generating the Simulation PMP files and Mission PMP files. Getting the CTL products to the EMCC platform is discussed in section 3.6.6.3.5 of this document. PMP is used to create baseline files of mass property data for ascent, orbit, and entry. Files for one cycle to flight (OCF) (if integrated sims will be performed with this load) and close to launch (CTL) should be generated once the flight design products are delivered. These files are the starting point for generating mass property data during integrated simulations and missions. The appropriate baseline file is selected from the PMP specific baseline data

```
(/mcc/uncert_apps/common/trj/Apps/PMP/Version<PMP Ver
#>/Data/current.xs<Xess Ver #> and then modified as necessary to support the
simulation or initial flight phase configuration during a mission.
```

All required data is included in PROP-34 and Data22a. The ascent FDO may have input into how much  $\Delta$ OMS to use for the ascent data, in which case that value should be used. If not, the default amount of  $\Delta$ OMS computed by PMP ( $\approx$ 5% OMS propellant remaining) can be used. The 5% value is the Flight Rules minimum limit. Historically, an OMS depletion with  $\Delta$ OMS to 22% propellant remaining is made to model maximum landing weight. This does not need to be saved in PMP but should be examined to note any weight or CG violations.

PMP computes the value of  $\Delta$ OMS by using approximately 95% of the remaining OMS propellant.  $\Delta$ OMS may be computed manually by taking the amount of OMS oxidizer on

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one side (which should be the same as the other side for pre-mission work) and subtracting 407 lbs (1788 lbs for 22%) to obtain usable oxidizer. Next, 246 lbs (1081 lbs for 22%) is subtracted from the fuel value to obtain usable fuel. The  $\Delta$ OMS is then two times the usable amounts of oxidizer and fuel.

### Ascent Example $\Delta$ OMS for STS-51 Flight Cycle R1

LOMS OX = 5193.5 lbs

LOMS FU = 3129.5 lbs

$\Delta$ OMS =  $2 \times (5193.5 - 407 + 3129.5 - 246) = 15340.0$  lbs

### Orbit Example $\Delta$ OMS for STS-51 Flight Cycle R1

LOMS OX = 3465.8 lbs

LOMS FU = 2082.4 lbs

$\Delta$ OMS =  $2 \times (3465.8 - 407 + 2082.4 - 246) = 9790.4$  lbs

The above procedure is valid for estimating ascent and orbit  $\Delta$ OMS values. The entry phase, however, is a little different but nonetheless straightforward. In the PROP-34 Fluid Budget, simply take the difference between pre and post-deorbit burn OMS propellant weight to obtain a good value for the actual amount of OMS to be used. In many cases, the remaining OMS value will be between 5% and 8%.

### Entry Example $\Delta$ OMS for STS-51 Flight Cycle R1

OMS OX Pre-Deorbit = 5534.0 lbs

OMS OX Post-Deorbit = 1068.0 lbs

OMS FU Pre-Deorbit = 3309.0 lbs

OMS FU Post Deorbit = 603.0 lbs

$\Delta$ OMS =  $5534.0 - 1068.0 + 3309.0 - 603.0 = 7172.0$  lbs

### 3.6.6.1 PROP-34 Inputs

Figures 3.6.6.1-1 through 3.6.6.1-22 generally seek to pair a weight-CG display with its inertia counterpart on a single page. All deleted lines contain only exact zeros. Data inputs to PMP are shaded. The Ascent PMP configuration comes from the L/O section of the PROP-34 product. The Orbit configuration comes from the Doors Open section of the product. The Entry configuration comes from the Deorbit section of the product. The Post Landing information is located in the Landing section of the product. This section contains items such as post-landing pressurants, gear down Orbiter weights, CGs, and inertias. Performance AOA information is in the "Other Data" section at the end of the product.

**CAUTION:** line numbers from the PROP-34 product will not necessarily correspond to line numbers for the same item in the PMP buildup pages. Refer to the item name to be sure that the PROP-34 data are input to PMP correctly. Deviations arise because PROP-34 contains lines for L/O to OMS-2 usage in all its sections, and these data are zeroed for all but the Liftoff section. Also, PROP-34 has some extra line items in the Liftoff section that PMP does not include (FRCS usage, together with AFT PROP usage broken into OMS and RCS).

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## Orbiter Build-Up

ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN	
1	INERT ORB (CL)	187051.0	1089.20	-1.50	368.00
2	TOTAL CARGO	34342.0	992.67	1.59	388.09
3	NON-PROP	3084.9	1076.85	-4.02	382.41
4	CRYOGENICS	6946.4	1088.48	-2.01	357.89
5	OMS FU R	2998.7	1431.31	71.76	501.04
6	OMS OX R	4978.5	1431.07	109.89	461.48
7	OMS FU L	2998.7	1431.31	-71.76	501.04
8	OMS OX L	4978.5	1431.07	-109.98	461.48
9	RCS FU FWD	594.0	317.0	-24.00	365.00
10	RCS OX FWD	952.0	317.0	24.00	365.00
11	RCS FU AFT R	856.0	1340.0	67.00	490.00
12	RCS OX AFT R	1356.0	1340.0	99.00	457.00
13	RCS FU AFT L	856.0	1340.0	-67.00	490.00
14	RCS OX AFT L	1356.0	1340.0	-99.00	457.00
15	OMS PROP MISC	245.6	1457.60	0.00	470.30
16	RCS UNUSABLE	912.0	960.60	2.00	431.00
17		0.0	0.00	0.00	0.00
18		0.0	0.00	0.00	0.00
19		0.0	0.00	0.00	0.00
20		0.0	0.00	0.00	0.00
<b>25</b>	<b>TOTAL ORBITER</b>	<b>254506.3</b>	<b>1097.01</b>	<b>-0.95</b>	<b>379.48</b>

Figure 3.6.6.1-1: Ascent PMP Input For Orbiter Build-Up

## Orbiter Inertia

	Ixx	Iyy	Izz	Pxy	Pxz	Pyz
1	8.8517E+05	6.7018E+06	6.9961E+06	1.2163E+04	1.2054E+05	9.6120E+02
2	1.9860E+04	2.4127E+05	2.3154E+05	-9.5112E+02	1.0839E+04	3.4426E+02
3	4.4483E+03	9.3048E+04	9.2610E+04	-1.9904E+03	9.9176E+03	8.2901E+01
4	1.1001E+04	6.8526E+04	6.9356E+04	-4.4223E+02	1.3300E+04	1.2423E+02
5	1.8500E+02	2.3476E+02	2.3476E+02	5.3773E+00	5.2304E+00	1.9229E-01
6	3.0722E+02	3.9364E+02	3.9348E+02	9.0258E+00	8.8249E+00	3.3899E-01
7	1.8500E+02	2.3476E+02	2.3476E+02	-5.3773E+00	5.2304E+00	-1.9229E-01
8	3.0722E+02	3.9364E+02	3.9348E+02	-9.0258E+00	8.8249E+00	-3.3899E-01
9	-1.9000E+00	-4.3000E+00	-5.6000E+00	-2.5000E+00	-1.2000E+00	-8.0000E-01
10	-3.5000E+00	-7.8000E+00	-1.0000E+01	4.5000E+00	-2.1000E+00	1.4000E+00
11	-4.5000E+00	-1.4960E+02	-1.5340E+02	-2.5300E+01	5.5000E+00	9.0000E-01
12	-7.1000E+00	-2.3350E+02	-2.2650E+02	-3.3000E+00	-4.0000E+01	-6.0000E-01
13	-4.5000E+00	-1.4960E+02	-1.5370E+02	2.5300E+01	5.5000E+00	-9.0000E-01
14	-7.1000E+00	-2.3350E+02	-2.2650E+02	3.3000E+00	-4.0000E+01	6.0000E-01
15	7.1500E+01	9.0000E-01	7.0600E+01	0.0000E+00	-1.0000E-01	0.0000E+00
16	1.5957E+03	5.4929E+04	5.5375E+04	-2.4800E+02	5.4923E+03	-2.5300E+01
17	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
<b>25</b>	<b>1.0126E+06</b>	<b>7.9482E+06</b>	<b>8.2239E+06</b>	<b>6.3542E+03</b>	<b>2.9379E+05</b>	<b>2.3352E+03</b>

Figure 3.6.6.1-2: Ascent PMP Input For Orbiter Inertia

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## Cargo Build-Up

	ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN
26	FXD-PAYLOAD	34152.0	994.80	1.10	387.80
27	RMS JETT	0.0	957.80	-88.40	443.90
28	KU JETT	190.0	610.00	90.00	440.00
29		0.0	0.00	0.00	0.00
30		0.0	0.00	0.00	0.00
31		0.0	0.00	0.00	0.00
32		0.0	0.00	0.00	0.00
33		0.0	0.00	0.00	0.00
34		0.0	0.00	0.00	0.00
35		0.0	0.00	0.00	0.00
36		0.0	0.00	0.00	0.00
37		0.0	0.00	0.00	0.00
38		0.0	0.00	0.00	0.00
39		0.0	0.00	0.00	0.00
40		0.0	0.00	0.00	0.00
41		0.0	0.00	0.00	0.00
42		0.0	0.00	0.00	0.00
49	<b>TOTAL CARGO</b>	<b>34342.0</b>	<b>992.67</b>	<b>1.59</b>	<b>388.09</b>

Figure 3.6.6.1-3: Ascent PMP Input For Cargo Build-Up

## Cargo Inertia

	lxx	lyy	lzz	Pxy	Pxz	Pyz
26	1.9418E+04	2.3600E+05	2.2516E+05	4.4400E+02	1.1658E+04	1.5500E+02
27	2.2000E+02	1.1736E+04	-1.4000E+01	-5.3000E+01	1.0000E+00	0.0000E+00
28	9.0000E+00	2.3000E+01	2.0000E+01	0.0000E+00	0.0000E+00	0.0000E+00
29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
31	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
32	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
33	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
34	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
35	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
36	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
37	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
38	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
39	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
41	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
42	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
49	<b>1.9860E+04</b>	<b>2.4217E+05</b>	<b>2.3154E+05</b>	<b>-9.5112E+02</b>	<b>1.0839E+04</b>	<b>3.4426E+02</b>

Figure 3.6.6.1-4: Ascent PMP Input For Cargo Inertia

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## Non Prop

ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN	
51	GN2 SYS 1	196.7	976.60	-29.70	
52	GN2 SYS 2	131.1	707.80	89.00	
53	GN2 TK-5	0.0	678.00	-89.00	
54	NH3 TK-1	49.0	1350.00	66.00	
55	NH3 TK-2	49.0	1370.00	67.00	
56	APU N2H4 TK-1	308.0	1400.00	-80.00	
57	APU N2H4 TK-2	308.0	1400.00	-85.00	
58	APU N2H4 TK-3	308.0	1400.00	80.00	
59	HYD H2O TK-1	122.0	1373.00	0.00	
60	HYD H2O TK-2	122.0	1393.00	0.00	
61	HYD H2O TK-3	122.0	1353.00	0.00	
62	POT H2O TK-A	56.6	518.00	0.00	
63	POT H2O TK-B	165.0	534.00	0.00	
64	POT H2O TK-C	157.0	545.00	0.90	
65	POT H2O TK-D	157.0	528.00	0.00	
66	POT H2O TK-E	0.0	470.00	-40.00	
67	POT H2O TK-F	0.0	486.00	-41.00	
68	WST H2O TK-1	20.0	512.00	0.00	
69	MISC PRESS & H2O	813.5	997.60	1.60	
70		0.0	0.00	0.00	
<b>100</b>	<b>TOTAL NON-PROP</b>	<b>3084.9</b>	<b>1076.85</b>	<b>-4.02</b>	<b>382.41</b>

Figure 3.6.6.1-5: Ascent PMP Input For Non Prop

## Non Prop Inertia

	Iyy	Izz	Pxy	Pxz	Ixx	Pyz
51	2.9890E+02	1.8891E+03	2.1880E+03	3.7570E+02	0.0000E+00	0.0000E+00
52	0.0000E+00	9.1900E+01	9.1900E+01	0.0000E+00	0.0000E+00	0.0000E+00
53	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
54	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
55	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
56	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
57	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
58	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
59	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
61	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
62	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
63	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
64	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
65	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
66	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
67	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
69	5.5310E+02	1.8809E+04	1.8316E+04	-9.7000E+01	4.3200E+01	6.0100E+01
70	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
<b>100</b>	<b>4.4483E+03</b>	<b>9.3048E+04</b>	<b>9.2610E+04</b>	<b>-1.9904E+03</b>	<b>9.9176E+03</b>	<b>8.2901E+01</b>

Figure 3.6.6.1-6: Ascent PMP Input For Non Prop Inertia

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## Cryogenics

ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN	
101	CRYO O2 TK-1	777.3	778.50	-77.50	308.00
102	CRYO H2 TK-1	91.0	891.00	-76.00	306.10
103	CRYO O2 TK-2	777.3	721.50	77.50	308.00
104	CRYO H2 TK-2	91.0	835.00	76.00	307.60
105	CRYO O2 TK-3	777.3	1115.50	58.30	294.80
106	CRYO H2 TK-3	91.0	1009.80	-73.90	302.90
107	CRYO O2 TK-4	777.3	1065.20	-76.50	300.50
108	CRYO H2 TK-4	91.0	891.00	76.00	306.10
109	CRYO O2 TK-5	0.0	949.30	-70.00	306.20
110	CRYO H2 TK-5	0.0	949.30	69.00	302.80
111	CRYO O2 TK-6	777.3	1257.70	56.70	392.00
112	CRYO H2 TK-6	91.0	1262.50	28.50	350.00
113	CRYO O2 TK-7	777.3	1257.70	-56.70	392.00
114	CRYO H2 TK-7	91.0	1262.50	-28.50	350.00
115	CRYO O2 TK-8	777.3	1257.70	48.70	439.00
116	CRYO H2 TK-8	91.0	1262.50	0.00	399.40
117	CRYO O2 TK-9	777.3	1257.70	-48.70	439.00
118	CRYO H2 TK-9	91.0	1262.50	0.00	454.00
119		0.0	0.00	0.00	0.00
<b>174</b>	<b>TOTAL CRYO</b>	<b>6946.4</b>	<b>1088.48</b>	<b>-2.01</b>	<b>357.89</b>

Figure 3.6.6.1-7: Ascent PMP Input For Cryogenics

## Cryogenics Inertia

	Ixx	Iyy	Izz	Pxy	Pxz	Pyz
101	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
102	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
103	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
104	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
105	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
106	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
107	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
108	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
109	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
110	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
111	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
112	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
113	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
114	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
116	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
117	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
118	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
119	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
<b>174</b>	<b>1.1001E+04</b>	<b>6.8526E+04</b>	<b>6.9356E+04</b>	<b>-4.4223E+02</b>	<b>1.3300E+04</b>	<b>1.2423E+02</b>

Figure 3.6.6.1-8: Ascent PMP Input For Cryogenics Inertia

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## OMS Fuel Depletion

<b>1.66</b>	: MIX RATIO	OMS FU RT	2998.70	OMS FU LT	2998.70
	TANK: 1=LT, 2=BT, 3=RT	OMS OX RT	4978.50	OMS OX LT	4978.50
<b>2</b>					
		WEIGHT	X CG IN	Y CG IN	Z CG IN
		253705.50	1096.97	-0.95	379.37
		252805.50	1095.87	-0.95	379.03
		251905.50	1094.74	-0.95	378.68
		251005.50	1093.60	-0.96	378.33
		250105.50	1092.44	-0.96	377.98
		249205.50	1091.26	-0.96	377.63
		248305.50	1090.07	-0.97	377.27
		247405.50	1088.85	-0.97	376.91
		246505.50	1087.62	-0.97	376.55
		245605.50	1086.37	-0.98	376.18
		244705.50	1085.10	-0.98	375.82
		243805.50	1083.80	-0.98	375.45
		242905.50	1082.48	-0.99	375.07
		242005.50	1081.15	-0.99	374.69
		241105.50	1079.79	-1.00	374.31
		240205.50	1078.41	-1.00	373.93
		239305.50	1077.02	-1.00	373.54
		<b>TVC WEIGHT</b>	<b>239459.2</b>	<b>1077.26</b>	<b>-1.00</b>
		PERCENT BL	65.04		<b>373.60</b>
		PITCH		YAW PARA	YAW CG
DOMS	<b>14246.30</b>	0.78	YL	-5.70	4.29
			YR	5.70	-4.54
DOMS	<b>0.0</b>	0.84	YL	-5.70	4.80
			YR	5.70	-5.03

**Figure 3.6.6.1-9: Ascent PMP Input For OMS Depletion**



# FDO Console Handbook Section 3.6: Orbit Mass Properties

CG Sum-Mass Prop					
ITEM		WEIGHT	X CG IN	Y CG IN	Z CG IN
176	L/O WEIGHT	254506.3	1097.01	-0.95	379.48
177	L/O TO OMS 2 PROP	-400.8	1015.78	-2.60	416.99
178	L/O TO OMS 2 NP	-400.0	1200.00	-2.00	410.80
<b>179</b>	<b>L/O WT - BIAS</b>	<b>253705.5</b>	<b>1096.97</b>	<b>-0.95</b>	<b>379.37</b>
180	TVC WT POST D/O	239459.2	1077.26	-1.00	373.60
181	SYS AOA D2EI	-323.9	1274.24	-5.91	420.32
182	SYS AOA FDMP	-1544.4	317.00	5.50	365.00
183	FDUMP AFT USAGE	-31.0	1340.00	0.00	490.00
<b>184</b>	<b>ENTRY INTERFACE</b>	<b>237559.9</b>	<b>1081.90</b>	<b>-1.04</b>	<b>373.58</b>
185	AOA EI TO M3	-559.3	1347.86	-5.95	454.19
186	AFT OMS CG	-1307.3	1455.75	0.00	477.33
187	FWD OMS CG	1307.3	1384.39	0.00	477.33
<b>188</b>	<b>TAEM INTERFACE</b>	<b>237000.6</b>	<b>1080.88</b>	<b>-1.03</b>	<b>373.39</b>
189	M3 TO LANDING	-81.2	1396.14	-19.81	423.93
<b>190</b>	<b>PRE-LANDING</b>	<b>236919.4</b>	<b>1080.77</b>	<b>-1.02</b>	<b>373.37</b>
191	GEAR UP	-7370.0	993.50	0.00	299.30
192	GEAR DOWN	7370.0	1046.20	0.00	221.50
<b>193</b>	<b>LANDING</b>	<b>236919.4</b>	<b>1082.41</b>	<b>-1.02</b>	<b>370.95</b>
194	INERT ORB (GDN)	187051.0	1091.30	-1.50	365.00
195	INERT ORB (CL)	187051.0	1089.20	-1.50	368.00
196	INERT ORB (OP)	187051.0	1089.20	-1.20	364.50
197					
198	OGD SLOPE SWPT	220000.0			
199					
22	ENTRY INTERFACE	237559.9	1081.90	-1.04	373.58
23	TAEM INTERFACE	237000.6	1080.88	-1.03	373.39
24	LANDING	236919.4	1082.41	-1.02	370.95

Figure 3.6.6.1-10: Ascent PMP Input For CG SUM

## FDO Console Handbook Section 3.6: Orbit Mass Properties

### CG Sum Inertia

lxx	lyy	lzz	Pxy	Pxz	Pyz	
176						
177						
178						
<b>179</b>						
180						
181						
182						
<b>183</b>						
184						
185						
186						
<b>187</b>						
188						
<b>189</b>						
190						
191						
<b>192</b>						
193	9.1627E+05	6.7266E+06	6.9948E+06	1.2289E+04	1.1365E+05	7.7350E+02
194	8.8517E+05	6.7018E+06	6.9961E+06	1.2163E+04	1.2054E+05	9.6120E+02
195	9.0124E+05	6.6853E+06	7.0277E+06	1.0754E+04	1.4132E+05	5.7360E+02
196						
197						
198						
199						

**Figure 3.6.6.1-11: Ascent PMP Input For CG Sum Inertia**

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## Orbiter Build-Up

ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN	
1	INERT ORB (CL)	187051.0	1089.20	-1.50	368.00
2	TOTAL CARGO	34342.0	992.67	1.59	388.09
3	NON-PROP	2773.6	1068.05	-3.01	385.70
4	CRYOGENICS	6932.2	1089.14	-2.01	357.99
5	OMS FU R	1962.7	1439.99	72.08	501.35
6	OMS OX R	3268.9	1439.79	110.30	461.79
7	OMS FU L	1962.7	1439.99	-72.08	501.35
8	OMS OX L	3268.9	1439.79	-110.30	461.79
9	RCS FU FWD	528.6	317.0	-24.00	365.00
10	RCS OX FWD	847.4	317.0	24.00	365.00
11	RCS FU AFT R	767.1	1340.0	67.00	490.00
12	RCS OX AFT R	1213.8	1340.0	99.00	457.00
13	RCS FU AFT L	766.9	1340.0	-67.00	490.00
14	RCS OX AFT L	1213.4	1340.0	-99.00	457.00
15	OMS PROP MISC	245.6	1457.63	0.00	470.30
16	RCS UNUSABLE	912.0	960.62	1.96	431.01
17		0.0	0.00	0.00	0.00
18		0.0	0.00	0.00	0.00
19		0.0	0.00	0.00	0.00
20		0.0	0.00	0.00	0.00
<b>25</b>	<b>TOTAL ORBITER</b>	<b>248056.8</b>	<b>1090.00</b>	<b>-0.96</b>	<b>377.22</b>

Figure 3.6.6.1-12: Orbit/Entry PMP Input For Orbiter Build-Up

## Orbiter Inertia

	Ixx	Iyy	Izz	Pxy	Pxz	Pyz
1	8.8517E+05	6.7018E+06	6.9961E+06	1.2163E+04	1.2054E+05	9.6120E+02
2	1.9860E+04	2.4217E+05	2.3154E+05	-9.5112E+02	1.0839E+04	3.4426E+02
3	3.9526E+03	8.4663E+04	8.4366E+04	-1.7591E+03	9.1668E+03	7.6188E+01
4	1.0976E+04	6.8195E+04	6.9013E+04	-4.3352E+02	1.3253E+04	1.2376E+02
5	1.1737E+02	9.9907E+01	9.9913E+01	1.5538E+00	1.5151E+00	4.8177E-02
6	1.9565E+02	1.6768E+02	1.6766E+02	2.6154E+00	2.5898E+00	9.2023E-02
7	1.1737E+02	9.9907E+01	9.9913E+01	-1.5538E+00	1.5151E+00	-4.8177E-02
8	1.9565E+02	1.6768E+02	1.6766E+02	-2.6154E+00	2.5898E+00	-9.2023E-02
9	-1.9000E+00	-4.3000E+00	-5.6000E+00	-2.5000E+00	-1.2000E+00	-8.0000E-01
10	-3.5000E+00	-7.8000E+00	-1.0000E+01	4.5000E+00	-2.1000E+00	1.4000E+00
11	-4.5000E+00	-1.4960E+02	-1.5340E+02	-2.5300E+01	5.5000E+00	9.0000E-01
12	-7.1000E+00	-2.3350E+02	-2.2650E+02	-3.3000E+00	-4.0000E+01	-6.0000E-01
13	-4.5000E+00	-1.4960E+02	-1.5370E+02	2.5300E+01	5.5000E+00	-9.0000E-01
14	-7.1000E+00	-2.3350E+02	-2.2650E+02	3.3000E+00	-4.0000E+01	6.0000E-01
15	7.1500E+01	9.0000E-01	7.0600E+01	0.0000E+00	-1.0000E-01	0.0000E+00
16	1.5957E+03	5.4929E+04	5.5375E+04	-2.4800E+02	5.4923E+03	-2.5300E+01
17	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
<b>25</b>	<b>9.8733E+05</b>	<b>7.7765E+06</b>	<b>8.0530E+06</b>	<b>6.3920E+03</b>	<b>2.5318E+05</b>	<b>2.2117E+03</b>

Figure 3.6.19.1-13: Orbit/Entry PMP Input For Orbiter Inertia

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## Cargo Build-Up

	ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN
26	FXD-PAYLOAD	34152.0	994.80	1.10	387.80
27	RMS JETT (900)	0.0	957.80	-88.40	443.90
28	KU JETT	190.0	610.00	90.00	440.00
29		0.0	0.00	0.00	0.00
30		0.0	0.00	0.00	0.00
31		0.0	0.00	0.00	0.00
32		0.0	0.00	0.00	0.00
33		0.0	0.00	0.00	0.00
34		0.0	0.00	0.00	0.00
35		0.0	0.00	0.00	0.00
36		0.0	0.00	0.00	0.00
37		0.0	0.00	0.00	0.00
38		0.0	0.00	0.00	0.00
39		0.0	0.00	0.00	0.00
40		0.0	0.00	0.00	0.00
41		0.0	0.00	0.00	0.00
42		0.0	0.00	0.00	0.00
49	<b>TOTAL CARGO</b>	<b>34342.0</b>	<b>992.67</b>	<b>1.59</b>	<b>388.09</b>

Figure 3.6.6.1-14: Orbit/Entry PMP Input For Cargo Build-Up

## Cargo Inertia

	Ixx	Iyy	Izz	Pxy	Pxz	Pyz
26	1.9418E+04	2.3600E+05	2.2516E+05	4.4400E+02	1.1658E+04	1.5500E+02
27	2.2000E+02	1.1736E+04	-1.4000E+01	-5.3000E+01	1.0000E+00	0.0000E+00
28	9.0000E+00	2.3000E+01	2.0000E+01	0.0000E+00	0.0000E+00	0.0000E+00
29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
31	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
32	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
33	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
34	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
35	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
36	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
37	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
38	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
39	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
41	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
42	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
49	<b>1.9860E+04</b>	<b>2.4217E+05</b>	<b>2.3154E+05</b>	<b>-9.5112E+02</b>	<b>1.0839E+04</b>	<b>3.4426E+02</b>

Figure 3.6.6.1-15: Orbit/Entry PMP Input For Cargo Inertia

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## Non Prop

ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN	
51	GN2 SYS 1	196.4	976.60	-29.70	
52	GN2 SYS 2	131.0	707.80	89.00	
53	GN2 TK-5	0.0	678.00	-89.00	
54	NH3 TK-1	49.0	1350.00	66.00	
55	NH3 TK-2	49.0	1370.00	67.00	
56	APU N2H4 TK-1	268.0	1400.00	-80.00	
57	APU N2H4 TK-2	265.0	1400.00	-85.00	
58	APU N2H4 TK-3	265.0	1400.00	80.00	
59	HYD H2O TK-1	115.0	1373.00	0.00	
60	HYD H2O TK-2	115.0	1393.00	0.00	
61	HYD H2O TK-3	115.0	1353.00	0.00	
62	POT H2O TK-A	73.6	518.00	0.00	
63	POT H2O TK-B	80.0	534.00	0.00	
64	POT H2O TK-C	157.0	545.00	0.90	
65	POT H2O TK-D	157.0	528.00	0.00	
66	POT H2O TK-E	0.0	470.00	-41.00	
67	POT H2O TK-F	0.0	486.00	-41.00	
68	WST H2O TK-1	22.1	512.00	0.00	
69	MISC PRESS & H2O	715.5	968.60	2.69	
70		0.0	0.00	0.00	
<b>100</b>	<b>TOTAL NON-PROP</b>	<b>2773.6</b>	<b>1068.05</b>	<b>-3.01</b>	<b>385.70</b>

Figure 3.6.6.1-16: Orbit/Entry PMP Input For Non-Prop

## Non Prop Inertia

	Iyy	Izz	Pxy	Pxz	Ixx	Pyz
51	2.9890E+02	1.8891E+03	2.1880E+03	3.7570E+02	0.0000E+00	0.0000E+00
52	0.0000E+00	9.1900E+01	9.1900E+01	0.0000E+00	0.0000E+00	0.0000E+00
53	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
54	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
55	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
56	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
57	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
58	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
59	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
61	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
62	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
63	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
64	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
65	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
66	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
67	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
69	3.9970E+02	1.7288E+04	1.6945E+04	-6.5800E+01	4.5900E+02	4.5700E+01
70	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
<b>100</b>	<b>3.9526E+03</b>	<b>8.4663E+04</b>	<b>8.4366E+04</b>	<b>-1.7591E+03</b>	<b>9.1668E+03</b>	<b>7.6188E+01</b>

Figure 3.6.6.1-17: Orbit/Entry PMP Input For Non-Prop Inertia  
Cryogenics

## FDO Console Handbook Section 3.6: Orbit Mass Properties

ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN	
101	CRYO O2 TK-1	771.3	778.50	-77.50	308.00
102	CRYO H2 TK-1	89.9	891.00	-76.00	306.10
103	CRYO O2 TK-2	771.3	721.50	77.50	308.00
104	CRYO H2 TK-2	89.9	835.00	76.00	307.10
105	CRYO O2 TK-3	777.3	1115.50	58.30	294.80
106	CRYO H2 TK-3	91.0	1009.80	-73.90	302.90
107	CRYO O2 TK-4	777.3	1065.20	-76.50	300.50
108	CRYO H2 TK-4	91.0	891.00	76.00	306.10
109	CRYO O2 TK-5	0.0	949.30	-70.00	306.20
110	CRYO H2 TK-5	0.0	949.30	69.00	302.80
111	CRYO O2 TK-6	777.3	1257.70	56.70	392.00
112	CRYO H2 TK-6	91.0	1262.50	28.50	350.00
113	CRYO O2 TK-7	777.3	1257.70	-56.70	392.00
114	CRYO H2 TK-7	91.0	1262.50	-28.50	350.00
115	CRYO O2 TK-8	777.3	1257.70	48.70	439.00
116	CRYO H2 TK-8	91.0	1262.50	0.00	399.40
117	CRYO O2 TK-9	777.3	1257.70	-48.70	439.00
118	CRYO H2 TK-9	91.0	1262.50	0.00	454.00
119		0.0	0.00	0.00	0.00
<b>174</b>	<b>TOTAL CRYO</b>	<b>6932.2</b>	<b>1089.14</b>	<b>-2.01</b>	<b>357.99</b>

**Figure 3.6.6.1-18: Orbit/Entry PMP Input For Cryogenics**

### Cryogenics Inertia

	Ixx	Iyy	Izz	Pxy	Pxz	Pyz
101	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
102	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
103	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
104	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
105	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
106	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
107	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
108	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
109	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
110	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
111	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
112	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
113	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
114	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
116	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
117	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
118	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
119	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
<b>174</b>	<b>1.0976E+04</b>	<b>6.8195E+04</b>	<b>6.9013E+04</b>	<b>-4.3352E+02</b>	<b>1.3253E+04</b>	<b>1.2376E+02</b>

**Figure 3.6.6.1-19: Orbit/Entry PMP Input For Cryogenics Inertia**

# FDO Console Handbook Section 3.6: Orbit Mass Properties

## OMS Fuel Depletion

<b>1.66</b>	: MIX RATIO	OMS FU RT	2998.70	OMS FU LT	2998.70
	TANK: 1=LT, 2=BT, 3=RT	OMS OX RT	4978.50	OMS OX LT	4978.50
<b>2</b>					
		WEIGHT	X CG IN	Y CG IN	Z CG IN
		248056.80	1090.00	-0.96	377.22
		247456.80	1089.19	-0.96	376.98
		246856.80	1088.38	-0.97	376.74
		246256.80	1087.55	-0.97	376.50
		245656.80	1086.72	-0.97	376.26
		245056.80	1085.87	-0.97	376.01
		244456.80	1085.02	-0.98	375.76
		243856.80	1084.16	-0.98	375.52
		243256.80	1083.28	-0.98	375.27
		242656.80	1082.40	-0.98	375.02
		242056.80	1081.51	-0.99	374.76
		241456.80	1080.61	-0.99	374.51
		240856.80	1079.70	-0.99	374.26
		240256.80	1078.79	-0.99	374.00
		239656.80	1077.86	-1.00	373.74
		239056.80	1076.93	-1.00	373.48
		238456.80	1075.98	-1.00	373.22
		<b>TVC WEIGHT</b>	<b>238921.20</b>	<b>1076.71</b>	<b>-1.00</b>
		PERCENT BL	65.00		<b>373.42</b>
		PITCH		YAW PARA	YAW CG
DOMS	<b>9135.60</b>	0.78	YL	-5.70	4.28
			YR	5.70	-4.52
DOMS	<b>0.0</b>	0.80	YL	-5.70	4.61
			YR	5.70	-4.85

Figure 3.6.6.1-20: Orbit/Entry PMP Input For OMS Depletion

## FDO Console Handbook Section 3.6: Orbit Mass Properties

CG Sum-Mass Prop					
ITEM	WEIGHT	X CG IN	Y CG IN	Z CG IN	
176	TVC WT POST D/O	238921.2	1076.71	-1.00	373.42
177	D/O to EI CONSUM	-247.2	1254.63	-4.35	436.89
178	FRCS DUMP	-1374.4	317.00	5.53	365.00
179	FDUMP AFT USAGE	-27.6	1340.00	0.00	490.00
<b>180</b>	<b>ENTRY INTERFACE</b>	<b>237272.0</b>	<b>1080.90</b>	<b>-1.03</b>	<b>373.39</b>
181	EI TO MACH3	-475.8	1310.42	-3.74	451.55
182	AFT OMS CG	-1327.6	1455.69	0.00	477.28
183	FWD OMS CG	1327.6	1384.44	0.00	477.28
<b>184</b>	<b>TAEM INTERFACE</b>	<b>236796.2</b>	<b>1080.04</b>	<b>-1.03</b>	<b>373.24</b>
185	M3 TO LANDING	-81.2	1396.14	-19.81	423.93
<b>186</b>	<b>PRE-LANDING</b>	<b>236715.0</b>	<b>1079.93</b>	<b>-1.02</b>	<b>373.22</b>
187	GEAR UP	-7370.0	993.50	0.00	299.30
188	GEAR DOWN	7370.0	1046.20	0.00	221.50
<b>189</b>	<b>LANDING</b>	<b>236715.0</b>	<b>1081.57</b>	<b>-1.02</b>	<b>370.80</b>
190	INERT ORB (GDN)	187051.0	1091.30	-1.50	365.00
191	INERT ORB (CL)	187051.0	1089.20	-1.50	368.00
192	INERT ORB (OP)	187051.0	1089.20	-1.20	364.50
193					
194	OGD SLOPE SWPT	220000.0			
195					
196					
197					
198					
22	ENTRY INTERFACE	237272.0	1080.90	-1.03	373.39
23	TAEM INTERFACE	236796.2	1080.04	-1.03	373.24
24	LANDING	236715.0	1081.57	-1.02	370.80

**Figure 3.6.6.1-21: Orbit/Entry PMP Input For CG Sum-Mass Prop**



## FDO Console Handbook Section 3.6: Orbit Mass Properties

CG Sum Inertia						
	<i>Ixx</i>	<i>Iyy</i>	<i>Izz</i>	<i>Pxy</i>	<i>Pxz</i>	<i>Pyz</i>
176						
177						
178						
<b>179</b>						
180						
181						
182						
<b>183</b>						
184						
<b>185</b>						
186						
187						
<b>188</b>						
189	9.1627E+05	6.7266E+06	6.9948E+06	1.2289E+04	1.1365E+05	7.7350E+02
190	8.8517E+05	6.7018E+06	6.9961E+06	1.2163E+04	1.2054E+05	9.6120E+02
191	9.0124E+05	6.6853E+06	7.0277E+06	1.0754E+04	1.4132E+05	5.7360E+02
192						
193						
194						
195						
196						
197						
198						

Figure 3.6.6.1-22: Orbit/Entry PMP Input For CG Sum Inertia

## FDO Console Handbook Section 3.6: Orbit Mass Properties

### 3.6.6.2 DSCT-04 Inputs

Figure 3.6.6.2-1 contains the Outer Glide Slope switch point used to configure PMP. This is part of the DSCT-04 Flight Design product (`dsct04.al.targets.mif`). Input the Selected OPS 3 weight switch point into the PMP cell labeled OGD Slope SWPT located below the INERT ORB lines on the CG SUM - Mass Prop page.

Parameter	Mission Phase			
	GRTL5	TAL	AOA	EOM
Selected Ops 3 weight switch point (lb)	N/A <sup>A</sup>	222001		
Vehicle weight used by Guidance (lb)	237991 <sup>B</sup>	235477 <sup>B</sup>	233710	222118
Vehicle weight at T/D (lb)	238869	235306	231442	220481
OGS $\gamma_{ref}$ (deg)	-18	-18	-18	-18 <sup>D</sup>
Nominal T/D target: Vel (KEAS) at 2500 ft Range	205	205	205	205 <sup>D</sup>
Shortfield T/D target: Vel (KEAS) at 2500 ft Range	195	195 <sup>C</sup>	195	195 <sup>D</sup>

- A OPS 1 has only one ILOAD set and does not use the weight switch point
- B This value is an ILOAD; it cannot change during the mission
- C A declared TAL will default to Shortfield "ON".
- D OGS geometry and touchdown target will change to lightweight values if the weight used by guidance becomes less than the weight switchpoint

**Figure 3.6.6.2-1: DSCT-04 Outer Glide Slope Data**

The Outer Glide Slope switch point is passed to DMP and EDS to enable the software to select the heavyweight or lightweight entry glide slope.

### 3.6.6.3 PMP File Generation Procedures

The following procedures assume Sections 3.6.6.3.1 through 3.6.6.3.4 are performed in the order presented. For example, entering deployable/retrievable payloads is included in the Ascent section, while Orbit and Entry sections assume Cargo Buildup has already been configured with flight-specific data. Also, the ASC CG Sum display is configured only for Ascent, and the ORB CG Sum display is configured only for Orbit/Entry. The ASC CG Sum display should NOT be used for Orbit/Entry and vice versa. Flight-specific data entered when configuring these files are displayed in blue font by PMP. However, check marks are included in the tables below to remind the user which data are required. To enter Inertia data, PMP's Display menu can be used to select the corresponding Inertia display, or simply scroll to the right when viewing the corresponding Buildup display.

Simulation PMP files must be available prior to flight-specific sims at about L-2 months. These sims will be based on the OCF trajectory and data products. The following inputs will initiate configuration of mass properties tables for all sims.

CTL PMP files must be available prior to flight at about L -3 days.

**NOTE:** AFT and Forward OMS lines in the CG Sum pages (Lines 186/187 for the Ascent Configuration and 182/183 for the Orbit and Entry Configurations) are automatically computed when the OMS Depletion or Ballast computations are run.

## FDO Console Handbook Section 3.6: Orbit Mass Properties

### 3.6.6.3.1 Ascent PMP File Generation

- 1) Use PROP-34 MCC Data product Liftoff Configuration
- 2) **FDO DNAV → Mass Props → Baseline Data → PMP-Baseline-ASC**
- 3) **File → Open...** and open  
/mcc/uncert\_apps/common/trj/Apps/PMP/Version<ver>/Data/current.xs<#>  
where <ver> is the version of PMP you are using and <#> is specific to the Xess version. When you bring up PMP, you can look at advisory services for the version number (e.g. 4.0).
- 4) **File → Save As...** and save in  
/users/fdo/<user\_id>/<flight\_id>/pmp\_default\_ASC\_data.xs<#>.
- 5) ✓ **ASC** spreadsheet
- 6) Configure **CG Sum** using PROP-34 Liftoff Configuration and DSCT-04 Outer Glide Slope switch point

PMP	PROP-34	Wt	CGs	Is
INERT ORB (GDN)	INERT ORB (Landing Configuration)	✓	✓	✓
INERT ORB (CL)	INERT ORB (Launch Configuration)	✓	✓	✓
INERT ORB (OP)	INERT ORB (Doors Open Configuration)	✓	✓	✓
L/O to OMS2 PROP BIAS	L/O to OMS 2 AFT PROP	✓	✓	
L/O to OMS2 NP BIAS	L/O to OMS2 NP	✓	✓	
SYS AOA D2EI	D2EI	✓	✓	
SYS AOA FDMP	FDMP	✓		
FDUMP AFT USAGE	FDMP ARCS USAGE		✓	
AOA EI TO M3	EI TO M3.5	✓	✓	
M3 TO LANDING	M3.5 TO LANDING	✓	✓	
GEAR UP	GEAR UP	✓	✓	
GEAR DOWN	GEAR DOWN	✓	✓	

NOTE: values in the Liftoff CG Sum page are for Systems AOA Only.

NOTE: the sign convention for PMP 4.0 and subs has changed for the CG Sum page. Weights that are removed in this page are now negative. Weights that are added are positive. An example of this can be found on Lines 191 and 192 in Figure 3.6.6.1-10.

PMP	DSCT-04	Wt	CGs	Is
OGD Slope SWPT	Selected Ops 3 weight switch point (lbm)	✓		

- 7) Configure **Cargo B/U** using PROP-34 Liftoff Configuration
  - a) Enter wt, CGs, and Is for FXD-PAYLOAD
  - b) Enter deployable/retrievable payload items, wts, CGs and Is
  - c) Include wt in item name and zero out items to be retrieved

## FDO Console Handbook Section 3.6: Orbit Mass Properties

**NOTE:** the item name in the first line of the Cargo B/U should be "FXD-PAYLOAD". The SpOC D/O Manager software is using this line in its electronic configuration interface.

- 8) Configure **Non-prop B/U** from PROP-34 Liftoff Configuration

PMP	PROP-34	Wt	CGs	Is
GN2 SYS 1	GN2 SYS 1	√	√	√
GN2 SYS 2	GN2 SYS 2	√	√	√
MISC PRESS & H2O	MISC PRESS & H2O	√	√	√
Other Non-prop consumables	same section of PROP-34	√		

- 9) Configure **Cryo B/U** from PROP-34 Liftoff Configuration

PMP	PROP-34	Wt	CGs	Is
CRYO O2 TK-X	CRYO O2 TK-X	√		
CRYO H2 TK-X	CRYO H2 TK-X	√		

- 10) Configure **Orbiter B/U** from PROP-34 Liftoff Configuration

PMP	PROP-34	Wt	CGs	Is
OMS FU/OX R/L	OMS FU/OX R/L	√		
RCS FU/OX AFT R/AFT L/FWD	RCS FU/OX AFT R/AFT L/FWD	√		
OMS PROP MISC	OMS PROP MISC	√	√	√
RCS UNUSABLE	RCS UNUSABLE	√	√	√

- 11) **Process** → **Xfer CL Doors** (doors must be reclosed to use new inert wt) √Orbiter B/U line 1 "(CL)", wt, and CGs

- 12) √Orbiter B/U line 25 ≈ Line 25 of PROP-34 Liftoff Configuration

- 13) Configure Cell C12 with the L/O to OMS 2 RCS Usage from PROP-34's L/O to OMS 2 ARCS PROP weight from the LIFTOFF section (line 178). This should be entered as a positive quantity per the following example.

RCS L/O - OMS 2	397.9
-----------------	-------

- 14) **Process** → **OMS Depletion**

- Set  $\Delta OMS$  = value provided by Ascent FDO or Line 182 minus Line 183 of the Liftoff PROP-34 CG Sum page
- √CG SUM landing weight < AOA limit

- 15) √**Displays** → **CG SUM** or **OMS Depletion**

- 16) **Process** → **Ballast**

- Enter minimum OMS from worksheet if available
- ARCS = 510 + FRCS Dump \* 0.020100595. Note: This should automatically be computed.

- 17) **Displays** → **Orbiter B/U**

- 18) √**File** /users/fdo/<user\_id>/<flight\_id>/pmp\_default\_ASC\_data.xls<#>

## FDO Console Handbook Section 3.6: Orbit Mass Properties

- 19) **File** → **Save**
- 20) Inform Ascent and Lead FDO of results (ballast, landing wt, etc.)
- 21) Using an xterm, perform the following steps to protect the file from accidental writes:
  - a) `cd /users/fdo/<user_id>/<flight_id>/`
  - b) `chmod 444 pmp_default_ASC_data.xs<#>`
- 22) Inform the Lead FDO of the new data file and its location.
- 23) Fill out a GA/Dynamics Initialization PAD requesting the file be moved into the appropriate cycle of the flight specific database, have the Lead FDO sign the request, and submit it to the TOCSS GA group.

### 3.6.6.3.2 Orbit PMP File Generation

- 1) Use PROP-34 MCC product Payload Bay Doors Open Configuration and start with Ascent PMP File
- 2) **File** → **Save As...** and save in `/users/fdo/<user_id>/<flight_id>/pmp_default_ORB_data.xs<#>`.
- 3) Select Orb/Entry spreadsheet, ✓**ORB**
- 4) Configure **CG Sum** using PROP-34 Payload Bay Door Open Configuration and DSCT-04 Outer Glide Slope switch point

PMP	PROP-34	Wt	CGs	Is
INERT ORB (GDN)	INERT ORB (Landing Configuration)	√	√	√
INERT ORB (CL)	INERT ORB (Launch Configuration)	√	√	√
INERT ORB (OP)	INERT ORB (Doors Open Configuration)	√	√	√
D/O TO EI CONSUM	D2EI	√	√	
FRCS DUMP	FDMP	√	√	
FDUMP AFT USAGE	FDMP ARCS USAGE		√	
EI TO M3	EI TO M3.5	√	√	
M3 TO LANDING	M3.5 TO LANDING	√	√	
GEAR UP	GEAR UP	√	√	
GEAR DOWN	GEAR DOWN	√	√	

NOTE: FRCS weight is computed based on FRCS in Orbiter B/U.

NOTE: the sign convention for PMP 4.0 and subs has changed for the CG Sum page. Weights that are removed in this page are now negative. Weights that are added are positive. An example of this can be found on Lines 191 and 192 in Figure 3.6.6.1-10.

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PMP	D SCT-04	Wt	CGs	Is
OGD Slope SWPT	Selected Ops 3 weight switch point (lbm)	√		

5) **√Cargo B/U**

NOTE: ORB Cargo B/U is the same as ASC since baseline data are at PLBD Open.

NOTE: the item name in the first line of the Cargo B/U should be "FXD-PAYLOAD". The SpOC D/O Manager software is using this line in its electronic configuration interface.

6) Configure **Non-prop B/U** from PROP-34 Payload Bay Door Open Configuration

PMP	PROP-34	Wt	CGs	Is
GN2 SYS 1	GN2 SYS 1	√	√	√
GN2 SYS 2	GN2 SYS 2	√	√	√
MISC PRESS & H2O	MISC PRESS & H2O	√	√	√
Other Non-prop consumables	same section of PROP-34	√		

7) Configure **Cryo B/U** weights from PROP-34 Payload Bay Door Open Configuration

8) Configure **Orbiter B/U** from PROP-34 Payload Bay Door Open Configuration

PMP	PROP-34	Wt	CGs	Is
OMS FU/OX R/L	OMS FU/OX R/L	√		
RCS FU/OX AFT R/AFT L/FWD	RCS FU/OX AFT R/AFT L/FWD	√		
OMS PROP MISC	OMS PROP MISC	√	√	√
RCS UNUSABLE	RCS UNUSABLE	√	√	√

9) **Process → Xfer OP Doors**

√Orbiter B/U line 1 "(OP)", wt, and CGs

10) √Orbiter B/U line 25 ≈ PROP-34 Line 25 Payload Bay Door Open Configuration

11) **Process → OMS Depletion**

- Set  $\Delta OMS = \text{Line 176} - \text{Line 183}$  of the Payload Bay Door Open PROP-34 CG Sum page
- √CG SUM landing weight < ATO (Day 1) limit

12) **√Displays → CG SUM or OMS Depletion**

13) **Process → Ballast**

- Enter minimum OMS from worksheet if available
- ARCS = 510 + FRCS Dump \* 0.020100595. Note: This should automatically be computed.

14) **Displays → Orbiter B/U**

## FDO Console Handbook Section 3.6: Orbit Mass Properties

- 15) ✓**File:** /users/fdo/<user\_id>/<flight\_id>/pmp\_default\_ORB\_data.xls<#>
- 16) **File** → **Save**
- 17) Inform Lead FDO of results (ballast, landing weight, etc.)
- 18) Using an xterm, perform the following steps to protect the file from accidental writes:
  - a) cd /users/fdo/<user\_id>/<flight\_id>/
  - b) chmod 444 pmp\_default\_ORB\_data.xls<#>
- 19) Inform the Lead FDO of the new data file and its location.
- 20) Fill out a GA/Dynamics Initialization PAD requesting the file be moved into the appropriate cycle of the flight specific database, have the Lead FDO sign the request, and submit it to the TOCSS GA group.

### 3.6.6.3.3 Entry PMP File Generation

- 1) Use PROP-34 MCC product Deorbit TIG Configuration and start with Orbit PMP File
- 2) **File** → **Save As...** and save in /users/fdo/<user\_id>/<flight\_id>/pmp\_default\_ENT\_data.xls<#>.
- 3) ✓**ORB** spreadsheet
- 4) ✓**CG Sum** using PROP-34 Deorbit TIG Configuration and DSCT-04 Outer Glide Slope switch point (same as ORB)

PMP	PROP-34	Wt	CGs	Is
INERT ORB (GDN)	INERT ORB (Landing Configuration)	✓	✓	✓
INERT ORB (CL)	INERT ORB (Launch Configuration)	✓	✓	✓
INERT ORB (OP)	INERT ORB (Doors Open Configuration)	✓	✓	✓
D/O TO EI CONSUM	D2EI	✓	✓	
FRCS DUMP	FDMP	✓	✓	
FDUMP AFT USAGE	FDMP ARCS USAGE		✓	
EI TO M3	EI TO M3.5	✓	✓	
M3 TO LANDING	M3.5 TO LANDING	✓	✓	
GEAR UP	GEAR UP	✓	✓	
GEAR DOWN	GEAR DOWN	✓	✓	

NOTE: FRCS weight is computed based on FRCS in Orbiter B/U.

NOTE: the sign convention for PMP 4.0 and subs has changed for the CG Sum page. Weights that are removed in this page are now negative. Weights that are added are positive. An example of this can be found on Lines 191 and 192 in Figure 3.6.6.1-10.

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PMP	DSCT-04	Wt	CGs	Is
OGD Slope SWPT	Selected Ops 3 weight switch point (lbm)	√		

- 5) Configure **Cargo B/U**
- Zero out weights for deployed cargo or transferred items
  - Enter weights for retrieved cargo or returned items
- NOTE: √ Cargo B/U against Deorbit section of PROP-34.

NOTE: the item name in the first line of the Cargo B/U should be "FXD-PAYLOAD". The SpOC D/O Manager software is using this line in its electronic configuration interface.

- 6) Configure **Non-prop B/U** from PROP-34 Deorbit TIG Configuration

PMP	PROP-34	Wt	CGs	Is
GN2 SYS 1	GN2 SYS 1	√	√	√
GN2 SYS 2	GN2 SYS 2	√	√	√
MISC PRESS & H2O	MISC PRESS & H2O	√	√	√
Other Non-prop consumables	same section of PROP-34	√		

- 7) Configure **Cryo B/U** weights from PROP-34 Deorbit TIG Configuration
- 8) Configure **Orbiter B/U** from PROP-34 Deorbit TIG Configuration

PMP	PROP-34	Wt	CGs	Is
OMS FU/OX R/L	OMS FU/OX R/L	√		
RCS FU/OX AFT R/AFT L/FWD	RCS FU/OX AFT R/AFT L/FWD	√		
OMS PROP MISC	OMS PROP MISC	√	√	√
RCS UNUSABLE	RCS UNUSABLE	√	√	√

- 9) **Process** → **Xfer CL Doors**  
√Orbiter B/U line 1 "(CL)", wt, and CGs
- 10) √Orbiter B/U line 25 ≈ Line 25 of Deorbit TIG Configuration
- 11) **Process** → **OMS Depletion**
- Set  $\Delta OMS = \text{PROP-34 Line 176} - \text{Line 183 of the Deorbit TIG PROP-34 CG Sum page}$
  - √CG SUM landing weight < Nominal EOM limit (FR A4-159)
- 12) √**Displays** → **CG SUM** or **OMS Depletion**
- 13) **Process** → **Ballast**
- Enter minimum OMS from worksheet if available
  - ARCS = 510 + FRCS Dump \* 0.020100595 (this computation is automated)
- 14) **Displays** → **Orbiter B/U**
- 15) √**File**: /users/fdo/<user\_id>/<flight\_id>/pmp\_default\_ENT\_data.xs<#>



## FDO Console Handbook Section 3.6: Orbit Mass Properties

- 16) **File** → **Save**
- 17) Inform Entry and Lead FDO of results (ballast, landing weight, etc.)
- 18) Using an xterm, perform the following steps to protect the file from accidental writes:
  - a) `cd /users/fdo/<user_id>/<flight_id>/`
  - b) `chmod 444 pmp_default_ENT_data.xs<#>`
- 19) Inform the Lead FDO of the new data file and its location.
- 20) Fill out a GA/Dynamics Initialization PAD requesting the file be moved into the appropriate cycle of the flight specific database, have the Lead FDO sign the request, and submit it to the TOCSS GA group.

### 3.6.6.3.4 DNAV Configuration

Once the ASC, ORB, and ENT files have been configured and verified, notify the GA and provide the full path name for the three files. The GA should copy these files to the `/user/trj/Database` so that the PMP-Baseline-XXX DNAV menu item will select these files when the corresponding activity is selected at login.

### 3.6.6.3.5 CTL EMCC File Transfer

CTL mass properties will be stored on a CD by the TOCSS GA's prior to launch. The EMCC FDO will load the baseline PMP files into the portable EMCC workstation if EMCC is activated. Current quantities will then be typed-in manually based on hardcopies obtained from the MCC.

## 3.6.7 Real Time Procedures

A systematic real time mass properties update method has been developed which benefits all flight control teams. Predicted next PLS mass properties duties are left to the Planning Team TRAJ, so only current mass properties are configured at the end of each shift (see Section 3.6.7.2). This method works very well and is a good way to keep track of all mass property data generated. However, for such major events as deploys, retrievals, unexpected prop usage, or large water dumps, the TRAJ on-duty must reconfigure current data, and quite possibly next PLS mass properties, to account for the situation.

The Planning TRAJ (usually Orbit 3) generates predicted mass properties as described in Section 3.6.7.3. Normally, neither the Orbit 1 TRAJ nor the Orbit 2 TRAJ will need to generate predicted mass property data, but either may need to sync the TSA DMP/EDS mass properties during their shift as the next PLS approaches. If an unplanned deorbit or some other contingency situation arises, TRAJ may need to reconfigure the TSA DMP/EDS display with current quantities by syncing the TSA DMP/EDS mass properties with the current PMP data.

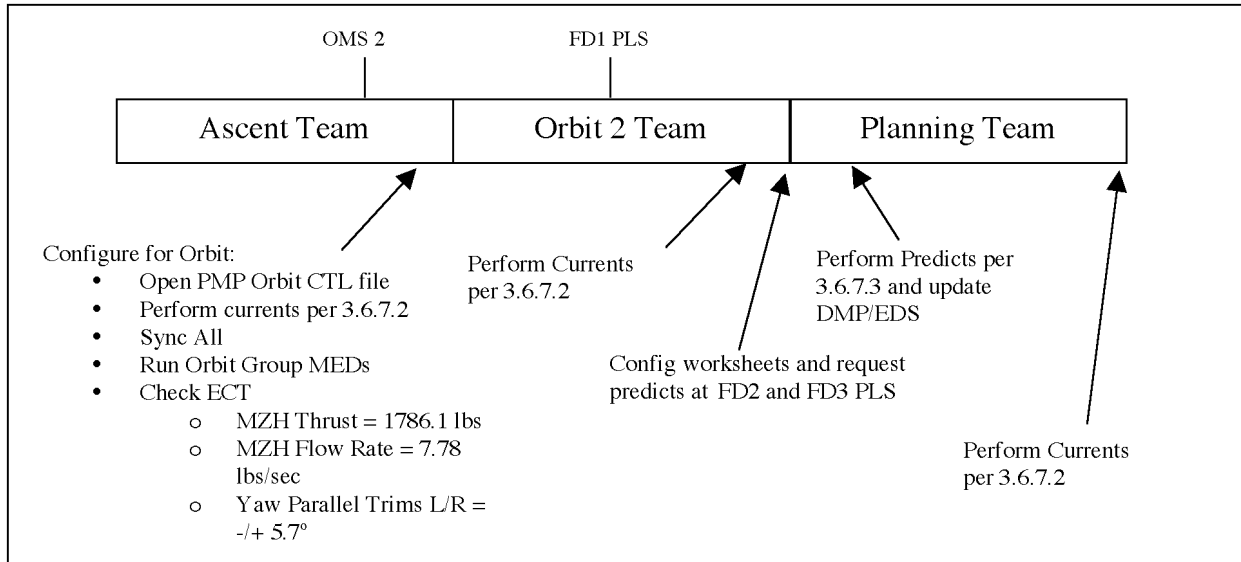
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**CAUTION:** when running an orb normal in EDS, DYNAMICS will need to fetch the latest DMP mass properties data prior to execution. This is because the orb normal EDS configuration does not contain up to date mass properties data.

Mass properties data are generally updated at standard times during the mission. For example, predicted mass property updates are initiated at the beginning of the Planning shift or by the prior shift when predicted quantities are requested from PROP, EECOM, EGIL, and MMACS. About two hours into the Planning shift, predicted quantities should be available, and predicted mass properties can be generated. The DMP/EDS mass props are updated with the PMP file for the next next PLS once the upcoming PLS is less than 4 hours in the future. Current mass properties are performed and the engine trims updated once per shift, usually just prior to handover, or for significant mass property events (e.g. deploy, retrieve, rendezvous/dock, etc.). ISS cargo transfer mass property updates are initiated when the updated cue cards are received and as time permits. The following timelines shown in Figures 3.6.7-1 through 3.6.7-3 provide an illustration of mass property activities performed during a mission. Refer to Section 3.6.7.1 for ISS Transfer procedures, Section 3.6.7.2 for Current Mass Property procedures, and Section 3.6.7.3 for Predicted Mass Property procedures.

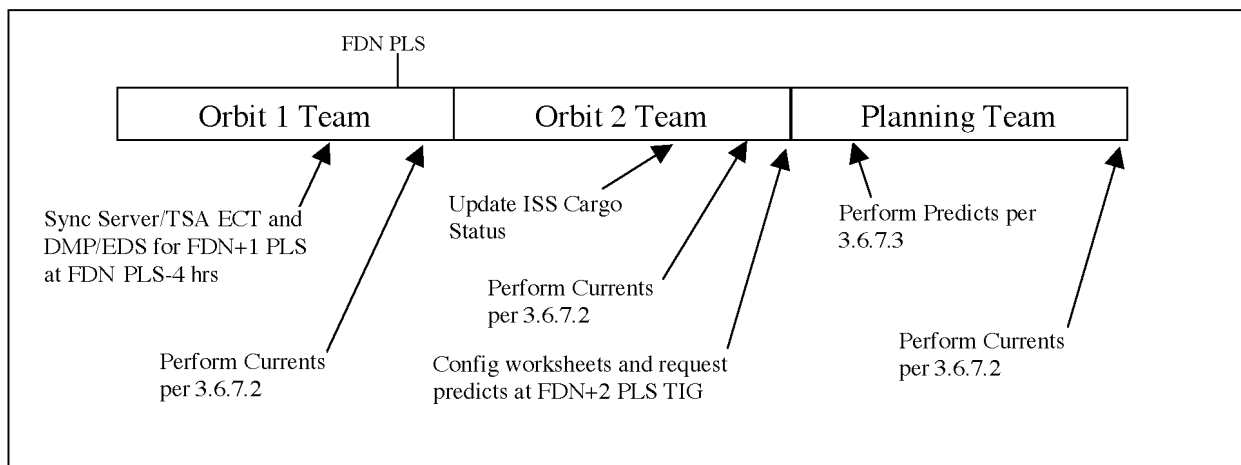
After OMS 2, the Ascent TRAJ configures the Engine Characteristics Table's OMS pitch and yaw CG trims in the Trajectory Server and TSA, and the DMP/EDS mass props in TSA using the Orbit CTL baseline PMP file updated with current mass properties. The Orbit PMP file rather than the Ascent PMP file is required to replace Systems AOA CG SUM data with orbit/entry data. Even though the DMP/EDS mass props are normally configured for the next PLS, they are configured with current data after OMS-2. Until predictions are available, current data will be reasonably close to FD1 PLS. The left and right yaw parallel OMS trims should have already been set prelaunch to  $-5.7^\circ$  and  $+5.7^\circ$ , respectively. Dynamics runs the Orbit Group MED to update the MZH thrust and weight loss rate for FRCS. The Ascent FDO/Traj will manually set the initial guess for C1, C2, and range at EI to zero before the Orbit 2 handover. The FD1 Planning Team shift will request predicted quantities and generate predicted mass properties for the next (FD2) and next next (FD3) PLSs in order to "catch up". At the end of each shift or following a significant mass property event, currents will be performed with doors open, and the ECT OMS pitch and yaw CG trims will be updated. The ECT pitch and yaw CG trims will be synced to the Trajectory Server and TSA.

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**Figure 3.6.7-1: Post-Insertion Mass Property Timeline**

Orbit mass property updates will be performed as necessary for dynamic events such as deploy, retrieve, rendezvous, and orbit adjust. Standard orbit mass property activities include updating the ISS Cargo Transfer spreadsheet as data become available, performing currents with the doors open and updating the TrS/TSA ECT OMS CG trims at the end of each shift, requesting predicted quantities at the beginning of the Planning shift, performing predicted mass properties for the next next PLS, and reconfiguring the DMP/EDS data for the next next PLS when the next PLS TIG is less than about 4 hours in the future.

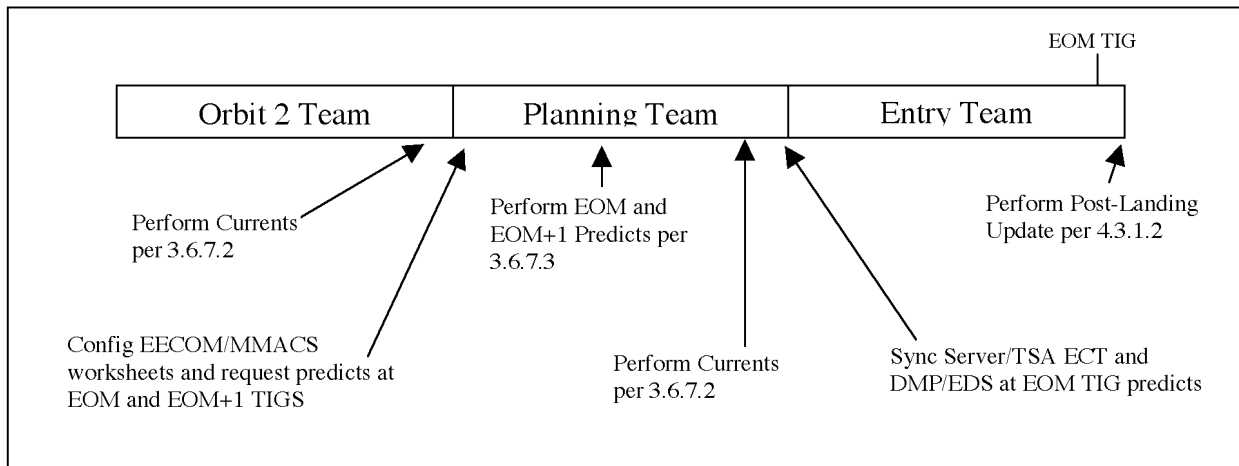


**Figure 3.6.7-2: Steady-State Orbit Mass Property Timeline**

During the Planning shift prior to EOM Entry Team arrival, EOM predicted quantities are requested again to further refine EOM mass properties (they were already requested the day before when EOM was the next next PLS). EOM+1 predicts are also requested during the EOM-1 Planning shift in case an EOM wave-off is necessary. Once the EOM predicted mass properties have been generated, the Trajectory Server and TSA ECT OMS pitch and yaw CG trims (doors closed) and DMP/EDS data are updated with EOM data. If a one-day wave-off is necessary, this activity will be repeated during the EOM Planning shift so that the ECTs/DMP/EDS are configured with EOM+1 data for the Entry

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Team. The EOM+2 predicted mass property data are generated in case another wave-off is necessary. Post-landing, the Entry TRAJ will perform post-landing mass properties per Entry FDO Console Handbook Section 4.3.1.2.



**Figure 3.6.7-3: Pre-Entry Mass Property Timeline**

### 3.6.7.1 ISS Cargo Transfer

While docked to the International Space Station (ISS), FDO will be required to accurately track all cargo transfers as they proceed during mated operations. Transferred cargo weight on these missions can amount to several tons, with some allocated for transfer to ISS (resupply) and some allocated for transfer back to the Orbiter (return). Although Orbiter weight may undergo only a small net change after all resupply and return transfers, a significant Orbiter CG shift is possible. In turn, the CG shift may change ballast required to maintain Orbiter CG within the nominal CG box.

The TDDP and Flight Design products provide cargo weights and CG for launch and landing only. However, it is necessary for FDO to have an accurate daily cargo config picture to plan PLS deorbit or in case of an emergency deorbit. It is for this reason that mass transfers must be tracked in greater detail than what is provided by preflight products. The Lead FDO usually delegates all cargo transfer responsibilities to the co-lead FDO (typically a TRAJ). The cargo transfer process is subject to frequent change, close to launch and even into real-time. As a result, the Co-Lead FDO is usually busy preparing cargo transfer console data throughout the two - three weeks prior to launch.

The first step in preparing mass transfer data is for the Co-Lead FDO to contact the Lead Assembly and Checkout Officer (ACO) and request to be placed on distribution for any cargo transfer e-mail correspondence. Then the Co-Lead will be notified of any Transfer Cue Card Reviews (typically held inside L -1 month). Following these tag-ups, an electronic copy of the Transfer Cue Cards (crew procedures governing cargo transfer activities) will be sent out to distribution. Another good source of information is the Assembly Ops Handbook, which documents planned cargo transfer operations.

At about L-2 weeks, the Co-Lead FDO should prepare an Excel spreadsheet listing expected middeck cargo transfer activities. Start with the mass transfer spreadsheet from the most recent mission, then use ACO's Transfer Cue Cards as the basis to update the spreadsheet. Cue card transfer items are manually entered into the FDO spreadsheet,

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which computes total weight and CG location of all cargo aboard the Orbiter. The spreadsheet outputs weight and CG location for both resupply and return items, and this data can be entered into PMP's CARGO BUILD-UP display.

**CAUTION:** the most recent Transfer Cue Cards should be considered the most accurate estimate of cargo transfer status at any time. The transfer planning process is very volatile, and changes can be expected even after launch. Console use of Flight Design cargo transfer data in PROP-34 should be limited to sims where an acceptable flight-specific spreadsheet is unavailable. The PROP-34 data may also be useful for gross reasonableness checks.

Figure 3.6.7.1-1 is an excerpt from the STS-105 FDO spreadsheet's Resupply Inventory List segment (some extraneous columns are hidden). It's followed by a description of each spreadsheet column from left to right.

	RESUPPLY INVENTORY LIST	Reference		Current			
#	Object description	Weight (lb)	Location	Weight (lb)	XCG (in)	YCG (in)	ZCG (in)
	<b>FD3 Clear Middeck</b>						
1	Shuttle XL EMU [S/N 3016]	208.0	External A/L Floor	0.0	649.0	0.0	325.7
2	LTA	53.0	External A/L Floor	0.0	649.0	0.0	325.7
3	Helmet	10.1	External A/L Floor	0.0	649.0	0.0	325.7
4	EMU Battery	9.9	External A/L Floor	0.0	649.0	0.0	325.7
5	LiOH CCC	6.4	External A/L Floor	0.0	649.0	0.0	325.7
6	"FR" Crew Pref Bag	15.0	External A/L Floor	0.0	649.0	0.0	325.7
7	Shuttle EV Comm Caps	1.3	External A/L Floor	0.0	649.0	0.0	325.7
8	IELK (1 bag (5MLE))	92.6	PORT CEILING BAG #1	92.6	535.8	-15.9	389.5
9	IELK (1 bag (5MLE))	92.6	PORT CEILING BAG #2	92.6	535.8	-15.9	372.0
10	IELK (1 bag (5MLE))	92.6	STBD FLOOR BAG #2	92.6	534.3	19.5	353.0
11	CHeCS Transfer Bag	169.0	PORT FLOOR BAG #1	169.0	534.3	-12.9	335.5
12	EVA/AMP/IMAX/SSMMU	115.0	STBD FLOOR BAG #1	115.0	534.3	19.5	335.5
13	SODF & CD Carrying Case	39.7	Volume F	39.7	491.0	33.0	315.0
	<b>MDK Floor Port Bag Xfers</b>						
30	ALSP Contents Kit [AMP CTB]	0.0	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
31	ALSP Drug Pack [S/N 1001]	9.7	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
33	Ambulatory Medical Pack	31.0	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
35	ACLS Booklet [SODF CTB]	0.0	Volume F	0.0	491.0	33.0	315.0
37	ISS Med Checklist [SODF bag]	0.0	Volume F	0.0	491.0	33.0	315.0
39	Microbial Air Sampler [S/N 1002]	11.5	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
41	Surface Sample Kit [S/N 1001-2]	4.4	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
43	Formaldehyde Monitor Kit (FMK)	0.2	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
45	Passive Dosimeter Sys	3.0	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
47	MEC CD Case	1.0	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5
50	Volatile Organic Analyzer	93.0	PORT FLOOR BAG #1	0.0	534.3	-12.9	335.5

**Figure 3.6.7.1-1: Cargo Transfer Spreadsheet Excerpt**

1) #: transfer item number corresponding to the item number in the ACO Transfer Cue Card

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- 2) Object description, Reference Weight (lb), Location: each item's name, followed by its reference weight and storage location at launch (in the Resupply worksheet) or landing (in the Return worksheet). The spreadsheet has links to automatically translate standard storage location names into x, y, and z CG data in the rightmost columns.
- 3) Current Weight (lb): this column is used to track the status of each item. In the Resupply worksheet, current weight is set to the reference weight at liftoff, then the weight is zeroed out once the item has been transferred. Thus, a zero weight in the Resupply Inventory indicates the item has already been transferred to ISS and is no longer being tracked by the spreadsheet as contributing to Orbiter mass properties. A non-zero weight would then indicate an item yet to be transferred. Opposite logic applies to the Return Inventory List. A zero weight would indicate the item has not yet been transferred to the Orbiter, and a non-zero weight indicates the transfer has occurred and is currently being tracked by the spreadsheet.

NOTE: the Transfer Cue Cards do not specifically call out whether a given item is a Resupply or Return item. Rather, the initial and final storage location must be examined to make this determination. For example, an item whose initial stowage location is LAB1D4\_D2 (ISS lab module) and final location MF71E (middeck locker) belongs in the Return category.

- 4) XCG (in), YCG (in), ZCG (in): each item's Orbiter Structure CG coordinates appear as inferred from the Location column.

Some special cases warrant further discussion. Note Items 30-50 in Figure 3.6.7.1-1 have their current weight "grayed out" and hardcoded to zero. This means the items are already included in a previous callout (in this case, the CHeCS transfer bag, item 11). Including the weight for each of these sub-items in the current weight column would result in a double-bookkeeping the CHeCS contents in the Resupply total weight and CG. Consequently, sub-item weights are set to zero, and notes are added to the appropriate cells explaining their inclusion in Item 11. Why track these items in the first place? That's to prevent confusion when real-time cue cards are published containing the complete list, while FDO's spreadsheet only contains a partial list. It would be unclear to the team whether or not the FDO spreadsheet was incomplete. Another special case is the scenario where Shuttle hardware, such as EMUs, are transferred to the ISS. For example, Items 1-7 above are to be transferred to ISS to support EVA operations. However, the TDDP already charges EMUs to Shuttle crew compartment weight, which gets included in Orbiter inert weight. If the reference EMU weights were entered into the FDO spreadsheet, then they would be counted twice for launch. A workaround is to set current weight for these items to zero at launch, and then enter a *negative* weight when the item is transferred. Again, appropriate notes to this effect should be included in the spreadsheet.

CAUTION: Condensate Water Containers (CWCs) should be tracked in the PMP Cargo page explicitly; not in the cargo transfer spreadsheet. Be careful to ensure CWCs specified in the ACO Transfer Cue Cards are not tracked in the FDO transfer spreadsheet. Since the CWC plan is always changing, it's easier to track CWCs in PMP's Cargo Page versus the FDO transfer spreadsheet.

Once FDO's transfer spreadsheet has been configured per ACO's Transfer Cue Cards, the Co-Lead FDO should contact ACO Transfer and the Boeing TDDP representative to conduct a *line-by-line review of each item*. This process will identify any items subject to inadvertent double-bookkeeping. A phone call to TDDP personnel should also be made if there is any doubt as to whether Transfer Cue Card entries are also included in Orbiter inert weight. This process may also uncover weight or stowage location errors. Once the

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transfer spreadsheet is verified, Resupply and Return weights and CGs from the Summary worksheet are entered into PMP's CARGO BUILD-UP display. These entries replace TDDP Logistics and Return items, respectively. It is important to check that the spreadsheet output matches these TDDP items to within about 50 lbm weight and 0.5 inches CG. If not, TDDP and ACO personnel should be contacted again to determine if late changes in the manifest have rendered the TDDP out-of-date. Otherwise, an error is likely present in the spreadsheet. This process can continue up until docking as the Transfer Cue Cards mature. If the TDDP isn't known to be outdated, it may be advisable to stick with its cargo items in PMP prior to docking. This provides additional time to stabilize last-minute changes in the Transfer Cue Cards.

Post-docking, TRAJ needs to pay close attention to crew calls during cargo transfer activities. At the conclusion of each crew day, a list of transferred items will be voiced from the crew to MCC. This list will contain numeric items whose nomenclature is consistent with the Transfer Cue Cards. For example, a crewmember might call down something like "we have transferred items 1 through 10, 12 through 15, 17, 19, and 21 through 23". TRAJ should note these comments, log them, and reconfigure the spreadsheet accordingly in order to compute a preliminary total cargo weight and CG based on the latest transfer status. Spreadsheet output then serves as input to the CARGO BUILD-UP; namely the Resupply and Return entries in the CARGO BUILD-UP are updated. A new Orbiter weight and CG are produced in accord with cargo transfer tracking. ACO also monitors the crew call and will develop official transfer activity summaries for the day.

This final account of cargo status for the flight day is published as an updated Cue Card inventory during the next Planning shift and is known as the Transfer List. Per ISS FCOH SOP 2.34, Transfer List updates are received from ACO Transfer as an internal Flight Note. Similar flight-specific cargo transfer update processes involving internal Flight Notes are supported under SOP 2.34 as follows.

- 1) EVA Task tracks transfers performed external to the mated habitable volume in updates to the EVA Transfer Cue Card.
- 2) IMC tracks total MPLM mass and CG.
- 3) SH STOW tracks total Spacehab mass and CG.

Updates received under SOP 2.34 should be checked against the Cargo Transfer spreadsheet to insure consistency. Figure 3.6.7.1-2 was taken from the STS-105 cargo transfer spreadsheet's Summary for Flight Day 4.

<b>MASS TRANSFER SUMMARY</b>				
	<b>WEIGHT</b>	<b>XCG (in)</b>	<b>YCG (in)</b>	<b>ZCG (in)</b>
<b>RESUPPLY (Middeck &amp; EVA) TOTAL</b>	368.3	272.0	-7.1	399.2
<b>RETURN (Middeck &amp; EVA) TOTAL</b>	551.2	558.2	-19.5	350.6

**Figure 3.6.7.1-2: Cargo Transfer Spreadsheet Summary**

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During Planning shifts affected by cargo transfer status crew calls, TRAJ will perform typical mass property duties with one exception. Two ballast values are computed, with the larger and more conservative ballast value relayed to PROP. The first ballast value is computed based on the current cargo transfer configuration. This assumes no further cargo transfer activities before undocking and deorbit. TRAJ will configure CARGO BUILD-UP with the current Resupply and Return lines, then compute the ballast requirement as described in Section 3.6.7.3. The second ballast value is computed with all cargo items transferred. The spreadsheet's Resupply segment will have *all* zero weights, and its Return segment will have *no* zero weights in support of this ballast case. With the "transfers complete" ballast run, all cargo transfer activities are assumed to proceed at an increased rate such that they are finished prior to undocking and deorbit.

NOTE: as long as the cargo transfer plan remains unchanged, the "transfers complete" spreadsheet configuration can be archived for repeated use.

MPLM up and down weights are also provided in the TDDP and Flight Design products as described above. TRAJ simply updates the MPLM entry in PMP's CARGO BUILD-UP based on pertinent internal Flight Notes from ACO. It is prudent to perform a sanity check on ACO-provided data by verifying MPLM weight lies between up and down values specified in the TDDP. In doing so, be aware that interim MPLM weight may be significantly lower than either TDDP value after unpacking and before restow. Center of gravity data should be checked against MPLM certification limits specified in ISS-MPLM-IDD-006 MPLM Interface Definition Document, Section 2.2.2 "CG Constraints". If CG falls outside the certification envelope, or if the weight looks suspicious, then a call to ACO Transfer is warranted to troubleshoot. By the time the MPLM is returned to the Orbiter cargo bay, its weight and CG should be quite close to those specified in the TDDP for landing. If not, contact ACO Transfer to get an explanation of the differences. Keep in mind, however, that overall Orbiter XCG is not very sensitive to changes in MPLM mass properties if the MPLM is berthed near the Orbiter's CG, as is typically the case. The same *cannot* be said for changes in middeck mass props: Orbiter CG is quite sensitive to changes in middeck weight (300 lb change in middeck moves X-CG about 1 inch).

### 3.6.7.2 Current Orbiter Mass Properties Console Procedures

Historically, the current set of mass properties is computed approximately once per shift or after any event that significantly alters propellant or payload configurations. The following procedure outlines a routine three-segment process using Paperless Mass Properties (PMP) to compute current Orbiter mass properties. Real time data are gathered electronically in the Data Snap segment, an OMS Depletion sequence is performed in the second segment, and dependent Trajectory Server/TSA data are updated in the third segment.

NOTE: static inertia tensor components are entered when generating the PMP baseline file pre-mission (see Section 3.6.6), and dynamic inertia tensor components are updated automatically as weight and CG inputs are processed in the following procedure. Inertia tensor output is not interfaced with any processor external to mass properties and is only used to satisfy verbal requests for data from other disciplines, notably GNC. Consequently, inertia tensor checks are only necessary when responding to a verbal request.

- 1) Call PROP, EECOM, EGIL, and MMACS for GO to "Snap" real-time data



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- 2) Select **FDO DNAV** → **Mass Props** → **PMP-Current**  
NOTE: if no currents are available, select **PMP Baseline** to start PMP, then select appropriate file using OPEN.
- 3) ✓**ORB** spreadsheet
- 4) **Data** → **Get Realtime...**
  - a) ✓good telemetry
  - b) ✓values for format (yellow means static data, red means out of limits)
  - c) ✓status indicators (“X” OK for OMS interconnect, if “<” or “>” ✓ with operator)
  - d) Select **Snap**
- 5) **Displays** → **Cargo Build-up**
  - a) Zero/enter weights of deployed/retrieved payloads
  - b) If ISS, enter mass transfer from spreadsheet summary
  - c) If required, **Displays** → **Cargo B/U Inertia**, ✓ vs. databook
- 6) **Displays** → **Non-Prop Build-up**
  - a) ✓EECOM and MMACS data
  - b) If required, **Displays** → **Non-PROP B/U Inertia**, ✓ vs. databook (zeroes except GN2 and pressurants)
  - c) ✓MISC PRESS & H2O = PROP-34 Payload Bay Door Open Configuration
- 7) **Displays** → **Cryo Build-up**
  - a) ✓EGIL data
  - b) If required, **Displays** → **Cryo B/U Inertia**, ✓zeroes
- 8) **Displays** → **Orbiter Build-up**
  - a) ✓PROP data
  - b) ✓Line 1 Payload Bay Door config = OP (orbit); = CL (entry)
  - c) If required, **Process** → **Transfer Doors <Open or Closed>**
  - d) If required, **Displays** → **Orbiter B/U Inertia**, ✓ vs databook
- 9) **Process** → **OMS Depletion...**
  - a) Enter  $\Delta$ OMS from PROP
  - b) ✓Mixture ratio
  - c) Enter FRCS if PMP’s default dump to depletion assuming 1.6 OX:FU ratio is inappropriate (zero out FRCS wt if no FRCS dump)
  - d) ✓Tank selection
  - e) ✓Doors open (orbit) or closed (entry)
  - f) Select “OK”
  - g) ✓Line 191 for  $\Delta$ OMS = 0
- 10) **Data** → **Sync TSU...**
  - a) ✓ Global, Select **SYNC ECT** button
  - b) Monitor Advisory Services
  - c) ✓MEDs complete
- 11) Select Server and TSA Global ENGINE CHAR TABLE, then ✓ OMS PITCH and YAW CG trims

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- 12) **File** → **Save As...** current.xs<#>
- 13) **File** → **Save As...** cur###.xs<#>, where ### = orbit number
- 14) Obtain new current weight by truncating decimal digits or subtracting one pound if zero after decimal place
- 15) Provide PROP with new current weight
- 16) Update Ephemeris Weights per FDO request

NOTE: usually WGL E1 at current time and INIT or chain other Orbiter ephemerides, as required. Since E2 is now the long-term planning ephemeris, it only gets updated about once per day or two unless there is a significant change in the Orbiter's trajectory.

CAUTION: if burns prior to the EPHB epoch reside in an MPT, any change to the corresponding INIT weight will generally result in an unintended CURRENT weight. This is a permanent TrS limitation (reference AR 019409 closure). Before making an INIT weight change, verify all burns prior to EPHB are deleted and converted to WGLs as appropriate.

- 17) Inform FDO of new current weight and log results

### 3.6.7.3 Predicted Orbiter Mass Properties Console Procedures

Procedures below explain how to operate displays and use other sources of information to accurately predict the Orbiter's future mass properties. Configuring the mass property tables for the next PLS or any other event in the future is usually required on the Planning shift. For single-shift crew operations, this task usually falls to the Orbit 3 Team. Since TRAJ has no future insight into consumable quantities, predicted quantities from EECOM, EGIL, MMACS, and PROP will be required in order to complete this task. EECOM will provide most NON-PROP quantities, EGIL will provide CRYOGENICS quantities, MMACS will supply APU quantities on the NON-PROP display, and PROP will provide OMS and RCS values on the ORBITER BUILD-UP. When requesting future quantities from other operators, it's important to communicate the MET to which they correspond, usually a PLS TIG. Check the weather sheet to determine which PLS site and opportunity will be used for predicts.

Normally, a request for predicted quantities is made at the beginning of the Planning shift or near the end of the preceding shift. During FD1's Planning shift, TRAJ will request predicted quantities for the upcoming PLS (FD2) and the PLS after the upcoming PLS ("next next PLS" on FD3). Subsequent Planning shifts will then normally only request predicted quantities for the "next next PLS". However, if there's a possibility that ballast will be required for EOM, TRAJ should also request EOM predicts after about FD4 or FD5, once EECOM and EGIL have an understanding of expected usage. Early analysis of ballast requirements may allow CG management techniques to be employed to provide ballast relief if required. Requesting predicted quantities for the "next next PLS" is repeated each Planning shift until that preceding the EOM Entry Team shift, when TRAJ will request two sets of predicted quantities. One request is at the EOM deorbit TIG and serves as an update to data received the day before. The other request is again at next next PLS

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(EOM+1) to cover an EOM wave off. Predictions should be processed in reverse chronological order, leaving the Entry Team with the best estimate of EOM mass properties. At this point in the mission, two requests for predicted data are repeated each day until the Orbiter lands or there are no more wave-off opportunities.

Predicted quantities should be supplied within about 2 hours after TRAJ has made the request. However, if an excessive amount of time has elapsed and the values are not yet available, FDO or TRAJ may wish to contact tardy operators to determine the problem. If it is not possible to get predicted values from operators working higher priority tasks, it's in TRAJ's best interest to estimate missing predicted values using trends from previous shifts or from PROP-34's Fluid Budget. Biasing future quantities in the FDO Data Book by the difference in quantities at present is a good estimate of future quantities. It should be emphasized this method is not proven but has provided better values than no predictions at all.

The following procedure outlines a routine five segment process using Paperless Mass Properties (PMP) to compute predicted Orbiter mass properties and to check for ballast requirements. These five segments include requesting predicted quantities, entering predicted quantities, performing an OMS Depletion sequence, computing ballast, and syncing the Trajectory Server and TSA. Based on the specific circumstances, it is possible only a subset of the five segments will be performed to carry out mass property computations. For example, predicted mass property data is usually generated for the next PLS after the upcoming PLS ("next next PLS"), but the DMP/EDS is configured for the upcoming PLS. The DMP/EDS is not configured for the "next next PLS" until the upcoming PLS is less than four hours in the future. At that time, the DMP/EDS is replaced with the new next PLS data.

**CAUTION:** perform an OMS Depletion sequence immediately before syncing the Trajectory Server/TSA Global to eliminate the possibility of transferring incorrect or stale data to the Trajectory Server/TSA Global. The OMS Depletion sequence will compute and update appropriate weights and CGs on the CG SUM page based on user inputs.

Request mass property Predicts.

- 1) Select **Data → Get Predicted**
- 2) Select the **Request** button
- 3) Enter Flight Day # (e.g. 3, not FD3), PLS site, D/O TIG REV, and TIG
- 4) Click **OK**
- 5) Verbally request predicted quantities from PROP and EGIL by giving them the PLS TIG

When Predicts become available, perform the following procedure.

- 1) Select **FDO DNAV → Mass Props → PMP-Predicted**  
**NOTE:** if no predicted data are available, select **PMP Baseline** or **PMP Currents** to start PMP, then select appropriate file using OPEN.
- 2) ✓**ORB** spreadsheet

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- 3) **Select Data** → **Get Predicted**
  - a) Select the PLS for each discipline
  - b) Click **OK**
  
- 4) **Displays** → **Cargo Build-up**
  - a) Zero/enter weights of deployed/retrieved payloads
  - b) If ISS, enter mass transfer from spreadsheet summary  
**CAUTION:** use more conservative of current transfer status or completed transfer status (for forward CG violations, current is usually more conservative since CG moves aft as items are transferred).
  
- 5) If required, **Displays** → **Cargo B/U Inertia**, √ vs databook
  
- 6) **Displays** → **Non-Prop Build-up**
  - a) √MISC PRESS & H2O = PROP-34 Payload Bay Door Configuration
  - b) If required, **Displays** → **Non-PROP B/U Inertia**, √ vs databook (zeroes except GN2 and pressurants)
  
- 7) If required, **Displays** → **Cryo B/U Inertia**, √zeroes
  
- 8) **Displays** → **Orbiter Build-up**, then √Line 1 Payload Bay Door config = **CL**
  
- 9) If required, **Process** → **Transfer Doors Closed**
  
- 10) If required, **Displays** → **Orbiter B/U Inertia**, √ vs databook
  
- 11) **Process** → **OMS Depletion...**
  - a) Enter  $\Delta$ OMS from PROP to FDO (for prelim predicts, use PMP's estimate)
  - b) √Mixture ratio (usually 1.66 for OMS)
  - c) Enter FRCS (PMP's default dump to depletion assumes a 1.6 OX:FU ratio)
  - d) √Tank selection
  - e) √Doors closed
  - f) Click **OK**
  
- 12) **Displays** → **OMS Depletion**
  - a) √predicted weight in first line
  - b) √ $\Delta$ OMS
  - c) √TVC WT = predicted wt -  $\Delta$ OMS
  
- 13) **Displays** → **CG SUM**
  - a) √TVC WT POST D/O line from OMS Depletion
  - b) √FRCS Dump from Step 11 (= 0 if no FRCS dump)
  - c) √EI, TAEM, and Landing wt and CGs
  
- 14) √**Displays** → **CG SUM** or **OMS Depletion**
  
- 15) **Process** → **Ballast...**
  - a) √OMS mins vs OMS Ballast Baseline Quantity Worksheet in FDO data book

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- b)  $\sqrt{\text{FRCS}}$  from Step 11
  - c)  $\sqrt{\text{ARCS min}} = 510 + \text{FRCS} * 0.201000959$
  - d) Compute for OMS (or ARCS at Prop's Request)
  - e) Perform ballast comps with and without payload for deploy/retrieve if required
- 16) **Displays** → **CG SUM**, then  $\sqrt{\text{TVC WT POST D/O CG SUM line vs OMS Depletion (wt and CGs)}}$ . If incorrect, repeat OMS depletion Step 11
- 17) **File** → **Save As...** predicted.xs<#>
- 18) **File** → **Save As...** XXX###.xs<#>, where XXX = PLS, EOM, EOM+1, etc, and ### = orbit number
- 19) If ISS Transfer not complete,
  - a) **Displays** → **Cargo B/U**
  - b) Zero Resupply weight
  - c) Enter Return weight assuming transfer complete (see Section 3.6.7.1)
  - d) **Process** → **Ballast...** per Step 15.
- 21) Provide PROP with predicted weight and ballast requirements.
- 22) Inform FDO of new predicted weight and any ballast requirements.
- 23) Log results and include cargo config per the following template
  - a) Orbit ## PLS wt ##### XCG ####.## YCG ±#.## ZCG ###.##
  - b) Ballast ### lbs OMS FRCS Dump ### lbs ΔOMS #####

Transfer OMS Depletion data to the TSA Global when required per the following steps.

- 1) Notify Dynamics of a TSA Global update
- 2) **Data** → **Sync TSU...**
  - a) Global,  $\sqrt{\text{filename}} \rightarrow \text{massprop.txt, SYNC DMP/EDS}$
  - b) Monitor Advisory Services
- 3) Verify DMP/EDS Data
  - a) Bring up DMP, select Global System, and then Mass Prop (F8)
  - b)  $\sqrt{\text{Displayed Filename}} \rightarrow \text{massprop.txt}$
  - c)  $\sqrt{\text{Depletion and CG Summary information}}$

### 3.6.7.4 PMP Entry FRCS Modeling and Implications

Orbit and Entry PMP configurations assume there is no FRCS usage between D/O TIG and the FRCS dump. PMP assumes all FRCS propellant contained in Orbiter Build Up Lines 9 and 10 is dumped to residual levels in CG Sum page Line 178. In reality, there is approximately 28 lbs of FRCS usage between the D/O burn and the FRCS Dump start time. FRCS is used for control during this timeframe. Therefore, if the FRCS system is healthy, but no FRCS dump is planned, TRAJ will need to model an FRCS dump of 28 lbs.

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NOTE: ARCS usage (0.6 lbs) due to an Orbit/Entry PMP FRCS dump is negligible and will not significantly impact entry weights or CGs.

The Ascent PMP configuration assumes there is no FRCS usage between Liftoff and the FRCS dump. PMP assumes all FRCS propellant contained in Orbiter Build Up Lines 9 and 10 are dumped to residual levels during the in CG Sum page FRCS dump Line 178. In reality, FRCS usage amounts to approximately 151 lbs between Liftoff and FRCS dump start time. Therefore, if the FRCS system is healthy but no FRCS dump is planned, TRAJ will need to model an FRCS dump of 151 lbs.

NOTE: ARCS usage (3 lbs) due to an Ascent PMP FRCS dump is negligible and will not significantly impact entry weights or CGs.

NOTE: if an FRCS failure prior to FD1 entry results in a cancelled dump, 151 lbs FRCS usage may not be correct. Consult PROP to determine how much FRCS to put in the dump line.

**Section 3.6 Concludes On This Page**

## FDO Console Handbook Section 3.7: Maneuver Operations

### 3.7 Maneuver Operations

During the orbit phase of flight, successful accomplishment of a maneuver typically involves FDO in the following processes.

- 1) Coordinate maneuver requirements and impacts among other controllers and facilities
- 2) Generate maneuver targeting data
- 3) Publish maneuver targeting data as a PAD and a command load
- 4) Monitor maneuver execution in near real time
- 5) Assess post-maneuver trajectory to determine targeting results

This section documents these processes for routine scenarios. Contingency maneuver operations, such as OMS leak responses and RCS leak responses, are documented in Section 3.9.

**CAUTION:** unless otherwise explicitly qualified by context in this handbook, the term "maneuver" should be interpreted as an action intended to accelerate a vehicle's CG (translation). This convention preserves a long history of precedent with respect to FDO jargon, facilities, and documentation including flight rules. However, other disciplines may use "maneuver" when referring to an action intended to change a vehicle's orientation about its CG (rotation). To avoid ambiguity when interacting with others, use the term "burn" for translations and the term "attitude maneuver" for rotations.

**NOTE:** crew procedures for executing on-orbit translation burns are contained in various flight data file books including ORBIT OPS, RENDEZVOUS, ORBIT POCKET, and others, both generic and flight specific. It is highly recommended that the reader consult these books during the reading of this section. It is mandatory that a FDO or TRAJ be thoroughly familiar with the appropriate crew maneuver procedures before participating in a simulation.

#### 3.7.1 MCC Maneuver Targeting Basics

Maneuver targeting is nearly always an iterative process, and it may be automated to some degree. An iteration begins as one or more maneuver input parameters or "targets" are systematically altered. The maneuver is then modeled in an ephemeris, where the post-maneuver trajectory is evaluated to determine if the desired results were achieved. Height offset from another vehicle's orbit, cross range to a landing site, and MET at an ascending node are all examples of maneuver objectives. If an objective

## FDO Console Handbook Section 3.7: Maneuver Operations

isn't achieved to sufficient precision, maneuver targets are readjusted to begin another iteration.

When manually iterating on maneuver targets, it's not uncommon to perform three or more "loops". Even in the fortunate case where a single objective is linearly related to a single target, it may be necessary to define the linear relationship with two iterations, then evaluate it with a third. A number of linear relationships pertinent to maneuver targeting are approximated by Appendix 3G's rules of thumb. In lieu of better information, these rules can often supply a good initial maneuver target "guess" with which to start iterating.

Some special-purpose targeting processors, such as OMP, are inconsistent to some degree with ephemeris maneuver models and trajectory propagation. These inconsistencies, together with nonlinear target-objective relationships or scenarios with multiple objectives, can lead to very complex iterations.

### 3.7.1.1 Mission Plan Table (MPT)

Each ephemeris contains a dedicated Mission Plan Table (MPT) which contains all the parameters required to define or model the maneuver in that ephemeris. In addition to burn targets, the MPT includes the TIG, burn initiate and burn out state vectors, available propellant, guidance mode, and thruster performance data from the Engine Characteristics Table (ECT). The ECT data define propellant flow rate and body frame thrust vector components specific to the engine or groups of engines that could be used for a maneuver. The MPT serves as the data interface between its ephemeris and the Powered Flight Numeric Integrator (PFNI). Using PFNI with a properly configured MPT, an ephemeris can model each maneuver as a non-impulsive event closely approximating associated vehicle mass loss, thrust duration, inertial body attitude, and velocity change. Nearly all MPT data serve as PFNI input, but a burnout state vector and remaining propellant weight from the PFNI output are also stored for each maneuver in the MPT.

NOTE: force models normally used to yield an ephemeris trajectory are abridged during a PFNI arc. In addition to engine thrust, PFNI only accounts for earth gravity through the low order oblateness harmonic, J2, and atmospheric drag. The '62 Standard Atmosphere is used by PFNI to model atmospheric density in its constant area drag force computation.

CAUTION: PFNI cannot integrate backward in time. Consequently, it's not possible to static start an ephemeris at a time prior to a maneuver with a vector that is after the maneuver time (see Section 3.3.1).

Typically, MPT maneuver data are configured using one of three possible methods.



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- 1) Replace one MPT with another as part of the ephemeris copy process.
- 2) Manually input, modify, or delete specific MPT maneuvers.
- 3) Replace or append a block of MPT maneuvers with targeting processor output as part of the maneuver transfer process.

In TrS, any of 10 MPTs (see Figure 3.7.1.1-1) can display data from up to two MPTs. The first displayed MPT is tied to that of the corresponding TrS ephemeris, while the second displayed MPT may be selected from any of the remaining 9. Each maneuver's TIG can be expressed in MET or in GMT. Up to 22 maneuvers can appear in any MPT display. MPT display configuration is controlled via the display controls on the FDO display.

107		E9 MERGED MISSION PLAN TABLE				B	
ORB VID EST 111		TGT VID				EXECUTE CANCEL	
GMTAV 023:13:35:00		GMTAV		TGT EPH 9		GMT 023:17:47:33	
CODE	TIG	ΔT	ΔV	ΔV REM	h a	h p	
E092XE01FC	023:15:39:00.0	01:00:00	1.0	161	154.2	142.0	
E090LE02FC	023:16:39:00.0	01:00:00	1.0	342	154.2	142.4	
E090RE03FC	023:17:39:00.0	01:00:00	6.0	334	155.8	144.2	
09BPE04FC	023:18:39:00.0	01:00:00	12.0	323	150.1	143.3	
094XE05FC	023:19:39:00.0	01:00:00	6.0	154	150.2	147.0	
09ZME06FC	023:20:39:00.0	07:00:00	6.0	127	148.5	145.2	
09BPE07FC	024:03:39:00.0		35.0	288	168.0	144.9	

**Figure 3.7.1.1-1: TrS Mission Plan Table (MPT) Display**

The CODE field in an MPT display contains multiple subfields, each with important information relating to each maneuver (see Section 3.7.1.6, Item M1). The first character in a maneuver's CODE may be "E" (Executed), "F" (Frozen), or blank (neither executed nor frozen).

Typically, a planned ephemeris maneuver is neither in an executed nor a frozen state. These maneuvers can easily be deleted during the maneuver planning process. When current TrS time passes an ephemeris maneuver TIG, the maneuver is "executed". Maneuver execution logic freezes the maneuver on the ephemeris TIG vector if it has not been previously frozen. It also sets a flag in the Mission Plan Table indicating the maneuver has been executed. This protects the maneuver from being inadvertently deleted. Maneuver execution occurs automatically. Thus, an executed maneuver always has a TIG prior to current TrS time.

Operationally, FDO removes an executed maneuver in a TrS ephemeris by asking DYNAMICS to delete the maneuver. DYNAMICS is responsible for carrying out the proper procedure configuring the ephemeris as if the maneuver had never been

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modeled. The procedure is somewhat more complicated than deleting a maneuver that has not executed. An executed maneuver lying within a TrS ephemeris cannot be deleted due to a software inhibit. DYNAMICS must therefore anchor the ephemeris on a post-maneuver vector, typically a post-burn vector from that same ephemeris. Then the maneuver can be deleted from the MPT. The ephemeris may then be reinitialized on the original anchor vector. Finally, DYNAMICS and FDO must verify the ephemeris is properly configured.

A frozen maneuver supports accurate ephemeris modeling in scenarios when it's impractical to uplink a better ephemeris state vector to the Orbiter. Typically, a downlisted state vector is used to freeze the maneuver. An ephemeris state vector at TIG is used by PFNI as initial conditions regardless of whether or not a maneuver is frozen. In an unfrozen maneuver, this state is also used with PFNI's Powered Explicit Guidance (PEG) simulation to steer the maneuver's thrust vector. In a frozen maneuver, however, the degraded downlisted state drives PEG steering as it will in the real world. Any future maneuver can be unfrozen as dictated by unexpected events.

**CAUTION:** executed or frozen maneuvers cannot be deleted from an MPT unless they no longer reside within the interval defined by the ephemeris start and stop times. Although a frozen maneuver in the future with respect to current TrS time can be unfrozen, it's not possible to "unexecute" a maneuver.

**NOTE:** if a future maneuver is frozen, any future maneuvers prior to it will be frozen automatically. The default steering state for a frozen maneuver, including those frozen automatically, is the ephemeris TIG state when the freeze is goes into effect.

**NOTE:** TSA neither executes nor freezes maneuvers. A maneuver may be deleted from a TSA MPT by the same procedure, regardless of ephemeris time span or current time.

An existing maneuver's delta velocity ( $\Delta v$ ) or duration ( $\Delta T$ ) can be overridden in its MPT. The override occurs as though the maneuver were stopped short or long while maintaining the same guidance profile. If both  $\Delta v$  and  $\Delta T$  overrides are entered, the  $\Delta v$  override will be honored and the  $\Delta T$  override will be ignored.

### 3.7.1.2 Direct Input Maneuvers

The term "direct input" refers to manual entry of maneuver definition data in an MPT. DYNAMICS uses the M66 and M40 MEDs to perform direct input in the TrS. The M66 MED specifies maneuver definition parameters to an MPT and automatically updates the associated ephemeris. Five M40 MED formats are used to define maneuver targets depending on the guidance mode selected (M50/PEG-7, RES, PEG-4A, PEG-4D, or BFI). Thus, maneuver targets are first input via the M40 MED, then the M66 is used to

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transfer targets and supplemental information to the appropriate MPT, triggering PFNI modeling of the maneuver's trajectory effects in an ephemeris. M66 MED inputs are described below, while M40 MEDs are documented under the applicable guidance modes in Section 3.7.1.3.

- 1) Ephemeris ID: the ephemeris to contain the maneuver (1-4).
- 2) Maneuver No.: blank unless replacing an existing MPT maneuver (1-24).
- 3) Ignition Time: maneuver TIG GMT or MET.
- 4) Thruster: thruster code according to Figure 3.7.1.2-1.

Code	Thruster(s)	Attitude Control	Guidance Mode(s)
OBP	Both OMS w/parallel trims	OMS TVC	All
OBC	Both OMS w/CG trims	OMS TVC	All
OL	Left OMS	OMS TVC	All
OR	Right OMS	OMS TVC	All
PX2	Two +X (aft-firing) RCS	Tail Only	All
PX3	Three +X (aft-firing) RCS	Tail Only	All
PX4	Four +X (aft-firing) RCS	Tail Only	All
MXL	Two -X (fwd-firing) RCS	Tail Only	BFI
YL	Two +Y (left-firing) RCS	Nose/Tail	BFI
MYL	Two -Y (right-firing) RCS	Nose/Tail	BFI
ZH	Three +Z (up-firing) RCS	Nose/Tail	BFI
ZL	Four +Z (fwd/aft-firing) RCS	Nose/Tail	BFI
MZL	Six -Z (down-firing) RCS	Nose/Tail	BFI
MZH	Two -X (fwd-firing) RCS	Nose/Tail	All
M	Miscellaneous +X	n/a	BFI

**Figure 3.7.1.2-1: Standard Thruster Options**

**NOTE:** the foregoing set of thrusters and associated guidance restrictions only pertain to the TrS Engine Characteristics Table (ECT). All guidance modes apply to TSA-resident ECT thrusters. Although the TrS ECT may be modified, it should be regarded as a flight-independent data set under formal configuration control (see Section 3.7.1.4). A TSA ECT may be user-reconfigured at any time.

**CAUTION:** only +X and OMS thrusters from the TSA ECT can be processed by DMP. Attempts to use other thrusters in DMP will result in a Signal 8 abort. Because the Global TSA ECT supports DMP and other targeting by MPSR personnel, changes to it must be coordinated with DYNAMICS and specialist disciplines such as MARS.

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CAUTION: the TSA ECT uses an "OCG" thruster code for both OMS with CG trims. This is incompatible with the corresponding TrS "OBC" code. Consequently, dual-OMS burns with CG trims targeted by OMP or DMP must be manually input to TrS by DYNAMICS.

- 5) Guidance Mode: options are defined in Section 3.7.1.3. Valid inputs are P4A (PEG-4A), P4D (PEG-4D), M50, P7 (PEG-7), RES (Residuals), and BFI (Body Fixed Inertial). Default is P7.

NOTE: workstation PFNI implementation supports an additional BFI sub-mode known informally as BFL (Body Fixed LVLH).

- 6) Delta-T Ullage: default is zero. Time in seconds of ullage thrust. This pre-maneuver acceleration is intended to force propellant to the rear of the tank, insuring subsequent uniform flow during the maneuver itself. Non-zero ullage has never been used during SSP operations.
- 7) Desired Local Roll: default is zero. Local roll angle or TVR at ignition.
- 8) D.L.R. Indicator: defines the local roll axis. Options are thrust vector (T), or the inertial X-axis (A). Default is T.
- 9) RELMAT/REFSMAT ID: identifies the Relative Matrix or the Reference Matrix to be used in computing vehicle attitude during the maneuver. The default value CURI is the identity matrix, and no other valid matrix is available in TrS.
- 10) Trim Angle Indicator: selects the trim angle source, either compute (C) or system parameters (S). Default is C, but S is almost always used to fetch trims from the ECT.
- 11) Maneuver Type: defines type of maneuver.
- 12) Thrust Level: pounds force generated by the selected thruster. Default values are retrieved from the ECT.
- 13) Weight Loss Rate: mass flow rate of the selected thruster in pounds per second. Default values are retrieved from the ECT.
- 14) Delta-T RCSoff: the time of RCS shutdown in seconds for simultaneous OMS/RCS burns.
- 15) Delta-T MEPon: start time for main engine purge function.

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16) Delta-T MEPOff: end time for main engine purge function.

NOTE: required inputs to the M66 MED are Items 1, 3, and 4.

Alternatively, a maneuver may be directly input into a TrS ephemeris by the FDO or TRAJ using the SAMMI MANEUVER DIRECT INPUT application (Figure 3.7.1.2-2). This application is essentially a menu 'front end' for the same MEDs DYNAMICS uses. The DYNAMICS officer should be notified whenever this is done because DYNAMICS is responsible for TrS ephemeris configuration.

The screenshot shows the 'MANEUVER DIRECT INPUT' application window. At the top right is the label 'MDIA'. The interface includes several input fields and buttons:

- EPH 4**: Ephemeris ID field.
- PET**: A checkbox.
- TIG PG: 10:47:21**: Time of day field.
- GUIDANCE NODE**: A section with buttons for **PEG7**, **RFT**, **M50**, **PEG4D**, **PEG1A**, and **RFS**.
- MNVR#**: Maneuver number field.
- THRUSTER PX2**: Thruster selection dropdown.
- TVR 000**: Thrust Vector Roll Angle field.
- MNVR TYPE**: A dropdown menu with options: **BLANK - INSERT MNVR** and **‡ - REPLACE MNVR**.
- OPTIONAL**: A box containing **DV OVERRIDE** and **DT OVERRIDE** fields.
- PEG7**: A box containing **DVX 6.8**, **DVY 0**, and **DVZ 0** fields.
- EXECUTE** and **CANCEL**: Action buttons.
- NOTE: INFORM DYN IF UPDATING EPH 1 OR EPH 3**: A warning message.

Figure 3.7.1.2-2: Sammi Maneuver Direct Input

### 3.7.1.3 Guidance Modes

Both onboard and ground-based maneuver models support a variety of guidance modes. The selected mode always performs two primary functions supporting a maneuver.

- 1) Reach and maintain an acceptably accurate vehicle body attitude such that the maneuver's thrust vector is properly oriented to achieve the targeted change in velocity ( $\Delta v$ ). Also maintained is the rotation degree of freedom about the thrust vector fixed by the specified thrust vector roll angle (TVR). A TVR is usually

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selected to optimize visual piloting cues, improve communications, or minimize attitude maneuver time and associated perturbations.

- 2) Maintain an estimate of "targeted minus achieved  $\Delta v$ " (VGO) during the maneuver such that thrusting may be terminated with an acceptably small residual. Some guidance modes accept a static or "external" targeted  $\Delta v$  held constant during the maneuver. More sophisticated modes cyclically recompute targeted  $\Delta v$  during the maneuver, providing closed loop guidance to account for the effects of TIG slips or finite burn arcs on maneuver objectives.

Targets associated with each of the modes documented in this section are manually input to TrS via M40 MED or by FDO's SAMMI Direct Input Application.

**CAUTION:** the M40 MED is equipped with " $\Delta v$  override" and " $\Delta T$  override" options with precedence over maneuver velocity change magnitude or duration otherwise computed by guidance software. An override can lead to apparent inconsistencies between corresponding achieved and targeted data on a DMT display PAD area. The Maneuver  $\Delta V$  Definition display (see Section 3.7.1.3.6) will indicate any overrides in effect.

### 3.7.1.3.1 PEG-4D Guidance

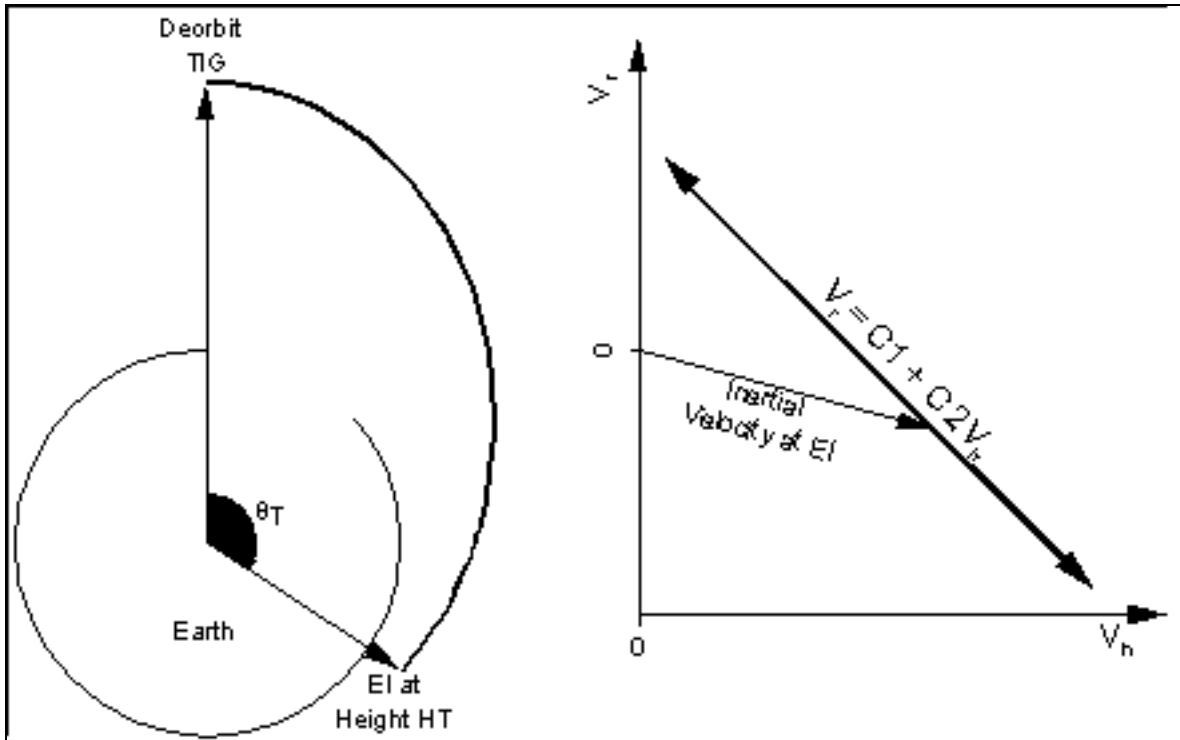
This mode is used for post-MECO maneuvers during ascent (PEG-4A) and deorbit (PEG-4D). Although capability exists to directly input PEG-4 maneuvers via M40 MED, they are almost always transferred to an ephemeris from a targeting processor. The Abort Maneuver Evaluator (AME) is used to compute OMS-1 and OMS-2 targets for the PEG-4A guidance mode, and the Deorbit Maneuver Processor (DMP) computes deorbit PEG-4D targets.

**NOTE:** because orbit trajectory operations routinely involve deorbit planning and an emergency deorbit is always a possibility, PEG-4D will be documented by this section. A discussion of PEG-4A is beyond the scope of orbit operations, however, and Volume 5 of this handbook must be consulted for further PEG-4A information. Use of the term "PEG-4" throughout this volume should therefore be understood as strictly applicable only to PEG-4D guidance.

PEG-4D maneuvers are executed in closed loop fashion to satisfy two objectives in the post-deorbit coasted trajectory. First, the trajectory will pass through an entry interface (EI) point whose location is fixed by a specified height "HT" (400000 ft or 65.832 nm) and specified geocentric angle " $\theta T$ " from the maneuver's targeted TIG location. Second, EI inertial velocity will satisfy a specified linear relationship between its radial and horizontal components  $V_r$  and  $V_h$ , respectively. This relationship is fixed by C1 and C2 targets, defining the Linear Terminal Velocity Constraint (LTVC) per the

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equation  $V_r = C1 + C2 V_h$ . PEG-4D geometric concepts are illustrated in Figure 3.7.1.3.1-1.



**Figure 3.7.1.3.1-1: PEG-4D Geometry**

Typically  $C1 > 0$ ,  $C2 < 0$ , and a negative EI inertial flight path angle results. PEG-4D targets are defined to the M40 MED as follows.

- 1) Guidance Mode = P4D.
- 2)  $H = 65.832$  nm (HT).
- 3) Theta =  $\theta_T$  in deg.
- 4) Burnoff Propellant = total deorbit propellant weight to be expended if post-deorbit vehicle weight or CG is an objective. The desired consumption is achieved by targeting deorbit  $\Delta v$  with an out-of-plane (OOP) component. If Propellant is positive, this OOP component will be "north", while negative Propellant drives OOP  $\Delta v$  "south". This sign convention would reverse if PEG-4D operated on a retrograde orbit. In general,  $\text{sign}\{\text{OOP } \Delta v\} = -\text{sign}\{\text{PEG-7 } \Delta VY\}$ . Set Propellant = 0 if unconstrained propellant consumption results in acceptable post-deorbit mass properties.

**CAUTION:** the Propellant PEG-4D target should not be confused with the Propellant input to the Deorbit Maneuver Processor (DMP). Computations

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performed by DMP ignore the sign of input Propellant, generating an output Propellant PEG-4D target whose sign reduces crossrange to the intended landing site unless overridden by the user.

- 5) C1 = LTVC V-intercept in fps.
- 6) C2 = LTVC slope.
- 7) Target TIG = targeted ignition in GMT or MET.
- 8) Delta V Override = achieved  $\Delta v$  in fps at which the maneuver is to be terminated unless targets are achieved first.
- 9) Delta T Override: elapsed time in sec since TIG at which the maneuver will be terminated unless targets are achieved first.

CAUTION: if both Delta-V and Delta-T values are input, Delta-T is ignored.

### 3.7.1.3.2 PEG-7 Guidance

This guidance mode is used primarily for on-orbit maneuvers. PEG-7 burn targets include  $\Delta v$  components for a burn specified in the Local Vertical/Local Horizontal (LVLH) coordinate system. Most direct input maneuvers use PEG-7 targets. In TrS, only OMS, PX2, PX3, PX4, or MZH thrusters may be paired with PEG-7 guidance. Any thruster defined in a workstation ECT may be used with a PEG-7 maneuver. Strictly speaking, PEG-7 maneuvers are executed open loop to satisfy a targeted  $\Delta v$ , assuming inertial attitude hold as thrust is applied. The only feedback to PEG-7 guidance is attitude and achieved  $\Delta v$ . Because onboard guidance does not regulate  $\Delta v$  in this mode, PEG-7 targets are often called "external  $\Delta v$ ".

NOTE: onboard the Shuttle, some PEG-7 maneuvers are executed with cyclic  $\Delta v$  updates from Lambert Guidance. These dynamic PEG-7 targets are only generated for specific rendezvous maneuvers when the Shuttle is within an orbit or two of prox ops. The onboard Maneuver EXEC Display shows which PEG-7 guidance mode is being used by the onboard maneuver processor, external  $\Delta v$  or Lambert Guidance. See Section 3.10 for additional information on Lambert Guidance.

The M40 MED receives PEG-7 inputs as follows:

- 1) Guidance Mode = P7.
- 2) Delta VX =  $\Delta v$  LVLH X-component (down-track) in fps.



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- 3) Delta VY =  $\Delta v$  LVLH Y-component (cross-track) in fps.
- 4) Delta VZ =  $\Delta v$  LVLH Z-component (radial) in fps.
- 5) Delta V Override = achieved  $\Delta v$  in fps at which the maneuver is to be terminated.
- 6) Delta-T Override = elapsed time in sec since TIG at which the maneuver will be terminated.

CAUTION: if both Delta-V and Delta-T values are input, Delta-T is ignored.

### 3.7.1.3.3 M50 Guidance

This guidance mode has no onboard counterpart. An M50 maneuver is modeled just like a PEG-7 burn (see Section 3.7.1.3.2) and should also be considered an open loop external  $\Delta v$  mode. The only difference between the PEG-7 and M50 modes lies in their targets. The former uses  $\Delta v$  components in LVLH, while the latter uses M50.

Although  $\Delta v$  components in M50 have less intuitive meaning than they do in LVLH, they nevertheless serve a very useful operational purpose. Sensed onboard acceleration is computed in M50, and the velocity increment associated with any sufficiently large sensed impulse is downlisted as accumulated  $\Delta v$  components in M50. Thus, a previously executed maneuver can be "confirmed" in ground-based systems by modeling it in the M50 guidance mode using targets from downlisted telemetry. The confirmed maneuver represents any dispersions, including TIG slips, associated with onboard burn execution. As such, it usually represents a better estimate of the post-burn trajectory as opposed to the originally targeted maneuver. The confirmed trajectory will usually remain the best source until empirical tracking data reveal the maneuver's effects.

The M40 MED requires M50 inputs as follows.

- 1) Guidance Mode = M50.
- 2) Delta VX =  $\Delta v$  M50 X-component in fps.
- 3) Delta VY =  $\Delta v$  M50 Y-component in fps.
- 4) Delta VZ =  $\Delta v$  M50 Z-component in fps.

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- 5) Delta V Override = achieved  $\Delta v$  in fps at which the maneuver is to be terminated.
- 6) Delta-T Override = elapsed time in sec since TIG at which the maneuver will be terminated.

CAUTION: if both Delta-V and Delta-T values are input, Delta-T is ignored.

### 3.7.1.3.4 Body Fixed Inertial (BFI) Guidance

In TrS, BFI guidance has application because it can be used with any thruster selection. For example, payload spring ejection maneuvers are often modeled with BFI targets in TrS because miscellaneous (M) thrusters are used and allow no other guidance mode. In the workstation, these guidance mode restrictions do not apply. The BFI guidance mode is open loop and has no onboard equivalent.

CAUTION: executed BFI maneuvers cannot be confirmed in TrS because they cannot be replaced by M50 guidance targets. Either model the maneuver with another thruster and guidance mode (typically PX2 and PEG-7) just before it's executed, or be prepared to delete the BFI targets and reinput them in M50 mode as part of the confirmation process.

BFI maneuvers are defined by the total  $\Delta v$  or  $\Delta T$ , TIG, thruster, and vehicle attitude in either the Attitude Direction Indicator (ADI), LVLH, or Inertial Measurement Unit (IMU) coordinate system. Although the Euler angle input order to the M40 MED is always roll-pitch-yaw, the inferred Euler angle sequence differs depending on the coordinate system option selected. For ADI, the Euler sequence is pitch-yaw-roll. For LVLH or IMU options, the sequence is yaw-pitch-roll.

NOTE: the ADI coordinate system is identical to M50 in this BFI application. The TrS RELMAT cosine matrix transforms the IMU coordinate system to the ADI coordinate system. Current TrS capability only supports a single RELMAT permanently set to the identity matrix. Consequently, IMU coordinate system axes also coincide with those of M50. The only distinction between ADI and IMU attitude in the BFI context is therefore the inferred Euler sequence: pitch-yaw-roll (the Universal Pointing convention) for ADI; yaw-pitch-roll for IMU.

CAUTION: when using the LVLH attitude option, bear in mind BFI maneuvers are modeled in inertial attitude hold. The specified LVLH attitude is transformed to an equivalent inertial attitude using the TIG state vector. It's this inertial attitude which is held during the maneuver. For an in-plane maneuver with body thrust in the X/Z LVLH plane, LVLH attitude at cutoff will be pitched up from that specified at TIG by an amount equivalent to the maneuver arc's geocentric angle.

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**CAUTION:** when requesting an LVLH equivalent attitude from POINTING for LVLH BFI input, be sure to specify a yaw-pitch-roll Euler sequence.

**NOTE:** a special BFI option exists in workstation software to hold LVLH attitude during the maneuver. Informally called "BFL", this capability is useful in modeling long-duration, low-thrust translations such as reboosts. Two important PFNI simplifications may appreciably affect long-duration maneuvers in TrS or the workstation. Geopotential modeling is limited to the J2 harmonic, and drag uses a '62 Standard atmosphere model. Moreover, both geopotential and drag accelerations must be transformed from an Earth true equator system where they're modeled to M50 where they're integrated. This transformation uses a nutation-precession matrix at a fixed epoch circa 1979 in PFNI, resulting in transformation errors exceeding  $0.1^\circ$ .

The M40 MED requires BFI inputs as follows.

- 1) Guidance Mode = BFI.
- 2) Delta V = total maneuver  $\Delta v$  in fps.
- 3) Delta T = total burn time in sec.
- 4) Roll = body attitude roll angle in deg.
- 5) Pitch = body attitude pitch angle in deg.
- 6) Yaw = body attitude yaw angle in deg.
- 7) Attitude Indicator: A (ADI), L (LVLH), or I (IMU).

The BFI guidance option is used with spring eject payloads, FRCS burns using the MXL thruster selection with tail only attitude control, some separation maneuvers, and any other maneuvers where the attitude and total  $\Delta v$  are known but not the LVLH (PEG-7)  $\Delta v$ .

### 3.7.1.3.5 RES Guidance

The Residuals (RES) guidance mode is intended for maneuver confirmation when burnout occurs during LOS. As such, it's rarely used in the TDRS era. RES guidance is open loop and has no onboard equivalent. Residuals mode maneuvers are defined by the velocity differences between the planned and actual  $\Delta v$  in the Orbiter Body coordinate system, the maneuver attitude, and the attitude reference coordinate system

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(ADI or IMU). Residual  $\Delta v$ , called body VGOs, can be read down by the crew or obtained from a telemetry-driven display following AOS.

The M40 MED requires RES inputs as follows.

- 1) Guidance Mode = RES.
- 2) Delta VX = X Body VGO at burnout in fps.
- 3) Delta VY = Y Body VGO at burnout in fps.
- 4) Delta VZ = Z Body VGO at burnout in fps.
- 5) Roll = body attitude roll angle in deg.
- 6) Pitch = body attitude pitch angle in deg.
- 7) Yaw = body attitude yaw angle in deg.
- 8) Attitude Indicator = ADI or IMU.

NOTE: the ADI coordinate system is identical to M50 in this RES application. The TrS RELMAT cosine matrix transforms the IMU coordinate system to the ADI coordinate system. Current TrS capability only supports a single RELMAT permanently set to the identity matrix. Consequently, IMU coordinate system axes also coincide with those of M50. The only distinction between ADI and IMU attitude in the RES context is therefore the inferred Euler sequence: pitch-yaw-roll (the Universal Pointing convention) for ADI; yaw-pitch-roll for IMU.

### 3.7.1.3.6 Maneuver Delta V Definition Display

DYNAMICS controllers use the Maneuver Delta V Definition Display to verify their M40 MED inputs. All M40 inputs for each guidance mode appear on this display, which has separate areas dedicated to the six M40 burn types: M50, P7, RES, P4A, P4D, and BFI (see Figure 3.7.1.3.6-1).

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107	Target Definition	A
PEG 7		
DVX	35.000	FPS
DVY	0.000	FPS
DVZ	0.000	FPS
DV-OR		FPS
DT-OR		SEC
<input type="checkbox"/> UNDO		
<input type="checkbox"/> UPDATE P7		
<input type="checkbox"/> QUIT		

Figure 3.7.1.3.6-1: Maneuver Delta V Definition

### 3.7.1.4 Engine Characteristics Table (ECT)

An accurate Orbiter body thrust vector and propellant flow rate must be provided to PFNI when a maneuver is modeled in an ephemeris. These data are obtained from the Engine Characteristics Table (ECT) for any thruster code defined therein. The ECT is accessed whenever maneuver inputs to the MPT are made requiring thruster definitions. The TrS ECT may be inspected via the Engine Characteristics Table display (see Figure 3.7.1.4-1).

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107		ENGINE CHAR TABLE						A	
					THRUST CHARACTERISTICS			CURRENT GMT	
MC	O	#	DAP					023:17:53:43	
EO	RD	J	M	C	EFFECTIVE				
DD	BI	E	O	O	THRUST	WT LOSS	THRUST	DIRECTION	
E	R	T	D	N	(LB)	(LB/S)	PITCH	YAW	
							(DEG)	(DEG)	
								NOTES	
OL	+	X			6075.0	19.250	-15.47	0.80	YAW PAR
								11.11	YAW CG
OR	+	X			6045.0	19.250	-15.47	-0.80	YAW PAR
								-11.20	YAW CG
PX4	+	X	4	NM TO	3474.8	13.020	-11.15	0.00	OPS 1/3
PX3	+	X	3	NM TO	2624.0	11.060	-11.30	0.00	OPS 1/3
PX2	+	X	2	NM TO	1753.5	6.530	-10.96	0.00	OPS 2/3
MXL	-	X	2	NM TO	1920.9	8.180	-157.16	0.00	-XTAIL ONLY
YL	+	Y	2	NM FL	1270.2	7.410	-64.47	84.33	
MYL	-	Y	2	NM FL	1270.2	7.480	-64.09	-84.27	
ZH	+	Z	3	NM FL	2458.0	8.769	-89.71	0.00	NORM Z
ZL	+	Z	4	LZ FL	277.9	14.100	-96.72	0.00	LOW Z
MZL	-	Z	6	NM FL	3519.4	17.920	77.01	0.00	
MZH	-	X	2	NM FL	1786.1	7.780	-169.64	0.00	-X FULL UP
M					500.0	1.610	0.00	0.00	MISC
PXA					3480.0	12.430	-10.00	0.00	ULL/DUAL
MEP					1470.0	0.100	-19.00	3.02	AME/ASCENT
SYSTEM PARAMETERS									
TRIMS:		PITCH	YAW PAR	YAW CG	NULLS:		PITCH	YAW	
L		0.35	L -5.70	L 4.61			L-15.817	L 6.500	
R		0.35	R 5.70	R -4.70			R-15.817	R -6.500	

**Figure 3.7.1.4-1: Engine Characteristics Table Display**

ECT thruster codes are defined and acceptable TrS guidance modes are listed in Figure 3.7.1.2-1. The ECT Pitch and Yaw columns constitute an Orbiter body-to-thrust vector transformation composed of a pitch-yaw Euler sequence. As an illustration of this concept, consider a fictitious thruster with Pitch = 180° and Yaw = 45°. Start by aligning the thrust vector with the +X body axis. In Orbiter Body coordinates, this would have the thrust vector initially pointing out the nose, much as aft-firing RCS jets would direct it. Next, pitch the thrust vector 180° to point it aft in the Orbiter Body frame, then yaw it +45°. When performing the yaw, remember the preceding pitch has directed the +Z axis of yaw rotation out the Orbiter's overhead windows. The pitch-yaw results in a thrust vector directed 45° starboard of aft in the Orbiter Body frame, as though a nose jet was firing in a direction 45° to port. A diagram of Orbiter RCS jet locations and nomenclature appears in Figure 3.7.1.4-2.

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**WARNING:** any TrS ECT value may be changed with the M10 MED, except the ECT Pitch and Yaw angles. These system parameters can only be modified in the TrS ECT when TAO correctly configures the Flight Mode. This action should only be taken when no other option is practical, as it leaves TrS memory open to modification until protection is restored. No such restrictions apply to workstation ECT modifications, which are fully supported by a dedicated user interface.

**NOTE:** the M10 MED contains a CANT ANGLE item only applicable to the PXA thruster code. The specified CANT then becomes PXA's ECT Pitch angle. Roughly equivalent to PX4, PXA is only used during ascent operations.

Standard ECT thruster codes "make sense" in that each serves as a mnemonic designating the Orbiter Body frame direction with which thrust is primarily aligned. The only exception to this rule is the MZH thruster code. Figure 3.7.1.2-1 shows MZH to be the only non-plus-X RCS thruster permitted to utilize PEG-7 guidance in TrS. As such, it routinely serves a dual purpose. During ascent, MZH is used to confirm the post-ET-sep MPS dump maneuver. During orbit, MZH models FRCS maneuvers. Fortunately, ascent's MZH application is only to confirm the correct MPS dump M50  $\Delta v$  in a ground-based ephemeris. Because burn attitude isn't significant to dump confirmation (it will be incorrectly displayed on the dump DMT), FRCS Pitch and Yaw values accompany MZH in the ECT at all times. Only when the Orbit D64 group MED is executed, do the MZH thrust and flow rate change from MPS dump to FRCS values.

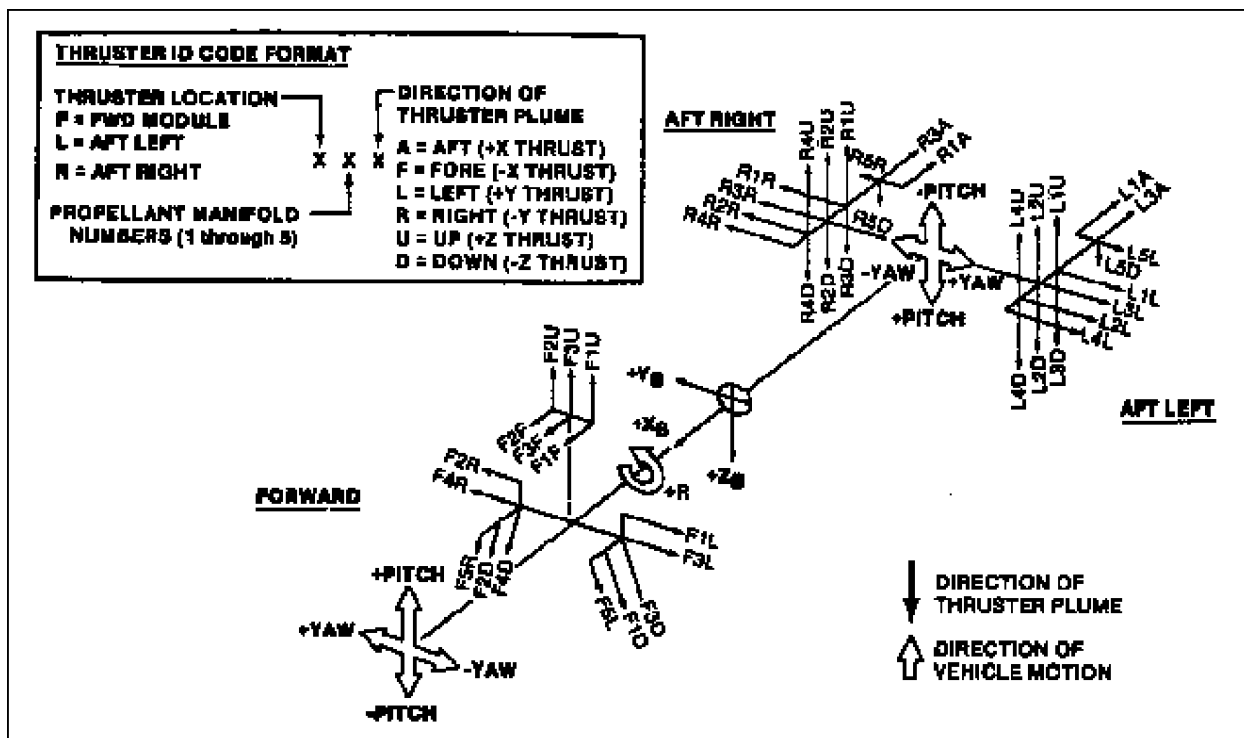


Figure 3.7.1.4-2: RCS Thruster Nomenclature

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In its SYSTEM PARAMETERS segment, the ECT displays OMS trim angles. These "system trims" are usually maintained according to OMS Depletion computations (see Sections 3.6.2.10 and 3.6.2.11), but any set of values may be entered. When an ephemeris containing an OMS maneuver is TUPed, PFNI uses the ECT's system trims to compute a biased thrust vector with respect to null pitch and yaw in the Orbiter Body frame. The trim bias results in a corresponding Body attitude shift for the maneuver such that the OMS thrust vector is properly oriented to achieve targets.

ECT system trims are also consulted by Command Off-The-MOC (COTM) software whenever a DSM 406xx Orbit PEG-7 command load is built. For single-engine OMS maneuvers (OL and OR thruster codes), YAW CG trims are retrieved for the 406xx. On rare occasions when suspect OMS TVC or engine integrity requires a dual-OMS maneuver to be trimmed through the Orbiter CG (OBC thruster code in TrS; OCG in TSA), YAW CG trims are also retrieved. All other thruster codes, including all RCS options, will retrieve YAW PAR trims from the ECT in association with a 406xx build. In this way, reasonable trims are available to the crew for short-notice OMS burns even if the last 406xx uplink wasn't associated with OMS TVC use.

CAUTION: it is possible an Orbiter systems failure may result in loss of OMS engine gimbal functions. During simulations, this kind of failure is common. With the loss of gimbal redundancy, the GNC officer can request an OMS engine be 'parked' with trims set such that the engine thrust vector passes through the end of mission (EOM) CG (see MAL GNC SSR-8). FDO provides EOM CGs to GNC for trim computations. In the event one of the OMS engines must be parked, the DMT processor will NOT contain the correct engine trims. The DMT will average the two engine trims in the ECT, even if the correct parked engine trims have been entered. When a command load is built using the DMT, the trims will have to be manually overridden to the correct values. See Section 3.6.5.4 for PMP-based trim override procedures.

CAUTION: the TSA ECT uses an "OCG" thruster code for both OMS with CG trims. This is incompatible with the corresponding TrS "OBC" code. Consequently, dual-OMS burns with CG trims targeted by OMP or DMP must be manually input to TrS by DYNAMICS.

### 3.7.1.5 Thrust Vector Roll (TVR)

Body frame thrust vector orientation specified by the ECT leaves one open rotation degree of freedom in computing a body frame attitude from maneuver targets. Without additional information, it would be possible to achieve maneuver targets using an infinite number of body attitudes rotated about the thrust vector. The additional information is supplied by a parameter known as Thrust Vector Roll (TVR). The "roll" in TVR should not be confused with the Orbiter Body X roll axis. Although some thrust vectors are



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*approximately* aligned with the Orbiter Body roll axis, this is certainly not the case for Z-body translations!

The role of TVR in defining Orbiter Body maneuver attitude is akin to that played by the omicron angle in Universal Pointing. A body-fixed pointing vector is established and aligned with an independently specified pointing target to yield TVR = 0 body attitude. The body frame is then rotated about the pointing vector by the specified TVR to arrive at the required maneuver attitude. Details of this process follow as inferred from JSC Internal Note No. 76-FM-90 (*Preliminary SMCC Level B/C Formulation Requirements for Orbital Prethrust Attitude Alignment*, JSC-11728) and by On-Orbit/Deorbit Guidance. Two options are supported by TVR-related software, but only one is used operationally. The Local Roll option is consistent with TVR concepts developed throughout this handbook and is used for any SSP maneuver requiring a TVR target. Early in SSP development, the ADI option was intended for flight crew use to manually achieve maneuver attitude with the ADI. Current maneuver flight procedures are incompatible with the ADI TVR option.

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+X Body-Fixed Thrust					-X Body-Fixed Thrust				
PEG-7 Targets					PEG-7 Targets				
$\Delta V_X$	$\Delta V_Y$	$\Delta V_Z$	TVR	LVLH Attitude	$\Delta V_X$	$\Delta V_Y$	$\Delta V_Z$	TVR	LVLH Attitude
+	0	0	0	+ZLV; +XVV	+	0	0	0	-ZLV; -XVV
-	0	0	0	+ZLV; -XVV	-	0	0	0	-ZLV; +XVV
0	+	0	0	+ZLV; -YVV	0	+	0	0	-ZLV; -YVV
0	-	0	0	+ZLV; +YVV	0	-	0	0	-ZLV; +YVV
0	0	+	0	+XLV; -ZVV <sup>1</sup>	0	0	+	0	-XLV; +ZVV <sup>1</sup>
0	0	-	0	-XLV; +ZVV <sup>1</sup>	0	0	-	0	+XLV; -ZVV <sup>1</sup>
+	0	0	90	+YLV; +XVV	+	0	0	90	+YLV; -XVV
-	0	0	90	+YLV; -XVV	-	0	0	90	+YLV; +XVV
0	+	0	90	+YLV; +ZVV	0	+	0	90	+YLV; -ZVV
0	-	0	90	+YLV; -ZVV	0	-	0	90	+YLV; +ZVV
0	0	+	90	+XLV; -YVV	0	0	+	90	-XLV; -YVV
0	0	-	90	-XLV; +YVV	0	0	-	90	+XLV; +YVV
+	0	0	180	-ZLV; +XVV	+	0	0	180	+ZLV; -XVV
-	0	0	180	-ZLV; -XVV	-	0	0	180	+ZLV; +XVV
0	+	0	180	-ZLV; +YVV	0	+	0	180	+ZLV; +YVV
0	-	0	180	-ZLV; -YVV	0	-	0	180	+ZLV; -YVV
0	0	+	180	+XLV; +ZVV <sup>1</sup>	0	0	+	180	-XLV; -ZVV <sup>1</sup>
0	0	-	180	-XLV; -ZVV <sup>1</sup>	0	0	-	180	+XLV; +ZVV <sup>1</sup>
+	0	0	270	-YLV; +XVV	+	0	0	270	-YLV; -XVV
-	0	0	270	-YLV; -XVV	-	0	0	270	-YLV; +XVV
0	+	0	270	-YLV; -ZVV	0	+	0	270	-YLV; +ZVV
0	-	0	270	-YLV; +ZVV	0	-	0	270	-YLV; -ZVV
0	0	+	270	+XLV; +YVV	0	0	+	270	-XLV; +YVV
0	0	-	270	-XLV; -YVV	0	0	-	270	+XLV; -YVV

**Figure 3.7.1.5-1: Approximate LVLH Attitudes at Various PEG-7s & TVRs**

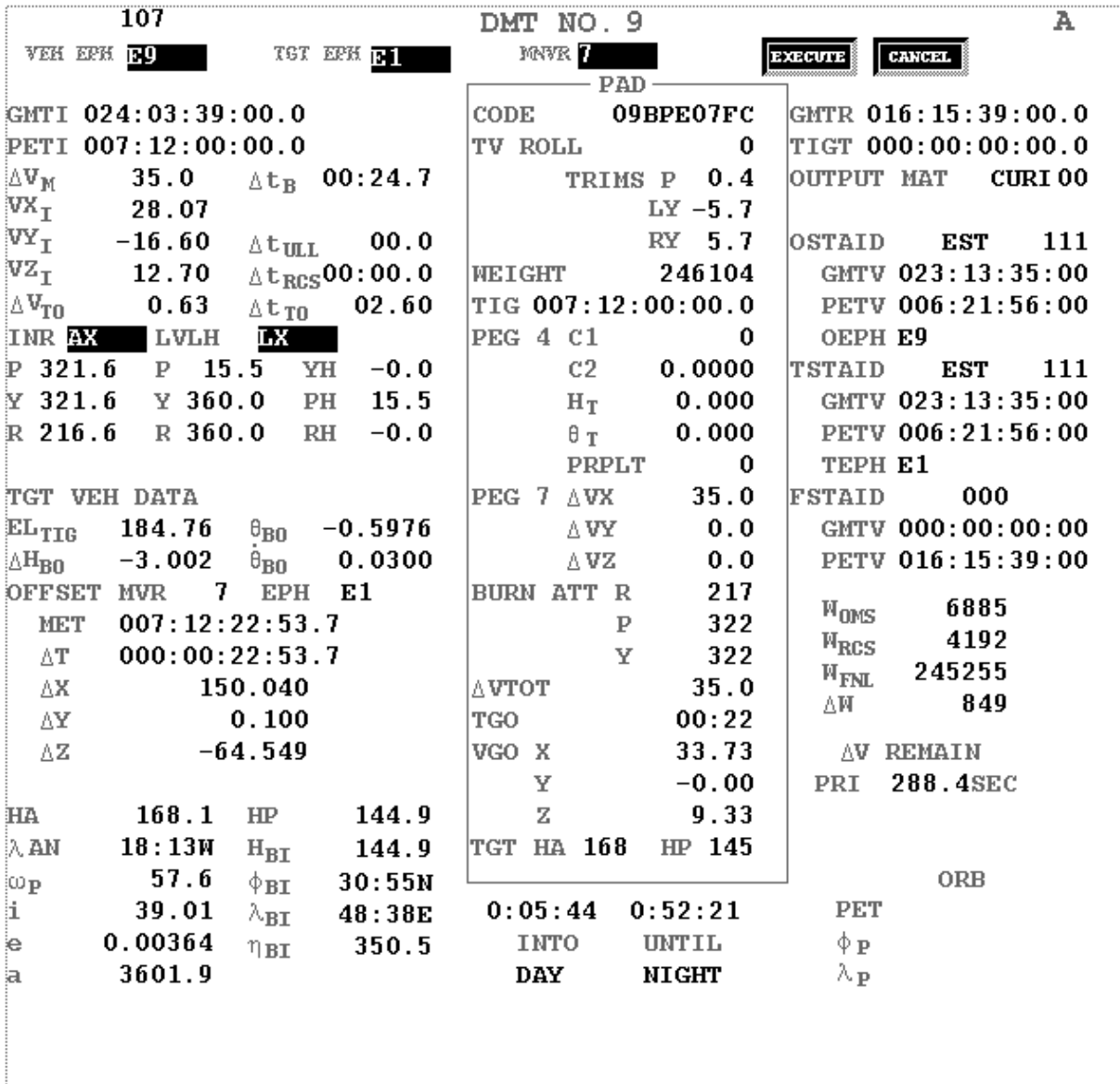
<sup>1</sup>Radial maneuver targets subject to alternate velocity-based pointing target.

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### **3.7.1.6 Detailed Maneuver Table (DMT)**

Any maneuver residing in an ephemeris (called the "referenced ephemeris" in the following discussion) may be placed in a DMT for display purposes. As such, DMTs function as the primary means of gaining insight into a maneuver's ephemeris-resident specifications. The central boxed portion of the DMT is associated with Pre-Advisory Data (PAD) parameters. This segment is used to generate a PAD Flight Note. These data are either polled by the Netscape Auto Maneuver PAD (NAMP) software or are manually entered onto a paper PAD form by FDO or TRAJ. The DMT's PAD section is also used to build maneuver command loads. A dedicated Command Off The MOC (COTM) processor builds command load DSMs 406xx (PEG-7 Orbit), 410xx (PEG-7 Deorbit), and 411xx (PEG-4D Deorbit by polling a TrS DMT. Ten functionally identical but independent DMTs exist in TrS, and four are supported in the workstation. Although TrS and workstation DMTs are nearly identical, the following description strictly relates to TrS DMTs. Consult the TSA Volume II Requirements Document, Section 3.3.1, for a workstation DMT description. Figure 3.7.1.6-1 shows the TrS DMT for a dual-OMS 35 fps posigrade phasing maneuver.

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**Figure 3.7.1.6-1: DMT NO. 9**

The DMT is formatted into 3 segments. As an aid in locating a particular DMT parameter description in the following list, each entry begins with an L (Left), M (Middle), or R (Right) corresponding to the pertinent DMT segment.

- L1 **GMTI** is the actual or planned GMT at TIG.
- L2 **PETI** is the actual MET at TIG.
- L3  **$\Delta V_M$**  is the actual total velocity change magnitude in fps, including tailoff, ullage, and any  $\Delta v$  or  $\Delta T$  overrides in effect (see Section 3.7.1.3).

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L4  **$\Delta t_B$**  is the actual total duration in min:sec, including tailoff, ullage, and any  $\Delta v$  or  $\Delta T$  overrides in effect (see Section 3.7.1.3).

L5  **$VX_i$ ,  $VY_i$ ,  $VZ_i$**  are the inertial Cartesian components of velocity change in fps, including tailoff, ullage, and any  $\Delta v$  or  $\Delta T$  overrides in effect (see Section 3.7.1.3) from the PFNI Input Table. Since the TrS RELMAT is always the identity matrix, the inertial coordinate system is always M50.

NOTE: burn  $\Delta v$  magnitude  $\Delta V_M$  (L3) may not be the RSS of  $VX_i$ ,  $VY_i$ , and  $VZ_i$  components because  $\Delta V_M$  is a PFNI output from step-by-step integration through the burn arc. The L5 components assume an inertially fixed thrust vector, and their RSS will differ significantly from  $\Delta V_M$ , particularly over a long burn arc in LVLH attitude hold.

L6  **$\Delta V_{ULL}$**  is the velocity change magnitude in fps due to ullage. If ullage is not performed,  $\Delta V_{ULL}$  is not displayed.

L7  **$\Delta t_{ULL}$**  is the ullage duration in min:sec.

L8  **$\Delta t_{RCS}$**  is the duration in min:sec of RCS thrust during an OMS maneuver.

L9  **$\Delta V_{TO}$**  is the velocity change magnitude in fps due to OMS thrust tailoff.

L10  **$\Delta t_{TO}$**  is the duration in sec of OMS thrust tailoff.

L11 **INR AX P-Y-R** is the targeted inertial-to-Orbiter-body pitch-yaw-roll Euler sequence at TIG in deg. Since the TrS RELMAT is always the identity matrix, the inertial coordinate system is always M50. This Euler sequence also appears in the DMT PAD segment's BURN ATT fields because Flight Software performs maneuvers with the same coordinate system (M50).

CAUTION: the PAD's BURN ATT Euler angles are numerically the same as the foregoing P-Y-R sequence, but they have been rounded to the nearest integer degree and reordered (incorrectly, in the context of Euler rotations) to facilitate cockpit procedures.

L12 **LVLH LX P-Y-R** is the targeted LVLH-to-Orbiter-body pitch-yaw-roll Euler sequence at TIG in deg.

L13 **YH-PH-RH** is the targeted LVLH-to-Orbiter-body yaw-pitch-roll Euler sequence at TIG in deg. This is the LVLH Euler sequence used for BFI LVLH maneuver modeling.

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- L14 **EL<sub>TIG</sub>** is the designated target's LVLH elevation in deg with respect to TIG position and time. The associated value is blank if a designated target ephemeris is unavailable.
- L15  **$\theta_{BO}$**  is the designated target's phase angle in deg with respect to burnout position and time. Phase is the geocentric angle from the burnout position to the designated target's position at burnout, measured in the target's orbit plane.  $q$  is positive if the burnout-to-target arc is posigrade; negative if retrograde. The associated value is blank if a designated target ephemeris is unavailable.
- L16  **$\Delta H_{BO}$**  is the designated target's orbit height at burnout, minus burnout orbit height, in nm. The associated value is blank if a designated target ephemeris is unavailable.
- L17  **$\dot{\theta}_{BO}$**  is the designated target's phase angle rate in rad/orbit period with respect to burnout position, velocity, and time. The associated value is blank if a designated target ephemeris is unavailable.
- L18 **OFFSET MVR** indicates which maneuver in the referenced MPT sequence is being displayed by the DMT.
- L19 **EPH** is the designated target ephemeris.
- L20 **MET** is the referenced ephemeris MPT TIG MET of the maneuver following that being displayed in the DMT. If there is no future maneuver, the time for the offsets is 0.24 orbit or 23 minutes in the future.
- L21  **$\Delta T$**  is the time interval from burnout to the next maneuver TIG in the referenced ephemeris MPT. If there is no future maneuver, the delta time for the offsets is 0.25 orbit or 23 minutes.
- L22  **$\Delta X$ ,  $\Delta Y$ ,  $\Delta Z$**  are the curvilinear LVLH components in kilofeet of referenced ephemeris position relative to the designated target ephemeris position at the Item L20 time. The associated values are blank if a designated target ephemeris vector is unavailable.
- L23 **HA** is the actual burnout height of apogee in nm, including tailoff, ullage, and any  $\Delta v$  or  $\Delta T$  overrides in effect (see Section 3.7.1.3). This value is calculated using the algorithm associated with TrS Checkout Monitor and may osculate by several nm over one orbit.
- L24 **HP** is the actual burnout height of perigee in nm, including tailoff, ullage, and any  $\Delta v$  or  $\Delta T$  overrides in effect (see Section 3.7.1.3).. This value is

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calculated using the algorithm associated with TrS Checkout Monitor and may osculate by several nm over one orbit.

- L25  $\lambda_{AN}$  is the first post-maneuver ascending node longitude in deg:min.
- L26  $H_{BI}$  is the orbit height above a spherical earth at TIG in nm.
- L27  $\omega_P$  is the burnout argument of perigee with respect to earth's true equator in deg.
- L28  $\phi_{BI}$  is nadir geodetic latitude at TIG in deg:min.
- L29  $i$  is the burnout orbit inclination with respect to earth's true equator (TEI) in deg.
- L30  $\lambda_{BI}$  is nadir longitude at TIG in deg:min.
- L31  $e$  is burnout osculating orbit eccentricity.
- L32  $\eta_{BI}$  is true anomaly at TIG in deg.
- L33  $a$  is the burnout osculating semi-major axis in nm.
- M1 **CODE** is the maneuver code. It has the format "abbccdeeff", where each CODE subfield is explained below.

**a** is the maneuver type.

E = executed

F = frozen

Blank = neither executed nor frozen (e.g. future, planned burn)

Figure 3.7.1.6-1 shows this field blank.

**bb** is the referenced ephemeris (1 through 10). Figure 3.7.1.6-1 shows '09'.

**cc** is the thruster code.

BP = both OMS with parallel trims

BC = both OMS with CG trims

MM = miscellaneous

MX = two -X (forward-firing) RCS

MY = two -Y (right-firing) RCS

MZ = six -Z (down-firing) RCS

OL = left OMS

OR = right OMS

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XH = three or four +X (aft firing) RCS

XL = one or two +X (aft firing) RCS

YL = two +Y (left-firing) RCS

ZH = three +Z (up-firing) RCS

ZL = four +Z (forward/aft-firing) RCS

ZM = two -X (forward-firing) RCS

Figure 3.7.1.6-1 shows 'BP'.

**d** is the guidance mode.

A = PEG-4A Ascent

D = PEG-4D Descent

E = External  $\Delta v$

I = BFI

Figure 3.7.1.6-1 shows 'E'.

**ee** is the referenced MPT's maneuver number (1 through 24). Figure 3.7.1.6-1 shows '07'.

**ff** is the maneuver ID (free-format such as "NC" or "NH" for rendezvous maneuvers).

CF = confirmed

DO = deorbit

FC = flight controller direct input

O1 = OMS-1

O2 = OMS-2

Figure 3.7.1.6-1 shows 'FC'. When the burn is confirmed, the ID will be CF.

M2 **TV ROLL** is the TVR in integer deg (see Section 3.7.1.5).

M3 **SYSP TRIMS P, LY, RY** are the corresponding OMS TVC trim pitch, left engine yaw, and right engine yaw angles in deg. Values are as obtained from the ECT configuration during the last TUP of the referenced ephemeris.

**CAUTION:** DMT trims are meaningless for RCS thrusters, yet they are always displayed. For example, a pitch trim of nearly 180° is displayed for -X RCS maneuvers. A PAD Flight Note generated by NAMP will ignore DMT trims for RCS maneuvers and designate them "N/A". Likewise, command load DSM 406xx (PEG-7 Orbit) will fetch OBP trims from the ECT for any RCS maneuver. This convention ensures reasonable trims will be available to the crew if an OMS maneuver can't be coordinated with MCC.



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**CAUTION:** it is possible an Orbiter systems failure may result in loss of OMS engine gimbal functions. During simulations, this kind of failure is common. With the loss of gimbal redundancy, the GNC officer can request an OMS engine be 'parked' with trims set such that the engine thrust vector passes through the end of mission (EOM) CG (see MAL GNC SSR-8). FDO provides EOM CGs to GNC for trim computations. In the event one of the OMS engines must be parked, the DMT processor will NOT contain the correct engine trims. The DMT will average the two engine trims in the ECT, even if the correct parked engine trims have been entered. When a command load is built using the DMT, the trims will have to be manually overridden to the correct values. See Section 3.6.5.4 for PMP-based trim override procedures.

- M4 **WEIGHT** is referenced ephemeris weight at TIG.
- M5 **TIG** is MET at TIG.
- M6 **PEG 4 C1** is a PEG-4D target specifying Y-intercept of the radial velocity versus horizontal velocity constraint at EI in fps. See Figure 3.7.1.3.1-1. The value is zero for PEG-7 maneuvers.
- M7 **C2** is a PEG-4D target specifying slope of the radial velocity versus horizontal velocity constraint at EI. See Figure 3.7.1.3.1-1. The value is zero for PEG-7 maneuvers.
- M8 **H<sub>T</sub>** is a PEG-4D target specifying orbit height at EI in nm. The value is zero for PEG-7 maneuvers.
- M9 **θ<sub>T</sub>** is a PEG-4D target specifying geocentric transfer angle from TIG to EI in deg. The value is zero for PEG-7 maneuvers.
- M10 **PRPLT** is a PEG-4D target specifying total propellant weight in lbm to be expended if post-deorbit vehicle weight or CG is an objective. The desired consumption is achieved by targeting deorbit  $\Delta v$  with an out-of-plane (OOP) component. If Propellant is positive, this OOP component will be "north", while negative Propellant drives OOP  $\Delta v$  "south". This sign convention would reverse if PEG-4D operated on a retrograde orbit. In general,  $\text{sign}\{\text{OOP } \Delta v\} = -\text{sign}\{\text{PEG-7 } \Delta VY\}$ . PRPLT = 0 if unconstrained propellant consumption results in acceptable post-deorbit mass properties or if a PEG-7 maneuver is displayed.

**CAUTION:** the PRPLT PEG-4D target should not be confused with the Propellant input to the Deorbit Maneuver Processor (DMP). Computations performed by DMP ignore the sign of input Propellant, generating an output Propellant PEG-4D

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target whose sign reduces crossrange to the intended landing site unless overridden by the user.

- M11 **PEG 7  $\Delta V_X$ ,  $\Delta V_Y$ ,  $\Delta V_Z$**  are the targeted LVLH components of velocity change in fps ( $+\Delta V_X$ =along velocity's projection in the local horizontal plane,  $+\Delta V_Y$ =opposed to angular momentum vector,  $+\Delta V_Z$ =radial down). These targets do not reflect any manual  $\Delta v$  or  $\Delta T$  override in effect (see Section 3.7.1.3).
- M12 **BURN ATT R, P, Y** are the roll, pitch, and yaw angles from the inertial frame to achieve the required Orbiter attitude at TIG. Since the TrS RELMAT is always the identity matrix, the inertial coordinate system is always M50. As noted in Item L11, the Euler sequence associated with these angles is actually pitch-yaw-roll. The PAD's TIG attitude uses roll-first ordering to facilitate cockpit procedures.
- M13  **$\Delta V_{TOT}$**  is the targeted velocity change magnitude in fps computed by Guidance software. It does not include ullage or tailoff. Unlike other velocity-related data in the PAD box,  $\Delta V_{TOT}$  *does* reflect any manual  $\Delta v$  or  $\Delta T$  override in effect (see Section 3.7.1.3).
- M14 **TGO** is the targeted duration in min:sec computed by Guidance software. It does not include ullage or tailoff. However, it *does* reflect any manual  $\Delta v$  or  $\Delta T$  override in effect (see Section 3.7.1.3).
- M15 **VGO X, Y, Z** are the Orbiter Body components of targeted velocity change in fps computed by Guidance software. They do not include ullage or tailoff. Neither do they reflect any manual  $\Delta v$  or  $\Delta T$  override in effect (see Section 3.7.1.3).
- M16 **TGT HA, HP** are the targeted burnout heights of apogee and perigee in nm computed by Guidance software. These values are calculated using the computation associated with TrS Checkout Monitor. They do not include ullage or tailoff. However, they *do* reflect any manual  $\Delta v$  or  $\Delta T$  override in effect (see Section 3.7.1.3).
- M17 **INTO aaaaa** is the time elapsed at TIG since the last referenced ephemeris sunrise (aaaaa = DAY) or sunset (aaaaa = NIGHT) in hrs:min:sec.
- M18 **UNTIL aaaaa** is the time to go at TIG before the next referenced ephemeris sunrise (aaaaa = DAY) or sunset (aaaaa = NIGHT) in hrs:min:sec.

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- R1 **GMTR** is the GMT at liftoff.
- R2 **TIGT** is the targeted (as opposed to actual "TIGA") MET associated with PEG-4D targets at PEG-4D TIG. A zero TIGT is displayed if TIGT = TIGA or when the maneuver uses a guidance mode other than PEG-4D.
- R3 **OUTPUT MAT** is the applicable RELMAT, defining the M50-to-inertial transformation for Items L5, L11, and M12. Because the only TrS RELMAT is the identity matrix, all inertial DMT data are with respect to M50.
- R4 **OSTAID, GMTV, PETV, OEPH** are the referenced ephemeris anchor state vector ID, anchor GMT.anchor MET, and ephemeris number followed by its live or static indicator.
- R5 **TSTAID, GMTV, PETV, TEPH** are the designated target's ephemeris anchor state vector ID, anchor GMT.anchor MET, and ephemeris number followed by its live or static indicator. These fields are blank if a target ephemeris hasn't been designated.
- R6 **FSTAID, GMTV, PETV** are the ID, GMT, and MET of the state vector supplied to Guidance in association with a frozen maneuver. The ID field becomes that of the designated ephemeris anchor vector after the maneuver executes (once current TrS time moves past TIG). For future unfrozen maneuvers, the ID field is blank. The GMT and MET fields reflect launch time if the maneuver isn't frozen.
- R7 **W<sub>OMS</sub>** is the referenced ephemeris OMS propellant weight remaining at burnout in lbs.
- R8 **W<sub>RCS</sub>** is the referenced ephemeris RCS propellant weight remaining at burnout in lbs.
- R9 **W<sub>FNL</sub>** is the referenced ephemeris total vehicle weight at burnout in lbs.
- R10 **ΔW** is the weight of propellant consumed in lbs.
- R11 **ΔV REMAIN PRI, SEC** are the velocity change capabilities in the primary and secondary propulsion systems at burnout in fps. The PRI field's value is based on the applicable referenced ephemeris propellant weight (OMS or RCS, depending on thruster selection) and total vehicle weight at burnout. The SEC field value is always blank.

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- R12 **ORB** is the specified M77 MED orbit number threshold from the referenced ephemeris pertaining to Item R13 computations. If the orbit is unspecified, this field is blank.
- R13 **PET**,  $\phi_p$ ,  $\lambda_p$  are MET, nadir geodetic latitude, and nadir longitude at the first perigee which occurs during the orbit specified by Item R12. If the orbit is unspecified or is unavailable in the referenced ephemeris, these fields are blank.

### 3.7.1.7 OMP for Single Vehicle Maneuvers

Automated targeting of entire impulsive maneuver sequences can be accomplished by using TSA's Orbit Maneuver Processor (OMP) in the workstation. Imagine the effort needed to direct input a complex maneuver sequence to an ephemeris, each time going through targeting iterations to obtain the required PFNI modeling! Thanks to the Maneuver Transfer Table (MTT), the process of sending sequences of maneuver targets to an ephemeris is largely automated. While OMP is more commonly used for dual vehicle maneuver computations, as in a deploy or rendezvous mission, this processor can also be used for single vehicle operations. The OMP processor and the MTT are discussed in Section 3.10.

### 3.7.2 Real Time Maneuver Procedures

Most translation maneuvers for which an Orbit FDO is responsible are performed in Operational Sequence (OPS) 2. Contingency deorbit burns and some perigee adjusts are done in OPS 3. FDO models all real-time maneuvers, provides updated vectors to the Guidance, Navigation and Control (GN&C) General Purpose Computers (GPC), generates the Pre-Advisory Data (PAD), monitors onboard guidance solutions, and determines actual burn values. This section explains the steps required to plan typical maneuvers and to perform maneuver monitoring after an on-orbit maneuver (OPS 2 only) has been modeled in an ephemeris. All OPS 2 maneuvers are performed in Major Mode (MM) 202 and are either Powered Explicit Guidance (PEG) 7 or Lambert targeted maneuvers. There is no onboard targeting capability for PEG-7 maneuvers, but there is for the Lambert targeted rendezvous maneuvers (SPEC 34). Therefore, targets for all but the Lambert targeted maneuvers must be generated on the ground by the FDO. The Lambert targeted maneuvers are also targeted on the ground, but the onboard solution is considered prime. See Section 3.10 Rendezvous Operations for more information on Lambert targeted maneuvers.

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### 3.7.2.1 Burn Criticality

Flight Rule A2-114 classifies maneuvers as "critical" or "non-critical". A critical maneuver cannot be postponed beyond a period called "TIG slip", usually no more than 5 to 10 minutes in extent. In contrast, non-critical maneuvers can be postponed by at least an orbit and often longer. Maneuver criticality usually governs which thrusters the crew can invoke in the event of an engine failure during maneuver execution, and it drives the number of redundant systems (such as GNC GPC's) required to support the maneuver. Critical maneuvers are further categorized into those essential to mission success and those essential to vehicle integrity or crew safety. For example, a large day-of-rendezvous maneuver is classified critical to mission success because sufficient propellant isn't available to achieve rendezvous unless the maneuver is performed within its allotted TIG slip. However, canceling the maneuver will not place the vehicle or crew in jeopardy. The criticality of a burn will determine what downmode options are specified on the PAD to the crew.

### 3.7.2.2 Optimal TIG

Objectives associated with a maneuver are each to some degree TIG-sensitive. Consider the following typical scenarios.

- 1) Deorbit maneuver  $\Delta v$  for a given opportunity exceeds Orbiter capabilities outside a TIG window only 10 minutes in duration.
- 2) A maneuver to achieve rendezvous target intercept must be executed within a few minutes following orbit noon, or lighting during terminal approach and proximity operations will be unacceptable.
- 3) If moved to a relative phantom node, a phasing maneuver may be combined with a planar correction to significantly reduce rendezvous  $\Delta v$  requirements.
- 4) A posigrade rendezvous stationkeeping maneuver must be performed near a relative apogee, or post-maneuver variations in target range may increase to the point where mission-critical communications with the target are lost during part of each orbit.
- 5) Perigee can be lowered 45 miles only from 50 to 70 minutes following ascending node passage, or steep deorbit capability to all northern hemisphere sites may be lost.
- 6) If postponed until the next crew day, phasing burn  $\Delta v$  to achieve precise zenith passage at Arecibo, Puerto Rico exceeds that allotted for this purpose in the Prop Priorities Table in the mission specific Flight Rules Annex.

An optimal "TIG window" is associated with each of the foregoing scenarios. In many cases, an equally acceptable window exists periodically from the standpoint of propellant consumption. The typical time interval between windows ranges from half an

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orbit period to once a day or longer, but many windows may be operationally unusable due to timeline constraints. Consequently, the best discipline with which to start checking optimal TIG feasibility is usually FAO. If all optimal windows are unacceptable, maneuver objectives or minimal propellant consumption must be compromised. With a non-critical maneuver, indefinite postponement and outright cancellation are always viable options.

In addition, the FDO must consider state vector requirements for the burn and whether sufficient ground or TDRSS communications are available to support and monitor the burn preparation and execution. Occasionally, because of trajectory or scheduling constraints, the burn will have to take place without MCC communication. This is usually not a major impact due to Orbiter systems reliability and crew proficiency.

### 3.7.2.3 TIG Slip

TIG Slip refers to the delay of the initiation of a burn past its planned time. The amount of slip that is acceptable for a given burn is dependent on the criticality of the burn, on the purpose of the burn, and on the amount of propellant margin that is available. The Lead FDO for a flight should evaluate TIG slips for all the maneuvers nominally planned for his assigned flight before launch, preferably prior to the first simulation. Typically, critical burns have fairly small TIG slip (< 5 min) due to mission success or crew safety concerns. Slipping a burn past its optimal TIG may result in increased propellant usage, either to accomplish the purpose of the burn or to accomplish the remainder of the flight's objectives. The PROP officer should be consulted early in the analysis process to determine available propellant margins. TIG slip for any specific burn will have to be assessed in the context of the specific mission. The burn can be slipped assuming either an LVLH "hold" or an inertial "hold".

CAUTION: the terms "Inertial Hold TIG Slip" and "LVLH Hold TIG Slip" can be misleading. They do NOT refer to Orbiter attitude hold DAP settings, but rather to the thrust vector's orientation as TIG is slipped.

During PEG-7 burn planning, FDO will calculate optimal burn specifications. The PEG-7  $\Delta v$  and TIG, along with a burn initiate vector, uniquely specify velocity change time, direction, and magnitude in inertial space. After PEG-7 targets are uplinked, the crew loads them using the Maneuver Exec Display on the GNC GPC. Onboard software then computes inertial burn attitude at the planned TIG. Prior to the burn, Orbiter attitude is changed such that the engine thrust vector is aligned with the inertial  $\Delta v$  vector computed onboard from the uplinked targets. During a PEG-7 burn, this inertial attitude is held within the DAP's deadband. Nominally, the burn is initiated on time and the inertial attitude hold results in uplinked PEG-7  $\Delta v$  being applied as desired to the trajectory. If some operational or systems problem prevents the burn from starting on time, a TIG slip occurs.

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Profile Support performs a TIG slip analysis pertaining to an upcoming rendezvous burn by building a table that includes all relevant subsequent burn  $\Delta v$  values. These values are then tabulated as the upcoming burn's TIG is slipped by an increased time interval for each case. One-minute time increments are typically used, but this choice depends heavily on the burn's size and purpose. Both LVLH and inertial TIG slips are evaluated. TSA is generally used to perform TIG slip studies, but TrS is an option, if available. For both kinds of slips, TIG is repeatedly slipped until some tolerance threshold is broken. Thresholds typically relate to propellant costs or safe relative motion.

### 3.7.2.3.1 Inertial TIG Slip

An inertial TIG slip occurs with minimal crew effort. Since the Orbiter is in an inertial hold at TIG, the crew can simply start the burn late and  $\Delta v$  is applied along the originally computed inertial burn direction. The actual PEG-7  $\Delta v$  burned is different than that computed by FDO because M50  $\Delta v$  only produces the same LVLH equivalents at the planned TIG. The burn arc is also different from that planned. The effects of the delayed burn will therefore be different than those intended by the FDO. The bigger the TIG slip, the bigger the difference between the planned and actual trajectories.

Inertial TIG slips are somewhat more difficult to model than LVLH slips. M50 attitude for the nominal maneuver is obtained from its DMT display. The nominal maneuver is then deleted from the ephemeris and replaced by a BFI maneuver with the recorded attitude, appropriate thrusters, and the nominal TIG. The new BFI burn with nominal TIG is used as a quality check, as the resultant burn should be identical to the original burn it replaced. The burn is then deleted and replaced with the same BFI input and a TIG slipped by the chosen interval. Effects on the subsequent trajectory and burns are evaluated to determine slip acceptability. If OMP is used to evaluate inertial TIG slip, the burn TIG is changed to the later time and PEG-7  $\Delta v$  is recomputed using trig functions and the LVLH orbit rotation rate of 4 degrees per minute.

CAUTION: although inertial TIG slips have no theoretical maximum limit, nominal targets must be loaded less than 12 hrs before and 5 min after their TIG. Loads outside this window will be rejected as an illegal entry.

### 3.7.2.3.2 LVLH TIG Slip

An LVLH TIG slip occurs when the crew selects a new, later TIG and reloads the targets onboard. The PEG-7 targets stay the same, but the new TIG results in a different inertial burn attitude. In an LVLH TIG slip, the Orbiter's burn attitude is changed to the new inertial attitude and the burn is executed. For example, a posigrade PEG-7 burn

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stays posigrade for an LVLH TIG slip, no matter how big the slip, but the effects on the trajectory can vary greatly.

In some TIG slip cases, it's desirable to be in LVLH attitude hold so the proper PEG-7 targets can be burned by simply reloading them with the slipped TIG. Inertial hold TIG slips, on the other hand, are easy for the crew to execute, but they don't produce the targeted PEG-7  $\Delta v$  in LVLH components during the delayed burn. Since onboard guidance maintains an inertial attitude hold while performing a Major Mode 202 burn, FDO must be familiar with how much TIG slip is acceptable using inertial hold. If that time is exceeded, then FDO must notify the crew to reload targets at a TIG one minute in the future. This action triggers computation of a new inertial attitude and preserves LVLH  $\Delta v$ . If the crew has loaded targets and a state vector uplink is performed afterward, FDO must remind the crew to reload targets. This reload forces burn attitude to be based on the new vector.

LVLH TIG slips are modeled with nominal PEG-7  $\Delta v$  and a TIG delayed by the chosen interval. This modified burn is then directly input into the ephemeris or used to replace the nominal burn from the ephemeris. The subsequent burns and trajectory are then recomputed to determine  $\Delta v$  and relative motion impacts. If OMP is used to evaluate the LVLH TIG slip, the upcoming burn's TIG is simply changed to the slipped time and trajectory effects are evaluated.

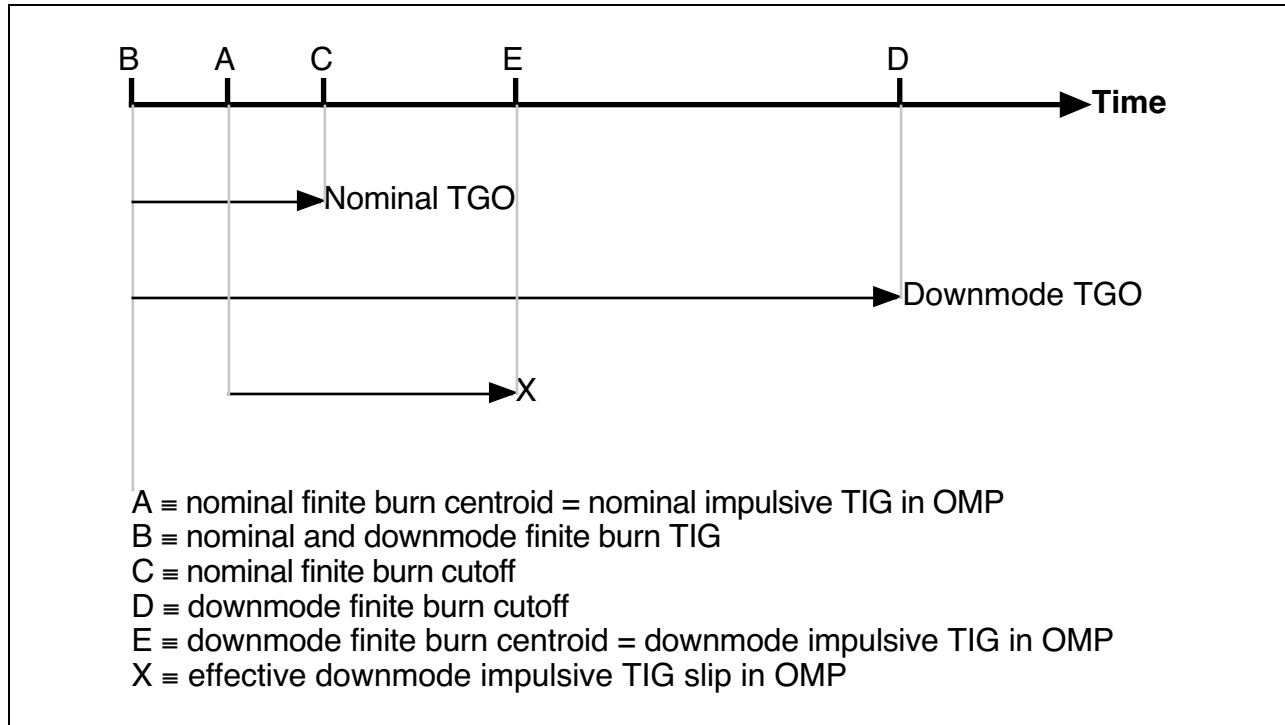
### **3.7.2.3.3 Engine Downmode Effects On TIG Slip**

In the case of an engine downmode immediately before a burn, a TIG slip is effectively imposed on the resulting trajectory. Since time isn't available to retarget the burn with new engine characteristics and the original TIG is being used, the impulsive TIG for the new engines will be at a different time. Since Profile Support runs TIG Slip analyses using impulsive TIGs, this effect must be accounted for in the case of a downmode.

The following figure describes a downmode with respect to time.



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**Figure 3.7.2.3.3-1: Engine Downmode with Respect to Time**

Effective impulsive TIG slip due to a downmode (X in Figure 3.7.2.3.3-1) is a function of the length of the burn and the thrust ratio between nominal and downmode engines.

$$X = \frac{TGO_{\text{Nominal}}}{2} \left( \frac{\text{Thrust}_{\text{Nominal}}}{\text{Thrust}_{\text{Downmode}}} - 1 \right)$$

Thruster	Thrust (lbf)
OBP	12000
LOMS or ROMS	6000
PX2	1740

In a dual-OMS to single-OMS downmode, effective TIG slip is therefore half the nominal TGO. For a single-OMS to PX2 downmode, effective TIG slip is about 1.25 times the nominal TGO. Nominal TGO can be found on the burn's DMT or PAD.

Once effective impulsive TIG slip has been determined for a given burn's thruster downmode, this slip is subtracted from the maximum allowable TIG slip Profile Support determines during the TIG slip analysis. This will be the maximum allowable TIG slip in the event of a downmode. FDO should request the maximum allowable TIG slip for a downmode from Profile Support and discuss this scenario with MARS before a critical burn. In the event of a late downmode that cannot be retargeted, FDO and MARS must ensure this slip is not exceeded.

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### **3.7.2.4 Maneuver Coordination and Planning**

Nearly every parameter associated with a maneuver may require some degree of coordination between FDO and one or more flight control disciplines. TIG selection, particularly for non-critical maneuvers, is often driven by FAO's Flight Plan constraints. Thruster selection may be a compromise between PROP, PAYLOADS, and PDRS considerations of available propellant, science objectives, plume impingement, and robotic joint loads. Based on USSTRATCOM assessment of FDO's predicted post-maneuver trajectory, TIG or  $\Delta v$  modifications may be desirable to avoid close conjunctions with orbiting objects (see Section 3.11).

Potential conflicts between propellant-dependent activities are addressed by each mission's Flight Rules Annex. The "Prop Priorities Table" (PPT) in Annex Section 2 lists each such activity in order of descending priority. Highest priority items tend to be generic activities critical to safe return of crew and vehicle, such as "target deorbit prebank = 45 to 90 degrees". At the bottom of the table are items like "perform FCS Checkout second RCS hot fire". Each activity receives a propellant allocation or budget maintained by PROP. Based in part on FDO's maneuver  $\Delta v$  predictions, PROP periodically updates an estimate of usable propellant over-and-above that budgeted to complete remaining mission activities. Should this "mission completion margin" go negative, it may be necessary for FDO to further optimize propellant consumption by retargeting maneuvers. If replanning by FDO and other disciplines fails to produce enough relief, remaining activities from the bottom of the PPT must be deleted until PROP's margin again becomes positive.

Each maneuver has its own unique coordination requirements, and the preceding introduction is by no means exhaustive. Maneuver coordination typically begins months before launch as part of the flight design process. Perhaps the most generic observation regarding this subject is that few maneuvers have been over-coordinated too far in advance.

### **3.7.2.5 Maneuver Computations**

This section describes maneuvers an Orbit FDO might expect to compute during a typical Shuttle mission. Examples include trim burns, orbit adjust burns to achieve desired EOM conditions, perigee adjust burns, orbit transfers, post deploy separation maneuvers, and unplanned maneuvers.

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### 3.7.2.5.1 Orbit Adjust Maneuvers

Spacelab missions have sometimes carried experiments with precise orbit period requirements for Earth remote sensing. The computers controlling these experiments have had no trajectory update capability, operating on the assumption the true Orbiter trajectory matches the pre-mission nominal orbit. To control orbit period and place the Orbiter over the correct Earth location at the proper time, FDO computes trim maneuvers. This section addresses trim maneuvers for period matching, for correcting nodal crossing times, and for achieving a desired longitude of the ascending node (LAN).

Trim maneuvers are planned with zero  $\Delta v$  to be executed only if necessary. As soon as the Orbiter ephemeris is updated on post-insertion tracking, FDO must determine whether or not a flight day 1 trim maneuver must be executed. To determine orbit period errors, FDO calculates the time in seconds between two successive ascending node crossings in the True of Date Rotating (TDR) Earth-fixed coordinate system.

**NOTE:** the period displayed in Checkout Monitor is generally of sufficient accuracy for these computations. The TrS Checkout period is more apsidal than nodal, and TSA Checkout only approximates geoharmonic perturbations to nodal period. A precise nodal period may be determined from the TrS TRAJ DIGITALS display or by using the TSA Ephemeris Nodal Crossings times.

FDO iteratively determines node crossing times by requesting a Checkout Monitor display in TDR near the node time and observing the magnitude of the z-component of the radius vector. The requested vector time is changed until the z-component of position approaches zero. If the z-component is within plus or minus 260 feet of zero, the node time is accurate to within about .01 seconds. In TrS, this iteration is automated by supplying Checkout Monitor a threshold "no earlier than" time, specifying a latitude trap of zero, and verifying the ZDOT velocity component is positive (signifying an ascending node).

To manually iterate on node time, obtain an approximate nodal crossing time from the Orbiter Trajectory Digitals display and request a Checkout Monitor at that time. To converge on the node, divide the z-component of position by the ZDOT-component of velocity. The result is a delta time in seconds to add to or subtract from the Checkout Monitor time. If z is positive, subtract the delta time; if it is negative, add the delta time. Request another Checkout Monitor at the new time and repeat the process until sufficient convergence occurs, typically after one or two iterations. If the difference between the planned period and the true period exceeds predefined limits, a period matching trim maneuver must be performed.

The  $\Delta v$  necessary to change orbit period by a specified amount may be determined analytically through an equation for velocity in terms of period. First, rearrange the

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energy equation and the period equation to put semi-major axis on the left side of both expressions.

$$E = \frac{v^2}{2} - \frac{\mu}{r} = -\frac{\mu}{2a} \Rightarrow a = \left( \frac{2}{r} - \frac{v^2}{\mu} \right)^{-1}$$

$$P^2 = \frac{4\pi^2 a^3}{\mu} \Rightarrow a = \left( \frac{\mu P^2}{4\pi^2} \right)^{\frac{1}{3}}$$

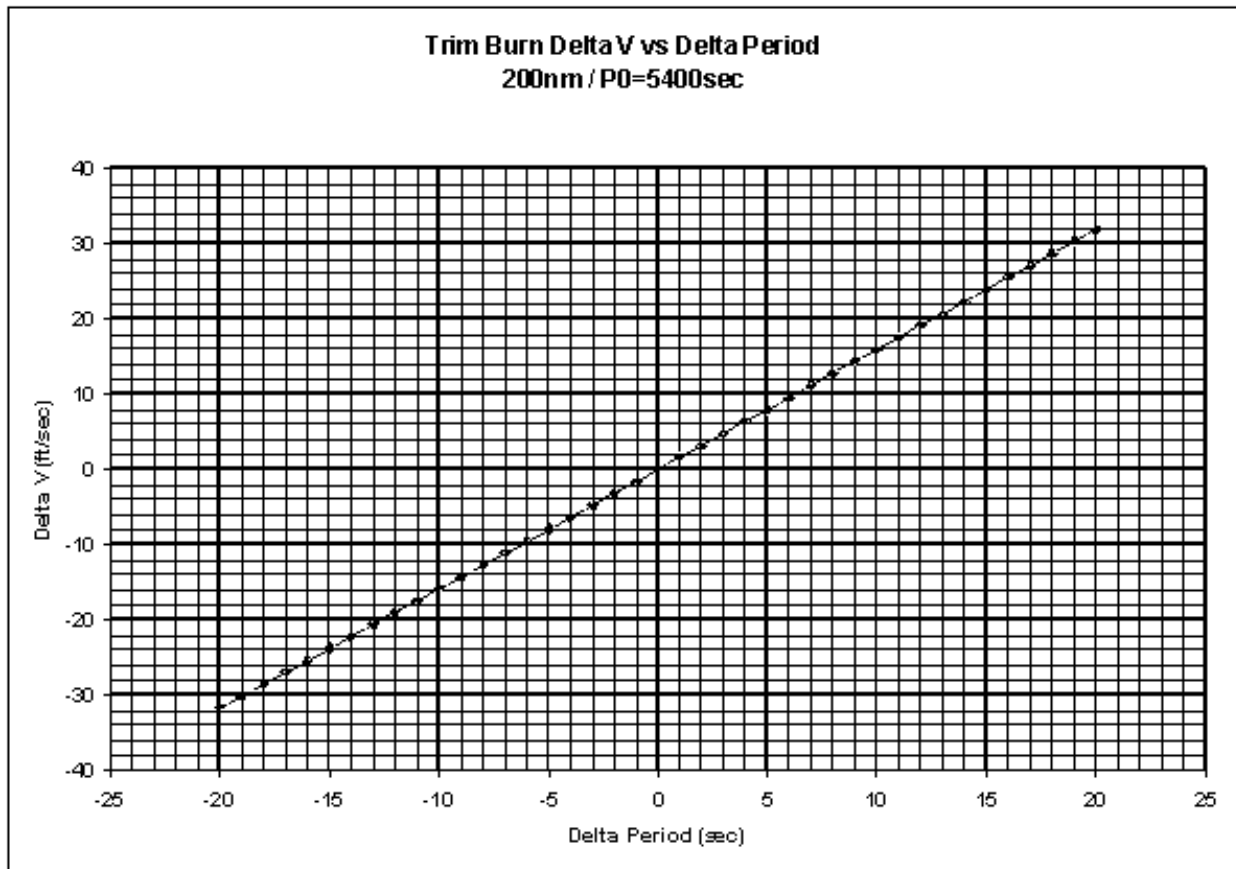
Equating these expressions and solving for velocity yields the desired result.

$$v = \sqrt{\mu \left\{ \frac{2}{r} - \left( \frac{4\pi^2}{\mu P^2} \right)^{\frac{1}{3}} \right\}}$$

Approximate  $\Delta v$  for the trim maneuver is  $\Delta v = v_0 - v$ , where  $v_0$  is the velocity in the initial orbit with period  $P_0$ , and  $v$  is the post-burn velocity with period  $P$ . The radius  $r$  remains the same in both computations.

Figure 3.7.2.5.1-1 is a plot of trim maneuver  $\Delta v$  versus delta period in seconds for an orbit height of 200 nm. The curve changes very little for other Shuttle orbit heights from 105 to 250 nm. Delta period is the difference between the actual orbit period and the desired period in sec. This curve provides an initial guess at trim maneuver  $\Delta v$ . FDO should model the maneuver in an Orbiter ephemeris, then determine a post-maneuver nodal period using one of the methods described above. If the difference in periods is still unacceptable, maneuver  $\Delta v$  should be slightly changed, and the above process repeated until the desired period is obtained.

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**Figure 3.7.2.5.1-1: Trim Burn  $\Delta v$  Versus  $\Delta$ Period**

A simple rule of thumb provides another way of estimating required  $\Delta v$ . A  $\Delta v$  of one foot per second produces about 16000 ft of downtrack change per orbit. At 200 nm orbit height, this rule equates to 16000 ft per rev/25214 fps = 0.63 sec per rev for each fps of  $\Delta v$ . Inertial velocity at TIG can be obtained from Checkout Monitor. If the period must be increased by 4 sec, the trim maneuver  $\Delta v$  would be  $4/0.63 = 6.3$  fps posigrade, which closely agrees with Figure 3.7.2.5.1-1.

For some experiments, the real trajectory must be maintained with nodal crossing times matching pre-mission predictions to within some specified tolerance. The tolerance on Spacelab 1 (STS-9) and STS-45 was  $\pm 60$  sec. Even if insertion errors are successfully corrected, unmodeled perturbations and small translations caused by uncoupled attitude maneuvers will gradually alter nodal crossing times. To correct them, trim maneuvers must be scheduled at several points during the mission. If perturbations are unexpectedly large, unscheduled trim maneuvers may be necessary, but these will be limited by the propellant budget.

Each time the Orbiter ephemeris is updated on a new tracking solution, FDO should iteratively determine the times of ascending nodes of interest as explained above. If the

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last tracking solution before a scheduled trim maneuver predicts an ascending node time outside of limits, the maneuver must be executed.

To estimate the required  $\Delta v$ , first calculate the delta time between the planned and actual ascending node times. Convert this to a downtrack error ( $\Delta x$ ) in feet by computing the product of inertial velocity from the Checkout Monitor  $V_i$  with delta time  $\Delta t$  in sec.

$$\Delta x = V_i (\Delta t) \text{ ft}$$

Now divide  $\Delta x$  by the number of orbits  $n$  between the trim maneuver TIG and the ascending node of interest.

$$\Delta x' = \Delta x/n \text{ feet/orbit}$$

Use the rule of thumb 1 fps  $\Delta v$  produces 16000 ft of downtrack error per orbit, to compute the approximate trim maneuver  $\Delta v$  required.

$$\Delta v = \Delta x'/16000 \text{ fps.}$$

If the actual ascending node time is earlier than the pre-mission time, the trim maneuver is posigrade. If the actual node time is late, the trim maneuver is retrograde.

The  $\Delta v$  obtained should be used as a first guess for modeling the trim maneuver. Once the maneuver is in an Orbiter ephemeris, FDO checks the post-maneuver node crossing time. The  $\Delta v$  should be changed iteratively until the ascending node time equals the pre-mission time. Consider the following example.

- 1) Pre-mission node time: 8/04:41:30 MET (orbit 130)
- 2) Predicted node time: 8/04:40:20 MET
- 3)  $\Delta t = 70$  seconds early; permissible  $\Delta t = 60$  sec
- 4)  $V_i = 25249$  fps from Checkout Monitor
- 5)  $\Delta x = V_i (\Delta t) = 1767396.5$  ft
- 6) Trim maneuver TIG is 6/02:21:00 MET (orbit 97), 33 orbits before the node of interest
- 7)  $\Delta x' = \Delta x/33 = 53557.5$  feet/orbit

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8)  $\Delta v = \Delta x' / 16000 = 3.3$  fps posigrade

The earlier a trim maneuver can be performed before the node of interest, the lower the  $\Delta v$  required. For example, if the above maneuver had been performed as late as 8 orbits before the node of interest, the  $\Delta v$  would have been 13.8 fps. For STS-9, the entire trim maneuver propellant budget was 14.0 fps. On the other hand, the FDO must be careful to evaluate all possible sources of perturbations between the maneuver and the node of interest such as water dumps, IMU aligns, and attitude maneuvers to make sure targeted burn effects are not corrupted. The longer the time between the maneuver and the targeted node, the more likely unmodeled perturbations will disturb the orbit. Trim burn placeholders should be included in the Flight Plan about every 2 or 3 days, depending on the size of the nodal crossing tolerance and known perturbations (number of attitude maneuvers, etc.).

For missions with precise groundtrack constraints, trim maneuver requirements are defined by LANs of interest. Trim maneuvers of this kind were required on STS 41-G in support of radar and photographic imaging experiments.

To compute the longitude adjust maneuver, the difference between the predicted and desired longitudes must be converted to a delta time. Once this is done, the computation is the same as for the node time correction maneuver, except the iteration is on LAN rather than time. The following procedure produces a good first guess at trim maneuver  $\Delta v$ .

- 1) Obtain the predicted LAN of interest  $\lambda_{an}$  from Checkout Monitor. Subtract the desired LAN  $\lambda_{des}$  from the predicted LAN.

$$\Delta\lambda = \lambda_{an} - \lambda_{des}$$

This yields the correct sign if eastern longitudes are used. To avoid confusion, convert western longitudes to eastern, and use the formula as it appears here.

- 2) Determine the number of orbits  $n$  between the trim maneuver TIG and the node of interest.
- 3) Convert delta LAN to a delta time per orbit.

$\Delta t = \frac{\Delta\lambda}{n\omega_e}$ , where  $\omega_e$  is Earth's rotation rate = .0041780746 deg per sec.  $\Delta t$  is the difference in node crossing time which would place the Orbiter at the correct LAN.

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- 4) Compute downtrack change in feet per orbit by multiplying  $\Delta t$  by velocity. Obtain inertial velocity  $V_i$  from Checkout Monitor at the ascending node time. This velocity does not have to be perfectly accurate.

$$\Delta x' = V_i \Delta t$$

- 5) Use the rule of thumb 1 fps delta velocity produces 16000 ft of downtrack error per orbit to compute the approximate trim maneuver delta velocity required.

$$\Delta v = \Delta x' / 16000 \text{ fps.}$$

On STS-41G, the last two steps were combined by using the shortcut formula  $\Delta v = 1.6 \Delta t$ . This holds approximately true for the usual range of Orbiter altitudes.

If  $\Delta \lambda$  is computed correctly, the sign of  $\Delta v$  will be correct. If  $\Delta \lambda$  is negative, the Orbiter is crossing the node westward of the desired groundtrack. This calls for a retrograde maneuver to get ahead of Earth's eastward rotation and arrive at the node the appropriate amount farther east. The opposite applies if  $\Delta \lambda$  is positive, and the Orbiter is crossing the node eastward of the desired groundtrack. In this case, a prograde maneuver allows Earth's eastward rotation to catch up.

Model the trim maneuver in an Orbiter ephemeris and check the LAN of interest using Checkout Monitor. If LAN remains outside the acceptable band of longitudes, slightly change the trim maneuver  $\Delta v$  iteratively until the longitude is as close as possible to the pre-mission value.

The types of trim maneuvers discussed here, period matching, nodal crossing correction, and longitude correction, have all been used operationally during Shuttle flights. There are other possible trim maneuver targeting schemes, but these represent a general approach applicable to other situations. General FDO responsibilities include monitoring the actual trajectory to determine whether or not trim maneuvers are required after new tracking is incorporated (trims are nominally zero  $\Delta v$ ) and computing the maneuvers. To minimize required  $\Delta v$ , trim maneuvers should be executed as early as possible before the node of interest. To allow for worst case post-maneuver perturbations, maneuvers should be targeted for the center of the allowable band of periods, times, or longitudes. There are uncertainties in the accuracy of trim maneuver execution. The required accuracy is 0.2 fps in all axes. This can result in as much as 3200 feet of error per orbit. FDO should work with FAO and other controllers, before the flight and in real time, to minimize planned attitude maneuvers, dumps, and vents which could perturb the nominal trajectory and corrective trims.



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### 3.7.2.5.2 Orbit Adjust for End of Mission Lighting or Cross Range

If otherwise desirable end-of-mission (EOM), EOM+1 day, or EOM+2 days landing opportunities cannot be used because of adverse lighting conditions or excessive crossrange, an orbit adjust maneuver may be scheduled to bring landing conditions within limits. Flight Rule A4-107A6 states that allowable limits for a daylight landing time are sunrise minus 15 minutes and sunset plus 15 minutes. Crossrange limits are mission-specific and determined by the Descent Analysis group in Flight Design.

**CAUTION:** mission-specific crossrange limits are published in the DSCT-05 Flight Design product. These limits are sensitive to orbit height and argument of perigee at deorbit TIG. If these parameters differ from values expected during DSCT-05's publication, a real time update should be requested from the Flight Design Manager if adequate notification (~1 day) can be given. In lieu of valid DSCT-05 data, it will be necessary to verify that marginal opportunities with large crossranges perform a first roll reversal at Earth-relative speeds greater than 6250 fps.

Orbit adjust maneuvers to improve EOM conditions are normally scheduled to occur after all other planned orbit maneuvers have been executed, avoiding adverse impacts to high priority mission objectives. This limits what the orbit adjust maneuver can accomplish because there may be only one or two flight days between the maneuver TIG and the deorbit burn. The earlier in the flight the orbit adjust can be accomplished, the less propellant is required to shift EOM crossrange or lighting. Mission specific rules are developed preflight to guide EOM burn planning and can be found in Section 4 of the Flight Rules Annex. Figure 3.7.2.5.2-1 is an STS-92 example.

**CAUTION:** if the orbit adjust is retrograde and performed at the "optimal" TIG, a one-for-one tradeoff between expended orbit adjust  $\Delta v$  and decreased steep deorbit  $\Delta v$  can be obtained for many deorbit opportunities to ConUS sites in the EOM time frame. Although an optimized adjust would then have virtually no impact to the *nominal* mission completion propellant margin, this will not be the case for all ELS opportunities. Particularly when a large adjust greatly increasing eccentricity is under consideration, gaps in achievable ELS opportunities no greater than 4.5 hrs in duration must be maintained per Flight Rule A4-103A3.

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**X4.1.2-5**

### EOM ORBIT ADJUST BURNS

- A. IF PROPELLANT IS AVAILABLE, ORBIT ADJUSTS MAY BE PERFORMED TO INCREASE THE NUMBER OF DEORBIT OPPORTUNITIES AVAILABLE. IF AN ELLIPTIC ORBIT IS TARGETED FOLLOWING THE ADJUST, STEEP DEORBIT CAPABILITY SHALL BE RETAINED TO SATISFY ALL FLIGHTS RULE {A4.1.3-3A}.3, OFF-NOMINAL ORBITAL ALTITUDE RECOVERY PRIORITIES.
- B. THE ORBIT ADJUST PLAN WILL ATTEMPT TO ACHIEVE THE FOLLOWING COMBINATIONS OF LANDING OPPORTUNITIES STATED IN ORDER OF DECREASING PRIORITY. ONLY OPPORTUNITIES WHICH SATISFY THE CREW DAY CONSTRAINTS IN APPENDIX K OF THE CREW PROCEDURES MANAGEMENT PLAN WILL BE CONSIDERED (8 HRS < AWAKE TIME BEFORE LANDING < 14 HRS). AN ORBIT ADJUST PLAN WHICH WOULD RESULT IN LOSS OF OPPORTUNITIES AT A HIGHER PRIORITY THAN THOSE GAINED WILL NOT BE PERFORMED EVEN IF DAYLIGHT OPPORTUNITIES ARE PROVIDED BY THE PLAN.

PRIORITY	SITE	EOM	EOM +1	EOM +2
1	KSC	1	1	1
	EDW	1	1	1
2	KSC	2		
3	KSC		2	
4	EDW		2	
5	KSC			2
6	EDW			2

- C. ORBIT ADJUST BURN TIG'S WILL BE SCHEDULED SUCH THAT SUBSEQUENT CLOSEST APPROACH TO ISS IS GREATER THAN HALF THE DISTANCE ACHIEVED ONE ORBIT FOLLOWING TERMINATION OF ACTIVE PROXIMITY OPERATIONS PILOTING.

*Since no propellant is budgeted for orbit adjust burns, they are limited in magnitude to predicted margins above mission completion following joint operations. Due to trajectory dispersions arising from ISS departure, prudent orbit adjust burn planning will avoid subsequent ISS approaches according to the "Rule of Halves" (ref. Level B Groundrules & Constraints, Section 4.5.2.6, Postrelease Requirements, Paragraph (3)). This criterion is considered conservative even if ground tracking in support of orbit adjust targeting is unavailable.*

**Figure 3.7.2.5.2-1: Flight-Specific EOM Orbit Adjust Rule**

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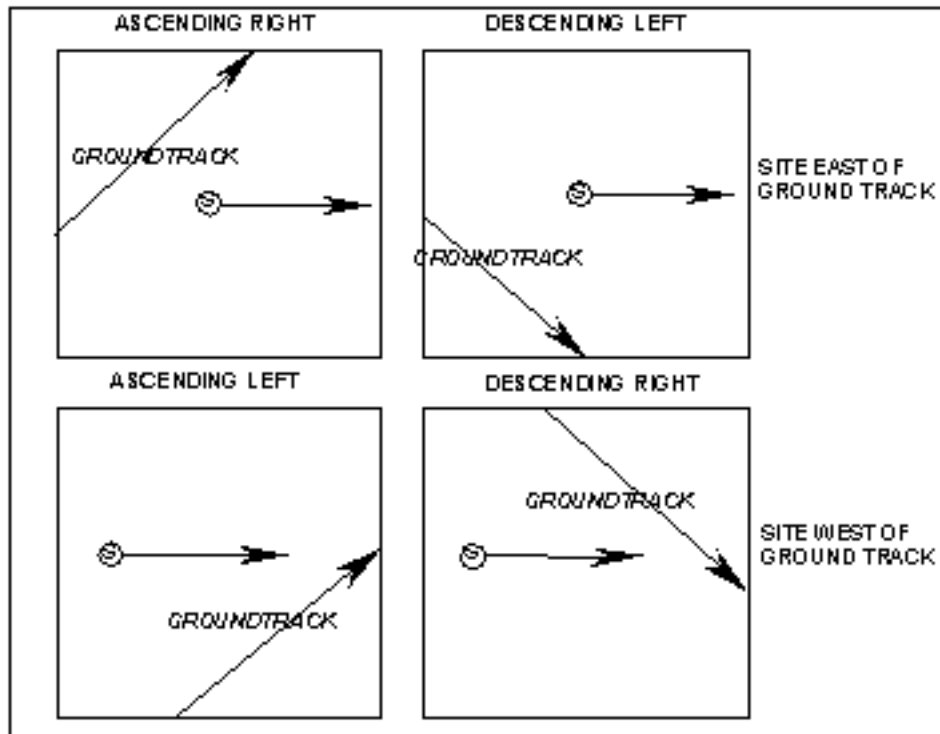
If the orbit adjust is retrograde, propellant is conserved by doing the burn at the optimum perigee adjust TIG. This reduces the deorbit cost, such that the sum of the orbit adjust  $\Delta v$  and the deorbit  $\Delta v$  is approximately equal to the nominal deorbit  $\Delta v$ . However, if for some reason the nominal opportunity is NO-GO, and the orbit adjust was large, resulting in a highly elliptical orbit, deorbit cost will be higher for later opportunities because of apsidal rotation. In some cases, the resultant deorbit  $\Delta v$  could be so high that ConUS landing opportunities are lost. This impact is much smaller for the only slightly elliptical orbits resulting from small burns. All of this argues for doing the maneuver as early in the mission as possible to keep  $\Delta v$  low.

NOTE: targeting needs to allow for prediction uncertainties, so target further inside the limit for longer propagation periods. Lower perigee height will also contribute to prediction uncertainty. Typical 'cushions' are 20 nm inside the crossrange limit 4 or 5 days prior to EOM and 10 nm inside the crossrange limit 2 or 3 days prior to EOM.

If the orbit adjust is large, a way of preserving more than one day's landing opportunities is to "optimize" adjust TIG for nominal EOM through EOM+2 opportunities. This TIG is not actually optimum for any single opportunity, but it splits the difference so that steep deorbit  $\Delta v$  is minimal over all three days. This is done in perigee adjust planning for OMS leaks, as described in Section 3.9. An alternative is to plan two orbit adjust burns. The first would optimize for EOM. The second, occurring after the EOM opportunity is waved off, would optimize for subsequent opportunities.

If the orbit adjust is posigrade, it is important to minimize deorbit propellant cost by keeping the perigee point in the northern hemisphere. To do this from a near circular orbit, the burn should be done at or near the "anti-perigee adjust" TIG, one half orbit from the optimum perigee adjust TIG. If the initial orbit is already elliptical and perigee is properly placed, the same guideline holds. Whether the burn is retrograde or posigrade, and regardless of the initial orbit, FDO must model the orbit adjust, compute deorbit solutions from the resultant orbit, iterate on the orbit adjust burn TIG and  $\Delta v$  to meet lighting or crossrange requirements, and also minimize total cost of the orbit adjust and the deorbit burn.

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**Figure 3.7.2.5.2-2: Crossrange Versus Ground Track Geometry**

If a site is east of the groundtrack, Earth rotation is steadily increasing crossrange. This geometry describes ascending right and descending left passes. In these cases, if crossrange is excessive for a landing opportunity, the orbit adjust burn must cause the Orbiter to "catch up" to the rotating Earth and arrive earlier. Therefore, a retrograde burn is necessary to decrease crossrange.

If a site is west of the groundtrack, Earth rotation is steadily decreasing crossrange. This geometry describes ascending left and descending right passes. In these cases, if crossrange is excessive for a landing opportunity, the orbit adjust burn must cause the Orbiter to "slow down" and arrive later, after crossrange to the site has decreased to within limits. This requires a posigrade burn.

Coordination and TIG determination to manage crossrange are the same as for orbit adjusts to shift lighting. Crossrange from the landing site to the groundtrack depends on LAN, site latitude, and inclination. By adjusting LAN, crossrange can be shifted. Therefore, the crossrange adjust problem is directly analogous to computing a trim burn to change LANs, as discussed in Section 3.7.2.5.1, but the orbit adjust maneuver is much larger than the typical trim burn. Figures 3.7.2.5.2-6a through 3.7.2.5.2-6c show the relationship between LAN and crossrange for the three ConUS landing sites at different orbit inclinations. Figure 3.7.2.5.2-7 describes how the plots in Figures 3.7.2.5.2-6 were generated. These plots are included for information only. In practice, FDO will use the TrS or workstation applications to determine an orbit adjust burn just as was described above for the lighting case.

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In planning orbit adjusts, the FDO needs to consider the effects the burn will have on parameters already within acceptable limits. It does no good to improve one parameter and create a violation in another. The "Orbit Adjust Maneuver Tradeoffs" matrix in Figure 3.7.2.5.2-3 below provides a quick means of qualitatively assessing orbit adjust effects on both lighting and crossrange.

The matrix in Figure 3.7.2.5.2-3 clearly shows that sometimes an orbit adjust will improve both parameters, and sometimes it will improve one but worsen the other. This is because the correct burn to improve lighting depends upon whether the initial landing time is too early (before sunrise) or too late (after sunset), but a burn to reduce crossrange depends on groundtrack geometry (ascending/descending, right/left).

An orbit adjust burn which improves one parameter but worsens the other is still acceptable if there is no crossrange limit or lighting violation for higher priority landing opportunities. The important thing is to consider all factors in planning the burn. If lighting is being adjusted, FDO needs to determine whether or not crossrange and lighting will still be acceptable for the EOM, EOM+1, and EOM+2 opportunities and their backups. If crossrange is being adjusted, FDO needs to determine whether or not any of these opportunities will become unusable due to lighting or crossrange violations. For those opportunities still occurring after sunrise or before sunset, FDO needs to determine whether or not the orbit adjust created a sun angle violation according to Flight Rule A4.1.4-5 (sun on final within 10° in azimuth and 0 to 20° in elevation). A sun angle violation would render a runway unusable.

In the Figure 3.7.2.5.2-3 matrix, the left hand column indicates the maneuver direction (posigrade or retrograde). The next column labels the lighting and crossrange effects. "LIT" stands for "lighting," and "BR" and "AS" stand for "before sunrise" and "after sunset," respectively. The next two columns are for ascending and descending landing opportunities. These are further divided into passes with the landing site to the right and to the left of the groundtrack.

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MNVR DIRECT ION	LIT & XRNG		ASCENDING OPPORTUNITY		DESCENDING OPPORTUNITY	
			RIGHT	LEFT	RIGHT	LEFT
POSI- GRADE	L I T	BR	IMPROVES LANDING LIGHTING			
		AS	WORSENS LANDING LIGHTING			
	CROSS RANGE		INCREASES	DECREASES	DECREASES	INCREASES
RETRO- GRADE	L I T	BR	WORSENS LANDING LIGHTING			
		AS	IMPROVES LANDING LIGHTING			
	CROSS RANGE		DECREASES	INCREASES	INCREASES	DECREASES

**Figure 3.7.2.5.2-3: Orbit Adjust Maneuver Trade Offs**

Figure 3.7.2.5.2-3 matrix examples follow.

**EXAMPLE 1:**

- 1) Landing time is sunset plus 20 min (violation).
- 2) Groundtrack geometry is ascending left.
- 3) Crossrange is within limits.
- 4) From the matrix, FDO concludes:
  - a) A retrograde burn will improve lighting.
  - b) A retrograde burn will increase crossrange.
- 5) FDO's task is now to:
  - a) Plan a retrograde burn at an optimum Hp Adjust time as early as possible in the remaining mission.
  - b) Determine  $\Delta v$  required to achieve landing no later than sunset plus 15 min, accounting for worst-case prediction dispersions.
  - c) Evaluate crossrange and lighting changes for all EOM, EOM+1, and EOM+2 ConUS opportunities if the burn is performed.
  - d) Make a burn recommendation to FD.

**EXAMPLE 2:**

- 1) Landing time is sunrise minus 8 min.
- 2) Groundtrack geometry is descending left.

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- 3) Crossrange is slightly outside of limits.
- 4) From the matrix, FDO concludes:
  - a) A retrograde burn will decrease crossrange.
  - b) A retrograde burn will worsen lighting.
- 5) FDO's task is now to:
  - a) Plan a retrograde burn at an optimum Hp Adjust time as early as possible in the remaining mission.
  - b) Determine  $\Delta v$  required to reduce crossrange within limits, accounting for worst-case prediction dispersions.
  - c) Evaluate crossrange and lighting changes for all EOM, EOM+1, and EOM+2 ConUS opportunities if the burn is performed.
  - d) Make a burn recommendation to FD.

Due east launches from KSC always produce ConUS landing opportunities with the landing sites exclusively to the left of the groundtrack, except for rare KSC opportunities which lie directly beneath it. This is because all other ConUS site latitudes are greater than  $28.5^\circ$  north. Higher inclination launches have ConUS landing opportunities with all possible combinations of groundtrack geometry.

Recall that orbit adjusts for landing lighting are a function of whether the Orbiter is arriving too early (>15 min before sunrise) or too late (>15 min after sunset) at the landing site. A posigrade burn is required to correct for pre-sunrise conditions since a posigrade maneuver increases orbit period and deorbit TIGs become later. The opposite is true for post-sunset conditions. A retrograde burn decreases the period, and the Orbiter arrives earlier.

Key personnel with whom FDO must coordinate this maneuver are the Entry Flight Director and/or the Entry FDO, who probably asked FDO to look at the feasibility of doing an orbit adjust. Other players are the FAO, who works with the FDO on placing the burn into the Flight Plan, and PROP, who will want to know cost of the orbit adjust combined with various ConUS deorbit burns. When the maneuver is planned and agreed to, FDO should create a count down clock 2 to 4 hours before TIG (see Appendix 3.F).

FDO should request from FAO the earliest possible time the maneuver can be placed in the Flight Plan. This is necessary to minimize orbit adjust  $\Delta v$  and eccentricity in the final orbit. High eccentricity limits the number of ConUS landing opportunities available. It also eliminates many Emergency Landing Site (ELS) opportunities due to excessive deorbit cost. If the burn is an EOM wave off orbit adjust, TIG is usually two orbits after the last ConUS opportunity of the day. The two revs allow the crew to back out of the deorbit prep and reconfigure for on orbit operations. Earlier orbit adjust TIGs are possible if the day's ConUS opportunities are called off early.

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Orbit adjust TIG will normally be either the optimum perigee adjust TIG for upcoming ConUS opportunities or the "anti-perigee adjust" TIG, so TIG is known in advance for most cases. The TSA PADJ processor can also be used to optimize orbit adjust TIG for a large number of deorbit opportunities at once. FDO must iterate to determine burn  $\Delta v$  of the burn. This iteration starts with a rough guess  $\Delta v$  of +/-10 to 20 fps at the planned TIG and evaluates resulting deorbit opportunities. Any reasonable initial guess will do. The speed of TrS/TSA processors reduces the iteration times, making a good initial guess less essential. FDO will then make a subsequent guess based on a linear function inferred from no burn deorbit opportunities and the those following the orbit adjust guess. A hand calculator will increase the precision of subsequent iterations. This iteration process continues until the desired precision is achieved. A procedure describing both the initial guess computation and subsequent iterations appears below.

- 1) Determine the number of orbits between the orbit adjust TIG and the deorbit TIG.

$$N = D/O \text{ ORB} - \text{ADJ ORB}$$

- 2) Determine the number of minutes by which the landing time must be shifted and convert this to seconds.

$$T = (\text{Landing Time} - \text{Desired Landing Time}) \times 60$$

NOTE: absolute times do not have to be subtracted here. One could simply take the delta time from sunrise or sunset from the DOPS output, and subtract the final delta time FDO desires. For example, if landing occurs at sunset plus 20 min ("20 as" on DOPS), and FDO is targeting for sunset plus 12 min,

$$T = (20 - 12) \times 60 = 480 \text{ sec.}$$

- 3) Determine the number of seconds per orbit by which the period must be changed (dP) to result in the above shift in deorbit TIG. It is valid to apply the desired landing time shift to the deorbit TIG since the time from deorbit to touchdown can be considered roughly constant.

$$dP = T/N \text{ seconds per orbit}$$

Retain the sign of T in this calculation.

- 4) From Figure 3.7.2.5.2-4, a change in period of about 60 sec results in low Earth orbits from a 90 fps posigrade or retrograde burn. The relation between change in period and burn  $\Delta v$  is linear. For example, a 45 fps burn will change the period by about 30 sec. If the desired time is earlier than the initial, the  $\Delta v$  is retrograde. It's posigrade if the desired arrival time is later than the initial guess.



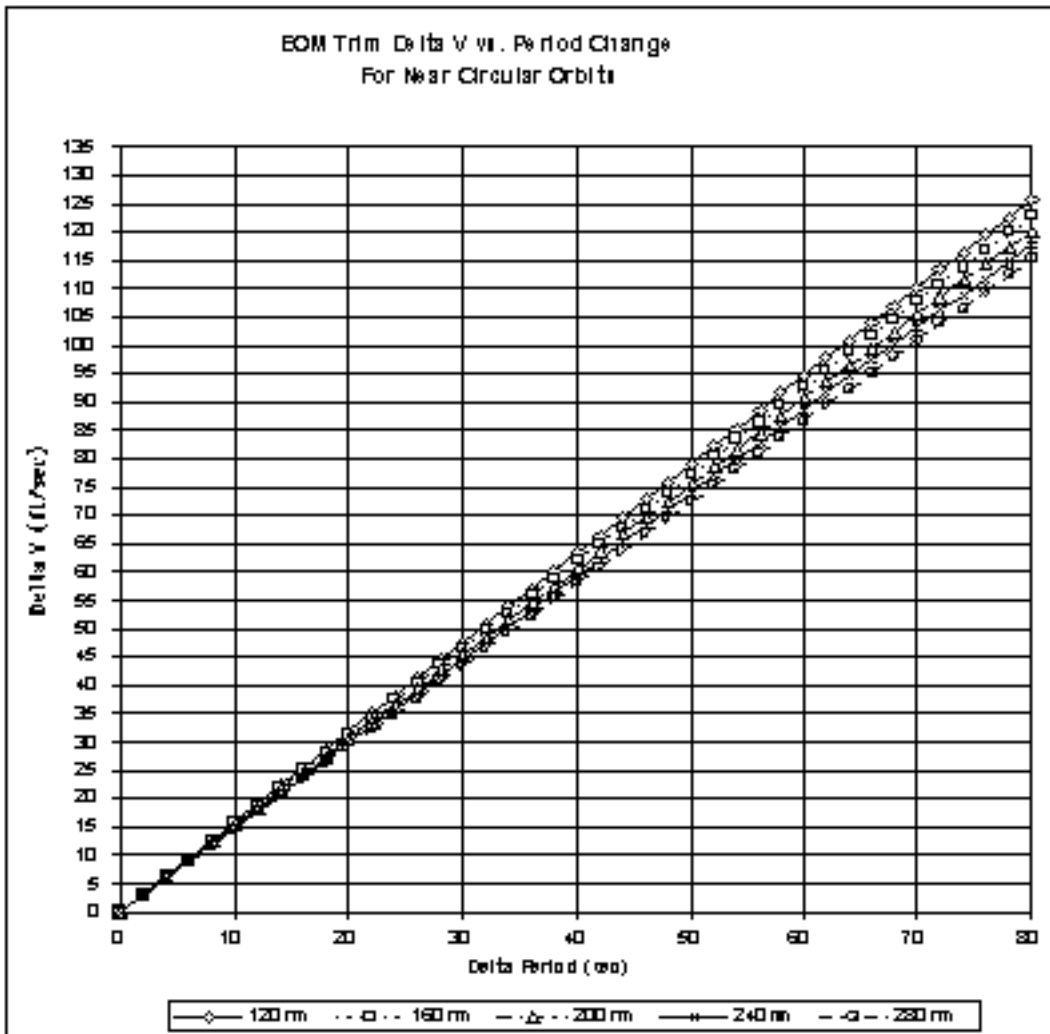
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- 5) Direct input the orbit adjust in TrS as follows,  
Guidance Mode: PEG-7  
Thrusters: per PROP  
TVR: 180  
TIG: predetermined optimum  
PEG-7 targets: DVX = value from Step 4; DVY = DVZ = 0

NOTE: if using the direct maneuver input application, first notify DYNAMICS.

- 6) Run DMP for the opportunity of concern and note deorbit TIG on the Deorbit Summary Table (DST). Compare this to the deorbit TIG for this landing site obtained with no maneuver in the ephemeris. If the TIG has not shifted by the desired amount, repeat Steps 5 and 6, increasing orbit adjust  $\Delta v$  magnitude slightly. Iterate until the desired deorbit TIG is obtained. If time overshoots that desired, decrease orbit adjust  $\Delta v$ .
- 7) To get actual landing time, a complete set of deorbit computations is necessary. Landing time can then be obtained from the Entry Elapsed Time display. It's a lot faster to get a post orbit adjust vector and have TRAJ run DOPS out through EOM+2 days. Crossrange can be checked for the targeted opportunity on the DST, and crossrange and lighting effects for all opportunities will show up on the DOPS run. FDO or TRAJ should verify that no higher priority deorbit opportunities are lost because of the orbit adjust.
- 8) Run the DMP for all acceptable EOM, EOM+1, and EOM+2 deorbit opportunities for both KSC and EDW to determine if the OA TIG is optimum for these opportunities. If they are reasonably close, give PROP the required orbit adjust and deorbit costs. Otherwise, move the OA TIG and repeat the process.

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**Figure 3.7.2.5.2-4: Trim Burn  $\Delta v$  Versus  $\Delta$ Period in Near-Circular Orbits**

From the matrix in Figure 3.7.2.5.2-3, it's evident the orbit adjust maneuver for crossrange depends upon groundtrack geometry. If Earth is visualized as rotating eastward beneath the orbit plane, an intuitive grasp of geometry effects is obtained (see Figure 3.7.2.5.2-2).

FDO should iterate to determine the  $\Delta v$  required to pull in crossrange by a specified amount, and a good first estimate will speed up this process. Evaluate cross range from this guess. The speed of TrS/workstation processors make the initial guess less critical. Use the following procedure to produce a good first guess.

- 1) First decide on the desired delta-crossrange (dXR). This is a FDO judgment. For example, if the current crossrange is 10 NM outside limits, the FDO might want to bring it 10 NM inside, for a dXR of 20 NM.

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- 2) Estimate the change in crossrange per degree of change in LAN (dX/dL). This quantity is the slope of the applicable curve in Figures 3.7.2.5.2-6 in the region of interest. The region of interest is generally the band of crossranges from 700 to 900 nm, since most dispersed crossrange limits fall within this range. These values are tabulated in Figure 3.7.2.5.2-5 below for orbit inclinations at 28.5° and 57.0° orbits. Use this matrix for an estimate.

GTRK GEOM		ASCENDING		DESCENDING	
SITE	INCL	RIGHT	LEFT	RIGHT	LEFT
EDW	28.5	N/A	18	N/A	18
	57.0	28	40	25	40
NOR	28.5	N/A	19	N/A	19
	57.0	28	40	25	40
KSC	28.5	N/A	25	N/A	25
	57.0	33	44	36	44

**Figure 3.7.2.5.2-5: dX/dL (nm/deg) From 700 –900 nm Crossrange**

- 3) Determine the desired change in longitude (dLAN).

$$dLAN = dXR/(dX/dL) \text{ deg}$$

- 4) Coordinate with FAO to determine the earliest possible orbit available to do the orbit adjust burn, and subtract the orbit adjust orbit number from the landing orbit number.

$$N = LND \text{ ORB} - ADJ \text{ ORB}$$

- 5) Convert the dLAN to a delta period (dP) per orbit.

$$dP = \frac{dLAN}{N\omega_e}, \text{ where } \omega_e \text{ is the sidereal Earth rotation rate} = 0.0041780746 \text{ deg/sec}$$

- 6) Estimate  $\Delta v$  by finding dP on the curves in Figure 3.7.2.5.2-4, just as for the lighting orbit adjust maneuver. Determine the sign of the orbit adjust maneuver (posigrade or retrograde) from the matrix in Figure 3.7.2.5.2-3, and model the burn as follows.

Guidance Mode: PEG-7

Thrusters: per PROP

TVR: 180

TIG: predetermined optimum

PEG-7 targets: DVX = value from Step 6; DVY = DVZ = 0

- 7) Run DMP from the ephemeris containing the burn, and observe crossrange on the Deorbit Summary Table (DST). Compare crossrange to the crossrange with no orbit

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adjust, and iterate on  $\Delta v$  as necessary until the desired crossrange is obtained. If necessary, examine effects of the burn on lighting by applying change in deorbit TIG to the landing time, then computing the new delta time with respect to sunrise or sunset. Run DOPS out through EOM+2 to check crossrange for all PLS and EOM opportunities post OA to make sure no higher priority opportunities are lost.

8) Inform PROP of the required orbit adjust and deorbit costs.

As an example, suppose FDO needs to pull in crossrange by 20 nm on an ascending left opportunity to EDW. Current conditions follow.

Orbit Height = 160 nm circular  
Current XR = 775 (dispersed limit = 765 nm)  
Desired XR = 755, so dXR = 20 nm  
Inclination = 28.5°  
N = 28 orbits  
Landing Time = Sunrise -2 min

From Figure 3.7.2.5.2-3, FDO draws the following conclusions.

A posigrade burn will reduce the crossrange  
A posigrade burn will also improve lighting

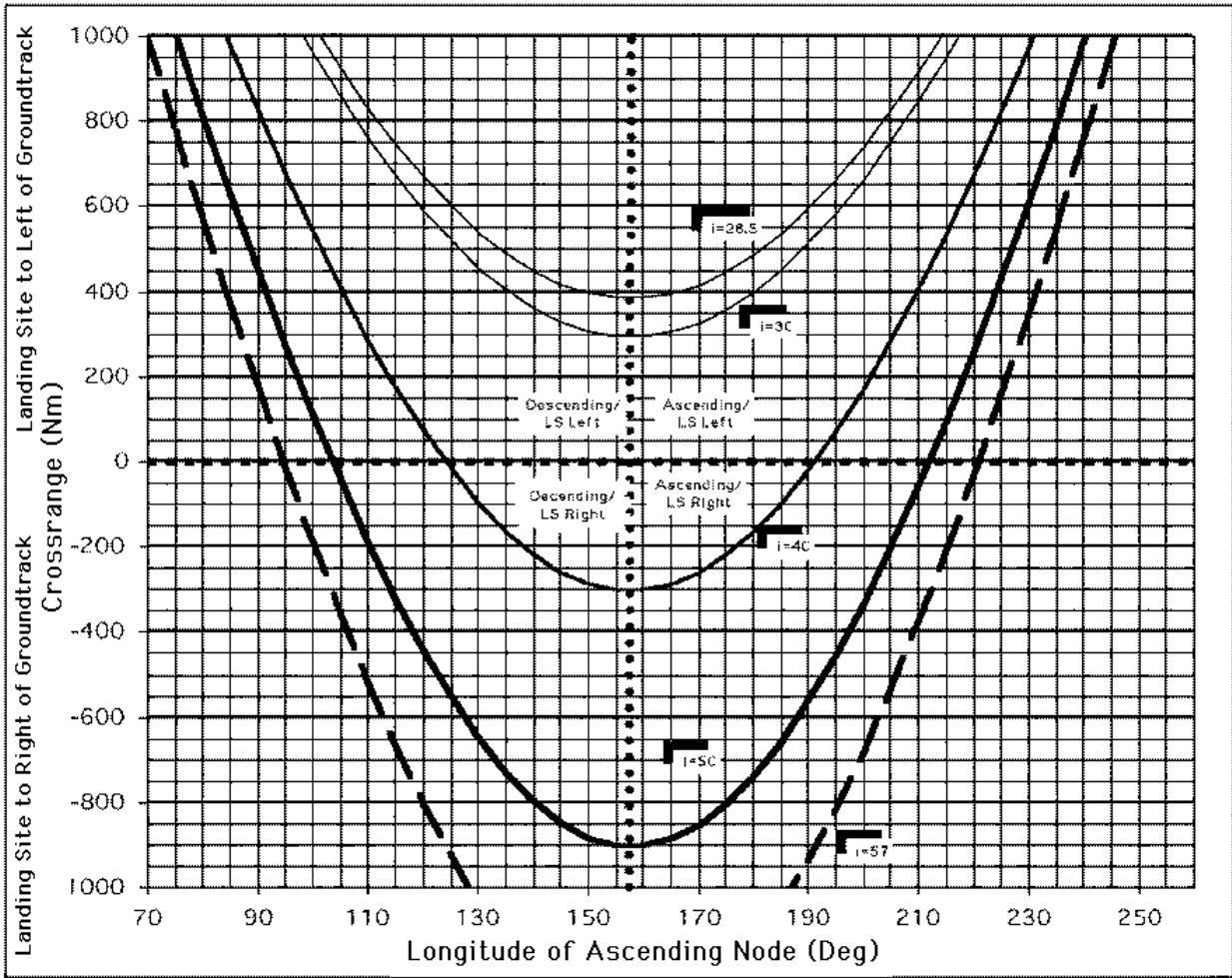
NOTE: in this case, the posigrade burn "improves" lighting by shifting pre-sunrise landing time later. However, FDO must still assess possible sun angle violations on final for viable runways and verify no other planned opportunities were lost because of lighting or crossrange violations.

FDO estimates  $\Delta v$  required to pull in crossrange.

From Figure 3.7.2.5.2-5,  $dX/dL = 18 \text{ nm/deg}$   
 $dLAN = dXR/(dX/dL) = 20/18 = 1.11^\circ$   
 $dP = \frac{dLAN}{N\omega_e} = 1.11/[28(0.0041780746)] = 9.48 \text{ sec/orbit}$

From Figure 3.7.2.5.2-4,  $\Delta v = +15 \text{ fps}$

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**Figure 3.7.2.5.2-6a: EDW Crossrange Versus LAN**

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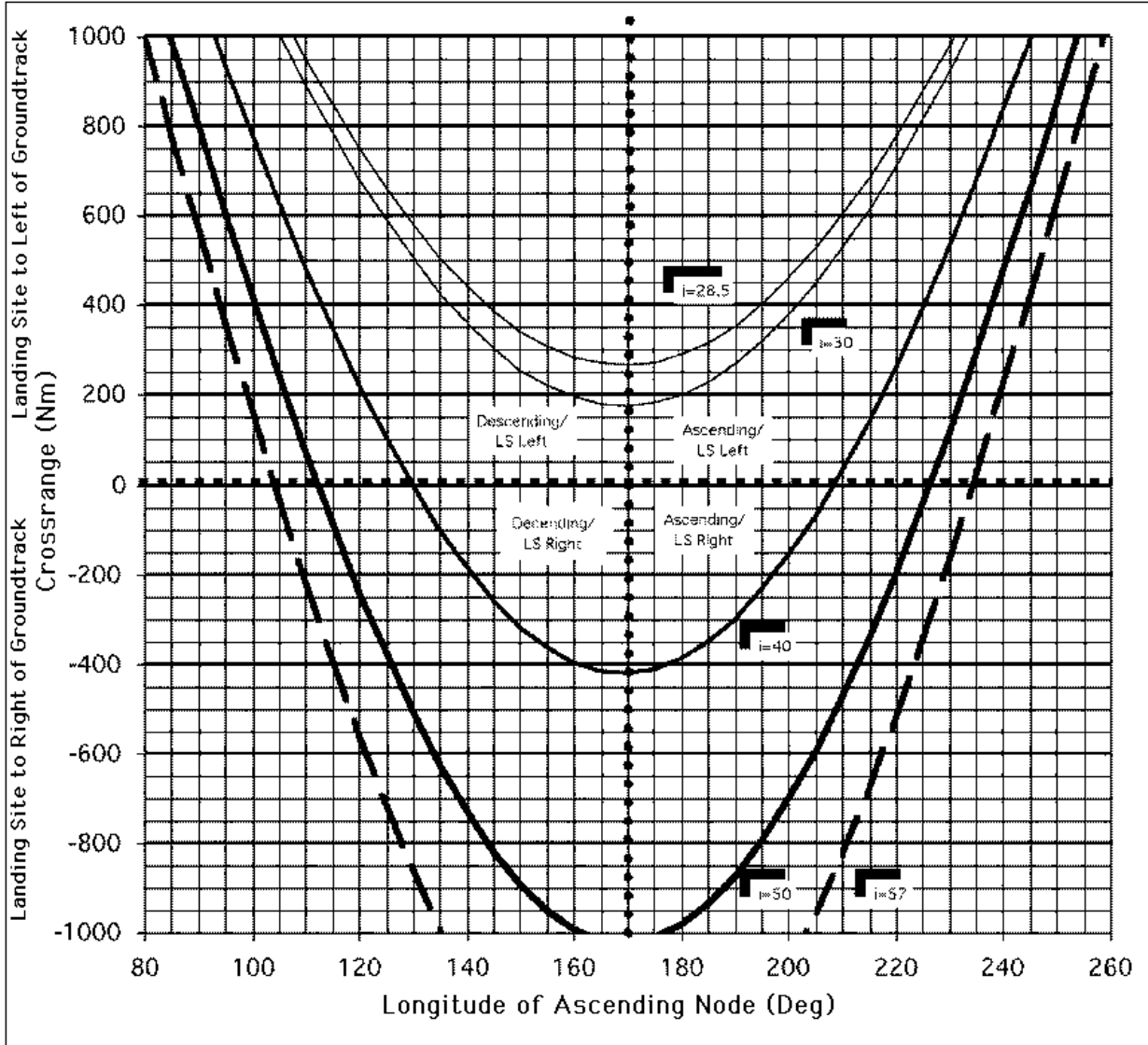
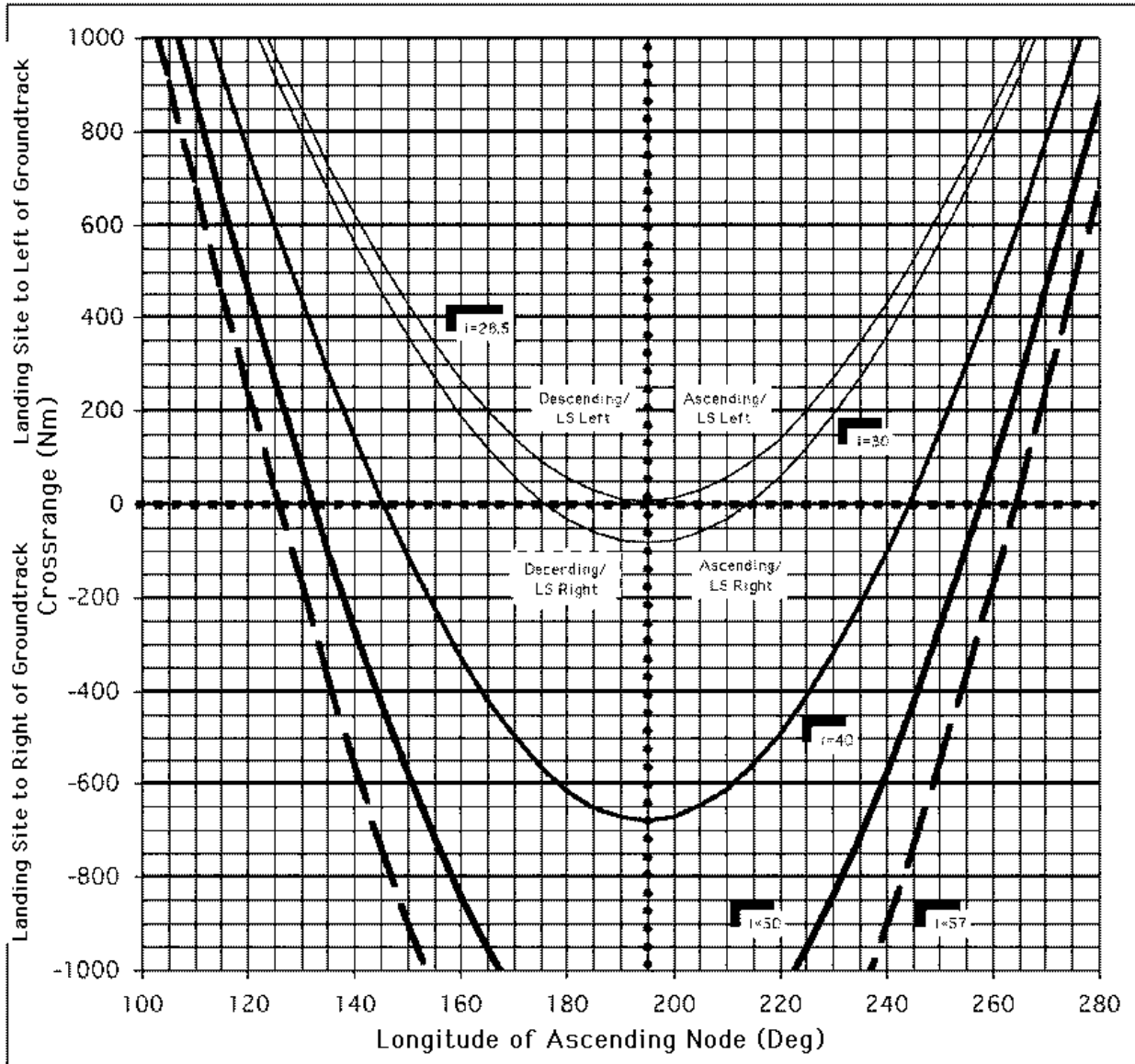


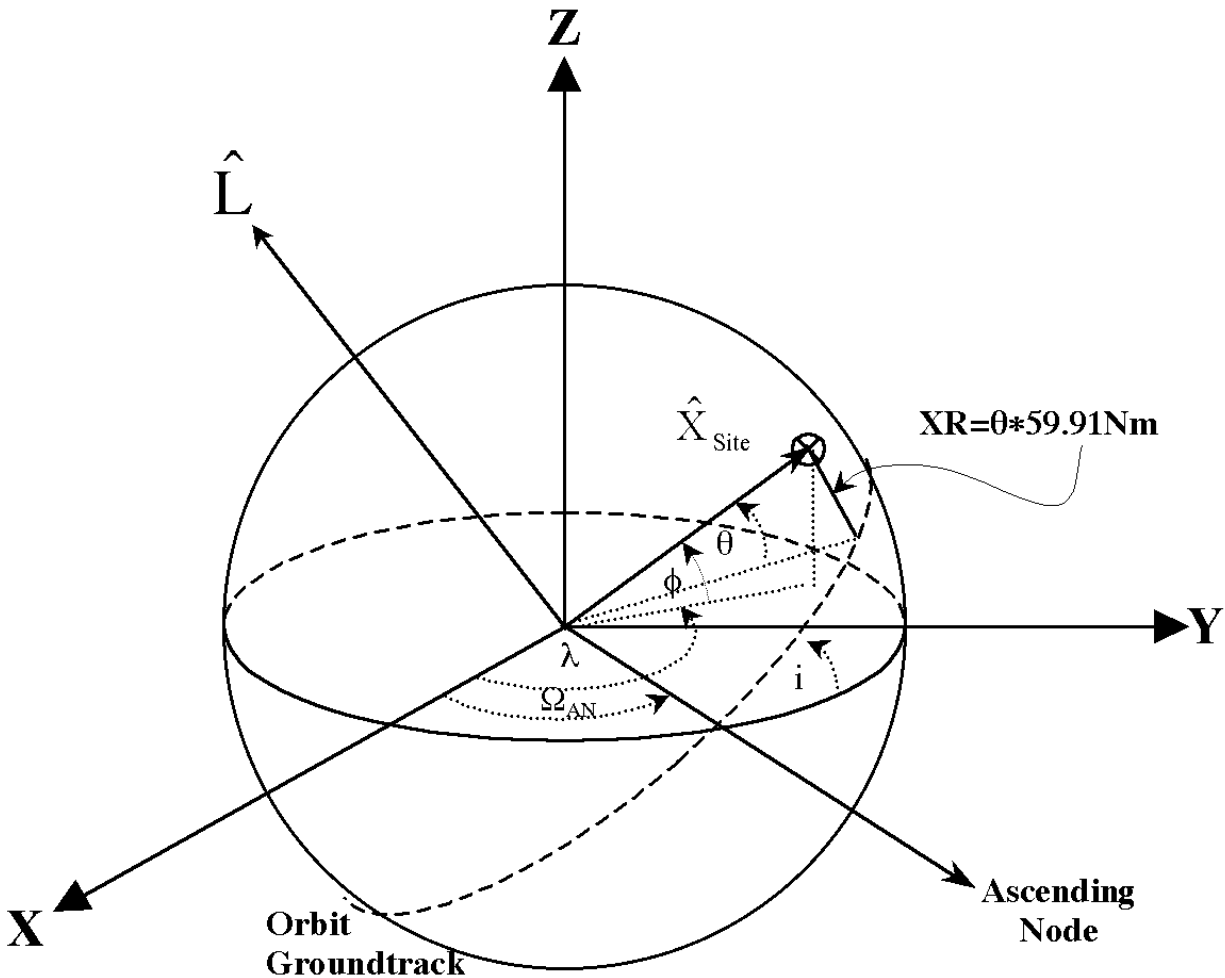
Figure 3.7.2.5.2-6b: NOR Crossrange Versus LAN

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**Figure 3.7.2.5.2-6c: KSC Crossrange Versus LAN**

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**Figure 3.7.2.5.2-7: Geometry Pertaining To Figures 3.7.2.5.2-6**

Assuming a circular orbit with period ~90 min and a spherical earth of radius 3432.44 nm with  $1^\circ$  of geocentric arc = 59.91 nm, the Figure 3.7.2.5.2-7 geometry leads to the following expressions. Vectors are expressed using Cartesian components of the earth-fixed reference frame defined by  $\hat{\mathbf{I}} \times \hat{\mathbf{J}} = \hat{\mathbf{K}}$ , unit vectors aligned with Figure 3.7.2.5.2-7's X, Y, and Z axes, respectively.

$$\text{Angular Momentum Unit Vector} \equiv \hat{\mathbf{L}} = \sin \Omega_{AN} \sin i \hat{\mathbf{I}} - \cos \Omega_{AN} \sin i \hat{\mathbf{J}} + \cos i \hat{\mathbf{K}}$$

$$\hat{\mathbf{X}}_{Site} = \cos \lambda \cos \phi \hat{\mathbf{I}} + \sin \lambda \cos \phi \hat{\mathbf{J}} + \sin \phi \hat{\mathbf{K}}$$

$$\theta = 90^\circ - \arccos\{\hat{\mathbf{L}} \cdot \hat{\mathbf{X}}_{Site}\}$$

$$XR = \theta \cdot 59.91 \text{ nm}$$



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### 3.7.2.5.3 Minimum Perigee for Orbit Lifetime

Criteria for orbit lifetime are addressed in Flight Rule A4-102. It requires deorbit maneuvers be scheduled at least 48 hours before decay to Entry Interface (EI). This provides 24-hour wave off capability. Planning a deorbit within 24 hours of EI decay is considered unsafe because of inability to accurately model the trajectory at low altitude. The wave off day protects for potential systems problems or forecast bad weather at the time of the deorbit/landing. Although perigee altitudes less than 80 nm may be acceptable if apogee altitude is high enough, perigee at the planned deorbit TIG shall not be less than 80 nm.

The perigee needed to meet minimum orbit lifetime requirements should not be confused with Flight Day 1 (FD1) MIN HP or the safe HP used on the DEL PAD. Flight Rule A2-52 addresses MIN HP, which provides capability to safely deorbit on FD1 but does not support a one day wave off. Starting at MIN HP, the orbit may decay to EI within 15 hours following the FD1 PLS TIG.

Safe HP provides capability to deorbit one day later if there is a broken deorbit burn. For the extreme "point of no return" case, this situation reduces to planning a deorbit TIG HP equal to the safe HP (typically 80 nm) satisfying orbit lifetime requirements. In this scenario, the planned burn is cancelled due to a systems problem or bad weather. Whether the deorbit burn was not performed or not completed, perigee will decay below 80 nm by the next day but is still considered safe for deorbit.

FDO works with NAV to determine the minimum perigee satisfying orbit lifetime requirements. NAV uses three methods, each of which are designed to provide the best solution depending on the amount of time available to analyze the situation. The quickest solution adopts the most conservative assumptions. More accurate solutions will require more time to assess actual flight conditions.

Method 1: when a time-critical estimate of orbit lifetime is required, the determination will be made utilizing the generic Orbit Lifetime plots in SOP 6.5 of the Orbit Navigation Console Handbook. Assumptions and models used to generate these plots are as follows.

- 30% drag uncertainty ( $C_D = 2$ ,  $KCON = 1.3$ )
- Orbiter weight = 200000 lbm (lightweight vehicle)
- Constant area = 2500 ft<sup>2</sup>
- Inclination = 28.5°
- Argument of perigee = 0
- Solar Flux (F10.7) = 240 Jansky\*10<sup>4</sup>
- Geomagnetic Index ( $K_p$ ) = 4.0
- Modified Jacchia 1970 atmospheric model
- GEM10 truncated 7x7 geopotential model

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The 30% drag uncertainty provides a margin of safety in the final solution to protect for unknown model errors. These errors increase significantly at low orbit altitudes. A lightweight Orbiter is assumed because it has greater drag acceleration than a heavy weight Orbiter. The 2500 ft<sup>2</sup> frontal area approximates average Orbiter frontal area for an inertial attitude hold. In critical lifetime cases, the Orbiter will usually be held in -ZLV +XVV attitude to obtain a frontal area near 1300 ft<sup>2</sup>. The combination of 28.5° inclination with zero argument of perigee (perigee at the ascending node) provides a worst-case trajectory from the standpoint of atmospheric drag. Empirical studies show lower inclinations produce slightly higher orbit decay rates than higher inclinations at the same altitude. A zero argument of perigee places the lowest point of the orbit in the region where earth's oblateness maximizes atmospheric density. Solar flux used to obtain the orbit lifetime data in the generic plots is a peak 90-day average value expected during the 11-year solar activity cycle. However, daily solar flux could significantly exceed this value in the event of a solar flare. The geomagnetic index used is also a high value that would represent a geomagnetic storm subsequent to a solar flare.

Method 2: when more time is available, NAV can provide valuable insight into orbit altitudes required to achieve desired lifetimes using the PUTREFY (Predict Ultimate Time of Re-Entry For You) program. The program outputs time to EI altitude decay given perigee, apogee, average vehicle area, vehicle weight, solar flux, orbit inclination, and K-factor. A K-factor should be used which accounts for 30% uncertainties in drag models. Using actual values for vehicle weight, average vehicle area, and solar flux can greatly increase the predicted orbit lifetime compared to using Method 1. The PUTREFY program contains a database of orbit lifetimes for 960 reference profiles as a function of altitude, inclination, and solar flux. Reference profiles are all generated using a ballistic coefficient of .02 ft<sup>2</sup>/lbm. For a 240000 lbm Orbiter weight, this equates to 4800 ft<sup>2</sup>. The program interpolates between values in its database for apogee, perigee, inclination, and solar flux values provided by the user. Orbit lifetime is then adjusted for vehicle weight, area, and K-factor provided by the user relative to the ballistic coefficient used in the reference cases. Reference profiles for the PUTREFY database result from HOPE runs using modified Jacchia 1970 atmosphere (geomagnetic index of 4.0) and GEM10 truncated 7x7 geopotential models. Argument of perigee for the elliptical orbits is zero.

Method 3: when time permits, the most accurate orbit lifetime procedure can be considered. FDO sets up an ephemeris with actual flight conditions, including maneuvers, attitude and vent timelines, Orbiter weight loss, and best estimates of solar flux and geomagnetic index. NAV then runs a vector compare with EI altitude as the stop option to obtain the time to EI. A K-factor should be input to account for 30% uncertainties in the drag model. This solution will be more accurate than other methods chiefly because the state vector is integrated using planned attitude and vent timelines.

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This method assumes the timelines accurately represent attitudes and vents during the period of integration.

Typically, a combination of all three methods is used. Methods 1 and 2 are employed to estimate minimum perigee altitude necessary to achieve the desired orbit lifetime. These estimates then serve as inputs to model any necessary orbit adjust. A vector compare is performed to confirm the desired lifetime is achieved.

### 3.7.2.5.4 Single and Multiple Stage Orbit Transfers

Occasionally, mission requirements demand the operational orbit be changed midway through the flight for reasons other than those described above to set up nodal crossings or end of mission conditions. Changing payload requirements may call for a lower or higher perigee or apogee, or a different mean altitude. Eccentricity requirements may impose a one or two burn orbit transfer or trim maneuver. Orbit raising/lowering in the event of an off-nominal MECO and for collision avoidance burns are described in Section 3.9. The OMP can be used to compute single vehicle maneuvers raising or lowering apogee/perigee, changing height at a specified time, or circularizing the orbit at a specified time. Section 3.10 describes OMP procedures targeting single vehicle maneuvers. Orbit transfer maneuvers can also be directly input into an ephemeris and manually iterated as described previously.

If possible, it is good practice to execute the first burn of a multistage orbit transfer (or the only burn of a single stage transfer) to minimize deorbit costs in the event no other burns are performed during the flight. This conserves available propellant in the event of unforeseen failures and events. For this reason, a PADJ curve and optimal perigee adjust time are maintained and updated in the FDO Data Book during each Planning shift. If the first burn in a pair is posigrade, it should ideally be placed such that it optimizes argument of the perigee for ConUS landing opportunities and would occur about half an orbit from the optimum perigee adjust time. If the first burn were retrograde, it would be placed at the optimal perigee adjust time.

**CAUTION:** standard PADJ procedures (see Section 3.9) fix perigee height at 95 nm and protect ConUS deorbit opportunities over the two flight days immediately following an orbit adjust burn. Time permitting, it may be advisable to dedicate a PADJ analysis to the specific orbit adjust(s) being contemplated.

These types of burns are almost always non-critical as they can usually be slipped one or more orbits. Exceptions include collision avoidance burns (crew/vehicle safety) and burns supporting mission success. Examples of burns required to satisfy customer requirements include SIMPLEX and MSX burns. Because these burns are tied to a particular ground site or satellite viewing opportunity, they cannot be easily slipped. If missed, they would have to be replanned for later in the flight, and observation

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opportunities may be limited. SIMPLEX requires OMS burns in various directions (radial, in plane, and out of plane) to take place over specific ground sites for plume observations. The customer plans these burns after receiving Orbiter state vectors from FDO. Parallel computations are performed by FDO to verify customer results. Acquisition times are computed using PSAT and viewed with AcqMon displays.

MSX burns are similar to SIMPLEX burns except the plume observations are made from a satellite in a high inclination orbit at a higher altitude than the Shuttle. For MSX observations, the DOD customer is provided with Orbiter state vectors and computes burn times and attitudes. FDO can obtain MSX vectors from the customer and evaluate the burn times, but the customer's times and attitudes are those that will be used. MSX burns may utilize OMS and/or RCS thrusters.

FDO must evaluate effects of these and any other burns on subsequent mission events, including deorbit opportunities. In addition, FDO must coordinate with PROP, FAO, the Flight Director, PAYLOADS/ACO, POINTING and any other appropriate discipline.

### **3.7.2.5.5 Separation Maneuvers**

Separation (sep) maneuvers fall into two categories: nominal and contingency. Separation maneuvers can and should be modeled as accurately as possible in an ephemeris so FDO can evaluate the short and long term trajectory effects, particularly Orbiter motion relative to the deployed or jettisoned "target".

Contingency sep sequences should be modeled on a best effort basis. At a minimum, each confirmed  $\Delta v$  should be modeled in E1. Whether Rendezvous-certified or not, FDO is responsible for safe relative motion following any sep sequence. Whenever an object is in proximity to the Orbiter, safe relative motion must be verified as soon as possible post-burn. In the case of the SPARTAN deploy during STS-87, an inadequate separation burn was performed, and an additional unplanned burn had to be added quickly to avoid payload recontact.

Nominal, planned sep maneuvers typically follow payload deploy or ISS undocking. Often a separation sequence includes several burns. These can include a back away maneuver, an out of plane burn, and a posigrade or retrograde burn. Planned separation burns can be modeled in an ephemeris at the most likely time of the burns. Subsequent maneuver confirmation can correct any TIG errors.

Unplanned separation burns generally follow inadvertent payload deploys, overboard loss of tools/parts during EVAs, or failed docking or grapple attempts. Unplanned sep maneuver sequences are developed preflight as contingency options with only burn TIGs to be determined. If possible, FDO should model sep burns with a best guess at

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TIGs. TIG errors amounting to several minutes are typically acceptable for preliminary safe relative motion evaluation pending confirmation.

### 3.7.2.5.6 Unplanned Maneuvers

Unplanned Shuttle translation maneuvers are rare in the real world, but they occur regularly during simulations. They are generally contingency burns resulting from some unplanned event or failure. Fuel wasting burns due to failures in the RCS or OMS systems merit detailed discussions found in Section 3.9. Occasionally, objects float free in the payload bay during an EVA and must be chased down or safely avoided. Translation maneuvers in these cases have not been extensively evaluated by FDO and have not been modeled in an ephemeris. The best FDO can do is model burn effects on the trajectory after the fact; then evaluate them. Often FDO has done enough preflight analysis and has sufficient awareness of the current trajectory to know maneuver general impact.

### 3.7.2.6 Thruster Selection Fundamentals

If constraints from PAYLOADS, plume impingement, Orbiter system failures, or propellant consumption aren't driving considerations, thruster selection for a maneuver may be made simply on the basis of targeted  $\Delta v$  magnitude. The following  $\Delta v$ -driven rules are often the starting point for thruster selection deliberations between FDO and PROP. Flight Rule A2-115 specifies the OMS/RCS transition guideline at 6 fps. More involved decisions may involve additional participants.

- 1)  $\Delta v < 4$  fps: use multi-axis PRCS.
- 2)  $4 \text{ fps} < \Delta v < 6$  fps: use aft-firing PRCS (PX2).
- 3)  $6 \text{ fps} < \Delta v < \sim 20$  fps: use single OMS (OL or OR).
- 4)  $\Delta v > \sim 20$  fps: use both OMS (nominally OBP).

In multi-axis mode, need to perform an attitude maneuver aligning the thrust vector with targeted  $\Delta v$  is eliminated. The maneuver is performed in current attitude, and the crew manually nulls Orbiter Body velocity-to-be-gained (VGOs) in "axis-by-axis" fashion. Remaining in current attitude for the maneuver may save propellant and reduce attitude maneuver perturbations as opposed to other thruster alternatives. On the other hand, multi-axis translations typically consume propellant from forward, left, and right RCS tanks. Particularly if FRCS propellant is at a premium, it may be more desirable to

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perform a tail-only attitude maneuver and only use PX2 thrusters for translation, even if  $\Delta v < 4$  fps.

For multi-axis maneuvers, the FDO and PROP should evaluate whether significant portions of the  $\Delta v$  are 'Y' translation burns (toward either wing). Large Y burns are not recommended due to cross-coupling between attitude control and translation portions of the burn. A good guideline is 1 foot per second as an upper acceptable limit for Y translation burns.

With PX2 thrusters selected, often called a "+X burn" by other disciplines, the  $\Delta v$  gap between multi-axis and OMS thrusters can be bridged. An OMS maneuver has never been planned for  $\Delta v < 6$  fps due to shutdown transients and a lack of guidance precision because no 'fine count' is possible. A PX2 maneuver requires little if any FRCS consumption, as already noted. It can also result in zero ARCS expenditure if an OMS-to-RCS interconnect is performed beforehand. When part of the crew is asleep, PX2 is the single viable thruster option for non-emergency maneuvers. Only PX2 thrusters can translate the Orbiter without disturbing a sleeping crewmember, assuming tail only attitude control is being used. Figure 3.7.2.6-1 relates limits pertaining to PX2 and other PRCS thrusters.

At maneuver  $\Delta v > 12$  fps, the threshold between single and dual OMS engine use is ill-defined in a generic context. All other factors being inconsequential, use of one OMS is preferred in order to minimize engine restarts. However, this consideration is often overwhelmed by desire to maintain a balanced Orbiter lateral CG without having to interrupt the maneuver and reconfigure OMS crossfeed propellant lines. In such cases, a straight-feed 2-OMS burn is the logical choice. When both OMS engines are used, their Thrust Vector Control (TVC) trim angles are nominally specified to direct thrust nearly parallel to the Orbiter Body frame's X/Z plane. This mode of operation is called "OMS both parallel" (OBP). On rare occasions where TVC or OMS engine integrity is lost or suspect, each engine's thrust vector is directed through the Orbiter's CG. This mode is called "OMS both CG" (OBC in TrS or OCG in TSA). Although OBC will maintain control in the event one OMS engine is shut down, effective thrust is reduced by approximately 2% over OBP when both engines are burning. This efficiency loss arises because the two OBC engines have mutually opposed Y-Body thrust components.

Depending on mission objectives documented by the Prop Priorities Table in the mission-specific Flight Rules Annex, FRCS propellant available for a given maneuver may suddenly increase. This might occur when mission duration is curtailed by an ascent underspeed, and an orbit-raising burn will restore at least some time on orbit. All remaining FRCS propellant will generally become available following completion of a rendezvous mission's proximity operations unless it's required for a post sep perigee adjust to achieve high-priority capability such as steep deorbit. In such cases, one or more maneuvers may be performed using FRCS thrusters, particularly if ARCS or OMS

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mission completion propellant margins are tight. From the standpoints of forward CG relief and expedited Orbiter turnaround, using surplus FRCS propellant for translation maneuvers is at least good for flight control "style points". An example of critical FRCS use is the post-deploy perigee adjust planned for the Hubble Space Telescope Servicing mission STS-103. A mission of this type requires a very high altitude rendezvous (~300 nm), stretching aft propellant margins to the limit. With FRCS used to lower deorbit propellant costs significantly, aft propellant margins are significantly enhanced. Any unused FRCS propellant following deorbit is usually dumped during OPS 303. Opposing thrusters are used during the FRCS dump such that imparted  $\Delta v$  is nearly zero.

**WARNING:** PRCS jets have both operational and contingency maximum firing time limits. An operational limit should only be exceeded by maneuvers critical to crew or vehicle safety (such as deorbit in lieu of OMS capability) because the jet will be considered unusable thereafter. Exceeding a contingency maximum risks Orbiter structural damage due to thermal soakback from the jet. Flight Rule A6-153 (RCS Jet Maximum Burn Time) documents these limits. Figure 3.7.2.6-1 summarizes implications of these limits to achievable  $\Delta v$  using thruster nomenclature consistent with Figure 3.7.1.4-2.

Thruster Code	Operational Maximum		Contingency Maximum	
	$\Delta t$ (sec)	$\Delta v$ (fps)	$\Delta t$ (sec)	$\Delta v$ (fps)
PX2	150	35.2 to 38.5	800	188.0 to 205.2
PX3	150	52.7 to 57.6	800	281.4 to 307.0
PX4	150	69.9 to 76.2	800	372.6 to 406.5
MZH (FRCS)	150	35.9 to 39.2	300	71.8 to 78.4

**Figure 3.7.2.6-1: PRCS Thruster Firing Limits Special Maneuver Types**

**NOTE:** the effective time of a PX2 maneuver might be increased if the crew switches selected jets part way through a targeted burn to avoid breaking the 150 sec limit. This would only be done to preserve a high priority mission objective.

### 3.7.2.6.1 Plume Impingement

A frequent concern during Orbiter operations near a rendezvous target or deployed payload is that of Orbit Maneuvering System (OMS) and Primary Reaction Control System (PRCS) exhaust plume impingement. Vehicles subjected to Orbiter plume impingement may be susceptible to contamination, undesirable motion, or structural damage. The Orbiter is also susceptible to plume and particle impingement from nearby upper stage rocket motors and jet firings from other maneuvering vehicles. Individual payloads or targets require plume susceptibility analyses on a flight-specific basis, but dynamic pressure fields about the Orbiter caused by its exhaust plumes are

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generic. Orbiter-induced pressure contour plots appear in the Rendezvous GPO Console Handbook (DM-CH-08). Often plume impingement concerns arising from Orbiter maneuvers are reduced or eliminated by selecting LOZ (Low Z) translation control for the Orbiter DAP. This mode inhibits up-firing PRCS jets and dramatically reduces dynamic pressure over the payload bay. Choice of LOZ must be tempered by awareness that it consumes over 10 times the propellant required by other DAP PRCS translation modes to achieve the same  $\Delta v$ . Fully half of LOZ consumption must come from FRCS propellant tanks. Orbiter susceptibility to maneuvering payload or target plumes also tends to require flight-specific analysis because plume dynamic pressure contours and contaminants for different vehicles vary greatly. For more frequently flown upper stage carriers, pressure contour plots are provided in Section 3.8.

### **3.7.2.7 Maneuver Attitude Considerations**

The DMT displays Orbiter burn attitude required to align an ECT body-fixed thrust vector with inertially-fixed  $\Delta v$ . If a special burn attitude will be required due to illumination, plume impingement, communications, or crew viewing requirements, FDO and TRAJ typically develop it in coordination with POINTING. Often, the rotation degree of freedom afforded by TVR can be used to optimize burn attitude for any of these requirements. The DMT-displayed attitude may also be overridden completely if  $\Delta v$  supports a multi-axis burn.

#### **3.7.2.7.1 POINTING Processors and Capabilities**

POINTING is a flight controller discipline in the FAO MPSR providing several useful services to FDO. A brief overview of these capabilities is presented here to familiarize FDO trainees with this resource. The primary software tool utilized by Pointing is the Multi-purpose Attitude and Pointing Software (MAPS). Supersighter is a MAPS application performing most computations outlined here and is a workstation based application. POINTING may be contacted on the MOCR DYN voice loop.

POINTING's primary function is to manage the Orbiter's Attitude Timeline (ATL). Diverse customer requirements are integrated with Orbiter constraints to determine Orbiter attitudes over the course of a mission. The planned ATL is documented pre-launch in the Flight Plan and revised in the daily Execute Package. It is also maintained electronically on POINTING's workstation. A simplified version of this ATL is periodically transferred to TrS for trajectory and communication processors to utilize (see Section 3.3.1.7.1.1). Ground ephemerides with an "A" integration option access the ATL to model the Shuttle's frontal area and drag coefficient.



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**CAUTION:** POINTING should notify FDO before an ATL update is performed, as well as after it has been completed. This update must also be coordinated between FDO/TRAJ and NAV. If DYNAMICS is updating an ephemeris or if NAV is performing batch processing when POINTING rolls in a new ATL, TrS results may be inconsistent or unexpected.

POINTING can provide useful information concerning Orbiter attitude maneuvers and Universal Pointing inputs. For example, POINTING can estimate time required to perform an attitude maneuver before it's initiated (GNC estimates "time to attitude" *after* a maneuver is initiated). With a "no later than" maneuver initiation time, FDO can keep the FCR situationally aware and thereby prevent burn delays. Also, inertial or local vertical/local horizontal (LVLH) attitudes can be determined by POINTING from a given Universal Pointing pitch, yaw, and omicron, or vice versa. An application of this capability is determining whether or not a particular burn can be performed with multi-axis procedures. Call POINTING to obtain the M50 or LVLH attitude at TIG of a planned maneuver. This attitude can then be input with BFI guidance to assess the multi-axis option.

**NOTE:** if the Orbiter is holding LVLH attitude prior to maneuvering to an inertial burn attitude, time to perform the maneuver may actually *decrease* as the maneuver is delayed until the last few minutes before TIG. This is particularly the case when LVLH is held between a height adjust burn and a circ burn half an orbit later. Presumably, both these burns are posigrade or retrograde and have similar LVLH attitudes if they both use aft or forward thrusters. Conversely, if a close pair of burns uses opposed thrusters (MZH/FRCS and PX2, for example), POINTING may recommend holding inertial attitude between the burns.

POINTING can provide ground, orbit, and celestial sighting data. For example, a vector from the Orbiter to a co-orbiting target can be computed using FDO's Orbiter and target ephemerides. Possible POINTING output from this comp might be in the form of right ascension and declination angles, Orbiter attitude to point the -Z body axis at the target, and best Orbiter window for viewing. Lighting conditions can also be computed for viewing or star tracker considerations. For ground targets, acquisition time, elevation angles, and length of pass can be determined for a point object or area. Similar information may also be computed by FDO using the SCT and PSAT (see Section 3.4), but it may be easier to obtain ground sighting information from POINTING. This is particularly the case for a transient target like a hurricane. POINTING can electronically access Orbiter and target ephemerides in TrS.

Orbiter burns performed in "multi-axis" mode require the THC be deflected in whatever sequence is required to null body VGOs. For a multi-axis maneuver PAD, TRAJ must compute body VGOs ( $\Delta v$  in each Orbiter body axis) in order for PROP to determine expected propellant usage out of the forward and aft systems. These VGOs are also included on the multi-axis burn PAD. POINTING assists in this task by providing Orbiter

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LVLH attitude at TIG. TRAJ then types this attitude into TSA RMM along with PEG-7  $\Delta v$  targets, and body VGOs are output. LVLH attitude at TIG is especially useful when the Orbiter is not in a fixed LVLH attitude, but is instead holding inertially, or tracking a target other than Earth's center.

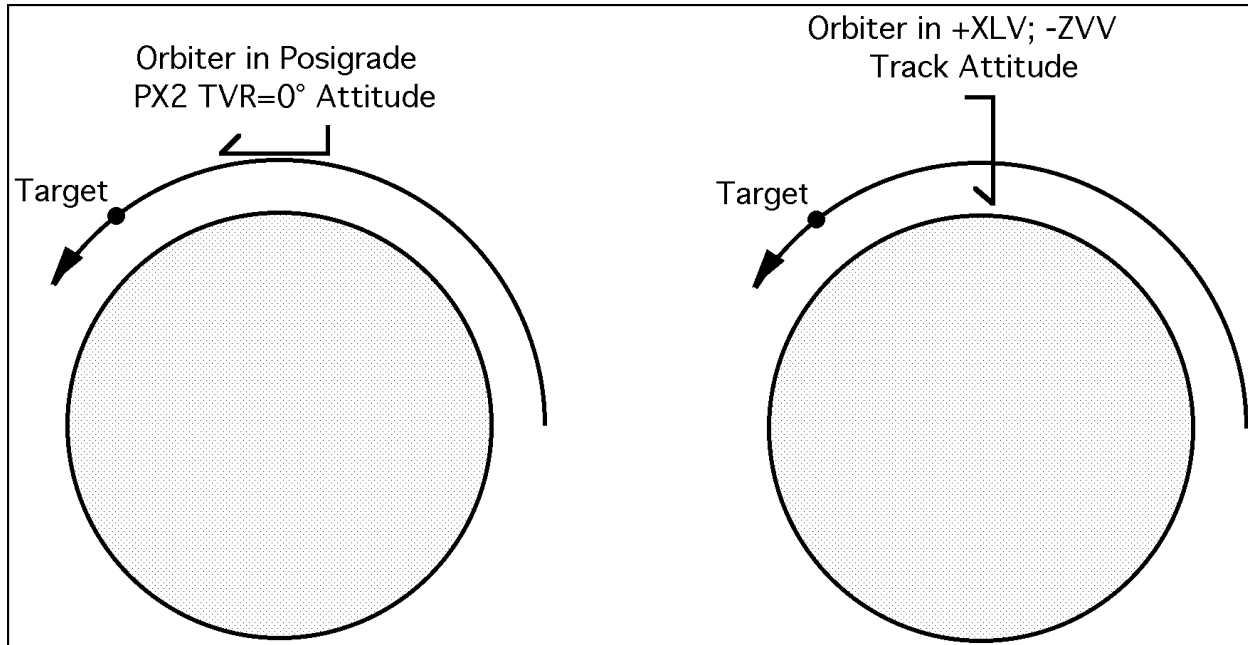
POINTING also assists in FRCS burn planning (see Section 3.7.2.12.1). Since MM202 guidance cannot handle FRCS thrusters for a burn, crew procedures call for using Universal Pointing to maneuver to the proper burn attitude. Inertial DAP mode is selected at TIG -30 sec to hold attitude through the burn. In order to prepare a FRCS burn PAD, TRAJ should first provide POINTING a DMT of the planned burn. The DMT should contain the burn correctly modeled with MZH thrusters, which are set to the FRCS pitch, yaw, thrust, and flow-rate on orbit for full up attitude control. POINTING will obtain the inertial attitude at TIG from the DMT, and compute an LVLH attitude at TIG -30 sec preserving this inertial attitude. This LVLH attitude is passed back to TRAJ, along with equivalent Universal Pointing pitch, yaw, and omicron values. These data are entered to the burn PAD for the crew to use.

**NOTE:** LVLH pitch provided by POINTING should be about 2° different from pitch shown by the DMT's PYR LVLH attitude.

### 3.7.2.7.2 Optimal Attitude

Maneuver attitude computed by the DMT properly directs the selected body-fixed thrust vector in inertial space, then rotates the body about this vector by the specified TVR (see Section 3.7.1.5 for additional TVR discussion). The degree of freedom provided by TVR specification is often used to afford the crew a view of the earth's horizon or of another orbiting vehicle during the maneuver. In addition, TVR can be used in coordination with thruster selection to minimize time or perturbations associated with Orbiter rotation to and from maneuver attitude or to improve communication during the burn. For example, consider the common rendezvous scenario of a posigrade (*retrograde*) phasing maneuver performed trailing the target and immediately prior to a -Z star tracker pass. Aft-firing PX2 thrusters will be used for the phasing maneuver. The star tracker pass must be made in standard attitude with -Z Body target track and zero omicron, essentially nose down; bay forward ("+XLV -ZVV" in ATL notation). Rotation to the target track attitude can be minimized to a 90° pitch down (*up*) using TVR = 0° (180°). Figure 3.7.2.7.2-1 illustrates the posigrade maneuver case.

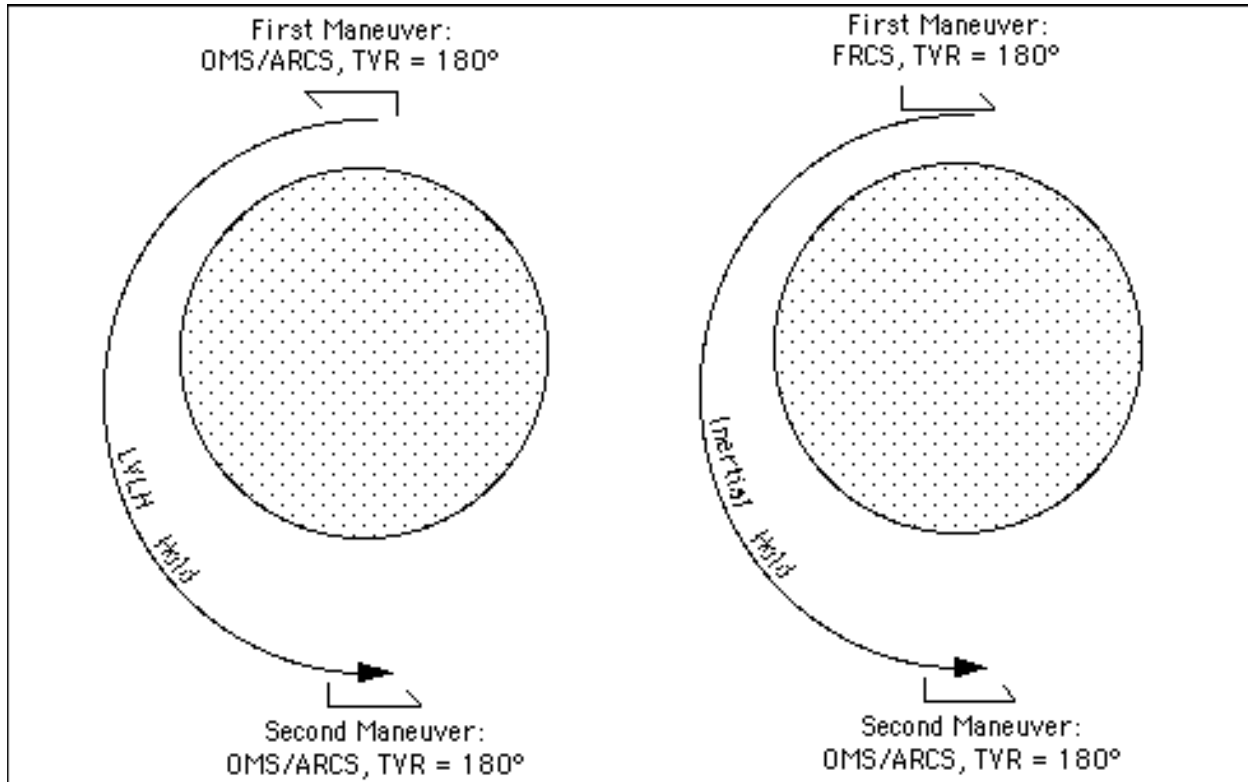
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**Figure 3.7.2.7.2-1: Minimal Rotation From Maneuver to Track Attitude**

Another optimal attitude consideration frequently arises when maneuvers are planned as posigrade or retrograde pairs half an orbit apart. If both maneuvers can use FRCS or ARCS/OMS thrusters with the same TVRs, the Orbiter DAP should be commanded to LVLH hold ASAP after the first maneuver. This action will result in a minimal rotation to the second maneuver's attitude if it's initiated a few minutes before TIG. On the other hand, consider a maneuver pair, which uses FRCS, then ARCS/OMS. In this case, inertial hold should be commanded after the first maneuver to minimize rotation for the second. Due to opposed Body thrust vectors between the maneuvers (see Section 3.7.1.5), both have the same TVR. Figure 3.7.2.7.2-2 illustrates LVLH and inertial hold techniques for posigrade burn pairs.

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**Figure 3.7.2.7.2-2: Attitude Hold Between Posigrade Maneuvers**

Regardless of what maneuver attitude is selected, it must be coordinated with POINTING to maintain an accurate ATL. Likewise, any special attitude hold strategy between burns must receive POINTING concurrence. Sometimes, GNC is also consulted.

### 3.7.2.8 State Vector Considerations

State vector accuracy during burn planning can significantly affect the post burn trajectory, especially for multi-vehicle operations.

#### 3.7.2.8.1 State Vector Planning

The best obtainable vectors should be used for burn computations and for burn execution. FDO works with NAV to schedule adequate TDRS and ground tracking to support ground targeted on orbit burns. Initial vector planning takes place prior to the mission and continues up through the shift in which the burn occurs. FDO will request vectors supporting multiple burn targeting cycles. Trends in these computations resulting from vector updates should be tracked. The vector supporting the final targeting cycle may also be uplinked with the resulting maneuver targets. In scheduling

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NAV vector deliveries, FDO must allow sufficient time to complete final targeting, command load builds, and PAD generation/publication. These products should be delivered about 40 min prior to TIG. Anytime this timeline cannot be met, FDO should notify FD of the expected delay. It may be better to keep the Flight Control Team waiting or postpone TIG an orbit than to execute an inaccurate burn.

### **3.7.2.8.2 Perturbation Effects On Burn Computations**

Events perturbing the Shuttle's orbit must be considered to ensure possible and actual effects are modeled. Perturbations include IMU aligns, HUD calibrations, water dumps, and miscellaneous attitude maneuvers. These events can impart as much as several fps  $\Delta v$  to the Orbiter and can require up to several orbits' tracking to quantify. For burns with a high precision requirement, it is advisable to work with FAO and other FCR disciplines to schedule perturbing events away from pre-burn tracking arcs. For the most accurate possible burn, it is ideal to use vectors relatively close to TIG for final computations and for uplink to the Orbiter. Presumably, these vectors will incorporate all effects from any pre-burn perturbations. Utilizing the latest possible set of vectors also tends to minimize error growth between final tracking and TIG. FDO should run computations on earlier vectors leading up to the final computations to establish trends indicating if a late vector update will significantly affect the burn.

### **3.7.2.8.3 Vector Command Load Uplinks Prior to Burns**

Uplinking a vector to the Orbiter prior to the burn is not always necessary, so long as onboard vector error isn't excessive. For single vehicle maneuvers, the primary effect of a large downtrack error is reflected in the burn attitude computed and used by the Orbiter. On the other hand, uplinking a new onboard state is generally a good idea if it can be accomplished with minimal impact. The size of acceptable onboard vector errors is more a FDO judgment call than any specific number, although some flights (such as SRTM, STS-99) do have more specific and rigorous requirements. It will depend on the burn in question as well as what else is going on in the mission. If in doubt, a vector uplink is recommended. Refer to *Flight Dynamics Command Procedures* (DM-CH-05) and Section 3.5.6 of this volume for uplink procedures and caveats.

In the case of a deploy or undock, it is usually good practice to update the onboard vector. If there is an off-nominal deploy or sep sequence execution, this makes it easier to evaluate relative motion between ground and onboard state vectors.

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### 3.7.2.9 Getting Maneuver Targets On Board

Most Shuttle maneuvers are computed by FDO, and the associated targets must be communicated onboard either by voice to the crew or via command load uplink to the General Purpose Computers (GPCs).

#### 3.7.2.9.1 Generic Orbit Maneuver Preadvisory Data (PAD)

FDO generates a Preadvisory Data (PAD) form for each on orbit maneuver except for critical sep burns and some on day-of-rendezvous targeted onboard by the crew. TRAJ checks the PAD against the DMT display for accuracy. A PAD is necessary to cover a possible loss of uplink capability and to provide onboard guidance solution verification. The crew can type burn target data into the GPC manually through ORBIT MNVR EXEC display ITEMS 1 thru 21. Targets are loaded with ITEM 22. If the target set has been uplinked, the crew can load targets using ITEM 22 without entering ITEMS 1-21.

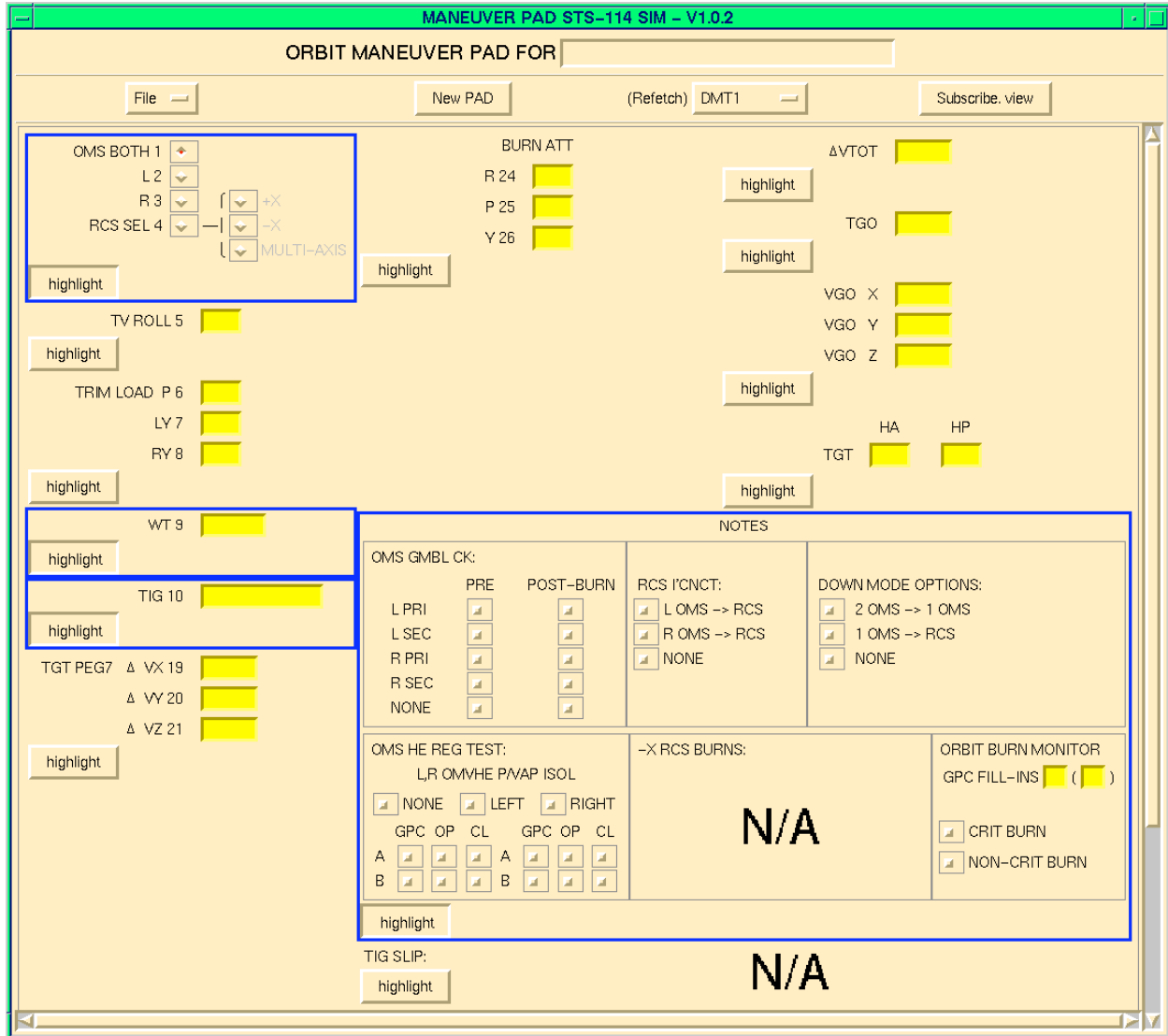
Inter-discipline procedures associated with PAD generation, distribution, transmission, and verification are documented in FCOH SOP 5.3, Maneuver PAD Policy. Because the SOP calls for Capcom's PAD read-up to the crew at approximately TIG -20 min, FDO's PAD publication is typically expected by approximately TIG -30 min.

NOTE: preliminary and final PADs are associated with some day-of-rendezvous burns. Preliminary PADs are typically included with the day-of-rendezvous execute package received by the crew in post-sleep. Prior to a day-of-rendezvous burn, CAPCOM reads only significant final PAD deviations from its preliminary baseline to the crew. See Section 3.10 for more day-of-rendezvous PAD details.

CAUTION: uplinked Orbiter TIG weight (ORBIT MNVR EXEC ITEM 9) is lost during transition from OPS 201 to OPS 202. Typically, burn targets are uplinked in OPS 201, and the crew manually enters PAD weight before loading targets in OPS 202.

NOTE: prior to January 2004, a PAD could be generated automatically from a DMT using the Netscape Auto Maneuver Pad (NAMP) application. At that time, a new PAD format was adopted in the Flight Data File (FDF), rendering NAMP obsolete. During the period NAMP was upgraded to a new Auto Maneuver PAD (AMP) application compatible with FDF format, paper PADs from the FDF were filled out manually by TRAJ. After AMP became operational in November 2005, paper PADs are only used as a downmode or workaround. A blank AMP menu prior to any DMT fetch or manual data entry appears in Figure 3.7.2.9.1-1.

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**Figure 3.7.2.9.1-1: Blank AMP Menu**

A PAD usually contains more information relating to an upcoming burn's execution than the crew requires. Only information FDO encloses in blue boxes is voiced to the crew. On a paper PAD, these boxes must be highlighted by hand. Use black ink to fill out the PAD and a blue highlighter to draw boxes. To distribute a paper PAD, TRAJ leaves a copy with FDO, brings the original to CAPCOM, and takes copies to FD, FAO, GNC, PROP, and RENDEZVOUS (if present). Post-burn, the FDO copy is filed in the Clipboard Binder. If electronic PADs are used, FDO files one hard copy in the Clipboard Binder. Two slightly different PAD formats exist in the FDF. One is generic to all orbit burns (see Figure 3.7.2.9.1-2), and one is specific to Ti and Ti Delay (see Figure 3.7.2.9.1-3).

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**MANEUVER PAD STS-114 SIM - V1.0.2**

**FINAL ORBIT MANEUVER PAD FOR NH (Rndz p. 3-5)** DELTA ONLY

File

<p>OMS BOTH 1 <input checked="" type="checkbox"/></p> <p>L 2 <input type="checkbox"/></p> <p>R 3 <input type="checkbox"/> ( <input type="checkbox"/> +X</p> <p>RCS SEL 4 <input type="checkbox"/> - <input type="checkbox"/> -X</p> <p style="text-align: center;">MULTI-AXIS</p> <p>TV ROLL 5 <input type="text" value="0"/> <input type="text" value="0"/> <input type="text" value="0"/></p> <p>TRIM LOAD P 6 <input <input="" type="text" value="0"/> <input type="text" value="."/> <input type="text" value="7"/></p> <p>LY 7 <input <input="" type="text" value="5"/> <input type="text" value="."/> <input type="text" value="7"/></p> <p>RY 8 <input <input="" type="text" value="5"/> <input type="text" value="."/> <input type="text" value="7"/></p> <p>WT 9 <input type="text" value="2"/> <input type="text" value="5"/> <input type="text" value="0"/> <input type="text" value="3"/> <input type="text" value="7"/> <input type="text" value="3"/></p> <p>TIG 10 <input type="text" value="0"/> <input type="text" value="1"/> / <input type="text" value="1"/> <input type="text" value="5"/> : <input type="text" value="3"/> <input type="text" value="7"/> : <input type="text" value="3"/> <input type="text" value="2"/> . <input type="text" value="8"/></p> <p>TGT PEG7 Δ VX 19 <input <input="" type="text" value="1"/> <input type="text" value="0"/> <input type="text" value="9"/> . <input type="text" value="8"/></p> <p>Δ VY 20 <input <input="" type="text" value="0"/> <input type="text" value="0"/> <input type="text" value="0"/> . <input type="text" value="0"/></p> <p>Δ VZ 21 <input <input="" type="text" value="0"/> <input type="text" value="0"/> <input type="text" value="4"/> . <input type="text" value="7"/></p>	<p>BURN ATT</p> <p>R 24 <input type="text" value="0"/> <input type="text" value="3"/> <input type="text" value="0"/></p> <p>P 25 <input type="text" value="1"/> <input type="text" value="7"/> <input type="text" value="1"/></p> <p>Y 26 <input type="text" value="3"/> <input type="text" value="0"/> <input type="text" value="2"/></p> <p>ΔVTOT <input type="text" value="1"/> <input type="text" value="0"/> <input type="text" value="9"/> . <input type="text" value="9"/></p> <p>TGO <input type="text" value="0"/> <input type="text" value="1"/> : <input type="text" value="1"/> <input type="text" value="0"/></p> <p>VGO X <input <input="" type="text" value="1"/> <input type="text" value="0"/> <input type="text" value="6"/> . <input type="text" value="0"/></p> <p>VGO Y <input <input="" type="text" value="0"/> <input type="text" value="0"/> <input type="text" value="0"/> . <input type="text" value="0"/></p> <p>VGO Z <input <input="" type="text" value="0"/> <input type="text" value="2"/> <input type="text" value="8"/> . <input type="text" value="7"/></p> <p>HA <input type="text" value="1"/> <input type="text" value="9"/> <input type="text" value="5"/></p> <p>HP <input <input="" type="text" value="1"/> <input type="text" value="2"/> <input type="text" value="8"/></p> <p>TGT <input type="text" value="1"/> <input type="text" value="9"/> <input type="text" value="5"/></p>	<p style="text-align: center;">NOTES</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;"> <p>OMS GMBL CK:</p> <p>L PRI <input type="checkbox"/></p> <p>L SEC <input type="checkbox"/></p> <p>R PRI <input type="checkbox"/></p> <p>R SEC <input type="checkbox"/></p> <p>NONE <input checked="" type="checkbox"/></p> </td> <td style="width: 33%;"> <p>PRE POST-BURN</p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input type="checkbox"/></p> <p><input checked="" type="checkbox"/> <input type="checkbox"/></p> </td> <td style="width: 33%;"> <p>RCS I'CNCT:</p> <p><input type="checkbox"/> L OMS -&gt; RCS</p> <p><input type="checkbox"/> R OMS -&gt; RCS</p> <p><input checked="" type="checkbox"/> NONE</p> </td> <td style="width: 33%;"> <p>DOWN MODE OPTIONS:</p> <p><input checked="" type="checkbox"/> 2 OMS -&gt; 1 OMS</p> <p><input type="checkbox"/> 1 OMS -&gt; RCS</p> <p><input type="checkbox"/> NONE</p> </td> </tr> </table> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;"> <p>OMS HE REG TEST:</p> <p>LR OMMHE PVAP ISOL</p> <p><input type="checkbox"/> NONE <input checked="" type="checkbox"/> LEFT <input checked="" type="checkbox"/> RIGHT</p> <p>GPC OP CL GPC OP CL</p> <p>A <input type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> A <input type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>B <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> B <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> </td> <td style="width: 33%;"> <p>-X RCS BURNS:</p> <p style="text-align: center; font-size: 2em;">N/A</p> </td> <td style="width: 33%;"> <p>ORBIT BURN MONITOR</p> <p>GPC FILL-INS <input type="text" value="1"/> ( <input type="text" value="3"/> )</p> <p><input checked="" type="checkbox"/> CRIT BURN</p> <p><input type="checkbox"/> NON-CRIT BURN</p> </td> </tr> </table> <p>TIG SLIP: Max TIG slip <input type="text" value="3"/> min <input checked="" type="checkbox"/> Do not update TIG <input type="checkbox"/> Update TIG after <input type="text" value=""/> min</p>	<p>OMS GMBL CK:</p> <p>L PRI <input type="checkbox"/></p> <p>L SEC <input type="checkbox"/></p> <p>R PRI <input type="checkbox"/></p> <p>R SEC <input type="checkbox"/></p> <p>NONE <input checked="" type="checkbox"/></p>	<p>PRE POST-BURN</p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input type="checkbox"/></p> <p><input checked="" type="checkbox"/> <input type="checkbox"/></p>	<p>RCS I'CNCT:</p> <p><input type="checkbox"/> L OMS -&gt; 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<p>OMS GMBL CK:</p> <p>L PRI <input type="checkbox"/></p> <p>L SEC <input type="checkbox"/></p> <p>R PRI <input type="checkbox"/></p> <p>R SEC <input type="checkbox"/></p> <p>NONE <input checked="" type="checkbox"/></p>	<p>PRE POST-BURN</p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input checked="" type="checkbox"/></p> <p><input type="checkbox"/> <input type="checkbox"/></p> <p><input checked="" type="checkbox"/> <input type="checkbox"/></p>	<p>RCS I'CNCT:</p> <p><input type="checkbox"/> L OMS -&gt; RCS</p> <p><input type="checkbox"/> R OMS -&gt; RCS</p> <p><input checked="" type="checkbox"/> NONE</p>	<p>DOWN MODE OPTIONS:</p> <p><input checked="" type="checkbox"/> 2 OMS -&gt; 1 OMS</p> <p><input type="checkbox"/> 1 OMS -&gt; RCS</p> <p><input type="checkbox"/> NONE</p>						
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FLIGHT NOTES:  
Treat GPC 3 fail as second gimbal fail on right.

**Figure 3.7.2.9.1-2: Published Final Orbit Maneuver PAD**



## FDO Console Handbook Section 3.7: Maneuver Operations

MANEUVER PAD STS-114 SIM - V1.0.2

FINAL ORBIT MANEUVER PAD FOR Ti (p. 3-7) DELTA ONLY

Exit Refresh PAD data Print

OMS BOTH 1  L 2  R 3  RCS SEL 4  +X  -X  MULTI-AXIS

BURN ATT  
R 24 3 2 5  
P 25 3 5 9  
Y 26 0 3 7

ΔVTOT 0 0 8 . 7  
TGO 0 0 : 1 1  
VGO X (+) 0 0 8 . 3  
VGO Y (+) 0 0 1 . 7  
VGO Z (+) 0 0 2 . 2  
HA HP  
TGT 1 9 4 (+) 1 8 3

TV ROLL 5 0 0 0

TRIM LOAD P 6 (+) 0 . 7  
LY 7 (+) 4 . 9  
RY 8 (-) 4 . 8

WT 9 2 4 5 5 4 4

TIG 10 0 1 / 1 7 : 5 1 : 1 4 . 0

TGT PEG7 Δ VX 19 (+) 0 0 8 . 7  
Δ VY 20 (-) 0 0 0 . 5  
Δ VZ 21 (-) 0 0 0 . 3

NOTES

OMS GMBL CK:  
L PRI  POST-BURN   
L SEC   
R PRI   
R SEC   
NONE

RCS I'CNCT:  
 L OMS -> RCS  
 R OMS -> RCS  
 NONE

DOWN MODE OPTIONS:  
 2 OMS -> 1 OMS  
 1 OMS -> RCS  
 NONE

Oms HE REG TEST:  
LR OMS/HE PVAP ISOL  
 NONE  LEFT  RIGHT  
GPC OP CL GPC OP CL  
A  A   
B  B

-X RCS BURNS:  
N/A

ORBIT BURN MONITOR  
GPC FILL-INS 1 ( 3 )  
 CRIT BURN  
 NON-CRIT BURN

TIG SLIP: If TI not started by nominal TIG + 4 min (G34 as req'd),  
reload original TIG and go to TI DELAY, 5-27  
Max Ti Delay TIG slip 5 min  Do not update TIG  
 Update TIG after min

FLIGHT NOTES:

**Figure 3.7.2.9.1-3: Published Ti Maneuver PAD**

As noted previously, the Flight Control Team expects FDO's PAD publication about 30 min prior to any burn. Exceptions to this guideline must be coordinated with FD. FDO's PAD generation timeline is influenced by the following factors.

- 1) Time to perform final burn targeting
- 2) Voice communications supporting PAD read-up
- 3) Burns with TIGs < 45 min apart
- 4) Other mission events possibly conflicting with PAD read up or command load uplink

FDO must also allow time to obtain Notes input, together with published PAD review feedback, from PROP, GNC, and any other source.

**CAUTION:** FDO or TRAJ must monitor PAD read-up by CAPCOM, as well as crew read back, to ensure correct PAD information is onboard. FDO should promptly correct any errors if CAPCOM or FD has not already done so.

## FDO Console Handbook Section 3.7: Maneuver Operations

Following is a brief description of PAD entries. Unless otherwise indicated, all values are contained on TrS DMT NO. 1 or 2. Per FCOH SOP 5.3, thruster selection, TIG, weight, and all notes are mandatory PAD items for Capcom read-up.

OMS BOTH: indicates both OMS engines will be used for the maneuver.

L: the maneuver will be accomplished using the Left OMS engine.

R: the maneuver will be performed using the Right OMS engine.

RCS SEL: the maneuver will be performed using a particular RCS engine configuration. If the desired thruster is RCS, an RCS thruster option (+X, -X, or Multiaxis) must also be selected.

TV ROLL: (TVR) indicates how the Orbiter is rolled about the thrust vector. If no other constraint is apparent, set TVR = 180° so the crew can use Earth's limb as a visual reference. There are instances, such as thermal or Orbiter S-Band antenna constraints, where TVR is a value other than 180°.

CAUTION: when two maneuvers occur less than an orbit apart, such as on day-of-rendezvous, FDO should insure TVRs are specified such that attitude maneuver time prior to the second burn is minimized. It may also be necessary for the crew to manually load a change in TVR prior to performing Ti or other Lambert targeting associated with an OMS burn. If TVR is entered after targeting, an undesirable downmode from Lambert to External  $\Delta v$  burn targeting and guidance will occur. Only by retargeting can this downmode be cleared. See Section 3.10 for detailed Rendezvous discussions.

P: indicates the TVC Pitch, in deg, of the OMS engine(s). N/A for RCS burns.

LY: indicates the TVC Yaw, in deg, of the left OMS engine. N/A for RCS burns.

RY: indicates the TVC Yaw, in deg, of the right OMS engine. N/A for RCS burns.

WT: specifies Orbiter TIG weight in lbm.

TIG: specifies maneuver Time of Ignition.

PEG-7 Targets

$\Delta VX$ : displays change in the LVLH X velocity component in fps ( $\Delta VX > 0$  indicates posigrade thrust;  $\Delta VX < 0$  indicates retrograde thrust).

## FDO Console Handbook Section 3.7: Maneuver Operations

$\Delta VY$ : displays change in the LVLH Y velocity component in fps ( $\Delta VY > 0$  indicates thrust south of a posigrade orbit plane;  $\Delta VY < 0$  indicates thrust north of a posigrade orbit plane).

$\Delta VZ$ : displays change in LVLH Z velocity component for the desired maneuver, in fps ( $\Delta VZ > 0$  indicates radial down thrust;  $\Delta VZ < 0$  indicates radial up thrust).

NOTE: in a Ti PAD, additional PEG-7 targets pertaining to the Ti Delay option are provided. These are supplemented with a 1-rev-delay Basetime, corresponding to TIG at the next delayed Ti opportunity.

Maneuver Attitude (N/A for RCS -X or Multi-Axis burns)

R: displays M50-to-Body roll angle (pitch-yaw-roll Euler sequence), in deg, at TIG.

P: displays M50-to-Body pitch angle (pitch-yaw-roll Euler sequence), in deg, at TIG.

Y: displays M50-to-Body yaw angle (pitch-yaw-roll Euler sequence), in deg, at TIG.

$\Delta VTOT$ : displays the resultant total  $\Delta v$  required for this maneuver.

TGO: displays Time to Go until completion of the burn. At TIG, this is the total burn time excluding any thrust tailoff time.

VGO X: displays velocity to be gained in fps along the Orbiter Body X-axis at TIG.

VGO Y: displays velocity to be gained in fps along the Orbiter Body Y-axis at TIG.

VGO Z: displays velocity to be gained in fps along the Orbiter Body Z-axis at TIG.

TGT HA: displays targeted apogee height in nm at maneuver completion.

TGT HP: displays targeted perigee height in nm at maneuver completion.

Notes

OMS GMBL: gimbal mounts allow the OMS engines to pivot up and down (pitch) and from side to side (yaw). Gimbal movements range  $\pm 6^\circ$  in pitch and  $\pm 7^\circ$  in yaw. Each OMS engine has independent primary and secondary gimbal drive mechanisms. Gimbal checks are operational function tests the crew may perform before and/or after the burn to determine if the gimbals are rotating the

## FDO Console Handbook Section 3.7: Maneuver Operations

engines through their full ranges. A gimbal check is performed for OMS-2 and most orbit burns. Obtain the OMS GMBL note information from GNC.

RCS I'CNCT: the RCS interconnect allows propellant from a particular OMS tank to be used by aft RCS jets. Obtain RCS interconnect data from PROP.

DOWN MODE OPTIONS: this information is burn-dependent and is negotiated with the PROP. Critical OMS maneuvers generally require a down mode option. In the case of RCS burns, redundancy management software switches jets among those selected in the event one with a similar thrust vector fails during a burn. Burn criticality is discussed in Section 3.7.2.1.

OMS HE REG TEST: the Left or Right HE PRESS/VAPOR ISOL switches control 2 sets of valves: the Helium pressure A or B and the Vapor Isolation valves. The He Press A/B are redundant paths by which the helium tanks pressurize OMS fuel and oxidizer tanks. The Isolation Valves are back-ups to the Check Valves, which prevent propellant vapors from flowing into the helium lines. Obtain Regulator Test information from PROP.

-X RCS BURNS: these data are N/A except for FRCS burns. When applicable to the PAD, values are obtained from POINTING. The P-Y-OM pertain to Universal Pointing inputs holding burn attitude in LVLH until TIG -30 sec, and the R-P-Y are the equivalent ADI attitude computed as a pitch-yaw-roll Euler sequence (see Section 3.7.2.7.1).

ORBIT BURN MONITOR: the GPC FILL-INS inputs are obtained from GNC. FDO will assign CRIT or NON-CRIT status to the burn according to trajectory considerations and input from PROP, GNC, DPS, FAO, or other disciplines (see Section 3.7.2.1).

TIG SLIP: these inputs are N/A for non-critical burns because they can be postponed at least an orbit without impact to safety or mission success. Otherwise, the slip duration is provided, together with when and if TIG should be reloaded. This section is supplemented in a Ti PAD to indicate the latest possible time to initiate Ti without downmoding to Ti Delay.

The bottom of the PAD is reserved for any otherwise unaddressed flight notes from FDO, PROP, or GNC pertaining to this burn. Although any free-format text can go into this section, there are a few notes appearing fairly regularly, particularly in simulations.

- 1) A FDO trim note is only required if the "Trim all VGOs < 0.2 fps." directive in FDF orbit burn procedures doesn't apply. Burns performed outside a rendezvous context may not require this precision in all VGOs, and the requirements should then be noted accordingly. In certain prop-critical situations, a note such as "Do

## FDO Console Handbook Section 3.7: Maneuver Operations

NOT trim a negative VGO-X." may be necessary (in this example, presumably to conserve FRCS margin).

- 2) GNC may provide a gimbal fail note such as "Treat GPC 3 as second gimbal fail." in certain systems failure situations. It tells the crew to perform steps under SEC GMBL Lost on the OMS BURN MONITOR cue card if a certain GPC is lost during the burn.
- 3) Other GNC and PROP notes will contain switch throws or ITEM entries to be performed before, during, or after the burn. These notes vary based on the systems configuration, but some examples are given below. If in doubt, confirm exact wording before PAD publication.
  - a) "At TIG - 5 sec, ITEM 32 EXEC (powers off left gimbals)."
  - b) "Post-burn, left OMS He reconfig: A to GPC."
  - c) "Expect right gimbal fail messages during burn."
  - d) "Post-burn, take Panel 08 LOMS He PRESS VAP/ISOL B to GPC."

### 3.7.2.9.2 Maneuver Command Load

Maneuver parameters can be viewed on Detailed Maneuver Table displays (DMTs) after a maneuver has been modeled in an ephemeris. The box in the middle of the display, labeled "PAD", encloses information the crew needs to perform the maneuver. This information is conveyed to the crew by voice (via PAD), and the minimum data required is uplinked directly to the GN&C GPC(s). Procedures generating command loads for uplink and for verifying the actual uplink are discussed in this section.

**WARNING:** the referenced TrS DMT must contain the correct maneuver for which a command load is being generated.

Governing work instructions to generate and uplink all command loads, including an on-orbit maneuver PEG-7 target set, can be found in *Flight Dynamics Command Procedures*, DM-CH-05. FDO and TRAJ should be thoroughly familiar with pertinent sections of this document. The following on-orbit maneuver target set uplink discussion is an overview of FDO/TRAJ procedures. Since MOC-based commanding is no longer available, only the Command Off The MOC (COTM) procedure is described.

**CAUTION:** PEG-7 targets may be uplinked to the Orbiter while in either Major Mode 201 or 202 (Maneuver EXEC). However, if uplink occurs in OPS 201, the crew will have to manually enter Orbiter weight after OPS 202 is entered. Weight is not carried across the mode transition.

**CAUTION:** some OPS workstations are Kerberos-inhibited. Any attempts to perform a Command Server login from these workstations will fail. No diagnostic regarding this

## FDO Console Handbook Section 3.7: Maneuver Operations

condition is issued, the same negative response signature received from an erroneous password at login. In the Trajectory MPSR, all workstations with an "IPS MPSR" ID are Kerberos-inhibited.

TARGET	DMT1	jns01	Onboard:EGP02
ENG SEC	CC		NO
PR ROLL	U. L00000		380.000000
WZIGPT	24.1533.168259		25.3164.000000
JIG	00:01:07.12.0		000.00:00:00
Trans. Pkch	0.387000		0.400000
Trms 1 Yaw	1.420000		-5.750000
Trms 2 Yaw	-7.020000		2.750000
RT	NA		U.000000.0
C2	NA		U.000000.0
ET	NA		U.000000.0
Delta 1	NA		U.000000.0
PRFIT	NA		U.000000.0
Eng 7 Delta X	7.007179		0.000000
Eng 7 Delta Y	0.048457		0.000000
Eng 7 Delta Z	-0.051751		0.000000
Delta 3 Pkch	NA		NA
Delta 3 Yaw	NA		NA
Delta 3 Roll	NA		NA
Delta 3 Yaw	NA		NA
Delta 3 Roll	NA		NA
Delta 3 Yaw	NA		NA

SOLUTION	DMT2	RES	PVS:1
Delta 7 Tot	2.022406	NA	U.000000
Delta 7	8.538868	NA	0.000000
Delta 7	1.208011	NA	0.000000
Delta 7	2.357900	NA	0.000000
Delta 7	00:11	NA	00:00
Delta 7	U.000000	NA	U.000000.0
Delta 7	280.482000	NA	U.000000
Delta 7	280.250600	NA	NA
Delta 7	181.724210	NA	U.000000
Delta 7	67.578058	NA	U.000000
Delta 7	19.591414	NA	U.000000

Figure 3.7.2.9.2-1: COTM PEG Targets Application

### A. Build The Command

- 1) Complete maneuver targeting as described in previous sections.
- 2) Model the maneuver in an ephemeris.
- 3) Display the maneuver in TrS DMT 1 or 2.
- 4) Verify all maneuver parameters are correct (engines, trims, source ephemeris, burn number, TVR, TIG, etc.).
- 5) Verify Command Manager is running.
- 6) Invoke the PEG Targets Command Application (See Figure 3.7.2.9.2-1).
- 7) Select '406'.
- 8) Select the appropriate sequence number for (##) View and Command Generation.
- 9) Select appropriate DMT as data source for the command.
- 10) Edit Command Titles if Desired
  - a) Select Cmd Title.
  - b) Edit appropriate title.
  - c) Select 'OK'.
- 11) Select 'GEN'.
- 12) Select 'Confirm' (data should appear in '406##' column)

### B. Verify The Command

- 1) Insure 'COMPARE' is selected.

## FDO Console Handbook Section 3.7: Maneuver Operations

- 2) Verify "GREEN" status between DMT input and '406##' column.
- 3) Obtain load concurrence from second source (TRAJ and FDO constitute two sources of command load verification).

### C. Uplink the Command

- 1) Launch the "Orbit FDO DDDs" ROSS application (for operational details, see Appendix 3.M and the Users Guide for this application on the DM Server S: Drive at DM32\Apps\Cert\_info\Enhanced\_Displays\MNVR\_MON\Ross\_Alarms\_MM\Mnvr Mon Users Guide.ppt). Click the "ACTIVATE MNVR MON panel in the Orbit FDO DDDs to activate the "Maneuver Monitor DDDs" ROSS application. Figures 3.7.2.9.2-2 and 3.7.2.9.2-3 show these ROSS displays. Alternatively, call up Maneuver Monitor or Rendezvous ONAV Status.
- 2) Notify FD when the command load is ready for uplink.
- 3) When FD gives a GO (typically in association with PAD read-up by CAPCOM), call INCO on DVIS and provide the following inputs.
  - a) DSM and Sequence Number such as "40602"
  - b) Title, such as "PEG-7 Targets"
  - c) Destination major function, such as "for the GNC"
  - d) Confirm having a GO from FD

### D. TRACK and Safe the uplinked command.

- 1) Monitor INCO's DVIS loop and watch for indication of uplink on the Command Tracking portion of the PEG Targets application. Verify correct DSMs and sequence numbers were transmitted and acknowledge INCO's uplink confirmation via DVIS.
- 2) Monitor the Onboard PASS column of the PEG Targets application. If PEG-7  $\Delta v$  and trims in the command load are different from the ones currently on the display, the values will change. This is also true for the burn attitude. TIG will not update until the crew loads burn targets. Similar information can be monitored on the FDO Maneuver DDDs display. Note VGOs will not be correct until burn attitude is achieved.
- 3) Make a Hard Copy of the 406xx as uplinked and file in the Hard Copy binder.
- 4) Delete the 406xx after the uplink has been confirmed and the hard copy printed.
  - a) Select the appropriate sequence number for View and Command Deletion.
  - b) Select 'DEL'.
  - c) Select 'Confirm'.
  - d) Content data should disappear from the 406## column and from the load inventory.

## FDO Console Handbook Section 3.7: Maneuver Operations

ACTIVATE MNVR MON	RNDZ NAV ENABLED	<input checked="" type="checkbox"/> DAP AUTO
<b>MM 202</b>	<input checked="" type="checkbox"/> FLT CTL PWR OFF	OMS OFF
<input checked="" type="checkbox"/> X RCS OFF	<input checked="" type="checkbox"/> THC +X OFF	PITCH ERROR <b>-1</b>
<input checked="" type="checkbox"/> Y RCS OFF	<input checked="" type="checkbox"/> THC +Y OFF	YAW ERROR <b>2</b>
<input checked="" type="checkbox"/> Z RCS OFF	<input checked="" type="checkbox"/> THC +Z OFF	ROLL ERROR <b>0</b>
<input checked="" type="checkbox"/> TARGETS LOADED	TGT SET <b>10</b>	GUID MODE LAMB

Figure 3.7.2.9.2-2: "Orbit FDO DDDs" ROSS Application

THRUSTER	DMT 1 NOT AVAIL	ONBOARD R OMS
TVR	<b>100</b>	<b>100</b>
P TRIM	<b>0.4</b>	<b>0.5</b>
LY TRIM	<b>5.3</b>	<b>5.0</b>
RY TRIM	<b>-4.6</b>	<b>-4.9</b>
WEIGHT	<b>240000</b>	NOT AVAIL
TIG	<b>5/16:25:02</b>	<b>5/16:25:03</b>
PEG 7 DVX	<b>-9.2</b>	<b>-9.3</b>
DVY	<b>-0.1</b>	<b>-0.1</b>
DVZ	<b>-0.6</b>	<b>-0.6</b>
BURN ATT ROLL	<b>291</b>	<b>290</b>
PITCH	<b>354</b>	<b>353</b>
YAW	<b>10</b>	<b>9</b>
DV TOT	<b>9.3</b>	<b>9.3</b>
TGO	<b>00:11</b>	<b>00:11</b>
<b>VGO X</b>	<b>7.60</b>	<b>0.48</b>
<b>VGO Y</b>	<b>-0.60</b>	<b>-1.88</b>
<b>VGO Z</b>	<b>1.50</b>	<b>3.37</b>
TGT CRHT HA	<b>216</b>	<b>219</b>
TGT CRHT HP	<b>214</b>	<b>216</b>

Figure 3.7.2.9.2-3: "MANEUVER MONITOR DDDs" ROSS Application



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### 3.7.2.10 Orbiter Target Solution Verification

To verify targets were uplinked and/or entered correctly, certain parameters can be checked on the PEG Command Application Display, on the Maneuver Monitor display, on the Rendezvous ONAV Status display, or on the MANEUVER MONITOR DDDs display (Figure 3.7.2.9.2-3), assuming the Orbiter is AOS. PEG-7  $\Delta v$  and trims are updated immediately. In addition, FDO or TRAJ should monitor all burn-related crew inputs on the FCR's projected scratch pad or on the Rendezvous ONAV Status display. These inputs include OPS 202 transition, ITEM 9's weight entry from the burn PAD, ITEM 22's load targets, ITEM 23's TIG countdown timer initialization, and ITEM 27's maneuver to attitude.

When the crew loads targets (ITEM 22), more information becomes available on FDO displays. If Orbiter telemetry is in Low Data Rate (LDR), TIG and the load flag are visible. If telemetry is in High Data Rate (HDR), the LDR information plus TVR and thruster selection appear. FDO should verify onboard targets and computed attitude against the burn's DMT or PAD. Target load status should be passed to FD. The above procedures verify the uplinked target set and crew entries are correct.

After the crew loads targets, the onboard guidance solution needs to be verified. OMS trims are initially displayed at their last commanded values. At TIG -10 sec (BURN ENA), the OMS engine(s) will be commanded to the specified trim value(s). If the TIG displayed by Maneuver Monitor display does not match the PAD, the crew entered TIG incorrectly, or GMTLO between the ground and onboard is different. In general, the onboard solution displayed on Maneuver Monitor or on the FDO MANEUVER MONITOR DDDs should correspond to data on the PAD or DMT if the target inputs are correct. The onboard ignition attitude is based on the onboard inertial RELMAT, the engine(s) to be used, and the TVR. If any of these items is in error, or a really bad state vector is onboard, the computed ignition attitude onboard will differ from the ground value. There will be acceptable differences between ground and onboard computed attitude because onboard software is using fleet averages for OMS engine values, while the ground is using engine-specific values.

**CAUTION:** inherent differences between ground and onboard burn attitude are numerically magnified in pitch and roll when yaw is near 90° or 270° in a pitch-yaw-roll Euler sequence (the onboard convention). Assuming reasonable yaw agreement, both attitudes are in all likelihood correct. Large attitude differences may also arise during rendezvous Lambert targeting because a ground PAD's attitude is driven by differing PEG-7 targets.

Since onboard engine selections are limited to +X RCS, OMS Both, Right OMS, or Left OMS, burns performed in current attitude (Multi-Axis) or with FRCS jets require special

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procedures for determining attitudes and body VGOs for the burn PAD. These special procedures are discussed in Section 3.7.2.12. The vehicle attitude displayed is from the Commander's (CDR) Attitude Direction Indicator (ADI). An asterisk appears next to either the inertial (I), reference (R), or LVLH (L) ADI mode switch setting. The inertial setting means the ADI attitudes are computed using the reference RELMAT. Because the ignition attitude is computed using the inertial RELMAT, the current and the ignition attitudes will match when the vehicle is in burn attitude.

**CAUTION:** if there is a Multiplexer/Demultiplexer (MDM) Flight Forward (FF) 1 failure, the ADI mode indicator will not correspond to the attitude displayed. If FF1 fails, the CDR's ADI is moded to the default or "green dot" mode, and LVLH attitudes are automatically displayed. On the MANEUVER MONITOR display, the current attitude may be flagged as inertial but actual values will be LVLH. Under these conditions, when the vehicle is in attitude, the CUR attitude will not match the inertial IGN attitude, even though actual attitude errors are very small.

A special case exists for RCS burns due to a difference in calculating burn attitudes between the ground and the Orbiter. The ground computes burn attitude assuming an "effective thrust" direction. The actual RCS thrust direction is different from the effective thrust direction because DAP attitude hold firing contributions to the translation's  $\Delta v$  are neglected. Onboard burn attitude uses an actual Orbiter Body thrust vector. For +X burns, the difference in actual pitch and effective pitch is  $1.1^\circ$ . The translation  $\Delta v$  error from using the onboard attitude is a maximum 2% of DVTOT for long burns, and it becomes more precise for very short burns. For burns longer than 20 sec, the ground computed attitude is much more precise and should be used for targeting purposes. The largest error in the ground computed attitude is for very short burns and is in the neighborhood of 2%. For -X RCS burns, the difference in the actual and effective pitch angle is about  $10^\circ$ . Onboard guidance does not have the logic to compute -X RCS burn attitudes and therefore the ground solution is used to achieve burn attitude through Universal Pointing. The difference between initial and steady state thrust is larger in FRCS burns due to two factors. First, thrust from these jets is not as closely aligned to the Orbiter CG as is that from +X jets. This generates a considerably larger torque for the DAP to control during FRCS burns. Second, all attitude control is performed by ARCS jets during an FRCS burn. The maximum translation  $\Delta v$  penalty for short (less than 10 sec) -X burns is 15% of DVTOT.

**WARNING:** if Body Vector 5 and Target ID x with associated pitch, yaw, and omicron are entered out of order, the yaw gets cleared and the DAP assumes a Z-axis controlled attitude. This can lead to the wrong burn attitude even though the ground sees the correct pitch, yaw, and omicron values in the downlink.

Orbit FDO may be on console when BFS is active. This might occur during contingency entry operations or during post-insertion. The following discusses how loaded targeting values are evaluated when both PASS and BFS are running.

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Attitude errors are displayed for both the PASS and BFS and represent differences between the current and desired attitudes. When the Orbiter is in burn attitude, errors will be small or within the DAP deadband. It is possible to be misled by the display if the vehicle is very far out of attitude. Depending on the scale selected by the crew for ADI error needles, the display value may be pegged at five or ten degrees when the actual errors are much larger. If BFS is to be used, BFS attitude errors are a good indication of the BFS guidance solution. They should match PASS errors if the BFS targets were entered and loaded correctly. Generally, BFS monitors data manually entered into the PASS. Procedural errors can cause differences to appear between the BFS and the PASS. For instance, if the crew modes BFS from standby after the PASS targets are loaded, different solutions are calculated. An indication of this problem is differing attitude errors although the difference might also be caused by BFS having a different RELMAT or state vector. Total  $\Delta v$  and components of the velocity to be gained in Orbiter Body coordinates (VGX, VGY, VGZ) are displayed on Maneuver Monitor for both PASS and BFS. VGOs are computed cyclically once the targets are loaded and will match the ground computed VGOs at ignition.

NOTE: due to a BFS downlist scaling problem, VGOs > 256 fps may not be displayed correctly. If VGOs and total  $\Delta v$  don't match, engine selection, TIG, or TVR entries may be incorrect. VGOs and total  $\Delta v$  decrement toward zero as the burn progresses. At cutoff, VGOs reflect Body residuals to be trimmed. TGO initially reflects burn duration in min and sec and does not include tailoff. As the burn progresses, TGO will count down toward zero. An initial mismatch here probably indicates an erroneous engine selection or TIG weight.

### **3.7.2.11 Maneuver Execution Monitoring**

Once burn PADs and command loads are on board and the crew has executed their procedures to put the Shuttle into the correct configuration and attitude for the burn, the FDO must devote attention to monitoring all vehicle parameters, crew actions, and voice loop traffic that might affect satisfactory burn completion.

#### **3.7.2.11.1 Crew Procedures**

Once the onboard solution has been verified as explained in Section 3.7.2.10 and the vehicle is in the correct burn attitude, the only remaining crew action for an OMS burn is to enable ignition by pressing the EXEC key. The "EXEC" starts flashing on the CRT 15 sec prior to TIG. Part of the standard burn procedure is for the crew to turn on flight controller power for the RCS translation hand controller (THC). Flight controller power status can be seen on Maneuver Monitor DDDs or on Rendezvous ONAV Status. If the

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burn is an RCS burn, the crew will begin to deflect the THC at TIG. FDO should be watching displays for either OMS on or RCS firings to verify the burn started on time. After the burn is complete and the residuals have been trimmed out, the crew will exit OPS 202, which disables PEG.

**NOTE:** normally, the crew loads the maneuver (ITEM 22) and starts the countdown timer (ITEM 23) well before TIG. To initiate the maneuver to burn attitude, the crew enters an ITEM 27. GNC FSSR Section 4.1.6, Premaneuver Display Support Task, documents software limits imposed on the time at which an ITEM 22 is performed. An ITEM 22 will only be accepted if  $\Delta t$ , the countdown time in sec to TIG, satisfies the conditions  $-300$  (5 min)  $< \Delta t < +43200$  (12 hrs). If these conditions are violated an 'ILLEGAL ENTRY' message will be displayed to the cre on their Display Electronics Unit (DEU). If targets have been loaded successfully, but the crew does not enter EXEC before an OMS burn TIG, no engine ignition will occur. Once burn attitude is achieved, it will continue to be held inertially for an indefinite period. EXEC will continue to flash on the cockpit DEU until EXEC is entered, the burn is successfully reloaded, or OPS 202 is exited. A delayed burn TIG is referred to as a TIG slip. TIG Slip is discussed in more detail in Section 3.7.2.3.

**CAUTION:** if a UNIVERSAL POINTING ROTATION or TRACK option is initiated with the orbit DAP in any non-AUTO mode (INERTIAL, FREE DRIFT, or LVLH), UNIVERSAL POINTING does not compute commanded body attitude (Q\_B\_M50\_CMD) and track rate. Once the DAP is moded to AUTO, it immediately accesses the last computed quaternion and track rate value. A maneuver in the wrong direction could then be commanded until UNIVERSAL POINTING detects AUTO and computes a new quaternion and track rate. Up to 3 sec may be required before the DAP responds to UNIVERSAL POINTING's data refresh and starts maneuvering in the correct direction. Consequently, any UNIVERSAL POINTING ROTATION or TRACK maneuvers (ITEM 51 on the Attitude Target Display) should only be initiated in the AUTO DAP mode. If the attitude option is initiated or interrupted by selecting any non-AUTO DAP mode, expect a delay in resumption of the attitude option after AUTO mode is entered (see PASS DR 050112).

**CAUTION:** if a state vector update is uplinked after the crew has loaded burn targets, FDO should remind the crew to reload targets. This needs to be done to drive the guidance solution with the new vector.

**NOTE:** OPS 202 attitude guidance activates at TIG and continually updates burn attitude based on remaining VGOs and the Body-fixed thrust vector. When TGO  $< 6$  sec, guidance will freeze burn attitude to avoid the possibility of large attitude deviations at the end of the burn due to residual  $\Delta v$ .

There are some parameters FDO should monitor before and during the burn. Prior to TIG, if the Orbiter is not within  $5^\circ$  of burn attitude in each axis, the burn is No-GO. For an OMS burn, at approximately TIG-10 seconds, FDO should see the crew enable the

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burn by observing the BURN ENABLE flag on the Maneuver Monitor display. At TIG, FDO should observe VGOs beginning to count down. Also, if the vehicle is in burn attitude at the TIG, attitude errors should remain near zero. If an OMS burn started before the Orbiter reached attitude, TVC steering should rapidly drive attitude errors to near zero.

NOTE: there is no software inhibit to OMS ignition based on burn attitude error. Although attitude maneuvers using TVC torques are less propellant-efficient than equivalent RCS maneuvers, loads imparted to the Orbiter by TVC steering are generally less than those from even VRCS pulses. Thus, it was possible to perform an immediate downmode from one OMS engine to the other during STS-88 when Node-1 *Unity* was mounted on the ODS. Even though 2-OMS burns violated loads constraints during this phase of STS-88, a single-OMS TVC attitude maneuver did not.

As the burn progresses, TGO should also be counting down. TGO should count down at a rate of 1 second of TGO per second of real time. If TGO counts down at a different rate, one of several anomalies may exist. The Orbiter weight used by guidance may be in error, causing measured acceleration levels to differ from those expected by guidance. This could happen if the PEG-7 command load was uplinked in MM201 and the crew failed to correct the Orbiter weight to the value on the PAD. The old weight value is used by guidance in that case. This error is avoided by the FDO and TRAJ monitoring the weight entry by the crew and verifying weight on Maneuver Monitor. Orbiter weight is part of the uplinked PEG-7 command load. If burn targets are uplinked in MM201, weight is not carried over the OPS transition to MM202. On the other hand, if the command load is uplinked with GPCs in MM202, weight entry by the crew is not required.

Another problem for an OMS burn could be that one or both OMS engines is experiencing anomalous performance. If an engine fails, the crew must turn the OMS engine switch to the OFF position to inform guidance only one engine is firing. In this case, the TGO value will be recomputed to reflect the one engine burn completion time. At burn completion, VGOs should be at or close to 0.0. For on-orbit burns, the crew will manually trim VGOs to less than 0.2 fps in each Body axis by default. After the burn is complete and differences between the pre and the post-burn accelerations have been computed, FDO confirms the maneuver in the ephemeris. Refer to Section 3.7.2.11.5, Maneuver Confirmation.

### 3.7.2.11.2 Maneuver to Burn Attitude

Attitude considerations and the support of the POINTING flight controller for maneuvers are discussed in detail in Section 3.7.2.7.1. Prior to publishing a burn PAD and uplinking targets, FDO or TRAJ should consult with POINTING to determine the time it will take for the vehicle to maneuver to burn attitude on available A or B DAP settings.

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FDO should provide FD with either the latest time to start the attitude maneuver or the delta time it will take to maneuver to attitude for both the high rate (usually B) and low rate (usually A) DAP selections. FDO should monitor the attitude maneuver and consult with GNC to let FD know if the rate needs to be bumped up. FDO should also be ready to prompt FD if the crew nears a no-later-than maneuver initiation deadline. A useful ROSS application called TIMERS can be found under FDO's Applications DNAV menu. This display can be used to find time remaining to arrive in attitude for the current, fast, and slow DAP's. Another useful application is the 3D Attitude Display included on the FDO ORBIT MONITOR display. Attitude errors are graphically depicted on this display.

### 3.7.2.11.3 Burn Execution

The following summarizes what the FDO and TRAJ do just prior to, during, and following a Shuttle maneuver.

- 1) Using the MANEUVER MONITOR DDDs (see Figure 3.7.2.9.2-3), Maneuver Monitor display, or Rendezvous ONAV Status (see Section 3.10.5.1 for details on this display), verify onboard software is in MM202 for PEG-7, or MM302 for PEG-4D. Occasionally, systems problems or other events can prompt the crew to take the GNC machines out of MM202/302. If this occurs, monitor crew actions to insure correct configuration is attained in plenty of time to execute the burn.
- 2) Prior to TIG, FDO should once again verify the vehicle is in burn attitude by comparing attitude on MANEUVER MONITOR DDDs, the Maneuver Monitor display, or Rendezvous ONAV Status with the PAD. If an error in any axis is  $> 5^\circ$  at TIG, the burn is No-GO per Flight Rule A4.1.4-8.3. Prior to TIG, TRAJ must prepare to confirm the burn either manually or using DV SENSOR (see the DV Sensor Users Guide, located on the DM S: Drive at DM32\Apps\Cert\_info\DV\_Sensor).

If manual confirmation is to be performed, hard copy Maneuver Monitor or Rendezvous ONAV Status and note preburn accumulated  $\Delta v$ .

- 3) During the burn, verify attitude errors don't diverge and VGO/TGO count down at a real time rate.
- 4) At burn completion VGOs should be trimmed by the crew to the tolerance appropriate to the burn. See Section 3.7.2.11.4 for a more detailed discussion of burn VGO trims.
- 5) Immediately after burn completion, use DV Sensor, RMM, or the manual method to confirm the burn in the ephemeris. Section 3.7.2.11.5 provides maneuver confirmation details.

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### 3.7.2.11.4 Burn Trim $\Delta v$

At burn completion, VGOs should be trimmed by the crew to the tolerance appropriate to the burn. Prior to a mission, the Lead FDO should determine the criticality and precision required for each maneuver. Rendezvous burns typically require the greatest precision, which is to trim each component to within 0.2 fps. Other non-critical burns can have tolerances of 2 fps or more. The criticality and trim tolerance for burns are generally documented by mission-specific flight rules in Section 4. If VGO residuals > the tolerance exist, verify the crew burns them out. If the crew does not satisfactorily burn out the residuals, inform FD.

### 3.7.2.11.5 Maneuver Confirmation

Maneuver confirmation is performed after a burn in order to update the ephemeris to reflect observed TIG, thruster, and  $\Delta v$ . Due to processor limitations, BFI maneuvers cannot be confirmed. They must be deleted and re-input. Prior to TIG, TRAJ is responsible for preparing to confirm an upcoming burn. TRAJ will note the preburn IMU sensed  $\Delta v$ . Either Maneuver Monitor or Rendezvous ONAV Status contain information necessary to monitor and confirm a burn.

Examples of DV Sensor displays are shown in Figures 3.7.2.11.5-1 and 3.7.2.11.5-2. The DV Sensor tracks cumulative  $\Delta v$  downlinked from the Orbiter. The  $\Delta v$  values are IMU-sensed changes in the Orbiter's velocity that are downlisted for monitoring. DV Sensor can be used to infer burn  $\Delta v$  from cumulative  $\Delta v$  values and update the maneuver modeled in an ephemeris accordingly. This is important since the actual executed burn is rarely exactly the same as the planned burn. It is important to keep the ephemeris as accurate as possible to assist subsequent trajectory planning and NAV post-burn orbit determination. The DV Sensor Users Guide is located on the DM S: Drive at DM32\Apps\Cert\_info\DV\_Sensor.

If manual confirmation is to be performed, hard copy Maneuver Monitor or Rendezvous ONAV Status and note preburn cumulative  $\Delta v$  values.

The values copied from the Maneuver Monitor are the accelerations sensed by the Inertial Measurement Units (IMU). These provide reasonable values for actual  $\Delta v$  imparted to the Orbiter CG, but they may not be the best available. This is because these values include some rotation accelerations sensed from IMUs located not at the Orbiter's CG, but rather at the NAV base in the Orbiter's nose, introducing error in  $\Delta v$  used to confirm the burn. Maneuver Monitor must be used for confirmation of burns performed in OPS 1 and 3 because Rendezvous ONAV Status parameters are not computed at those times. In OPS 2, however, Rendezvous ONAV Status provides better burn confirmation support than does Maneuver Monitor. During a burn, every

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time an acceleration exceeding 3  $\mu$ Gs is sensed, the DV\_COUNT is incremented and COUNT\_ACC contains the measured acceleration in  $\mu$ Gs. The accelerations sensed by the IMUs are then mathematically translated to the Orbiter CG, and those values are added to the DV\_DISP values for X, Y, and Z. These DV\_DISP values can be used to determine the  $\Delta v$  imparted to the Orbiter CG. Values on Rendezvous ONAV Status will be a little more accurate than those on the Maneuver Monitor display since they are corrected to the CG of the Orbiter. These values have the 3  $\mu$ G threshold, which nearly eliminates IMU acceleration noise. This is the standard display for confirming on-orbit OPS 2 burns.

IMU  $\Delta v$  values are written down or entered into the TSA RMM display in the burn confirmation area. Prior to the advent of DV Sensor, RMM was used to record and compute M50  $\Delta v$  of every on orbit burn. The portion of the display used for confirmation is illustrated in Figure 3.7.2.11.5-3. Verify IMU data and record actual TIG in the Log Book.

At times, a burn takes place during Loss Of Signal (LOS). This makes it extremely difficult to get good M50  $\Delta v$  with which to confirm the maneuver. The best the FDO can do is record the accumulated  $\Delta v$  before the vehicle goes LOS, record them again at AOS, and get a crew report on actual maneuver TIG. This may be fine for a short LOS, but for long ones, attitude maneuvers, water dumps, etc. may contribute to the accumulated  $\Delta v$ , causing components to be unacceptably incorrect. If this occurs, FDO must use judgment to decide whether or not to use accumulated  $\Delta v$ , or to leave the originally targeted maneuver in the ground ephemeris. As an alternative, FDO can request burn confirmation and residuals from the crew before LOS. At AOS, the crew reports this information, and FDO performs a residual burn confirmation with it. For this type of confirmation, FDO provides DYNAMICS with residual VGOs read down by the crew for RES guidance input (see Section 3.7.1.3.5).



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fdo dv sens

Close   Print   Pre-Burn DV Counts   Confirm   Input   Page # 1

Post-Burn DV Count:   Cron: white-fcr10

**FDO DV SENSOR**

8890%

DV COUNT	DV DISPL (FPS)	DV DISP2 (FPS)	DV DISP3 (FPS)	LVX1 X DISP (FPS)	LVX2 Y DISP (FPS)	LVX3 Z DISP (FPS)	RSS DISP (FPS)	RECORD TIME	MNVR
3	0.04	-0.03	-0.11	-0.02	-0.00	0.10	0.11	135:03:37:27.2	
4	-0.06	0.03	-0.05	0.01	0.02	-0.14	0.14	135:06:00:31.2	
5	-0.11	0.03	-0.11	0.04	0.04	-0.03	0.06	135:05:00:26.2	
6	84.24	-59.78	-88.23	135.76	0.05	-6.08	135.91	135:05:20:19.2	MN
7	84.20	-59.78	-88.23	0.01	0.01	-0.06	0.06	135:05:21:42.2	

Figure 3.7.2.11.5-1: FDO DV Sensor

**CONFIRM MANEUVER**

EPHEMERIS   1

MANEUVER NO.   02   # - REPLACE MNVR

TVR:   0

TIG   001:13:35:15.3    MET  
 GMT

M50 Δ VX:   84.34

M50 Δ VY:   -59.78

M50 Δ VZ:   -88.23

OMS-BOTH

OMS-BOTH-CEN

OMS-LEFT  

OMS-RIGHT

PX2  

PX3

PX4

MZH

DMT SELECTION

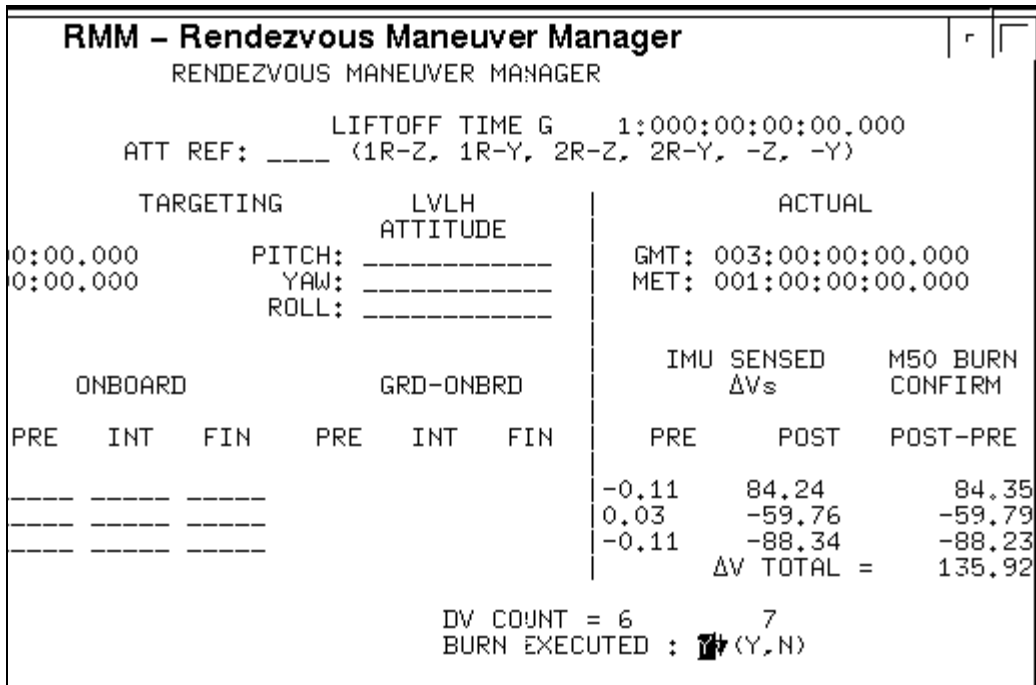
DMT1    DMT2

SYSTEM

MOC    TSA    BOTH

Figure 3.7.2.11.5-2: DV Sensor Confirmation Display

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**Figure 3.7.2.11.5-3: RMM Burn Δv Computation**

Immediately after burn completion, TRAJ uses DV Sensor or the RMM-based method to confirm the burn in the ephemeris. If the manual method is used, hardcopy Maneuver Monitor or Rendezvous ONAV Status, then record post-burn Δv. Compute M50 Δv by subtracting pre-burn Δv components from corresponding post-burn component. These values are given to DYNAMICS for M50 maneuver confirmation.

**CAUTION:** if a GPC or IMU data string failure occurs *during* the burn followed by a manual shutdown, IMU-sensed Δv may be in error, reflecting only the burn segment prior to the failure. A confirmation using this partial Δv will show large residuals on NAV's post-burn batch plots. In such cases, a better confirmation can be achieved by consulting PROP to obtain actual burn duration. The burn can then be confirmed based on a ΔT override input.

If DV Sensor is not used to confirm the burn, the confirmation must be done via DYNAMICS. Once TRAJ has computed M50 Δv and determined thrusters and TIG, these confirmation data are voiced to DYNAMICS for input to the M40 (Maneuver Delta-V Definition) and M66 (Maneuver Definition) MEDs. TRAJ's request to DYNAMICS takes the following form.

- 1) Confirm maneuver number X; ephemeris number Y
- 2) TIG: on time or actual

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- 3) Thrusters if a downmode was made
- 4) M50  $\Delta v$  components

After confirmation inputs have been made, TRAJ should place the maneuver in TrS DMT NO 1 or 2 for viewing. TRAJ checks the M50  $\Delta v$  and TIG for accuracy and lets FDO know the burn and ephemeris in which confirmation is complete.

### 3.7.2.12 Special Maneuver Types

Two special types of Shuttle burns require more detailed discussion. These burn types are Forward RCS (FRCS) burns and multi-axis burns. Since the onboard guidance software supports PEG-targeted maneuvers for OMS and Aft RCS thrusters only, special procedures are necessary to execute targeted FRCS translation maneuvers. FRCS and multi-axis maneuver targeting can be confusing to both the crew and FDO because of ground and onboard software limitations. This section explains modeling these maneuvers in TrS, FDO PAD procedures, and provides a FRCS burn crew procedures summary.

#### 3.7.2.12.1 Forward RCS (FRCS) Maneuvers

Equivalent terms Minus X, -X, and FRCS are used interchangeably in this section. Translation burns using FRCS are executed for several reasons. For example, during STS-103 (HST Repair), propellant was extremely limited for aft RCS and OMS, but significant margin existed in the FRCS system. Therefore, several -X burns were planned and executed. FRCS burns are also sometimes used for nominal (IUS) or contingency (ARCS failure) separation maneuvers from deployed payloads.

In TrS, FRCS burns can be directly input using the body-fixed inertial (BFI) guidance mode with MXL thrusters. More commonly, FRCS PEG-7 targets (a guidance mode easily confirmed in TrS) are directly input into TrS using the MZH thruster code once the post-insertion reconfiguration of the ECT has been made. Prior to orbit ops, MZH (Minus Z High) thrusters are nominally used only to model the MPS dump impulse post-MECO. After the Orbit D64 reconfigures the TrS ECT, the MZH slot is available for FRCS modeling. The MXL thruster slot in the ECT models tail only attitude control for a -X burn and can not be used with PEG-7 targeting. The MZH thruster slot is reconfigured post-insertion to model full up attitude control for a -X burn. Full up attitude control is typically the DAP used for FRCS burns. PEG-7 and BFI guidance modes are explained in Section 3.7.1.3.

NOTE: MZH reconfiguration can only modify thrust and flow rate because Body thrust vector pitch and yaw angles require the TrS be configured by TAO (see Section

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3.7.1.4). Consequently, the Ascent Team uses a FRCS Body thrust vector to confirm MPS dump. This only distorts attitude on the dump confirmation's DMT, and it has no effect on the Orbiter ephemeris. The MPS dump DMT attitude data can be ignored by the Ascent Team because the dump isn't PADed, and it occurs in the known MECO inertial attitude. The Ascent Team also uses an infinitesimal MZH flow rate to conform the MPS dump. This preserves Orbiter ephemeris initial weight at its OMS-2 TIG value.

When RCS thrusters are selected, onboard software always computes a burn attitude for ARCS thrusters. It is therefore up to FDO to provide a maneuver PAD with the correct FRCS burn attitude. To avoid confusion, PAD content and read up to the crew must be compatible with the FRCS burn procedure in the Orbit Ops Checklist, pages 10-13 through 10-14.

The FRCS maneuver PAD looks like any other orbit maneuver PAD with the following notes added. In a manual paper-based FRCS PAD, insure the following annotations are made.

- 1) Print "Use Orbit Ops C/L FRCS burn procedure, p. 10-13." at the top.
- 2) Cross out the BURN ATT section and print "N/A" beside it.
- 3) Cross out the TRIM LOAD section and print "N/A" beside it.
- 4) Cross out OMS HE REG TEST section and put "N/A" beside it.
- 5) Obtain P,Y,OM BURN ATT and R,P,Y LVLH ATT from POINTING based on LVLH attitude at TIG -30 sec corresponding to the DMT's M50 attitude.

Burn attitude on the PAD is correct for FRCS thrust, but it will not match what the crew sees computed onboard as the burn attitude. This is, of course, an attitude supporting ARCS thrust. Reminding the crew to use Orbit Ops Checklist -X procedures is important when reading up the PAD. After reading the checklist reminder to the crew, the -X RCS burn attitude should be read up, referencing ITEMS 15, 16, and 17, and then the rest of the PAD.

### **3.7.2.12.1.1 FRCS Burn Execution**

Orbit Ops Checklist pages 10-13 to 10-14 direct the crew to load -X burn attitude into Universal Pointing, then auto maneuver to burn attitude. After transition to OPS 202, the crew loads target data from the PAD, modes the DAP to inertial at TIG -30 sec, and performs the burn by deflecting the THC at TIG in current attitude to null VGOs. No maneuver to the computed OPS 202 attitude (no ITEM 27 EXEC) is performed.

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Separation maneuvers, which place the Orbiter in a safe trajectory relative to a deployed payload, are considered critical for crew safety. Although sep burns are normally planned for OMS or ARCS thrusters, mission requirements or system failures can result in a decision to use FRCS. Special procedures have been developed (for sep burns only) allowing the crew to determine correct posigrade or retrograde FRCS burn attitude without help from MCC.

For FRCS sep maneuvers, the crew does not receive a PAD from MCC, but instead uses the procedure found in the applicable deploy checklist. Since a separation maneuver has a standard posigrade or retrograde character, a set of dummy PEG-7 targets can be placed in the deploy checklist on a FRCS Burn PAD. Loading the dummy targets causes the onboard software to compute an Aft RCS burn attitude which is actually correct for the desired FRCS burn. Therefore, the crew can use an ITEM 27 EXEC to go to the burn attitude in these cases.

When the Orbiter is in attitude, the crew loads the actual separation burn targets, which are also provided in the checklist on the FRCS Burn PAD. The crew executes the burn by deflecting the THC at TIG and nulling VGOs in the current attitude, ignoring the computed attitude (no ITEM 27 EXEC this time).

The general FRCS burn procedures and FRCS sep burn procedures have noteworthy differences. Dummy targets apply only to the FRCS sep attitude maneuver. This is because PEG-7 sep  $\Delta v$  is always the same, the burn is critical for crew safety, and data in the payload deploy checklist allow the crew to perform the burn if a loss of communications occurs after GO for deploy. Other FRCS maneuvers are not normally critical for crew safety and can be postponed for a loss of comm. Since these maneuvers may not be purely posigrade or retrograde, MCC provides a PAD with dedicated attitude data.

Because FRCS burn procedures are unusual, it is important to monitor crew inputs during burn preparation so any problems can be identified and corrected promptly. The following discussion assumes telemetry and voice communications are available. Before reading the rest of this section, become familiar with Maneuver Monitor and Rendezvous ONAV Status displays. These are described in FDO Console Volume IX. Also be familiar with MANEUVER MONITOR DDDs (see Appendix 3.M and the Users Guide for this application on the DM Server S: Drive at DM32\Apps\Cert\_info\Enhanced\_Displays\MNVR\_MON\Ross\_Alarms\_MM\Mnvr Mon Users Guide.ppt). Finally, be familiar with burn confirmation using DV Sensor (see Section 3.7.2.11.5).

For general FRCS burns, verify the crew has input correct attitude to Universal Pointing by observing the right column in Rendezvous ONAV Status (ITEMs 15, 16, and 17 - Pitch, Yaw, and Omicron, respectively). This attitude should match the one on the FRCS PAD's BURN ATT section. Watch the crew typing in the attitude by observing

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the "SCRATCH PAD" inputs in the lower left part of the same display or on the projected FCR display. Attitude inputs are ITEMS 15, 16, and 17 EXEC, and the command to initiate TARGET TRACK attitude in Universal Pointing is ITEM 19 EXEC.

When the maneuver to attitude has begun, INRTL and LVLH attitudes (in Roll, Pitch, Yaw) also appear in the right hand column of Rendezvous ONAV Status. These will begin to change, and errors (ERR) between current and required attitude angles will begin to decrease. When ERR values are within deadband limits in all axes, the Orbiter is in attitude. Rendezvous ONAV Status also has a scratch pad field in the lower left where crew keypad inputs can be monitored.

Use Maneuver Monitor to observe burn targets loaded by the crew. Targets also show up on Rendezvous ONAV Status. Maneuver Monitor DDDs can also be used to monitor the onboard configuration. Check TIG, engines (RCS), weight, PEG-7  $\Delta v$ , and VGOs, all of which should be correct according to the maneuver PAD if the Orbiter is in the attitude input to Universal Pointing. The attitude under "CUR R, P, Y," should match the burn PAD, and the errors (ERR R, P, Y) between the current and onboard computed burn attitude should total about 180°. The onboard computed burn attitude (IGN R, P, Y) will not match the PAD because it is computed assuming ARCS thrusters.

At this point, FDO should monitor crew keystrokes to ensure an ITEM 27 EXEC is not entered on ORBIT MNVR EXEC. This would initiate an incorrect ARCS thrust attitude maneuver. FDO should also pay attention to the Air-to-Ground loop in case the crew indicates confusion about why the IGN attitude doesn't match PAD attitude. If this happens, a reminder to use the Orbit Ops Checklist -X procedure and to ignore the onboard computed burn attitude will be in order. FDO should notify FD immediately if the crew takes action initiating an errant attitude maneuver.

When the crew deflects the Translation Hand Controller (THC), a minus sign will appear next to the "X" under "RCS" in the MNVR EXEC portion of Rendezvous ONAV Status. Note actual TIG if the burn is not on time.

FDO and TRAJ should use standard burn confirmation procedures as described in Section 3.7.2.11.5. If the FRCS maneuver was modeled using the BFI guidance mode, it must be deleted and then re-input into the ephemeris rather than confirmed. The re-input maneuver will be a direct input, using the M50 guidance mode, actual TIG, PX2 thrusters, and M50  $\Delta v$ . Hardcopy DMTs containing the modeled FRCS BFI maneuver and the confirmed M50 maneuver.

Pre-burn monitoring tasks are a little different for FRCS sep maneuvers because the crew does not use Universal Pointing to input burn attitude. The crew loads dummy targets from the deploy checklist which cause the onboard software to compute a burn attitude for a fictitious aft RCS maneuver. This attitude is correct for the FRCS sep burn.

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The crew will be loading sep burn targets twice. Both should be monitored on Maneuver Monitor or Rendezvous ONAV Status. The first time the crew loads targets, PEG-7  $\Delta v$  on Maneuver Monitor or Rendezvous ONAV Status should match the dummy targets in the deploy checklist, and the onboard computed attitude (IGN R, P, Y) will match the burn attitude on the DMT computed by FDO using MZH thrusters and PEG-7 targets. The crew will do an ITEM 27 EXEC to maneuver to attitude. When "CUR" attitude matches "IGN" attitude with errors (ERR) within DAP limits, the Orbiter is in attitude.

The second set of sep targets the crew loads will be the actual PEG-7  $\Delta v$  from the burn PAD in the deploy checklist. After these ITEM entries, a new burn attitude is computed and will appear under IGN R, P, Y. The crew should ignore this attitude and not perform an ITEM 27 EXEC. Monitor crew keystrokes and voice loops to make sure an attitude maneuver is not initiated at this point. The VGOs will also change after dummy targets are replaced. Both PEG-7s and VGOs should now match their counterparts on the FRCS sep DMT and the FRCS burn PAD in the deploy checklist.

### 3.7.2.12.2 Multi-Axis Maneuvers

In some situations, there are advantages to performing small RCS maneuvers in a vehicle attitude requiring an arbitrary mix of FRCS and ARCS thruster firings. These are referred to as "multi-axis" maneuvers.

In general, the reasons for doing burns multi-axis boil down to FRCS propellant savings and/or a desire to avoid maneuvering to burn attitude. There are many possible reasons for wanting to maintain attitude through a maneuver, including payload thermal or sun in the bay constraints, antenna and sensor pointing requirements, or minimization of trajectory dispersions caused by the attitude maneuver.

One of the most common applications of multi-axis maneuvers is rendezvous. Flight Rule A2-121E.1 states that if the total  $\Delta v$  of a rendezvous maneuver is less than 4 fps, the maneuver may be done multi-axis. Four fps was chosen as the criterion because for certain attitudes, such as target track for Ti and NCC burns, it equates to 2 fps out of the FRCS, assuming an equal contribution from forward and aft RCS thrusters. This also satisfies Flight Rule A-121F, which says a maneuver to burn attitude may be performed if more than 2 fps (50 lbm) is coming from the FRCS.

A multi-axis burn advantage is elimination of at least one, and probably two, attitude maneuvers. These impulses always introduce small, unmodeled perturbations to the trajectory. In rendezvous, this is especially significant at Ti, when the maneuver to burn attitude creates dispersions affecting most midcourse corrections (MCs). A maneuver to burn attitude may also force sensors to lose target acquisition. A multi-axis

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maneuver allows sensors to continuously point at the target. For further discussion of this topic with regard to rendezvous, see Section 3.10. Rendezvous is not the only application of multi-axis RCS maneuvers, as they are appropriate for any small maneuvers, such as the trim burns discussed in Section 3.7.2.5.1.

It does not matter to the ground ephemeris exactly how the maneuver is modeled, as long as the TIG,  $\Delta v$  and engines are correct. It is a good idea that the correct TVR is also modeled in case the crew has to downmode to plus X and needs to maneuver to the correct attitude. What does matter is what appears on the PAD read to the crew. Model the maneuver as a PEG-7 direct input, with PX2 thrusters selected. The resulting DMT will reflect the correct TIG, weight, and PEG-7  $\Delta v$ . Burn attitude will be correct only for PX2 thrusters. A similar erroneous attitude will also be what the crew sees displayed on the Maneuver Execute display (ITEMs 24-26) after PEG-7 targets are entered and LOADED (ITEM 22 EXEC). This is because onboard software assumes ARCS thrusters for any non-OMS burn.

In real-time, FDO or TRAJ computes body VGOs using RMM. Consult with POINTING to determine the inertial and LVLH attitude of the Orbiter at TIG. The LVLH attitude POINTING supplies and the PEG-7  $\Delta v$  are entered into the left side of the TSA RMM display for the burn. Body VGOs are computed and displayed. TRAJ will then voice VGOs to PROP, who will accurately determine FRCS/ARCS propellant usage. Since the crew will be doing the burn in current attitude, VGOs displayed on Maneuver Execute will correspond to the ones TRAJ computes using the LVLH attitude from POINTING.

The following items are noteworthy in publishing a multi-axis burn PAD on paper.

- 1) Print "MA Procedures ORB OPS 10-15" at the top.
- 2) Check RCS SEL; MULTI-AXIS.
- 3) Although TV ROLL doesn't nominally apply, use the appropriate TVR for +X jets to minimize changes to the PAD if +X is selected later.  
Prograde: TVR = 0  
Retrograde: TVR = 180
- 4) Cross out TRIM LOAD (ITEMs 6 - 8) and print "N/A".
- 5) Use WT from the DMT.
- 6) Use TIG from the DMT.
- 7) Use PEG-7  $\Delta v$  from the DMT.



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- 8) Cross out MNVR ATT and print "Burn in Current Attitude".
- 9) Use  $\Delta VTOT$  from the DMT.
- 10) Use TGO from the DMT.
- 11) Use VGOs computed from RMM with the LVLH burn attitude from POINTING and PEG-7  $\Delta v$  as inputs. Do NOT use VGOs from the DMT.
- 12) Use TGT HA, HP from the DMT.
- 13) NOTES are as required from PROP and GNC.

### 3.7.2.13 ISS Mated Reboost

This section describes procedures to model reboost maneuvers and monitor their execution. The following table lists the different reboost Configurations (CFs), in order of decreasing preference, as available for STS-113/11A. Reboost modeling data are shown in the two right hand columns. When input to a TSA ECT, reboost pitch and yaw values are set to zero such that posigrade thrust is obtained with null LVLH attitude regardless of CF. In TrS, effective thrust becomes the V-component of a UVW vent, and M-dot is irrelevant. Effective thrust is updated in real time as actual flight performance becomes known.

**CAUTION:** data in the following table are provided for reference purposes only. Consult the appropriate flight-specific FDO Console Handbook Annex for operational reboost data.

CF	Translation/Pitch Control, LVLH Attitude	$\Delta V$ ~fps/hr	Effective Thrust lbf	lbm/sec M-dot (Draper numbers)
3	VRCS/VRCS, -Z VV*	11.2	59.4	0.312
4	+X/VRCS, +XVV pitch bias*	2.7	14.5	0.101

\*A minimum 20-hr wait between VRCS reboosts is required. Each VRCS session must be no greater than 1hr in duration. No more than 3 hrs VRCS reboost allowed per mission.

#### 3.7.2.13.1 TSA Reboost Modeling Procedures

The following procedures assume a reboost is being modeled in Orbiter Global Ephemeris 1 (G1) during pre-mission planning.

- 1) Prior to modeling a reboost maneuver with TSA, update the pertinent Local/Global ECT. Be sure to use Pitch and Yaw values of zero.

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- 2) Compute the total "stack" vehicle weight at TIG by adding the current (or projected) Orbiter weight plus the ISS weight. Enter a total weight WGL into G1 with a time tag 5 min prior to reboost TIG. Enter another total weight WGL to restore Orbiter-only weight 5 min after the reboost period ends, then TUP G1.
- 3) Use Maneuver Edit to input the reboost to G1. Verify stack weight was picked up with the TIG vector. Input the appropriate thruster, and use guidance mode "BFI" with LVLH reference attitude and attitude hold (collectively known as "BFL" Guidance). Enter pitch, yaw, and roll burn attitude of zero deg each. Enter reboost duration in sec, press Execute, verify the DMT, and transfer to G1.

NOTE: because mated reboost arcs are relatively long compared to Orbiter-only burns, some DMT data are unreliable. In particular, PEG-7  $\Delta v$  components are a simple vector difference between TIG and burnout velocities expressed in the TIG state's LVLH frame. A better  $\Delta v$  parameter to check is the DMT's  $\Delta VM$  field. This is a step-by-step propulsive velocity increment summation over the burn arc performed during PFNI execution.

Similar procedures can be utilized to model reboost maneuvers in the TSA Global ISS ephemeris, G3. The only difference is that in step 2, a total weight WGL is used to restore G3 to ISS-only weight vice Orbiter-only weight.

CAUTION: TSA's PFNI model truncates geopotential terms beyond J2 and utilizes a '62 Standard atmosphere model. For this reason, TSA BFL burnout conditions will differ from TrS vent termination conditions, particularly for long mated reboosts. In general, a vent-based TrS reboost simulation is considered to be of higher fidelity than TSA's.

CAUTION: do not use the TSA ECT's MEP thruster to model finite burns. Previous MEP testing yields near-zero PFNI  $\Delta v$  regardless of MEP configuration and burn  $\Delta T$ .

### 3.7.2.13.2 TrS Reboost Modeling Procedures

Reboost modeling procedures on TrS are facilitated by UVW vent capability in the VIT/VTL.

- 1) Have NAV input a reboost entry to the Vent Initialization Table (VIT) for each planned reboost config, using Effective Thrust from the pertinent flight-specific FDO Console Handbook Annex (flight-derived thrust values computed by NAV should be utilized once these data become available). NAV should enter reboost vents to the VIT as UVW vents, each with the thrust value entirely in the V direction (U & W components = 0 lbf).

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- 2) Compute the total "stack" vehicle weight at TIG by adding the current (or projected) Orbiter weight plus the ISS weight. Enter a total weight WGL into desired ephemerides with a time tag 5 min prior to the reboost TIG. Enter another total weight WGL returning to the appropriate vehicle weight 5 min after the end of the reboost period. E1 and E2 should include reboost modeling.

NOTE: E3 does not require reboost modeling, as DFE can pull mated vectors from E1/E2 with the ISS vehicle code.

CAUTION: using V integration options in E3 will incorporate any VTL vent that occurs during the ephemeris time span. This could include vents intended only for the Orbiter. Standard procedure maintains E3 with DM integrator options so as to be configured for an unanticipated emergency undocking. If unusual circumstances call for reboost modeling in E3, this can be performed using VDM integrator options, appropriate WGLs to and from stack weight, and ephemeris start/stop times excluding vents in the VTL only intended for Orbiter ephemerides.

- 3) Have NAV insert the reboost vent into the VTL, TUP affected ephemerides, and notify TOPO as required.
- 4) Log any changes to VIT, VTL, WGL, and integrator options configurations. Transcribe any active non-standard configurations in the handover sheet to alert oncoming teams.

### 3.7.2.13.3 Reboost Execution Procedures

FAO and TOPO should be consulted during reboost planning to determine TIG and length of the maneuver. In flights with slim propellant margins, it may also be necessary to optimize reboost TIG with respect to ConUS steep deorbit  $\Delta v$ . As a pre-flight guess, reboosts centered on ascending node +2 min have been shown to nearly optimize subsequent steep deorbit  $\Delta v$  associated with ascending approaches to ConUS latitudes. Without consistently optimized reboost placement, deorbit costs may vary by ~20 fps as differing arguments of perigee and eccentricity prevail. Once a reboost plan has been modeled, TOPO can assess it to assure acceptable end conditions are achieved. GNC should also be advised of the plan in progress. Coordinate reboost planning with Pointing to facilitate Attitude Change Request (ACR) transmissions to MCC-M in a timely manner.

See Section 3.11.2.3 for reboost screening procedures. The screening box associated with reboosts requires flight-specific analysis and is documented in the appropriate FDO Console Handbook Annex.

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During the reboost itself, jet pulses appear on FDO Orbit Monitor DDDs. Another useful monitoring tool is found on the Master DNAV path Shuttle : Prop : Displays from Prop : Real Time Plots : RCS Jet Monitor. Select Pc plots for the +X jets. The plots will show a spike when an aft jet fires. The FDO Orbit Monitor display can be used to monitor energy growth during reboost. Select GPS for the onboard state and compare against Traj Server Ephemeris 1 ("M1" on the display). Good ground modeling in M1 will result in approximately constant  $\Delta a$  and  $\Delta \text{downtrack}$  throughout the reboost. The onboard IMUs do not accurately sense all reboost accelerations due to short pulse durations and heavy stack weight. Therefore, a 401xx uplink should be performed ASAP following termination of the reboost in order to keep the onboard state within accuracy limits.

**Section 3.7 Concludes On This Page**

## **FDO Console Handbook Section 3.8: Payload Deploys**

### **3.8 Payload Deploys**

This section details procedures and considerations associated with propulsive upper stages and other payloads deployed from the Space Shuttle cargo bay. Because safe separation must be achieved between the Orbiter and these payloads, some of which have potentially hazardous propulsion systems, a number of safety-critical activities are encountered even under routine scenarios. Ejectable subsatellites, usually manifested under the Get-Away Special (GAS) program, are the only recurring class of deployable payload not explicitly addressed in this section. Because subsatellite ejection mechanisms are required to provide safe relative motion in the event of all credible failures, Section 3.9 should be consulted in the event of a subsatellite ejection contingency requiring Orbiter translations.

This section presents FDO methods and operational activities for all upper stage deploys accomplished by the Space Shuttle Program (SSP). Upper stage deploy missions have not been attempted in recent years, and some information may be somewhat out of date. Information presented is considered current when the last deploy of this type was performed. Some displays may have changed but the methods have not. If a deploy mission is manifested in the future, the assigned Deploy FDO should carefully check the appropriate section to verify all displays, and software, and procedures are current.

#### **3.8.1 Introduction to Upper Stages**

The following subsections outline various missions flown by upper stages during the SSP. This discussion leads to an appreciation of what these missions share in common and how they differ.

##### **3.8.1.1 Purpose of Upper Stages**

Since the Orbiter is limited to altitudes generally less than 330 nm, any payload required to operate at a significantly higher altitude requires additional propulsive capability. This capability usually comes from an upper stage boosting the payload to the desired orbit. There are several types of upper stages the Orbiter has deployed in the past. Each has the capability of boosting payloads to substantially higher altitudes depending on payload requirements, payload weight, and any extra propulsive performance the payload may have from its own consumables.

##### **3.8.1.2 Satellites Requiring Upper Stages**

Throughout the SSP, numerous satellites have been deployed from the Orbiter and boosted to their final altitude by means of an upper stage. In most cases, these upper stages have been very reliable. Recent examples of satellites deployed with upper stages are the TDRS-F/IUS (STS-54), ACTS/TOS (STS-51), LAGEOS-II/IRIS (STS-52), and IntelSat-6/Orbus 215 (STS-49). All of these payloads required geosynchronous orbits well above Orbiter operating altitudes. In each case, the upper stage successfully raised altitude to the required range and deposited the satellite for operational use. There have also been several interplanetary payloads departing Earth with the aid of IUSs: Galileo (STS-34), Magellan (STS-30), and Ulysses (STS-41).

## **FDO Console Handbook Section 3.8: Payload Deploys**

### **3.8.1.3 Types of Upper Stages**

In general, there are three types of upper stage that have been deployed during the SSP.

- 1) Spin-Stabilized Upper Stage (SSUS)
- 2) Inertial Upper Stage (IUS)
- 3) Transfer Orbit Stage (TOS)

While upper stages are quite unique in terms of onboard software and operations, several identical aspects of each relate to FDO console procedures. These common aspects of upper stages will be covered in Section 3.8.2. Immediately following sections relate concepts specific to each upper stage.

#### **3.8.1.3.1 Spin-Stabilized Upper Stage (SSUS)**

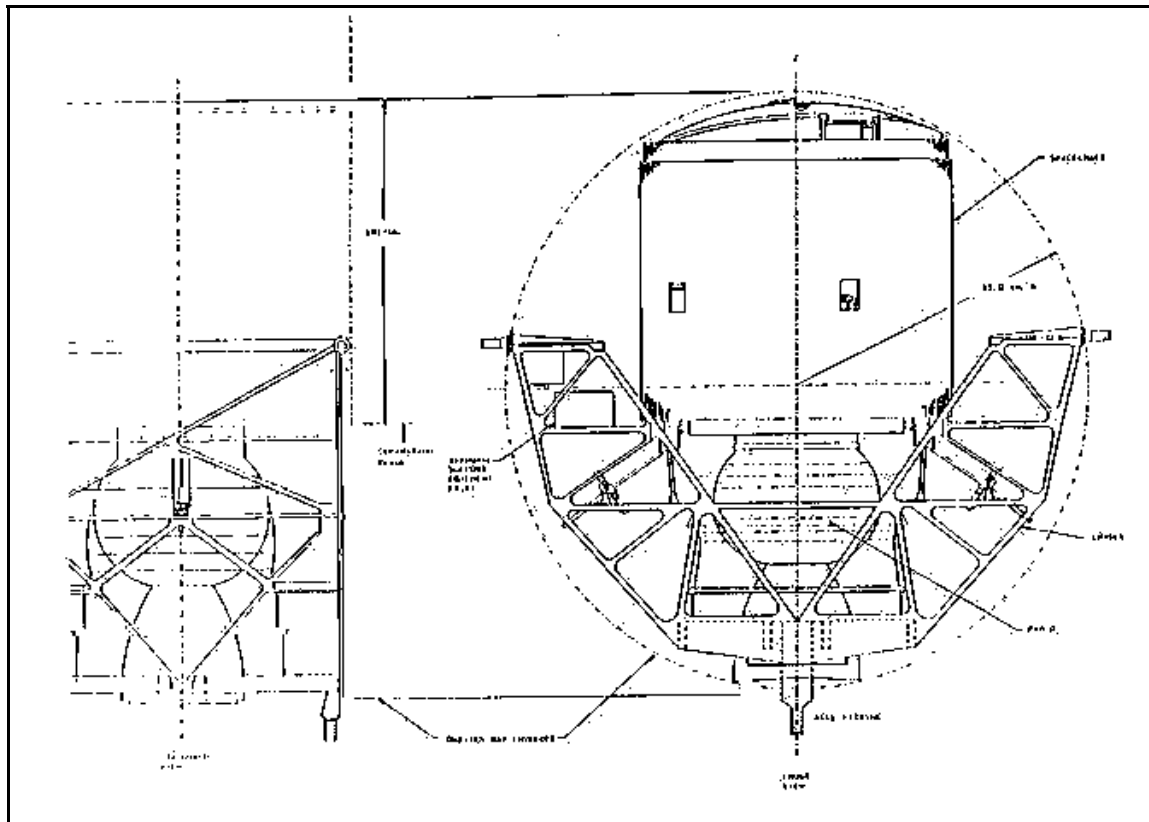
An upper stage classified as a SSUS will be one of three different specific types.

- 1) Payload Assist Module Delta class (PAM-D)
- 2) Payload Assist Module Delta II class (PAM-D2)
- 3) Frisbee

Each PAM (Figure 3.8.1.3.1-1) has a payload attached to it, while the Frisbee (Figure 3.8.1.3.1-2) has the solid rocket motor (SRM) built into the spacecraft. Each rotates around its longitudinal axis once it's deployed in order to maintain longitudinal stability (to prevent tumbling) and to aid in thermal conditioning of the stage and its payload. The PAM-D and PAM-D2 are deployed such that the rotating longitudinal axes are aligned with the Orbiter Z-axis, and the Frisbee is deployed with its longitudinal axis aligned with the Orbiter X-axis. All other SSUS aspects are identical. The last mission to deploy a SSUS was STS-52 in October 1992. LAGEOS II, a joint effort between NASA and the Italian Space Agency, was deployed on flight day two and boosted into an initial elliptical orbit by the Italian Research Interim Stage (IRIS), flying for first time. The LAGEOS II apogee kick motor later fired to circularize the spacecraft's orbit at an operational altitude of 3666 nm (6789 km).

After deploy, most FDO procedures are such that it does not matter which SSUS is being considered. The SSUS contains no guidance software. Its SRM will ignite exactly 45 minutes after deploy in the same inertial deploy attitude. The SRM burn occurs at the perigee of the resultant transfer orbit and therefore is often referred to as the Perigee Motor Firing (PMF), while the SRM itself is sometimes referred to as the Perigee Kick Motor (PKM).

## FDO Console Handbook Section 3.8: Payload Deploys

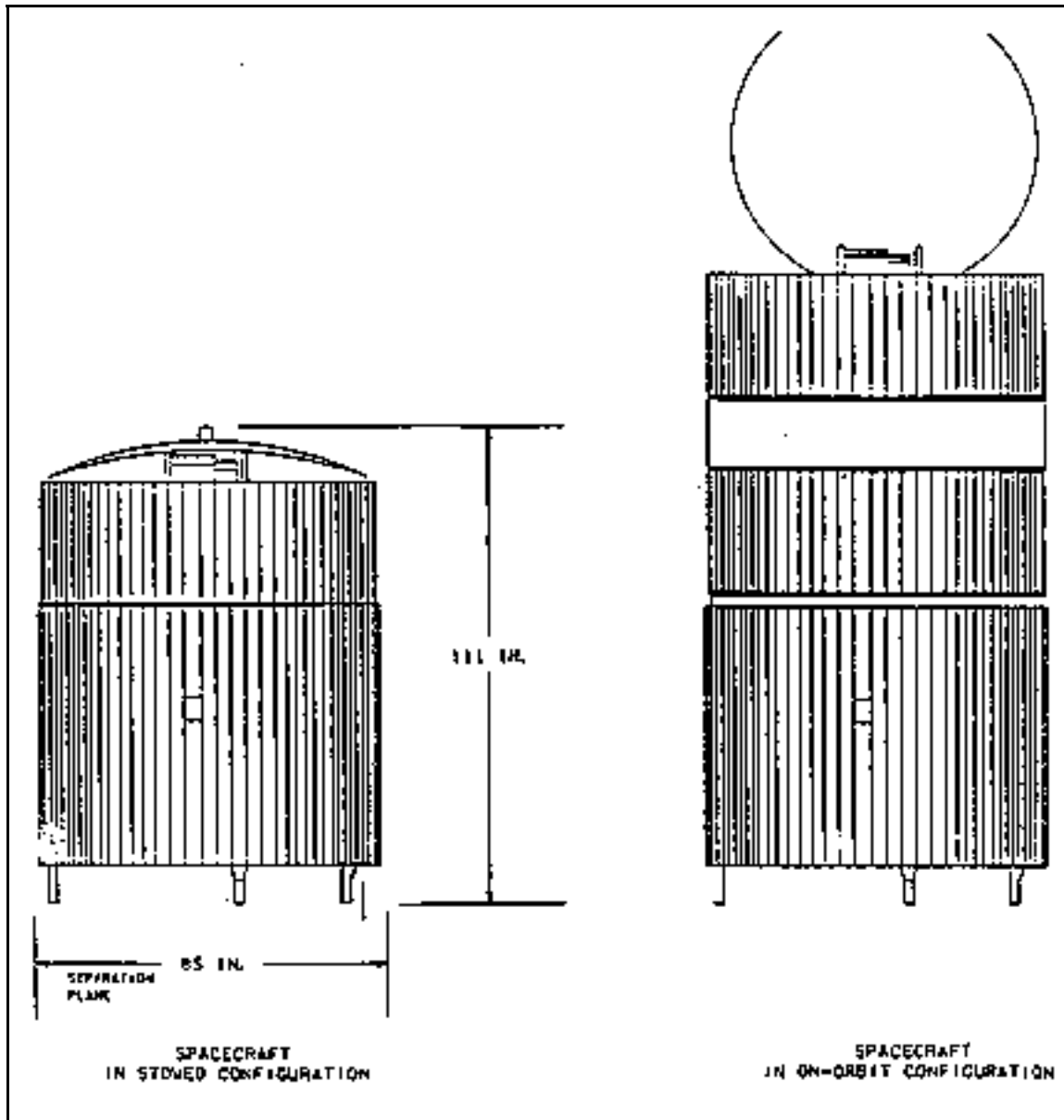


**Figure 3.8.1.3.1-1: Spacecraft Mounted on PAM-D Cradle**

The PAM-D upper stage can boost 2320 lbs into geosynchronous transfer orbit, and the PAM-D2 can boost up to 4100 lbs into geosynchronous transfer orbit. Spin-stabilized stages are generally smaller than the IUS and the TOS. Thus, up to 4 spin-stabilized deployables can be carried in on the same mission. In fact, on STS-61B, 3 PAMs were successfully deployed.

Both the PAM-D and PAM-D2 are attached to the Orbiter cradle assembly located in the payload bay. This assembly houses avionics and thermal control systems protecting the stage/payload from temperature extremes prior to deploy. PAMs also have a sunshield on top of the cradle assembly to protect the spacecraft from direct sunlight. Sunshields are open during launch because they cannot be closed with the payload bay doors closed. Each sunshield is closed as soon as practical after payload bay door opening. Frisbee deployables have heaters built in and therefore do not require the use of a sunshield. However, the Frisbee deployables are limited in the amount of solar and deep space exposure they can tolerate prior to deploy.

## FDO Console Handbook Section 3.8: Payload Deploys



**Figure 3.8.1.3.1-2 Hughes 376 Spacecraft**

The PKM firing attitude and TIG are constrained by customer-supplied Relative Right Ascension (RRA), Declination (DEC), and time bias (DT) values. The RRA is added to the injection node's right ascension to determine total right ascension. The injection node is defined by the M50 equator and the post-deploy payload trajectory with no PKM burn. Total right ascension, together with DEC, define the inertial target for pointing the spacecraft spin axis. The inertial target is then used to partially determine Orbiter deploy attitude. Secondary attitude constraints further constraining Orbiter attitude at deploy may be specified in the spacecraft Payload Integration Plan (PIP). The DT is defined as time relative to the injection node at PKM TIG. A positive DT is defined as being after injection node passage, and a negative DT is before the injection node passage. Deploy time is 45 minutes prior to the PMF. All angles (RA, RRA, DEC) are in degrees and based on the M50 coordinate system. DT is in seconds and is sometimes referred to as "offset time" or "the offset".



## FDO Console Handbook Section 3.8: Payload Deploys

Prior to flight, the customer documents best available RRA, DEC, and DT values in PIP Annex 2, Part 3. Due to the wide variety of customers, however, format and detail of the data provided varies considerably from payload to payload. In the past, customers have provided these parameters as a function of injection altitude. This is required for cases where nominal altitude is not achieved. The Lead FDO supplies an Orbiter state vector for computing pre-flight targeting based on the nominal trajectory. It's preferred to have targeting data supplied as a function of ascending node right ascension and altitude at injection time. These data cover cases like launch delays or slips. Figure 3.8.1.3.1-3 is an example of the matrix format used by many customers to provide targeting data.

**CAUTION:** Figure 3.8.1.3.1-3 contains example data for illustrative purposes only. Do not use these values for actual sim or flight operations.

Deploy Altitude (nm)						
RAAN	100	120	140	160	180	200
80	89.898	89.901	89.905	89.908	89.912	89.915
	25.094	22.038	19.638	17.731	16.154	14.743
	-53.060	-53.060	-53.060	-53.060	-53.060	-53.060
70	90.491	90.492	90.493	90.493	90.494	90.494
	25.080	22.023	19.623	17.716	16.139	14.728
	-44.173	-44.173	-44.173	-44.173	-44.173	-44.173
60	91.036	91.034	91.031	91.029	91.026	91.024
	25.060	22.004	19.604	17.697	16.120	14.709
	-36.469	-36.469	-36.469	-36.469	-36.469	-36.469
50	91.518	91.513	91.507	91.502	91.496	91.491
	25.037	21.981	19.580	17.674	16.096	14.685
	-29.946	-29.946	-29.946	-29.946	-29.946	-29.946
40	91.925	91.916	91.907	91.899	91.891	91.883
	25.009	21.953	18.897	17.646	16.037	14.626
	-24.607	-24.607	-24.607	-24.607	-24.607	-24.607
30	92.242	92.231	92.220	92.209	92.197	92.186
	24.978	21.924	19.521	17.614	16.037	14.626
	-20.449	-20.449	-20.449	-20.449	-20.449	-20.449
20	92.459	92.445	92.430	92.416	92.402	92.387
	24.942	21.885	19.485	17.578	16.001	14.590
	-17.475	-17.475	-17.475	-17.475	-17.475	-17.475
10	92.560	92.543	92.526	92.509	92.491	92.474
	24.902	21.845	19.445	17.538	15.961	14.550
	-15.682	-15.682	-15.682	-15.682	-15.682	-15.682
0	92.534	92.514	92.494	92.474	92.453	92.433
	24.857	21.801	19.401	17.494	15.917	14.506
	-15.072	-15.072	-15.072	-15.072	-15.072	-15.072

**Figure 3.8.1.3.1-3 Customer-Provided Pre-Launch Targeting Data**

It's also desirable to obtain targeting data in polynomial form, if possible. This makes it easier to compute targets in real time, and it yields more accurate results than linear interpolation from the matrix. Sample coefficients are illustrated in Figure 3.8.1.3.1-4 according to the following nomenclature.

$$RRA = a_0 + a_1x + a_2y + a_3xy + a_4y^2 + a_5y^3,$$

$$DEC = b_0 + b_1x + b_2y + b_3x^2 + b_4y^2 + b_5x^3, \text{ and}$$

$$DT = c_0 + c_1y + c_2y^2.$$

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In the foregoing,  $x$  is the deploy altitude in nm, and  $y$  is the M50 parking orbit ascending node right ascension.

Coefficient Subscript, $i$	RRA $a_i$	DEC $b_i$	DT $c_i$
0	92.635470	55.705262	-15.07224
1	-0.1011880E-02	-0.4790445	-0.1874030E-02
2	0.7952349E-02	0.4640801E-02	-0.5912212E-02
3	0.1485179E-04	0.2046070E-02	N/A
4	-0.7040969E-03	-0.2095600E-04	N/A
5	0.2176860E-05	-0.3404167E-05	N/A

Figure 3.8.1.3.1- Sample Polynomial Targeting Data

### 3.8.1.3.2 Inertial Upper Stage (IUS)

The Inertial Upper Stage (IUS) has been used extensively since STS-6 as the primary means of boosting very large payloads into geosynchronous orbits and interplanetary trajectories (see Figure 3.8.1.3.2-1). The last IUS deploy flight carried the Chandra X-Ray Observatory payload during STS-93 in July 1999. In general, the IUS has performance to deliver 5000 lbm into geosynchronous orbit. This capability is distinct from that offered by a SSUS, which only provide the payload with a geosynchronous *transfer* orbit. The IUS is built and operated by Boeing Aerospace Company (BAC) and is controlled by the Shuttle Operations Support Complex (SOSC) at the Air Force Consolidated Satellite Test Center (CSTC). The guidance software, as well as flight-specific Mission Data Loads (MDLs), are supplied by BAC along with technical support during real time mission operations. The FDO interface with CSTC is through a console position called SUNNYVALE ORBIT. Voice communication with SUNNYVALE ORBIT can be accomplished over the OPS SUPPORT loop. However, on recent IUS deploy flights, most communication has been over the OPS ACTION loop since OPS SUPPORT has considerable voice traffic.

# FDO Console Handbook Section 3.8: Payload Deploys

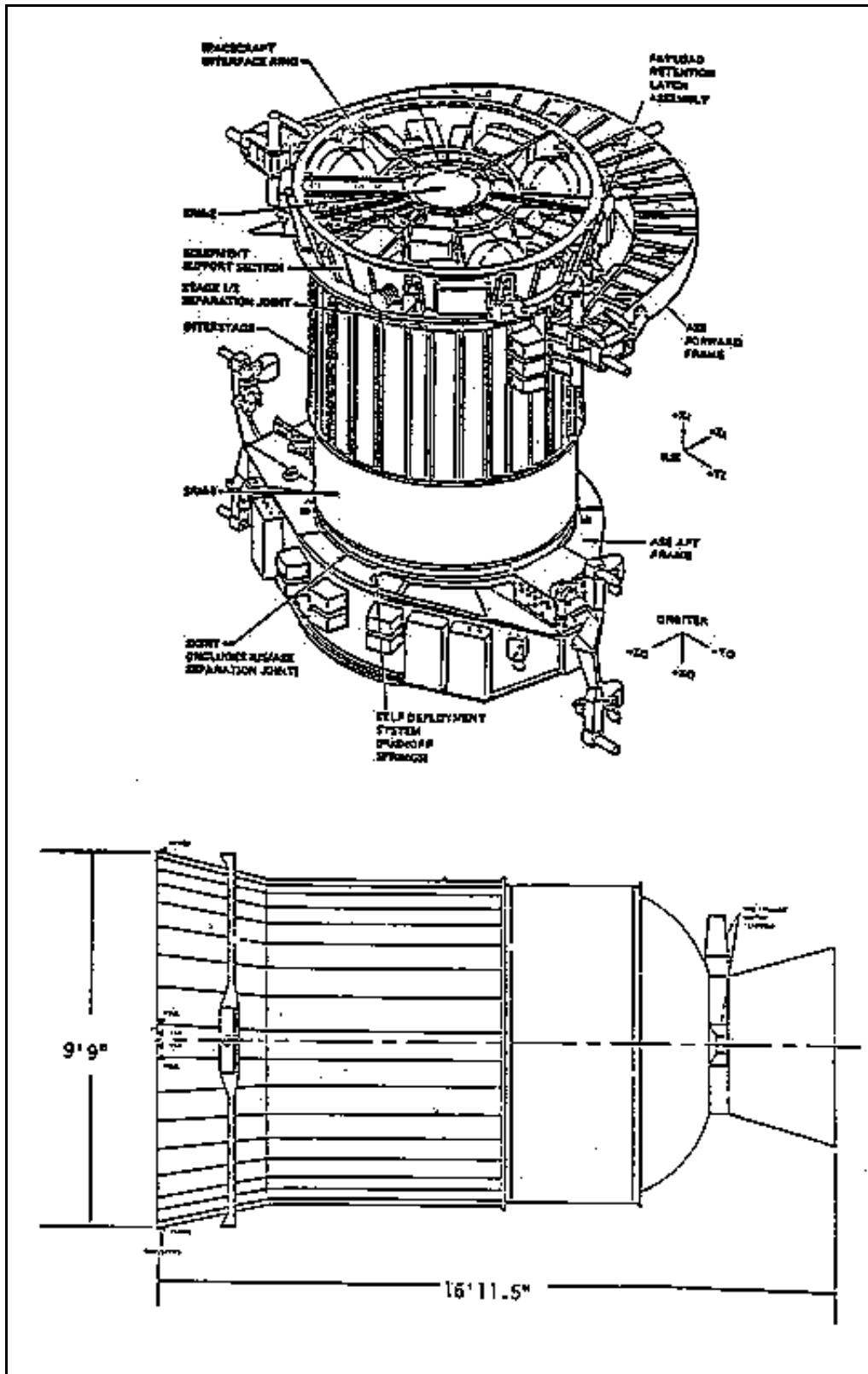


Figure 3.8.1.3.2-1: The Inertial Upper Stage

## FDO Console Handbook Section 3.8: Payload Deploys

The IUS is not deployed like the PAM or Frisbee. It slides out of an attachment ring called the tilt table. A vector normal to the ring plane at its center is also the IUS longitudinal axis before deploy. At launch, the normal is parallel to the Orbiter's X-Body axis at an elevation of 0°. At deploy, the normal is nominally pitched up to 58° elevation, but elevations as low as 40° are permissible. Springs in the attachment ring achieve an ejection velocity of approximately 0.4 fps at deploy. Crew deploy procedures use manual switches on a unique aft flight deck panel similar to the Frisbee. Although Orbiter GPCs deploy a PAM, crew actions are required to deploy an IUS.

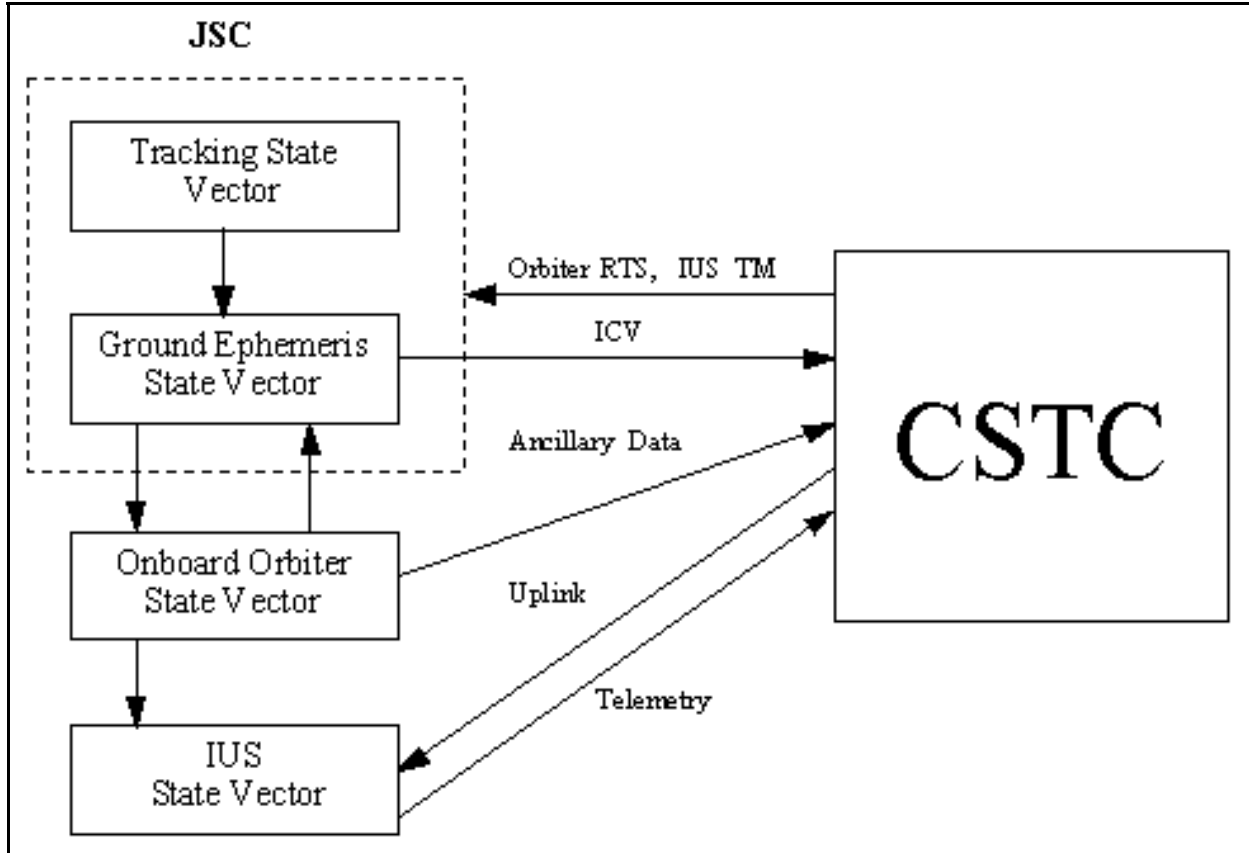
The IUS is quite sophisticated in that it has its own IMUs, its own state vector, and its own internal guidance known as gamma guidance. Gamma guidance is a closed loop system that computes an entire sequence of burns to the spacecraft's destination orbit based on trajectory control variables. Hence, the term "smart booster" can be applied to the IUS. FDO-specific procedures for deploying an IUS are therefore made easier by the spacecraft's ability to adapt to off-nominal situations, such as low altitude or elliptical orbits. Sophisticated avionics aboard IUS also provides insight into systems health and burn targeting.

Gamma guidance flexibility supports inhibiting SRM ignition in the event of a contingency. The inhibit command (F31) is called Master Safe. Once executed, current agreements with CSTC state that Master Safe recovery will be issued only from the ground and must be attempted within two orbits of Master Safe execution due to limited IUS battery lifetime. Three sequential commands are necessary to re-enable gamma guidance: F32 (RCS Enable), F34 (Master Safe Enable Ordnance Inhibit Reset), and F35 (Master Safe Ordnance Inhibit Reset). Once Master Safe is recovered, the IUS will perform its first SRM burn on the next ascending node, provided the F32 command is received by the IUS at least 14.8 min prior to that node. Subsequently, both the F34 and F35 commands must be received by the IUS at least 7.6 min prior to that node. In addition, deploy must have occurred at least 53.6 min prior to the injection node. This interval is the sum of earliest guidance initiate (deploy +46 min) and time required by the IUS slew to burn attitude maneuver (7.6 min).

**NOTE:** CSTC is responsible for all decisions concerning IUS state vector health. These decisions are supported by CSTC comparisons made between the FDO ground ephemeris, the onboard IUS state vector, and the onboard Orbiter state vector at least once per orbit during pre-deploy activities. FDO's responsibilities are limited to supplying CSTC with ground ephemeris state vectors and maintaining a backup state vector comparison capability. Coordination of comparison results or state vector transfers can be accomplished with SUNNYVALE ORBIT.

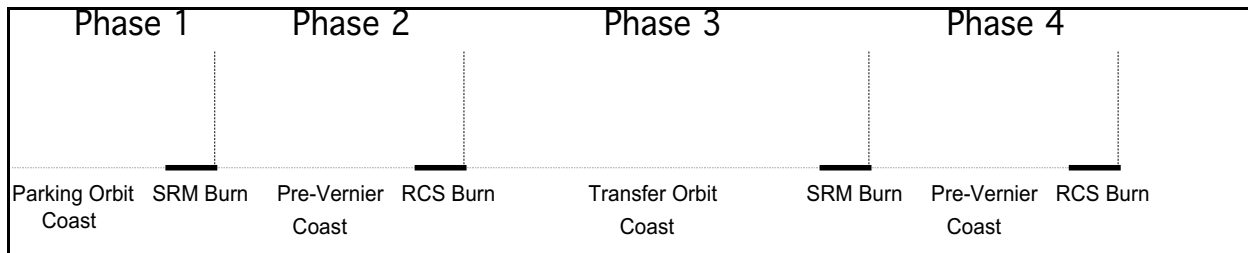
Figure 3.8.1.3.2-2 illustrates the flow of state vectors between FDO and CSTC. The IUS telemetry (TM) state vector and the Remote Tracking Site (RTS) uplink state vector are routed directly from IUS to CSTC and vice versa. Note that FDO does not have any direct insight into IUS state vector health. The Orbiter ancillary data set contains the onboard Orbiter state vector (UPP and FILT) and is shipped automatically to CSTC from JSC whenever downlink is available. Inter-Center Vectors (ICVs) are routed from JSC to CSTC in two ways. First, CSTC receives the automatic queue ICV every GMT hour like GSFC and the rest of the world. Second, manual queue state vectors are sent to the CSTC according to a schedule agreed upon pre-mission and documented in the Operations Support Timeline (OST).

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**Figure 3.8.1.3.2-2: IUS State Vector Flow**

Trajectory control variables used by IUS are the impulsive TIG of each burn and three direction cosines defining the thrust unit vector of each burn. To achieve geosynchronous orbit, IUS computes a four-burn sequence. Two major burns use SRMs at perigee and apogee of the transfer orbit. An RCS trim burn follows each major burn to remove any trajectory dispersions. For the purpose of control variable selection, the IUS trajectory is broken down into a series of phases (Figure 3.8.1.3.2-3). A phase is defined as a coast arc, together with a subsequent burn arc.



**Figure 3.8.1.3.2-3: IUS Trajectory Phases**

During each phase of the trajectory, gamma guidance uses a unique combination of pre-selected control variables. Figure 3.8.1.3.2-4 shows a typical combination of control variables used by gamma guidance during each phase.

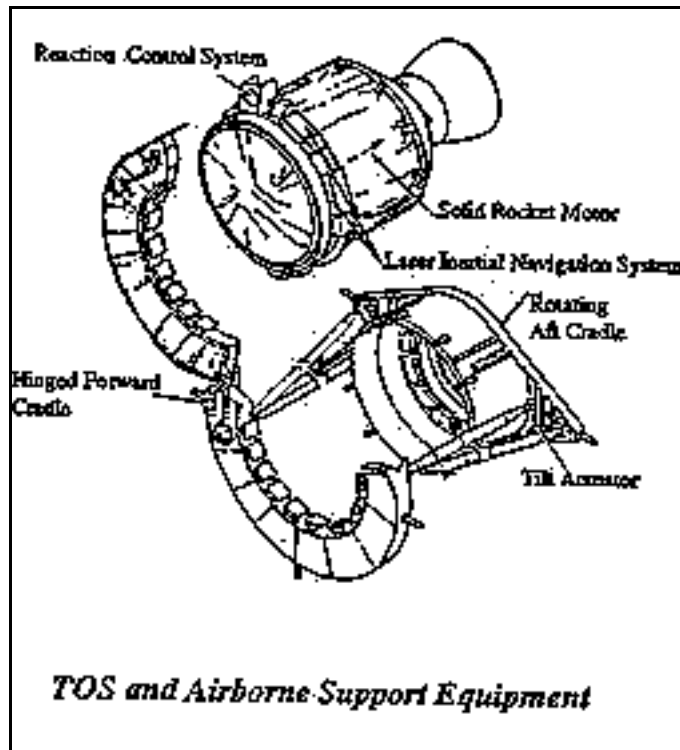
## FDO Console Handbook Section 3.8: Payload Deploys

Phase	Trajectory Arc	Trajectory Control Variables						
		1st SRM		1st RCS	2nd SRM		2nd RCS	
		t <sub>11</sub>	DVS <sub>1</sub>	DVR <sub>1</sub>	t <sub>12</sub>	DVS <sub>2</sub>	t <sub>13</sub>	DVR <sub>2</sub>
1	Parking Orbit Coast 1st SRM Burn	x	x		x	x		
			x		x	x		
2	Pre-Vernier Coast 1st RCS Burn			x	x	x		
				x	x	x		
3	Transfer Orbit Coast 2nd SRM Burn				x	x		x
						x	x	x
4	Pre-Vernier Coast 2nd RCS Burn						x	x
								x

**Figure 3.8.1.3.2-4: Gamma Guidance Trajectory Control Variables**

### 3.8.1.3.3 Transfer Orbit Stage (TOS)

TOS is the latest upper stage to be deployed by the Shuttle (Figure 3.8.1.3.3-1). The Space Systems Project Office at MSFC in Huntsville, Alabama manages the TOS program for NASA. That role involves insuring TOS compliance with flight safety requirements and overall mission requirements, including those for integration with the launch vehicle and satellite.



**Figure 3.8.1.3.3-1: TOS and Airborne Support Equipment**

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TOS has some, but not necessarily the best, characteristics of SSUS and IUS vehicles. These attributes require FDO to interact with the customer more than would be the case with SSUS and IUS deploys. Like IUS, TOS is used primarily for boosting large payloads into geosynchronous orbits or interplanetary trajectories. The first operational TOS launch was on an Expendable Launch Vehicle (ELV), which boosted the first Mars observatory into an interplanetary trajectory. In September 1992, STS-51 deployed the Advanced Communication Technology Satellite (ACTS) into a super-synchronous orbit prior to its geosynchronous insertion a few months later.

Built by Lockheed-Martin Astronautics Group in Denver, Colorado for Orbital Sciences Corporation in Dulles, Virginia, TOS is a single stage, solid propellant rocket system. TOS is constructed primarily of high-strength aluminum alloy and weighs 20780 lbs including propellant. Overall TOS dimensions are approximately 11 ft long and 7.5 ft in diameter. Portions of both the satellite and TOS are covered with gold foil multi-layered insulation for thermal protection from the sun. Major elements of the TOS system are a solid rocket main propulsion system, a navigation and guidance system, a reaction control system used to adjust TOS attitude or local pointing, and an airborne support equipment cradle which holds TOS and its payload in the cargo bay and facilitates deploy from the Orbiter.

The Orbus-21 solid rocket motor main propulsion system, manufactured by United Technologies Chemical Systems Division in San Jose, California, gives primary thrust for approximately 110 sec during TOS powered flight. While providing 59000 lbs of thrust to inject the satellite into its transfer orbit, the motor uses 18013 lbs of hydroxyl terminated polybutadiene (HTPB) solid rocket propellant. Pitch and yaw are controlled during the burn by gimbaling the solid rocket motor nozzle with two thrust vector control actuators.

TOS guidance and control avionics are based on a laser inertial navigation system manufactured by Honeywell, Inc. in Clearwater, Florida. It acts as the vehicle's brain, sensing orientation while maintaining the proper attitude and trajectory. All TOS operations are performed autonomously with no ground commanding required. The guidance system uses laser gyroscopes with no moving parts, thus reducing chances for malfunctions. A telemetry and encoder unit records performance data from all on-board electronics and sends it to ground controllers at KSC.

The reaction control system thruster assembly, manufactured by UTC/Hamilton Standard Division in Windsor Locks, Connecticut, correctly positions TOS and its payload based on information from the Laser Inertial Navigation System (LINS). This three-axis control system uses 12 small maneuvering rockets, with decomposed hydrazine as their propellant, to fine-tune TOS orientation before solid rocket motor ignition. The reaction control system also slowly turns the TOS and its payload for thermal control to avoid overheating from the sun. Before TOS separates from its payload, the reaction control system makes final attitude adjustments.

A TOS upper stage has been deployed only once during the SSP. This was accomplished during STS-51 in September 1993, when the TOS successfully delivered the Advanced Communication and Technology Satellite (ACTS) payload to super-synchronous orbit.

### **3.8.2 Generic Upper Stage Deploy Concepts**

All three types of upper stage have some degree of similarity in FDO procedures, from pre-mission planning to deploy shift execution. This section presents aspects of FDO

## **FDO Console Handbook Section 3.8: Payload Deploys**

procedures common to all. The concepts will be presented in generic form with specific data and upper stage information confined to subsequent sections.

### **3.8.2.1 Pre-Mission Planning and Customer Interface**

The Lead FDO will normally consult with the customer's trajectory analyst prior to the mission. This is done to exchange data and discuss any issues with trajectory implications. The Lead FDO usually provides nominal pre-deploy Orbiter and post-deploy upper stage state vectors so the analyst can compute targeting data and assess expected upper stage performance to predict the resulting trajectory. ATO vectors are sometimes requested from the Lead FDO in order to assess degraded upper stage performance and consequences arising from low-altitude deploys.

In consultation with NAV, the Lead FDO generates deploy tracking timelines for the mission. Timelines must be generated for the nominal, backup, and any contingency cases for each deployable payload. During tracking timeline development, the Lead FDO should verify all attitude maneuvers scheduled by the Lead FAO occur either before or after the final tracking arc (see Section 3.8.2.3). This "quiet arc" must also exclude maneuvers for IMU aligns and COAS calibrations. Having all attitude maneuvers executed prior to the final tracking arc detects and corrects any dispersion introduced by performing attitude maneuvers. However, if maneuvers or venting must be executed between the final tracking arc and deploy, it's best to schedule them as close to deploy as possible. This strategy will minimize the amount of time during which perturbations can propagate. Venting effects may be estimated by comparing two predicted deploy vectors. One vector is modeled accounting for the vent, and the other ignores it.

The Lead FDO may also be asked to provide Flight Data File inputs, which include nominal state vectors and DMTs, so POINTING can compute a pre-mission separation burn attitude and deploy attitude. These values will be input to the ATL, which will be published in the Flight Plan and Deploy Checklist. Usually, one state vector will be required for the Orbiter and spacecraft at SRM ignition.

The Lead FDO also plays a trajectory point-of-contact role for the customer analyst should any questions arise concerning real time procedures. Most customers have little real time experience and need to be informed regarding MOD operations during Shuttle missions. The Lead FDO is responsible for providing technical direction to the customer in Shuttle trajectory operations and insures appropriate documentation reflects all trajectory requirements. The Operational Support Timeline (OST), Joint Operations Integration Plan (JOIP), flight rules, and crew checklists need to reflect all pre-mission trajectory coordination. Historically, the Lead FDO is in contact with the customer analyst regularly, starting several months or more than a year prior to the first Joint Integrated Sim (JIS). This interface is maintained through post flight reconstruction.

### **3.8.2.2 Deploy Opportunity Constraints**

Any upper stage deploy is a crew-intensive procedure requiring thorough coordination between the crew, ground controllers, and the customer. In order for the crew and deployed vehicle to perform optimally, all constraints must be satisfied prior to deploy. Some constraints are obvious. For example, deploy procedures are not attempted during crew sleep and generally not carried into the pre-sleep and post-sleep periods. Other constraints imposed by MOD include the FDO's computation period and tracking timeline.



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Sufficient Orbiter tracking prior to deploy assures optimum upper stage performance. In general, deploy prior to Orbit 6 or less than 4 orbits after another deploy or major burn is to be avoided. Such deploys shorten or eliminate time available to evaluate deploy computations, which may be based on degraded state vector accuracy.

Constraints imposed by the customer may include Right Ascension of the Ascending Node (RAAN) versus time and longitude limits. RAAN data serve two purposes. First, they protect spacecraft thermal and attitude sensor interference limits. Second, they prevent long spacecraft eclipses while in the transfer orbit. For example, the Hughes 376 spacecraft has a 30-min eclipse duration limit due to battery power limitations. The customer usually supplies RAAN data in the True Equator and Equinox of epoch (TEE) coordinate system. Epochs appear in month/day/year format, and each has a time tag of midnight GMT.

The customer may also supply longitude limits. These longitude bands define an Earth-relative range of positions where the SRM burn can occur. When longitude constraints are satisfied, the resultant transfer orbit ground track will be optimum for spacecraft tracking, telemetry, and commanding prior to circularization at the geosynchronous orbit.

Customer constraints on deploy opportunities are usually documented in PIP Annex 2 and in the Ground Rules and Constraints. These constraints are combined in Flight Design's launch window product, which the Lead FDO then submits to the flight-specific flight rules annex. The launch window combines customer data with SSP lit landing constraints and other payload constraints from the flight. Figure 3.8.2.2-1 shows the launch window for STS-41D.

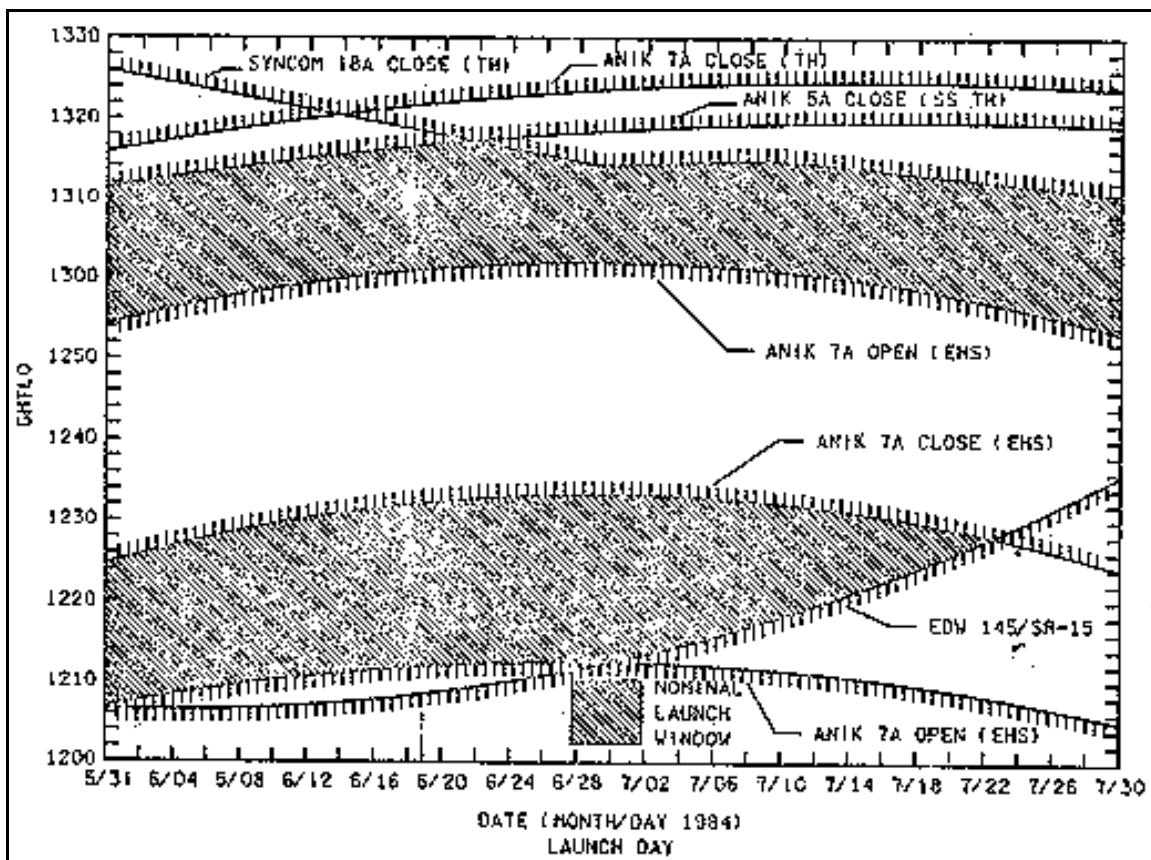


Figure 3.8.2.2-1 STS-41D Launch Window

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### **3.8.2.3 Tracking Arc**

An ideal tracking arc spans a time interval during which ground-based tracking can determine a very accurate Orbiter state vector. There are no attitude maneuvers or burns planned, and the Orbiter is very quiescent in order to give the highest quality tracking. In general, the tracking arc should be greater than one orbit in duration. It should contain at least one C-Band radar performing orbit determination on consecutive orbits. Longer arcs usually produce higher state vector confidence. Obviously, FDO would like to have the longest possible arc. However, payload pre-deploy activities require some attitude maneuvers for payload checks and IMU aligns. Sometimes, stars of opportunity can provide an IMU align without a dedicated attitude maneuver. In this case, the tracking arc can be extended to take in that much more data, thus improving state vector quality. For example, STS-54's actual tracking arc was extended to ASC 03, providing an additional 15 minutes worth of S-Band tracking and one additional C-Band site.

On occasion, tracking may be broken into two independent tracking arcs. Unavoidable attitude maneuvers during a period of time usually reserved for high quality tracking may result in this strategy. Situations requiring deviation from the traditional tracking arc are Attitude Matching Update (AMU) sequences for IUS or preliminary deploy targeting for the PAM. In these cases, coordination with NAV is essential to provide the best state vector after each tracking arc. Usually, the Lead FDO will coordinate with the Lead NAV and the customer pre-flight to determine optimum tracking arcs yielding the best state vectors possible in accord with payload requirements and constraints.

### **3.8.2.4 Deploy Attitude**

Generally, the Orbiter's deploy attitude must be chosen so that the sun is not within 20 degrees of the crew line of sight during payload viewing post-deploy. Attitude is also a function of the upper stage being deployed. For example, PAMs do not perform any attitude maneuvers post-deploy, remaining in inertial hold due to their gyroscopic spin. Therefore, PAM deploy attitude must also be its PMF attitude. While a PAM would perform a retrograde PMF at deploy, by the time it traverses a 180° geocentric arc to its real PKM TIG, the actual thrust direction is posigrade. The IUS and TOS have their own internal guidance and therefore can maneuver to the correct SRM burn attitude post deploy. This capability permits a deploy attitude which shades the payload bay from direct sunlight, providing thermally benign conditions to the payload as well as clear viewing to the crew.

### **3.8.2.5 Deploy Window**

Just as with deploy attitude, deploy window is a function of the upper stage being used. The deploy window is defined as the interval, commencing the nominal deploy time, in which the payload can be deployed and achieve a nominal transfer orbit. In general, an upper stage whose SRM ignition is tied to a timer activated at deploy has a very short window, usually less than 30 sec. An upper stage whose SRM ignition is driven by internal guidance has a window approaching 8 min.

## FDO Console Handbook Section 3.8: Payload Deploys

### 3.8.2.6 Spring Ejection

At deploy, all upper stage payloads receive initial velocity with respect to the Orbiter known as spring ejection  $\Delta v$ . Magnitude of this  $\Delta v$  is a payload-specific and varies from 0.4 fps to 2.5 fps. Modeling spring ejection  $\Delta v$  at the time of payload deploy is important for FDO to determine safe relative motion in the post-deploy time frame.

### 3.8.2.7 Separation Sequence

Safe relative motion is the key driver in separation sequence design. Defined as the payload spring eject, plus any Orbiter separation burn(s), the separation sequence must satisfy several constraints. Above all, the Orbiter must be behind the payload's Rbar at SRM ignition, and the expected Orbiter tile erosion from the SRM plume must be acceptable. Maximum tile erosion allowable over the lifetime of an Orbiter has been fixed at 10%. It has also been assumed that an Orbiter would deploy 135 SRM-equipped payloads over its 100-flight lifetime. Therefore, 10% tile erosion/lifetime, divided by 135 SRM firings/lifetime, equals 0.074% tile erosion allowable per SRM firing. Tile erosion of 0.074% is usually referred to as the "1X" limit, which is considered a nominal value for separation planning purposes. It is also generally accepted that the nominal separation sequence protects the Orbiter from an SRM explosion at SRM ignition. The explosion limit is considered to be a range of 10 nm, regardless of upper stage.

The separation sequence must allow the payload to be visible by the crew from ejection until a range of 200 ft. In addition, the Orbiter should never have a negative range rate at ranges less than 1000 ft. In the past, separation profiles were designed so that the payload would be outside the  $10^{-4}$  psf OMS plume pressure contour during an OMS separation burn. This results in acceptable levels of contamination and dynamic pressure on the payload.

In propellant-limited situations, the nominal separation burn (nom sep) can be reduced to a minimum separation (min sep)  $\Delta V$ . Min sep thrust direction is unchanged from nom sep's: only  $\Delta V$  magnitude is reduced. Although downmoding to min sep does consume less propellant, other trajectory tradeoffs must be evaluated. First, the min sep  $\Delta V$  magnitude must place the Orbiter beyond the 10X (0.74% erosion) SRM plume contour by PKM TIG. In this case, the requirement of getting beyond the 10 nm SRM explosion range by PKM TIG is waived. A fortuitous exception arises in association IUS min sep. If both deploy and separation from an IUS occur on time, min sep  $\Delta V$  will satisfy both the 10X erosion constraint as well as the 10 nm explosion limit.

### 3.8.2.8 FRCS Separation Burns

Nominally, separation burns from an upper stage are performed using one or both OMS engines. In cases where two out of three deorbit systems (LOMS, ROMS, and PX4) are failed, flight rules prohibit use of the remaining system for any purpose other than deorbit. Since FRCS does not have deorbit capability and usually has enough propellant to achieve min sep, upper stage deploy checklists contain procedures to properly execute this downmode. Since flight software does not support selection of FRCS thrusters with PEG-7 guidance, these procedures are essential. Regardless of upper stage context, the procedures are quite similar.

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Once the upper stage is deployed, the Orbiter will maneuver to the proper burn attitude for a FRCS translation. This attitude is requested through UNIVERSAL POINTING by selecting TGT ID +2 (earth center) and BODY VECTOR +5 (crew-defined pointing vector), then entering Pitch, Yaw, and Omicron values from the checklist. Once the Orbiter is maneuvering to the correct FRCS attitude, the crew will load PEG-7 targets for the burn. After the targets are loaded (ITEM 22 EXEC) and the timer is initiated (ITEM 23 EXEC), the burn is performed in the UNIVERSAL POINTING attitude ignoring MNVR EXEC attitude. The advantage of using UNIVERSAL POINTING for attitude control is the Orbiter maintains LVLH attitude for min sep with no need to maneuver in the event of TIG slips (see Section 3.8.2.9). The only time the Orbiter will go to inertial DAP mode is approximately 30 sec prior to the burn. In the event TIG is postponed inside this 30-sec mark, a corresponding attitude maneuver will need to be performed once a new TIG is selected.

### **3.8.2.9 Separation Burn TIG Slips**

Separation TIG slips may occur if system and/or payload problems prohibit performing the burn at the nominal time. A separation slip does not affect the payload, but it may compromise crew and Orbiter safety if the delay is long enough to violate separation burn constraints described in Section 3.8.2.7. Generally, the burn can be slipped as long as the separation achieved results in the Orbiter being behind the payload Rbar at SRM ignition with less than 10X tile erosion. In some cases, there may be no TIG slip allowed for min sep, since the min sep  $\Delta v$  was derived assuming the burn was on time. This is the case with all PAM deploys.

### **3.8.2.10 Payload Viewing Attitude**

To aid the crew in visually acquiring the payload post deploy, the Orbiter will maneuver to a -Z target track. The deploy checklist calls for this maneuver at deploy +18 min, even though it will most likely be executed as soon as possible after the Orbiter separation burn.

### **3.8.2.11 Window Protect Attitude**

The Orbiter's windows and RCS thrusters are vulnerable to damage from high velocity aluminum oxide particles in the SRM exhaust plume. Consequently, the Orbiter maneuvers to a window protect attitude (WPA) prior to SRM ignition. Relative motion of the IUS during the PMF causes the apparent point of origin of the exhaust particles (the radiant) to move with respect to the Orbiter. Figure 3.8.2.11-1 indicates exhaust particle impingement with respect to the Orbiter's +X axis should remain between pitch angles of -27° and -48°. To satisfy this requirement, Orbiter window protect attitude has UNIVERSAL POINTING inputs as follows.

- 1) TGT ID +1 (rendezvous target)
- 2) BODY VECTOR +5 (crew-defined pointing vector)
- 3) Pitch = 320°, Yaw = 0°, Omicron = 0°

## FDO Console Handbook Section 3.8: Payload Deploys

These inputs effectively pitch the Orbiter Body +X axis up 40° from the SRM radiant, which lies in the Orbiter Body X/Z plane.

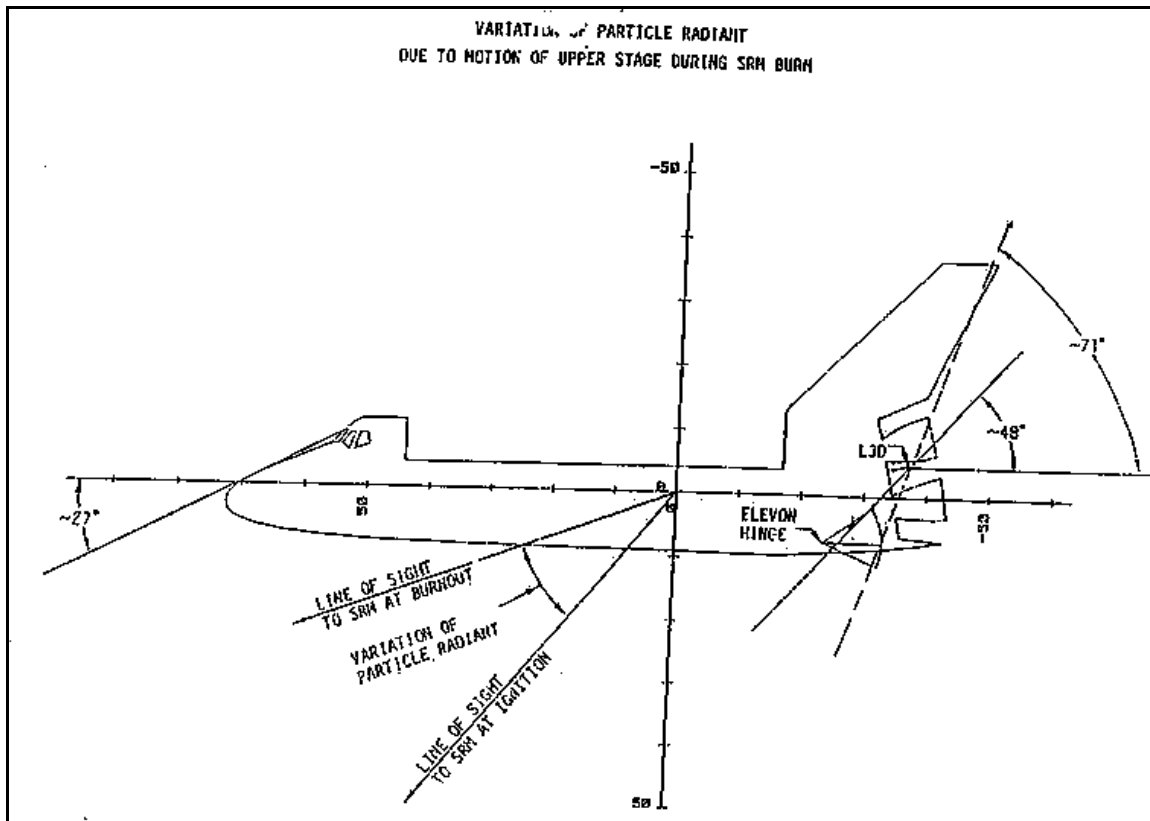


Figure 3.8.2.11-1: Window Protect Attitude

Rendezvous NAV is used by UNIVERSAL POINTING to automatically maneuver the Orbiter to WPA. The omicron (OM) will be adjusted by POINTING as required in real time to keep the SRM plume in the Orbiter's X-Z plane during the burn. At SRM TIG, the crew will put the Orbiter into inertial attitude hold for the duration of the SRM burn. The STS-54 deploy checklist maintained WPA for 10 min.

### 3.8.3 Spin Stabilized Upper Stage (SSUS) Deploy Procedures

It has been many years since the last SSUS deploy (STS-52 in October, 1992). Much of the information in this section reflects procedures, displays, and nomenclature used up to that point. Today, some displays and applications have been modified or abandoned entirely. For example, FDO DEPLOY COMP, MOC-based SUPERSIGHTER, and even the HP-9000 are obsolete since it is unlikely that the SSP will ever deploy PAMs again. However, procedures documented in this section are applicable to a wide variety of payloads still on the SSP manifest.

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### 3.8.3.1 Standard SSUS Concepts

<b>Deploy Attitude</b>	+X (Frisbee) or -Z (PAM) axis pointed toward inertial target
<b>Deploy Window</b>	2 sec
<b>Spring Ejection <math>\Delta V</math></b>	2.5 fps (PAM-D), 2.0 fps (PAM-D2), 1.3 fps (Frisbee).
<b>Separation TIG</b>	Deploy +15 minutes
<b>Nom Sep Targets</b>	$\Delta V_x=10.6$ , $\Delta V_y=0.0$ , $\Delta V_z=-3.0$ (PAM-D) $\Delta V_x=13.5$ , $\Delta V_y=0.0$ , $\Delta V_z=-3.9$ (PAM-D2) $\Delta V_x=17.3$ , $\Delta V_y=0.0$ , $\Delta V_z=-5.0$ (Frisbee - Syncom)
<b>Min Sep Targets</b>	$\Delta V_x=1.9$ , $\Delta V_y=0.0$ , $\Delta V_z=-0.55$ (PAM-D) $\Delta V_x=2.9$ , $\Delta V_y=0.0$ , $\Delta V_z=-0.80$ (PAM-D2) $\Delta V_x=6.0$ , $\Delta V_y=5.8$ , $\Delta V_z=-1.65$ (Frisbee - Syncom)
<b>Separation TIG Slip</b>	20 minutes (Nom Sep) 0 minutes (Min Sep)

### 3.8.3.2 SSUS-Specific Concepts

The nominal FDO deploy timeline includes a preliminary and a final computation cycle. Preliminary computation is based on post-insertion tracking data obtained at approximately deploy minus 6 hours and deploy minus 4 hours, depending on network acquisitions. Forty minutes are allotted to perform computation cycles. The Payload Operations Control Center (POCC) will receive a copy of preliminary deploy computation cycle results with one hour to evaluate these data. Any POCC updates to deploy targeting parameters are used by FDO in the final computation cycle. These parameters are discussed in Section 3.8.3.5.

Final tracking data are obtained between start times for the two computation cycles, and the Orbiter ground ephemeris is updated. Results of the final computation are also sent to the POCC. Final results are only evaluated by the POCC to make a GO/No-GO deploy call, since there is no time allocated for further target updates.

### 3.8.3.3 SSUS Deploy Timeline

Figure 3.8.3.3-1 shows the generic SSUS FDO deploy computation timeline. As mentioned in the note, event times are given with respect to deploy and are approximate. Times between successive events will always remain the same. Final computation completion will always be 50 min after LOS at the final tracking pass. After completion of the final computation, the Deploy PAD and Separation Burn PAD are generated and read up to the crew. See Figure 3.8.3.3-2 for an example Deploy PAD.

The Separation Burn PAD is a standard translation maneuver PAD and is documented in detail by Section 3.7. Separation burn targets are uplinked at the time the PAD is read up to the crew. A target state vector for the payload post-deploy is uplinked also. If a one-orbit-late deploy opportunity exists, a backup computation cycle will be performed after the final computation is completed.

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Event	Time (Deploy -h:mm)	Comment
Preliminary tracking arc begins	-6:00	
Preliminary computation cycle begins	-3:50	Based on preliminary tracking
POCC evaluation and final tracking arc begin	-3:10	Preliminary comp results sent to POCC
Final computation cycle begins	-2:10	Final comp based on final tracking
PADs to crew	-1:30	Crew enters deploy checklist
Backup deploy computation cycle begins (if required)	-1:20	
Rndz NAV enable	-1:00	
Maneuver to deploy attitude	-0:40	PAM deploy (-0:20 for a Frisbee)
Deploy	0:00	
Maneuver to sep burn attitude	+0:03	
Sep burn TIG	+0:15	Nom or min sep
Maneuver to payload viewing attitude	+0:18	-ZLV, +XVV
Maneuver to window protect attitude	+0:29	
Actual deploy data to POCC	+0:30	Actual data reflect actual deploy attitude and time
DAP inertial	+0:45	
SRM ignition	+0:45	

**Figure 3.8.3.3-1: Nominal FDO SSUS Deploy Timeline**

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Telesat **DEPLOY PAD, 3 3 0 DEPLOY**

**DEPLOY TIME**

MET            002 / 00 : 42 : 44

GMT-DISP      245 / 13 : 24 : 34

17 GMT-TABL   (\*)21    216    274

**DEPLOY ATT**

5R            113 - 77

6P            099 - 82

7Y            286 - 49

JSC Form 826 (Rev Mar 85) NASA/SC

**Figure 3.8.3.3-2 SSUS Deploy PAD**

A Table Maintenance Block Update (TMBU) request form must also be filled out for PAM deploys, but it's not required for Frisbee deploys. The GMT of deploy, converted to sec since start of the year, and the deployed spacecraft identifier are sent up by this TMBU. Figure 3.8.3.3-3 gives a TMBU request form example. Measurement Stimulus Identifiers (MSIDs) for these parameters always remain the same. The old value for each parameter is either the Initial Load (ILOAD) value in the case of the first deploy of a flight (86400 for deploy time and 1 for the ID) or the value of these numbers from the previous deploy. Page number on the TMBU request form is references the Deploy Checklist page citing these parameters. Only data appearing in the example need to be filled out by FDO on the TMBU request form. The spacecraft ID can be found in the Deploy Checklist in the INITIATE DEPLOY COUNTDOWN section. TMBU request forms are sent to the Data Processing Systems (DPS) backroom position DPS SUPPORT.



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T M B U   R E Q U E S T									
<input type="checkbox"/> M3 <input type="checkbox"/> M4		APPROVED BY E. P. Gonzalez			OF APPROVAL FDO		DATE 2 1 5 2 0 1 4		
NO.	HEH	SET	ELSP	LIB CASE	OLD PARC	NEW PARC	SEE	REFERENCE DATA NAME	PAGE NO.
1	192120507			C	1	2	SSUS TO		1-2
2	192120510			C	86000	27375831	SSUS DEPLOY TIME		1,3-2
3									
4									
5									
6									
7									
8									
9									
10									

DATA SET	DEPT	PARAMETER NO	NEW VALUE
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			

ATTENTION: THIS FLIGHT DAY.      REQ'D BY  
 STATUS:      UNIT      M/L      DATE      TWR NO  
 REASON:      PROVIDES IDENTITY AND DEPLOY TIME OF SATELLITE.

JSC Form 452 (Rev 04-88) MCSA-152

**Figure 3.8.3.3-3: TMBU Request Form Example**

### 3.8.3.4 SSUS Real Time Data Transfer and PADs

FDO distributes several items following a deploy computation. These will be discussed in detail here. One product of each deploy computation is the FDO DEPLOY COMP form (see Figure 3.8.3.4-1). This form arises from a display containing a deployed spacecraft state vector at the injection node (except in the "actual" case) using M50 Cartesian (in meters and meters/sec), spherical, and Keplerian orbit elements. It also contains deploy time, inertial deploy attitude, separation burn data, and the targets used. All data on the display come from other displays that must be properly configured. The separation burn must be in DMT 1. The spring ejection impulse must be in DMT 2. The spacecraft injection node vector (without the SRM burn), rounded to the nearest second, must be in CHECKOUT MONITOR. The Orbiter deploy attitude must be in SUPERSIGHTER.

**NOTE:** the FDO DEPLOY COMP display is obsolete and no longer available in MCC. A new version of this display may need to be re-developed if the need arises on future flights.

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FDO DEPLOY COMP		#0431:CH092
C/D MON M50 SV EV4 000 L/D GMT 243:12:41:59.00 SV GMT 245:14:10:37.33 SV MET 2:01:28:47.33 X 6484431.35 M Y -1644530.59 M Z 8.75 M VX 1683.550539 MPS VY 6578.922675 MPS VZ 3677.965434 MPS <hr/> A 3615.7955 NM E 0.002141 ITEI 28.48825 DEG WP <sub>M50</sub> 297.90734 DEG RAAN <sub>M50</sub> 345.76900 DEG RA <sub>M50</sub> 152.63300 DEG N 62.09282 DEG M 61.87616 DEG <hr/> V 25337.7708 FPS T 0.108306 DEG φ <sub>M50</sub> 61.5599 DEG φ <sub>C</sub> 0.185467 DEG λ 152.632996 DEG R 3612.15890 NM HA 174.242 NM HP 160.440 NM	DMT2 DEPLOY/SPRING ΔV 42XE01FC MET 2:00:42:48.00 GMT 21216278 245:13:24:38.00 S/C ID 25GMT 243:20:40:18.025 M50 ΔVX 0.606 PEG7 ΔVX-002.4 ΔVY 2.342 ΔVY 000.6 ΔVZ 0.632 ΔVZ-000.1 <hr/> SUPERSIGHTER ADI ATTITUDES ATT MET 2:00:42:48.00 DEPLOY R 114.29 R 276.77 +X P 100.66 -Z P 75.50 Y 286.10 Y 14.64 <hr/> DMT1 SEPARATION MNVR IORE01FC MET 2:00:57:48.00 EMT 245:13:39:38.00 LVLH LX R 176.9 PEG7 ΔVX 010.6 P 0.2 ΔVY 000.0 Y -11.0 ΔVZ-003.0 <hr/> COMPUTATION CYCLE PRELIM _____ BACKUP _____ FINAL <input checked="" type="checkbox"/> ACT DEPLOY _____ TGTS USED _____ TGTS UPDATE _____ RRA <u>89.73</u> RRA _____ DEC <u>14.94</u> DEC _____ OFFSET <u>-59.4</u> OFFSET _____ FDO <u>E.P. [Signature]</u> POCC REP _____	

Figure 3.8.3.4-1: FDO Deploy Comp Display

After each deploy computation, copies of the FDO DEPLOY COMP form are sent to the customer. Before transmission, FDO must sign the form to certify all data are valid. One signed copy is retained at the FDO Console, and the signed original is routed to PAYLOADS for transmission to the appropriate payload representative. The preliminary computation cycle's original copy will be returned to FDO after POCC evaluation and will have target updates annotated on it. Distribution for the deploy PAD, sep PAD, and TMBU request are as follows.

Deploy PAD	Sep Burn PAD	TMBU Request
FD	FD	FD
FDO	FDO	FDO
CAPCOM	CAPCOM	DPS
FAO	FAO	DPS SUP
GNC	PROP	

### 3.8.3.5 SSUS Deploy Computations

FDO computations are an iterative process. Once the M50 node has been determined, geocentric distance to the Orbiter at that time (and the semi-major axis in some cases) is used to compute targets in the first iteration. A signed DT is added to the nodal crossing

## FDO Console Handbook Section 3.8: Payload Deploys

time to determine PKM TIG. Finally, deploy time is computed by subtracting 45 minutes from the PKM TIG.

Based on M50 pointing constraints (injection node RAAN, RRA, and DEC), M50  $\Delta v$  imparted to the spacecraft by the spring ejection impulse is computed. Typical spring  $\Delta v$  magnitudes are 2.5 fps for PAM-Ds, 2.0 fps for PAM-D2s, and 1.3 fps for Frisbee deploys. These values vary from spacecraft to spacecraft and must be obtained pre-mission. An ephemeris for the spacecraft is then updated in the second iteration, accounting for the spring ejection impulse. Finally, nodal crossing time, PKM TIG, and deploy time are re-computed using the updated ephemeris. With this second iteration, the deploy time is considered to be converged.

The FDO deploy computation proceeds as follows.

- 1) An Orbiter state vector is used by the first iteration to approximate M50 injection node time. For ascending node injections, a good first guess of this time can be obtained from the TRAJ DIGITALS display (MSK 0470) by executing a requested orbit. For descending node opportunities, adding half the orbit period to the time of the previous ascending node time will be a good initial guess. Another means of determining nodal passage time is CHECKOUT MONITOR run with an appropriate threshold time and latitude stop option of 0.
- 2) Iterate on the requested time of an Orbiter M50 CHECKOUT MONITOR until the Z component is nearly zero. When near the node, divide Z by VZ to get the  $\Delta T$  correction required to the current CHECKOUT MONITOR. For a 28.5° inclination orbit,  $|Z| < 60$  ft (20 m) is within 0.005 sec of the node and is a good convergence criterion. Once converged, record the injection node time and its right ascension (RAm50) on the Deploy Data Worksheet (see Section 3.8.3.10).
- 3) Computed inertial targets by using the pre-mission value of DEC and by adding RRA to RAm50 to get the actual RA target value. RRA varies as function of payload. This step is only performed in the preliminary computation cycle or for a contingency which allows only a final computation cycle.
- 4) Determine the PKM TIG. This is accomplished by adding the signed DT offset time to the injection node time determined in Step 2.
- 5) Determine the deploy time for this iteration. It's exactly 45 min prior to PKM TIG. Enter results from Steps 4 and 5 on the Deploy Data Worksheet.
- 6) Anchor the payload ephemeris off an Orbiter vector or ephemeris a few minutes prior to deploy. An ephemeris length of 6 hours is typically used with DM integrator options and the payload's drag profile.
- 7a) For a PAM deploy, use the Excel spreadsheet RADEC. Inputs required are the RAm50, RRA, DEC, and ejection spring  $\Delta v$  magnitude. Outputs are the M50 ejection spring  $\Delta v$  components. The equations used by RADEC follow.

$$\begin{aligned}\Delta V_x &= \Delta v \cos (R_{Am50} + RRA) \cos DEC \\ \Delta V_y &= \Delta v \sin (R_{Am50} + RRA) \cos DEC \\ \Delta V_z &= \Delta v \sin DEC\end{aligned}$$

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- 7b) For a Frisbee deploy, run the notebook program FRISDV. Inputs required are RAm50, RRA, DEC, spring  $\Delta v$  magnitude, and the Orbiter M50 state vector at deploy. FRISDV will then compute M50 spring ejection  $\Delta v$  components and the RA and DEC of the state vector's angular momentum vector.

**NOTE:** the program or spreadsheet FRISDV cannot be located as of CY 2003. It will need to be re-developed if its use is required on future flights.

**CAUTION:** verify use of RAm50 in FRISDV. Use of an *ascending* node right ascension with a *descending* injection node will produce a retrograde PKM burn.

- 8) Direct input an M50 spring ejection burn into the payload ephemeris at deploy time using components computed in Step 7. Use PX2 or PX4 thrusters and display the burn in DMT 2.
- 9) Iterate on M50 nodal crossing time, as in Step 2, using the payload ephemeris. If injection node time equals that from the previous iteration, the solution has converged. If so, proceed to Step 10. Otherwise, another iteration is required. Record the new node time and its RA on the worksheet. Complete steps 4, 5, 7, and 8 once again.

**NOTE:** in most cases, Step 7 results do not change from one iteration to the next. Consequently, only burn TIG changes are expected in Step 8 reiteration.

- 10) Deploy time must now be rounded to the nearest second. Change the spring ejection burn to reflect the new time.
- 11) After TIG is corrected in Step 10, request another CHECKOUT MONITOR at the injection node time.
- 12) Inform GNC and POINTING of the injection node RA from the last iteration, and have POINTING use SUPERSIGHTER to compute payload deploy attitude. FDO should check POINTING's inputs to verify the attitude is correct. First, verify SUPERSIGHTER MODE = 6. This can be checked on the display near the top in the middle of the page. For all cases (PAMs and Frisbees), Target 1 (in the middle left part of the display) should be the payload spin axis target. Figures 3.8.3.5-1 and 3.8.3.5-2 are examples of SUPERSIGHTER for PAM and Frisbee deploy attitude computations. Annotated on each example are inputs FDO should check. The primary target (Target 1) is the sum of injection node RA and RRA to yield target RA. The DEC is equal to the payload target DEC.

**NOTE:** SUPERSIGHTER displays shown in Figures 3.8.3.5-1 and 3.8.3.5-2 are no longer operationally obtainable by FDO. They must be sent to the FDO workstation from the POINTING workstation in order to be viewed. SUPERSIGHTER display format currently differs from that illustrated below. Section 3.8.4.5 has the latest known SUPERSIGHTER display format.

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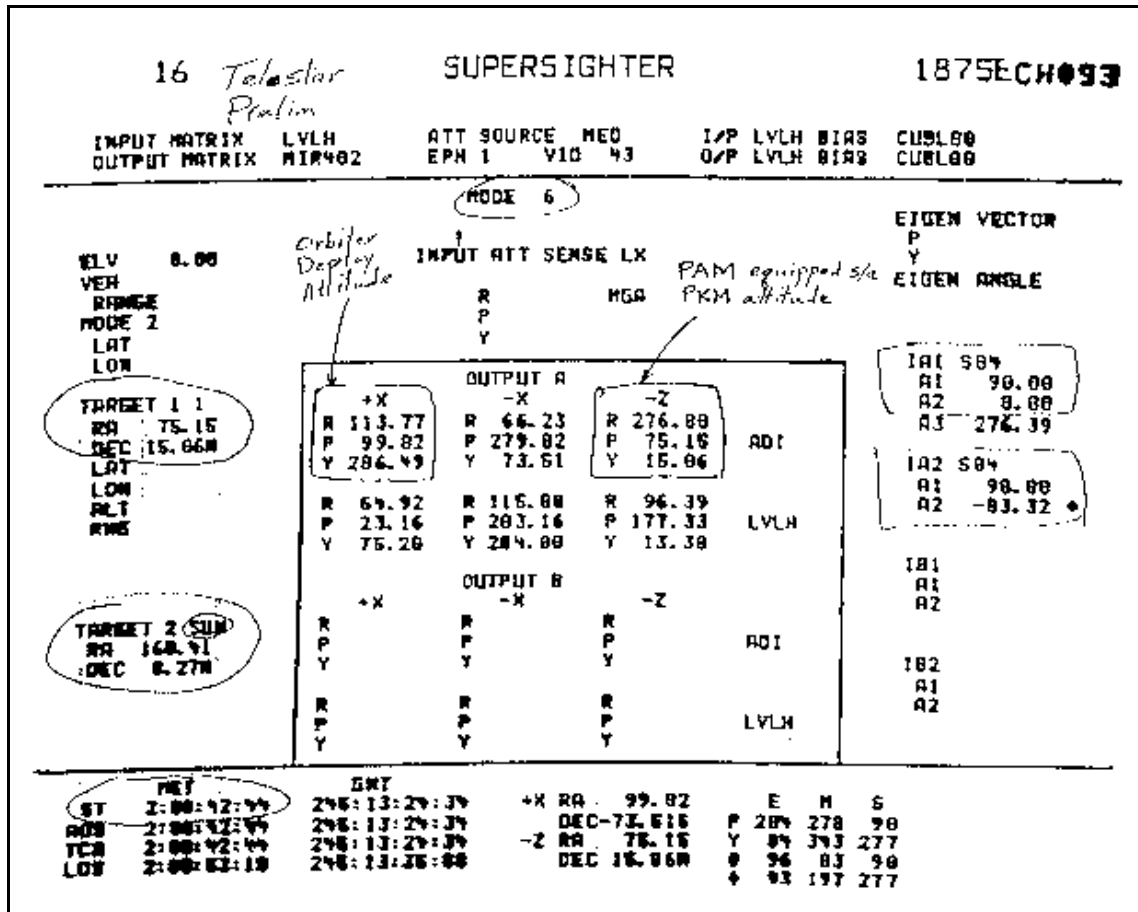


Figure 3.8.3.5-1: SUPERSIGHTER Display for PAM Deploy Attitude

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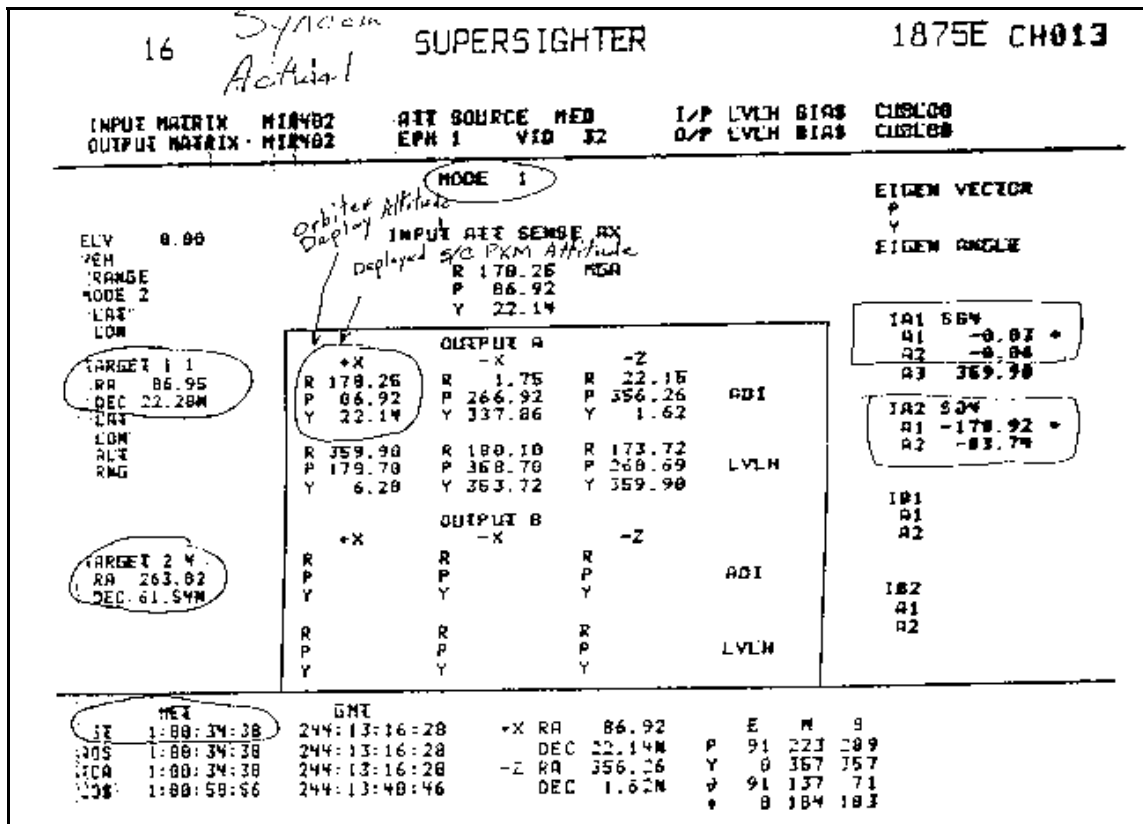


Figure 3.8.3.5-2: SUPERSIGHTER Display for Frisbee Deploy Attitude

Instrument Axis 1 (IA1) defines the axis pointing to Target 1, which is output in the middle right of the SUPERSIGHTER display. The instrument axis is defined by a pitch and yaw (in that order) from the Orbiter +X Body axis. A1 and A2 are the pitch and yaw respectively. For a Frisbee deploy, the payload's spin axis is parallel to the Orbiter's +X axis and therefore the values for A1 and A2 should be 0.0.

For a PAM deploy, the payload's spin axis should be parallel to the Orbiter's -Z axis. Therefore, the A1 value should be 90.0, and the A2 value should be 0.0. In all cases, IA2 will be used to constrain orientation about the Orbiter's target-pointing axis. For example, the Orbiter's -Z axis in a PAM deploy will be pointed at the payload's spin axis target. However, the Orbiter can satisfy this requirement and still yaw 360° about the -Z axis. Therefore, a secondary constraint is required to confine the yaw (or roll in the case of Frisbee deploy) axis.

IA2 is chosen to be perpendicular to the primary IA1 and is pointed at a secondary target (Target 2) in order to constrain the third axis. The combination of IA2 and Target 2 make up the secondary attitude constraint. IA2 is defined in the same way as IA1, with a pitch and yaw from the Orbiter's +X Body axis. The IA2 pitch (A1) and yaw (A2) are directly under SUPERSIGHTER's IA2 heading. For a PAM deploy, the Orbiter's -Y Body axis is usually the secondary axis, and it's pointed towards the Sun. For a Frisbee deploy, the Orbiter's -Y axis is also usually the secondary axis, and it's pointed at the RA and DEC of the deploy state vector's angular momentum vector (+H).

A specific payload may have unique secondary attitude constraints differing from those above. Such constraints would be stated in the payload's PIP. Secondary

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attitude constraints are important because they may shade the payload prior to deploy. Inertial Orbiter deploy attitude is under the +X column and in the ADI row. This is the same attitude that appears on the FDO DEPLOY COMP display. The attitude is displayed in a roll- pitch-yaw order even though the Euler sequence is pitch-yaw-roll. For a PAM deploy, the -Z sense ADI (M50) attitude would be used to model PKM burn attitude with standard M thrusters (aligned with Orbiter Body +X). For a Frisbee deploy, the +X sense ADI attitude would be used to model PKM burn attitude with standard M thrusters.

- 13) Subtract the payload weight from the Orbiter's ephemeris at deploy time and update OMS trims to reflect the post-deploy Orbiter CG.
- 14) For a PAM deploy, input the separation burn into the Orbiter ephemeris. Nominal TIG is deploy +15 min. Nominal PEG-7 targets for PAMs follow.

<u>PAM-D</u>	<u>PAM-D2</u>
$\Delta V_x = 10.6$	$\Delta V_x = 13.5$
$\Delta V_y = 0.0$	$\Delta V_y = 0.0$
$\Delta V_z = -3.0$	$\Delta V_z = -3.9$
RSS = 11.0 fps	RSS = 14.0 fps

Display the burn in DMT 1.

- 15) For a Frisbee deploy, input the separation burn into the Orbiter ephemeris. Nominal TIG is deploy +15 min. Nominal PEG-7 targets are dependent on the booster. In the case of a SYNCOM with a TU-882 booster, the nominal targets follow.

<u>SYNCOM (TU-882)</u>
$\Delta V_x = 17.3$
$\Delta V_y = 0.0$
$\Delta V_z = -5.0$
RSS = 18.0 fps

Display the burn in DMT 1.

- 16) Now that the sep burn and deploy have been modeled, have POINTING compute WPA. Make sure that POINTING computes both the Omicron for the prime attitude (which uses the Orbiter's Rndz NAV as target) and the pitch, yaw, and Omicron for the backup attitude (which uses a geocenter target). If, for some reason, the plan calls for using a min sep, the modeled sep burn should reflect this plan.
- 17) Make a minimum of 3 copies of the FDO DEPLOY COMP. Verify all data are correct. The left side should have the injection node state vector assuming no PKM. The top right corner should have deploy time and spring  $\Delta v$ . The middle right should have the separation burn data. Fill in the targets used, check off the appropriate comp cycle, and sign the 3 copies. Keep one copy, send one to POINTING, and give one to PAYLOADS.
- 18) If this is the preliminary comp cycle, you are now finished. Otherwise, Deploy and Sep PADs need to be generated. Also, if this is a PAM deploy, a TMBU request must be filled out. For a Frisbee deploy, GMT-DISP and GMT-TABL on the Deploy PAD are not required.

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- 19) If this is the final comp cycle, and if a one orbit late opportunity exists, the whole process must be repeated for the backup case. A wave-off to a one orbit late deploy is assumed. Therefore, another Orbiter ephemeris without the nominal deploy and sep must be paired with a dedicated payload ephemeris. The PADs, deploy comp hardcopies, and TMBU request will be distributed only if the primary deploy opportunity is canceled.
- 20) This step is required post-deploy. FDO will "confirm" the spring ejection burn based on the actual deploy attitude and time. POINTING and GNC will compute actual payload spin axis RA and DEC based on actual Orbiter deploy attitude. GNC is the prime source for these data. FDO uses them to compute "confirmation"  $\Delta v$ . After confirming ejection, have DYNAMICS display the burnout of the spring ejection burn in the C/O Monitor. Have POINTING display the actual deploy in SUPERSIGHTER so all actual data register on the FDO DEPLOY COMP display. Make 3 copies of the display and fill in the actual RRA, DEC, and DT. Sign and distribute the copies.

### 3.8.3.6 SSUS Relative Motion

Figures 3.8.3.6-1 and 3.8.3.6-2 illustrate relative motion of PAM and Frisbee upper stages after deploy and separation on large and small scales, respectively. These trajectories assume deploy and separation occur as designed and do not include any deploy/TIG slips effects or off nominal burn durations. Min sep cases are noticeably different and are included in Figures 3.8.3.6-3 and 3.8.3.6-4.

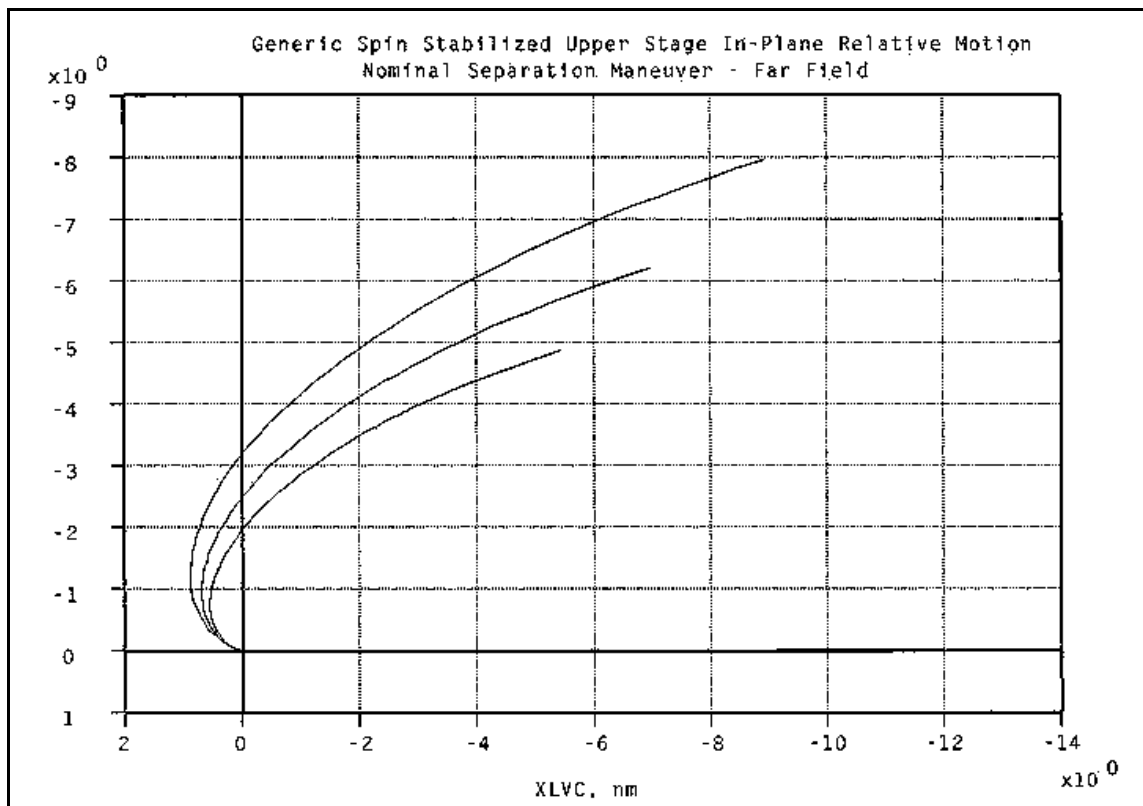


Figure 3.8.3.6-1: SSUS Nom Sep Relative Motion (Far Field)



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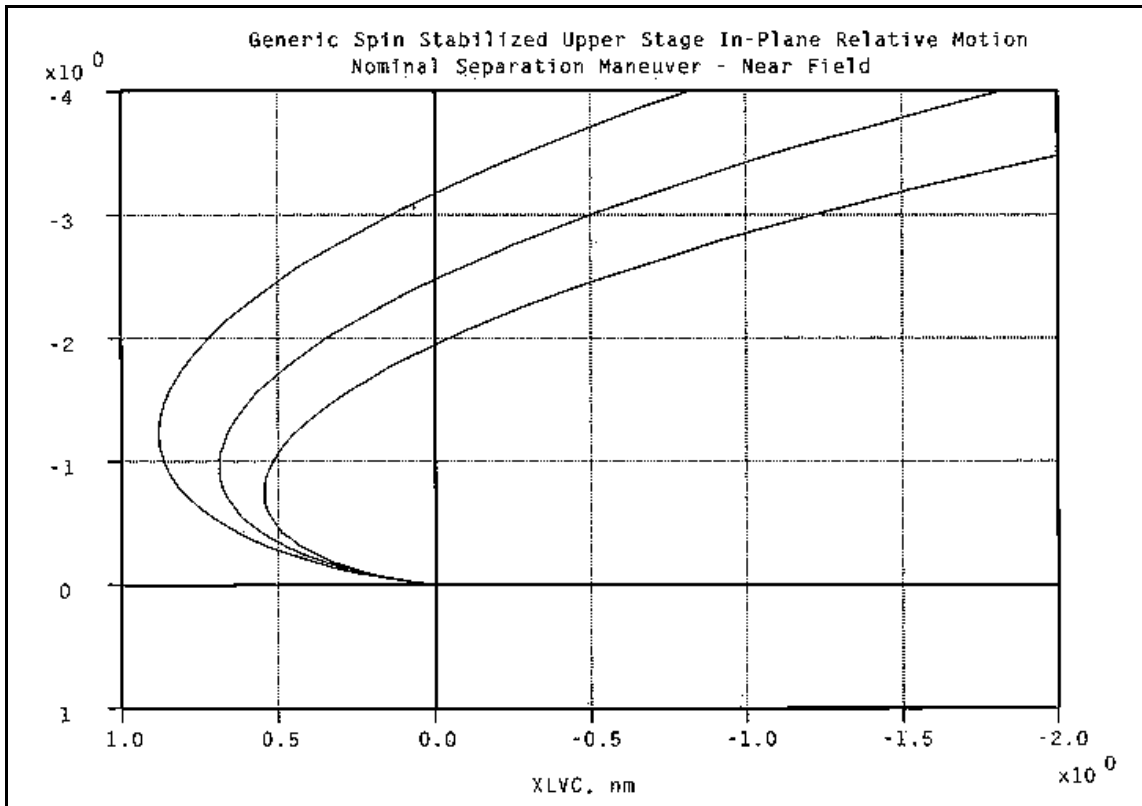


Figure 3.8.3.6-2: SSUS Nom Sep Relative Motion (Near Field)

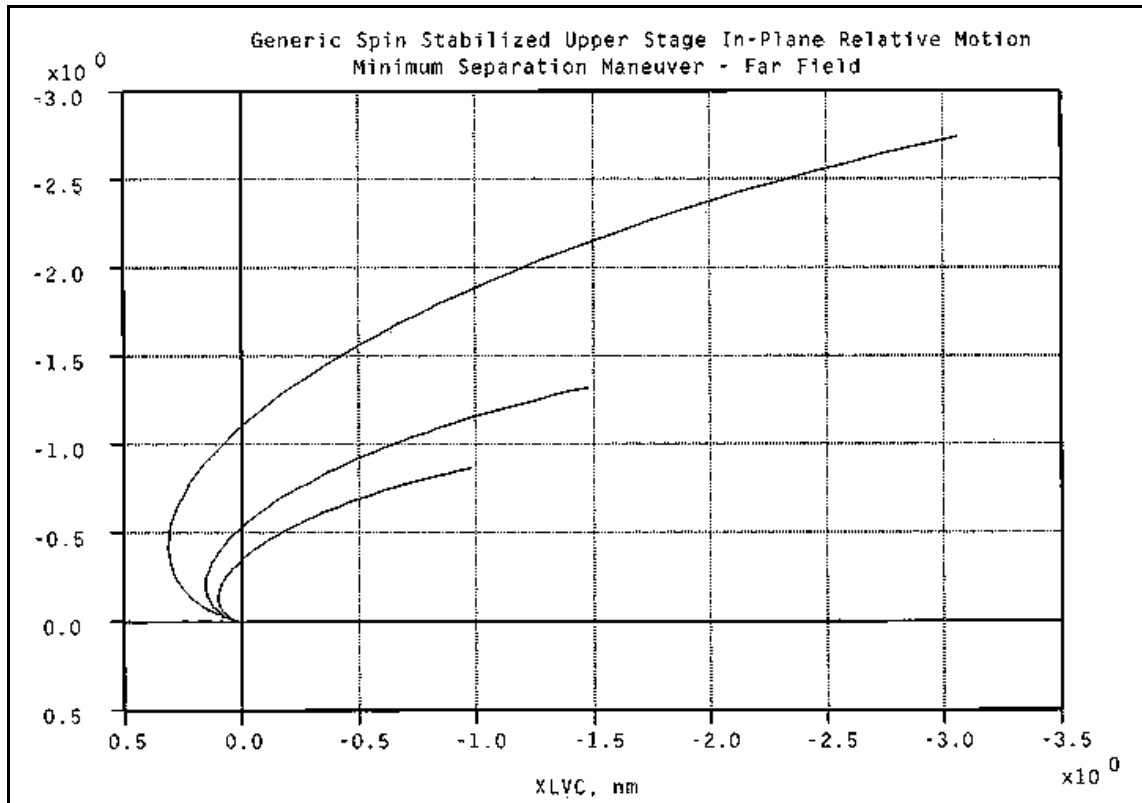
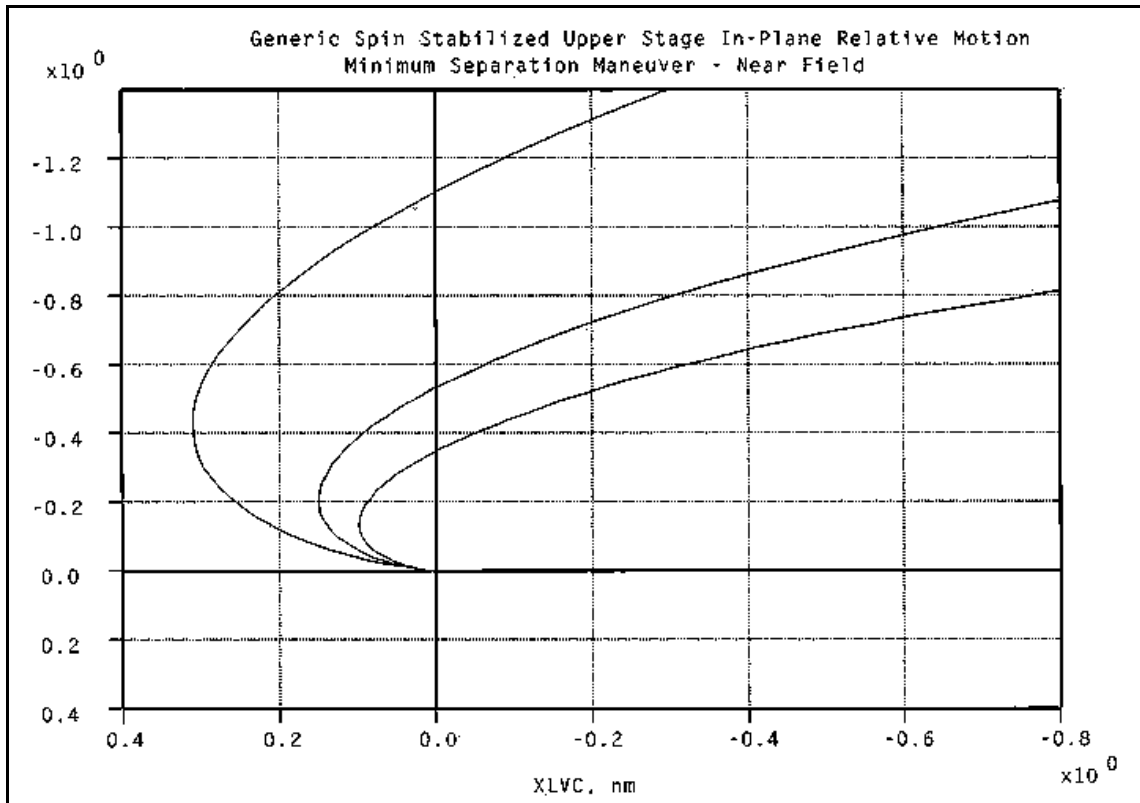


Figure 3.8.3.6-3: SSUS Min Sep Relative Motion (Far Field)

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**Figure 3.8.3.6-4: SSUS Min Sep Relative Motion (Near Field)**

### 3.8.3.7 Modeling the SSUS SRM Burn

FDO does not normally have to model the payload post-SRM ignition, since the customer can usually provide an SRM burnout vector in relatively short order. However, in some cases, FDO may be asked to provide a post-SRM-burn PSAT and ground track plotting when no post-burn vector is available. The following documentation is provided to incorporate an *approximation* of the SRM burn into the payload ephemeris.

**NOTE:** before modeling the burn, FDO must configure M thrusters in the Engine Characteristics Table to reflect the proper thrust and flow rate. These values can be obtained from the customer. Remember TrS BFI guidance uses RCS propellant from the ephemeris when modeling M thrusters. An error message may be generated when trying to model the SRM burn if there is insufficient RCS propellant in the ephemeris.

Ephemeris 3 should be configured with the correct weight, area, KCON, and spring ejection burn. The SRM firing is modeled as follows.

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<b>Guidance Mode</b>	BFI
<b>Thrusters</b>	Misc
<b>TIG</b>	Deploy +45 minutes
<b>Attitude Indicator</b>	A (Inertial) or L (LVLH) depending on where you look on SUPERSIGHTER.
<b>Attitude</b>	For a PAM, -Z attitude on the SUPERSIGHTER display showing deploy attitude; for a Frisbee, the +X attitude should be used
<b><math>\Delta v</math> or <math>\Delta T</math></b>	From payload customer or real time estimate

This burn should place the payload in the proper transfer (or initial interplanetary) orbit. Check the solution for reasonableness on the DMT prior to releasing the ephemeris for use.

**CAUTION:** a post-PKM payload ephemeris may produce a high-energy trajectory with eccentricity approaching or exceeding 1. Some applications may fail if they process such an ephemeris under the assumption all trajectories are of low eccentricity.

### 3.8.3.8 SSUS Contingency Operations

This section details anomalous scenarios associated with SSUS deploys, together with appropriate response strategies.

#### 3.8.3.8.1 SSUS Sunshield-Failed-Open Generic Deploy Timeline

If a sunshield fails to close after payload door opening, deploy is required immediately to prevent hydrazine in the satellite from freezing and posing a potential safety hazard. The prime deploy/injection opportunity for a sunshield failure is on the Orbit 4 descending node, with injection on the Orbit 5 ascending node (4D/5A). For this case, there is not enough time to execute the nominal FDO deploy computation timeline. FDO will be able to perform only one computation and will have to base it on pre-mission deploy targeting data provided by the customer. This is why it's important the customer provides the best possible deploy targeting data prior to flight. Figure 3.8.3.8.1-1 is an example of the generic FDO deploy computation timeline leading to a 4D eject. In this case, the Orbiter will be in -ZLV, +XVV attitude with a roll bias to shade the payload bay. The Orbiter will remain in this attitude from payload bay door opening through the time of the maneuver to deploy attitude. Therefore, there will be no IMU align attitude maneuvers.

Event	MET (h:mm)	Comment
Begin tracking arc	1:07	KMRC
End tracking arc	2:53	KPTC
Begin final computation cycle	3:05	
End computation cycle/PADs	3:45	
Deploy	4:58	4D
SRM ignition	5:13	5A

**Figure 3.8.3.8.1-1: Generic 4D/5A PAM Deploy Timeline**

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### 3.8.3.8.2 SSUS Sep Burn TIG Slips

In case the nominal separation burn cannot be performed on time, there is the possibility of slipping the TIG. This is *not* true in the min sep case, however. An inertial attitude hold cannot be supported because LVLH attitude will change through the TIG slip. This makes it necessary for the crew to change TIG (ITEM 10) on the MNVR EXEC display to its slipped MET, then re-execute the ITEM 22/23/27 (LOAD/TIMER/MNVR) to attain the new inertial burn attitude.

**WARNING:** min sep  $\Delta v$  magnitude is determined assuming the TIG is on time. A nom sep burn can be delayed up to 20 min, assuming the same LVLH targets are used, but min sep cannot be slipped without posing hazards to the crew and Orbiter.

A 20-min TIG slip capability is valid for all three SSUSs mentioned in previous sections. If a new booster comes on-line, it too would have to be checked to see how much TIG slip is acceptable. Originally, the criterion used in determining TIG slip capability was the same one used for the min sep case: Orbiter outside the 10X SRM plume contour by PKM TIG. However, it was shown in March 1987 that nominal window protect attitude was not effective in TIG slip cases. A procedure was therefore developed and presented at Flight Techniques to remedy this situation.

This procedure employs a table of different pitch values as a function of TIG slip. Each pitch value employs an adjusted Orbiter LVLH attitude protecting forward windows and down firing ARCS jets. Note that yaw and roll line-of-sight values remain constant at zero. The following table summarizes WPA as a function of sep TIG slip for all SSUS deploys.

Sep TIG Slip (min)	WPA Pitch (deg)
0	50
1	50
2	52
3	53
4	53
5	54
6	54
7	55
8	55
9	56
10	57
11	58
12	58
13	59
14	60
15	60
16	57
17	57
18	55
19	55
20	53

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### **3.8.3.8.3 Leaking OMS Propellant During SSUS Deploy Ops**

These procedures should be used in the extremely unlikely case of an OMS propellant leak during deploy. They apply to all SSUSs. Some special considerations may arise in flights with an ascending injection node or with payloads such as GPS injecting significantly off the node.

If the OMS leak is detected pre-deploy, abort deploy and perform the leaking OMS burn to depletion immediately. If the OMS leak is detected after deploy, perform the leaking OMS burn either retrograde or out-of-plane (OOP), depending where in the orbit the leak occurs and the amount of propellant available post burn to support deorbit. In either case, normal perigee adjust procedures should be followed to determine the burn direction.

For post-deploy cases, a retrograde leaking OMS burn should be executed no earlier than deploy +15 minutes. The reason for this is to provide sufficient range between the Orbiter and payload after deploy before a large OMS burn is attempted. PAM-equipped spacecraft are usually deployed retrograde. If the OMS burn is also performed retrograde, adequate time between deploy and the depletion burn is essential to insure no recontact hazard exists.

In some cases, the deploy may occur such that at deploy +15 minutes the Orbiter is outside the ConUS perigee adjust window. This will probably be true for all ascending node deploys. If this is the case, a couple of options are available. First, FDO must assess whether or not shallow deorbit capability exists from the current orbit with one OMS tank gone. If it does not, then the leaking OMS must be burned retrograde. However, if shallow capability does exist in the "good" OMS pod, and the Orbiter is outside the ConUS perigee adjust window, the leaking OMS must be burned OOP. The best course of action in this case is to perform a min sep immediately before the OOP burn. The min sep's TIG can be as soon as the Orbiter is in burn attitude. It's followed immediately by the maneuver to the OOP burn attitude.

If the leak is detected after the nominal sep burn, the leaking propellant can also be burned either retrograde or OOP. However, in order to have enough separation between the Orbiter and deployed spacecraft at PKM, the minimum retrograde  $\Delta v$  required is 32 fps. This will guarantee the Orbiter experiences less than 10X tile erosion. After deploy +35 minutes, the depletion burn should be delayed until after PKM because there may not be sufficient time to execute the burn and complete the maneuver to WPA. In the case of PAMs, the Orbiter must remain in WPA for at least 3 min, after which it can maneuver to the depletion burn attitude.

### **3.8.3.8.4 Off-Nominal Orbit Insertion SSUS Options**

Prior to each flight, the Lead FDO generates a list of options to recover from insertion into an unplanned orbit, such as one resulting from an ATO. These options require raising the orbit to several different altitudes, checking deploy opportunities, finding new deploy times, then determining deorbit opportunities and deorbit  $\Delta v$  costs.

EOM lighting and crossrange are driving factors in determining altitudes to which the orbit should be raised. Should the Orbiter end up in the classic 105 nm ATO orbit, OMS-3 and OMS-4 would be needed to raise the orbit. Good TIGs for these burns are around 4.5 hrs and 5.25 hrs MET. This allows enough time for the flight control team to develop an initial recovery plan, and it places the post-OMS-3 argument of perigee in the vicinity of 90°.

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This is close to the optimum argument of perigee location at 28.5° inclination in case a problem arises, and OMS-4 is not executed.

A trajectory timeline for each viable off-nominal insertion option should be generated with a sum of the  $\Delta v$  cost to execute each plan through deorbit. A binder with detailed data for all these options should be on console prior to launch. If power flight does place the Orbiter in an unexpected orbit, the Ascent Team can review these data and decide which option to execute.

### **3.8.3.8.5 Frisbee Deploy Manual Separation**

This procedure was developed prior to the first Frisbee deploy flight. It's intended to provide minimum separation for cases with a GPC/IMU problem preventing nominal separation. The crew would manually maneuver to the burn attitude and manually execute the burn with FRCS thrusters as follows.

- 1) Manually maneuver to burn attitude. Since deploy attitude is fairly close to -ZLV, -XVV (tail forward), the Orbiter is very close to correct LVLH burn attitude if -X thrusters are used to perform the posigrade sep burn. However, since the burn does not occur until deploy +15 min, inertial burn attitude is considerably different from inertial deploy attitude. Allowing for FRCS thrust in the Orbiter Body frame, the maneuver to sep burn attitude is a negative pitch through about 60°.
2. Manually execute the sep burn by pulling out on the forward THC. TIG is at the nominal Deploy +15 min with -X thrusters. Burn duration is around 22 sec in order to achieve min sep  $\Delta v = 6$  fps. If there's enough FRCS propellant, it's preferred to perform nom sep, which requires  $\Delta v = 18$  fps and  $\Delta t \sim 66$  sec.
3. Maneuver to WPA at deploy +29 min. Hopefully, the problem requiring manual sep would have been corrected by this time. If this is the case, the standard Rend NAV procedure driving a maneuver to WPA can be used. Otherwise, a manual WPA maneuver would be required.

### **3.8.3.9 SSUS Deploy Checklist**

The FDO SSUS deploy checklist is a quick look summary of most nominal and contingency procedures and rules governing a SSUS deploy. Experience has shown this is a good memory aid when used with deploys of this type. Note the targeting parameters and separation targets are specific to STS-52's IRIS/LAGEOS deploy.

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<b>Payload Characteristics:</b>	
WEIGHT:	5166 lbs
AREA:	52 ft <sup>2</sup>
KCON:	1.1
SPRING $\Delta v$ :	1.64 fps
<b>STS-51 Targeting Data:</b> (Descending injection: for Ascending, use -DEC)	
RRA:	271.0°
DEC:	-85.4°
DT <sub>node</sub> :	-34 sec
<b>OMS Sep (Deploy +15 min):</b>	
TVR:	120°
Thruster:	ROMS
<b>Nom Sep PEG-7s (13 fps):</b>	
$\Delta V_x$ :	+10.5 fps
$\Delta V_y$ :	+0.0 fps
$\Delta V_z$ :	-7.6 fps
<b>Min Sep PEG-7s (6 fps):</b>	
$\Delta V_x$ :	+4.9 fps
$\Delta V_y$ :	+0.0 fps
$\Delta V_z$ :	-3.5 fps
<b>TIG SLIP:</b>	
<ul style="list-style-type: none"> <li>• <math>\leq 20</math> min (<math>\leq</math> Deploy +35 min)</li> <li>• <math>\leq 12</math> min for nutation thruster failure (out of control payload)</li> <li>• If Min Sep and any TIG slip, increase <math>\Delta v</math> to Nom Sep (13 fps)</li> </ul>	
<b>TMBU: (MSK 1400)</b>	
ID:	4
GMT TABL:	From PAD
DSM:	12341 ( $\sqrt{w/PLO}$ )

<b>FDO Deploy Computation:</b>
<ul style="list-style-type: none"> <li>• Determine M50 injection node time MET<sub>node</sub> from EPH 1 (iterate Z<sub>M50</sub> &lt; 60 ft)</li> <li>• Compute RA = RA<sub>node</sub> + RRA</li> <li>• Compute TIG<sub>PKM</sub> = MET<sub>node</sub> + DT<sub>node</sub></li> <li>• Compute MET<sub>deploy</sub> = TIG<sub>PKM</sub> - 45 min (round to nearest sec)</li> <li>• Anchor EPH 3 from EPH 1 at MET<sub>deploy</sub> - 15 min</li> <li>• Compute spring <math>\Delta v</math> from RADEC</li> <li>• Input M50 spring eject impulse to EPH 3 at MET<sub>deploy</sub> (DMT 2 for FDO DEPLOY COMP)</li> <li>• Recompute MET<sub>node</sub> from EPH 3</li> <li>• Request C/O at EPH 3 MET<sub>node</sub> (for FDO DEPLOY COMP)</li> <li>• Pass MET<sub>deploy</sub>, RA<sub>node</sub>, and DEC to POINTING for deploy OMICRON comp</li> <li>• Input WGL in EPH 1 at MET<sub>deploy</sub></li> <li>• Update OMS trims to post-deploy</li> <li>• Model Nom Sep burn in EPH 1 (DMT 1 for FDO DEPLOY COMP)</li> <li>• Hardcopy FDO DEPLOY COMP once POINTING computes deploy attitude</li> <li>• Have POINTING compute Nom Sep Window Protect Omicron</li> <li>• If time permits, override Nom Sep <math>\Delta v</math> to Min Sep and have POINTING compute Min Sep WPA</li> <li>• Post deploy, confirm EPH 3 spring eject based on actual deploy attitude and time (POINTING will compute actual RA and DEC of payload spin axis)</li> <li>• Have POINTING display actual deploy attitude (final FDO DEPLOY COMP)</li> <li>• OMS leak/PADJ rules are similar to IUS</li> </ul>

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### **3.8.3.10 SSUS Deploy Worksheet**

This section contains a FDO deploy worksheet used to document relevant data generated during a TOS deploy. The worksheet is used in conjunction with the FDO SSUS deploy checklist.



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Spacecraft \_\_\_\_\_  
 Injection Node \_\_\_\_\_  
 Comp Cycle P\_\_F\_\_B\_\_A\_\_

RRA \_\_\_\_\_  
 DEC \_\_\_\_\_  
 OFFSET \_\_\_\_\_  
 SPRING DV \_\_\_\_\_

First Iteration		Second Iteration
____/____:____:____	<b>M50 Node MET</b>	____/____:____:____
+ _____:_____	<b>Offset Time</b>	+ _____:_____
= ____/____:____:____	<b>PKM TIG</b>	= ____/____:____:____
-           30 : 00	<b>Separation TIG</b>	-           30 : 00
= ____/____:____:____	<b>Deploy</b>	= ____/____:____:____
-           15 : 00	<b>Node RA<sub>M50</sub></b>	-           15 : 00
= ____/____:____:____	<b>RRA</b>	= ____/____:____:____
_____	<b>RA</b>	_____
+ _____	<b>M50 ΔV<sub>x</sub></b>	+ _____
= _____	<b>M50 ΔV<sub>y</sub></b>	= _____
_____	<b>M50 ΔV<sub>z</sub></b>	_____
_____		_____
_____		_____

Nominal Sep	Window Protect Attitude	Minimum Sep
_____	<b>Target Centered OM</b>	_____
_____	<b>Earth Centered Pitch</b>	_____
_____	<b>Earth Centered Yaw</b>	_____
_____	<b>Earth Centered OM</b>	_____

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### 3.8.4 IUS Deploys

Following subsections detail concepts and procedures specific to IUS deploys.

#### 3.8.4.1 Standard Concepts

The following table summarizes IUS deploy operations pertinent to FDO.

<b>Deploy Attitude</b>	Shades IUS during deploy; provides OOP relative motion after Orbiter backoff burn
<b>Deploy Window</b>	Varies with payload, but usually around 8 min
<b>Spring Eject <math>\Delta v</math></b>	0.4 fps OOP
<b>Separation TIG</b>	Deploy +15 min
<b>Nom Sep PEG-7s</b>	$\Delta V_x=29.9$ , $\Delta V_y=0.0$ , $\Delta V_z=8.0$ fps
<b>Min Sep PEG-7s</b>	$\Delta V_x=9.7$ , $\Delta V_y=0.0$ , $\Delta V_z=2.6$ fps
<b>Sep TIG Slip</b>	Nom Sep = 31 fps: Deploy Window Open +39 min Min Sep = 15 fps: Deploy Window Open +39 min Min Sep = 10 fps: Deploy Window Open +31 min

#### 3.8.4.2 IUS-Specific Concepts

Detailed IUS information concerning FDO operations is provided in the following subsections.

##### 3.8.4.2.1 IUS End-to-End Test Requirements

Since the IUS navigation state is updated via the cargo interface unit (CIU), demonstration of a successful navigation state transfer via this path is required during the pre-mission cargo end-to-end test (ETET). The Lead FDO supports this test with an Orbiter state vector uplink. Valid CIU transfer is subsequently verified by a CSTC vector compare between the Orbiter and IUS vectors. To do the compare, CSTC must use a base time set to the time of Orbiter state vector transmission to IUS. The compare will be bad if any other time, such as the time IUS accepts the vector, is used. FDO cannot do this compare, unless CSTC sends vectors via FAX, because MCC cannot access the IUS state. A good comparison between the propagated and TM state vectors verifies the CIU is working properly.

**NOTE:** at one time, a problem with IUS onboard software prevented it from accepting a normal on orbit vector during ETETs. The IUS could not get into the correct NAV/Flight mode while still on the pad. As a result, it rejected all vectors with heights greater than 150 nm circular. This problem was corrected for the STS-26 ETET. The only remaining limitation is the vector must be within Mission Data Load (MDL) limits, nominally 100-200 nm.

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### **3.8.4.2.2 Direct Remote Tracking Site (RTS) IUS Checks**

Direct ground-based RTS checks of the IUS and spacecraft are required pre-deploy. The IUS direct check occurs during the tracking arc, typically over HTS. It doesn't require an attitude maneuver. The spacecraft direct check occurs after the tracking arc, state vector uplink, and CIU transfer are complete. It may require an attitude maneuver.

### **3.8.4.2.3 IUS Pre-Deploy Orbiter Attitude**

Typical pre-deploy Orbiter attitude is -Z axis local vertical (-ZLV) or -ZLV with a roll bias. This orientation is required for IUS and spacecraft direct checks, but more importantly, it's necessary for thermal reasons. A -ZLV, -YVV (nose north) attitude may be flown instead of nose forward. This enhances probability the -Y star tracker will acquire stars of opportunity for IMU alignment.

### **3.8.4.2.4 IUS Sequence Time**

In the past, the IUS used two different sequence times, covering the interval from deploy to SRM-1, depending on whether the deployed spacecraft had an ascending or descending node injection. The nominal injection opportunity was on orbit 8D with a 55-min separation sequence, designed for optimal perigee placement following the sep burn. The ascending injection sequence was 67 min. This sequence placed perigee in the northern hemisphere, but near the descending node. In this case, oblate Earth perturbations quickly rotate the line of apsides south of the equator by end-of-mission, creating poor perigee placement for ConUS deorbits. Originally, the 67-min sequence was designed for a specific flight carrying an IUS and a PAM. Perigee placement would have been favorable after both separation burns had been performed. Although the sequence was unique, it was retained for later flights. There is no way to obtain truly good perigee placement for the ascending injection case. On some missions post-separation burn perigee placement may not be an issue due to recircularization burns.

In the old sequences, the sep burn occurred 19 minutes after deploy, and each sequence required a different  $\Delta v$  and thrust vector pitch. This was necessary to position the Orbiter at SRM such that tile erosion caused by aluminum oxide particles in the exhaust plume would be kept at an acceptable level (.074%).

In an effort to standardize and simplify deploy procedures, the IUS separation sequence has been modified for use with both ascending and descending injections. The sequence is 60 min from deploy to SRM TIG, and the sep TIG has been moved from deploy +19 min to deploy +15 min, consistent with PAM and Frisbee deploy sequences. The same sep burn  $\Delta v$  is used for ascending and descending cases.

### **3.8.4.2.5 IUS Injection Node**

The nominal injection node is now 6A. This makes for a more compressed timeline on the deploy day and shifts the tracking arc earlier than when 8D injection was prime. Crew scheduling constraints drive the new deploy timeline. Appendix K of the Space Shuttle Crew Procedures Management Plan (March 1987) defines the acceptable length of a crew day. Maximum scheduled crew awake time is 16 hrs, and the maximum allowable awake

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time with launch holds is 18 hrs. Primary deploy opportunities are always scheduled to meet the 16 hour limit. A backup opportunity violating this constraint may be scheduled only if crew sleep will begin no later than wakeup +18 hrs. If a launch slip occurs which would push the crew day beyond 18 hrs, the backup opportunity is lost.

NOTE: the *Chandra* X-ray telescope (STS-93) was injected at the southern-most point in its deploy orbit. Analysis shows this plan affords *Chandra* the best earth shadow profile over its lifetime, a thermal concern. The nominal deploy is only a few min past the 6A node, leaving a pre-deploy timeline similar to that for a 6A injection.

The deploy 8D injection timeline violates the 16-hr awake time constraint. Therefore, it can no longer be scheduled as the nominal opportunity. A typical 8D timeline is outlined in the following table.

Event	MET (hh:mm)	Awake Time (hh:mm)
Wakeup	-04:20	00:00
Liftoff	00:00	04:20
Deploy	10:00	14:20
8D Injection	11:00	15:20
Pre-Sleep	11:15	15:35
Sleep	13:15	17:35

Only a 25-min launch hold is necessary to eliminate 8D even as a viable backup injection. Consequently, 8D is retained as a "contingency" opportunity, assuming launch is on time. It would only be used if a high probability of deploy exists, or if the 16A FD2 opportunity cannot be used due to Orbiter, IUS, or payload problems.

The scheduled backup to 6A is 7A, which meets all crew timeline constraints. However, if 7A is used on an IUS/TDRS mission, the TDRS has no line-of-sight communications with the White Sands Ground Terminal (WSGT) until after 10 days of orbit drift. Commanding during this period must be through an RTS patch. If this indirect link fails, it could cause loss of the spacecraft.

### 3.8.4.2.6 IUS Deploy Window

Deploy time is computed by a guidance simulation initiated at CSTC based on ground ephemeris state vectors supplied by FDO. These simulations occur twice during pre-deploy activities. Refer to the Operations Support Timeline (OST) for preliminary and final guidance simulation METs.

An approximate deploy time can be generated by computing the injection node minus the 60-min sequence time minus 85 sec. SRM burn duration is from 2 min 29 sec to 2 min 31 sec. The burn is not quite centered on the node to account for apsidal rotation during the transfer orbit. About 56% of the burn occurs before the node.

The deploy window defines how long deploy can be delayed before IUS software will postpone SRM-1 firing by one orbit. SUNNYVALE ORBIT will provide the exact window. Deploy window duration is calculated as follows.

$$\text{(sequence time) + (time from SRM-1 to node) - (ORBIAS x period) - (latest guidance initialization time)}$$

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With numbers plugged in for an IUS/TDRS, the following window duration is obtained.

$$60 + 1.3 - 7.6 - 46 = 7.7 \text{ min} = 7 \text{ min } 42 \text{ sec}$$

ORBIAS is a quantity expressed in decimal orbits. It's the sum of time from SRM-1 to the injection node, plus slew time to ignition attitude, plus a time factor (.3 min), all divided by the orbit period. ORBIAS is a flight-specific parameter peculiar to each IUS payload. A TDRS-based example appears below.

$$\text{ORBIAS} = (1.3 + 6.0 + .3) / T = 7.6 / T, \text{ where } T \text{ is the orbit period in min}$$

It should be noted that gamma guidance can accommodate deploy at any point in the orbit. After initialization at deploy +46 min, the internal guidance system will evaluate time remaining until the next injection node. If this time is insufficient, the IUS will delay injection one orbit.

### 3.8.4.2.7 IUS Deploy Attitude

The IUS must be shaded from direct sun at deploy. Orbiter attitude at deploy is designed generically such that it satisfies this requirement. Additionally, this attitude results in relative motion between the IUS and Orbiter being directly out of plane after the backoff burn (see Figure 3.8.4.2.7-1). The LVLH deploy attitude, starting from Orbiter Body pitch = yaw = roll = 0 (nose forward and heads up) is computed at deploy time by the following sequence.

- 1) Pitch to place the sun in the Body X/Y plane.
- 2) Yaw  $\pm 75^\circ$ , pointing post-backoff IUS/Orbiter relative velocity directly out-of-plane. The sign of this yaw rotation is selected to direct the +X Body axis away from the sun. After the yaw, the sun remains in the Body X/Y plane.
- 3) Roll  $\pm 90^\circ$  to point the +Z Body axis at the sun. The sun is now in the Body X/Z plane with the payload bay in shadow. Relative to IUS, the sun is off the -X axis by  $46^\circ - |\beta|$ .

These rotations can be expressed as a function of the sun's LVLH position unit vector components  $[X_{\text{SUN}}, Y_{\text{SUN}}, Z_{\text{SUN}}]^T$ . The sign of  $Y_{\text{SUN}}$  is negative the sign of  $\beta$ .

Orbiter Deploy Attitude:

$$\begin{aligned} P &= \arccos \{X_{\text{SUN}}\} \text{ sign } \{-Z_{\text{SUN}}\} \\ Y &= -75^\circ \text{ sign } \{Y_{\text{SUN}}\} = 75^\circ \text{ sign } \{\beta\} \\ R &= -90^\circ \text{ sign } \{Y_{\text{SUN}}\} = 90^\circ \text{ sign } \{\beta\} \end{aligned}$$

IUS Deploy Attitude:

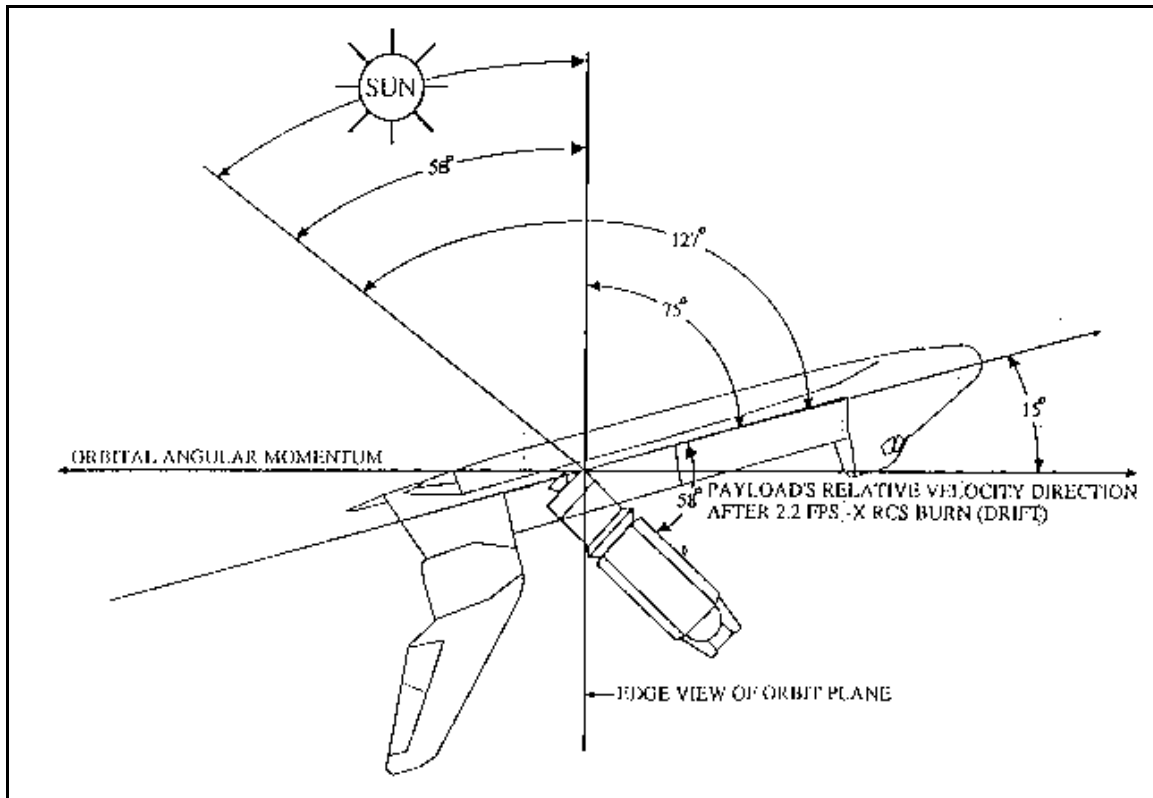
$$\begin{aligned} P &= \arccos \{X_{\text{SUN}}\} \text{ sign } \{-Z_{\text{SUN}}\} \\ Y &= -(75^\circ + \text{Tilt Table Elevation}) \text{ sign } \{Y_{\text{SUN}}\} \\ &= (75^\circ + \text{Tilt Table Elevation}) \text{ sign } \{\beta\} \\ R &= \text{N/A} \end{aligned}$$

The Deploy Checklist utilizes Universal Pointing for the maneuver to deploy attitude at deploy -40 min. Maneuvering could be initiated later if deploy -40 min occurs during an

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RTS pass needed for commanding. The checklist expresses deploy attitude in terms of an Orbiter Body vector directed at the sun as follows.

TGT ID = 4 (Sun)  
BV = 5 (crew-specified P-Y-OM)  
P =  $360 - (75 + |\beta|)$   
Y = 0  
OM = 090 ( $\beta > 0$ ) or 270 ( $\beta < 0$ )



**Figure 3.8.4.2.7-1: Inertial Upper Stage Deploy Attitude**

For Mission Control Center (MCC) modeling, POINTING displays attitudes of both the Orbiter and IUS at deploy on SUPERSIGHTER. These attitudes can be used for BFI burn modeling of the backoff burn and spring ejection. The IUS attitude may not be the same as formulas in this section, depending on how POINTING inputs data to the SUPERSIGHTER processor. Options are attitude conversion from LVLH to M50 or a simple pitch of the Orbiter's attitude to the tilt table's elevation angle. However, in all cases, attitude POINTING gives FDO will be equivalent to the attitude computed from the given formulas.

### 3.8.4.2.8 IUS Spring $\Delta v$

The IUS is deployed using a specially configured aft flight deck panel. The IUS slides out of the tilt table at only 0.4 fps. In the payload ephemeris, typically EPH 3, FDO models the spring  $\Delta v$  with a BFI burn using the IUS deploy attitude POINTING has supplied and miscellaneous (M) thrusters. Miscellaneous thrusters are used because they are the only

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thrusters aligned with the +X body-fixed axis. This condition is consistent with POINTING's IUS deploy attitude.

### 3.8.4.2.9 IUS Backoff Burn

Since the IUS is deployed at only 0.4 fps, an Orbiter backoff burn is required. One minute after deploy, the crew deflects the translational hand controller (THC) in the -X direction until a pitch rate of  $-0.8^\circ/\text{sec}$  is achieved. This equates to approximately 2.2 fps  $\Delta v$ . The IUS backoff is one of very few Orbiter burns performed in free drift.

When the Orbiter has pitched down  $70^\circ$ , the crew nulls pitch rate and selects inertial attitude hold. This maintains the IUS in the Orbiter's overhead windows. To model the backoff, specify Orbiter inertial deploy attitude with a TIG at deploy plus one minute for a BFI burn. This is a 2.2 fps  $\Delta v$  using the -X jets. To expedite confirmation procedures, PEG-7 components from this BFI burn can be re-input to the MOC using MZH thrusters.

Minimum acceptable FRCS backoff burn  $\Delta v$  is 1.0 fps or a  $-0.4^\circ/\text{sec}$  pitch rate. The crew will monitor  $\Delta v$  on the REL NAV display. If  $\Delta v_x$  is less than 1.0 fps, and all FRCS jets are down, the loss of FRCS procedure is performed from the Deploy Checklist. In this case, +X thrusters will be used to enhance the opening rate by performing a 4.0 fps burn at deploy +5 min. The separation burn remains at deploy +15 min.

### 3.8.4.2.10 IUS Attitude Matching Updates (AMUs)

Small misalignments between the Orbiter and the IUS body axis are inevitable. Structural and thermal stresses may even cause the magnitude of a misalignment to change during a mission, which may cause errors in attitude angles transferred from the Orbiter to the IUS. The Attitude Matching Update (AMU) procedure is performed to allow CSTC to compute an attitude correction which can be uplinked to the IUS before deploy. The AMU improves injection attitude accuracy and is considered mandatory for mission success with interplanetary payloads such as Magellan and Galileo. Other payloads may or may not require an AMU. TDRS missions only require an AMU for deploys after FD1 since the attitude mismatch on FD1 is considered insignificant to geosynchronous transfer.

The AMU consists of two consecutive attitude maneuvers about body axes  $90^\circ$  ( $\pm 30^\circ$ ) apart. Angular rotations can be from  $60^\circ$  to  $180^\circ$  in magnitude but  $90^\circ$  is considered optimum. The minimum data-gathering interval is 60 sec at a rotation rate of  $< 0.1^\circ/\text{sec}$ . No primary or vernier RCS thruster firings are allowed during the data-gathering interval. At least one uninterrupted minute of IUS and Orbiter telemetry data is required at the beginning and end of each rotation.

When the rotations occur, the Orbiter's IMUs and the IUS's redundant IMUs (RIMUs) both sense accelerations in their respective axes. From these sensed accelerations, the rotation axis in Orbiter and IUS body-fixed components can be computed. The two computed rotation axes will be slightly different because of body misalignment. After repeating the data gathering process for both AMU maneuvers, a body misalignment quaternion is computed. Using these data, CSTC computes an attitude correction to IUS coarse alignment and uplinks it.

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### 3.8.4.3 IUS Deploy Timeline

Event	MET (hh:mm)	Comment
Predicted post-OMS-2 SV to CSTC	00:30	A fair approximation to the final Orbiter parking orbit is provided by this SV. It will only be used to predict acquisitions.
Confirmed post-OMS-2 SV to CSTC	01:20	Nominal 6A deploy time and preliminary RCS-1 and RCS-2 vectors are computed from this SV.
Begin tracking arc	01:25	VTS 02
Start hourly automatic ICV queue to SOSC	02:00	In turn, the CSTC will transmit to JSC an IUS TM SV (normally via FAX). This SV will be used if JSC is required to perform a backup vector compare.
CSTC sends nominal 6A deploy time and preliminary RCS-1 and RCS-2 SVs to JSC.	02:30	
CSTC sends preliminary 7A deploy time and RCS-1 and RCS-2 SVs to JSC.	03:30	
Tracking arc ends.	03:40	ASC 003
Post-tracking-arc Orbiter SV to SOSC. Uplink this SV to both FILT and TGT.	04:05	FILT is used for CIU transfer to the IUS; TGT is used to initialize Rndz NAV.
Read up deploy and separation burn PADs	04:30	
Final guidance sim complete. SOSC reports final 6A deploy time to FDO.	04:45	PADs will only be updated if change in deploy time > 30 sec
IUS deploy for 6A injection	06:05	
Orbiter separation burn	06:20	Nom or Min Sep.
DAP inertial	07:05	
SRM ignition	07:05	
IUS RCS-1 burnout SV to JSC	07:20	

### 3.8.4.4 IUS PADs

Two sets of PADs are read up to the crew before an IUS deploy. FDO fills out two forms, the IUS Deploy PAD (see Figure 3.8.4.4-1), and the Separation Burn PAD, distributes copies, and monitors PAD read-up and read-back for accuracy.



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### IUS DEPLOY PAD

ORBIT \_\_\_\_\_ INJ

DEPLOY ATT            P     .

OM                     .

INITIATE TRK                    /                    :                    :                   

DEPLOY TIME                    /                    :                    :                   

DEPLOY WINDOW                    :                   

BETA                                   

WINDOW PROT OM                     .

Figure 3.8.4.4-1: IUS Deploy PAD

Most inputs on the IUS deploy PAD are generic. However, certain items are included for interplanetary trajectories that are not included for geosynchronous transfers.

Deploy PAD Item	Source/Remarks
ORBIT__INJ	Fill in the injection orbit and node, such as "6A"
DEPLOY ATT	Obtain from POINTING's SUPERSIGHTER display. Specify deploy attitude in terms of UNIVERSAL POINTING inputs. Check the pitch value based on $\beta$ at deploy.
P	UNIVERSAL POINTING Body vector pitch for deploy
OM	UNIVERSAL POINTING Omicron for deploy: $OM = 90^\circ$ ( $\beta > 0$ ), $OM = 270^\circ$ ( $\beta < 0$ ).
INITIATE TRK	Deploy -40 min: the MET at which the crew maneuvers the Orbiter to deploy attitude
DEPLOY TIME	Deploy MET from SUNNYVALE ORBIT
DEPLOY WINDOW	The actual deploy window provided by SUNNYVALE ORBIT in M:SS
BETA	The sign of $\beta$ (+ or -)
WINDOW PROT	Omicron for window protect OM attitude (nominally near-zero, but varies depending on IUS SRM-1 attitude) obtained from POINTING using IUS SRM-1 burn pitch and yaw provided by SUNNYVALE ORBIT.

The original Deploy PAD goes to CAPCOM, with copies to FLIGHT, FDO, PAYLOADS, and FAO.

#### 3.8.4.5 IUS Deploy Computations

- 1) Prior to OMS-2, a predicted post OMS-2 state vector is sent to SUNNYVALE ORBIT at 0/00:30 MET. The SV is used for acquisition planning only.

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- 2) After OMS-2, TRACK sends an OMS-2 cutoff vector to Sunnyvale for their initial Gamma Guidance run. TRACK coordinates with Sunnyvale Orbit on OPS SUPPORT.
- 3) SUNNYVALE ORBIT responds with deploy time, together with IUS pitch and yaw angles at injection. Later, SUNNYVALE ORBIT sends preliminary post-RCS-1 and RCS-2 vectors via FAX.
- 4) FDO gives the deploy time, IUS pitch and yaw, the ephemerides being used, and the sun's  $\beta$  at deploy (from Checkout Monitor) to POINTING on MOCR DYN.
- 5) FDO makes two entries to the Orbiter ephemeris: a WGL to remove the IUS/payload weight at deploy time, and a sep burn at deploy +15 min. Nominal sep PEG-7s are  $\Delta V_x = 29.9$ ,  $\Delta V_y = 0.0$ , and  $\Delta V_z = 8.0$  fps. Since the Orbiter is protecting the IUS from direct sunlight during deploy, the sep burn's TVR is a function of  $\beta$ . This keeps the IUS in the overhead windows during the sep burn. For  $\beta \geq 0.0^\circ$ , use a TVR of  $90^\circ$ . For  $\beta < 0.0^\circ$ , use a TVR of  $270^\circ$ . Mass Properties tables should be modified to reflect the deploy so OMS engine trims are correct for sep. Post-deploy trims must be in the Engine Characteristics Table.
- 6) POINTING displays the Orbiter's M50 deploy attitude on the SUPERSIGHTER display for FDO (see underlined comment, P-Y-R, and MET fields in Figure 3.8.4.5-1).

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```

=====
MODE 7 - TRACK OPTION: INPUT OMICRON
RUN #: 2 PAGE 1 OF 1
Rev 6 Orbiter Deploy Att
=====
VIDFILE: REV6
VID: 1
EPOCH: M50
=====
LOS 1: ( S ) TARGET 1: SUN BODY AXIS
S04/+X BODY (P,Y) E: VID: +X:
OFFSETS RA: 107.562 RA: 277.307
A1 234.15 DEC: 22.463 N DEC: -76.366 S
A2 360.00 LAT: LON: -Z:
OM: 90.00 ALT: nm RA: 289.348
RANGE: nm DEC: 13.344 N
=====
LOS 2: ( ) TARGET 2: STAR TRACKERS
/ E: VID: -Y: ( E )
LOOK ANG TO TGT RA: 16.204
DEC: -13.017 S
LAT: LON: -Z: ( )
ALT: nm RA: 291.236
RANGE: nm DEC: 10.980 N
=====
ATTITUDE OUTPUT
+X -X -Z
OUTMAT: R: 250.77
INRT: IPYR01 P: 88.23
Y: 346.48

OUTMAT R: 90.00
LV LH: LPYR01 P: 194.51
Y: 75.07
=====
LOOK ANGLES FROM +X TDRS ANG SEP
COE SUN MOON V GP W ( ) S ( ) E(E) COE SUN MOON HORZ GP
P: 285 234 231 105 236 P: 76 344 256 INST 1: 86 126 114 13 124
Y: 285 0 310 345 352 Y: 335 86 320 TGT 1: 81 0 50 8 8
R: 256 180 237 345 190 AZ: 25 -91 140 INST 2:
P: 86 126 114 104 124 EL: 13 4 -11 TGT 2:
=====
REQUESTED TIME: MET: 000/07:17:30* GMT: 190/12:36:30*

TGT 1 MET GMT TGT2 MET GMT
AOS: 000/06:21:51 190/11:40:51 AOS:
TCA: 000/06:51:18 190/12:10:18 TCA:
LOS: 000/07:20:43 190/12:39:43 LOS:

ELEV ANG: 0.00 INCLUDE EARTH OCCULTATION: Y
=====

```

**Figure 3.8.4.5-1: Orbiter M50 IUS Deploy Attitude on SUPERSIGHTER**

- 7) FDO uses Orbiter deploy attitude to model the 2.2 fps -X backoff burn in the Orbiter ephemeris. TIG = deploy +1.0 min. If the FRCS is not available, model the backoff burn using the same attitude with ARCS (4.0 fps at deploy +5 min).
- 8) POINTING displays IUS deploy attitude on SUPERSIGHTER (see underlined comment, P-Y-R, and MET fields in Figure 3.8.4.5-2).

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```

=====
MODE 3 - INERTIAL ROTATION ABOUT AN EIGEN VECTOR
RUN #: 3 PAGE 1 OF 1
Rev 6 IUS Deploy Att
=====
VIDFILE: REV6 INPUT ATTITUDE: +X EIGEN VECTOR
VID: 1 R: 250.77 INMAT: IPYR01 P: 0.00
P: 88.23 Y: 90.00
EPOCH: M50 Y: 346.48 ANG: 58.00
=====
LOS 1: ( S ) TARGET 1: SUN BODY AXIS
S04/+X BODY (P,Y) E: VID: +X:
LOOK ANG TO TGT: RA: 107.562 RA: 287.776
A1 176.15 DEC: 22.463 N DEC: -18.618 S
A2 360.00 LAT:
OM: 90.00 LON: -Z:
ALT: nm RA: 296.765
RANGE: nm DEC: 71.167 N
=====
LOS 2: ( ) TARGET 2: STAR TRACKERS
/ E: VID: -Y: ( E )
LOOK ANG TO TGT: RA: RA: 8.636
DEC: DEC: -6.058 S
LAT:
LON: -Z: ( )
ALT: nm RA: 301.177
RANGE: nm DEC: 68.578 N
=====
ATTITUDE OUTPUT
+X -X -Z
OUTMAT: R: 221.99
INRT: IPYR01 P: 47.82
Y: 295.52

OUTMAT R: 270.00
LVLH: LPYR01 P: 14.50
Y: 46.93
=====
LOOK ANGLES FROM +X TDRS ANG SEP
COE SUN MOON V GP W( ) S( ) E(E) COE SUN MOON HORZ GP
P: 227 176 173 47 178 P: 18 286 198 INST 1: 100 176 129 27 172
Y: 285 0 310 345 352 Y: 335 86 320 TGT 1: 81 0 50 8 8
R: 259 360 276 340 285 AZ: 56 -94 111 INST 2:
P: 100 176 129 49 172 EL: 60 1 -47 TGT 2:
=====
REQUESTED TIME: MET: 000/07:17:30* GMT: 190/12:36:30*

TGT 1 MET GMT TGT2 MET GMT
AOS: 000/06:21:51 190/11:40:51 AOS:
TCA: 000/06:51:18 190/12:10:18 TCA:
LOS: 000/07:20:43 190/12:39:43 LOS:

ELEV ANG: 0.00 INCLUDE EARTH OCCULTATION: Y
=====

```

**Figure 3.8.4.5-2: M50 IUS Deploy Attitude on SUPERSIGHTER**

- 9) FDO uses IUS deploy attitude to model the 0.4 fps IUS spring ejection in the payload ephemeris.
- 10) FDO models the min sep burn in a contingency Orbiter ephemeris by anchoring on the burnout vector of the backoff burn in the prime Orbiter ephemeris. Initial weight should be the same as the backoff burnout weight. Min sep PEG-7s are  $\Delta V_x = 9.7$ ,  $\Delta V_y = 0.0$ , and  $\Delta V_z = 2.6$  fps.
- 11) When the previous steps have been accomplished, FDO informs POINTING ephemerides are ready for window protect attitude calculation. POINTING also uses the IUS injection pitch and yaw in this calculation.
- 12) POINTING gives FDO the window protect Omicron (see underlined comment, P-Y-OM, and MET fields in Figure 3.8.4.5-3), which FDO records on the IUS Deploy PAD.

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```

=====
MODE 6 - DUAL LOS:  LOS 1 EXACT ON TGT 1, LOS 2 NEAR TGT 2
                      RUN #: 1                               PAGE 1 OF 1
                      Rev 6 WPA
-----
VIDFILE:  REV6          LOS 1:          LOS 2:
VID: 2      S04/+X BODY (P,Y)          S04/+X BODY (P,Y)
OFFSETS          OFFSETS
A1  320.00      A1  0.00
EPOCH:  M50     A2  0.00              A2  0.00
-----
LOS 1:  ( E )          TARGET 1:EPH          BODY AXIS
S04/+X BODY (P,Y)    E: REV6  VID: 3          +X:
OFFSETS              RA:  207.581          RA:  172.596
A1  320.00          DEC:  8.127 N          DEC: -11.608 S
A2  0.00            LAT:
OM:  1.67           LON:
ANG SEP:  0.00      ALT:                -Z:
                      RANGE:  37.64 nm          RA:  76.492
                      DEC: -27.369 S
-----
LOS 2:  ( )          TARGET 2:CC          STAR TRACKERS
S04/+X BODY (P,Y)    E:  VID:          -Y:  ( )
LOOK ANG TO TGT      RA:  189.427          RA:  120.119
A1  340.87          DEC: -2.263 S          DEC:  54.429 N
A2  0.00            LAT:
ANG SEP:  19.13     LON:                -Z:  ( )
                      ALT:                RA:  79.440
                      RANGE:  nm          DEC: -25.935 S
-----
ATTITUDE OUTPUT
          +X      -X      -Z
OUTMAT:  R:  119.49
INRT: IPYR01 P:  168.30
          Y:  7.25

OUTMAT   R:  1.58
LVLH: LPYR01 P:  13.14
          Y:  0.71
-----
          LOOK ANGLES FROM +X          TDRS          ANG SEP
          COE SUN MOON V GP          W(E) S(E) E( )          COE SUN MOON HORZ GP
P:  257  60  125  347  270 P:  213  309  83 INST 1: 103  72  119  31  90
Y:  2  308  326  0  317 Y:  22  10  326 TGT 1:  63  96  144  9  62
R:  178  304  321  181  223 AZ: -143 -167  34 INST 2: 103  72  119  31  90
P:  103  72  119  13  90 EL: -51  39  5 TGT 2:  84  83  133  12  76
-----
REQUESTED TIME:  MET:  000/08:17:30*  GMT:  190/13:36:30*
-----
TGT 1  MET          GMT          TGT2  MET          GMT
AOS:          AOS:  000/08:14:30  190/13:33:30
TCA:  000/07:32:40  190/12:51:40  TCA:  000/08:41:43  190/14:00:43
LOS:          LOS:  000/09:08:30  190/14:27:30
ELEV ANG:  0.00          INCLUDE EARTH OCCULTATION:  Y
=====

```

**Figure 3.8.4.5-3: Orbiter Window Protect Attitude on SUPERSIGHTER**

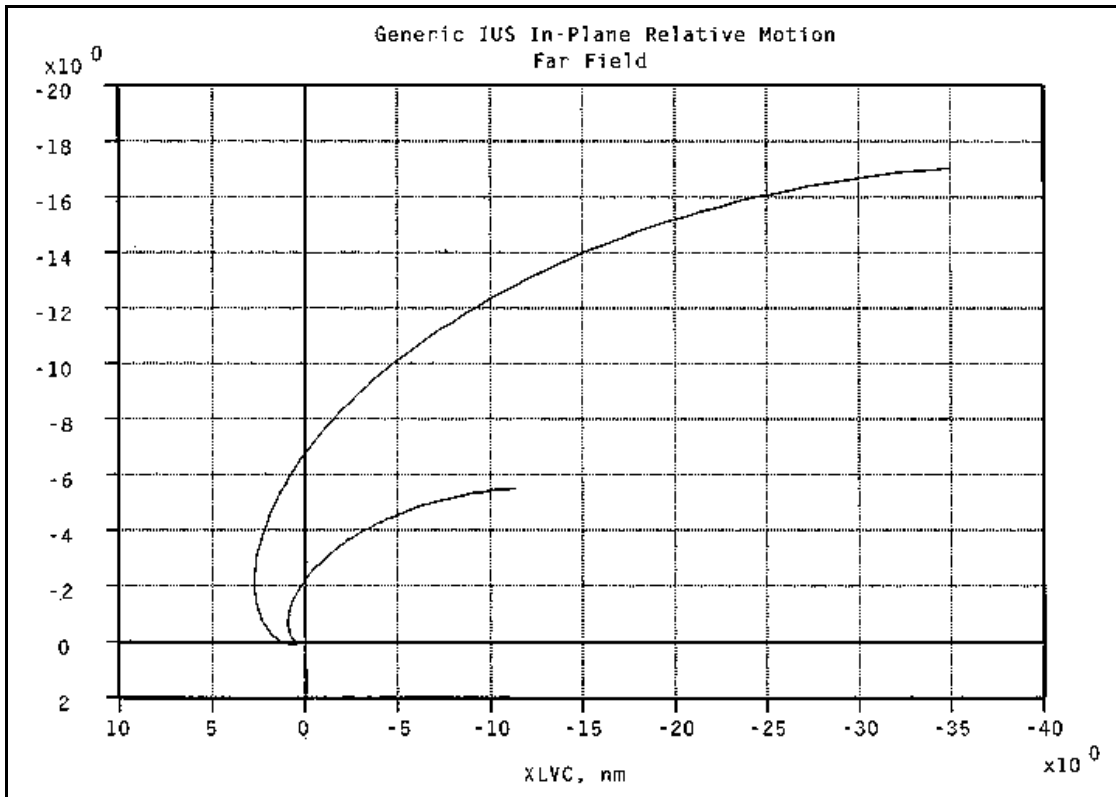
13) FDO fills out and distributes Deploy and Sep PADs.

A nominal set of hardcopies to document FDO computations includes 3 DMTs (backoff, sep, and spring ejection), 3 SUPERSIGHTERS (Orbiter and IUS deploy attitudes, and WPA), a WGL display showing deploy weight loss, and an MSK 2310 showing ephemeris status.

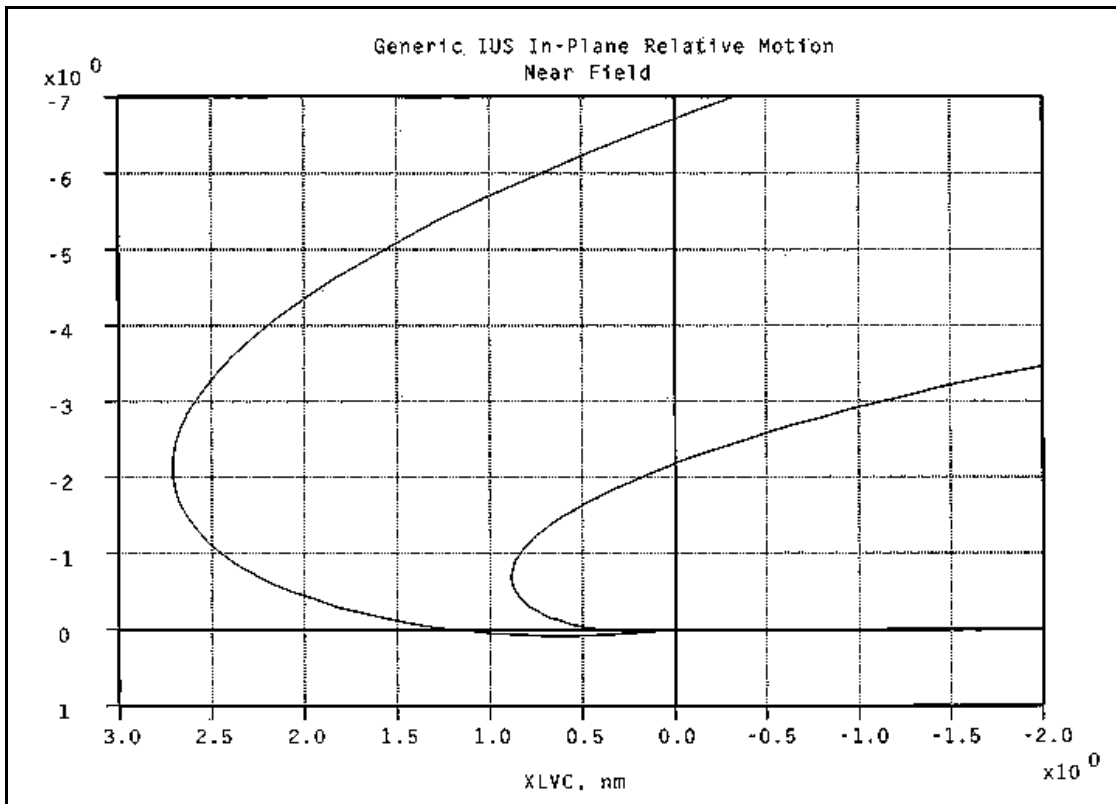
### 3.8.4.6 IUS Relative Motion

Typical relative motion plots between the Orbiter and IUS are shown in Figures 3.8.4.6-1 and 3.8.4.6-2. These plots, which are IUS-centered, show both the nominal and min sep relative motion trajectories at large and small scale, respectively.

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**Figure 3.8.4.6-1: Nom and Min Sep Motion Relative IUS (Far Field)**



**Figure 3.8.4.6-2: Nom and Min Sep Motion Relative IUS (Near Field)**

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### 3.8.4.7 Modeling the IUS SRM Burn

FDO does not normally have to model the IUS SRM-1 burn because CSTC supplies a predicted post RCS-1 state vector after the final gamma guidance simulation. However, in some IUS simulations, FDO is asked to provide a post-SRM-1 PSAT or groundtrack, and no simulated vector is available. The following information is provided to approximate the SRM-1 burn in the payload ephemeris. Since SRM-1 is modeled as a perfect burn, the RCS-1 burn is ignored because it's targeted to trim out SRM residuals.

**CAUTION:** a payload ephemeris modeling post-SRM-1 flight may produce a high-eccentricity trajectory with values approaching or exceeding 1. Applications such as PPD or 2-D DEMOS may fail if they process such an ephemeris because they assume all trajectories are of low eccentricity.

Before modeling the burn, FDO must configure Miscellaneous thrusters in the Engine Characteristics Table to reflect IUS thrust and mass flow rate.

Thrust = 42206 lbs  
Flow Rate = 144 lbs/sec

The IUS ephemeris should be configured with correct IUS/payload weight, Area = 230 ft<sup>2</sup>, KCON = 1, and the spring ejection burn modeled as described in Section 3.8.4.5. The SRM-1 burn is modeled with the following inputs.

Guidance Mode = BFI  
Thrusters = Miscellaneous  
TIG = Deploy +60 min  
Attitude Indicator = L (LVLH)  
LVLH R = 0  
LVLH P = value from SUNNYVALE ORBIT, or canned sim value = -5.57°  
LVLH Y = value from SUNNYVALE ORBIT, or canned sim value = +7.94°  
Burn Time = 150 sec

This burn should place the IUS/payload in a semisynchronous transfer orbit with 12-hour period. Check your solution for reasonableness on a DMT.

**NOTE:** for STS-93's *Chandra* payload, IUS is programmed to perform all burns (SRM-1, RCS-1, SRM-2, and RCS-2) ASAP at injection. This normally takes about 6 min.

### 3.8.4.8 IUS Contingency Operations

The following subsections describe IUS failure scenarios and associated FDO responses.

#### 3.8.4.8.1 IUS Emergency Deploy Timeline

The emergency timeline compresses nominal deploy events as much as possible. Mandatory crew procedures are denoted in the Deploy Checklist by a preceding box. The separation sequence has four modifications.

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- 1) Move the maneuver to separation burn attitude from deploy +7 min to +2.5 min, a point directly after pitch rate is nulled.
- 2) Move OMS separation TIG from deploy +15 min to ASAP after achieving burn attitude.
- 3) Delete the IUS viewing attitude maneuver. If the IUS is hazardous, pointing the payload bay towards it is not acceptable and may delay maneuvering to window protect attitude.
- 4) Move the window protect attitude maneuver from deploy +39 min to ASAP after the separation burn.

### 3.8.4.8.2 Loss of FRCS During IUS Deploy

There are three forward RCS jets (F1F, F2F, and F3F) supporting -X translation. OPS 2 guidance allows only two of the three jets to fire, normally F1F and F2F. If either of these jets fails, F3F will automatically be substituted. However, this downmode generates an effective thrust yaw moment because the Y-Body component of F3F will not cancel the Y-Body component of F1F or F2F. Fortunately, this yaw amounts to only  $0.8^\circ$  during an otherwise nominal backoff burn, and it can be ignored.

If two of the three FRCS jets are known to be failed pre-deploy, consideration should be given to increasing burn time of the backoff. With only half of the backoff  $\Delta v$ , single-jet pitch rate will be half its nominal value, and it will take twice as long to pitch down  $70^\circ$ . More importantly, Orbiter/IUS range at separation TIG will be half its nominal value. This is still a safe distance from which to execute the OMS separation burn, but doubling the backoff burn time and maintaining nominal relative motion is a better single-jet backoff plan. The crew will double the backoff burn time since they are using pitch rate as the burn termination criterion.

Procedures addressing complete loss of FRCS utilize nominal actions with two modifications.

- 1) Replace the 2.2 fps -X RCS backoff burn at deploy +1 min with a 4.0 fps +X RCS "backoff" burn at deploy +5 min.
- 2) Terminate free-drift-induced negative pitch rate when IUS line-of-sight is near the Orbiter tail instead of at  $70^\circ$ .

**CAUTION:** the Deploy Checklist has the crew send the Master Safe command if they do not execute the separation burn. Following a no-FRCS backoff burn, however, the IUS has +Z Orbiter Body position at separation TIG, and Master Safe won't be received. A 482 was submitted requiring the crew to send Master Safe post-deploy if backoff is performed with ARCS jets. This 482 was rejected because sending Master Safe anticipates a second failure (no separation burn) before it occurs.



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### 3.8.4.8.3 IUS Tilt Table Over 29°

The nominal tilt table elevation angle at deploy is 58°. Flight rules require deploy be aborted if the tilt table cannot be raised to a minimum of 40°. Two considerations drive the 40° limit. First, Boeing analysis of an IUS ejection 40° concludes adequate clearance exists in the presence of various dispersions. Second, visual markings giving the crew a tilt table elevation indication are provided at 40°, 45°, 50°, and 59°. Any angle less than 40° would be difficult for the crew to verify.

Part of Boeing's analysis establishes maximum Orbiter pitch rates at deploy as a function of tilt table elevation at deploy. The study analyzed 59° because this was formerly the nominal tilt table pitch at deploy.

Tilt Table Elevation (°)	Max Orbiter Pitch Rate (°/sec)
40	0.05
45	0.15
59	0.20

Flight Design has studied deploy from a tilt table stuck at 29°, which is the intermediate tilt table elevation at which the ground performs IUS direct checks. Three cases were examined with pre-deploy Orbiter pitch rates of 0.0, 0.10, and 0.22 °/sec. Clearances between the forward payload bay bulkhead and the IUS were 10, 6, and 0 feet, respectively. Orbiter FRCS plume impingement forces and moments from the backoff burn were considered acceptable for a 29° deploy. Unfortunately, RCS contamination was unacceptable because it exceeded the 0.001 psf dynamic pressure limit. Flight Design concluded deploy from 29° is possible but would not support a decision to execute a deploy of this nature without further analysis.

Should the tilt table stall between 40° and 58°, there is no reason to modify deploy attitude to maintain exactly out-of-plane relative motion after the -X backoff burn. An ejection rate of 0.4 fps has no long-term implications after the 2.2 fps backoff burn is added to it.

### 3.8.4.8.4 IUS Tilt Table Not Locked Down

If the tilt table cannot be lowered and locked down post-deploy, flight rules dictate the separation burn will use a single OMS engine. Pre-deploy, no translations of any kind can take place without the tilt table being locked down. These restrictions are due to structural load concerns with an unlocked tilt table.

### 3.8.4.8.5 IUS Separation TIG Slips and Early/Late Deploys

Both the deploy time and separation TIG effect "coast time" from the sep burn to SRM ignition. For example, an early deploy (before the nominal deploy time) followed by a sep burn 15 min later, increases nominal coast time. Late deploys within the deploy window decrease coast time, as do late sep burns. All of these cases place the Orbiter in an off-nominal position with respect to the IUS at SRM-1. Anomalous relative motion can lead to changes in sep burn  $\Delta v$  or in window protect attitude to insure both tile and window erosion limits are satisfied.

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### 3.8.4.8.5.1 IUS Sep TIG Slip with On-Time or Late Deploys

Two criteria define safe distance from the IUS at SRM-1 TIG. The Orbiter must be in a position to receive no more than 10X erosion from the exhaust plume, and it must be on or behind the IUS Rbar. Relative motion plots illustrate the Orbiter is ahead of IUS for a time following separation. There is a separation  $\Delta v$  which will allow the Orbiter to cross the minus Rbar and satisfy the 10X erosion limit at the same time. Associated coast time to the minus Rbar is the minimum required to satisfy both safe distance criteria at the given sep  $\Delta v$ . Using the 60-min sequence's  $-15^\circ$  thrust vector LVLH pitch for the sep burn yields a  $\Delta v$  of 18 fps with a coast time of 21 min. Therefore, if the 18 fps sep is executed by SRM-1 -21 min (deploy +39 min), the Orbiter would be at a safe distance by SRM-1 TIG. This defines the maximum allowable separation burn TIG slip.

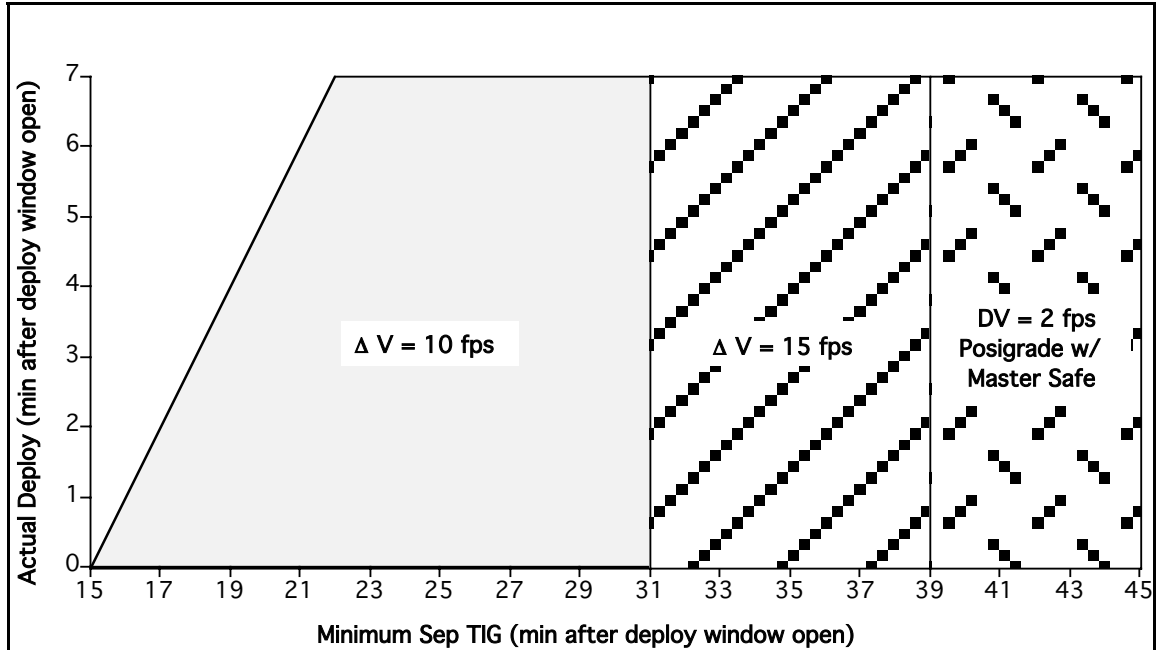
An RSOC presentation entitled "Inertial Upper Stage Analysis for Early/Late Deploys", presented at the April 8th, 1988 Orbit Flight Techniques, describes two late (deploy +31 min) sep burn cases, one following an on-time deploy, and one with deploy at the end of the window (nominal deploy +8 min). In both cases, window protect attitude (WPA) pitch line-of-sight (PLOS) adjustments are necessary. These are discussed further in the next sections. The following table shows minimum sep  $\Delta v$  required after TIG slip has occurred for on time and late deploy cases.

	Deploy On Time	Deploy at End of Window
Sep TIG	Deploy +31 min	Deploy +31 min
Min Sep $\Delta v$	10 fps	15 fps
WPA PLOS	$62^\circ$	$95^\circ$
Tile Erosion	9.4X	10.0X

In summary, a separation burn  $\Delta v$  greater than or equal to 10 fps must be executed by nominal deploy +31 min if deploy is on time. If deploy is late, at least 15 fps must be obtained by deploy +31 min. If the appropriate  $\Delta v$  cannot be obtained by deploy +31 min, the crew must send Master Safe and then obtain at least 2 fps posigrade  $\Delta v$  by deploy +39 to avoid recontact with the IUS, which was deployed out-of-plane and will "rendezvous" half an orbit later. These limits are illustrated in Figure 3.8.4.8.5.1-1.

Do not confuse these limits with ordinary minimum separation  $\Delta v$ . Remember, min sep burns are executed at the nominal TIG, and place the Orbiter well behind the Rbar at SRM-1. Burns in this discussion have minimum required  $\Delta v$  assuming TIG slip has already occurred due to a delayed deploy or burn.

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**Figure 3.8.4.8.5.1-1: IUS Deploy Min Sep  $\Delta v$**

### 3.8.4.8.5.2 Early IUS Deploys

Various Orbiter or IUS/Payload systems problems could force an early deploy. This increases the coast time between the sep burn and SRM-1 TIG. RSOC analysis referenced in the previous section determined window protect attitude can remain at 40° PLOS for min sep  $\Delta v$ , but  $\Delta v$  must change with deploy time. If nom sep is planned, both burn magnitude and window protect attitude are independent of deploy time. These results are summarized in the following table.

Early Deploy (min)	Min Sep					Nom Sep				
	PEG-7 Targets (fps)			WPA (°)		PEG-7 Targets (fps)			WPA (°)	
	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	PLOS	Pitch	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	PLOS	Pitch
0	9.7	0.0	2.6	40	320	29.9	0.0	8.0	40	320
5	10.6	0.0	2.8	40	320	29.9	0.0	8.0	40	320
10	10.6	0.0	2.8	40	320	29.9	0.0	8.0	40	320
15-45	9.7	0.0	2.6	40	320	29.9	0.0	8.0	40	320

### 3.8.4.8.5.3 IUS WPA Changes for Off-Nominal Coast Times

System failures or other events demanding the crew's immediate attention could cause a delay in executing a separation burn, which decreases coast time between sep and SRM ignition. If a late sep burn has occurred, WPA pitch adjustments may be required. The following table summarizes necessary WPA adjustments as a function of coast time, assuming late nominal sep  $\Delta v = 31$  fps or minimum sep  $\Delta v = 10$  fps.

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Coast Time (Min)	WPA Pitch (Nom Sep $\Delta v$ )	Coast Time (Min)	WPA Pitch (Min Sep $\Delta v$ )
45-43	320	45-41	320
42-36	310	40-36	285
35	306	35	285
34	303	34	285
33	302	33	285
32	299	32	285
31	296	31	285
30	293	30	285
29	290	29	285
28	286	28	251
27	282	27	251
26	279	26	251
25	274	25	251
24	269	24	251
23	264	23	251
22	259	22	251
21	253	21	251

Using the above data, WPA can be determined for odd combinations of deploy and sep times as long as the coast time can be determined.

**NOTE:** an on time deploy followed by a late sep requires only a change to WPA. If both deploy and sep are late, min sep  $\Delta v$  may also change. Should the deploy occur at the window close (8 min late for a typical IUS/TDRS), and sep TIG slips to deploy +31 min, a 15 fps separation is required to achieve 10X erosion with a window protect PLOS of 95° (Pitch = 265°).

### 3.8.4.8.6 Leaking OMS Propellant During IUS Deploy Operations

Standard on-orbit procedure calls for a burn to depletion of the leaking OMS as soon as possible after detecting the leak. If there is insufficient propellant in the good pod to support a deorbit to shallow targets from the current orbit, the depletion burn will always be a perigee adjust. If the good pod can support a shallow deorbit, FDO evaluates whether performing a perigee adjust will increase or decrease deorbit  $\Delta v$  to a ConUS landing site. If  $\Delta v$  will decrease, the burn will be a perigee adjust. If  $\Delta v$  will increase, the burn will be executed out-of-plane in the direction that will decrease crossrange to the next PLS.

If the leak occurs in the middle of an IUS deploy, matters become more complicated. Flight rules in the IUS section of the flight-specific annex require no OMS burns be executed with an unstowed IUS. Therefore, the IUS must either be restowed or deployed before the OMS burn can take place.

The decision to deploy or to restow depends on whether or not IUS umbilical pull has occurred. Umbilical pull is the irreversible event disconnecting IUS from Orbiter power. If the leak is detected before umbilical pull, IUS will be restowed, and the OMS burn will be performed according to non-deploy OMS leak procedures. If the leak occurs after umbilical pull, the IUS will be deployed using emergency procedures.

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If the IUS is to be deployed, FDO's next decision depends on whether or not shallow deorbit capability exists to a ConUS site from the post-deploy, post-min-sep orbit. If this capability does exist, the crew will do a min sep ASAP following the 2.2 fps backoff, then burn the leaking OMS to depletion out-of-plane. In this case, it was decided to simplify procedures and always burn OOP, regardless of OOP TIG window limits.

If there is no shallow ConUS deorbit capability, the crew will first transmit Master Safe. If leak rate is high, the crew will perform a perigee adjust burn ASAP. In this case, a minimum perigee adjust  $\Delta v$  of 57 fps is required to insure the Orbiter is in a safe position at SRM-1 ignition. If  $\Delta v \geq 57$  fps, the crew will send Master Safe Recovery.

If OMS leak rate is extremely low, a 2 fps retrograde burn will be performed at the nominal sep TIG, and a perigee adjust will be executed at the next optimum perigee adjust TIG. An "extremely low" leak rate is so low that it takes hours to detect. It's therefore possible to wait for optimum perigee adjust TIG. Optimum TIG perigee adjust burns can only be performed if no OMS pod thermal effects are seen due to leaking propellant. Again,  $\Delta v \geq 57$  fps must be obtained from the leaking OMS before Master Safe recovery can be sent. The minimum perigee adjust  $\Delta v$  required may be less for cases in which the leak is not detected until after a nominal or minimum separation burn has already been performed.

If a perigee adjust is required after a nominal or minimum separation burn but before SRM-1 ignition, relative position of the Orbiter and IUS at SRM depends on perigee adjust TIG and  $\Delta v$ . For cases in which perigee adjust occurs soon after the sep burn, the Orbiter will be below and ahead of the IUS at SRM-1. If the perigee adjust occurs very late in the sequence, the Orbiter may be well behind and slightly below the IUS at SRM-1. These variations obviously call for very different window protect attitudes.

Another RSOC analysis, entitled "Inertial Upper Stage Contingency Analysis for Perigee Adjust Cases" (July 27, 1988), determined WPA adjustments needed for post-sep perigee adjusts. The crew first transmits Master Safe, then executes the perigee adjust. Minimum perigee adjust  $\Delta v$  required before Master Safe Recovery may be sent varies as a function of perigee adjust TIG and what kind of sep burn was performed. The criteria used for determining the minimum acceptable  $\Delta v$  were the 10X tile erosion limit, and the 10 nm explosion limit distance at SRM-1. Results are summarized in Figure 3.8.4.8.6-1. For rationale and additional details, refer to the original analysis.

In Figure 3.8.4.8.6-1, TIG PET refers to the perigee adjust TIG in phase elapsed time, with PET 00:00 being deploy at window open. The window protect attitude is given as an LVLH pitch, yaw, and roll for the sake of clarity, since more than a simple pitch from the line-of-sight to IUS is required in this case. Because the Orbiter is below IUS, a roll of 180° is required to point the belly at IUS.

	Minimum Sep Burn						Nominal Sep Burn		
	<b>PADJ TIG PET (mm:ss)</b>	18:30-39:00		39:00-52:00				18:30-34:00	34:00-52:00
<b>PADJ Min <math>\Delta v</math></b>	45 fps		80 fps				57 fps	0	
<b>LVLH WPA</b>	P	Y	R	P	Y	R	P	Y	R
	306°	0°	180°	322°	0°	180°	306°	0°	180°

**Figure 3.8.4.8.6-1: Perigee Adjust (PADJ) Minimum  $\Delta v$  and WPA**

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### 3.8.4.8.7 OMS Tank Failure During IUS Deploy Operations

The term "OMS tank failure" means OMS fuel or oxidizer in the failed pod is present but inaccessible to either OMS engine. In the leaking OMS case, propellant from the leaking pod can be used to lower perigee and reduce deorbit  $\Delta v$  to at least some landing sites. Using the propellant also reduces Orbiter weight, and prevents a violation of OMS landing weight constraints. A tank failure can have much more serious implications because the trapped propellant cannot contribute any  $\Delta v$ , and it can lead to both CG and landing weight violations. A tank failure puts the Orbiter in a propellant-critical situation, and a two-stage deorbit may be required. The first priority in this case is to develop a plan for safe return of the crew.

If a tank failure occurs before deploy, the deploy is aborted until a new flight plan can be developed. The plan will almost certainly involve some type of deploy because landing with a stowed IUS and its payload will violate end-of-mission Orbiter weight limits. Two options are possible, depending on propellant available in the good pod. The first option involves a small posigrade sep, and a delay of the SRM-1 burn. The other option is a two-stage deorbit with the first stage being a retrograde perigee adjust.

The more attractive choice from a trajectory standpoint is to deploy on time, send Master Safe, perform a 3.3 fps posigrade separation burn at the nominal TIG, and recover from Master Safe after the prime injection node has passed. This forces the SRM-1 burn to occur one orbit late, and also places the Orbiter outside the 10X erosion contour. Of course, this option is only available if there is enough propellant in the good pod to perform a ConUS deorbit to shallow targets after doing the uphill sep. The small sep burn adds about 1.0 fps to the shallow deorbit  $\Delta v$ , and it avoids disadvantages of the elliptical orbit resulting from a perigee adjust. If enough propellant is available to cover this option, it can be used for a tank failure determined either before or after umbilical release.

If a pre-deploy tank failure demands a two-stage deorbit, the deploy will be done first because it significantly reduces Orbiter weight, which in turn reduces deorbit propellant requirements. Deploy has the secondary advantage of providing some hope for payload mission success. The deploy is scheduled for 15 min prior to TIG of the first-stage deorbit burn, which has an optimum perigee adjust TIG.

If the tank failure occurs between deploy and the nominal separation TIG, the crew will perform a 2 fps retrograde burn at the nominal TIG, maneuver to the viewing attitude, and transmit Master Safe. The first stage of the two-stage deorbit burn must be executed before Master Safe Recovery can be sent.

A retrograde separation burn following deploy places the Orbiter ahead of and below the IUS at SRM-1 firing. For safety reasons, a minimum miss distance of 30 nm, along with a minimum miss angle of 19° at closest point of approach (CPA), are required. Retrograde sep  $\Delta v$  must be quite large to meet these criteria. The minimum  $\Delta v$  is a function of IUS LVLH attitude at SRM-1 TIG, whether injection occurs at an ascending or descending node, and the perigee adjust time relative to IUS injection. Differences between the ascending and descending injection cases break down as follows.

	Ascending Injection	Descending Injection
Deploy	After end of deploy window	15 to 30 min early
SRM-1	Delayed one orbit	At next descending node
Coast Time	1.75 to 2.0 hrs	1.0 to 1.25 hrs

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The following table illustrates how the minimum retrograde sep  $\Delta v$  varies as a function of injection node and perigee adjust TIG. These data assume an IUS LVLH SRM-1 attitude of  $P=-5.57^\circ$  and  $Y=7.94^\circ$  (STS-26 values), together with a maximum IUS pitch attitude error of  $1.8^\circ$ . Constraints imposed were the minimum 30 nm miss distance, and  $19^\circ$  miss angle at CPA.

<b>Optimum TIG (min after asc node)</b>	<b>ASC Injection RETRO Sep <math>\Delta v</math> (fps)</b>	<b>DSC Injection RETRO Sep <math>\Delta v</math> (fps)</b>
-30	75	138
-25	84	126
-20	99	111
-15	124	90

IUS/Orbiter relative motion for cases with perigee adjust TIG 25 min before ascending node is illustrated in Figures 3.8.4.8.7-1 and 3.8.4.8.7-2. Unlike the usual relative motion plots, paths of both vehicles are shown with respect to a no-burn trajectory. The plot origin is therefore both spacecraft would be if there had been no sep or SRM burns.

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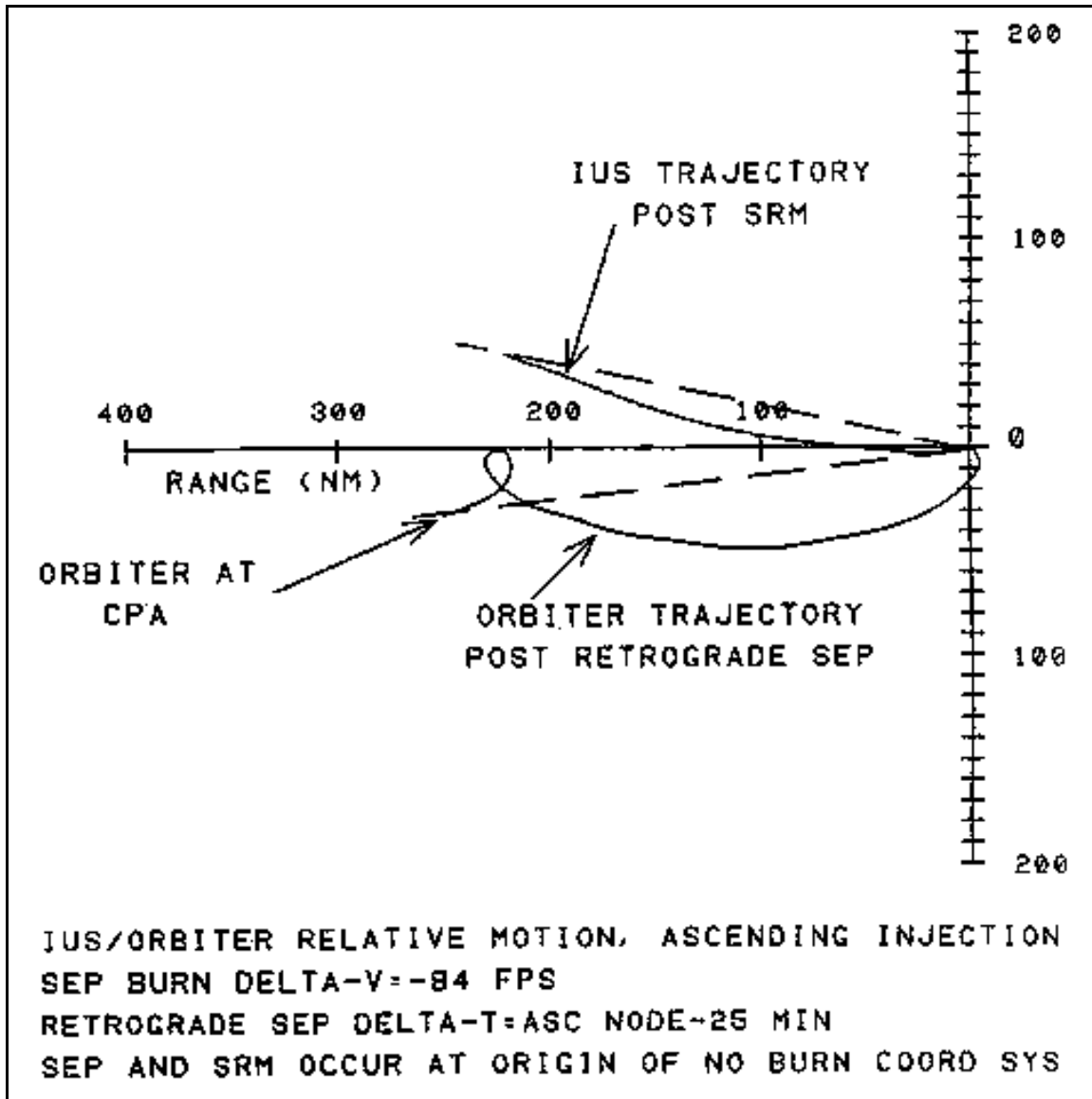


Figure 3.8.4.8.7-1: RETRO Sep Relative Motion (ASC Injection)



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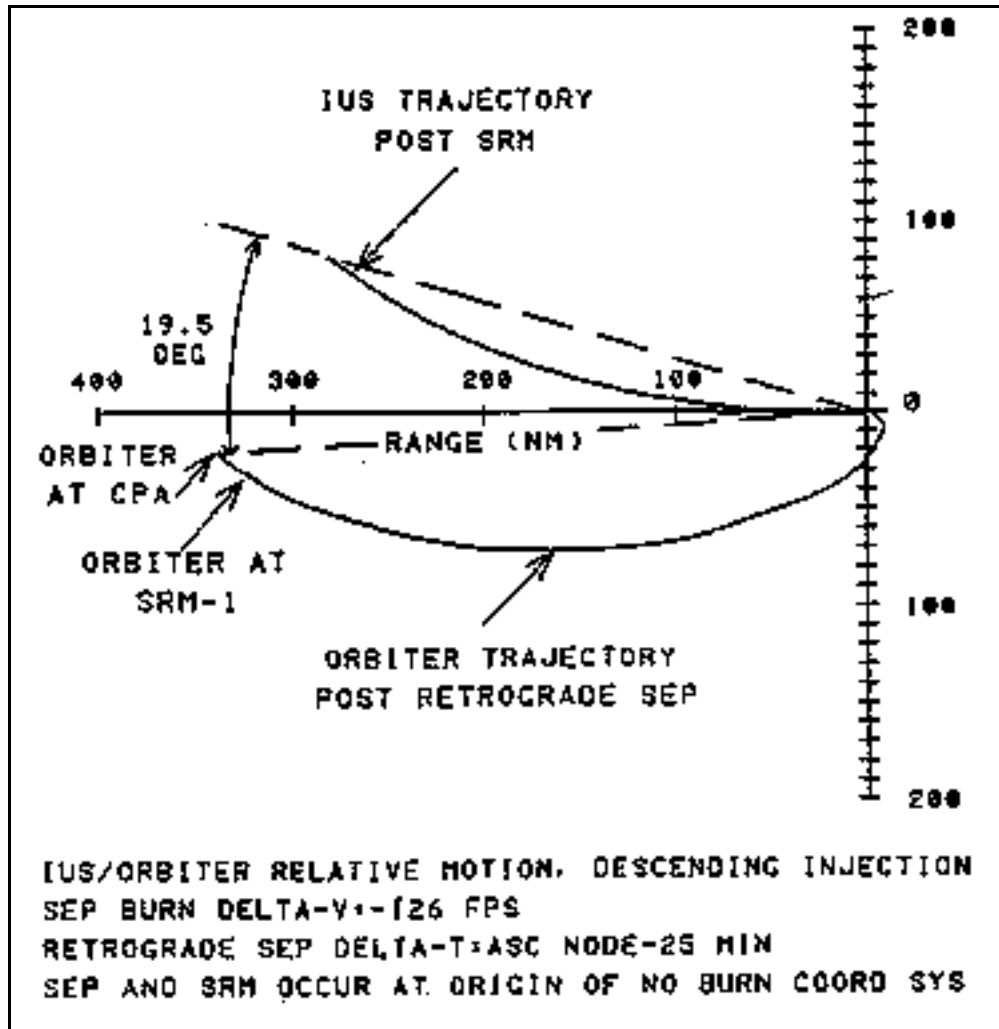


Figure 3.8.4.8.7-2: RETRO Sep Relative Motion (DSC Injection)

### 3.8.4.8.8 Off-Nominal Orbit Recovery Prior to IUS Deploy

What happens if the Orbiter is forced into an off-nominal orbit? Current flight rules say FD1 orbit raising burns may be performed to raise the parking orbit prior to the IUS deploy. Three scenarios exist in the following priority: First, raise the orbit to nominal altitude, protecting for a nominal separation burn. Second, raise the orbit as high as possible circular, protecting for a minimum separation burn. Third, raise the orbit elliptically only if it cannot be made circular. The third option also protects for a minimum separation burn, and the argument of perigee is optimized for ConUS deorbit. Steep deorbit on all ConUS opportunities for the entire mission, including extension days, must be protected by each option. Propellant-viable ELS deorbit opportunities must also be protected such that gaps never exceed 4.5 hrs (see FR A4.1.3-3, Off-Nominal Orbital Altitude Recovery Priorities).

An orbit altitude less than 135 nm would require overwriting the nominal IUS Mission Data Load (MDL) with the Operational Digital Data Load (ODDL) overlay uplink. Typically, the decision has been made to go as high as possible circular, but this decision is mission-specific and should be revisited each flight.

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### 3.8.4.8.9 IUS/TDRS Eclipse Constraints for Off-Nominal Orbits

Following a perigee adjust burn, or insertion into an off-nominal elliptical or very low circular orbit, special thermal constraints must be considered in determining IUS/TDRS deploy time. Thermal problems may arise from the effects of solar and free molecular heating at low altitudes. Constraints apply if the 16-min time interval following deploy occurs at heights between 80 and 105 nm. Above 105 nm, nominal deploy procedures apply.

The following eclipse constraints apply.

- 1) If  $90 \text{ nm} \leq \text{height} \leq 105 \text{ nm}$ , reschedule deploy window opening to occur between orbit noon and sunrise -24 min. The sunrise limit is the 8-min deploy window added to the 16 min during which the IUS/TDRS must be protected from direct sunlight. This 16-min period includes the worst-case time between deploy and initiation of TDRS thermal rolls, along with a 4-min pad which protects for one IUS jet failure and one spring failure.
- 2) If  $80 \text{ nm} \leq \text{height} \leq 90 \text{ nm}$ , reschedule deploy window opening to occur between noon +11 min and sunrise -24 min.

The nominal deploy procedure will be used if the period from deploy to deploy +16 min does not occur below 105 nm orbit height. This is an IUS/TDRS rule, and other payloads may have differing eclipse constraints.

### 3.8.4.8.10 IUS Revisit

To provide contingency commanding, it may be necessary for the Orbiter to come back towards the IUS after the separation burn has been executed. The act of coming back toward the IUS has become known as the "IUS Revisit" option. The Orbiter would have to stop the opening rate, begin a closing rate, stop the closing rate within Payload Interrogator (PI) range, and then initiate an opening rate before commanding can be done. The opening rate must place the Orbiter in a position at SRM at least equivalent to the relative position after a min sep. Crew procedures for an IUS Revisit are found in the Contingency Ops section of the Deploy Checklist.

It's easy to understand why this plan would be very expensive after having completed a large separation burn. On most flights, propellant margins will prohibit being able to execute an IUS Revisit. However, there will be some flights for which this capability will exist if some burns in the revisit plan are performed with RCS propellant.

Figures 3.8.4.8.10-1 and 3.8.4.8.10-2 are rendezvous constraints and eval tables constituting an IUS Revisit example. TIG for the first burn must be at least one orbit after separation. The exact time is determined by scanning relative motion digitals to find when the Orbiter will be nearest the -Vbar. If an NSR is performed when the Orbiter is on the -Vbar, opening rate will become near zero and the Orbiter will stationkeep at that range. As soon as the ground and crew can support it, an NC burn will be performed to start the Orbiter coming back towards IUS. A modification to the plan is to target the NC to bring the Orbiter to within 25 nm of the IUS. The second NSR burn is performed one orbit after the NC. This should result in putting the Orbiter on the -Vbar with near-zero closing rate. The THET secondary constraint on the second NSR is the phasing constraint used by the NC burn. If a different range is desired after the second NSR, the THET constraint must be adjusted. If commanding is successful and the IUS is going to perform SRM-1 at the next

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appropriate node, the  $\Delta v$  of the EXDV final sep burn is a function of coast time available the sep and SRM-1.

MANEUVER CONSTRAINTS TABLE REVISIT				
COMMENT: STS-54 IUS Revisit				CURRENT
				MNVRS: 6 / 40
MANEUVER	THRESHOLD	SECONDARIES		
1 EXDV	T 000:06:13:46.000	DVLV=0.0 = =	DVLV=2.2 = =	DVLV=0.0 = =
2 EXDV	T 000:06:27:46.000	DVLV=29.9 = =	DVLV=0.0 = =	DVLV=8.0 = =
3 NSR	M 1	= = =	= = =	= = =
4 NC	DT 000:00:10:00.000	= = =	= = =	= = =
5 NSR	M 1	DR. =.30 = =	= = =	= = =
6 EXDV	DT 000:00:10:00.000	DVLV=5 = =	DVLV=0 = =	DVLV=0 = =
		= = =	= = =	= = =

**Figure 3.8.4.8.10-1: Rendezvous Constraints Table for IUS Revisit**

MANEUVER EVALUATION TABLE REVISIT						
COMMENT: STS-54 IUS Revisit						
		MCT : REVISIT	OVT : PLOT			
		GMTR : 1992:338:13:43:00.000				
VECTOR	TIME	COMMENT:				
CHASER E5	M 000:06:00:00.000	STS-54 post CMS-2 (SGL)				
TARGET E3	M 000:06:12:46.000	IUS post deploy				
CHASER	DVtot = 107.21	DVx = 102.84	DVy = 2.20	DVz = 16.27		
TARGET	DVtot = 0.00	DVx = 0.00	DVy = 0.00	DVz = 0.00	6 MNVRS	
MNVR	NAME	GMTIG IMP	DVX	HA	RANGE	Y
COMMENT	METIG	DT	DVy	HP	PHASE	Ydot
DVMag			DVz	DW	Noon/Mid	SR/SS
1	EXDV	338:19:56:46.000	0.00	162.43	0.7094	-37.7
2.2		000:06:13:46.000	2.20	159.73	0.0113	2.0
		000:00:14:00.000	0.00	-0.01	N-00:09:17	SS-00:37:33
2	EXDV	338:20:10:46.000	29.90	177.71	0.7112	1434.1
31.0		000:06:27:46.000	0.00	162.08	0.0106	1.2
		000:01:30:51.274	8.00	0.04	M-00:40:37	SS-00:23:31
3	NSR	338:21:41:37.274	-30.04	162.47	81.3530	1042.1
31.2		000:07:59:37.274	0.00	159.62	1.2926	1.1
		000:00:10:00.000	-8.26	0.04	M-00:40:15	SS-00:23:07
	NC	338:21:51:37.274	-18.95	162.51	81.2943	1419.5
19.0		000:08:08:37.274	0.00	149.01	1.2915	0.5
		000:01:30:19.690	0.00	0.04	M-00:30:12	SS-00:13:02
5	NSR	338:23:21:56.964	18.94	162.43	30.0797	1631.9
18.9		000:09:38:56.964	0.00	159.63	0.4779	0.1
		000:00:10:00.000	-0.01	0.05	M-00:30:21	SS-00:13:10
6	EXDV	338:23:31:56.964	5.00	163.22	30.0272	1194.0
5.0		000:09:48:56.964	0.00	161.98	0.4771	-1.0
		000:00:00:00.000	0.00	0.05	M-00:20:19	SS-00:03:08

**Figure 3.8.4.8.10-2: Rendezvous Eval Table for IUS Revisit**

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The table in Figure 3.8.4.8.10-1 is not "canned" for all cases. Range achievable at the second NSR burn depends on current propellant budgeted. The minimum allowable range is 20 nm. To target a range, DR must be altered in the constraints table.

### **3.8.4.9 IUS Deploy Checklist**

The FDO IUS deploy checklist is a quick-look summary of most nominal and contingency procedures and rules governing an IUS deploy. Experience has shown the checklist to be a good memory aid for deploys of this type.

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<b>Tracking Arc:</b> (Check Autoque)
<b>POINTING Inputs:</b> <ul style="list-style-type: none"> <li>• Deploy Time, Beta, Ephemeris</li> <li>• Pitch and Yaw of IUS at SRM-1</li> </ul>
<b>WGL in EPH 1 at Deploy Time</b>
<b>Model Sep: Deploy +15 min, OL</b> <ul style="list-style-type: none"> <li>• PEG-7 Targets (fps): <ul style="list-style-type: none"> <li>29.9/0.0/8.0 = 31.0</li> <li>14.5/0.0/3.9 = 15.0</li> <li>09.7/0.0/2.6 = 10.0</li> </ul> </li> <li>• TVR: 90° (+β); 270° (-β)</li> <li>• Nom Sep in EPH 1; Min Sep in EPH 2</li> </ul>
<b>Orbiter Deploy Att from POINTING:</b> <ul style="list-style-type: none"> <li>• TGT ID 4 (Sun), BV 5</li> <li>• Pitch = 360° - (75° +  β ), Yaw = 0.0</li> <li>• Omicron = 90° (+β); 270° (-β)</li> </ul>
<b>IUS Deploy Att from POINTING:</b> <ul style="list-style-type: none"> <li>• Orbiter Attitude Pitched Up 58°</li> </ul>
<b>Model Spring Eject at Deploy:</b> <ul style="list-style-type: none"> <li>• EPH 3 : 0.4 fps Δv</li> <li>• BFI, MISC, Indicator A</li> </ul>
<b>Model Backoff at Deploy +1 min:</b> <ul style="list-style-type: none"> <li>• EPH 1: 8 sec ΔT (Δv = 2.2 fps)</li> <li>• BFI, MXL, Indicator A</li> </ul>
<b>Nom + Min Sep Eph to POINTING</b>
<b>Window Protect Attitude:</b> <ul style="list-style-type: none"> <li>• TGT ID 1 (Target SV), BV 5</li> <li>• Pitch = 320° = f(Coast Time)</li> <li>• Yaw = 0.0</li> <li>• Omicron = POINTING call in real time</li> </ul>
<b>PEG-7 Sep Command Load:</b> <ul style="list-style-type: none"> <li>• Check Maneuver Monitor to Verify Correct Targets (DMT 1)</li> <li>• Incorrect TIG until Crew Loads Targets (ITEM 22)</li> </ul>
<b>PADs Distribution (~4:30 MET):</b> <ul style="list-style-type: none"> <li>• Deploy: CC, FD, FDO, FAO, PYLDS</li> <li>• Initiate Track at Deploy -40 min</li> <li>• Sep: CC, FD, FDO, FAO, PROP, GNC</li> </ul>
<b>Rendezvous NAV Enable:</b> <ul style="list-style-type: none"> <li>• ITEM 1 SPEC 33 (Deploy -25 min)</li> <li>• Notify FD</li> </ul>
<b>Backoff (Pitch Rate = -0.8°/sec):</b> <ul style="list-style-type: none"> <li>• Monitor MASK 1888 for Rates</li> <li>• Null Pitch Rate When: Pitch = 70° (FRCS); LOS = Tail (ARCS)</li> <li>• If 1 FRCS jet BAD, 2x TGO = 16 sec</li> <li>• &gt;1 fps Required or Use ARCS <ul style="list-style-type: none"> <li>• 14s PX2 at 5 min PET (4 fps)</li> <li>• Pitch Rate = 0.3 °/sec</li> </ul> </li> </ul>

<b>Tilt Table Angle &gt; 40°</b>
<b>Tilt Table Not Locked Down:</b> <ul style="list-style-type: none"> <li>• 1 OMS Sep Only</li> <li>• No Translation Pre-Deploy</li> </ul>
<b>Sep TIG Slips:</b> <ul style="list-style-type: none"> <li>• Behind Rbar, &lt;10X</li> <li>• 10 fps by Nom Deploy +31 min</li> <li>• If Coast Time &lt; 29 min <ul style="list-style-type: none"> <li>• 15 fps by Nom Deploy +39 min</li> <li>• Else, Send Master Safe and 2 fps posigrade by Deploy +39 min</li> </ul> </li> </ul>
<b>OMS Leak:</b> <ul style="list-style-type: none"> <li>• Pre-Umbilical Pull: Abort Deploy</li> <li>• Post-Umbilical Pull to Pre-Sep: <ul style="list-style-type: none"> <li>• Deploy ASAP, BA at Deploy +1m</li> <li>• Shallow Post-Min-Sep? <ul style="list-style-type: none"> <li>• Yes: Min Sep ASAP, deplete OOP, sign (ΔVy) = Sign (β)</li> <li>• No: Master Safe <ul style="list-style-type: none"> <li>• Fast: PADJ ASAP</li> <li>• Slow: 2 fps retro, then PADJ at optimum TIG</li> <li>• If PADJ &gt; 57 fps, Master Safe Recover</li> </ul> </li> </ul> </li> </ul> </li> <li>• Post-Sep to Deploy +52 min, see back</li> <li>• Post-Deploy +52 min <ul style="list-style-type: none"> <li>• WPA Until SRM-1 TIG +6 min</li> <li>• OMS Depletion Burn As Required</li> </ul> </li> </ul>
<b>OMS Tank Fail, Use FRCS Sep:</b> <ul style="list-style-type: none"> <li>• Pre-Umbilical-Pull: Abort Deploy, Plan Retro Sep, Deploy 15 min Prior to Optimum PADJ TIG</li> <li>• Post-Umbilical-Pull: Send Master Safe, Good Pod has Shallow? <ul style="list-style-type: none"> <li>• Yes: 3.3 Posi at Nom TIG, Master Safe Recover after Ascending Node.</li> <li>• No: 2.0 fps Retro at Nom TIG, Can Use Posi Aft Attitude for Retro Fwd Attitude but Increase Sep to 2.5 fps, Execute Deorbit 1st Stage Prior to Master Safe Recover</li> </ul> </li> </ul>
<b>FRCS Sep:</b> <ul style="list-style-type: none"> <li>• For Loss of 2 Deorbit Systems</li> <li>• Model BFI/MXL/LVLH</li> <li>• RPY = -85.4°/14.3°/-161.8° (β &gt; 0)</li> <li>• RPY = +85.4°/14.3°/+161.8° (β &lt; 0)</li> </ul>

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### **3.8.4.10 IUS Deploy Worksheet**

The FDO IUS deploy worksheet is used to document relevant data generated during an IUS deploy. It's intended to be used in conjunction with the FDO IUS deploy checklist.

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DEPLOY TIME

	/	:	:	
+	0	/	00	:
			01	:
				00

DEPLOY ATTITUDE		
ORBITER ADI/LVLH		IUS ADI/LVLH
____/____	R	____/____
____/____	P	____/____
____/____	Y	____/____

**DEPLOY PAD:**

PITCH \_\_\_\_\_

OMICRON \_\_\_\_\_

DEPLOY WINDOW \_\_\_\_\_:\_\_\_\_\_

NOM WPA OM \_\_\_\_\_

MIN WPA OM \_\_\_\_\_

FRCS BACKOFF TIG

	/	:	:	
+	0	/	00	:
			14	:
				00

OMS SEP TIG

	/	:	:	
--	---	---	---	--

BETA @ DEPLOY \_\_\_\_\_

**IUS @ SRM TIG:**

PITCH \_\_\_\_\_ YAW \_\_\_\_\_

	D/O Δv (ST/SH) NOM SEP	NO DEPLOY MIN SEP
ORB	____/____ ____/____	____/____ ____/____
ORB	____/____ ____/____	____/____ ____/____
VEHICLE WEIGHT	_____ _____	_____ _____

WINDOW PROTECT ATTITUDE		
NOM SEP ADI/LVLH		MIN SEP ADI/LVLH
____/____	R	____/____
____/____	P	____/____
____/____	Y	____/____

SHALLOW DV AVAILABLE (L/R) \_\_\_\_\_/\_\_\_\_\_

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### 3.8.5 TOS Deploy Procedures



Information specific to Transfer Orbit Stage (TOS) deploys is contained in the following subsections.

#### 3.8.5.1 Standard TOS Concepts

<b>Deploy Attitude</b>	Shades TOS during deploy; provides OOP relative motion
<b>Deploy Window</b>	30 sec (90 sec for last opportunity)
<b>Spring Ejection <math>\Delta v</math></b>	1.2 fps
<b>Separation TIG</b>	Deploy +17 min
<b>Nom Sep Targets</b>	$\Delta V_x=23.6$ , $\Delta V_y=0.0$ , $\Delta V_z=-4.6$ fps
<b>Min Sep Targets</b>	$\Delta V_x=07.9$ , $\Delta V_y=0.0$ , $\Delta V_z=-1.4$ fps (Deploy +17 min) $\Delta V_x=11.8$ , $\Delta V_y=0.0$ , $\Delta V_z=-2.1$ fps (Deploy +18 min) $\Delta V_x=18.7$ , $\Delta V_y=0.0$ , $\Delta V_z=-3.3$ fps (Deploy +24 min)
<b>Sep TIG Slip</b>	Nominal Deploy +39 min (Nom Sep) Nominal Deploy +31 min (Min Sep = 10 fps) Nominal Deploy +39 min (Min Sep = 15 fps)

#### 3.8.5.2 TOS-Specific Concepts

As noted earlier, TOS has characteristics similar to both the SSUS and the IUS. However, if one were to make a comparison, the TOS would behave more like the IUS than the SSUS. There are really only small changes in FDO deploy procedures between the IUS and TOS. Once IUS procedures are mastered, it will take little time to become proficient in TOS deploys. As a result, many of the procedures and concepts discussed in Section 3.8.4 are repeated in 3.8.5 for the sake of completeness.

**CAUTION:** TOS has only flown aboard the Shuttle once. Conversely, IUS has flown a total of 9 times, including STS-26, arguably the most-analyzed flight in Shuttle history. Numerous studies performed for the IUS during the pre-STS-26 stand down were never performed for TOS. Consequently, many deploy parameters in this section are specific to STS-51 and should be closely scrutinized before the next flight utilizing TOS as an upper stage.

##### 3.8.5.2.1 TOS Sequence Time

TOS employs a 45.1-min sequence from deploy until SRM ignition. This TOS characteristic most closely resembles SSUS. Since the SRM is activated via a hard-coded internal timer initiated at the time of deploy, this time is constant and cannot be changed. There is no equivalent to IUS Master Safe capability for TOS.

At deploy, TOS receives a 1.2 fps spring ejection impulse from its tilt table. The Orbiter provides additional opening rate by performing a 2.2 fps FRCS backoff burn in free drift at deploy +25 sec. This is exactly the same backoff as for IUS. By performing the backoff in free drift, FRCS engine cant will force the Orbiter to pitch down. This pitch rate will continue



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until a pitch value of  $-68^\circ$  is achieved, at which time the rate will be nulled for TOS viewing. At deploy plus 17 min, the Orbiter will perform a nominal separation burn of 24 fps posigrade. TOS injection occurs at deploy +45.1 min.

### 3.8.5.2.2 TOS Injection Node

The nominal injection node for ACTS/TOS on STS-51 was driven by RAAN constraints. For STS-51, this equated to a 7A injection. See Figure 3.8.5.2.2-1 for the STS-51 launch window. This is one orbit later than the traditional IUS timeline and relieves a pretty compact sequence of events. An 8D opportunity exists as with IUS, but it is not considered viable because it violates *SSP Crew Procedures Management Plan* Appendix K constraints for the length of a crew day. Backup deploy opportunities include 23A on FD2 and 38A on FD3.

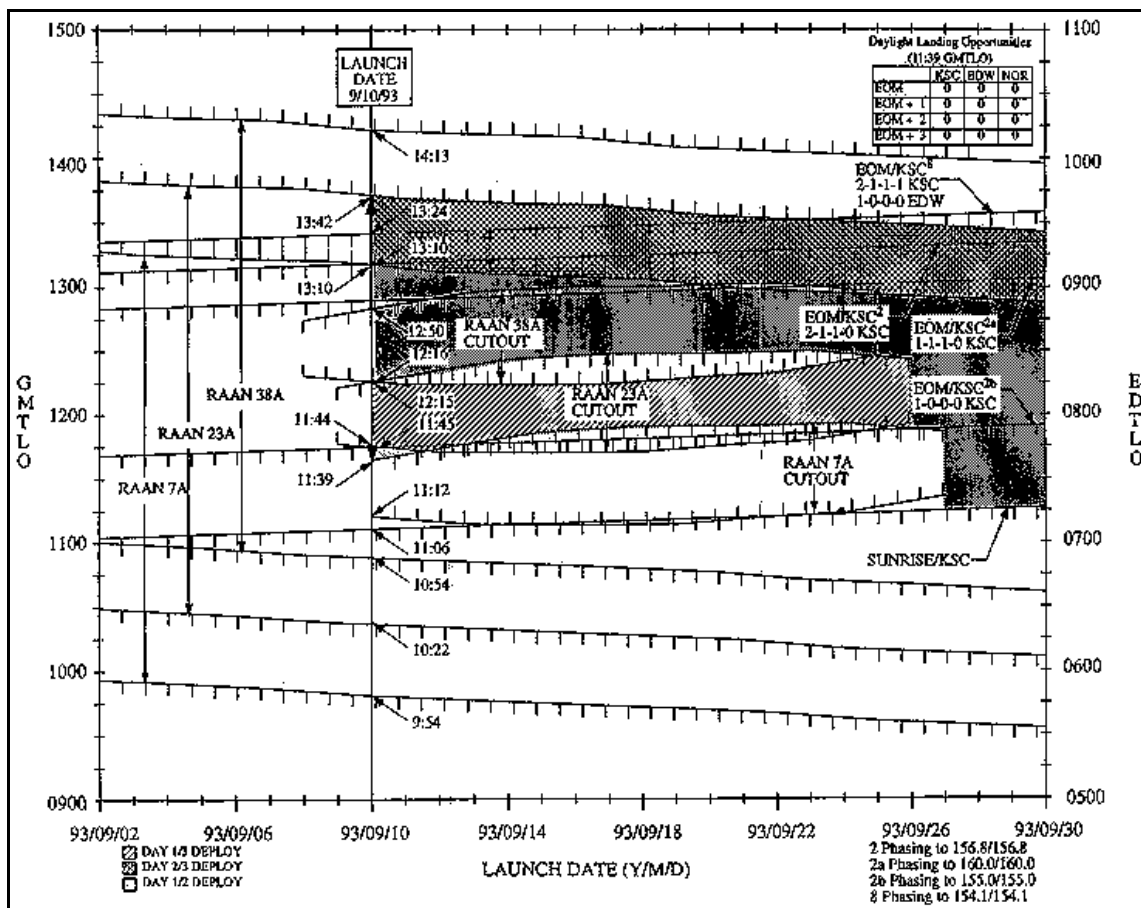


Figure 3.8.5.2.2-1: STS-51 Launch Window

### 3.8.5.2.3 TOS Deploy Window

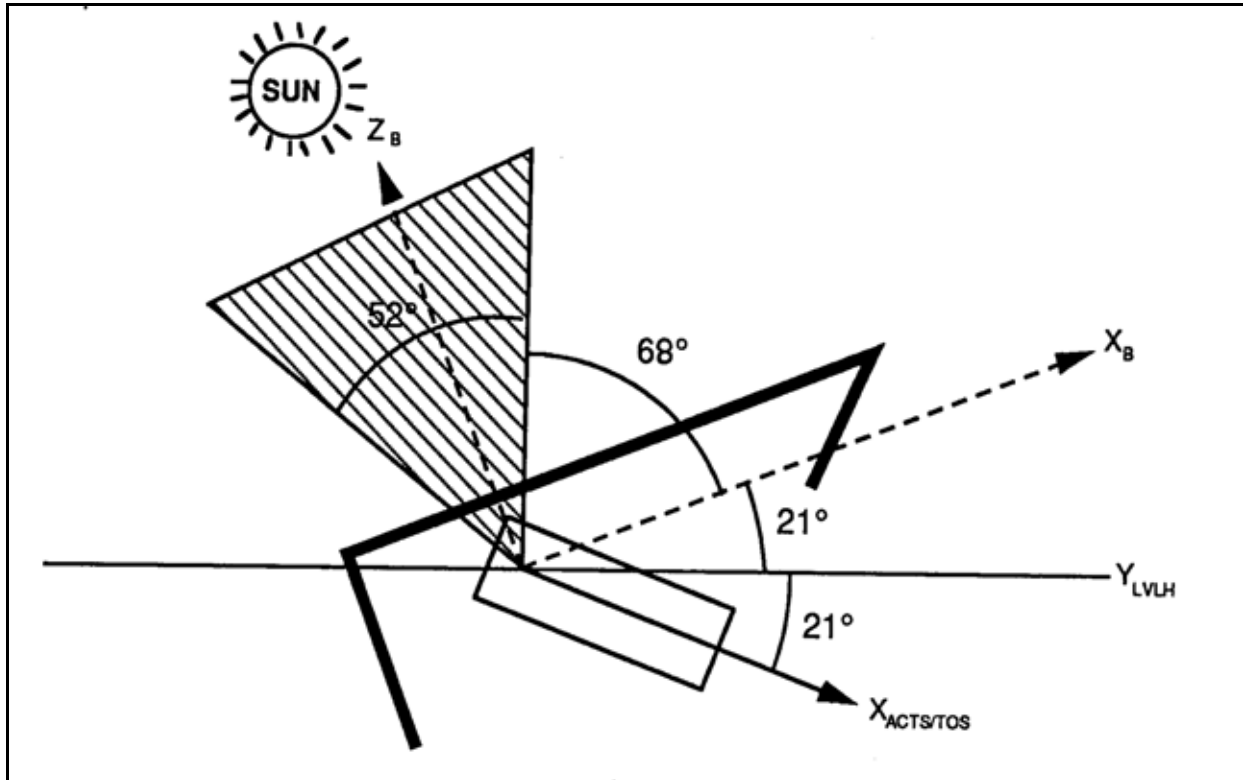
The TOS deploy window is nominally only 30 sec in duration. This short window, like that of a SSUS, is driven by SRM ignition's constraint to occur precisely at deploy +45.1 min. However, in the event the last deploy opportunity for the entire mission is reached, the 30

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sec window is relaxed up to 90 sec. The larger window could spell the difference between some kind of viable payload mission and return or jettison.

### 3.8.5.2.4 TOS Deploy Attitude

TOS must be shaded from direct sun at deploy to optimize subsequent crew visual acquisition. Deploy attitude, like that for IUS, has been designed generically such that it satisfies this requirement. Additionally, this attitude results in relative motion between the TOS and Orbiter being directly out-of-plane after the backoff burn (see Figure 3.8.5.2.4-1).



**Figure 3.8.5.2.4-1: Orbiter/TOS Deploy Attitude**

The LVLH deploy attitude, starting from Orbiter Body pitch = yaw = roll = 0 (nose forward and heads up) is computed at deploy time by the following sequence.

- 1) Pitch to place the sun in the Body X/Y plane.
- 2) Yaw  $\pm 68^\circ$ , pointing post-backoff IUS/Orbiter relative velocity directly out-of-plane. The sign of this yaw rotation is selected to direct the +X Body axis away from the sun. After the yaw, the sun remains in the Body X/Y plane.
- 3) Roll  $\pm 90^\circ$  to point the +Z Body axis at the sun. The sun is now in the Body X/Z plane with the payload bay in shadow. Relative to TOS, the sun is off the -X axis by  $42^\circ - |\beta|$ .

These rotations can be expressed as a function of the sun's LVLH position unit vector components  $[X_{SUN}, Y_{SUN}, Z_{SUN}]^T$ . The sign of  $Y_{SUN}$  is negative the sign of  $\beta$ .

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Orbiter Deploy Attitude:

$$P = \arccos \{X_{\text{SUN}}\} \text{ sign } \{-Z_{\text{SUN}}\}$$
$$Y = -68^\circ \text{ sign } \{Y_{\text{SUN}}\} = 68^\circ \text{ sign } \{\beta\}$$
$$R = -90^\circ \text{ sign } \{Y_{\text{SUN}}\} = 90^\circ \text{ sign } \{\beta\}$$

TOS Deploy Attitude:

$$P = \arccos \{X_{\text{SUN}}\} \text{ sign } \{-Z_{\text{SUN}}\}$$
$$Y = -(68^\circ + \text{Tilt Table Elevation}) \text{ sign } \{Y_{\text{SUN}}\}$$
$$= (68^\circ + \text{Tilt Table Elevation}) \text{ sign } \{\beta\}$$
$$R = \text{N/A}$$

The Deploy Checklist utilizes Universal Pointing for the maneuver to deploy attitude 15 min after the TOS Burn Initialization Maneuver (BIM) uplink is complete at approximately deploy -45 min. It expresses the deploy attitude in terms of an Orbiter body vector directed at the sun as follows.

$$\text{TGT ID} = 4 \text{ (Sun)}$$
$$\text{BV} = 5 \text{ (crew-specified P-Y-OM)}$$
$$P = 360 - (68 + |\beta|)$$
$$Y = 0$$
$$\text{OM} = 090 \text{ } (\beta > 0) \text{ or } 270 \text{ } (\beta < 0)$$

For MCC modeling, POINTING displays the attitudes of both the Orbiter and TOS at deploy on SUPERSIGHTER. These attitudes can be used for BFI burn modeling of the backoff and spring ejection. The TOS attitude may or may not be the same as the formulas in this section, depending on how POINTING inputs data to the SUPERSIGHTER processor. Options are an attitude conversion from LVLH to M50 or a simple pitch of the Orbiter's attitude to the tilt table's elevation angle. However, in all cases, the attitude POINTING gives FDO will be equivalent to the attitude computed from the given formulas. Figures 3.8.5.2.4-2 and 3.8.5.2.4-3 show the Orbiter and TOS attitudes at deploy, respectively.

**NOTE:** similar to IUS deploy procedures, the SUPERSIGHTER display for any future TOS missions will be sent to the FDO workstation from the POINTING workstation. SUPERSIGHTER format is different than when TOS was last deployed and is illustrated in Section 3.8.4.5.

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51		SUPERSIGHTER				1875G CH005		
INPUT MATRIX	MIR603	ATT SOURCE	MED	I/P LVLH BIAS	CUBL00			
OUTPUT MATRIX	MIR603	EPH 1	YID 29	O/P LVLH BIAS	CUBL00			
MODE 58								EIGEN VECTOR
ELV -72.00	INPUT ATT SENSE AX				P			
VEH		R	MEG		Y	EIGEN ANGLE		
RANGE		P						
MODE 2		Y						
LAT								
LON 0.00								
TARGET 1 SUN		OUTPUT A				IA1 S04		
RA 170.29		+X	-X	-Z		A1	291.50	
DEC 4.18		R 178.77	R 1.23	R 30.40	AOI	A2	0.00	
LAT		P 113.57	P 293.57	P 22.95		A3	90.00	
LON		Y 30.39	Y 329.61	Y 1.06		IA2 S04		
ALT						A1	15.90	
RNG		R 90.00	R 90.00	R 90.00	LVLH	A2	-43.65	
		P 93.21	P 273.21	P 273.21		IB1		
		Y 68.04	Y 291.96	Y 21.96		A1		
TARGET 2 1		OUTPUT B				A2		
RA 65.82		+X	-X	-Z	AOI	IB2		
DEC -17.56		R	R	R		A1		
		P	P	P	LVLH	A2		
		Y	Y	Y				
		R	R	R				
		P	P	P				
		Y	Y	Y				
MET		GMT		E M S				
\$T	0:07:58:09	255:19:43:09	+X RA	124.29	P	112	303 292	
AOS	0:07:58:09	255:19:43:09	-Z RA	1.15	Y	357	314 360	
TCA	0:07:58:09	255:19:43:09	DEC	-52.248	0	112	68 68	
LOS	0:08:24:20	255:20:09:20	DEC	-22.948	+	357	231 180	

7A FINAL  
 ORBITER DEPLOY ATT

Figure 3.8.5.2.4-2: Orbiter Deploy Attitude

# FDO Console Handbook Section 3.8: Payload Deploys

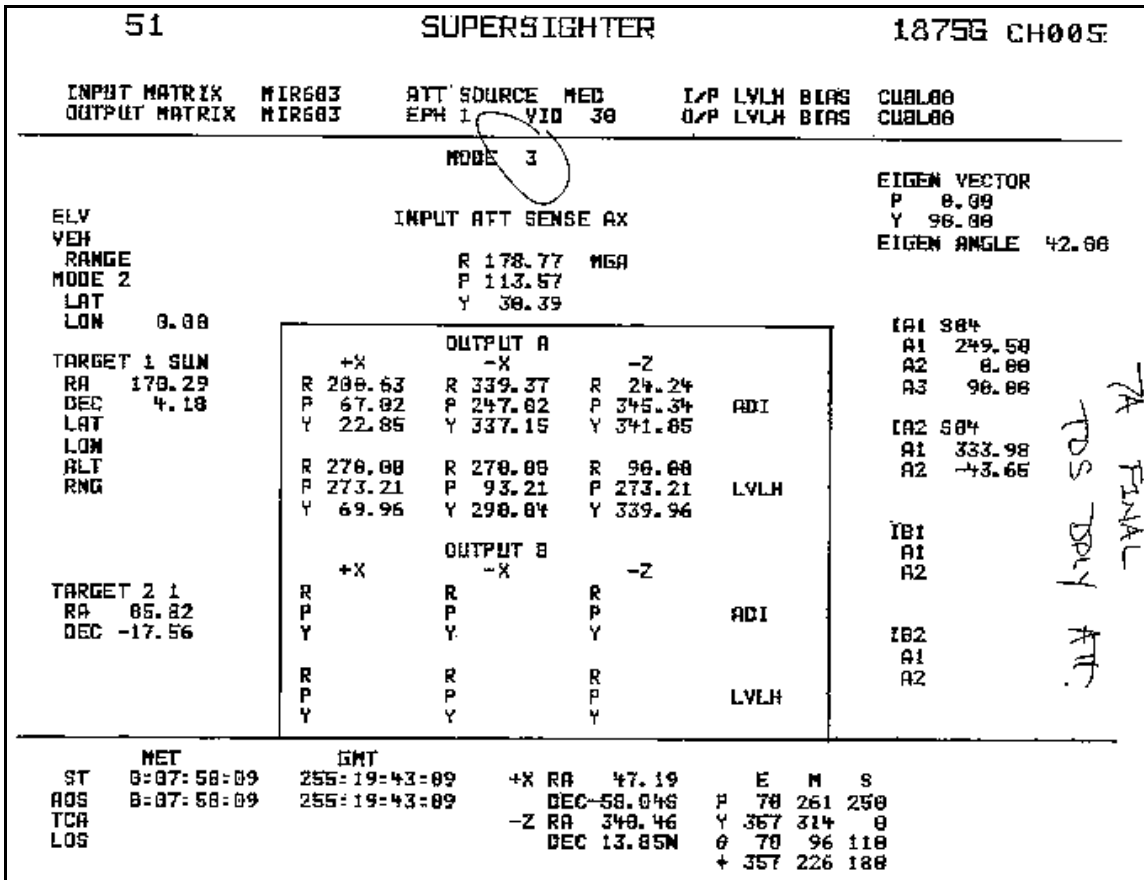


Figure 3.8.5.2.4-3: TOS Deploy Attitude

### 3.8.5.2.5 TOS Spring Δv

TOS is deployed using a specially configured aft flight deck panel. The TOS slides out of the tilt table (or tilt actuator) at 1.2 fps. In the payload ephemeris, typically EPH 3, FDO models the spring Δv with a BFI burn using the TOS deploy attitude POINTING has supplied and the miscellaneous (M) thrusters. Miscellaneous thrusters are used because they are the only thrusters aligned with the +X body-fixed axis. This condition is consistent with POINTING's TOS deploy attitude.

### 3.8.5.2.6 TOS Backoff Burn

The backoff burn is very similar to that for IUS and is required because spring ejection is only 1.2 fps. Only a few parameters are changed.

Post deploy, the Orbiter will perform the 2.2 fps backoff in free drift. Due to FRCS jet canting, the Orbiter will begin a pitch down. The crew will command FRCS thrusting until the pitch rate climbs to -0.8°/sec. Nominally, this will take about 8 sec. When the pitch value approaches 68°, the rate will be nulled.

## **FDO Console Handbook Section 3.8: Payload Deploys**

For the FRCS failure scenario, one jet can still be used. The total jet on time, however, will be increased to approximately 16 sec. The same  $-0.8^\circ/\text{sec}$  pitch rate and  $68^\circ$  final pitch value still apply.

If the FRCS is lost entirely, or if a pitch rate magnitude of less than  $0.8^\circ/\text{sec}$  cannot be achieved, ARCS can be used to provide safe relative motion. In this case, the backoff will occur at deploy +5 min, and a 4 fps burn will be performed in free drift. Total pitch rate will be  $+0.3^\circ/\text{sec}$ , and the rate will be nulled when the TOS line-of-sight approaches the Orbiter's tail.

### **3.8.5.2.7 TOS Attitude Improvement Maneuvers (AIMs)**

Like AMU data takes for IUS, TOS has its own attitude refinement methods. Attitude Improvement Maneuvers (AIMs) are used to correct small misalignments between Orbiter body-fixed axes and those fixed to TOS. An AIM is composed of 4 Orbiter attitude maneuvers. After each maneuver, the Orbiter will collapse its attitude deadbands to  $0.1^\circ$  and  $0.01^\circ/\text{sec}$  in all three axes. By comparing differences between the TOS LINS and the Orbiter IMUs, an error quaternion can be developed which will increase BIM attitude accuracy.

It is not required to complete the AIM sequence in order to compute BIM attitude. However, improved accuracy means longer mission lifetime for satellites that rely on TOS. In time-critical situations like hazardous payload deploys, AIMs can be deleted and corresponding decreases in SRM performance accepted. Known as "AIM-less BIMs", TOS attitude is deemed acceptable for continuing deploy ops, since the alternative is to jettison TOS with no hope for a mission.

### **3.8.5.2.8 TOS Burn Initialization Maneuver (BIM)**

Like a SSUS, TOS SRM ignition is triggered by an internal timer that counts down to zero 45 min 6 sec after deploy. Therefore, no Master Safe capability exists for the TOS. However, like IUS, TOS can be deployed in any attitude since the TOS has its own internal guidance and can maneuver to the correct SRM ignition attitude. This attitude, known as the Burn Initialization Maneuver (BIM) attitude, is not computed on-board the TOS but is uplinked via ground command. So as long as a BIM is on-board TOS, deploy can occur in any attitude because TOS will maneuver to BIM attitude post-deploy.

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### 3.8.5.3 STS-51 TOS Deploy Timeline

MET (hh:mm)	Event (DPLY +mm:ss)
01:00	Post-OMS 2 SV to TOS MISSION and ACTS MISSION for preliminary computations
01:45	Preliminary 5A SRM TIG and BIM attitude to FDO from TOS MISSION
02:30	Preliminary 7A SRM TIG and BIM attitude to FDO from TOS MISSION
03:00	Preliminary 7A deploy time voiced to FD after ACTS MISSION confirmation
03:15	Preliminary 6A SRM TIG and BIM attitude to FDO from TOS MISSION
03:30	End of tracking arc (Orbit 3 ANTC)
03:45	Tracking arc SV to TOS MISSION and ACTS MISSION for 7A and 8A opportunities and uplink
04:30	Final 7A SRM TIG and BIM attitude to FDO from TOS MISSION
05:00	7A TOS DEPLOY PAD to crew after ACTS MISSION confirmation
05:15	Final 8A SRM TIG and BIM attitude to FDO from TOS MISSION
05:30	Approximate 7A AIM sequence start
06:10	Approximate 7A BIM uplink
07:15	7A MNVR PAD and deploy Flight Rule updates to crew
07:50	GO for deploy to crew
07:58	Approximate 7A TOS Deploy
07:59	RCS backoff burn (DPLY +00:25)
08:07	MNVR to sep burn attitude (DPLY +09:00)
08:15	OMS separation burn (DPLY +17:00)
08:27	MNVR to Window Protect Attitude (DPLY +29:00)
08:44	Approximate 7A TOS SRM TIG (DPLY +45:06)

### 3.8.5.4 TOS PADs

Two sets of PADs are read up to the crew before a TOS deploy. FDO fills out two forms, the TOS Deploy and the Sep Burn PAD, distributes copies, and checks accuracy as the CAPCOM reads them up and the crew reads back. The TOS deploy PAD is illustrated in Figure 3.8.5.4-1.

# FDO Console Handbook Section 3.8: Payload Deploys

## TOS DEPLOY PAD

INJ ORBIT \_\_\_\_\_

BIM ATTITUDE

R	<input type="text"/>	<input type="text"/>	<input type="text"/>	.	<input type="text"/>
P	<input type="text"/>	<input type="text"/>	<input type="text"/>	.	<input type="text"/>
Y	<input type="text"/>	<input type="text"/>	<input type="text"/>	.	<input type="text"/>

---

DEPLOY ATT

P	<input type="text"/>	<input type="text"/>	<input type="text"/>	.	<input type="text"/>
OM	<input type="text"/>	<input type="text"/>	<input type="text"/>	.	<input type="text"/>

INITIATE TRK

\_\_\_ / \_\_\_ : \_\_\_ : \_\_\_

DEPLOY TIME

<input type="text"/>	/	<input type="text"/>	<input type="text"/>	:	<input type="text"/>	<input type="text"/>	:	<input type="text"/>	<input type="text"/>
----------------------	---	----------------------	----------------------	---	----------------------	----------------------	---	----------------------	----------------------

DEPLOY WINDOW

<input type="text"/>	:	<input type="text"/>	<input type="text"/>
----------------------	---	----------------------	----------------------

BETA

<input type="text"/>
----------------------

WINDOW PROT OM

<input type="text"/>	<input type="text"/>	<input type="text"/>	.	<input type="text"/>
----------------------	----------------------	----------------------	---	----------------------

Figure 3.8.5.4-1: TOS Deploy PAD



## FDO Console Handbook Section 3.8: Payload Deploys

Inputs for the TOS deploy PAD are as follows.

Item	Source/Comments
BIM Attitude ( R )	Orbiter LVLH Roll from POINTING's SUPERSIGHTER display
BIM Attitude ( P )	Orbiter LVLH Pitch from POINTING's SUPERSIGHTER display
BIM Attitude ( Y )	Orbiter LVLH Yaw from POINTING's SUPERSIGHTER display
Deploy Attitude ( P )	Orbiter's Universal Pointing pitch input from POINTING's SUPERSIGHTER display: check value based on equation as a function of beta angle
Deploy Attitude ( OM )	Orbiter's universal pointing omicron input from POINTING's SUPERSIGHTER display
Initiate Track	BIM uplink +15 min (~deploy -45 min)
Deploy Time (MET)	From TOS MISSION
Beta	Sign of $\beta$ at deploy (+ or -)
Window PROT OM	Window Protect Omicron from POINTING's SUPERSIGHTER display

The original PAD goes to CAPCOM, and one copy each is routed to Flight Director, FDO, PAYLOADS, and FAO.

### 3.8.5.5 TOS Deploy Computations

The following FDO computations and procedures can be used for either preliminary or for final state vectors.

- 1) With a TOS SRM TIG provided by TOS MISSION, compute deploy time by subtracting 45.1 min from SRM TIG. TOS MISSION will also provide TOS pitch and yaw at SRM TIG.
- 2) Provide POINTING with the deploy time,  $\beta$  at deploy, BIM attitude, and the nominal Orbiter ephemeris.
- 3) Make two entries to the Orbiter ephemeris: a WGL to remove the TOS/payload weight at deploy time, and a sep burn at deploy +17 min. Nominal PEG-7s are  $\Delta V_x = 23.6$ ,  $\Delta V_y = 0.0$ ,  $\Delta V_z = -4.6$  fps. Since the Orbiter is protecting TOS from direct sunlight, sep burn TVR is a function of  $\beta$ . This keeps TOS in the overhead windows during the sep burn. For  $\beta \geq 0.0$ , use a TVR of  $90^\circ$ . For  $\beta < 0.0$ , use a TVR of  $270^\circ$ .
- 4) Modify mass properties tables to reflect deploy so engine trims are correct for the sep burn.
- 5) POINTING displays Orbiter and TOS deploy attitudes on SUPERSIGHTER for FDO.
- 6) Use TOS deploy attitude to model the TOS spring ejection impulse in the payload ephemeris. This attitude is simply the Orbiter attitude pitched up  $42^\circ$ . The spring ejection burn is modeled with BFI guidance, indicator A, and a total  $\Delta v$  of 1.2 fps.

## FDO Console Handbook Section 3.8: Payload Deploys

- 7) Uses Orbiter deploy attitude to model the 2.2 fps FRCS backoff burn in the Orbiter ephemeris. Input a TIG = deploy +25 sec, BFI guidance, indicator A, and  $\Delta v = 2.2$  fps. If FRCS is not available, model the backoff burn using the same attitude with ARCS and  $\Delta v = 4.0$  fps at Deploy +5 min.
- 8) Model the min sep burn in a secondary Orbiter ephemeris by anchoring on the burnout vector of the backoff burn in the prime Orbiter ephemeris. Initial weight should be the same as the backoff burnout weight. Min sep PEG-7s are  $\Delta V_x = 7.9$ ,  $\Delta V_y = 0.0$ ,  $\Delta V_z = -1.4$  fps.
- 9) When all of the above has been accomplished, inform POINTING Orbiter ephemerides are ready for window protect attitude calculations. POINTING also uses the TOS pitch and yaw for this task.
- 10) POINTING gives FDO the window protect Omicron via SUPERSIGHTER, which FDO records on the TOS Deploy PAD.
- 11) FDO fills out the Deploy and Sep PADs, then generates a PEG-7 command load for the separation burn.

A "perfect" set of hardcopies documenting TOS computations includes 3 DMTs (backoff, sep, and spring ejection), 3 SUPERSIGHTERS (Orbiter and TOS deploy attitudes and WPA), a WGL showing deploy weight loss, and an MSK 2310 showing ephemeris status.

### 3.8.5.6 Modeling the TOS SRM Burn

FDO does not normally have to model the TOS SRM-1 burn because TOS MISSION will supply a predicted vector. However, in some simulations, FDO is asked to provide a post-SRM-1 PSAT or groundtrack, and no simulated vector is available. The following information is provided to approximate the SRM-1 burn in the payload ephemeris.

**CAUTION:** a payload ephemeris modeling post-SRM-1 flight may produce a high-eccentricity trajectory with values approaching or exceeding 1. Applications such as PPD or 2-D DEMOS may fail if they process such an ephemeris because they assume all trajectories are of low eccentricity.

Before modeling the burn, FDO must configure Miscellaneous thrusters in the Engine Characteristics Table to reflect the TOS thrust and mass flow rate. The following values are only approximations to support PFNI modeling.

Thrust = 50000 lbs  
Flow Rate = 150 lbs/sec

The TOS ephemeris should be configured with correct TOS/payload weight, Area = 230 ft<sup>2</sup>, KCON = 1, and the spring ejection burn modeled as described in Section 3.8.5.2.5. The SRM-1 burn is modeled with the following inputs.

Guidance Mode = BFI  
Thrusters = Miscellaneous  
TIG = Deploy +45.1 min

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Attitude Indicator = L (LVLH)

LVLH R = 0

LVLH P = value from TOS MISSION, or canned sim value =  $356.35^\circ$  (STS-51)

LVLH Y = value from TOS MISSION, or canned sim value =  $46.03^\circ$  (STS-51)

Total  $\Delta v$  = 10580 fps (STS-51)

This burn should typically place the TOS/payload in a semisynchronous transfer orbit with 12-hour period. STS-51 values reflect transfer with a supersynchronous apogee. Check your solution for reasonableness on the DMT.

### 3.8.5.7 TOS Contingency Operations

The following subsections describe IUS failure scenarios and associated FDO responses.

#### 3.8.5.7.1 TOS Emergency Timeline

The emergency timeline compresses nominal deploy events as much as possible. Mandatory crew procedures are denoted in the Deploy Checklist by a preceding box. The separation sequence has three modifications.

- 1) Move the maneuver to separation burn attitude from deploy +9 min to deploy +2.5 min, a point directly after pitch rate is nulled.
- 2) Move OMS separation TIG from deploy +15 min to ASAP after achieving burn attitude.
- 3) Delete the TOS viewing attitude maneuver. If TOS is hazardous, pointing the payload bay towards it is not acceptable and may delay maneuvering to window protect attitude.

#### 3.8.5.7.2 Loss of FRCS During TOS Deploy

There are three forward RCS jets (F1F, F2F, F3F) supporting -X translation. OPS 2 guidance allows only two of the three jets to fire, normally F1F and F2F. If either of these jets fail, F3F will automatically be substituted. However, this downmode generates an effective thrust yaw moment because the Y-Body component of F3F will not cancel the Y-body component of F1F or F2F. Fortunately, this yaw amounts to only  $0.8^\circ$  during an otherwise nominal backoff burn, and it can be ignored.

If two of the three FRCS jets are known to be failed pre-deploy, consideration should be given to increasing burn time of the backoff. With only half of the backoff  $\Delta v$ , single-jet pitch rate will be half its nominal value, and it will take twice as long to pitch down  $68^\circ$ . More importantly, Orbiter/TOS range at separation TIG will be half its nominal value. This is still a safe distance from which to execute the OMS separation burn, but doubling the backoff burn time and maintaining nominal relative motion is a better single-jet backoff plan. The crew will double the backoff burn time since they are using pitch rate as the burn termination criterion.

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Procedures addressing complete loss of FRCS utilize nominal actions with two modifications.

- 1) Replace the 2.2 fps -X RCS backoff burn at deploy +25 sec with a 4.0 FPS +X RCS “backoff” burn at deploy +5 min.
- 2) Terminate free-drift-induced negative pitch rate when TOS line-of-sight is near the Orbiter tail instead of at 68°.

### 3.8.5.7.3 TOS Tilt Table Not Locked Down

If the tilt table cannot be lowered and locked down post-deploy, flight rules dictate the separation burn will use a single OMS engine. Pre-deploy, no translations of any kind can take place without the tilt table being locked down. These restrictions are due to structural load concerns with an unlocked tilt table.

### 3.8.5.7.4 TOS Sep TIG Slips

Two criteria define safe distance from the TOS at SRM-1 firing. The Orbiter must be in a position to receive no more than 10X erosion from the exhaust plume, and it must be on or behind the TOS Rbar. Even with a nominal, on-time separation burn, relative motion plots reveal the Orbiter is ahead of TOS for some time after TIG. Generally, the Orbiter can delay sep TIG up to 29 min after deploy. The separation  $\Delta v$  will need to increase for the min sep case as slip is increased. Per the Deploy Checklist, the crew will increase min sep  $\Delta v$  as follows.

**If TIG slip or unable to accomplish MIN SEP:  
Determine min delta V reqd using new TIG:**

	MIN SEP	TIG SLIP	TIG SLIP
	8 fps	12 fps	19 fps
TIG relative to TOS DPY	+17	+18	+24

**Repeat step 3 for new TIG & targets from SEP  
BURN PAD, p. 6-57  
Do not slip TIG past DPY +29**

### 3.8.5.7.5 Leaking OMS Propellant During TOS Deploy Operations

Standard on-orbit procedure calls for a burn to depletion of the leaking OMS as soon as possible after detecting the leak. If there is insufficient propellant in the good pod to support a deorbit to shallow targets from the current orbit, the depletion burn will always be a perigee adjust. If the good pod can support a shallow deorbit, FDO evaluates whether performing a perigee adjust will increase or decrease deorbit  $\Delta v$  to a ConUS landing site. If  $\Delta v$  will decrease, the burn will be a perigee adjust. If  $\Delta v$  will increase, the burn will be executed out-of-plane in the direction that will decrease crossrange to the next PLS.

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If the leak occurs in the middle of a TOS deploy, matters become more complicated. Flight rules require that no OMS burns be executed with an unstowed TOS. Therefore, the TOS must be either restowed or deployed before the OMS burn can take place.

The decision to deploy or to restow depends on whether or not TOS umbilical pull has occurred. Umbilical pull is the irreversible event disconnecting TOS from Orbiter power. If the leak is detected before umbilical pull, TOS will be restowed, and the OMS burn will be performed according to non-deploy OMS leak procedures. If the leak occurs after umbilical pull, the TOS will be deployed using emergency procedures.

If the TOS is to be deployed, FDO's next decision depends on whether or not shallow deorbit capability exists to a ConUS site from the post-deploy, post-min-sep orbit. If this capability does exist, the crew will do a min sep ASAP following the 2.2 fps backoff, then burn the leaking OMS to depletion out-of-plane. In this case, it was decided to simplify procedures and always burn OOP, regardless of OOP TIG window limits.

If there is no shallow ConUS deorbit capability, the crew will jettison TOS and perform a perigee adjust ASAP. The jettison is required because there is no Master Safe capability for TOS like there is on IUS. If the OMS leak is extremely slow, a 2 fps retrograde burn will be performed at the nominal sep TIG, and a perigee adjust will be executed at the next optimum perigee adjust TIG. An "extremely slow" leak is so slow that it takes hours to detect, and it is therefore possible to await optimum perigee adjust TIG.

If a perigee adjust is required after a nominal or minimum separation burn but before SRM-1 ignition, relative position of the Orbiter and TOS at SRM depends on perigee adjust TIG and  $\Delta v$ . For cases in which the perigee adjust occurs soon after the sep burn, the Orbiter will be below and ahead of the TOS at SRM-1. If the perigee adjust occurs very late in the sequence, the Orbiter may be well behind and slightly below the TOS at SRM-1. These variations obviously call for very different window protect attitudes. If shallow deorbit capability will exist after a 12 fps posigrade separation, the crew performs min sep from the leaking side, followed by the perigee adjust. Otherwise, a retrograde separation, combined with a perigee adjust to yield at least 12 fps  $\Delta v$ , is required to maintain the 10X erosion limit.

Generally, if shallow deorbit capability exists after the separation, an OOP OMS depletion is executed. Otherwise, a perigee adjust is required of at least 50 fps in order to adhere to the 10X erosion limit.

### **3.8.5.7.6 OMS Tank Failure During TOS Deploy Operations**

The term "OMS tank failure" means OMS fuel or oxidizer in the failed pod is present, but inaccessible to either OMS engine. In the leaking OMS case, propellant from the leaking pod can be used to lower perigee and reduce deorbit  $\Delta v$  to at least some landing sites. Using the propellant also reduces Orbiter weight, and prevents a violation of OMS landing weight constraints. A tank failure can have much more serious implications because the trapped propellant cannot contribute any  $\Delta v$ , and it can lead to both CG and landing weight violations. A tank failure puts the Orbiter in a propellant-critical situation, and a two-stage deorbit may be required. The first priority in this case is to develop a plan for safe return of the crew. A TOS jettison will likely be required since there is no Master Safe capability to delay SRM TIG. In the event that the good pod does indeed have shallow deorbit capability, a 12 fps min sep will be performed out of the FRCS. If the failure occurs after

## **FDO Console Handbook Section 3.8: Payload Deploys**

deploy but before separation, the FRCS min sep plan should be implemented ASAP, with the separation burn performed on time.

No known analysis has been performed to identify retrograde TOS separation strategies. The hard-wired SRM-1 ignition timer, together with no Master Safe capability, are too constraining to provide much chance for successful TOS deploy and transfer orbit injection.

### **3.8.5.7.7 Off-Nominal Orbit Recovery Prior to TOS Deploy**

In the event of off-nominal orbit insertion, TOS can be successfully deployed from 105 nm circular orbits. Pre-mission analysis confirms no orbit-raising burns are required, provided the Orbiter achieves this minimum altitude threshold. Unlike the IUS, an initial guidance run isn't required to clear deploy from a lower orbit.

### **3.8.5.8 TOS Deploy Checklist**

The FDO TOS deploy checklist is a quick-look summary of most of nominal and contingency procedures and rules governing a TOS deploy. Experience has shown the checklist to be a good memory aid for deploys of this type.

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<b>Tracking Arc:</b> (Ends ~3:30 MET)
<b>POINTING Inputs:</b>
<ul style="list-style-type: none"> <li>• Deploy Time, <math>\beta</math>, Nominal Ephemeris</li> <li>• LVLH P-Y of TOS at SRM (BIM Att)</li> </ul>
<b>WGL In EPH 1 At Deploy Time = -26889 lbs</b>
<b>Model Sep: DEPLOY +17 min, Single OMS</b>
<ul style="list-style-type: none"> <li>• PEG-7 Targets: <ul style="list-style-type: none"> <li>+23.6/0.0/-4.6 = 24.0 fps</li> <li>+18.7/0.0/-3.3 = 19.0 fps</li> <li>+11.8/0.0/-2.1 = 12.0 fps</li> <li>+07.9/0.0/-1.4 = 8.0 fps</li> </ul> </li> <li>• TVR: 90° (<math>\beta &gt; 0</math>); 270° (<math>\beta &lt; 0</math>)</li> <li>• Nom Sep in EPH 1; Min Sep in EPH 2</li> </ul>
<b>ORB Dply Att From POINTING (+X ADI):</b>
<ul style="list-style-type: none"> <li>• TGT ID 4 (Sun), BV 5</li> <li>• Pitch = 360° - (68° + <math> \beta </math>), Yaw = 0.0</li> <li>• Omicron = 90° (<math>\beta &gt; 0</math>); 270° (<math>\beta &lt; 0</math>)</li> </ul>
<b>TOS Deploy Att From POINTING:</b>
<ul style="list-style-type: none"> <li>• Orbiter Attitude Pitched Up 42°</li> </ul>
<b>Model Spring Eject at Deploy:</b>
<ul style="list-style-type: none"> <li>• EPH 3: 1.2 fps <math>\Delta v</math></li> <li>• BFI, MISC, Indicator A</li> </ul>
<b>Model Backoff at Deploy +25 sec:</b>
<ul style="list-style-type: none"> <li>• EPH 1: 8 sec <math>\Delta T</math> (2.2 fps)</li> <li>• BFI, MXL, Indicator A</li> </ul>
<b>Nom and Min Sep EPH to POINTING</b>
<b>Window Protect Attitude:</b>
<ul style="list-style-type: none"> <li>• TGT ID 1 (Target SV), BV 5</li> <li>• Pitch = 276° = f(Coast Time)</li> <li>• Yaw = 0.0</li> <li>• Omicron = POINTING Real Time Call</li> </ul>
<b>Tilt Table Angle = 42° (Min = 35°)</b>
<b>Sep Burn PEG-7 Command Load:</b>
<ul style="list-style-type: none"> <li>• Check Maneuver Monitor to Verify Correct Targets (DMT 1)</li> <li>• Incorrect TIG until Crew Loads Targets (ITEM 22)</li> </ul>
<b>Final PAD Distribution:</b>
<ul style="list-style-type: none"> <li>• Deploy PAD (5:00 MET): CC, FD, FDO, FAO, PAYLOADS</li> <li>• Initiate Track at BIM + 15m (approx. 6:30)</li> <li>• Sep Burn PAD (7:00 MET): CC, FD, FDO, FAO, PROP, GNC</li> </ul>
<b>Rndz NAV Enabled (Dply -15 min):</b>
<ul style="list-style-type: none"> <li>• ITEM 1 SPEC 33 (Verify ITEM 4 (FILT))</li> <li>• Notify FLIGHT</li> <li>• Approx. DPLY -1 min, ITEM 10 SPEC 33 (ORB TO TGT)</li> </ul>
<b>Backoff (Pitch Rate = -0.8 °/sec):</b>
<ul style="list-style-type: none"> <li>• Monitor MSK 1888 for Rates</li> <li>• Null Pitch Rate When Pitch = 68° (FRCS) or LOS = Tail (ARCS)</li> <li>• If 1 FRCS jet only, 2x TGO = 16 sec</li> <li>• &gt;1 fps Required or use ARCS <ul style="list-style-type: none"> <li>• 14s PX2 at Dply +5 min (4 fps)</li> <li>• Pitch Rate = 0.3 °/sec</li> </ul> </li> </ul>
<b>Tilt Table Not Locked Down:</b>
<ul style="list-style-type: none"> <li>• 1 OMS or RCS SEP Only!!</li> </ul>

<b>Min Sep/TIG Slips:</b>
<ul style="list-style-type: none"> <li>• Behind Rbar and &lt; 10X</li> <li>• <b>Do Not Slip TIG &gt; Dply +29 min!!!</b> <ul style="list-style-type: none"> <li>• Dply +17: <math>\Delta v = 8</math>, PLOS = 84°</li> <li>• Dply +18: <math>\Delta v = 12</math>, PLOS = 99°</li> <li>• Dply +24: <math>\Delta v = 19</math>, PLOS = 123°</li> </ul> </li> </ul>
<b>OMS Leak:</b>
<ul style="list-style-type: none"> <li>• Prior to elevation: abort deploy</li> <li>• Post elevation to pre-deploy: <ul style="list-style-type: none"> <li>• Shallow post-min-sep (12 fps)? <ul style="list-style-type: none"> <li>• Y: jettison, then Min Sep ASAP from leaking side, then deplete OOP</li> <li>• N: jettison, then: <ul style="list-style-type: none"> <li>• If slow leak: 2 fps retro, then perform retro PADJ at optimum TIG</li> <li>• If fast leak or no comm: perform retro PADJ ASAP</li> </ul> </li> </ul> </li> </ul> </li> <li>• Post-deploy to pre-sep: <ul style="list-style-type: none"> <li>• Shallow post-min-sep (12 fps)? <ul style="list-style-type: none"> <li>• Y: min sep from leaking side ASAP, then deplete OOP</li> <li>• N: retro sep/PADJ &gt; 12 fps</li> </ul> </li> </ul> </li> <li>• Post-sep: <ul style="list-style-type: none"> <li>• Shallow post sep? <ul style="list-style-type: none"> <li>• Y: deplete OOP ASAP (remember WPA omicron)</li> <li>• N: retro PADJ &gt; 50 fps (&gt;10X)</li> </ul> </li> </ul> </li> </ul>
<b>OMS Tank Fail; FRCS Min Sep:</b>
<ul style="list-style-type: none"> <li>• Prior to deploy: if good pod has shallow post-min-sep (12 fps), proceed with deploy (use FRCS min sep), else abort</li> <li>• Post-deploy: switch to FRCS min sep ASAP (perform burn on time)</li> </ul>
<b>FRCS Sep:</b>
<ul style="list-style-type: none"> <li>• Loss of 2 Deorbit Systems</li> <li>• Model BFI / MXL / LVLH</li> <li>• RPY = +090°/+190°/+349° (<math>\beta &gt; 0</math>)</li> <li>• RPY = +270°/+190°/+011° (<math>\beta &lt; 0</math>)</li> </ul>
<b>Use LVLH TOS Att. To Model TOS SRM:</b>
<ul style="list-style-type: none"> <li>• BFI, MISC, L Indicator (10580 fps <math>\Delta v</math>)</li> <li>• M66 MISC Thrust = 50000; Wdot = 150</li> </ul>

## **FDO Console Handbook Section 3.8: Payload Deploys**

### **3.8.5.9 TOS Deploy Worksheet**

The TOS deploy worksheet is used to document relevant data generated during a TOS deploy. It's intended to be used in conjunction with the FDO TOS Deploy Checklist.



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**TOS SRM TIG**

/	:	:
---	---	---

- 0 / 00 : 45 : 06

**NOMINAL DEPLOY TIME**

/	:	:
---	---	---

+ 0 / 00 : 00 : 25

**FRCS BACKOFF TIG**

/	:	:
---	---	---

+ 0 / 00 : 16 : 35

**OMS SEP TIG**

/	:	:
---	---	---

β @ DEPLOY \_\_\_\_\_

**TOS @ SRM TIG:**

PITCH \_\_\_\_\_

YAW \_\_\_\_\_

DEPLOY ATTITUDE		
ORBITER ADI/LVLH		TOS ADI/LVLH
____/____	R	____/____
____/____	P	____/____
____/____	Y	____/____

DEPLOY PAD:	
PITCH	_____
OMICRON	_____
DEPLOY WINDOW	____:____
NOM WPA OM	_____
MIN WPA OM	_____

WINDOW PROTECT ATTITUDE		
NOM SEP ADI/LVLH		MIN SEP ADI/LVLH
____/____	R	____/____
____/____	P	____/____
____/____	Y	____/____

D/O DV (ST/SH)	NO DEPLOY	NOM SEP	MIN SEP
ORB _____	____/____	____/____	____/____
ORB _____	____/____	____/____	____/____
VEHICLE WEIGHT _____	_____	_____	_____

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### **3.8.6 Remote Manipulator System (RMS) Deploy Procedures**

A variety of the mission requirements and physical characteristics apply to payloads deployed by the RMS. These payloads range from very small objects, such as the Plasma Diagnostics Package (PDP) experiment on STS 51-F, to the huge Hubble Space Telescope (HST) on STS-31, 61, 82, and 103. Passive payloads, such as the Long Duration Exposure Facility (LDEF), have no active attitude control or telemetry systems and impose very few constraints on RMS deploy operations. Others, such as the Shuttle-Pointed Autonomous Research Tool for Astronomy (SPARTAN), have precise inertial deploy attitude and ephemeris requirements calling for a number of special procedures. Large complex payloads, such as HST or Gamma Ray Observatory (GRO), may require predeploy thermal conditioning. Special requirements for solar array pointing during deploy, or communications links after deploy, complicate matters considerably. Because of these differences, RMS deploy procedures vary appreciably among payloads.

This section provides general information on many variables governing RMS deploys and explains related nominal FDO actions. Although some anomalies are discussed, Section 3.9 provides details addressing RMS payload jettison, RMS jettison, and the emergency "quick sep".

#### **3.8.6.1 Tracking Arcs and State Vector Updates**

A minimal RMS deploy tracking arc typically consists of two passes from a single C-band site, an additional C-band pass, and TDRS passes during two consecutive orbits. Before each mission, the Lead FDO develops a tracking plan in conjunction with NAV, TRACK, and FAO. As with any deploy, it's usually in the best interest of mission success to minimize or eliminate attitude maneuvers and water dumps from the tracking arc in order to control trajectory dispersions.

The Flash Evaporator System (FES) should be used in place of water dumps whenever possible, both to reduce trajectory dispersions and to avoid contaminating the payload's environment with ice crystals. If possible, IMU alignments should be scheduled outside the tracking arc. Sometimes attitude maneuvers will be unavoidable, especially if predeploy attitudes required by the payload are incompatible with the deploy attitude.

FDO updates the ground ephemeris after the tracking arc. Special trajectory data may then be provided to the Payload Operations Control Center (POCC). For example, SPARTAN missions may require orbit elements and eclipse duration data to update SPARTAN's navigational computer. FDO fills out a mission-specific PAD, which is passed to the Flight Control Team, POCC, and the crew. The Lead FDO works with payload customers to satisfy data requirements and develop unique PAD formats.

Using an anchor from the updated ground ephemeris, FDO creates a payload ephemeris with which to assess relative motion through separation operations. Both Orbiter (401xx) and target (402xx) state vector command loads are prepared for predeploy uplink. The 402xx is required before the crew can enable Rendezvous Nav and use Universal Pointing to maintain a target track attitude after separation. This is done to view the payload through separation while tracking it with the rendezvous radar. Because an Orbiter-to-target state vector transfer usually overwrites the uplinked target state immediately prior to deploy, the 402xx can use any reasonable state vector as long as it supports enabling

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Rendezvous Nav. State vector command load procedures are maintained in DM-CH-05, *Flight Dynamics Command Procedures*.

### 3.8.6.2 RMS Operations

The RMS, popularly known as the "Canada arm", is only one element in what is collectively the Payload Deploy and Retrieval System (PDRS). The following subsystems are PDRS components.

- 1) RMS
- 2) Manipulator Positioning Mechanism
- 3) Payload Retention Mechanisms
- 4) SM GPC Software
- 5) Controls and Displays
- 6) Electrical Power System and Data Interface
- 7) Thermal Protection System
- 8) Closed Circuit Television (CCTV) Cameras

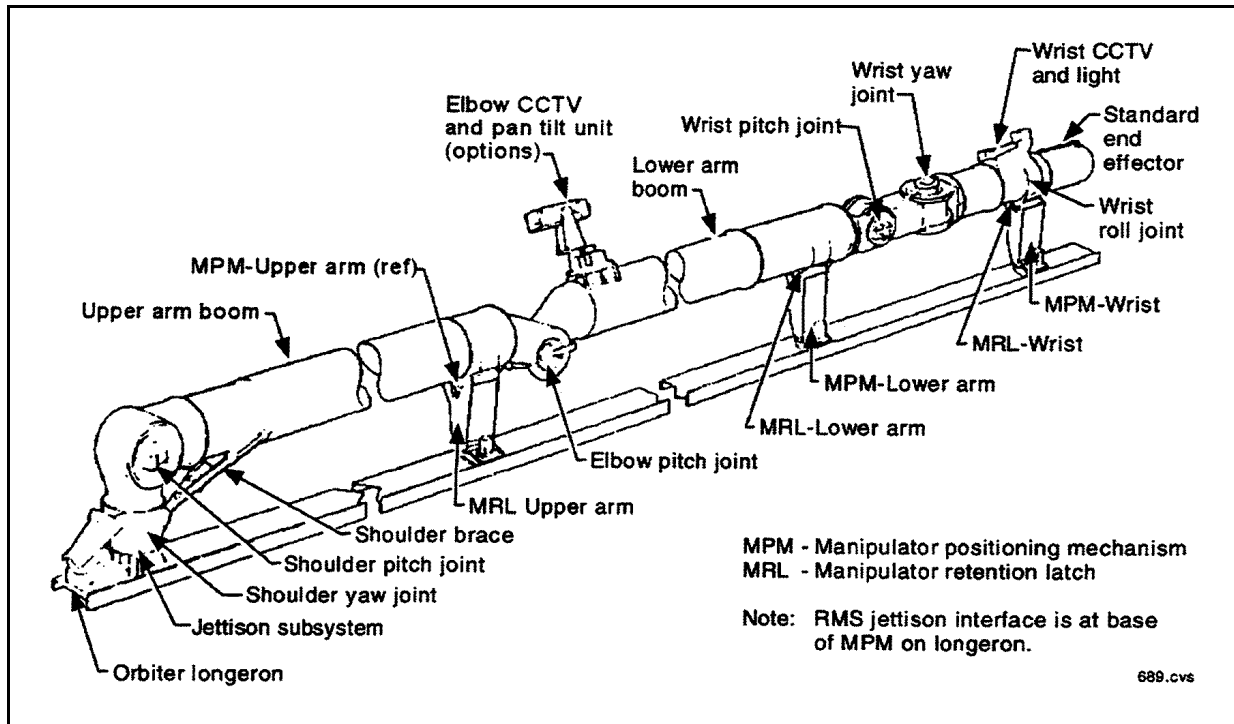
This discussion is limited to those RMS aspects directly affecting trajectory and FDO activities.

#### 3.8.6.2.1 RMS System Description

The RMS is a 50-foot-long, 6-jointed mechanical arm with a payload-interfacing "end effector". The joints include two "shoulder" joints (pitch and yaw) near the arm's longeron attach point, one "elbow" joint (pitch only) in the middle, and three "wrist" joints (pitch, yaw, and roll) near the end effector. Normally, a single RMS is mounted on the port payload bay longeron, but starboard mounting is also possible. Two RMSs may be flown simultaneously, but only one may be used at a time due to software and crew control hardware limitations.

The RMS is attached to the longeron at the shoulder and at three other points via Manipulator Positioning Mechanisms (MPMs) and Manipulator Retention Latches (MRLs). Flight Rule A12.1.1-6D nominally permits OMS usage (planned burns) only if two of three MRLs are latched or RMS is in its pre-cradle position. The shoulder attach point does not unlatch, but it can be severed by the RMS jettison mechanism. Figure 3.8.6.2.1-1 shows RMS components and its stowed position. This illustration appears in Section 2.19 of SFOC-FL0884, the *Shuttle Crew Operations Manual (SCOM)*.

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**Figure 3.8.6.2.1-1: Stowed RMS Configuration**

The RMS can be controlled in five different modes, full descriptions of which are beyond the scope of this discussion. A GPC can maneuver the RMS to preprogrammed positions, a crewmember can manually enter a desired position, to which the GPC will command the RMS, or the RMS can be manually controlled by a crewmember using the Translation Hand Controller (THC) and Rotation Hand Controller (RHC). RMS operations are completely "man in the loop" and require continuous monitoring of the payload and RMS using windows, the CCTV system, or aids like the Space Vision System (SVS). Flight Rule A12.1.1-5 requires a pilot be available at all times during loaded RMS operations to perform collision avoidance maneuvers in case of an uncommanded payload release.

The standard end effector is an open cylinder capable of capturing or releasing a payload equipped with a grapple fixture. When captured, a payload is locked in place with respect to the end effector. A capture is accomplished by means of three snare cables. Initially, the cables are stored around the inner periphery of the end effector, and the RMS can place the end effector over the payload's grapple fixture pin without contacting a cable. When attached rings are rotated on command, the cables are drawn together toward the center of the end effector. As the cables contract towards the end effector's center, they engage the grapple pin and force it to the center as well. Finally, screw/nut assemblies pull the rings and cables towards the rear of the end effector, forcing the payload's grapple fixture tightly up against the end effector's outer rim and three alignment ramps. This latter process is called "rigidization".

To release a payload, derigidization must first occur, followed by opening the snare cables and maneuvering the end effector clear of the grapple fixture pin. This must be done slowly to avoid imparting rotational rates to the payload. A payload grapple fixture and the standard end effector are shown in Figure 3.8.6.2.1-2, also taken from the SCOM.

## FDO Console Handbook Section 3.8: Payload Deploys

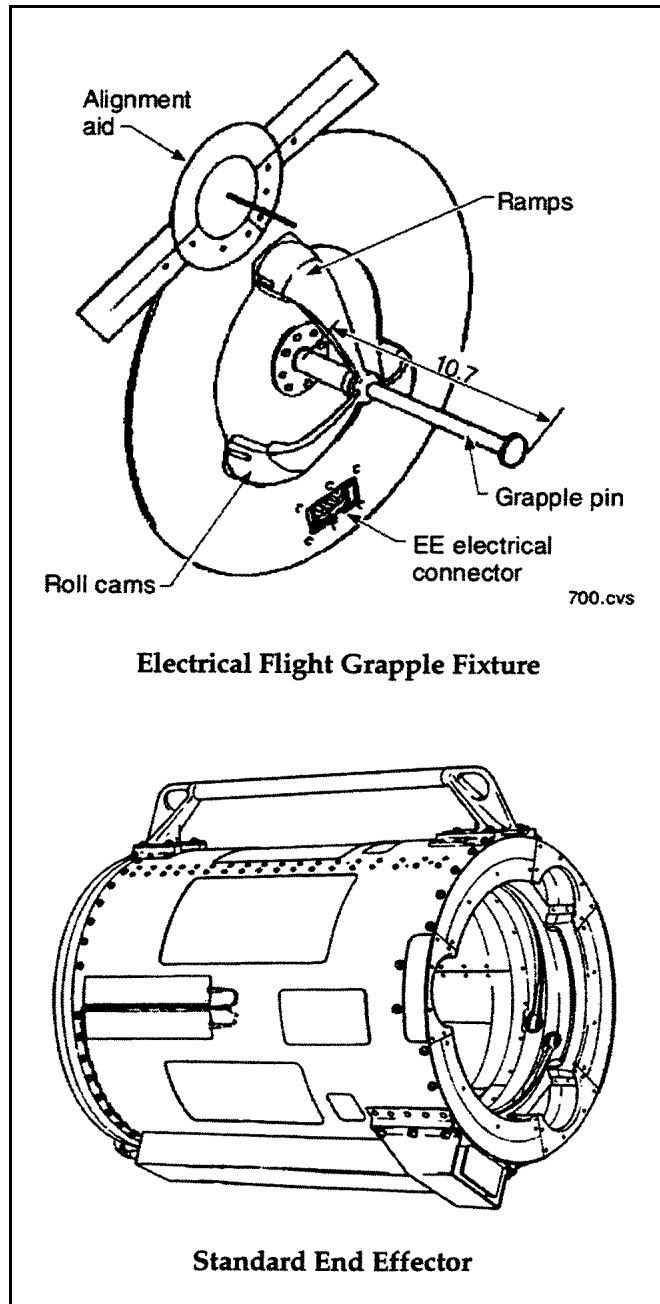


Figure 3.8.6.2.1-2: Grapple Fixture and Standard End Effector

### 3.8.6.2.2 RMS Release Position Considerations

PDRS controllers consider many variables when determining RMS release position during pre-mission planning. The release position, together with lines-of-sight to the sun and TDRS, can drive the Orbiter's deploy attitude. FDOs working RMS deploy missions should understand the impact of payload requirements on release position, the sep sequence, and contingency procedures. The release position must be compatible with payload deploy requirements and Orbiter operational constraints such as appear in the following list.

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- 1) The nominal release position should be valid for both a healthy RMS and an RMS with failures requiring "single joint" operation.
- 2) The release position should result in a total Orbiter/RMS/payload center of gravity and inertia tensor consistent with stable VERN DAP control.
- 3) The release position should minimize the possibility of imparting payload tipoff rates.
- 4) The release position should satisfy RMS-mounted CCTV camera payload viewing requirements.
- 5) The release position, combined with the Orbiter's deploy attitude, should satisfy payload solar array, sensor, and communications antenna pointing requirements.
- 6) The release position and deploy attitude must allow for a safe Orbiter backoff maneuver following deploy.
- 7) Intermediate RMS positions, and sometimes the release position, must be compatible with contingency EVA requirements, such as accessibility of payload components to EVA crewmembers.
- 8) RMS positions and the Orbiter's attitude should allow for safe relative motion with respect to payload components jettisoned by EVA crewmembers (solar arrays, antennas, etc.).

It is not always possible to satisfy all of the above conditions at once, and tradeoffs must then be made. The following list cites some complications with potential FDO impact.

- 1) Multiple separation burns
- 2) Complex and time consuming contingency burn procedures
- 3) A dedicated separation sequence for RMS deploy in single joint mode
- 4) Unexpected attitude maneuver perturbations during the tracking arc
- 5) Safe relative motion assessment for a jettisoned article

### **3.8.6.3 Separation Burns**

Separation burn sequences following an RMS deploy depend on payload requirements and typically entail one, two, or three Orbiter translations. FDO models these burns in a ground ephemeris. Some payloads, such as the Wake Shield Facility (WSF) nominally perform their own separation translations without Orbiter assistance. Sep burn PADs are normally not required because these safety-critical translations typically utilize flight-specific procedures in a Deploy Checklist.

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### 3.8.6.3.1 Single-Burn Sep

The single-burn separation is usually a small, purely posigrade (or retrograde) translation of around 2 fps. This technique is used when Orbiter deploy attitude is belly (or payload bay) forward, and NORM-Z RCS thrusters can be used for the separation without contaminating or dynamically disturbing the payload. The small  $\Delta v$  is acceptable because most RMS deploys do not involve potentially hazardous PKM burns. Small RMS deployables, such as SPARTAN, can often accommodate the single burn sequence. The Orbiter is normally in a  $\pm ZVV$  (belly/bay into the velocity vector) attitude for deploy and the sep burn. Orientation of the other body axes depends on inertial deploy attitude requirements and RMS joint angle limitations. Figure 3.8.6.3.1-1 shows typical relative motion for posigrade separation  $\Delta v = 1, 2,$  and  $3$  fps.

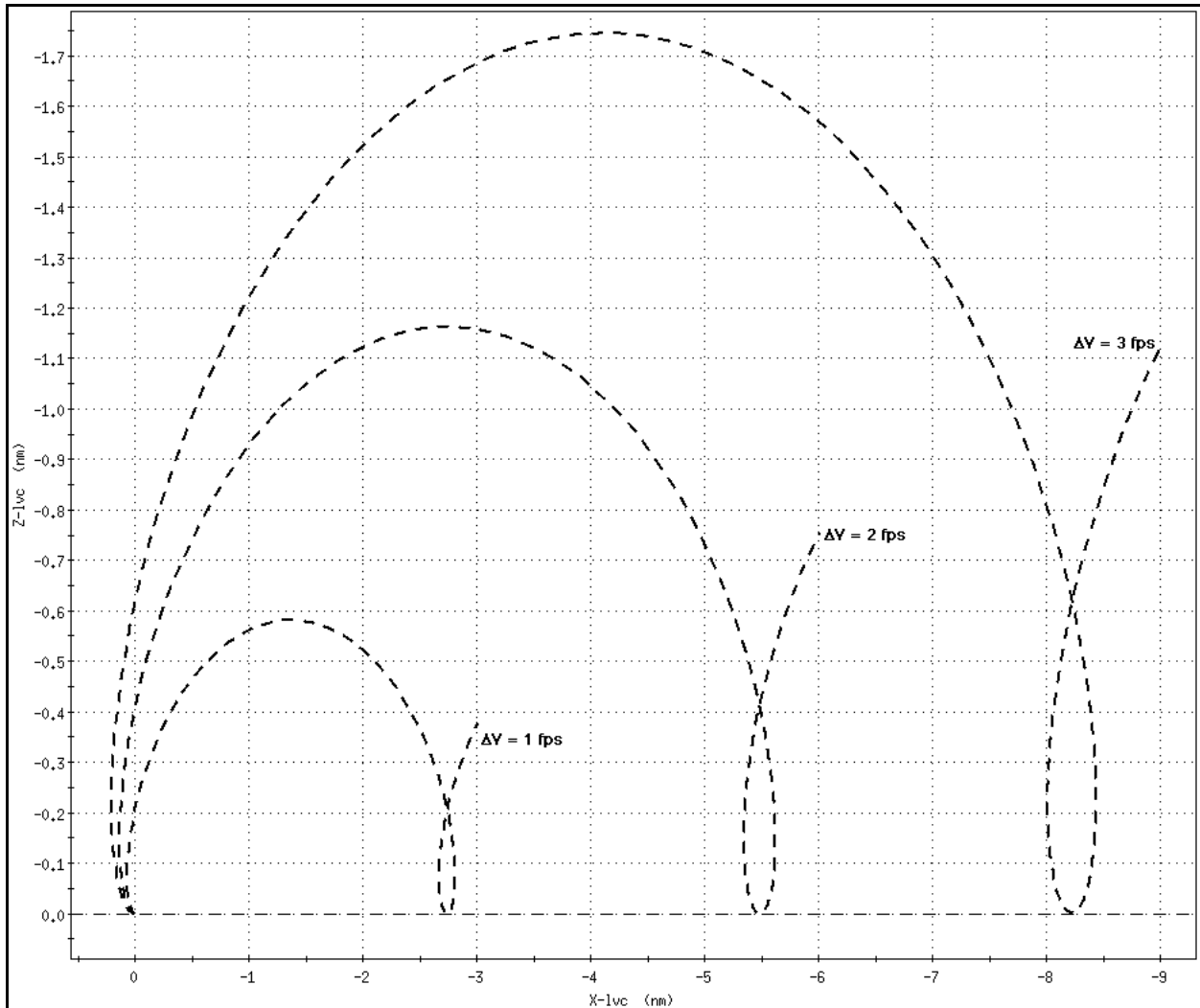


Figure 3.8.6.3.1-1: Inplane RelMo After a Single Posigrade Sep

### 3.8.6.3.2 Two-Burn Sep Sequences

Two-burn sep sequences can be initiated from either the payload's  $+Vbar$  or  $-Rbar$ , depending on the Orbiter's deploy attitude. The  $+Vbar$  sequence usually consists of two

## FDO Console Handbook Section 3.8: Payload Deploys

posigrade burns of about 1 fps each. The first is a backoff burn, with TIG after the end effector has moved sufficiently clear of the released payload. It's performed in LOW-Z to minimize contamination and dynamic disturbance of the payload. The second burn uses +X RCS thrusters about 15 min later. The  $\Delta v$  of the first burn may be lower, especially if the payload is large, and tipoff rates or Orbiter pitch rates due to the RCS burn cause concern about recontact with either end of the payload bay. A first burn of 0.5 fps, followed by a second burn of 1.5 to 2.0 fps, is typical. The Orbiter is in +ZVV attitude for the first burn and posigrade +X RCS attitude for the second burn.

The two-burn sequence from the -Rbar is similar, except the first burn is done radially upward with the Orbiter in a -ZLV attitude (payload bay to earth), and the second burn is about 15 min later in a posigrade +X RCS attitude. Since the first burn does not contribute any net downtrack separation, the total  $\Delta v$  of the -Rbar sequence may be slightly larger than that of a similar +Vbar deploy. Reasoning behind the two-burn -Rbar separation is the same as for the +Vbar sequence. Figure 3.8.6.3.2-1 illustrates relative motion for three two-burn sep sequences. All three have a 1 fps posigrade Sep-2  $\Delta v$  following Sep-1 by 15 min. Although all three also have 1 fps Sep-1  $\Delta v$  magnitude, one Sep-1 is posigrade (+X), one is radial down (+Z), and one is radial up (-Z).

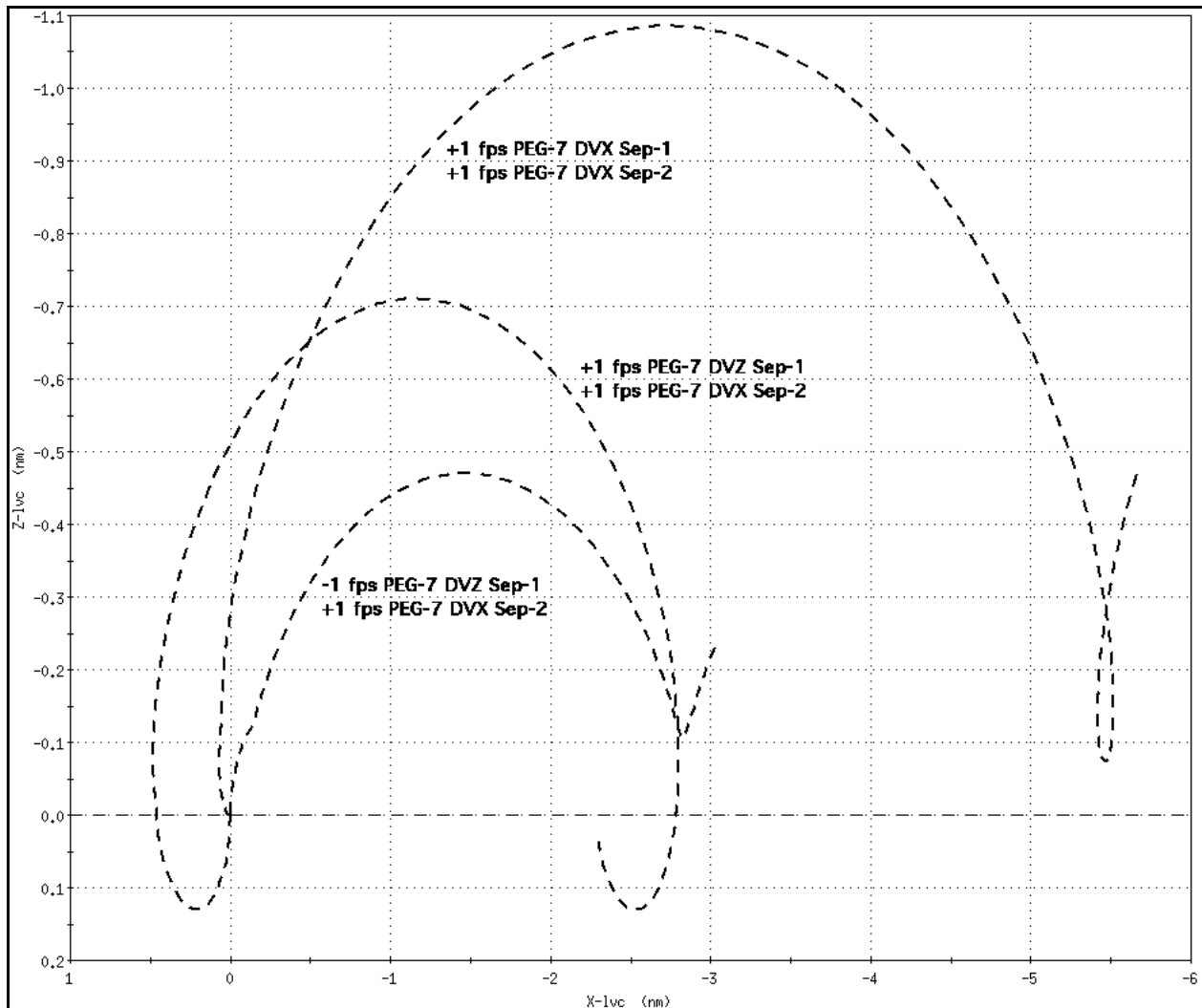


Figure 3.8.6.3.2-1: Inplane RelMo From 2-Burn Sep Sequences



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Two-burn sep sequences are fairly common, and there are many variations not necessarily corresponding to purely posigrade or retrograde profiles described above. The first sep burn will often not be in plane because it's performed in all three axes depending on deploy attitude. This first burn is designed simply to move away from the payload and position the second burn at an appropriate relative distance. In order to correctly model the first burn, FDO must coordinate with POINTING to obtain the correct deploy attitude.

As an example, consider the STS-103 deploy and sep sequence from HST. In this case, one of two sep sequences is invoked depending on the solar beta angle. Beta angle in this case is carefully monitored so Orbiter attitude will provide HST solar arrays with full charging capability during pre-deploy checkout and release. For positive beta, a 1.0 fps Sep-1 will be performed (nominally radial down and posigrade) followed by a 2.5 fps retrograde Sep-2 at the -Rbar crossing. Conversely, negative beta angles require Sep-1 to be a 1.0 fps burn (nominally radially up and retrograde) followed by a 1.0 fps retrograde Sep-2 at the +Rbar crossing.

### **3.8.6.3.3 Three-Burn Sep Sequences**

A three-burn separation sequence is necessary when deploy attitude is such that neither of the simpler sequences would provide safe post-sep relative motion. This can happen if the RMS is unable to meet the payload's inertial deploy attitude constraints with the Orbiter on the +Vbar or -Rbar. The three burns will normally follow the generic "1-2-3" sequence, or something very similar.

The generic sep sequence is described fully in Section 3.9 of this handbook, and crew procedures are documented in Section 11 of the Orbit Ops Checklist. In short, the sequence consists of a 1 fps +Z maneuver (NORM-Z or LOW-Z), followed at least 2 min later by a 2 fps out-of-plane burn, followed 15 min later by a 3 fps posigrade burn. This sequence insures safe relative motion following release from the RMS in any attitude. Sometimes the first burn of the sequence may have a lower  $\Delta v$  in LOW-Z to protect the payload from RCS plume impingement.

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Due to unconstrained Sep-1 PEG-7  $\Delta v$  components, three-burn relative motion is difficult to characterize. It must also be visualized in 3 dimensions. Figures 3.8.6.3.3-1 and 3.8.6.3.3-2 initiate the visualization process by assuming Sep-1 is inplane. The former increments the LVLH pitch of Sep-1's 1 fps  $\Delta v$  at 30° intervals from 30° to 150° (radial upward Sep-1), while the latter ranges from 210° to 330° (radial downward Sep-1).

**NOTE:** relative motion illustrations in this section result from a simulated deploy at 210 nm orbit height. Small variations, chiefly in phase rate, will exist at other deploy heights in the Shuttle flight envelope. However, salient features in these illustrations will be applicable throughout the flight envelope. In general, relative motion variations due to orbit height will be overwhelmed by real world dispersions due to burn execution  $\Delta v$  residuals or attitude maneuver perturbations.

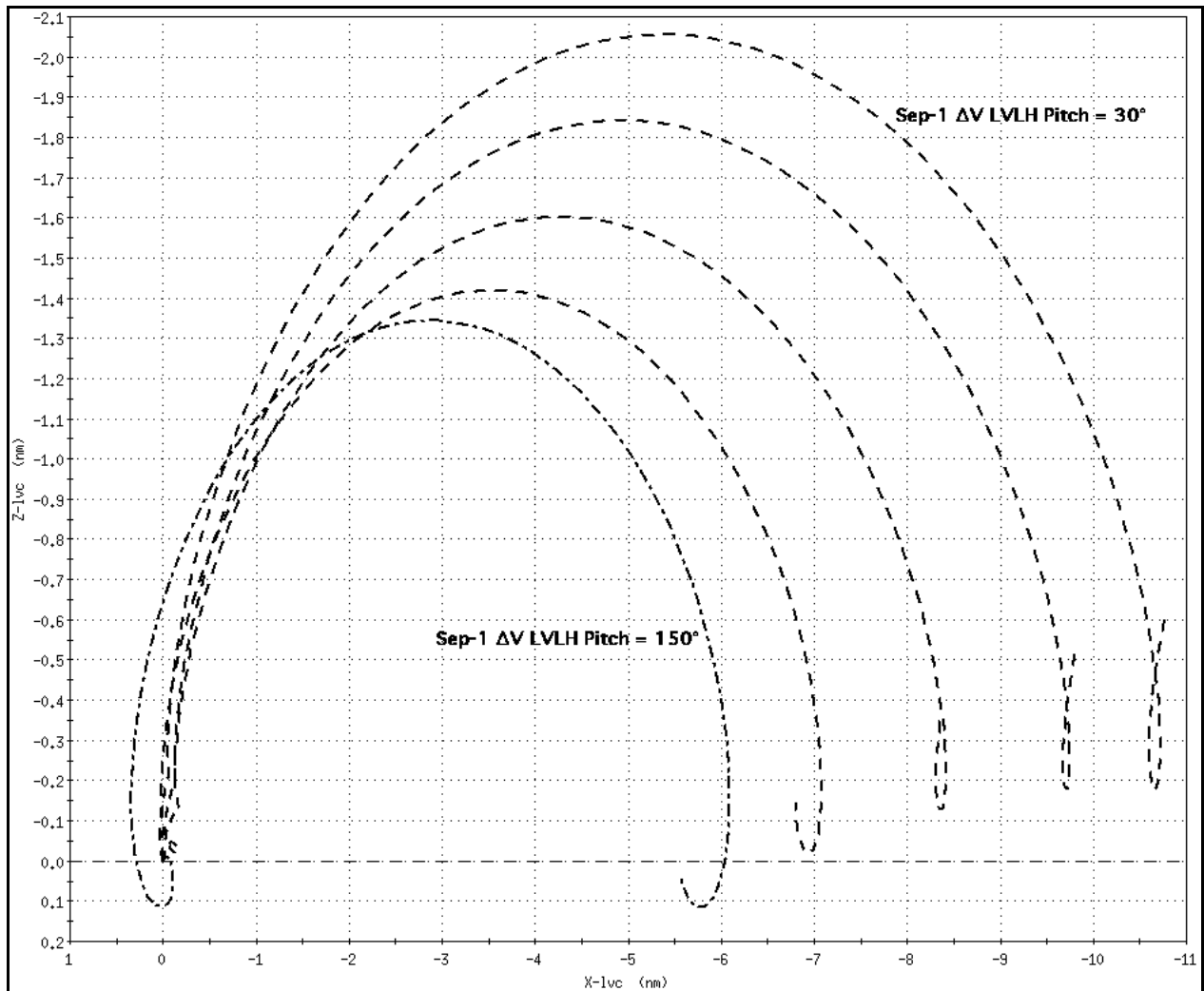


Figure 3.8.6.3.3-1: Radial-Upward Sep-1 In A "1-2-3" Sequence

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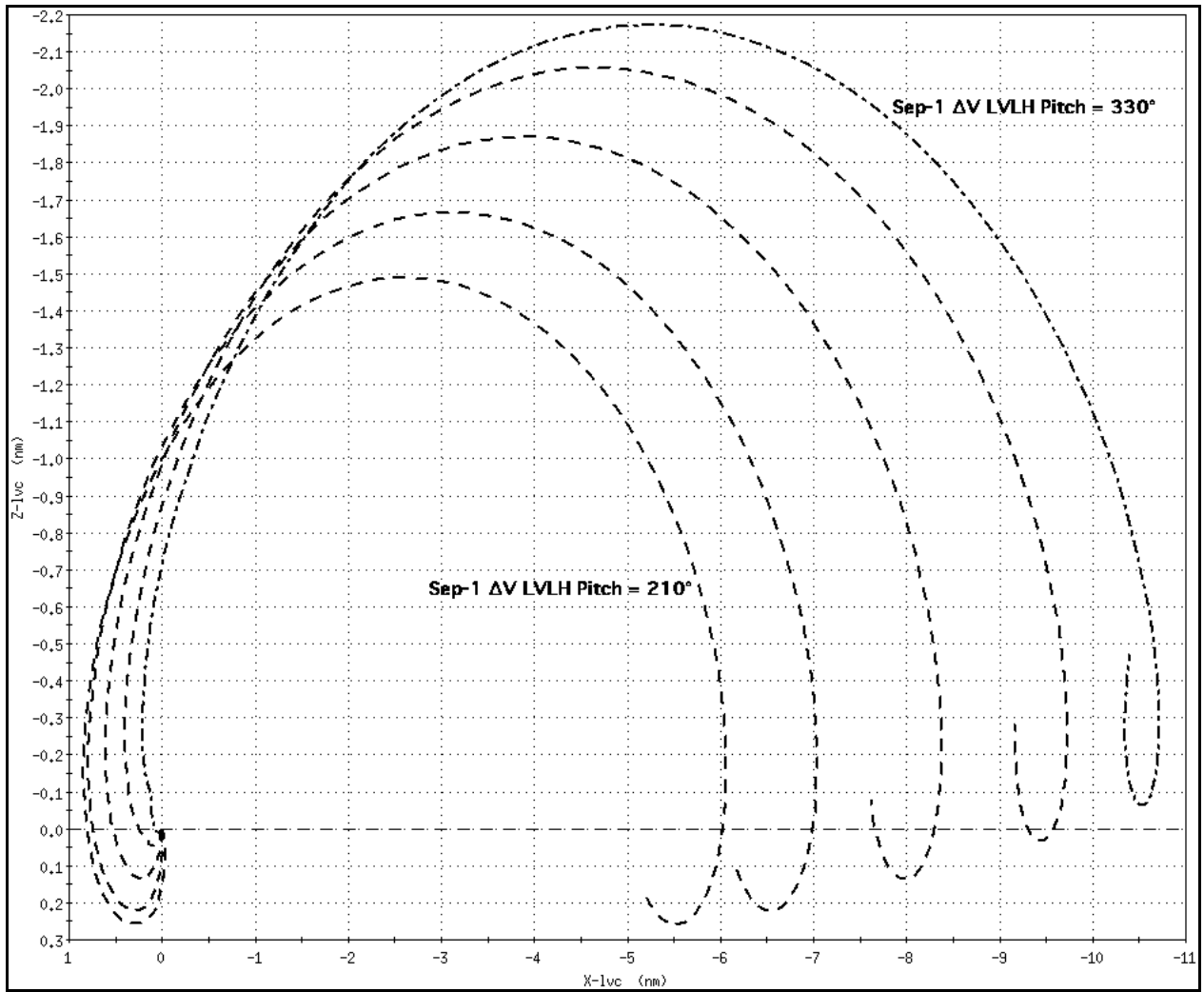


Figure 3.8.6.3.3-2: Radial-Downward Sep-1 In A "1-2-3" Sequence

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The 1-2-3 sep relative motion visualization process continues by considering consequences of a Sep-1  $\Delta v$  in the XY local horizontal LVLH plane. Previous figures in this section are equivalent to "side" views, but Figure 3.8.6.3.3-3 illustrates horizontal Sep-1 relative motion implications from a "top" perspective looking down the +Rbar. The 6 curves in Figure 3.8.6.3.3-3 have Sep-1  $\Delta v$  LVLH yaw from the +Vbar = 0°, 10°, 30°, 50°, 70°, and 90°.

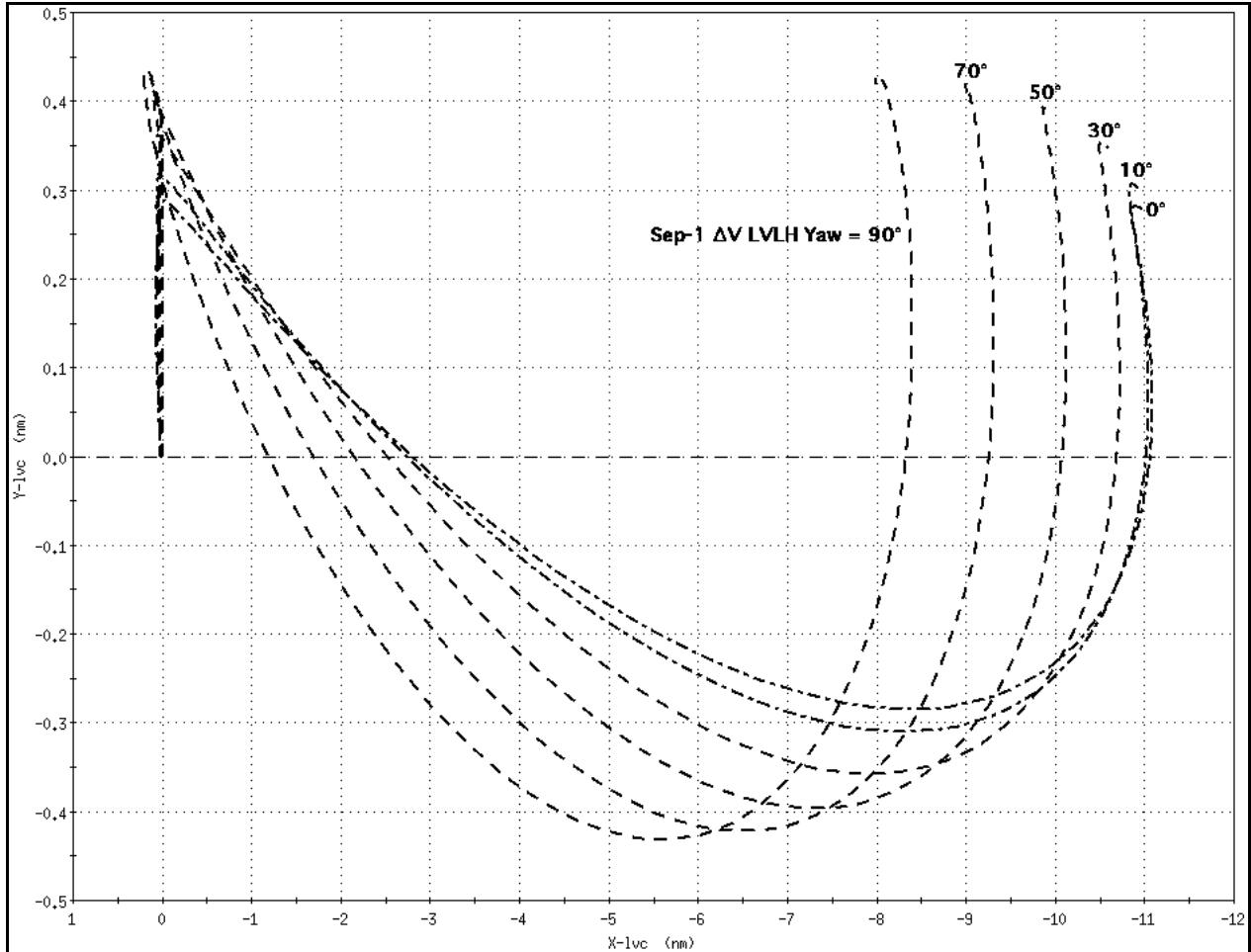


Figure 3.8.6.3.3-3: Horizontal Sep-1 In A "1-2-3" Sequence

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Finally, 1-2-3 sep relative motion visualization must consider consequences of a Sep-1  $\Delta v$  in the YZ local horizontal LVLH plane. Figure 3.8.6.3.3-4 illustrates YZ Sep-1  $\Delta v$  relative motion implications from an "end" perspective looking down the +Vbar. The 6 curves in Figure 3.8.6.3.3-4 have Sep-1  $\Delta v$  LVLH roll from the -Rbar = 0°, 10°, 30°, 50°, 70°, and 90°.

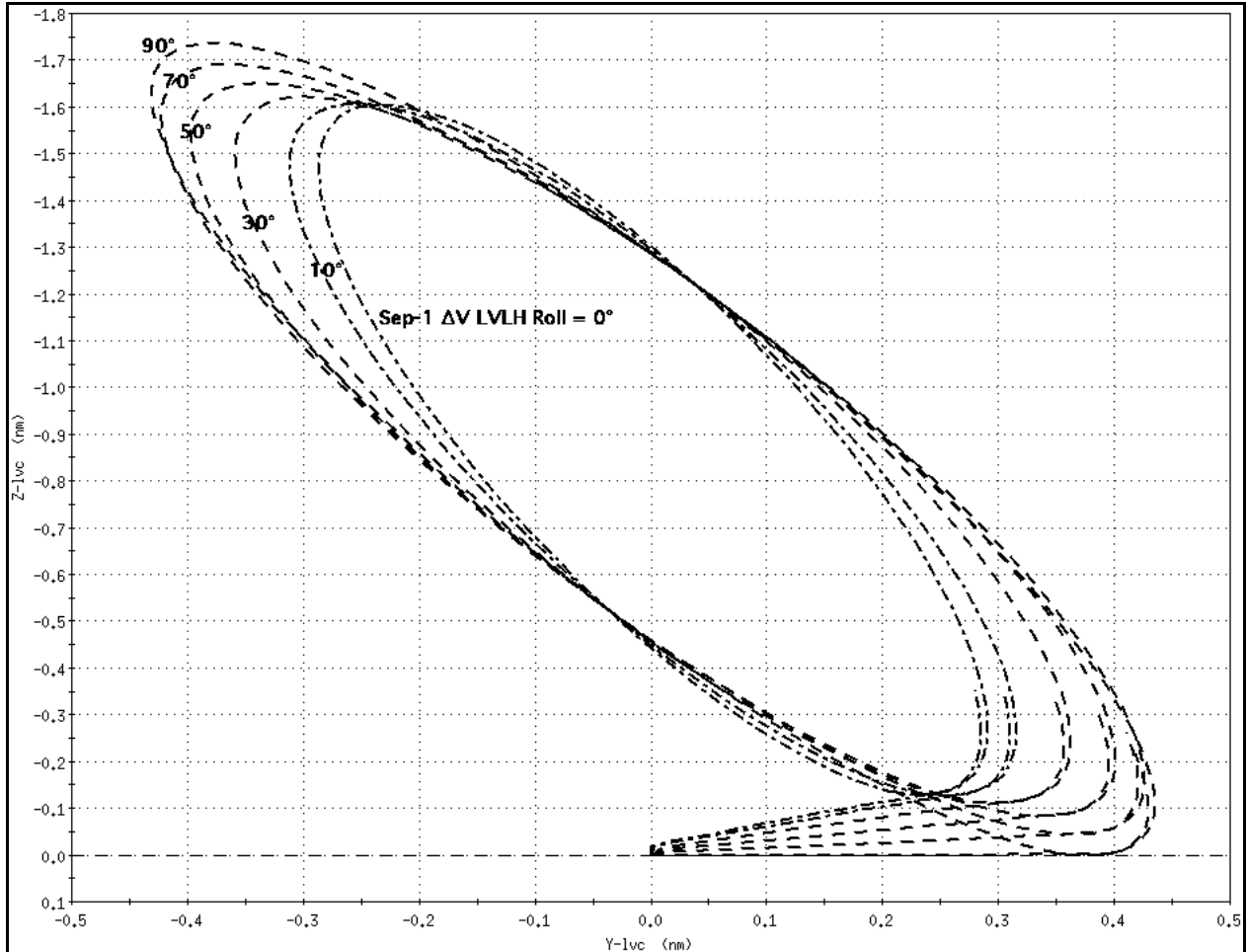


Figure 3.8.6.3.3-4: LVLH YZ Sep-1 In A "1-2-3" Sequence

### 3.8.6.3.4 Modeling Sep Burns

For RMS deploys, the FDO maintains an Orbiter ephemeris (typically, Ephemeris 1), which contains sep burns, together with a payload ephemeris (typically, Ephemeris 3). Both ephemerides are required to predict post-separation relative motion. The payload ephemeris is anchored with a vector from the Orbiter ephemeris at deploy time and static-started at least 15 min beforehand. The payload ephemeris weight, average frontal area, and KCON are configured appropriately for use with DM integrator options.

Up to three sep burns may be required in the Orbiter ephemeris: a +Z backoff burn, an out-of-plane multiaxis burn, and a posigrade/retrograde +X RCS burn. The  $\Delta v$  values provided in the following subsections are typical of RMS deploy sep sequences, but mission specific deviations are common.

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If the deploy is part of a rendezvous, sep burns will be contained in the rendezvous plan. In this case, they are defined in a rendezvous constraints table (RCT) and computed automatically. See Section 3.10 for rendezvous burn procedures.

FDO must determine sep burns and subsequent relative motion for release times throughout the deploy window. This task is especially important to perform during the pre-release Planning shift, where detailed relative motion analysis can be conducted. If deploy attitude is inertial, any release time slip will generally produce Sep-1  $\Delta v$  changes in each LVLH axis.

**NOTE:** sep burn sequences typically contain one or more BFI burns. To obtain PEG-7 targets and verify POINTING inputs, it's usually desirable to model these burns with BFI inputs initially. However, confirming BFI burns in the MOC can be onerous in real time because they must be deleted and input again. Consequently, BFI sep burns should evolve to PX2 thrusters with PEG-7 targets before deploy.

### 3.8.6.3.4.1 The Single-Burn Sep or Other +Z Backoff

If the separation sequence uses a single burn, or the first burn of a multi-burn sequence (+Z backoff) is to be modeled, FDO gives DYNAMICS the following information.

Guidance Mode:	BFI.
Thrusters:	+Z (High or Low).
Attitude Indicator:	"A" (M50 ADI) or "L" (LVLH). Model initially using nominal values and obtain updates from POINTING as necessary.
R,P,Y:	M50 or LVLH Roll, Pitch, and Yaw angles.
$\Delta v$ or $\Delta T$ :	in fps or sec.
TIG:	Deploy time +1 sec. FDO determines deploy time, usually according to lighting or TDRSS comm events.

### 3.8.6.3.4.2 The Two-Burn Sequence (Second Burn)

If the burn is the second in a two-burn sep sequence (+X RCS in plane), model it as follows.

Guidance Mode:	PEG-7.
Thrusters:	PX2.
TVR:	180°.
TIG:	typically Sep-1 TIG +15 min.
$\Delta VX$ :	in fps (typically $\pm 1.0$ to $\pm 2.0$ ).
$\Delta VY$ :	0.0.
$\Delta VZ$ :	0.0.

### 3.8.6.3.4.3 The Three-Burn Sequence (Second Burn)

If the burn is the second (out-of-plane) translation in a three-burn sequence, model it as follows.

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Guidance Mode:	PEG-7.
Thrusters:	PX2.
TVR:	180°.
TIG:	typically Sep-1 TIG +2 min.
$\Delta VX$ :	0.0.
$\Delta VY$ :	+2.0 fps.
$\Delta VZ$ :	0.0.

### 3.8.6.3.4.4 The Three-Burn Sequence (Third Burn)

If the burn is the final (posigrade) translation in a three-burn sequence, model it as follows.

CAUTION: TVR logic reverses if the third burn is retrograde. Values applicable to retrograde final sep burns appear in square "[ ]" brackets below.

Guidance Mode:	PEG-7.
Thrusters:	PX2.
TVR:	if Sep-2 PEG-7 $\Delta VY > 0$ , TVR = 270° [90°]; if Sep-2 PEG-7 $\Delta VY < 0$ , TVR = 90° [270°].
TIG:	typically Sep-2 TIG +15 min.
$\Delta VX$ :	$\pm 3.0$ .
$\Delta VY$ :	0.0.
$\Delta VZ$ :	0.0.

### 3.8.6.3.5 RMS Deploy Window

FDO is generally required to determine the RMS deploy window. Constraints for the window are always included in flight-specific annex rules. Usually constraints are comprised of TDRS communication coverage, lighting, post separation relative motion, or a combination of all three. It's also possible the window can be driven by RCS jet availability (such as VRCS failure) or RMS position hold capability. With HST deploy procedures as an example, the nominal deploy window extends from orbit noon -22 min to orbit noon -2 min for a positive beta and VRCS available. For a negative beta angle, the window opens at orbit noon -6 min and extends until orbit noon +16 min. Both cases achieve safe relative motion when HST is released anywhere in the window.

Note that payload releases outside the window may be possible if FLIGHT and the payload customer agree to the change and the window is not constrained by post-separation safe relative motion. Usually this type of change is in response to a late deploy on the last opportunity of the day or mission and communication coverage cannot be guaranteed.

### 3.8.6.4 RMS Deploy PADs

FDO is responsible for filling out and distributing the RMS deploy PAD. An example from STS-103's HST Deploy Checklist appears in Figure 3.8.6.4-1. FDO maintains and updates the Orbiter ephemeris and determines deploy time. Other PAD inputs are typically contributed by POINTING, PDRS, and GNC. The RMS deploy PAD is unlike

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PADs for other deployable payloads in that most, if not all, entries can be computed during the pre-deploy Planning shift and uplinked to the crew with Mission Summary message traffic. Such is the case for an HST deploy. Note that RMS PADs are usually as unique as the payload and not all Figure 3.8.6.4-1 entries will be used on all payloads. There may be other parameters not listed here that are required.

<b>HST RMS RELEASE PAD</b>	
RELEASE ORBIT	□ □ □
<b>RETROGRADE/POSIGRADE</b>	
WINDOW OPEN MET =	□ / □ □ : □ □ : □ □
WINDOW CLOSE MET =	□ / □ □ : □ □ : □ □
(NLT SS-10 MIN)	
ORBITER WEIGHT =	□ □ □ □ □ (3-3)
RELEASE ATT RA	= □ □ □ . □ □ □ (2-10,3-8)
DEC	= □ □ □ . □ □ □
OMICRON	= □ □ □ . □ □ □
TGT TRK OMICRON	= □ □ □ . □ □ □ (3-9)

**Figure 3.8.6.4-1: An RMS Deploy PAD Example**

The following summary explains PAD input sources and contains a typical sequence of events.

- 1) FDO updates ground-based Orbiter and payload ephemerides at the conclusion of the tracking arc. Orbiter and target state vector uplinks are also performed.
- 2) FDO computes mission-specific orbit and acquisition data as required and provides them to PAYLOADS.
- 3) FDO computes deploy (derigidization) time and Orbiter separation burn TIG(s).
- 4) FDO notifies FLIGHT, POINTING, RNDZ GPO, GC, and PAYLOADS of deploy time and separation TIG(s). FDO coordinates with PDRS, who determines the XYZ position and RMS joint angles.
- 5) POINTING computes Orbiter and payload deploy attitudes and notifies FDO.



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- 6) POINTING computes RMS RPY angles for deploy and notifies FDO and PDRS.
- 7) PDRS computes the deploy XYZ position and RMS joint angles and transmits them to FDO for the deploy PAD.
- 8) FDO computes nominal Orbiter sep burns using Orbiter deploy attitude from POINTING.
- 9) FDO obtains the IMU deselect (IMU DES) choice from GNC for the Deploy PAD.
- 10) POINTING computes Orbiter single-joint-release deploy attitude (if different from nominal) and notifies FDO.
- 11) FDO fills out the nominal Deploy PAD and distributes it.
- 12) FDO computes single-joint-release Orbiter sep maneuver if different from nominal.

### **3.8.6.5 Sep Burn Monitoring and Confirmation**

FDO and TRAJ utilize standard burn monitoring and confirmation procedures for the sep burns. Section 3.7 covers these tasks in detail.

If a sep burn is modeled with BFI guidance, MOC confirmation procedures are considerably more complicated than if PEG-7 guidance had been used. The BFI burn must be deleted and replaced with a direct-input M50 guidance mode burn using PX2 thrusters. An ephemeris start time after sep TIG must be TUPed in a MOC ephemeris before the executed BFI burn can be deleted.

Burn confirmation is important to keep the Orbiter's ephemeris as accurate as possible so that safety-critical post-sep relative motion may be accurately predicted. If Orbiter ephemeris integrity becomes suspect, more accurate relative motion portrayal may be achieved by anchoring an ephemeris pair off downlisted Orbiter and target state vectors following sep.

### **3.8.6.6 Post-Sep Relative Motion Predictions**

To predict post-sep relative motion, FDO uses the Relative Motion Digitals (RMD) processor and displays in Mode 1. Section 3.4.2.2 documents RMD operation and display content. Both PAYLOADS and INCO often request times at which the Orbiter will be at various ranges from the payload. These requests are routinely handled with RMD in Mode 2. The Real Time Relmo graphic display is also used, both as a tool to determine safe relative motion and as a projected situational awareness display for the entire Flight Control Team.

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### **3.8.6.7 Contingencies**

Payload problems, RMS malfunctions, or Orbiter systems anomalies can disrupt or even terminate RMS deploy operations. This section reviews typical contingencies and outlines responses as they occur in mission planning and the flight rules.

#### **3.8.6.7.1 Payload Problems**

Payload problems may be discovered while the payload is still latched in the bay, or while the RMS is grappled to it before release. Problems discovered while payloads are still latched usually result in deploy delays, ranging from one orbit to days. RMS operations usually include periods of payload checkout immediately after grapple to avoid discovering serious problems only after release has occurred. During grappled checkout, the payload is sometimes placed in an intermediate RMS position to allow the crew to observe solar array and/or antenna deploys. For some payloads, a contingency EVA prep is scheduled, so crewmembers are prepared to begin an EVA immediately after a checkout failure. Mission extensions may also be planned to accommodate extra EVA days if deploy is delayed. These measures may seem extreme, but they are necessary for missions dedicated to payloads such as HST or GRO. FDO must be aware of potential delays and be prepared to perform deploy computations for backup opportunities.

Some deploy/retrieve payloads can operate as berthed experiments if RMS deploy is not possible. The SPARTAN-Halley payload, for example, could have operated latched in the payload bay using Orbiter pointing capability to acquire celestial targets. Propellant for attitude maneuvers would have come from the rendezvous budget. Berthed operation is normally an extremely undesirable last resort because of the relatively polluted environment around the Orbiter. This is not an option for payloads to be left in orbit, nor should it interfere with other payload operations of equal or higher priority.

If the payload or its components need to be jettisoned, FDO must compute appropriate sep burns and model jettisoned articles in an ephemeris. Payload jettison involving the RMS is described in Section 3.9.

#### **3.8.6.7.2 RMS Malfunctions**

RMS malfunctions often affect FDO deploy operations. They may result in non-standard deploy and sep attitudes, jettisons, or unplanned avoidance burns.

##### **3.8.6.7.2.1 Single-Joint Failures**

A single-joint failure robs the RMS of three of its six degrees of freedom, and it restricts the range of attainable release positions. When possible, PDRS controllers plan nominal release positions compatible with a single-joint RMS failure. This avoids having to maneuver the Orbiter to a different deploy attitude if a single-joint failure occurs, and it also avoids having to use a different sep sequence. In the event of a single-joint failure, FDO should expect to see deltas to the payload's release position and RMS joint angles on the RMS Deploy PAD.

## **FDO Console Handbook Section 3.8: Payload Deploys**

### **3.8.6.7.2.2 RMS Jettison**

Complete failure of the RMS will require RMS jettison if it cannot be latched. This is because OMS translations introduce forces on the unlatched RMS which are too large for its mechanical brakes to overcome. Jettison is therefore necessary before deorbit or other OMS burns. RMS jettison procedures are found in Section 3.9.

### **3.8.6.7.2.3 Uncommanded or Anomalous Payload Release**

Uncommanded or off-nominal release ultimately requires the crew to maneuver the Orbiter away from the payload to prevent recontact in the event regrabble isn't possible. Initially, collision avoidance entails an unplanned +Z RCS translation in whatever attitude the Orbiter is in at release. FDO's task in this case is to be aware of the Orbiter's LVLH attitude at release and be prepared to recommend further action. Options include completion of a 1-2-3 generic sep, completion of the nominally planned sep sequence, and a purely posigrade or retrograde sep. FDO's call depends on accurate knowledge of Orbiter/payload relative motion. To this end, it's important to obtain the time and magnitude of the initial sep following uncommanded release from standard burn monitoring tools. Depending on crew progress in the Deploy Checklist, it may also be possible to model relative motion based on an ephemeris pair anchored off downlisted Orbiter and target state vectors.

**WARNING:** prior to initiating any unplanned separation sequence, the crew must insure the payload is stationary over the payload bay. Relative motion assessment and separation procedures are, in general, critically dependent on these initial conditions.

### **3.8.6.7.3 OMS Leak/Perigee Adjust**

An OMS leak during RMS payload deploy operations is an extremely undesirable situation, even if the payload is berthed. Typically, it takes up to 20 min to jettison a payload and stow the RMS. In contingencies like an OMS leak, Flight Rule 12.1.1-6D states OMS burns are not permitted until the RMS is unloaded and in a configuration best able to approach the pre-cradle position under prevailing conditions. It's also permissible to perform an OMS burn under this rule if the RMS is grappled to a berthed payload. The intent of this rule is not merely to protect the arm, but also to prevent its joint brakes from slipping and causing RMS/payload contact with the Orbiter. Unfortunately, there is no way to eliminate the time necessary to safely separate from a jettisoned payload before doing the OMS burn to depletion, even for a fast OMS leak.

If the payload is deployed, or the RMS is jettisoned, a sep burn of at least 1 fps is necessary before it's safe to perform the OMS depletion burn. The sep sequence is dependent on payload release attitude and may incorporate the depletion burn as one of its translations. Because of variations in RMS payload deploy procedures, flight rules governing response to OMS leaks during RMS deploys will normally appear in the flight-specific rules annex. Typical responses are related in the following subsections.

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### 3.8.6.7.3.1 Pre-Unberth OMS Leak Procedures

If the payload is still latched (pre-unberth), the crew will postpone deploy operations and treat the OMS leak as a "no deploy" case, as described in Flight Rule A4.1.3-4 and Section 3.9. The RMS must be stowed or grappled to the berthed payload before the OMS depletion burn can occur.

### 3.8.6.7.3.2 Post-Unberth, Pre-Release OMS Leak Procedures

If the payload is unberthed and grappled to the RMS when the OMS leak occurs, the least time-consuming course of action is to release the payload, safe the RMS, perform separation burns to insure safe relative motion after the OMS depletion burn, then perform the OMS burn. This approach is applicable to both types of depletion burn: out-of-plane (OOP) and retrograde perigee adjust (PADJ).

#### 3.8.6.7.3.2.1 Fast OMS Leak

- 1) Release the payload immediately.
- 2) Perform a "quick separation". This quick sep is a variant of that described in Section 3.9.
  - A) If the Orbiter is in an attitude requiring a 3-burn sep sequence, or if the Orbiter is in an attitude for a +Vbar deploy, the quick sep is as follows.
    - i) If the OMS depletion burn will be retrograde, perform the following sequence.
      - a) Sep-1 (multi-axis): 1 fps away from payload 1 sec after release
      - b) Sep-2 (multi-axis): 4 fps OOP at least 4 min after Sep-1
      - c) Sep-3 (leaking OMS): PADJ/OOP to depletion at least 4 min after Sep-2
    - ii) If the OMS depletion burn will be OOP, perform the following sequence.
      - a) Sep-1 (multi-axis): 1 fps away from payload 1 sec after release
      - b) Sep-2 (leaking OMS): OOP to depletion at least 4 min after Sep-1
      - c) Sep-3 (PX2): PEG-7 = +2, 0, 0 at least 15 min after Sep-2
  - B) If the Orbiter is in a -ZLV attitude for -Rbar release, the quick sep is as follows.
    - i) If the OMS depletion burn will be retrograde, perform the following sequence.
      - a) Sep-1 (multi-axis): 1 fps away from payload 1 sec after release (radial up)
      - b) Sep-2 (leaking OMS): PADJ/OOP to depletion at least 4 min after Sep-1
    - ii) If the OMS depletion burn will be OOP, perform the following sequence.
      - a) Sep-1 (Multi-axis): 1 fps away from payload 1 sec after release (radial up)

## **FDO Console Handbook Section 3.8: Payload Deploys**

- b) Sep-2 (leaking OMS): OOP to depletion at least 4 min after Sep-1
- c) Sep-3 (PX2): PEG-7 = +2, 0, 0 at least 15 min after Sep-2

### **3.8.6.7.3.2.2 Extremely Slow OMS Leak**

- 1) Expedite payload release.
- 2) Perform the nominal sep sequence, followed by the OMS depletion burn.
  - A) If the OMS burn will be retrograde, burn the leaking system at optimum TIG. Even a posigrade sep sequence will pose no significant increase to deorbit cost.
  - B) If the OMS burn will be OOP, it may be performed at any time after the sep sequence, and may be substituted for any OOP sep burn in that sequence as long as the sequence is completed.

## **FDO Console Handbook Section 3.8: Payload Deploys**

**Section 3.8 Concludes On This Page**

## **FDO Console Handbook Section 3.9: Contingency Maneuvers**

### **3.9 Contingency Maneuvers**

An Orbit FDO has to be prepared to deal with a variety of contingency situations. These include Orbiter or payload system failures impacting mission duration, trajectory requirements and trajectory capability. For example, an Orbiter system failure that affects mission duration would be an insertion to an off nominal altitude requiring contingency orbit raising maneuvers to be considered. An example of an Orbiter system failure impacting trajectory requirements would be an RMS failure for which stowage and latching is not possible. This would require the Orbiter to jettison the RMS and remain clear of it during the rest of the flight. An example of an Orbiter failure affecting the trajectory would be propellant systems leaks requiring actions to regain and remain within deorbit capability. While FDO has no direct systems responsibility, an overall vehicle status and capability awareness must be maintained.

#### **3.9.1 Overview**

This section addresses general contingency situations and general FDO Console responses to these situations. For published procedures and flight rules, FDO Console response is detailed along with the rationale. By altering the published procedures, a large number of unique (but unpublished) contingency situations can be addressed. In like manner, by preparing for contingencies included in this section, FDO Console responses to a wide range of contingencies is possible. General situations included in this section are separations and jettisons, propellant system leaks, and off-nominal orbit insertions. Contingency situations arising during entry or in flight-specific cases are not included. Consult DM-CH-04, *FDO Console Handbook Volume IV Deorbit/Entry and EMCC*, or flight-specific annexes to Volume 3 for responses to these contingencies.

#### **3.9.2 Contingency Separation and Jettison**

Off-nominal situations can bring the Orbiter into close proximity with another object previously attached or under controlled relative motion. This object then poses a collision (or recontact) threat. If there is an immediate danger of collision, the crew must respond with appropriate piloting actions. Longer term, over time scales of an orbit or more, MCC will consider the best course to take. This often involves a contingency separation burn providing safety from recontact, contamination, explosion, or radiation while satisfying propellant system limitations and, ideally, supporting remaining mission objectives. The threat object may be a payload or an unsafe, hazardous, or non-stowable Orbiter component. For these cases, a controlled and timely jettison can be executed to avoid recontact, minimize contamination, and expedite separation to a safe distance. The FDO Console plays a major role in MCC contingency maneuvers such as these.

## **FDO Console Handbook Section 3.9: Contingency Maneuvers**

The generic Flight Data File (FDF) contains 5 published procedures addressing jettisons and separations. Generally any situation may be time critical, and FDO will need to quickly direct the crew to the correct procedure. Due to the quick response requirement and the possibility of no communications with MCC, these procedures have been designed such that PADs are not required. Jettison and sep procedures are designed to guarantee safe relative motion if executed correctly. Therefore, monitoring crew actions will be the primary task.

Depending on the flight, some payload-specific actions may be published in the flight specific FDF or the Flight Rules Annex. Descriptions and rationale for these procedures can be found in the appropriate FDOCH Volume 3 Annex. ISS contingency separation procedures are documented herein because they're included in the FDF for a large number of flights. If present, Rendezvous GPO monitors these procedures along with FDO.

Time permitting, the crew generally prefers a jettison between orbit sunrise and noon. This constraint insures the jettisoned object will be visible in daylight for an adequate period. After separation, a lit object may also be tracked using any relative motion sensor. The jettisoned object will be referred to as the payload or target in the remainder of this section.



## FDO Console Handbook Section 3.9: Contingency Maneuvers

### 3.9.2.1 Separation/Jettison Procedures Overview

Procedure	Description	Location
SEP Maneuver	Used to get away from target in any initial attitude, also referred to as the Generic 1-2-3 SEP	Orbit Ops, p 11-1
Ku or RMS Jettison	Generally tried after all efforts to recover Ku or RMS have failed. Not time critical. RMS version may include payload.	Orbit Ops, p 2-8 (Ku), PDRS Ops, p 8-1
Quick Response Jettison	For use during a <u>time critical</u> deorbit scenario with the Orbiter in any attitude. Includes Ku and/or RMS jettison if needed with or without payload.	Cont D/O Prep, p 12-1
Simplified Quick Response Jettison	For use during a <u>time critical</u> deorbit scenario when the Orbiter attitude is within 10° of -ZLV (bay earth). Includes Ku and/or RMS jettison if needed with or without payload.	Cont D/O Prep, p 12-1
Hazardous Payload Separations	Flight or payload specific procedures for separating from hazardous payload. See FDOCH Volume 3 Annex for flight.	Payload Ops, Contingency Ops Section
ISS Expedited or Any Attitude Separation	Flight specific procedures for expedited contingency separations from ISS while docked.	Rend C/L, Section 5
ISS Emergency Separation	Flight specific procedures for <u>time critical</u> contingency separations from ISS while docked followed by a deorbit or propellant depletion burn	Rend C/L, Section 5
Separation & Leaking OMS	Combines depletion burn with 1-2-3 separation and payload specific constraints. Not usually published in the FDF as an end-to-end procedure.	Orbit PCL p 7-7 & Orbit Ops p11-1, Flt Specific Rules, & Payload Ops (Contingency Ops)
No FRCS Deploy	Deploy despite loss of FRCS. Not part of FDF. Not published.	FDOCH Volume 3, Section 3.9.2.8.3

**Table 3.9.2-1: Overview of Separation/Jettison Procedures**

### 3.9.2.2 Big Picture Actions

- 1) Get the crew to the right procedure and follow along. The first priority is getting the crew to the right procedure. Follow their actions to avert errors. These procedures

## FDO Console Handbook Section 3.9: Contingency Maneuvers

were developed to insure safe relative motion if performed correctly, so verifying relative motion in advance is lower priority than verifying procedural execution.

- 2) No PADS are required. None of these maneuvers will be PADed with the exception of deorbit targets in Quick Response Jettison procedures and the emergency undock from ISS. The crew will be referred to appropriate procedures by the C/L.
- 3) No BFI modeling unless time permits. There is generally not enough time for FDO to model BFI maneuvers and then convert them to PEG-7 or M50 for confirmation. TRAJ can confirm a maneuver with direct inputs or DV Sensor after it's performed. The exception may be jettison procedures, since they are generally not time-critical.
- 4) When possible, jettison between sunrise & noon. The crew prefers to have maximum duration visual contact.
- 5) Confirm delta-velocity ( $\Delta v$ ) and opening rate to FD. As this information becomes available, it's good situational awareness for FD. The  $\Delta v$  information is immediately available using the DV Sensor application. Also confirm opening rate to FD after the final separation burn. A projected relative motion plot may also be provided to the FCR.

### 3.9.2.3 Helpful Hints

- 1) The steep/shallow deorbit  $\Delta v$  cost FDO passes to PROP for entry redlines determination should always account for any possible contingency separation. This will assure  $\Delta v$  and propellant required for steep or shallow deorbit is worst case. Since deorbit  $\Delta v$  is a function of sep TIG, the worst case can be estimated by having PROP add sep  $\Delta v$  to deorbit  $\Delta v$  from the pre-sep orbit.
- 2) FDO should monitor the crew while burn targets are loaded to promptly report any errors.
- 3) For OOP burns, FDO should monitor PEG-7 targets and resulting VGOs and notify FD if VGO Z is negative. The crew can then be reminded, if necessary, to change the DVY and reload prior to TIG. The importance of these steps, if they appear in the procedure, is critical to crew safety.
- 4) Use DV Sensor or the pre and post-burn sensed  $\Delta v$  displayed on RNDZ/Prox Ops Proc or ROSS Alarms with RMM to verify expected  $\Delta v$  as well as to confirm maneuvers in the ephemeris.

## FDO Console Handbook Section 3.9: Contingency Maneuvers

### 3.9.2.4 Generic Separation Maneuver (1-2-3)

The Generic Separation Maneuver<sup>1</sup> provides a separation procedure from a detached payload or other object in close proximity to the Orbiter and insures safe relative motion, regardless of initial Orbiter attitude. As such, it can be used in many situations and even when nominal separation procedures go awry or no longer provide safe relative motion. The  $\Delta v$  magnitudes and the time between burns can easily be altered to fit the situation. For example, the third posigrade burn can be replaced with a retrograde translation, and the separation will still be safe. Modified, it can be used to expedite separation from a recently deployed payload so that an Orbiter propellant depletion burn can safely be performed. This modified procedure can be placed in the Contingency Ops section of a Payload Ops C/L. The Generic Separation procedure may be applied to lost hardware and back away deploy EVA scenarios, and it may be used to terminate prox ops or to get away from an unexpectedly released or jettisoned piece of hardware. The three-maneuver sequence (back away, out-of-plane, and posigrade/retrograde burns) forms the core of many payload or flight-specific separation techniques.

**WARNING:** analysis supporting generic 1-2-3 sep safe relative motion assumes the initial condition of an object over the Orbiter's payload bay with no closure rate. Under other conditions, the best course of action may be no Orbiter translations until relative motion is known or a means to safely achieve the 1-2-3 initial condition is devised.

The generic 1-2-3 separation procedure calls for the following actions.

- 1) Attitude maneuver to visually place the payload out the overhead windows
- 2) Null the closing rate between the Orbiter and payload
- 3) 1 fps burn away from the payload (NORM-Z or LOW-Z)
- 4) 2 fps out-of-plane (OOP) burn 2 minutes later
- 5) 3 fps posigrade burn 15 minutes after OOP burn

It's called the "1-2-3" separation based on  $\Delta v$  magnitudes for the three burns. If the crew executes the generic separation, FDO must model or confirm the three burns in an Orbiter ephemeris and create a new ephemeris for the target in order to model the post-separation relative motion and verify safe relative motion to FD. Section 3.8.6.3.3 illustrates relative motion during the first orbit following various 1-2-3 sep burns.

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<sup>1</sup> *Generic Orbit Operations Checklist*, SEP Maneuver, p 11-1.

## FDO Console Handbook Section 3.9: Contingency Maneuvers

### 3.9.2.4.1 Target Ephemeris

If an accurate target ephemeris already exists, use it as is. If not, and the target is motionless in the immediate vicinity of the cargo bay, anchor the target ephemeris (usually E3) out of the Orbiter ephemeris at the current time and static start 15 min earlier. Configure the target ephemeris as follows.

Integrator Option: DM (constant drag)  
KCON: 1.0 (multiply supplied Area by supplied  $C_D / 2.0$ )  
Weight: target weight in lbm  
Area: Average cross-section area in  $\text{ft}^2$ .  
STDN OPT: NO  
Eph Length: 6 hrs  
Orbit: Orbit # at static start time

If the target is not motionless in the immediate vicinity of the payload bay, as is often the case in prox ops, the crew will probably try to acquire the object with Ku-band radar, which is the optional step 4 in the procedure. MCC may request this be done. In any case, if the MCC or FDO desires relative navigation (Relnav) data on the ground, a valid ( $\leq 15$  hrs from current time) target vector must be onboard in order for the crew to enable Relnav. To determine the time of the last target uplink, check the TUDT parameter at the top of the RNDZ/Prox Ops Proc display. If there is no target vector onboard or it's more than 15 hrs from the present, FDO will need to uplink a new target state. Build and uplink the 402xx command (target state vector) using either the current Orbiter or target ephemeris as a source for the state vector. Command procedures are in *Flight Dynamics Command Procedures* (DM-CH-05).

### 3.9.2.4.2 Separation Maneuvers

In order to accurately model separation maneuvers, FDO must know the time of the first maneuver and the attitude from which it will be performed. The attitude at TIG can be obtained from POINTING (or use the inertial or LVLH attitude digitals off Orbit Monitor or the ROSS 3D Attitude application). Use the BFI<sup>2</sup> guidance mode to model the back away (SEP-1). If the crew has to perform an attitude maneuver to make the target visible through the overhead windows, the separation attitude may not be available until very close to the TIG of the first maneuver. If the Orbiter and target are in a well-defined relative position and stable, the inertial or LVLH attitude at SEP-1 TIG should be available earlier. If it's not practical to model SEP-1 in advance, relative motion situational awareness can be maintained by confirming it with M50  $\Delta v$ .

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<sup>2</sup> BFI LVLH attitude requires a Y, P, R Euler sequence, whereas BFI inertial attitude uses a P, Y, R Euler sequence.

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The second maneuver, SEP-2, is performed multi-axis (no ITEM 27 maneuver to burn attitude), keeping the target visible through the OVHD windows. SEP-2 TIG is only 2 min after the first maneuver. Its purpose is to guarantee out-of-plane clearance of the payload in preparation for the final maneuver. The crew will input the following PEG-7 targets: DVX = 0, DVY = +2, DVZ = 0. Upon executing the load, ITEM 22, the onboard will compute body VGOs using the current attitude (not the burn attitude). Per the Orbit Ops C/L procedure, the crew will check the sign of the VGO Z. A negative VGO Z means that the Orbiter will travel along its -Z body axis (up out of the payload bay). If the target is right above the bay, that means the Orbiter will be moving toward the target as it goes out of plane. For a negative VGO Z, the crew must negate the SEP-2 PEG-7 DVY target to -2 fps and reload, verifying VGO Z is now positive. FDO should monitor this targeting process. Then the crew will execute the maneuver by deflecting the THC to trim out VGOs.

To model the second maneuver, FDO uses PEG-7 inputs with PX2 thrusters. Since maneuver PADs are not being provided to the crew, the correct  $\Delta v$  and TIG are all that's required to model this multi-axis maneuver. Burn attitude is not needed.

For the third burn, the crew will maneuver to +X thrust attitude. This burn establishes a good opening rate and eliminates any possibility of recontact. Since the payload is still in the vicinity of the Orbiter, the crew would like to maintain visual contact. By selecting a TVR corresponding to the sign of the SEP-2 DVY, OVHD windows can be pointed in the direction of the payload. For DVY = +2, the procedure calls for TVR = 270 (-90). For DVY = -2, TVR = 90.

FDO should monitor execution of all three maneuvers. Since the first maneuver is modeled as BFI, it cannot be confirmed as is. If the components or TIG of SEP-1 are different than planned, DYNAMICS will have to TUP past the BFI maneuver in order to delete it (since it will have executed). DYNAMICS can then direct input SEP-1 with M50  $\Delta v$  and PX2 thrusters. Although SEP-1 attitude is not correct following this direct input, the relative motion is. To avoid BFI execution, FDO could replace the modeled BFI maneuver with an M50 or PEG-7 maneuver using  $\Delta v$  shown on the DMT for the maneuver modeled using BFI. SEP-2 and 3 can be confirmed in the normal way. To reiterate, FDO can skip modeling the BFI maneuver in advance and just confirm it (using M50 direct input with DV Sensor or RMM  $\Delta v$ ) after the fact.

Table 3.9.2-2 summarizes Generic Separation modeling inputs. Remember SEP-1 cannot be confirmed as a BFI burn.

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SEP Maneuver, ORB OPS p 11-1			
	SEP-1	SEP-2	SEP-3
Guidance Mode	BFI	PEG-7	PEG-7
TIG	SEP-1 TIG	SEP-1 +2 min	SEP-2 +15 min
Thrusters	ZH	PX2	PX2
& Targets	Att indicator = ADI or LVLH	TVR=180 DVX = 0.0	TVR=90 or 270* <sup>3</sup> DVX = +3.0
	Inertial or LVLH <sup>4</sup> angles	DVY = ± 2.0 DVZ = 0.0	DVY = 0.0 DVZ = 0.0
	DV = 1.0 fps or DT = 3 sec		

**Table 3.9.2-2: Generic 1-2-3 Summary**

A quick method of modeling the separation maneuvers in advance is available using the Orbit Maneuver Processor (OMP). The separation sequence is input into a maneuver constraints table (MCT) using a dummy TIG and PEG-7  $\Delta v$  targets for the first maneuver. Then the table is stored for use when needed. Create an appropriate maneuver transfer table (MTT) at the same time. If the contingency arises, create and anchor the target ephemeris at the expected separation time and fill in the time and  $\Delta v$  for the first separation maneuver in the Constraints Table. Then fetch from the Orbiter and target ephemerides (normally from E1 and E3) 15 min prior to the expected separation, run the plan, and transfer it to the Orbiter ephemeris (normally E1). The separation sequence is modeled and ready for confirmation.

OMP Constraints and Evaluation tables illustrating an arbitrary 1-2-3 sep sequence appear in Figure 3.9.2-1. Figures 3.9.2-2/3 show near/far field relative motion plots corresponding to this example. Systematic variations in relative motion arising from other 1-2-3 sep geometries are illustrated in Section 3.8.6.3.3.

<sup>3</sup> If DVY of SEP-2 = +2 fps, use TVR = 270, If DVY of SEP-2 = -2 fps, use TVR = 90.

<sup>4</sup> BFI LVLH requires a Y, P, R Euler sequence. For BFI inertial, use a P, Y, R sequence.

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LOCAL		MANEUVER CONSTRAINTS TABLE SEP		
		COMMENT: Generic 1-2-3 Separation		CURRENT MNVRS: 3 / 40
MANEUVER	THRESHOLD	SECONDARIES		
1 EXDV SEP-1	T 000:13:00:00.000	DVLV =0.7 = =	DVLV =-0.2 = =	DVLV =0.6 = =
2 EXDV SEP-2	DT 000:00:02:00.000	DVLV =0 = =	DVLV =-2 = =	DVLV =0 = =
3 EXDV SEP-3	DT 000:00:15:00.000	DVLV =3 = =	DVLV =0 = =	DVLV =0 = =

LOCAL		MANEUVER EVALUATION TABLE SEP					
		COMMENT: Generic 1-2-3 Separation					
		L	L				
		MCT : SEP	OVT : SEP				
		GMTR : 2002:213:22:42:30.000					
VECTOR	TIME	COMMENT					
CHASER L E1	M 000:13:00:00.000	Orbiter					
TARGET L E3	M 000:13:00:00.000	Target					
CHASER	DVtot = 5.94	DVx = 3.70	DVy = 2.20	DVz = 0.60			
TARGET	DVtot = 0.00	DVx = 0.00	DVy = 0.00	DVz = 0.00			
3 MNVRS							
MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
	COMMENT	METIG		DVy	HP	PHASE	Ydot
	DVMag	DT		DVz	DH	Noon/Mid -	SR/SS -
1	EXDV	214:11:42:30.000		0.70	210.52	0.0000	0.0
	SEP-1	000:13:00:00.000		-0.20	209.88	0.0000	-0.2
	0.9	000:00:02:00.000		0.60	0.00	N-00:05:51	SS-00:37:02
2	EXDV	214:11:44:30.000		0.00	210.49	0.0186	-23.9
	SEP-2	000:13:02:00.000		-2.00	209.86	-0.0002	-2.2
	2.0	000:00:15:00.000		0.00	0.01	N-00:03:51	SS-00:35:04
3	EXDV	214:11:59:30.000		3.00	211.99	0.3032	-1663.7
	SEP-3	000:13:17:00.000		0.00	209.74	-0.0019	-1.1
	3.0	000:00:00:00.000		0.00	-0.04	M-00:35:02	SS-00:20:00

**Figure 3.9.2-1: Example OMP Tables for 1-2-3 Separation**

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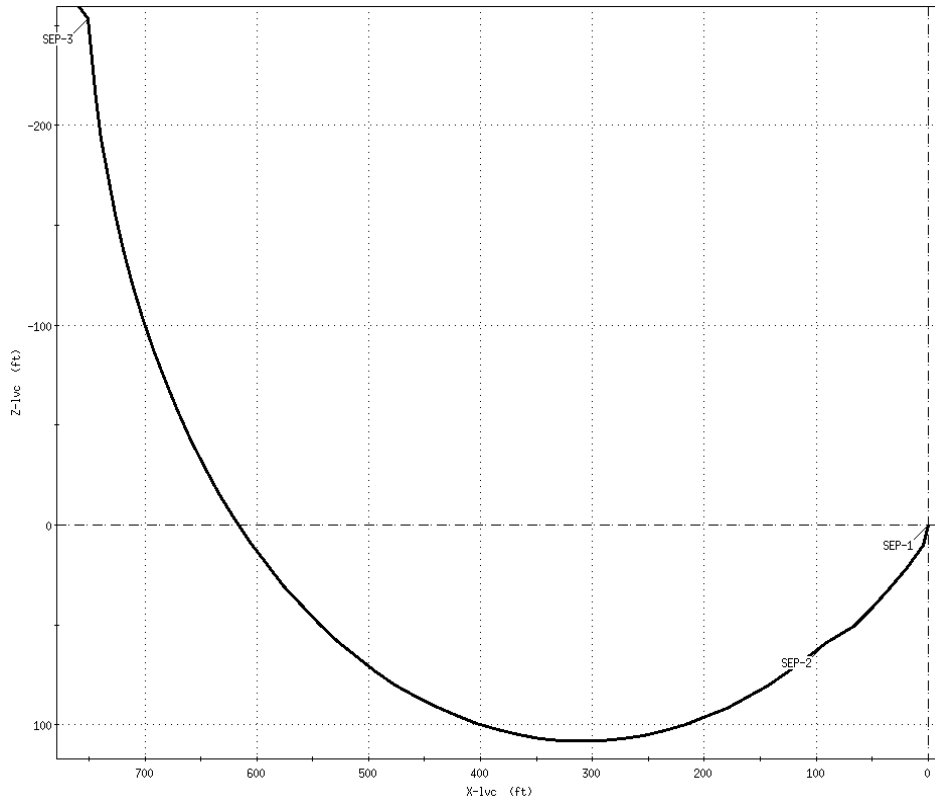


Figure 3.9.2-2: Near-Field Relative Motion for the 1-2-3 Separation



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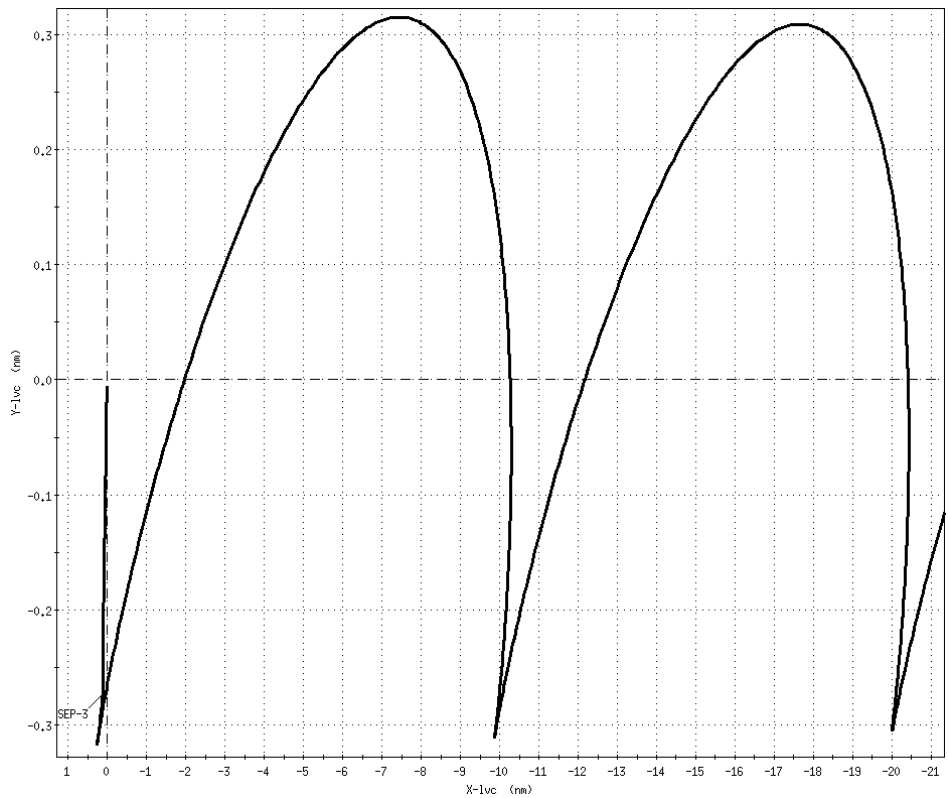
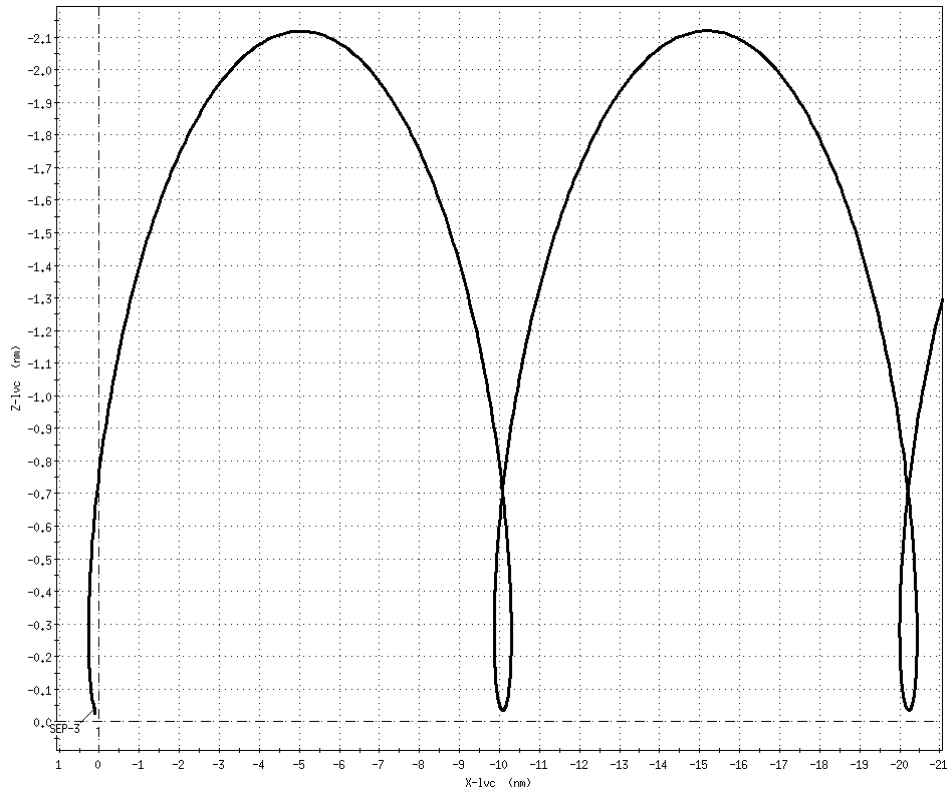


Figure 3.9.2-3: Far-Field Relative Motion for the 1-2-3 Separation

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Foregoing relative motion plots graphically illustrate relative motion for the sequence modeled using OMP (Figure 3.9.2-1). The SEP-2 DVY target for the first sequence is negative because the previous burn (SEP-1) has a negative OOP component. Thus, the SEP-2 burn will reinforce motion already established north of the target's orbit plane.

### 3.9.2.5 Ku Band/Radar Antenna or RMS Jettison

Reference: Generic Orbit Operations Checklist, Section 2 – Ku-BD Ant Jett, page 2-8. Generic PDRS Operations Book, Section 8 – RMS Jettison, page 8-1.

Unstowable payload bay equipment is normally jettisoned retrograde with the Orbiter in a -XLV +ZVV (tail to Earth, belly into velocity vector) attitude<sup>5</sup>. As this is generally not a time critical situation, procedures have the crew maneuver the Orbiter to the jettison attitude. The avoidance strategy jettisons the equipment with the payload bay facing retrograde. This attitude maintains the jettisoned equipment in view as the crew performs two one fps posigrade maneuvers to avoid recontact. Most jettisoned items will have a much higher area-to-mass ratio than the Orbiter, resulting in higher drag and faster orbit decay. With posigrade separation, jettison procedures are designed to take advantage of this differential drag acceleration over the long term.

Jettison attitude allows the crew to visually monitor relative motion following separation, provided the jettison occurs between orbit sunrise and noon. To facilitate this, the crew initiates the maneuver to jettison attitude at least 15 min prior to sunrise. The crew then waits until rates are damped, sets the DAP to FREE, and performs the jettison. Immediately after jettison, the crew performs the separation sequence. In the case of a Ku Band jettison, the sequence consists of two 1.0 fps maneuvers. The first maneuver, 1.0 fps along the +Z body axis (essentially posigrade) using THC pulses. Two minutes later, a second 1.0 fps posigrade maneuver is performed. In the case of a RMS jettison, the sequence consists of a small back-away maneuver, followed by one larger sep burn. The back-away maneuver is 0.2 fps (two THC pulses) along the +Z body axis. The larger sep burn is a 1.6 fps (5 sec) +Z body axis maneuver. After sep burns are complete, the crew controls Orbiter attitude as necessary to maintain jettisoned equipment visibility through the overhead windows.

#### 3.9.2.5.1 Target Ephemeris

The first step in modeling post-jettison relative motion is to set up an ephemeris for the jettisoned hardware. Configure the target ephemeris with the appropriate Table 3.9.2-3 characteristics and anchor it out of the current Orbiter ephemeris at the expected

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<sup>5</sup> *Generic Orbit Operations Checklist*, p 2-8; *Generic PDRS Operations Book*, p 8-1.

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jettison time with a static start 15 min earlier. Update this static start to reflect actual jettison time.

<b>Ku or RMS Jettison: Target Eph Config</b>			
Config Item	Ku-Band Jettison	RMS Jettison	RMS/Payload Jettison
Integrator Option	DM	DM	DM
KCON	1	1	1
Weight	190 lbm	1043 lbm	(payload + RMS) lbm
Area	10 ft <sup>2</sup>	42.4 ft <sup>2</sup>	(payload + RMS) ft <sup>2</sup>
STDN OPT	NO	NO	NO
Eph Length	6 hrs	6 hrs	6 hrs

**Table 3.9.2-3: Ku or RMS Jettison Target Ephemeris Characteristics Summary**

Because Ku and RMS jettison pyrotechnics impart near-zero separation  $\Delta v$ , no maneuvers are modeled in the target ephemeris.

### 3.9.2.5.2 Jettison Procedures

To model a Ku-Band, RMS, or RMS with payload jettison, give DYNAMICS appropriate Table 3.9.2-4 information. In the Ku Jettison case, notice the 98° LVLH pitch for the second maneuver, versus 90° for the first. This is because the two SEP burns are performed in inertial attitude hold 2 min apart (geocentric orbit rate is about 4 deg/min). In the RMS Jettison case, only one maneuver is modeled even though the procedure calls out a two-part sep sequence. This simplification is acceptable because of the short time between the back-away maneuver and primary sep maneuver, as well as the low collective  $\Delta v$  of the back-away pulses.

	<b>Ku Jettison (ORB OPS p 2-8)</b>		<b>RMS Jettison (PDRS OPS p 8-1)</b>
	SEP-1	SEP-2	SEP-1
Guidance Mode <sup>6</sup>	BFI	BFI	BFI
TIG	Jettison	Jettison +2 min	Jettison
Thrusters	ZL (+Z low)	ZL (+Z low)	ZL (+Z low)
Attitude Indicator	L (LVLH)	L (LVLH)	L (LVLH)
Y, P, R Angles	0, 90, 0	0, 98, 0	0, 90, 0
Total $\Delta v$	DVTOT = 1.0 fps	DVTOT = 1.0 fps	DVTOT = 1.8 fps

**Table 3.9.2-4: Ku and RMS Jettison Summary**

<sup>6</sup> BFI LVLH attitude requires a Y, P, R Euler sequence.

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Prior to jettison, the Orbiter maneuvers to a -XLV +ZVV attitude. Orbiter +Z thrust applied in this attitude results in a posigrade LVLH translation.

NOTE: if desired, FDO can consult with NAV after the separation sequence to discuss modeling back-away pulses in the ephemeris. Standard perturbation modeling criteria should be used as recorded in the FDO/NAV Tag-Up minutes of September 3, 2004 (S:\Divisions\DM\Shared\FDO-NAV Tagup\Minutes\).

CAUTION: at jettison +15 min, the Orbiter should maneuver back to a -ZLV -XVV attitude. This attitude insures Orbiter minimum drag following jettison. Should another attitude be required, FDO can alter Orbiter ephemeris drag characteristics to evaluate the resulting relative motion after coordinating with POINTING.

### 3.9.2.6 Quick Response Jettison Procedures for Any Attitude

Quick response jettison procedures<sup>7</sup> were developed to address a time critical jettison within a pending deorbit scenario. Due to the time it takes to maneuver to attitude, the normal jettison procedures may be too time consuming for use in an emergency deorbit situation. The possibility of recontact also exists in some cases due to deorbit burn geometry and timing. For this situation, the most important thing is to get the crew to the right procedure and follow along, ready to provide timely assistance.

#### 3.9.2.6.1 Assumptions

- 1) Jettison may occur from any Orbiter attitude.
- 2) There is an emergency Orbiter situation with deorbit pending.
- 3) Failed Ku and/or RMS (possibly with payload) are not stowed and require jettison ASAP.
- 4) At least 1 G2 GPC is up.
- 5) OPS 2 or OPS 3 is OK for this procedure.

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<sup>7</sup> *Generic Contingency Deorbit Prep*, p 12-1.

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### 3.9.2.6.2 Requirements

- 1) SEP-1 is always directly away from the payload with  $\Delta v = 0.8 \pm 0.1$  fps.
- 2) SEP-2 must be  $\geq 4.0$  fps OOP such that it reinforces any OOP separation imparted by the first burn.
- 3) If range  $< 500$  ft, range must be increasing.
- 4) The Orbiter must not return within 500 ft after attaining 500 ft range.
- 5) SEP-1 and SEP-2 are multi-axis (no maneuver to burn attitude).
- 6) TIGs must be  $\geq 4$  min apart for adequate crew preparation.
- 7) If deorbit TIG  $> 28$  min after SEP-1, there must be a SEP-3 with a TIG greater than 4 min after the previous SEP-2.  
If deorbit TIG  $\leq 28$  min after SEP-1, the deorbit burn can replace the SEP-3.
- 8) If SEP-3 is posigrade, SEP-3 TIG must be within 8 to 42 min after SEP-1 in order to satisfy the clearance requirements  
If SEP-3 is deorbit burn, D/O TIG should be 9 to 28 min after SEP-1 in order to guarantee clearance
- 9) Resultant relative motion will be safe for any deorbit TIG after separation sequence completion.

<b>Quick Response Jettison, C D/O p12-1</b>					
<b>SEP 3 is Posigrade</b>			<b>SEP-3 is Deorbit</b>		
Burn	TIG (min)	Description	Burn	TIG (min)	Description
--	0	Jettison	--	0	Jettison
SEP-1	0	0.8 fps away	SEP-1	0	0.8 fps away
SEP-2	$\geq$ SEP-1 TIG+4	4 fps OOP <sup>8</sup>	SEP-2	$\geq$ SEP-1 TIG +4 min	4 fps OOP <sup>6</sup>
SEP-3	SEP-2 TIG+ 4 $\leq$ TIG $\leq$ SEP-1 TIG +42	DVX=+3.0 DVY=0.0 DVZ=-2.0	Deorbit	Should be SEP-1 TIG +9 $\leq$ TIG $\leq$ 28	
Deorbit	$\geq$ SEP-3 TIG+4				

**Table 3.9.2-5: Quick Response Jettison Maneuver Summary**

<sup>8</sup> Select sign of OOP such that it adds to OOP component of SEP-1

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### 3.9.2.6.3 Third Burn TIG Rationale

Time constraints applied to the third burn are not intuitively obvious. Analysis supporting these times was presented at On-Orbit Flight Techniques in May of 1988 ([http://jsc-mod-ops/flt\\_rule/FlightTechniquesMinutesandAgendas/orbit](http://jsc-mod-ops/flt_rule/FlightTechniquesMinutesandAgendas/orbit)). The maneuver TIG limits are a function of worst-case attitude for the first burn combined with decreasing range at the Orbitier/target nodes arising from SEP-2. Worst-case is defined by combining a radial-down SEP-1 with the deorbit burn's worst-case radial and OOP components.

Deorbit TIG constraints assume SEPs 1 and 2 are complete, the deorbit burn is the third burn, and no intervening posigrade maneuver has occurred. An LVLH pitch of 295° defines the worst-case SEP-1 thrust vector. As a result, the Orbiter will move radially down and slightly ahead of the target. If the deorbit burn occurs later than 28 min after SEP-1, the deorbit  $\Delta v$  worst-case radial component sends the Orbiter back within 500 ft of the target. This is true for a broad range of SEP-1 thrust directions having a large radial component. The deorbit  $\Delta v$  OOP component also factors into the 28 min constraint. In the worst case, which was assumed to be a 45° OOP thrust vector, deorbit could send the Orbiter back within 500 ft of the target. The OOP component of the deorbit burn is actually more constraining than the radial. If SEP-3 is the deorbit maneuver, 9 min is the minimum time necessary to insure worst-case deorbit burn OOP motion does not return the Orbiter within 500 ft of the target.

Consequently, if deorbit TIG will be more than 28 min after the SEP-1 TIG, a posigrade SEP-3 must be performed prior to the deorbit maneuver. Posigrade SEP-3 TIG constraints assume SEPs 1 and 2 are complete. The 8-min minimum assumes minimal 4-min crew prep time between each of the separation burns. The 42-min maximum insures the posigrade SEP-3 will occur before the Orbiter passes within 500 ft of the target when the two orbit planes cross.

In summary, this quick jettison separation maneuver sequence is designed to protect worst-case jettison attitude and deorbit geometry during an emergency deorbit. In most cases, these time constraints are conservative. However, there is no time during an emergency deorbit to determine the real burn windows, and this procedure assures safe relative motion for all cases.

### 3.9.2.7 Simplified Quick Response Jettison for -ZLV Attitude

In the absence of other requirements, the Orbiter is generally in a -ZLV attitude (bay to Earth). If an unexpected short-fuse jettison becomes necessary, an OOP evasive burn

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is not required be the simplified procedure following a jettison within  $\pm 10^\circ$  of -ZLV attitude. Again, 4 min are required between burns to insure crew preparation time. SEP-3 and deorbit burn TIG envelopes change slightly with respect to the Quick Response Jettison to reflect different relative motion.

<b>“Simplified” Quick Response Jettison, Contingency Deorbit p 12-1</b>					
<b>SEP 3 is Posigrade</b>			<b>SEP-3 Deorbit (TIG &lt; SEP-1 +45)</b>		
Burn	TIG (min)	Description	Burn	TIG (min)	Description
--	0	Jettison	--	0	Jettison
SEP-1	0	0.8 fps away	SEP-1	0	0.8 fps away
SEP-2	SEP-1 TIG +4 $\leq$ TIG $\leq$ 45	DVX = +3.0 DVY = 0.0 DVZ = -2.0	Deorbit	SEP-1 TIG +9 $\leq$ TIG $\leq$ 45	
Deorbit	SEP-2 TIG +5 $\leq$ TIG $\leq$ 68	$\geq$ 5min SEP-2 to D/O			

**Table 3.9.2-6: Simplified Quick Separation Maneuver Summary**

### 3.9.2.8 Other Separation Procedures

Separation procedures of a more flight specific nature are listed below.

- 1) Hazardous Payload Separation
- 2) Separation and Leaking RCS/OMS
- 3) Expedited Deploy

The Lead FDO will need to work with the Lead Payloads Officer and prox ops personnel to develop appropriate rules and procedures related to deploy/jettison/separation on a particular flight. Individual procedures are described briefly in this section.

Hazardous Payload separation arises after a payload is suspected or confirmed to be an Orbiter safety hazard. A deployable/jettisonable payload typically becomes hazardous after a hydrazine leak or loss of safety inhibits to a propulsive system. The payload's mission may be lost, and crew response is time-critical. Retrograde separation techniques (like RMS/Ku Jettison) are often the baseline for non-time-critical separations, while the generic 1-2-3 separation technique serves this function for time-critical separations.

Separation in conjunction with a leaking RCS/OMS generally arises during an otherwise nominal deploy after the crew has passed a point where the payload can be quickly restowed and safed. An OMS or RCS leak then occurs. Prior to that point, flight rules

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generally call for a deploy abort of the deploy and, if applicable, RMS or payload safing for a large OMS or RCS burn. Past this point, however, recovery options may be too time consuming in the context of a non-isolated leaking RCS/OMS emergency. For instance, an EVA to put back a pulled IUS umbilical is too time consuming to be a viable option. In this case, the crew must deploy the payload as quickly as possible, usually with an expedited deploy sequence. The leaking RCS/OMS burn is then performed. Because this procedure is time critical, its separation sequence may be based on the generic 1-2-3 separation, with the leaking system's depletion burn substituted for either the out-of-plane (SEP-2) or the posigrade/retrograde (SEP-3) burn.

For many flights with a deployable payload, an expedited or emergency deploy procedure is developed to circumvent non-essential steps in the more deliberate nominal deploy procedures. This may involve changes to the separation sequence and relative motion as well.

The Lead FDO, PAYLOADS, PROP and FD usually spend considerable time considering these and any other flight unique separation scenarios. Usually, these unique contingency procedures are documented in the Contingency Ops section of the Payload Ops Checklist and in a flight-specific annex to this handbook. Section 3.8 covers rationale and procedures associated with many contingency payload deploys. Some separation procedures support recurring missions to the point they can be considered generic. Procedures common to all ISS missions appear in the following subsections.

### **3.9.2.8.1 EVA Crewman Assisted Jettison**

A large number of flights schedule EVA for repair, servicing, or cargo transfer. A contingency often encountered during EVA applies to loose equipment that cannot be restowed or otherwise secured. If the piece of equipment is large and cannot be stowed using planned provisions, jettison may be the only available alternative. Such was the case for the Spacelab Scientific Airlock (SAL) Experiment Table. A simple jettison procedure was developed for this flight in which an EVA crewman pushes the SAL away from the Orbiter along the -Z body axis (out of the payload bay) in +ZVV attitude. This jettison is followed by a small Orbiter posigrade translation. The resulting relative motion looks very much like that of the RMS/Ku-band jettison detailed in Section 3.9.2.5. For the SAL procedure, however, a maneuver must be modeled in the target ephemeris.

The Orbiter will maneuver to the +ZVV jettison attitude, damp rates, and set the DAP to FREE. An EVA crewman will push the target as accurately as possible along the -Z axis with a rate of 1 fps. After 1 min, the Orbiter performs a +Z translation of 1 fps and then sets the DAP to INRTL. The combined effect should be approximately equivalent to a posigrade separation of 2 fps. Additional procedural provisions can be inserted for



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tracking the target, either visually or with the rendezvous radar, for a sufficient time to confirm the expected relative motion.

To model the jettison, FDO anchors a target ephemeris out of the Orbiter ephemeris at the jettison time with a static start 15 min earlier. The target ephemeris has the following characteristics.

Integrator Option: DM (constant drag)  
KCON: CD/2 (or use KCON = 1 if CD unavailable)  
Weight: Target weight in lbm  
Area: Average cross-section area in ft<sup>2</sup>.  
STDN OPT: NO  
Eph Length: 6 hrs  
Orbit: Orbit # at anchor time

**CAUTION:** because a Miscellaneous thruster BFI maneuver will deplete initial weight in this ephemeris to simulate jettison  $\Delta v$ , do not use a Weight value less than 5000 lbm. Otherwise, the jettison burn may appreciably distort the target's drag profile or even result in software limiting due to a near-zero or negative burnout weight. If true weight  $W < 5000$  lbm, scale target true area  $A$  in the ephemeris to  $A \frac{5000}{W}$  for input with Weight = 5000 lbm.

The maneuver to model EVA jettison is inserted in the target ephemeris using direct input as follows.

Guidance Mode: BFI  
Attitude Ind: L (LVLH)<sup>9</sup>  
Thruster: Miscellaneous  
TIG: Jettison time or crew report  
 $\Delta v$ : 1 fps or crew estimate  
Yaw: 0  
Pitch: 180  
Roll: 0

The M thrusters are used because they do not have a cant angle, but they require BFI guidance. The LVLH attitude (PYR Euler sequence) is not an Orbiter attitude. Rather, it's one placing the "M", thrust vector retrograde. This maneuver cannot be confirmed, as the jettison push is based completely on crew judgment. If onboard rendezvous navigation is desired, FDO will have to uplink a target state. If this is done prior to jettison, fetch the uplink vector from the Orbiter ephemeris. However, the exact effect of the EVA crewman's push will not be modeled onboard until the relative state is updated

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<sup>9</sup> BFI LVLH attitude requires a Y,P,R Euler sequence.

## FDO Console Handbook Section 3.9: Contingency Maneuvers

using radar data or until FDO uplinks a new target state post-jettison. FDO can update the target ephemeris with C-band tracking if available and the target can be acquired. Nevertheless, the best estimate target state must be transmitted to USSPACECOM to facilitate debris catalog maintenance.

NOTE: during STS-61 (HST SM-1), an unstowable replaced solar array was jettisoned using a similar EVA technique. Because this array had a large area-to-weight ratio, post-jettison +Z burn  $\Delta v$  was greatly augmented by PRCS plume impingement. Although it's not practical to accurately model this retrograde impingement acceleration on the target, its effects should be expected. In such cases, the initial target ephemeris can be regarded as a "maximum energy" approximation. This is conservative and worst-case from a relative motion standpoint.

### 3.9.2.8.2 ISS Contingency Procedures

Two contingency separation procedures are associated with ISS flights, The Any Attitude Separation and the Shuttle Emergency Separation<sup>10</sup>. These procedures may be invoked following Joint Expedited Undocking and Separation (JEUS), published in the Joint Ops book. Either separation technique is intended as a response to time-critical Orbiter failures requiring emergency deorbit or OMS depletion. However, the Any Attitude procedure can also address non-critical undock situations in which the ISS/Orbiter stack cannot be maneuvered within 30° of the standard -XLV +ZVV undock attitude. JEUS documents procedures through physical separation (release of the undocking hooks and powerdown of the docking mechanism). The two separation procedures pick up crew actions with setup and execution of the first Orbiter translation away from ISS.

Like other contingency separations, no PADs are required. FDO's primary role during this contingency is to assure the crew references procedures in the proper sequence. Using voice and data, FDO then monitors crew actions and confirms they're performed correctly. FDO should be ready with modifications to the published procedures should they be required. These actions must assure recontact is avoided as intended, remembering the crew and MCC may not be proficient. RGPO has procedural responsibility for the Rendezvous book and thus has a similar role. Other FDF articles may also be pertinent, notably the Contingency Deorbit Prep (containing the Emergency Deorbit and Quick Response Jettison, if required) and the Orbit Pocket Checklist (containing the OMS Leak/Depletion Burn procedure).

The FDO Console must also model the best post separation trajectory possible from available data. This may entail deorbit burn targeting, followed by command uplinks as soon as OPS 3 transition is completed. Emergency deorbit console procedures are

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<sup>10</sup> *Rendezvous*, Section 5.

## FDO Console Handbook Section 3.9: Contingency Maneuvers

published in Section 3.9.7 (narrative) and Appendix 3.E (checklist). If deorbit isn't immediately required, FDO must assure safe post-separation relative motion is achieved in the long term (many orbits).

For the most part, modeling ISS separation burns in advance is a lower priority task that could needlessly preoccupy the FDO Console. By the time smaller separation burns are actually executed, TIGs will change and  $\Delta v$  components will be altered or covered up with IMU accelerometer noise. Only the final posigrade/retrograde separation will contribute significantly to deorbit targeting. A propellant depletion burn can be modeled in advance, but it won't be predictable with a great degree of accuracy unless PROP can estimate  $\Delta v$  with confidence.

For purposes of emergency deorbit targeting, even the ISS orbit is adequately accurate. Targeting accuracy is more dependent on current tracking updates prior to the emergency. Updating the ground ephemeris with the most recent tracking will be more valuable than modeling or confirming small separations. TRAJ can then target the deorbit burn as soon as tracking is incorporated. Later, if time allows, the deorbit burn can be retargeted and commands uplinked based on confirmed separation burns. Selection of the landing site/opportunity and notification of entry controllers should take priority over modeling or confirming smaller separation burns. Confirming larger separation burns, using direct input or the DV Sensor application, is TRAJ's next most important task.

Assuming time is available to model separation burns, the quickest method is to have an OMP maneuver constraints table (MCT) ready with the separation burn sequence set up as external  $\Delta v$  (EXDV) maneuvers. The first maneuver time in this plan can be input based on an estimate. The ISS ephemeris is anchored out of the Orbiter ephemeris at the time of separation and static started at least 15 min beforehand. This will insure the Orbiter and ISS ephemerides are starting with "zero-zero" relative motion. Fetch from the Orbiter and newly created ISS ephemerides at the estimated first maneuver time to run the plan, then transfer it to the Orbiter ephemeris.

PEG-7 targets required by OMP for separation burns specified as translations along an Orbiter body axis can be calculated using BFI modeling. Current Orbiter LVLH attitude can be read from the Universal Pointing downlist or verified with POINTING.

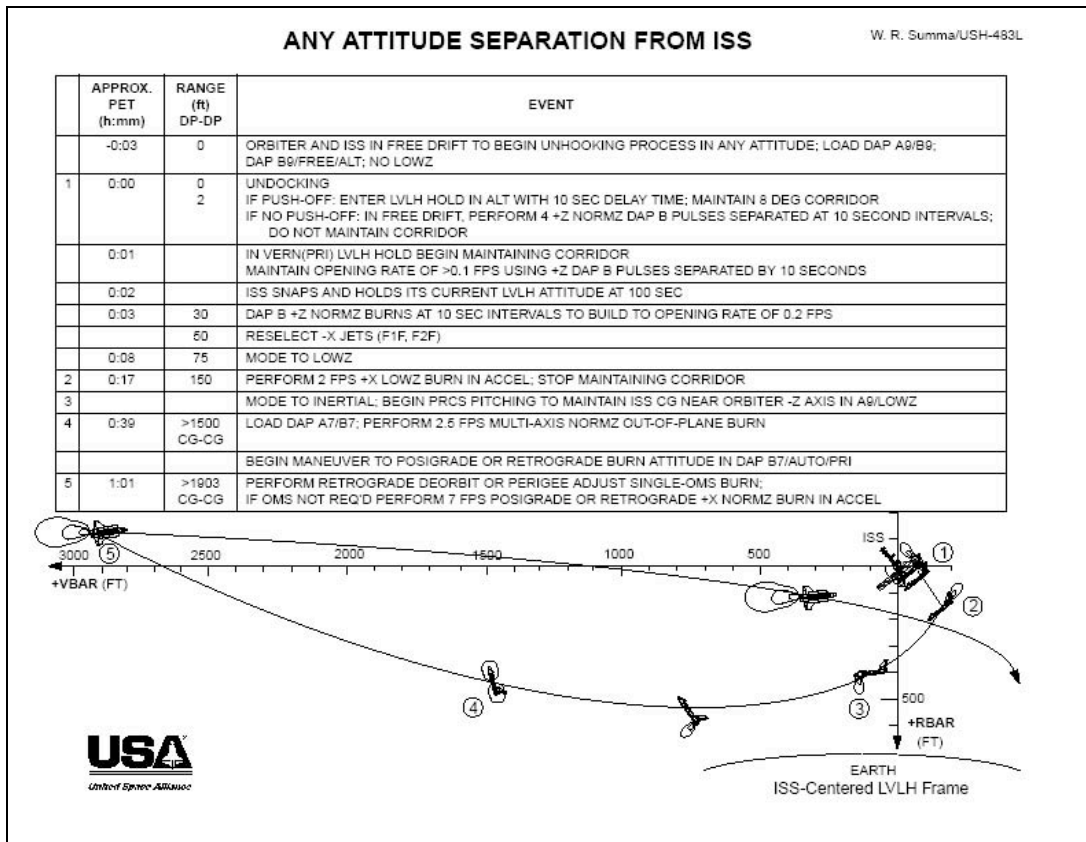
The MCT and target ephemeris can be set up in advance with only the separation time unknown. When undock occurs, it will be an easy task to anchor the target ephemeris and fetch/run/transfer the OMP plan.

# FDO Console Handbook Section 3.9: Contingency Maneuvers

## 3.9.2.8.2.1 ISS/SSP Any Attitude Separation

The Any Attitude Separation (AAS) procedure is intended for use in situations where the stack cannot be maneuvered back to nominal undocking attitude. The most likely scenario resulting in AAS execution is a failure of the APDS mechanism such that hard mate cannot be achieved. The stack will likely be in free drift for an extended period of time while troubleshooting occurs, resulting in an off-nominal attitude when undocking is attempted. The procedure is designed to provide safe relative motion from any initial mated attitude. ISS is required to snap and hold attitude after the Shuttle undocks to ensure clearance is maintained during back-away.

The AAS consists of a back-out to 150 ft, a 2 fps +X body oriented initial separation burn, a 2.5 fps multi-axis OOP burn, and a 7 fps posigrade/retrograde final separation burn. The final burn must be executed 22 min after the OOP burn to ensure acceptable relative motion. An overview of the separation sequence appears in Figure 3.9.2-7.



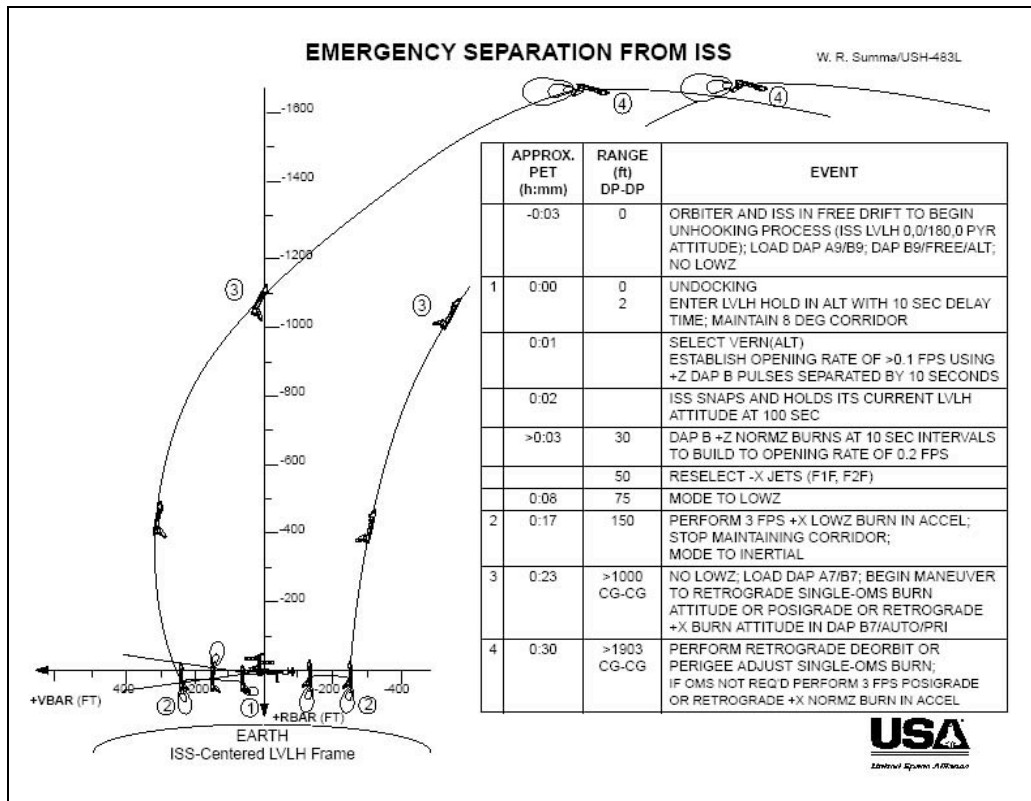
**Figure 3.9.2-7: Any Attitude Separation**

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## 3.9.2.8.2.2 ISS/SSP Shuttle Emergency Separation

The Shuttle Emergency Separation (SES) procedure is intended for use in time-critical situations. The SES is called from the Joint Expedited Undock and Separation (JEUS) procedure in the Joint Ops procedures book (SODF). Reasons for executing the JEUS include a Shuttle failure requiring emergency deorbit, an ISS failure requiring evacuation, or a Shuttle OMS/RCS leak requiring propellant depletion ASAP. The procedure is designed to meet the "two hours to the ground" constraint documented in the OPCL's Loss of Two Freon Loops procedure. The procedure assumes that the stack attitude can be controlled, and that a maneuver to the  $\pm Vbar$  attitude will be executed while the crews prepare for undocking.

The SES must be executed within  $\pm 30^\circ$  of the  $\pm Vbar$  attitude, whichever requires the smallest attitude maneuver. The procedure consists of a backout to 150 ft, a 3 fps radial up initial separation burn, and a final burn. The final burn can be deorbit, a leaking OMS/RCS depletion burn, or a 3 fps posigrade/retrograde separation burn. An overview of the separation sequence can be seen in Figure 3.9.2-8.



**Figure 3.9.2-8: Shuttle Emergency Separation**

If the final burn in the SES is a deorbit, it may be desirable to delay it slightly to target a landing site. The procedure states the burn must occur no earlier than 13 min after the radial sep, but no later than 1 hr after the radial sep. Figure 3.9.2-8 shows the location

## **FDO Console Handbook Section 3.9: Contingency Maneuvers**

of the deorbit burn if it is executed 13 min after the radial burn. If the deorbit burn is executed 1 hr after the radial burn, it will occur near the  $-V_{bar}$  and  $\sim 15,000$  ft behind ISS. Executing a deorbit burn during this window guarantees safe relative motion. It may be possible, in some cases, to execute the deorbit burn safely after this window expires. For deorbit outside the window, FDO would need to verify relative motion to ensure adequate clearance before advising the crew to burn beyond procedural constraints.

Plume impingement and loads constraints on the ISS solar arrays require minimum separation be achieved before OMS burns are executed. Single OMS burns must be performed at a range of no less than 1900 ft (CG to CG). Dual OMS burns must be performed at a range of no less than 6500 ft (CG to CG). The SES procedure is designed to achieve a range of at least 1900 ft by the final burn. An emergency deorbit burn executed as part of the SES procedure must be a single OMS burn, due to the separation design and ISS loads constraints.

### **3.9.2.8.3 No FRCS Deploy**

The Generic RMS Deploy Technique for loss of Forward RCS was presented to On-Orbit Flight Techniques Panel #116 on March 8, 1991. It's a plan for maneuvering away from an RMS deployable if the FRCS has failed. With the FRCS failed, firing the Z jets in DAP = FREE to move away, would pitch the nose into the payload. The plan is to move the payload out over the left wing with the RMS and perform a 2.0 fps +X RCS burn. The payload would be placed far enough to port such that recontact concerns with the Orbiter's aft section are alleviated.

Other than a slight difference in modeling the separation burn, FDO Console actions are the same as for other RMS deploys (see Section 3.8.3). Procedural details are published in the OFTP minutes, but they may be quickly developed by modifying more current RMS deploy procedures.

### **3.9.2.9 Monitoring Post-Separation Relative Motion**

To verify the Orbiter and jettisoned hardware have safe relative motion after the separation sequence is complete, FDO obtains a digital relative motion display with TSA's Real-Time RELMO application. Use Mode 1 with 30-min steps, starting after final separation. The change in down track relative position (X) every third point gives an indication of opening rate per orbit.

If the crew obtains good rendezvous radar data and telemetry is available, FDO should also check relative motion using onboard Orbiter and target state vectors (V56 and V54

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respectively). Configure E5 and E6 to look like the Orbiter and payload. Then TUP them off of V56 and V54.

If there's time, Real-Time RELMO can provide a good visual picture of the relative motion. Select Compute/Ground and use TrS ephemeris mirrors to display ground-based relative motion in M1/M3. To display onboard relative motion, select Compute/Filt or utilize M5/M6. More detailed instructions may be found in the TSA User's Guide for Real-Time RELMO.

### 3.9.3 Onboard Weight Update

After MECO, OPS 1 software obtains an I-loaded "current" value for Orbiter weight. Subsequent weight updates are computed using jet on-times and mass flow rates during translations only. The onboard software does not track weight changes due to deploy or jettison. The same is true for weight changes due a retrieved payload, non-prop/cryo consumables usage, and equipment transfers to ISS. When the DAP is in PULSE mode, the onboard software computes jet ON times using onboard vehicle weight to achieve specified pulse  $\Delta v$  magnitude. Each pulse  $\Delta v$  will therefore be in error to the degree onboard weight is in error.

Certain circumstances will require an onboard weight update. One example would be a scheduled maneuver in PULSE DAP mode after a large weight change, such as a payload deploy. Usually the most accurate current weight is known in the MCC by FDO, so an update to the onboard weight would have to be uplinked to the software or voiced to the crew for ITEM entry. The crew procedure is designed to update onboard weight and force the DAP to re-compute jet pulse sizes. This procedure is usually located in the Deploy C/L or RNDZ C/L Section 2. Perform the weight change as late as possible prior to deploy because onboard drag accelerations use onboard weight. By prematurely changing the weight, onboard vector prediction/propagation will compute incorrect drag accelerations.

After transition to OPS 202, uplink a PEG-7 command load consisting of maneuver targets for any of the separation burns or a dummy burn and include the new weight as part of the target set. The crew then loads the maneuver in MM202, which updates onboard weight. For the maneuver to load, at least one PEG-7 DV component must be nonzero, and the TIG must be less than 12 hrs in the future and less than 5 min in the past. The procedure would be performed as late as possible prior to deploy or whenever the actual weight change takes place.

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CRT OPS 202 PRO  
GNC ORBIT MNVR EXEC  
Load weight and maneuver per PAD  
LOAD - ITEM 22 EXEC  
OPS 201 PRO

The crew would return to MM201 and proceed with the deploy or other orbit activity. If burn targets applied to a real burn, the updated weight would be used to compute the burn as part of its normal execution.

### 3.9.4 Leaking OMS Maneuvers

Generally, a perigee adjust (PADJ) is an orbit-lowering maneuver. For the scenario in which one of the OMS propellant tanks has developed a leak that cannot be isolated, such a maneuver could make use of propellant before it leaks into the OMS pod or overboard. In most cases, leaking propellant must be burned immediately to depletion in order to minimize leakage into the OMS pod. Propellant leaking into the pod will probably solidify and may freeze other components, including the RCS propellant lines required for entry. If ARCS lines freeze, control may be lost during a subsequent entry with disastrous results. Potential for fire in the affected pod also exists during entry, together with an environmental hazard posed to recovery personnel at the landing site. No data currently exists regarding how long or under what conditions frozen OMS propellant remains frozen.

The current OMS leak procedure, with one exception, is to burn leaking propellant immediately. The exception occurs when the leak rate is extremely slow, and both the leak rate and pod thermal environment are stable. In this case, a retrograde burn will be executed at a point in the orbit minimizing deorbit  $\Delta v$  at upcoming PLS opportunities. For all cases, FDO must quickly determine depletion burn direction and time. The burn may be performed either retrograde (RETRO) or out-of-plane (OOP), depending on the circumstances. The crew must have these data in advance in case the leak occurs during a loss of communications with the ground. Flight Rule A4-104 governs OMS leak actions. The crew procedure is the Leaking OMS PRPLT/He Burn procedure and associated Cue Card in the Orbit Pocket Checklist.

Deorbit targeting places perigee of the entrant orbit in the general vicinity of the targeted landing site. When selecting a perigee adjust TIG to minimize loss of deorbit capability, FDO's strategy is to place the post-PADJ orbit's perigee above the location required following deorbit to the primary landing site(s). In Figure 3.9.4-1's left drawing, a PADJ at the optimum TIG has placed perigee in the northern hemisphere near ConUS landing site latitudes. A deorbit burn from this post-PADJ orbit would be executed near apogee and would require relatively little  $\Delta v$  to lower perigee in achieving an appropriate entrant orbit.



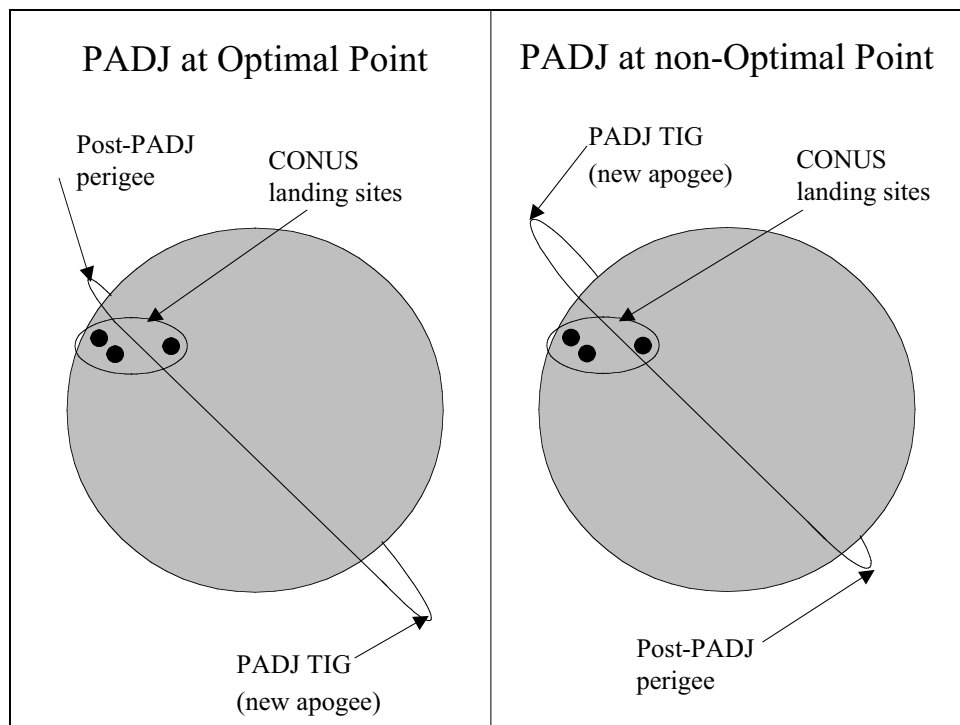
## FDO Console Handbook Section 3.9: Contingency Maneuvers

$$\Delta v_{DO} = 1.76 \left( HP_{\text{post-PADJ}} - HP_{\text{entrant}} \right)$$

In contrast, Figure 3.9.4-1's right drawing illustrates a PADJ TIG at the orbit's anti-optimum point, placing perigee in the southern hemisphere 180° in mean anomaly away from ConUS landing site latitudes. A deorbit burn from this post-PADJ orbit would be executed at perigee and would require relatively large  $\Delta v$  to lower apogee past the initial perigee altitude in achieving an appropriate entrant orbit.

$$\Delta v_{DO} = 1.76 \left( HA_{\text{post-PADJ}} - HP_{\text{entrant}} \right)$$

From this illustration, it's evident a large PADJ with TIG at a non-optimal point can dramatically increase required deorbit  $\Delta v$  to ConUS sites. In fact, steep deorbit capability to ConUS sites can be lost if a large perigee adjust is executed at a non-optimal TIG. A PADJ at points between these two extreme cases will require more deorbit  $\Delta v$  than the optimal case but less than the anti-optimal one.



**Figure 3.9.4-1: Effect of PADJ on ConUS Deorbit Capability**

A secondary consideration arising from an OMS propellant depletion maneuver is loss of deorbit  $\Delta v$  available. Depending on  $\Delta v$  required for a particular deorbit, this loss in prop availability may be critical. In such cases, the depletion maneuver must occur before too much propellant leaks away. Otherwise,  $\Delta v$  will be reduced to the degree deorbit capability is lost. A "partial deorbit" or retrograde PADJ reduces  $\Delta v$  required in critical deorbit opportunities. In non-critical cases, required deorbit  $\Delta v$  is preserved with

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an OOP depletion maneuver. Loss of  $\Delta v$  capability with a misdirected or tardy depletion maneuver can result in loss of all deorbit opportunities, stranding the crew in orbit.

Deorbit  $\Delta v$  capability can also be lost when a sufficiently large OMS helium (He) leak develops. Although leaking He is inert and presents no direct hazard, its total loss will eliminate capability to re-pressurize the OMS tank, possibly making a large amount of propellant unusable. In extreme cases, the amount of unusable propellant remaining in the tank can result in lateral CG or weight violations during entry even if deorbit capability exists. Loss of OMS  $\Delta v$  capability due to He leaks must be addressed by a "max-blowdown" maneuver. Assuming affected propellant tanks can be isolated from the leak, this maneuver does not totally deplete them. During a max-blowdown maneuver, remaining He backfills the affected tanks. When enough He is accumulated to permit remaining propellant to be pressurized, the maneuver may be terminated. Affected tanks are subsequently isolated from the He leak.

NOTE: extremely slow OMS leaks are addressed by the Flight Rules. In such cases, a delayed response planned over a time scale of hours is permitted. Associated leak rates are small compared to onboard instrumentation sensitivity. The "slow leak" scenario is therefore highly improbable, if detectable at all. Untracked orbit debris collision is considered the most likely cause of an OMS leak, and propellant or He loss rates in this case will almost certainly demand immediate action.

After PROP reports an OMS leak that can't be isolated, FDO's most critical task is to determine if the depletion or max-blowdown maneuver will be performed OOP or RETRO. With this information in hand, the crew refers to the Leaking OMS PRPLT/He Burn procedure in the Orbit Pocket Checklist. Should a leak occur during LOS, the crew can refer to the latest Mission Summary Message (MSM) and obtain a suggested maneuver direction based on trajectory and consumables predictions. During AOS, however, PROP and FDO can relieve crew workload and provide a more accurate assessment of the correct maneuver direction. See Appendix 3.C for Flight Rule references pertinent to leaking OMS.

### **3.9.4.1 PADJ Analysis Overview**

PADJ analysis answers the question, "What is the best way to deplete the leaking pod's propellant given that TIG must be as soon as possible (a matter of minutes)?" For the slow leak case, the question of what the TIG should be adds a minor complication, but time permits the burn to be RETRO at the PADJ-optimal TIG. Actions are planned in advance to cover any time-critical situation arising during the upcoming flight day, even in the absence of crew communication with MCC. Supported by PROP inputs, the Planning FDO determines which OMS depletion burn direction is best throughout the next flight day. Results from this analysis are included in the Mission Summary

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Message (MSM) uplinked to the crew on a daily basis near wake-up. The crew must be advised whether to burn RETRO or OOP.

In marginal cases where both RETRO and OOP actions are possible, the crew must be informed which path is taken at what time. The MSM contains OOP/RETRO transition points in a marginal orbit. These transitions are expressed in terms of min since the previous ascending node passage. Assuming no major OMS consumption is planned, this technique requires only two times for the entire flight day. By convention, the first time is the transition from RETRO to OOP and the second is from OOP to RETRO. Together, they define the "OOP TIG window". In the event of a leak, the crew (with FDO assistance, if communication permits) will estimate depletion burn TIG and determine if it is in the OOP TIG window.

To determine the OOP TIG window, FDO models PADJ burns using the largest single-tank  $\Delta v$  available starting in an orbit typical of the upcoming flight day. As PADJ TIG is incremented from the orbit's ascending node at regular intervals, required deorbit  $\Delta v$  is computed at representative PLSs from the post-PADJ orbit. The application automating this analysis is called the PADJ processor. Input data are a predicted Orbiter state vector immediately prior to the ascending node of the assumed PADJ orbit, anticipated PLS deorbit opportunities, and DMP targets. Output data are specific to each PLS opportunity and consist of post-PADJ steep or shallow deorbit  $\Delta v$  required at each PADJ TIG, expressed in min after the ascending node. The data sets are collectively called the "PADJ curves". By convention, the PADJ orbit is selected at an arbitrary point midway through the next flight day. As a starting point, midway through the period between the next two PLS wave-offs (at TIG -4 hrs) can be used, but the crew's noon meal would probably serve as well. Given an ascending node regression rate  $\sim 7$  deg/day, this choice assures the resulting PADJ curves will be sufficiently accurate. Representative sites are chosen such that the PADJ curves for all upcoming ConUS opportunities will be bracketed within the representative subset of PADJ curves.

For circular or near circular orbits, the PADJ curve will show a definite minimum. The corresponding TIG (in minutes past the ascending node) is labeled the optimum PADJ TIG and is significant because the propellant burned at this point can be deducted from the deorbit cost of the pre-PADJ orbit. The opposite point in the orbit is called the anti-optimum. At the points in-between, the PADJ curve will show the increase or decrease in deorbit cost as a result of performing the PADJ. There will be only one maximum and one minimum for the overwhelming majority of orbits. Given this wealth of data, it will be easy for FDO to determine at which points in the orbit the post-PADJ  $\Delta v$  required for deorbit exceeds the available propellant.

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### 3.9.4.2 Optimizing Deorbit $\Delta v$ From An Elliptical Orbit

Three geometric effects govern which argument of the perigee ( $\omega_p$ ) will produce minimal deorbit  $\Delta v$  from the elliptical orbit following a retrograde leaking propellant depletion burn.

- 1) The latitude ( $\phi$ ) of the landing site influences  $\omega_{popt}$ . The farther north the landing site, the larger the value of  $\omega_{popt}$ . Since EDW's latitude is  $6.5^\circ$  north of KSC's, the optimal TIG for EDW should be later than for KSC at similar crossranges. Note that NOR's latitude is between EDW's and KSC's.
- 2) Approach direction and crossrange to the landing site exert a daily influence on optimal  $\omega_p$  as the Orbiter's ground track shifts westward due to Earth rotation. For ascending approaches on a given flight day, L turns give way to R turns, and optimal  $\omega_p$  increases from one deorbit opportunity to the next. For descending approaches, R turns give way to L turns, but the same increase in optimal  $\omega_p$  is experienced with time. This geometric effect is illustrated for ascending approaches in Figure 3.9.4-2. From this diagram, the difference  $\Delta\omega_p \equiv \omega_{pR} - \omega_{pL}$  can be estimated for a near equatorial landing site. This assumption permits the Euclidean approximation  $\Delta\omega_p = \Delta\lambda \cos i$  to be invoked, where  $\Delta\lambda$  is Earth rotation between successive ascending nodes initiating Orb N and Orb N+1, and  $i$  is orbit inclination. If orbit period is 1.5 hrs and  $i = 51.6^\circ$ ,  $\Delta\omega_p = 1.5 \cdot 15 \cos 51.6^\circ = 14^\circ$ .

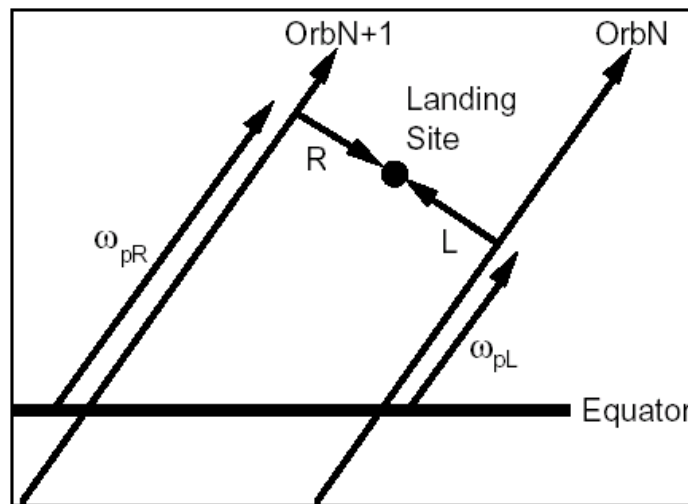


Figure 3.9.4-2: Optimal Perigee Placement for Deorbit

- 3) Apsidal advance due to Earth's excess equatorial mass (the  $J_{20}$  gravity harmonic) causes  $\omega_p$  to steadily increase from day to day at Orbiter inclinations. For  $i = 51.6^\circ$ , a 210x95 nm orbit will undergo apsidal advance amounting to  $5^\circ$  per day.

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Although  $\omega_p$  is strictly related to the foregoing geometric influences, "Node +" TIGs computed by PADJ from 0 to 90 min may, for conceptual purposes, be mapped into corresponding  $\omega_p$  values from 0 to 360°. In selecting deorbit opportunities to be processed by PADJ, the strategy is to minimize processing by identifying cases bounding all those to be protected. To this end, the three geometric influences are assessed in the PADJ context to determine which opportunities require minimum and maximum  $\omega_p$  yielding minimum deorbit  $\Delta v$ .

The maximum optimal  $\omega_p$  is associated with the last opportunity of the first day to be protected (one day after the depletion burn) at the landing site with the highest latitude (EDW). This case has maximum  $\omega_p$  for the day due to  $\Delta\lambda$  and  $\phi$ . Because there's minimal time between the depletion burn and deorbit TIGs on this day, minimal apsidal advance has accumulated. Consequently, minimal reduction in  $\omega_p$  is required to compensate.

The minimum optimal  $\omega_p$  is associated with the first opportunity of the last day to be protected (two days after the depletion burn) at the landing site with the lowest latitude (KSC). This case, in general, has minimum  $\omega_p$  for the day due to  $\Delta\lambda$  and  $\phi$ . Because there's maximum time between the depletion burn and deorbit TIGs on this day, maximum apsidal advance has accumulated. Consequently, maximum reduction in  $\omega_p$  is required to compensate.

For more information on this topic see the following document.

S:\Divisions\DM\Private\DM32\Pitches>Selecting Curves for Optimal Perigee Adjust Analysis.doc

**NOTE:** in  $i=51.6^\circ$  ISS-altitude orbits, crossrange to a particular PLS follows a three day pattern. For three days, the crossrange for the prime opportunity will increase. On the fourth day, the crossrange will decrease dramatically and the cycle will start over. The reason for this behavior is that the ascending node of two orbits ~24 hours apart is shifting eastward due to the near three day phase repeat at ISS altitude. After two days of eastward shift, crossrange increases to the point where Orbiter capability is violated. When this occurs after three days, the prime opportunity shifts one rev earlier. This shift is also manifested as a dramatic crossrange decrease after three days. As the crossrange is increasing, the  $\omega_{popt}$  is decreasing. So the  $\omega_{popt}$  on flight day N is greater than the  $\omega_{popt}$  on flight day N+1. However, on the day where the prime opportunity jumps to an earlier rev, the crossrange may decrease so much that  $\omega_{popt}$  for flight day N is less than the  $\omega_{popt}$  for flight day N+1.

**CAUTION:** DOPS output used to select opportunities for PADJ processing typically doesn't include the leaking propellant depletion burn. This can result in significant crossrange shifts between "no-PADJ" DOPS selections (those within crossrange limits)

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and deorbit burns actually computed by PADJ, particularly two days after the depletion burn. Because PADJ's depletion burn is retrograde, it tends to shift viable opportunities to higher orbit counts than ones appearing in "no-PADJ" DOPS output. With PADJ deorbits two days after the depletion burn tending to be selected early to minimize optimal  $\omega_P$ , associated deorbit targeting is in jeopardy of failing due to excessive crossrange.

### 3.9.4.3 OMS Leak Decision Criteria

Decision criteria for determining the best burn are always based on remaining deorbit capability compared to deorbit  $\Delta v$  required at upcoming ConUS opportunities, assuming the leaking side is depleted. The process determining numbers pertinent to this decision occurs at the end of each flight day during the Planning shift. Assume the crew is in Flight Day N (FDN) sleep. FDO first calculates worst-case STEEP and SHALLOW deorbit  $\Delta v$  required for FDN+1 and FDN+2 PLSs from the pre-PADJ orbit using DMP. These are the same numbers given to PROP for propellant redlines determination. PROP provides a table showing the remaining deorbit capability after the leaking OMS has been depleted. This table is called the OMS Tank Fail Analysis form and is described in Section 3.9.4.4.

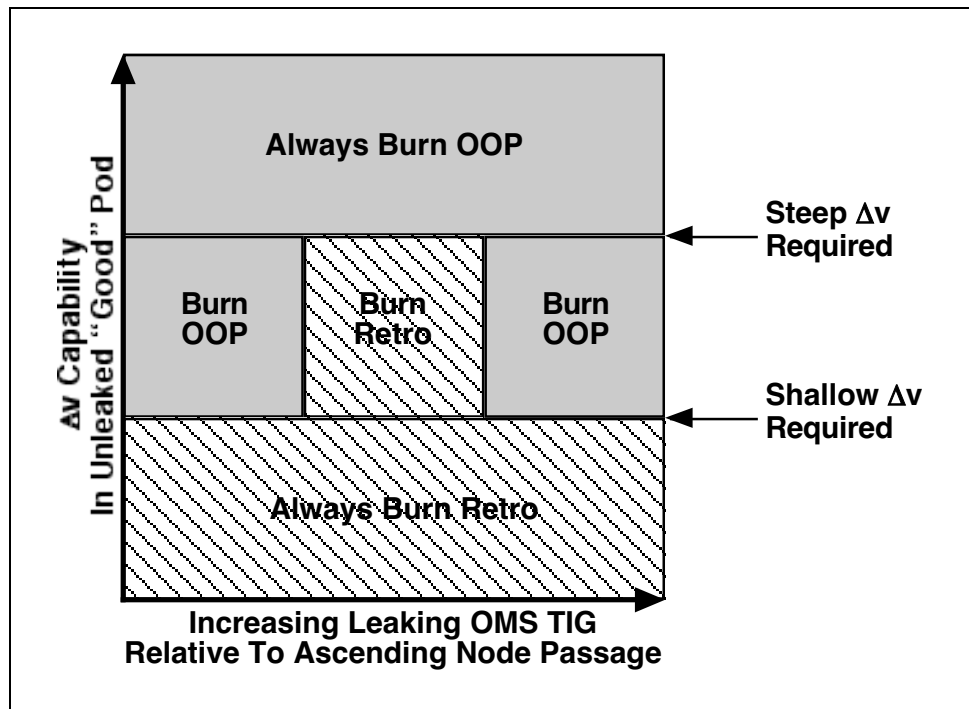
If  $\Delta v$  capability in the good (non-leaking) pod exceeds that required for a steep PLS deorbit from the pre-depletion burn orbit, the depletion or max-blowdown maneuver is performed OOP regardless of TIG. In this case, any existing required deorbit  $\Delta v$  is nearly identical after the maneuver because neither the semi-major axis nor the argument of perigee shifts. The situation cannot be improved upon by performing a PADJ and the possibility exists that a non-optimal PADJ TIG would increase required deorbit  $\Delta v$ . The best depletion burn for this case will always be OOP. There are no OOP/RETRO changeover points, and the OOP TIG window expands to include the whole orbit.

The opposite situation occurs when there is not enough propellant in a good pod for even a shallow deorbit from the pre-PADJ orbit. A RETRO depletion burn is mandatory for this situation so that at least shallow capability may be regained, even if a non-ConUS landing site must be targeted. There is no OOP TIG window for this case.

If there is not enough propellant in the good pod for steep deorbit, but there is enough for a shallow deorbit, a PADJ may regain ConUS steep capability or, depending on node-relative TIG, it may increase ConUS deorbit cost to the point all capability is lost. The best burn for depletion will be OOP if the deorbit cost would be increased by a PADJ, and the best burn will be RETRO if the deorbit cost will be decreased by a PADJ. The part of the orbit for which a PADJ would increase the deorbit cost from the pre-PADJ orbit will be the OOP TIG window. The plot of PADJ curves created by the PADJ

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processor will show just this sort of relationship. Figure 3.9.4-3 summarizes selection logic governing depletion burn direction.



**Figure 3.9.4-3: Depletion Burn Selection Logic**

For the slow leak case, the best depletion burn will be RETRO at the optimum TIG for steep deorbit. This PADJ will place post-PADJ orbit's perigee near enough to the upcoming PLSs at the time of deorbit such that depletion propellant  $\Delta v$  also reduces required deorbit  $\Delta v$  in nearly a one-for-one manner. This is the only case when a deliberate depletion burn can be planned by FDO. Higher leak rates require an immediate depletion for which the only control of the effect on post-depletion deorbit  $\Delta v$  will be the selection of OOP or RETRO.

**NOTE:** "STEEP" and "SHALLOW" terminology refers to the EI flight path angle targeted by a deorbit maneuver in response to the input prebank parameter. Because small bank angles direct the Orbiter's lift vector vertically, a STEEP deorbit must target a more negative flight path angle at EI to avoid skip-out. This steeper rate-of-descent also requires additional deorbit  $\Delta v$ .

### 3.9.4.4 The OMS Tank Fail Analysis Form

To determine the proper maneuver direction, FDO must have a breakdown of the current  $\Delta v$  capability in each OMS pod, the ARCS, and FRCS. Enough propellant will be held back from this breakdown to support entry and pre-deorbit coast. FDO can tell

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from these data how much propellant is available for deorbit out of the non-leaking OMS with RCS completion. These  $\Delta v$  magnitudes are obtained from the PROP Officer on the OMS Tank Fail Analysis Form (see Figure 3.9.4-4). The form shows the propellant remaining for deorbit (according to Flight rule A4-104) converted to  $\Delta v$  for the engine (OMS or RCS) and the predicted Orbiter weight. The form is divided into left and right OMS failed columns. Each column has three sections, one each for STEEP deorbit  $\Delta v$  capability, SHALLOW deorbit  $\Delta v$  capability, and  $\Delta v$  capabilities for OOP TIG WINDOW computations.

LOMS Failed			ROMS Failed		
System	fps	STEEP	System	fps	
ROMS	208.7		LOMS	204.9	
LRCS	7.4		LRCS	7.4	
RRCS	7.9		RRCS	7.9	
FRCS	53.6		FRCS	53.6	
=====			=====		
TOTAL	277.7		TOTAL	273.9	
System	fps	SHALLOW	System	fps	
ROMS	208.7		LOMS	204.9	
LRCS	4.8		LRCS	4.8	
RRCS	5.3		RRCS	5.3	
FRCS	53.8		FRCS	53.8	
=====			=====		
TOTAL	272.6		TOTAL	268.8	
System	fps	WINDOW	System	fps	
ROMS	208.7		LOMS	204.9	
LRCS	7.1		LRCS	7.1	
RRCS	7.7		RRCS	7.7	
=====			=====		
TOTAL	223.6		TOTAL	219.7	

**Figure 3.9.4-4: OMS TANK FAIL ANALYSIS Form Example**

**NOTE:** although the Tank Fail form is most often used in connection with leaking OMS propellant or He, it's named after a scenario in which all propellant in a pod is immediately unusable (no depletion burn is possible). Tank fail cases are rarely simulated because no action can be taken to improve the situation. A full pod with failed tanks would also present a lateral CG violation post-deorbit, possibly resulting in catastrophic loss of control during entry.

OMS  $\Delta v$  capability considers all the non-leaking OMS remaining (to 5%) on the form and will be the same for the STEEP, SHALLOW, and WINDOW sections. Note the right



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OMS  $\Delta v$  capability shows up in the left OMS tank failed column, and vice versa. This is because  $\Delta v$  from the unfailed, "good" pod will ultimately be used for deorbit.

Left and right ARCS (LRCS and RRCS)  $\Delta v$  capabilities are dependent on the STEEP, SHALLOW, and WINDOW sections in which they reside. STEEP ARCS  $\Delta v$  values include propellant down to Aft Quantity 1. In the SHALLOW section, ARCS  $\Delta v$  values include propellant down to the OMS Tank Fail Quantity. Protection is required for 48 hrs of attitude control on VRCS, one deorbit prep, and two 15-sec ullage burns. The LRCS and RRCS capabilities in the window section contain all the propellant above Aft Quantity 1 but no FRCS is included in this section. At first glance, it may seem WINDOW  $\Delta v$  may never exceed SHALLOW  $\Delta v$  because SHALLOW  $\Delta v$  includes FRCS  $\Delta v$ . However, a case may exist where FRCS is minimal or not available and since more aft RCS propellant is held back for SHALLOW, this may result in WINDOW  $\Delta v$  being greater than SHALLOW  $\Delta v$ . This is the reason for the available WINDOW  $\Delta v$  versus required SHALLOW  $\Delta v$  check in Figure 3.9.4-9's Out-of-Plane TIG Window Worksheet.

FRCS  $\Delta v$  capability appears in the STEEP and SHALLOW sections because it could be used to lower perigee prior to the deorbit burn in a two-stage deorbit. Use of the FRCS *during* deorbit is never planned because it requires a contingency "fast-flip" attitude maneuver. In a fast flip, the crew first burns all available OMS propellant, then continues the deorbit with all ARCS allowed. Finally, the Orbiter is quickly pitched in order to complete the deorbit on FRCS propellant. This is an awkward, difficult procedure and should be avoided whenever possible. Moreover, the high pitch rate during fast flip is an inefficient use of ARCS and FRCS propellant.

The WINDOW section data are used to calculate the OOP TIG window opening and closing times when used in conjunction with the PADJ curves. Only when good pod capability lies between steep and shallow deorbit  $\Delta v$  requirements does an OOP TIG window exist. During this window, subsequent shallow PLS deorbit  $\Delta v$  requirements would *increase* if the depletion or max-blowdown maneuver were to be performed RETRO. The limit used to fix OOP TIG window endpoints will be the lesser of the  $\Delta v$  required for shallow deorbit and the  $\Delta v$  available from the window section of the OMS Tank Fail Analysis form. Thus, it can be said the OOP TIG window has FRCS capability as a fall back or safety margin. It will also be noted from the data that FDO should begin planning for a FRCS PADJ after the depletion burn has completed. A plan for deorbit based on accumulated post FRCS tracking data would follow.

### 3.9.4.5 Generating the PADJ Curves

The TSA PADJ processor automates the process of calculating post PADJ deorbits versus PADJ TIG placement (expressed in minutes from the ascending node). Also automated is OOP TIG window determination and the PADJ optimum TIG. Output is

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typically presented in graphic format for easy interpretation. Steep deorbit curves at the upcoming PLSs are used to calculate the optimum PADJ TIG. Shallow PLS deorbit PADJ curves will be used to calculate the OOP TIG window because it's only required to maintain shallow deorbit capability.

Required PADJ inputs are shown in Figures 3.9.4-5 through 3.9.4-7, which illustrate menus to be completed. Most of the inputs are straightforward and do not require further explanation. However, the PADJ input vector, deorbit TIG orbits, and the targeted PADJ altitude require some explanatory remarks.

```
PERIGEE ADJUST MAIN MENU                                CURRENT
                PADJ data set _____
Comment _____
      System      Location
Vector source   __ (T,M)  _____
Vector comment  _____
Launch time     G _____
Vector/Fetch time (G,M)  __ _____
Vector orbit count ?  ____
Pre-orbit adjust XCG _____
Pre-orbit adjust YCG _____
Pre-orbit adjust ZCG _____
NCYCLE         ____
D23C           _____
Flight ID      _____
Flight day     _____
Title comment  _____
Curves to be (re)generated _____
Current plot title is ...
_____
```

**Figure 3.9.4-5: PADJ Main Menu**

The input vector for the PADJ processor is essentially a threshold vector, and thus should be approximately 15 min prior to the PADJ orbit. The procedure is to obtain PADJ orbit ascending node time. A vector 15 min prior to this time should be input to PADJ. Be sure to verify the orbit number corresponding to the vector is specified to the processor. Since this analysis is performed prior to any failure, a guess must be made as to when the failure would occur and use this as the PADJ orbit for the processor inputs. If analysis is being performed at the end of FDN, the PADJ orbit is normally centered during the time period from wave-off of the FDN+1 PLS (at TIG -4 hrs) to wave-off of the FDN+2 PLS. This period also applies to OMS leak data, transmitted to the crew each flight day via the Mission Summary message. If a major trajectory event is scheduled to occur during the next flight day, the Planning Team may have to perform

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two PADJ computations, each with a different set of OMS Tank Fail Analysis data and PADJ orbits. In this case, both OOP TIG windows are sent to the crew (if there's a substantial change) with instructions to use one before and one after the trajectory event, if it occurs nominally. Examples of trajectory events with possible PADJ impact are a massive payload deploy and sep or a major posigrade burn.

FD2_PADJ_EX	ORBIT ADJUST CURVE INPUTS				MODIFIED
CURVE 1	OA orbit _____	OA target mode _____	OA target _____	nm	
	Deorbit orbit _____	Landing site _____	Prebank _____	deg	
	Start/stop time wrt node ____ / ____		Step ____		
	Legend comment _____				
CURVE 2	OA orbit _____	OA target mode _____	OA target _____	nm	
	Deorbit orbit _____	Landing site _____	Prebank _____	deg	
	Start/stop time wrt node ____ / ____		Step ____		
	Legend comment _____				
CURVE 3	OA orbit _____	OA target mode _____	OA target _____	nm	
	Deorbit orbit _____	Landing site _____	Prebank _____	deg	
	Start/stop time wrt node ____ / ____		Step ____		
	Legend comment D/O 50 EDW22 STEEP (OA 27)				
CURVE 4	OA orbit _____	OA target mode _____	OA target _____	nm	
	Deorbit orbit _____	Landing site _____	Prebank _____	deg	
	Start/stop time wrt node ____ / ____		Step ____		
	Legend comment _____				

**Figure 3.9.4-6: PADJ Curve Inputs**

A PADJ curve could be generated for deorbits at each of the primary and backup opportunities at upcoming PLSs for which depletion burn decision data are required. This would normally exceed the limit for curves generated in a single run of the PADJ processor and unnecessarily complicate the procedure. The same answers could be derived based on a composite of four curves generated for the next two EDW and KSC opportunities and their one orbit late backups. Shallow deorbit curves bounding the OOP TIG window turn out to be the last (backup) EDW opportunity on the first day and the first (prime) KSC opportunity of the second day. These curves envelop all shallow deorbit curves for all ConUS opportunities over the two days being protected. The bounding curves insure PLS opportunities, plus backups, plus some number of other ConUS deorbit opportunities are available with shallow targets if a perigee adjust is performed outside the OOP TIG window.

**CAUTION:** PLSs should never be excluded from PADJ processing due to weather violations. Weather is not available for the last day of PLS opportunities used in the PADJ processing. Excluding a site from the first day, but not the second day, can introduce errors into the PADJ output.

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The Planning Team shift at the end of FDN will calculate an OOP TIG window to be used by the crew for the OMS depletion burn decision during the next flight day. Since the anticipated OMS leak and depletion will occur during FDN+1, opportunities protected for shallow deorbit will be on FDN+2 and FDN+3. Opportunities on FDN+1 are deliberately excluded from the OOP TIG window calculation because time will be required to assess Orbiter health following leaking propellant depletion before committing to a deorbit and entry. The Tank Fail Analysis form will be requested for the FDN+2 "next-next" PLS opportunity. The most conservative (longest duration) OOP window is desired, and it results from computing shallow deorbit curves (90° prebank) to the last FDN+2 EDW opportunity and the first FDN+3 KSC opportunity.

The standard target used in determining the PADJ maneuver is  $\Delta v$  magnitude (DVM) unless this places the perigee below 95 nm. A 95 nm minimum altitude is used because that should leave the Orbiter with sufficient orbit lifetime to deorbit two days later, and it should also buy back adequate deorbit capability. This is the lowest altitude targeted during execution of the Leaking OMS/He Burn procedure, as it calls for cutoff at 95 nm followed by depleting the rest of the OMS (if any) OOP. At relatively high altitudes, leaking pod propellant may be insufficient to lower perigee to 95 nm. In these cases, OOP TIG window curves will have to assume a different post-PADJ perigee target. Consult the OMS Tank Fail Analysis form and obtain the greater  $\Delta v$  available from either OMS pod ( $\Delta v_A$ ). This value will be used to lower perigee as much as possible and is used as a DVM target in the PADJ curve inputs menu.

**CAUTION:** even though DVM is defined as  $\Delta v$  *magnitude*, the PADJ processor applies a sign convention to its value. This permits PADJ to process retrograde (DVM < 0) and posigrade (DVM > 0) orbit adjust burns. Consequently, DVM is operationally the PEG-7  $\Delta V_x$  target of a horizontal burn.

The PADJ Plot menu (Figure 3.9.4-7) facilitates OOP TIG window and PADJ optimum TIG computations. Required steep and shallow deorbit  $\Delta v$  are obtained by considering FDN+1 worst-case scenarios. This routinely includes appropriate DMP runs to upcoming ConUS opportunities, providing the highest steep and shallow  $\Delta v$  required. Uphill effects from other possible contingencies (such as emergency separation burns, COMBO burns, or jettisons) are applied to DMP results to arrive at the worst-case deorbit requirement. Available  $\Delta v$  estimates are taken directly from the OMS Tank Fail Analysis form.

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```
PADJ PLOT CONTROL MENU

PADJ data set _____
Display mode _____
Curves to be plotted _____
Gridlines ____

Steep DV required _____      Shallow DV required _____

DV Available
Left OMS Leak      Right OMS Leak
Steep _____   |   Steep _____
Shallow _____ |   Shallow _____
Window _____  |   Window _____
```

**Figure 3.9.4-7: PADJ Plot Menu**

The PADJ analysis procedure follows and assumes Planning Team execution at the end of FDN.

- 1) Select an orbit for the PADJ burn. This orbit should be ~halfway between FDN+1 PLS waveoff (at TIG -4 hrs) and FDN+2 PLS waveoff.
- 2) Fetch the PADJ Main Menu (see Figure 3.9.4-5) vector at about 15 min before the ascending node of the PADJ orbit.
- 3) Enter predicted Orbiter CG from PMP (see Figure 3.9.4-5).
- 4) Enter N-cycle, D23C, the flight ID, the flight day and any desired comments (Figure 3.9.4-5).
- 5) The curves to be generated are 1-4 (see Figure 3.9.4-6). Consult the OMS Tank Fail Analysis form and obtain the greater  $\Delta v$  available from either OMS pod ( $\Delta v_A$ ).
  - a) Curve 1
    - OA orbit = orbit chosen in Step 1
    - OA target mode = DVM (if  $[H_{avg} - \Delta v_A/1.8] < 95$  nm, use ALT mode)
    - OA target =  $-\Delta v_A$  (or 95 nm)
    - Deorbit orbit = last EDW opportunity on FDN+2
    - Landing site = EDWXX, where XX is prime runway
    - Prebank = 0

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- Start/stop time wrt node = time span that will include minimum steep  $\Delta v$  (40/70 is a good value for ISS flights)
  - Step = 2
- b) Curve 2
- OA orbit = orbit chosen in Step 1
  - OA target mode = DVM (if  $[H_{avg} - \Delta v_A/1.8] < 95$  nm use ALT)
  - OA target =  $-\Delta v_A$  (or 95 nm)
  - Deorbit orbit = last EDW opportunity on FDN+2
  - Landing site = EDWXX, where XX is prime runway
  - Prebank = 90
  - Start/stop time wrt node = 0/90
  - Step = 5
- c) Curve 3
- OA orbit = orbit chosen in Step 1
  - OA target mode = DVM (if  $[H_{avg} - \Delta v_A/1.8] < 95$  nm, use ALT mode)
  - OA target =  $-\Delta v_A$  (or 95 nm)
  - Deorbit orbit = first KSC opportunity on FDN+3
  - Landing site = KSCXX, where XX is prime runway
  - Prebank = 0
  - Start/stop time wrt node = time span that will include minimum steep  $\Delta v$  (40/70 is a good value for ISS flights)
  - Step = 2
- d) Curve 4
- OA orbit = orbit chosen in Step 1
  - OA target mode = DVM (if  $[H_{avg} - \Delta v_A/1.8] < 95$  nm use ALT)
  - OA target =  $-\Delta v_A$  (or 95 nm)
  - Deorbit orbit = first KSC opportunity on FDN+3
  - Landing site = KSCXX, where XX is prime runway
  - Prebank = 90
  - Start/stop time wrt node = 0/90
  - Step = 5
- 6) Execute the PADJ run.
- 7) On the PADJ Plot Control menu (see Figure 3.9.4-14), enter the steep and shallow deorbit  $\Delta v$  required from DMP (see Figure 3.9.4-10) and the right and left tank fail numbers from the Tank Fail form (see Figure 3.9.4-11).
- 8) Print out a copy of the plot and file in the FDO Data Book.
- 9) Log optimal steep deorbit TIG.

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## 3.9.4.6 The Out-of-Plane TIG Window Worksheet

As an aid to correctly interpreting OMS Tank Fail Analysis form inputs, an OMS Leak OOP TIG window worksheet has been devised (see Figures 3.9.4-8 and 3.9.4-9 for a sample). STEEP and SHALLOW sections of the form are used in conjunction with page 1 of the worksheet to determine whether or not an OOP TIG window must be computed. If a window is required, the form's WINDOW section supplies data to complete page 2 of the worksheet. The workstation's PADJ processor has automated worksheet logic. Consequently, OMS Tank Fail Analysis form data are frequently input directly into the PADJ processor. The worksheet provides an illustration of logic programmed into the PADJ processor.

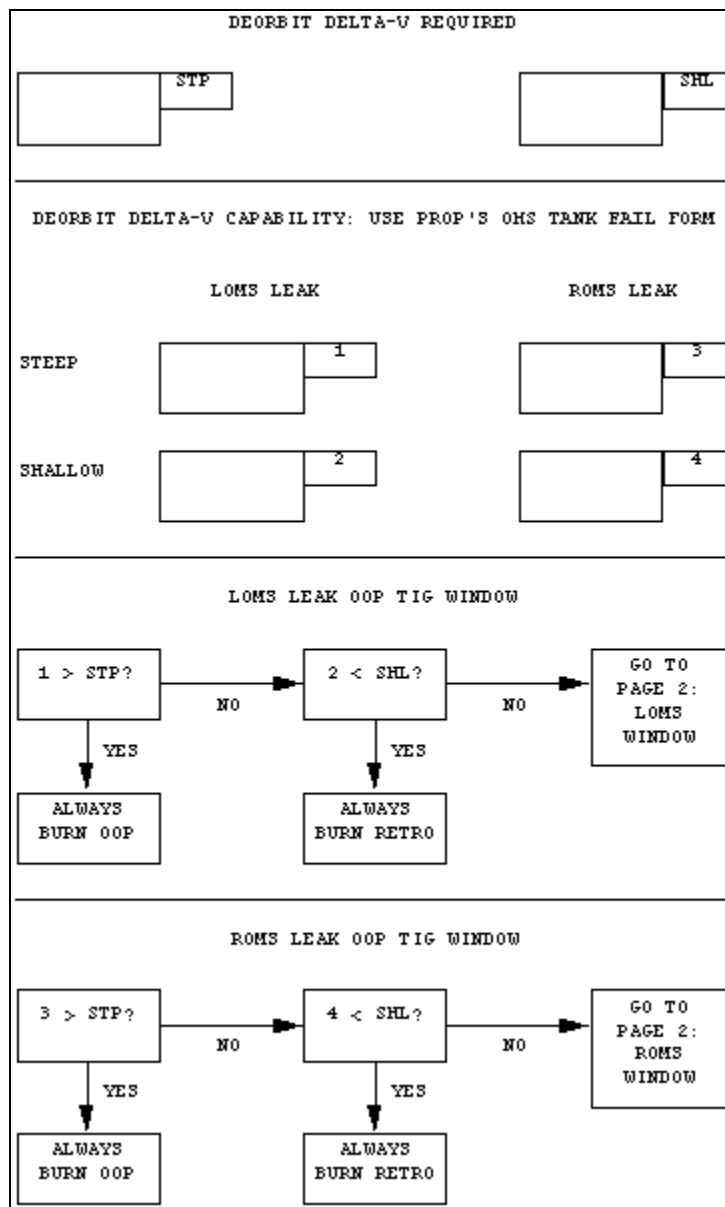


Figure 3.9.4-8: OOP TIG Window Worksheet, Page 1

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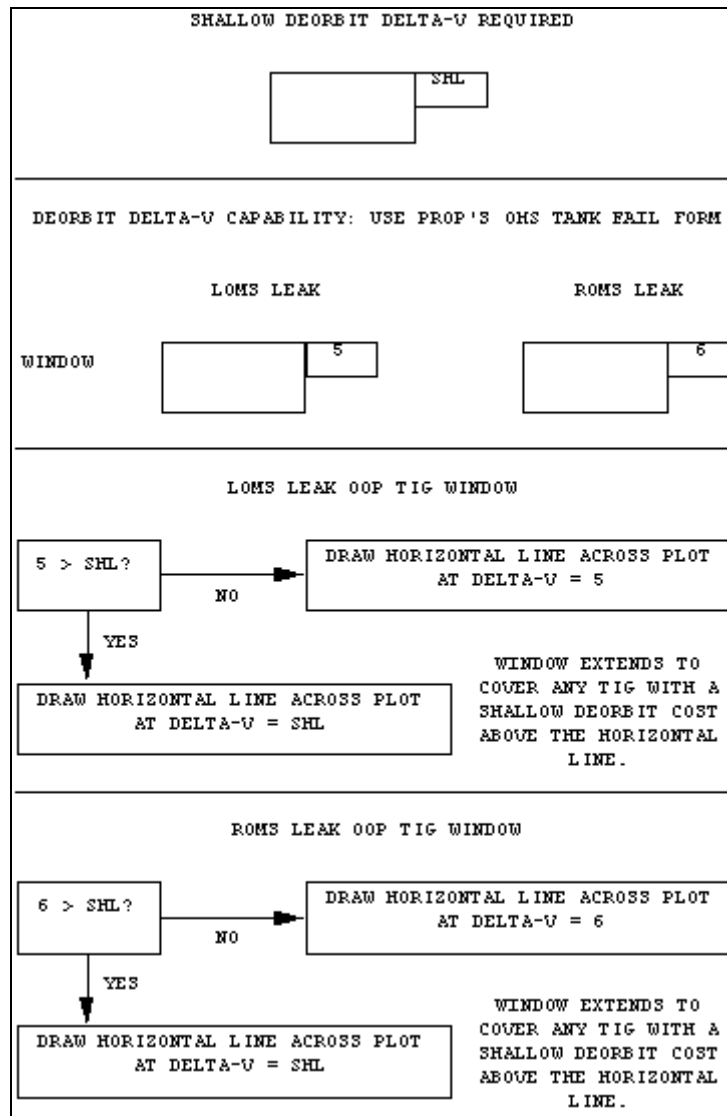


Figure 3.9.4-9: OOP TIG Window Worksheet, Page 2

### 3.9.4.7 OOP TIG Window Example

Figures 3.9.4-10 through 3.9.4-15 track an example calculation of the OOP TIG widow and PADJ TIG Optimum.

**NOTE:** Figure 3.9.4-10 DMP output is the result of PLS selections subject to weather and other considerations made in real time. The process selecting PLS opportunities for DMP assessment is independent of that selecting opportunities for PADJ processing (*always* use EDW, followed by KSC, for PADJ). Figure 3.9.4-10's DMP example happens to reflect EDW-only PLS selections, but some or all KSC deorbit opportunities could easily have been processed at the time under differing circumstances.



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LOCAL		DEORBIT SUMMARY TABLE					
SOL/SEQ	METIG	DVPR	PREBANK	VEI	OOP		
PLSID	METIG THRESH	OFUP	PROPUSG	DIAGNOSTICS	CEI	TFF	
RLSID	VID/EPH/COL	OFI	TGMD	REI	RLCMD		
ORB	METV	DVIMP	PRI BU	XR	HP		
=====							
1/16	002:01:18:30.190	279.8	0	M01 F03	25831	0.0	
EDW22	002:01:00:00.000	6604	IPLANE	P01 T01	-1.12	28:13	
EDW04	L PADJ FDO/1 /1	0	FREE	B01 V01	4471	0.	
33	002:01:00:00.000	303	OBP OL	C01 S01	L91	20.5	
=====							
2/17	002:01:12:43.844	246.8	-90	M01 F03	25867	0.0	
EDW22	002:01:00:00.000	5836	IPLANE	P01 T01	-0.83	32:04	
EDW04	L PADJ FDO/1 /3	0	FREE	B01 V01	4957	0.	
33	002:01:00:00.000	260	OBP OL	C01 S01	L93	39.0	
=====							
3/18	002:02:54:24.922	283.9	0	M01 F03	25821	0.0	
EDW22	002:02:30:00.000	6701	IPLANE	P01 T01	-1.17	27:30	
EDW04	L PADJ FDO/1 /1	0	FREE	B01 V01	4419	0.	
34	002:02:30:00.000	295	OBP OL	C01 S01	R596	17.7	
=====							
4/19	002:02:48:50.747	250.2	-90	M01 F03	25857	0.0	
EDW22	002:02:30:00.000	5914	IPLANE	P01 T01	-0.89	31:21	
EDW04	L PADJ FDO/1 /3	0	FREE	B01 V01	4854	0.	
34	002:02:30:00.000	252	OBP OL	C01 S01	R595	37.0	
=====							
5/27	003:00:22:48.763	277.9	0	M01 F03	25889	0.0	
EDW22	002:23:30:00.000	6592	IPLANE	P01 T01	-1.18	29:40	
EDW04	L PADJ FDO/1 /1	0	FREE	B01 V01	4356	0.	
48	002:23:30:00.000	305	OBP OL	C01 S01	L822	24.0	
=====							
6/28	003:00:17:09.651	248.2	-90	M01 F03	25921	0.0	
EDW22	002:23:30:00.000	5898	IPLANE	P01 T01	-0.91	33:37	
EDW04	L PADJ FDO/1 /3	0	FREE	B01 V01	4764	0.	
48	002:23:30:00.000	261	OBP OL	C01 S01	L824	39.0	
=====							
7/22	003:01:36:14.699	280.8	0	M01 F03	25827	0.0	
EDW22	003:01:30:00.000	6628	IPLANE	P01 T01	-1.14	27:55	
EDW04	L PADJ FDO/1 /1	0	FREE	B01 V02	4462	0.	
49	003:01:30:00.000	299	OBP OL	C01 S01	R242	19.5	
=====							
8/23	003:01:30:44.253	247.0	-90	M01 F03	25863	0.0	
EDW22	003:01:30:00.000	5841	IPLANE	P01 T01	-0.85	31:36	
EDW04	L PADJ FDO/1 /3	0	FREE	B01 V02	4926	0.	
49	003:01:30:00.000	256	OBP OL	C01 S01	R240	38.3	
=====							

**Figure 3.9.4-10: Deorbit  $\Delta v$  Required at the PLSs**

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LOMS Failed			ROMS Failed		
System	fps	STEEP	System	fps	
ROMS	208.7		LOMS	204.9	
LRCS	7.4		LRCS	7.4	
RRCS	7.9		RRCS	7.9	
FRCS	53.6		FRCS	53.6	
=====			=====		
TOTAL	277.7		TOTAL	273.9	
System	fps	SHALLOW	System	fps	
ROMS	208.7		LOMS	204.9	
LRCS	4.8		LRCS	4.8	
RRCS	5.3		RRCS	5.3	
FRCS	53.8		FRCS	53.8	
=====			=====		
TOTAL	272.6		TOTAL	268.8	
System	fps	WINDOW	System	fps	
ROMS	208.7		LOMS	204.9	
LRCS	7.1		LRCS	7.1	
RRCS	7.7		RRCS	7.7	
=====			=====		
TOTAL	223.6		TOTAL	219.7	

**Figure 3.9.4-11: OMS TANK FAIL ANALYSIS Form**

The Planning Team is working during crew sleep at the end of FD1. The deorbit requirements for steep and shallow are shown in the Deorbit Summary Table (DST, Figure 3.9.4-10) for the EDW PLS opportunities on orbits 33, 34, 48 and 49. The FD2 PLS opportunities are on orbits 17 and 18. These are not to be protected by the PADJ processor because an OMS Leak/depletion burn is assumed to occur anytime on FD2, and PLS deorbit opportunities to be utilized would be during FD3 and FD4. The OMS Tank Fail Analysis has been done with predictions for the Orbit 33 PLS TIG and is shown in Figure 3.9.4-11. The propellant available after the depletion burn is less than that required for steep deorbits and greater than that required for shallow deorbits. Consequently, an OOP TIG window must be computed.

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```
PERIGEE ADJUST MAIN MENU                                MODIFIED
System                      Location
PADJ data set               L (L,G)                     FCOCH

Comment FDOCHB EXAMPLE

System                      Location
Vector source               L (L,G,M)                  E1
Vector comment              PADJ FDOCHB
Launch time                 G 2003:017:03:11:13.000
Vector/Fetch time (G,M,C)  M 001:12:00:00.000
Vector orbit count         @ 24

Pre-orbit adjust XCG       1080.00
Pre-orbit adjust YCG       -0.0400
Pre-orbit adjust ZCG       375.000

NCYCLE                      8
D23C                       28.0000
Flight ID                   115
Flight day                  2
Title comment               FDOCHB EXAMPLE
Curves to be (re)generated 1-4

Current plot title is ...

Orbit Adjust Curves for STS-115 FD2: FDOCHB EXAMPLE
```

**Figure 3.9.4-12: PADJ Main Menu**

The PADJ orbit has been selected as Orbit 25, being midway between the FD2 and FD3 PLS opportunities. A vector has been fetched from the Orbiter ephemeris for the PADJ processor ~15 min before the beginning of Orbit 25.

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E1	ORBIT ADJUST CURVE INPUTS						CURRENT
CURVE 1	OA orbit	25	OA target mode	ALT	OA target	95	nm
	Deorbit orbit	34	Landing site	EDW22	Prebank	0	deg
	Start/stop time wrt node 40 /70 Step 2						
	Legend comment D/O 34 EDW22 STEEP (OA 25)						
CURVE 2	OA orbit	25	OA target mode	ALT	OA target	95	nm
	Deorbit orbit	34	Landing site	EDW22	Prebank	90	deg
	Start/stop time wrt node 0 /90 Step 5						
	Legend comment D/O 34 EDW22 SHALLOW (OA 25)						
CURVE 3	OA orbit	25	OA target mode	ALT	OA target	95	nm
	Deorbit orbit	46	Landing site	KSC15	Prebank	0	deg
	Start/stop time wrt node 40 /70 Step 2						
	Legend comment D/O 46 KSC15 STEEP (OA 25)						
CURVE 4	OA orbit	25	OA target mode	ALT	OA target	95	nm
	Deorbit orbit	46	Landing site	KSC15	Prebank	90	deg
	Start/stop time wrt node 0 /90 Step 5						
	Legend comment D/O 46 KSC15 SHALLOW (OA 25)						

**Figure 3.9.4-13: PADJ Curve Inputs**

The curve inputs are shown in Figure 3.9.4-13, indicating the proper PADJ orbit, deorbit orbits, and steep/shallow selections in the 4-curve set. The ALT option is used for this PADJ run because the largest  $\Delta v$  available from any single OMS tank (209 fps) will cause the perigee to drop below 95 nm. Steep curves only need be plotted near their minima, so they're calculated only for points in the range 40 to 70 min after the ascending node. Shallow curves need to be plotted in their entirety for the OOP TIG window because this could turn out to be a significant part of the orbit depending on shallow deorbit capability or required  $\Delta v$ . Curve points are calculated every 2 min for steep targeting and every 5 min for shallow.

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```
PADJ PLOT CONTROL MENU

PADJ data set FDOCH

Display mode ENHANCED

Curves to be plotted ALL

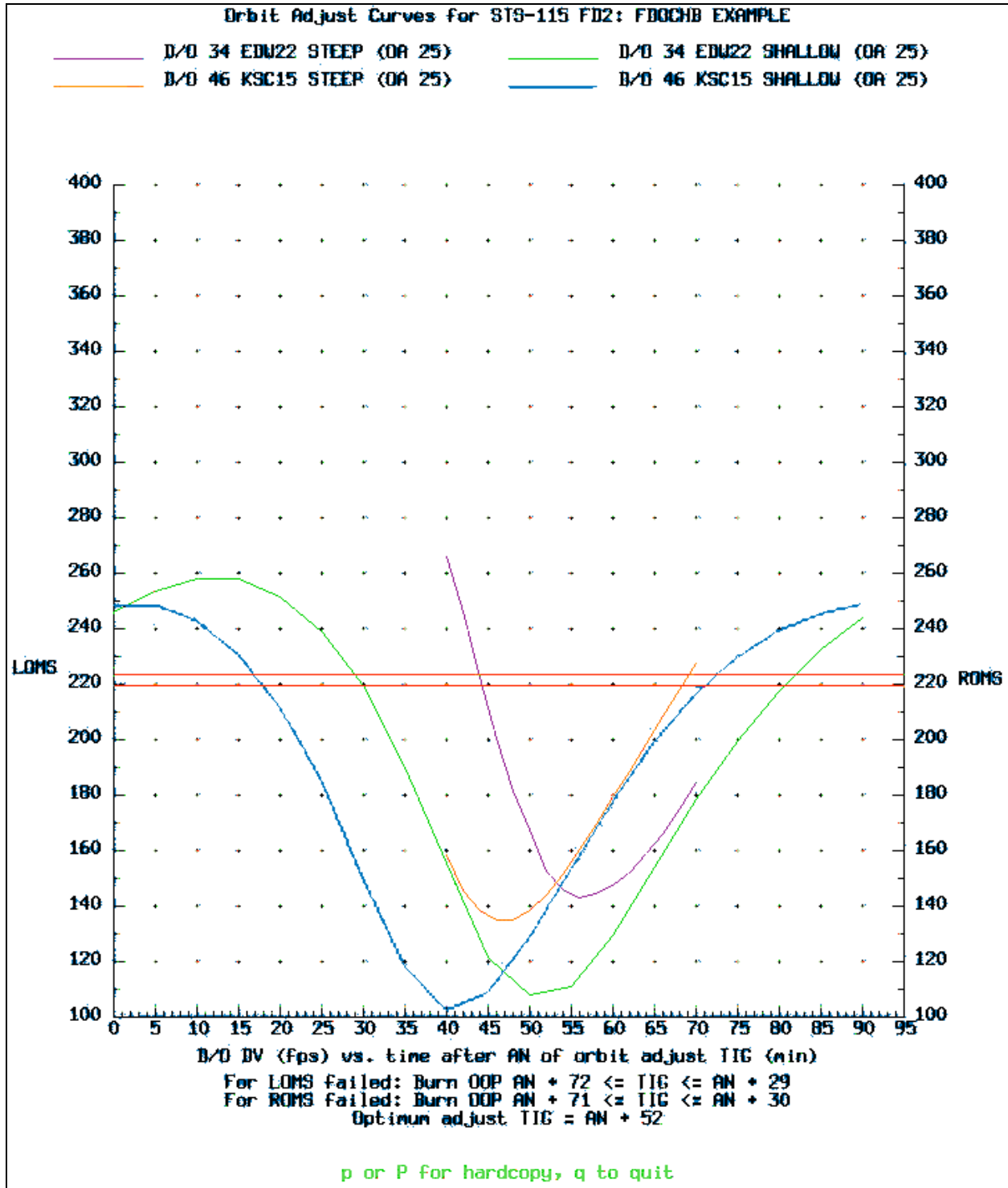
Gridlines Y

Steep DV required 283.9          Shallow DV required 250.2

          DV Available
Left OMS Leak          Right OMS Leak
Steep  277.7          |          Steep  273.9
Shallow 272.6          |          Shallow 268.8
Window  223.6          |          Window  219.7
```

**Figure 3.9.4-14: PADJ Plot Menu**

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**Figure 3.9.4-15: PADI Curves With OOP TIG Window PADI OPT**

The region of the shallow PADI curves from 72 or 71 min to 29 or 30 min past the node, respectively, lies above horizontal lines denoting window availabilities for the Left and Right OMS shown on the OMS Tank Fail Analysis form. This indicates that, if a PADI were to be performed at these times, subsequent ConUS deorbit Δv would exceed the

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available propellant. Anywhere else in the orbit, a PADJ would decrease deorbit  $\Delta v$  required for ConUS shallow and may regain a ConUS steep capability as indicated by the PADJ curve being below the horizontal line. This is the graphic operation required when using the OOP TIG Window Worksheet (see Section 3.9.4.6).

### **3.9.4.8 OOP TIG Window Updates and Mission Summary Messages**

The crew must have enough information on hand to allow them to execute the depletion burn correctly in case a non-isolatable OMS leak occurs outside of communication coverage. This is done for launch day by providing the required information on the Block 1 Trajectory Message (FDOCH, Section 3.12.5). On subsequent flight days, the information is included on the Mission Summary Message, uplinked at the beginning of each crew day (FDOCH, Section 3.12.7). Sample messages appear in Figures 3.12.5-1 and 3.12.7-1, and a full explanation of how to generate all inputs except the OOP TIG window is given. In both cases, FDO supplies this information with the output of the PADJ processor. If there are updates to the information during the crew day (a change in PLS selection or unplanned change in propellant quantities could cause this), a flight note referring to the message can be formulated. FDO needs to update the message data, if needed, before pre-sleep to cover the entire sleep period because the crew will not be awakened to update these data.

### **3.9.4.9 OMS Leak Procedure Non-Deploy Case**

Flight Rule A4-104 documents OMS Leak/Perigee Adjust actions and rationale in a manner consistent with crew and FDO Console procedures. The rule's B paragraph governs cases when the OMS leak occurs during the timeframe of a deploy. This handbook's Section 3.8 covers payload deploys, citing rules, rationale, and console procedures to address non-isolatable OMS leaks during these operations. Figure 3.9.4-16 is a flow diagram illustrating logic applicable to non-deploy cases. OMS Leak/Perigee Adjust procedures and rationale for deploy cases are complicated by the critical need to provide separation from the nearby payload and its hazardous condition (if any) while trying to achieve OMS depletion as promptly as possible.

This section provides a briefing on FDO actions during execution of the Leaking OMS Propellant/He burn procedure for non-deploy cases. Any FDO response to this emergency is closely coordinated with PROP to assure the most current system status and propellant availabilities are used in making decisions. Although beyond the scope of this handbook, advance PROP systems knowledge conveying possible leak sites and failure scenarios is most helpful.

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### 3.9.4.9.1 Orbit Pocket Checklist Leaking OMS Procedure

Non-isolatable OMS leaks are normally reported by PROP. Depending on leak severity and OMS configuration, this call can occur before, during, or after the crew has executed the isolation procedure. PROP will call for the depletion burn and will inform FDO of changes to expected burn duration to achieve depletion or max blowdown. From these inputs, an estimate can be made of the  $\Delta v$  involved. The rules of thumb are 25 lbm or 0.2% OMS propellant for each fps  $\Delta v$ , but PROP may be able to calculate a more accurate estimate quickly.

At some point, the crew will be sent to the Leaking OMS Propellant/He Burn procedure in the Orbit Pocket Checklist. FDO must then make depletion burn execution inputs. The crew will be looking for PEG-7 targets to load near the beginning of the procedure. If the maneuver is OOP, the DVY target can be +500 or -500. If the maneuver is RETRO, a DVX target must be loaded. The procedure includes a table and chart to determine targets when MCC is LOS, but FDO may be able to expedite crew response by being ready to supply burn direction and targets on request.

FDO can estimate the change in perigee to be one nm for each 1.8 fps in  $\Delta v$  to determine if 95 nm will be achieved before depletion. It may be easier to consult the " $\Delta V_X$  vs ORB ALT" plot provided with the procedure. The remaining propellant is burned OOP so perigee height doesn't go below 95 nm.

If the depletion burn is to be OOP, FDO would have to visualize the effect a sizable OOP burn will have on upcoming PLS opportunities to pick one direction over another. This is difficult to do in any orbit inclination other than  $28.5^\circ$ , and it will have insignificant impact to opportunities except in the most marginal cases. Since the most important consideration for this emergency is time, choose the direction (+500 for nose south, -500 for nose north) minimizing burn attitude maneuver time.

After monitoring and confirming the depletion burn, FDO attention shifts to entry planning. The entry team should be notified ASAP. A FRCS burn must be targeted well before deorbit if FRCS propellant is required to minimize targeted prebank. Recall steep and shallow  $\Delta v$  availabilities on the Tank Fail analysis form include FRCS propellant. The PLS should be selected and a deorbit burn modeled.



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### 3.9.4.9.2 Summary of Rules/Rationale

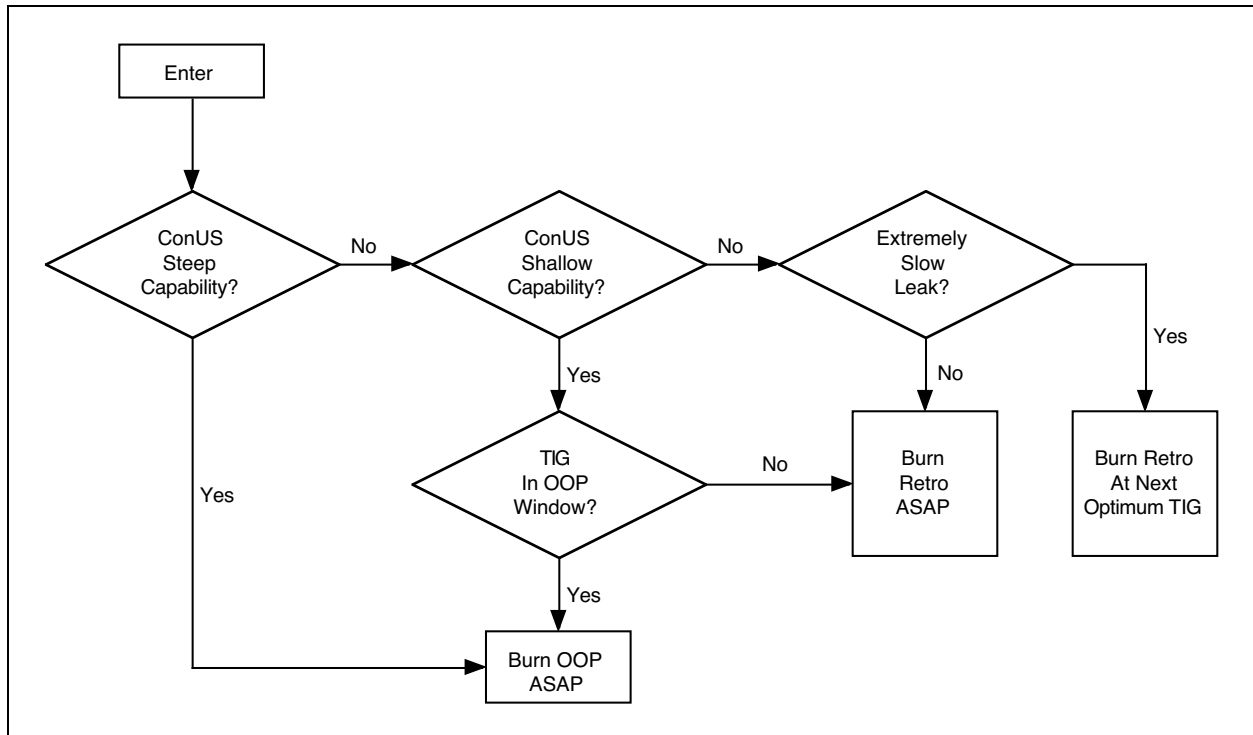


Figure 3.9.4-16: OMS Leak Procedure Non-Deploy Case

### 3.9.4.10 Flight Rule and Procedural References

References include the following items.

- 1) *Space Shuttle Operational Flight Rules, Volume A, All Flights, Rule A4-104*
- 2) *Space Shuttle Flight Data File, Orbit Pocket Checklist, Leaking OMS PRPLT/He Burn, p 7-7*

### 3.9.5 Leaking RCS Maneuvers (non-deploy case)

Hazards resulting from non-isolatable RCS propellant/He tank leaks are similar to those in the OMS leak scenario. An RCS leak can result in possible fire/explosion or loss of control during entry from damaged or frozen lines if propellant leaks into a pod. Flight Rule A6-205 requires an immediate depletion burn for RCS propellant tank leaks, and Rule A6-201 requires a blowdown burn for RCS He tank leaks to maximize remaining  $\Delta v$  capability. The procedure for these burns is found in the Malfunction Book, RCS SSR-5, Leaking RCS Propellant/He Burn.

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Loss of propellant critical to deorbit or entry attitude control due to ARCS depletion is unlikely. FRCS propellant is usually not needed for entry or deorbit unless redlined during a contingency. Propellant critical for entry attitude control is redlined in both ARCS pods. If one side is depleted due to a tank leak, the entry can still be flown by cross feeding from the other side. Loss of this propellant would result in a next PLS deorbit, shortening the mission as dictated by Flight Rule A6-1001.

NOTE: HST servicing missions through STS-109 have been designed with FRCS propellant redlined to restore steep deorbit OMS capability following HST deploy. This design requires a FRCS perigee adjust after the HST sep sequence. TIG for this PADJ is optimized to bring all ConUS deorbit  $\Delta v$  requirements below OMS steep capability on EOM through EOM+2.

### **3.9.5.1 Theoretical Background**

The question arising during non-isolatable RCS system leaks is identical to that the OMS leak scenario presents. Should the depletion burn be OOP or RETRO? Typically, the burn is performed OOP because deorbit capability is not impacted significantly by the expelled propellant. Scenarios in which an RCS leak develops in a system critical to deorbit capability can arise, however. For these cases, PADJ and OOP TIG window data calculated by the Planning Team for the Leaking OMS scenario are applicable.

ARCS propellant redlines always involve quantities needed for entry attitude control, and each pod carries enough ARCS propellant to support all entry control requirements by cross feeding. Should this propellant be depleted in one ARCS system due to a non-isolatable leak, the mission would be shortened to next PLS.

### **3.9.5.2 RCS Leak Decision Criteria**

The most important leaking RCS action is to perform the depletion burn (also called a dump) as quickly as possible to lower risks from pod damage or freezing. Assuming leaking propellant isn't critical to deorbit capability, FDO should choose the OOP direction providing shortest maneuver time to depletion burn attitude. For the FRCS, there is the option of dumping in the current attitude using the OPS 3 null dump procedure.

Other considerations may contribute to burn attitude selection. Payload constraints on PRCS translations are quite common, and an RCS depletion burn following payload deploy may require some effort to insure safe relative motion. If the RMS is in certain configurations (near a singularity or structure), constraints against RCS translations are

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another consideration. For the non-deploy case, however, the overriding consideration will be to get to burn attitude as quickly as possible.

### **3.9.5.3 RCS Leak Procedure Non-Deploy Case**

If an RCS leak cannot be isolated, the crew works Malfunction Book RCS SSR-5, the RCS Leaking Propellant/He Burn procedure. This procedure covers all the RCS leak scenarios (ARCS, FRCS, blowdown, depletion, and FRCS dump), so navigating to the applicable procedure requires some familiarity from advance study. FDO should follow the crew's actions, inform them of the burn direction to be used and, if it will not interfere with crew actions, uplink burn targets. A command load requires the depletion or blowdown burn be modeled in an ephemeris. If the crew will be entering targets by the time the command is built, an uplink serves no purpose. Modeling the burn in advance only gives a rough estimate of the resulting orbit because burn termination will depend on system response, and this is typically unpredictable during a leak. Of primary importance is completing the depletion or blowdown burn as quickly as possible.

### **3.9.6 Off-Nominal Altitude Recovery**

Following an abort to orbit (ATO) or off-nominal insertion during ascent, the Orbiter is in a lower orbit than planned after OMS-2. Even with main engine performance losses and OMS propellant dumped, capability to raise the orbit and accomplish some mission objectives may exist, depending on propellant margins available at launch. In some cases, orbit raising to the nominal altitude will be possible using pre-launch margin or curtailing mission objectives. When nominal altitude recovery is not possible within the margin, priorities governing remaining on-orbit propellant allocation are documented in the mission's Flight Rules Annex. Actual propellant remaining, together with the amount needed for orbit raising and mission completion, are determined post-OMS-2. Nevertheless, various scenarios can be anticipated with considerable pre-launch preparation. Deriving propellant priorities pre-launch is a valuable process, and it usually affects how the nominal mission is designed and flown.

NOTE: rendezvous recovery is beyond the scope of this section. A specialized Joint Underspeed Recovery (JURe) capability has been developed to invoke cooperative dual-vehicle rendezvous with ISS and is documented in Section 3.10.6.

Even with exhaustive preparation and simulation, activities following insertion follow a compressed timeline both in MCC and aboard the Orbiter. The orbit raising profile results from an iterative computation depending on inputs from nearly all flight control disciplines. After all inputs have been coordinated, the raising profile propellant requirement is compared to the propellant available and then iterated until the two agree within a small error allowance. During this process, the actual orbit achieved becomes

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available from tracking data. This section describes a generic FDO procedure used to determine the orbit raising profile.

### **3.9.6.1 Flight Rule References**

If the Orbiter inserts into a lower than nominal altitude, Flight Rule A4-103 defines priorities used to recover. This All Flights flight rule spells out how OMS-3 and OMS-4 should be used to raise the orbit "as high as possible". In most cases, the two burns will be targeted to a higher circular orbit from the current off-nominal orbit. Conditions for raising into an elliptical orbit are contained in the rule and rationale. The mission's flight rules annex will further define priorities given the payloads carried, mission objectives, and actual flight design numbers.

### **3.9.6.2 Iteration Procedure to Determine OMS-3 & 4**

Assuming recovery to a circular orbit is feasible, a two-burn raising sequence will probably be used. This discussion assumes both burns use OMS thrusters, but ARCS and FRCS may be preferable in these maneuvers depending on  $\Delta v$  requirements and where propellant margins reside. Some scenarios may dictate simply circularizing the post-OMS-2 orbit with a single burn at apogee. Typically, an OMS-3 burn is planned to occur no earlier than Orbit 3. This gives FDO and PROP time to gather inputs, determine the propellant available for orbit raising, iterate on a plan, and discuss the plan with FD. The OMS-4 "circ" burn would occur half an orbit later to minimize time spent in an elliptical orbit.

Having a preliminary plan in place and coordinated between the Orbit 2 FDO and PROP pre-launch helps expedite post insertion activity. Recovery coordination can be further enhanced if the Ascent Team is involved. This facilitates initiating orbit raising actions with OMS-2.

#### **3.9.6.2.1 Orbit Raising Prop Available**

To begin the iterative procedure, FDO must first obtain orbit raising propellant available. This is defined as the amount of usable OMS propellant available (above 5%) in both lbm and fps equivalent  $\Delta v$ . When supplying these values, PROP withholds propellant needed to deorbit from the current orbit. Current orbit steep  $\Delta v$ , ballast requirements, and current Orbiter weight are FDO inputs to PROP's orbit raising computation. PROP will also withhold daily attitude maintenance, separation burns, mission extension days, and any other propellant allocation in the flight rules annex at a higher priority than objectives facilitated by orbit raising.

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FDO needs to carefully consider current steep deorbit cost. The  $\Delta v$  passed to PROP should be a worst-case deorbit requirement, including effects from an elliptical post-insertion orbit. Steep deorbit costs at upcoming PLS and ELS opportunities must be covered such that gaps do not exceed 4.5 hrs through EOM+2 in accord with FR A4-103 Paragraph A.3. Sometimes deorbit  $\Delta v$  will vary considerably even for a circular orbit, particularly at lower altitudes encountered in off-nominal orbit insertion scenarios. Using current Orbiter weight (vice predicted weight at deorbit) is usually worst-case, assuming Orbiter weight decreases with MET, and it typically protects for payload return.

Available orbit raising  $\Delta v$  will be used to compute an equivalent achievable height change  $\Delta H$  initial guess using rules-of-thumb. Burns attaining  $\Delta H$  are then modeled in an ephemeris anchored on the current orbit. The  $\Delta v$  required for orbit raising burns, together with the *increase* in subsequent steep deorbit costs over the current worst-case, is compared with  $\Delta v$  available. A significant deviation between orbit raising  $\Delta v$  costs and  $\Delta v$  available, particularly a shortfall, is cause for continued  $\Delta H$  iteration.

### 3.9.6.2.2 Using OMP to Calculate OMS-3 and OMS-4

The easiest way to iterate on achievable altitude uses the Orbit Maneuver Processor (OMP) to model OMS-3 and OMS-4. This makes it easy to iterate on both the altitude and OMS-3 TIG. The Maneuver Transfer Table (MTT) should be set up to facilitate transfer to a planning ephemeris. See Figure 3.9.6-1a for the Constraints Table used in this iteration. The iteration utilizes Maneuver 1 (OMS-3) T and HD constraints. The CIRC maneuver is OMS-4.

**NOTE:** a good rule-of-thumb conversion is 1.8 fps in  $\Delta v$  equates to 1 nm in apsis height. An achievable altitude first guess can be computed with the following equation.

$$HD = ((\Delta v \text{ available in fps} / 3) / 1.8) + \text{Current Altitude in nm}$$

Because HD is in nm, its value can be input to the Constraints Table without modification. An OMS-3 TIG = 0/04:20 MET is an arbitrary starting value and will be optimized subsequently. The one-third factor appearing in the above equation is approximate and assumes roughly circular orbits before and after OMS-3/4. It's necessary because only one third of available  $\Delta v$  can be used for the first raising burn. The circ burn will use the second third, and the increase in steep deorbit will use the last third. Execute OMP by fetching an Orbiter state vector about 15 min prior to OMS-3 TIG. The Orbiter and target initial state vectors will be fetched from the same ephemeris for these single vehicle maneuvers. Set up the MTT with the appropriate thrusters, optimized or "split" TIG, active "yes" iterations, and transfer the plan to an ephemeris.

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A deorbit  $\Delta v$  is computed from this ephemeris using a post-OMS-4 fetch time. The DMP solution should employ steep targets to the FD3 PLS. For a high inclination flight, approach direction should be consistent with the baselined Minimum Duration Flight (MDF) opportunity. The D23C should reflect orbit raising, and Ncycle should be set to its  $3\sigma$  value. To obtain a DMP search threshold, it may be advisable to run a new DOPS from the orbit raising ephemeris.

The difference between deorbit  $\Delta v$  required from the insertion orbit and that required from the post-OMS-4 orbit is added to the propellant required for OMS-3 and OMS-4 to arrive at the  $\Delta v$  required for orbit raising. This requirement is compared to the  $\Delta v$  available for raising. HD is changed in the OMP constraints table and the process repeated until this comparison is acceptable.

GLOBAL	SSP	MANEUVER CONSTRAINTS	TABLE RAISE_ATO	CURRENT
			MNVRs: 2 / 40	
COMMENT: OMS3/4 ATO RAISING				
MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-3	T 000:04:20:00.000	HD =125 = =	= = =	
2 CIRC OMS-4	M 0.4	APS =1 = =	= = =	

**Figure 3.9.6-1a: OMP Constraints Supporting OMS-3/4 Iteration**

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GLOBAL		SSP		MANEUVER EVALUATION TABLE RET										
COMMENT: OMS3/4 ATO RAISING														
MCT : RAISE_ATO						OVT : PLOT								
GMTR : 1999:014:12:26:31.000														
VECTOR		TIME		COMMENT										
CHASER	G	SSP	E5	M	000:04:00:00.000	ATO - RAISING								
TARGET	G	SSP	E5	M	000:04:00:00.000	ATO - RAISING								
CHASER	DVtot =		72.60	DVx =	72.60	DVy =	0.00	DVz =	0.03					
TARGET	DVtot =		0.00	DVx =	0.00	DVy =	0.00	DVz =	0.002					
MNVRS														
-----														
	MNVR	NAME		GMTIG	IMP		DVx		HA		RANGE		Y	
	COMMENT			METIG			DVy		HP		PHASE		Ydot	
	DVMag			DT			DVz		DH		Noon/Mid -		SR/SS-	
-----														
	1	HA		014:16:46:31.000		35.97		125.07		0.0000		0.0		
	OMS-3			000:04:20:00.000		0.00		104.58		0.0000		0.0		
	36.0			000:00:43:47.350		0.00		0.00		N-00:27:06		SR-0:01:26		
-----														
	2	CIRC		014:17:30:18.350		36.64		125.51		50.2401		25.2		
	OMS-4			000:05:03:47.350		0.00		125.32		0.7414		0.7		
	36.6			000:00:00:00.000		-0.03		-20.08		M-00:27:29		SS-0:08:56		
-----														

**Figure 3.9.6-1b: OMP Output Supporting OMS-3/4 Iteration**

### 3.9.6.2.3 Convergence Limits

The  $\Delta v$  available should agree with that required to within 2 fps. This degree of convergence is not mandatory. If time precludes iterations to this threshold, curtailed orbit raising may be necessary to remain conservative and retain steep deorbit capability. If it's necessary to work lbm propellant available, rather than fps  $\Delta v$ , a good rule-of-thumb conversion is 25 lbm in propellant equates to 1 fps in  $\Delta v$  for typical post-insertion Orbiter weights. To adjust HD for the next iteration, use the following approximation.

$$HD = (\text{prop available} - \text{prop used}) / (3 * 25 * 1.8) + \text{Current Altitude in nm}$$

### 3.9.6.2.4 Optimizing OMS-3 TIG

After iterating the desired altitude, OMS-3 TIG should be adjusted so perigee is placed to minimize deorbit  $\Delta v$  to upcoming PLS opportunities, assuming OMS-4 is not executed. A similar adjustment would be required to OMS-4 TIG for EOM deorbit  $\Delta v$  if the post-OMS-4 orbit is planned to be elliptical. The "no OMS-4" contingency costs nothing to protect assuming there is flexibility in OMS-3 TIG selection. If OMS-4 cannot

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be executed, generally a next PLS or MDF will be declared, and all upcoming FD2, FD3, and FD4/MDF PLS opportunities need to be considered.

The PADJ processor can be used to find an optimum OMS-3 TIG. In a PADJ context, this task equates to finding an anti-optimum TIG because OMS-3 is a posigrade *apogee* adjust burn. Often, elliptic orbit raising can be accomplished without significantly adding to deorbit  $\Delta v$  required for many ConUS opportunities over several days. At 28.5° inclination, a post-OMS-3 argument of perigee around 50° will be nearly optimal. At 57°, this optimum shifts to approximately 10° for ascending ConUS approaches and to about 110° for descending approaches.

Calculate the post OMS-3 optimum argument of perigee by starting a PADJ run, fetching a state vector prior to the OMS-3 orbit (about 15 min prior to the ascending node), and calculating steep PADJ curves for the last FD2 EDW opportunity and the first FD4/MDF KSC opportunity. Use the DVM (PEG-7  $\Delta V_X$ ) option with a positive value equal to the expected OMS-3  $\Delta v$ .

Once OMS-3 TIG is calculated, transfer the final plan to Ephemeris 1. Pass OMS-3, OMS-4, and deorbit TIGs with  $\Delta v$  values to PROP.

**NOTE:** when a node-relative optimal OMS-3 TIG  $\Delta t_\Omega$  is known, it can be incorporated into OMP's constraints table by adding an argument of perigee ARGP secondary constraint to the OMS-3 burn. The value in deg to be specified for ARGP is simply  $360^\circ \frac{\Delta t_\Omega}{P}$ , where P is the orbit period prior to OMS-3 in min. If this were done in the Figure 3.9.6-1a example RCT, OMS-3's primary T constraint would become a "no earlier than" TIG threshold.

### 3.9.6.2.5 Raising to a Minimum Altitude

The foregoing procedure assumes orbit altitude is to be maximized with available propellant. With some modifications, it can also be used to raise the orbit to a minimum acceptable threshold. This minimum altitude may be dictated by a payload constraint or requirement, or it may arise from an orbit lifetime concern.

### 3.9.6.3 Flight-Specific Considerations and Options

A few orbit raising considerations must be evaluated based on flight-specific data. These include steep versus shallow deorbits, using RCS to raise the orbit, and payload deploy concerns.



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### **3.9.6.3.1 Steep vs. Shallow Deorbit Capability**

Steep deorbit capability must be maintained throughout altitude recovery. If altitude or the argument of perigee is extremely critical to mission success, preflight consideration can be given to protecting only shallow deorbit capability between burns as the orbit is raised. Steep deorbit capability should always be protected from the destination orbit. This consideration only applies when RCS thrusters are used to raise the orbit.

In some situations, orbit raising can be accomplished in whole or part by using RCS propellant. Raising altitude with RCS is not as desirable as with OMS because RCS specific impulse is lower. Also, jet on-time constraints may require several RCS burns to attain  $\Delta v$  equivalent to that from a routine OMS burn.

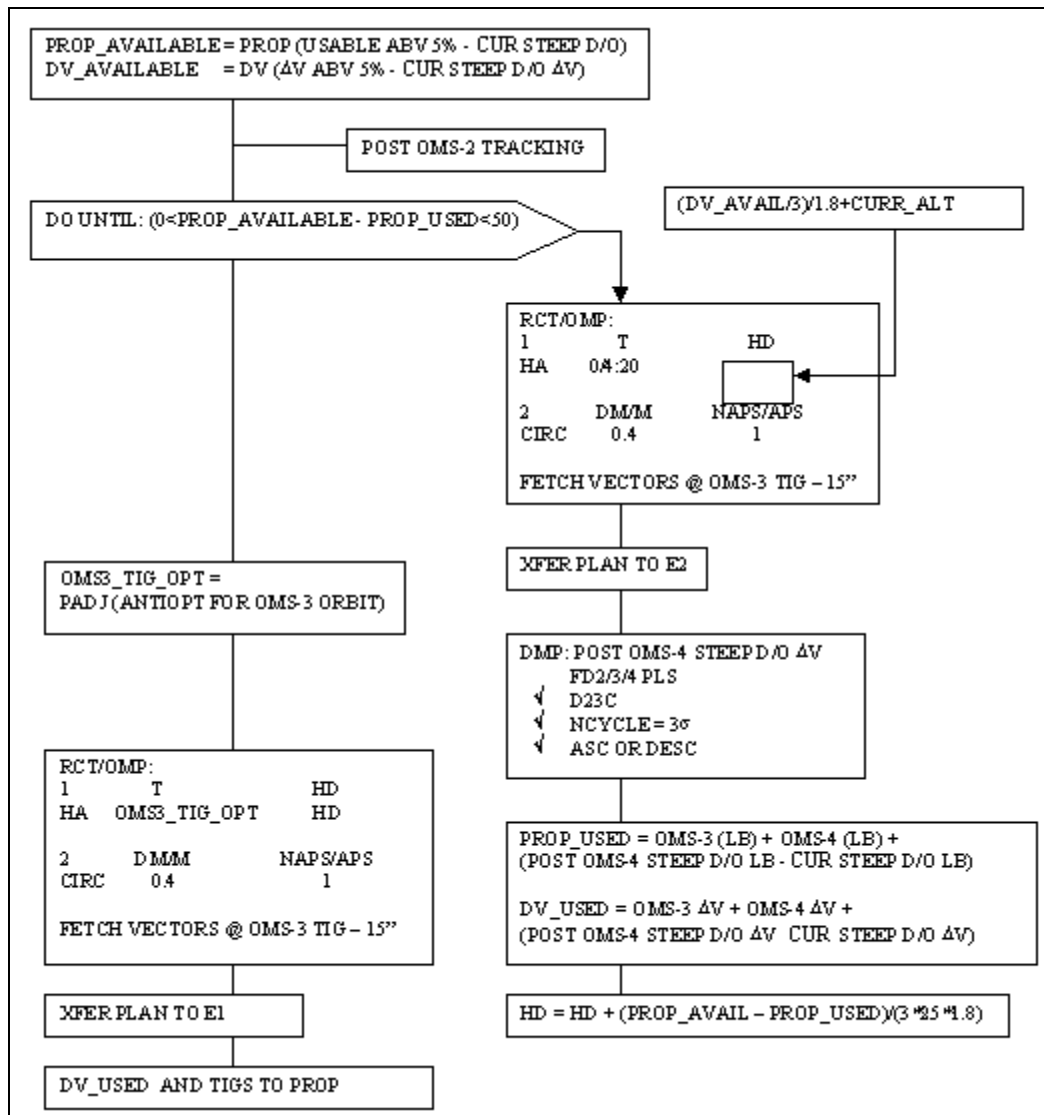
### **3.9.6.3.2 Payload Deploy Considerations**

There are two considerations for deployable flights. Steep deorbit capability for the no-deploy case is usually mandatory to insure payload return. This requirement may compromise capability to reach minimum deploy altitude. In such cases, an alternative may be to protect only shallow deorbit capability with the payload or steep capability without the payload. The strategy requiring more propellant is usually adopted. This is not particularly desirable and may depend on whether or not the Orbiter is too heavy to land with the payload and if the payload can be jettisoned.

The other deployable flight consideration is to protect the separation burn when raising the orbit. For heavy deployables, a payload return propellant "buy-back" may cover posigrade separation burn and increased deorbit costs post-deploy. This may not be the case for a lighter payload, such as a PDRS deployable. Propellant for the separation burn and increased deorbit  $\Delta v$  must be held back from the portion used to increase orbit altitude. If there is a minimum separation capability, consideration should be given to using it, allowing for some increase in achievable altitude. This consideration is usually addressed pre-launch, and is documented by flight-specific rules.

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## 3.9.6.4 Orbit Raising Procedure Flow Chart



**Figure 3.9.6-2: Off-Nominal Altitude Recovery Procedure**

## 3.9.7 Emergency Deorbit

This section contains the Assumptions (3.9.7.1), Actions/Rationale (3.9.7.2), and Supporting Documentation (3.9.7.3) for console procedures to execute a successful Emergency Deorbit and subsequent Entry.

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### 3.9.7.1 Emergency Deorbit Assumptions

Orbit FDO is required to get the Orbiter and crew safely out of orbit and to Entry Interface, thereby ensuring crew survivability. The Emergency Deorbit Checklist is designed to accomplish this by ensuring atmospheric capture, ensuring vehicle controllability, and minimizing thermal loads in accord with the following conditions.

- 1) An immediate deorbit burn is necessary with little or no warning from the crew (Section 3.9.7.2, Block A). The crew may be able to call down and ask for advice, or they may be forced to call down and indicate they are already burning and require some indication of how long to burn.
- 2) If the crew is not already performing a deorbit, the minimum time to deorbit TIG is 20 minutes after the deorbit decision (refer to Contingency Deorbit Prep, Section 10, Emergency Deorbit). This protects the minimum amount of activity necessary to configure Orbiter systems from an on-orbit to deorbit/entry ready (Section 3.9.7.2 Block C). Nevertheless, procedures for TIG within 20 minutes are maintained in the interest of total preparation (Section 3.9.7.2 Block B).
- 3) The original orbit is circular or nearly circular. Analysis of this type is made easier with this assumption, and all tables and figures reflect this. Therefore, cases such as highly elliptical orbits (as would be the case with orbits after a perigee adjust) should only be treated with great care.
- 4) Shuttle Portable Computer (SPoC) software in the Payload and General Support Computer (PGSC) is unusable. This assumption is necessary not because of hardware failures but because the SPOC deorbit processor results are unpredictable when there is no definite landing site.
- 5) There will be sufficient time to close the payload bay doors post-burn during the deorbit coast. Performing the burn is the immediate task.
- 6) There are no propellant shortages. However, some scenarios resulting in a shallow trajectory will be addressed if there is a propellant-critical situation.
- 7) The most likely landing scenario is a crew bailout over water. This situation should be considered a contingency case, so an appropriate runway and vehicle reusability are not considered.
- 8) There is communication with the crew. If there is no communication, actions taken by the FDO will be very limited. Since this discussion is FDO based, the topic of possible updates to the Flight Data File and crew actions in the absence of communication will not be addressed.

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**NOTE:** the following checklist does not cover all scenarios and all cases that could be termed “Anytime”, “Emergency”, or “Contingency” deorbit. In general, any checklist cannot substitute for a trained console operator’s ability to make decisions and implement actions based on the actual failures presented. The checklist does try to provide steps for some of the more time-critical (not necessarily the most probable) scenarios that an Orbit FDO might face. These steps are guidelines; not an all-encompassing procedure.

### 3.9.7.2 Checklist Actions/Rationale

This section contains rationale for each step in the Emergency Deorbit Checklist (refer to Appendix 3.E). Checklist actions appear in numbered/lettered steps that follow. After each step, italicized text provides rationale or supplemental information for that step not appearing in Appendix 3.E. Bold-faced text delimits subsections or "blocks" composed of multiple steps in the procedure or directs non-sequential steps be performed.

**Immediately perform the following actions.**

- 1) \_\_\_\_\_ TRAJ pages or calls ENTRY FDO and LSO. Provide landing GMT and landing site/runway.

*LSO and LSO ALP as well as ENTRY FDO pager/home phone/cell phone numbers will be in the FDO Data Book on console.*

- 2) \_\_\_\_\_ Delete all future maneuvers in E1.

*This action clears out maneuvers that will not be performed and ensures targeting will use the correct vector.*

- 3) \_\_\_\_\_ Enter checklist segment based on scenario in the following table.

Checklist Usage	
SCENARIO	ACTION
A. Deorbit burn has occurred	Go to Block A (then D, E, F as directed)
B. Deorbit immediately	Go to Block B (then D, E, F as directed)
C. Deorbit ASAP (TIG > 20 min from now)	Go to Block C (then D, E, F as directed)

*Three mutually exclusive scenarios are addressed in this checklist (A, B, and C). All scenarios will execute Sections D, E, and F of this checklist.*

#### **BLOCK A CREW HAS BURNED ALREADY**

*A possible scenario is extended loss of comm with stale or no PLS vector onboard, GPS unavailable and/or other system failure (cabin leak): obviously a very bad day and*

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*multiple failures deep. The crew deorbits per FR A11-52. If comm is restored, these are the steps FDO should execute.*

A1) \_\_\_\_\_ Direct crew to ENT FS p 3-34 (starred block) for MM303 Attitude (also located in Cont. D/O Prep p 10-16).

NOTE: if a PEG-7 deorbit burn is in progress after a protracted comm outage, supply FD and crew with equivalent PEG-7 targets from DMP. In lieu of applicable DMP targets, refer to Figure 3.9.7-1.

*FD will want a procedure and page number from which the crew can obtain the post-burn attitude maneuver. This page gives post-burn attitude (INRTL) for a proper entry attitude at EI-5. The starred block specifies roll and yaw. The table specifies pitch in relation to time to EI, which the crew has based on the MNVR EXEC display's timer. In MM301/302, the timer counts down to TIG when ITEM 23 is executed and counts up from TIG thereafter. Upon transition to MM303, the timer starts counting down to EI based on deorbit targets, specifically time of free fall.*

A2) \_\_\_\_\_ Have NAV run DAE using post-burn vector (B70, START, NONE, V53\$) and then proceed with remaining steps in NAV CHB SOP 6.7, ANY TIME DEORBIT procedure.

*This step produces a predicted impact point and footprint showing approximate entry guidance capability. The Downrange Abort Evaluator (DAE) will give a crude estimate of entry guidance capability because it's a TAL support processor and is based on flying a ballistic trajectory down to 280 Kft, followed by cubic equations which define a range/crossrange footprint at Earth's surface. "B70" is the DAE command (old MED name), "START" enables DAE processing, "NONE" is the dump option, and "V53" is the vector to fetch. Orbit Navigation Console Handbook (USA007512) SOP 6.7 is the NAV position console handbook procedure for emergency deorbit support. To use it, FDO normally provides NAV with an ephemeris #, targets, and TIG. In Block A of this checklist, the burn has already happened, so NAV's procedure is somewhat modified. No burn input is necessary, so tell NAV to run DAE using the onboard vector (V53) and continue with subsequent steps in SOP 6.7. These remaining actions update the EDS and TrS LST and run Orb Normal in EDS to the NOW24 site.*

A3) \_\_\_\_\_ Access 'OUTPLANE Plot' and 'CUR DAE Output' from the FDO DNAV's ASCENT menu.

*These displays allow FDO to view the footprint and impact point coordinates, respectively. See Figures 3.9.7-2 and 3.9.7-3.*

A4) \_\_\_\_\_ Check for a Landing Site within the DAE footprint on 'OUTPLANE PLOT'.  
NOTE: to zoom plot, draw box around region using left mouse button. To unzoom plot, click right mouse button. To extend plot to show high/low latitudes, hold CNTRL key and draw small box in center of screen using left mouse button. Then draw box around entire region using left mouse button without holding CNTRL key.

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*Even though this is most likely a bailout scenario, a landing site may be in or near the footprint. The note gives some info on how to navigate the DAE display. Extreme southern or northern latitudes are not displayed by default. In order to see a footprint in these regions, it is necessary to perform the extend plot step above. See Figures 3.9.7-2 and 3.9.7-3.*

### **If a landing site exists in the DAE footprint, perform Steps A5 and A6.**

*Whether the landing site is onboard or not onboard, DOD or non-DOD, start checking weather, try to contact the site, and alert FD that a site is available to steer toward. Further instruction on this coordination effort can be found in Block E of this checklist.*

A5) \_\_\_\_\_ Choose best site based on WX, if available, and LSO Priority list. *A quick check of weather can be done using the SMG ELS Wx web site from the DNAV or PC ([www.srh.noaa.gov/smg/els\\_obs.txt](http://www.srh.noaa.gov/smg/els_obs.txt)). The ChronDOPS application's "Get ELS Wx" function can be employed to import Wx data from the SMG web. The LSO ELS priority list (link on FDO home page) can also be used to choose between sites of differing priority. The ChronDOPS application incorporates this check as well.*

A6) \_\_\_\_\_ Check ENT FS p. 3-2 through 3-4 to determine if site is in the O/B LST.

a) \_\_\_\_\_ If YES, no LST synch required. **Go to SYNC LANDING SITE TABLES (Step D5).**  
*An onboard landing site is available. This step sends you to D5 so that an Orb Normal can be run to this site (NAV has only run Orb Normal for NOW24 up to this point).*

b) \_\_\_\_\_ If NO, an LST synch is required. **Go to SYNC LANDING SITE TABLES (Step D1).**  
*A landing site is available, but it needs to be uplinked to the onboard LST. This landing site will, by definition, already be in the TSA and EDS LSTs since the emergency deorbit ops concept is to only assess sites in the LSO list (DAE output will only show landing sites in the TSA and EDS LSTs). Step D1 will synch the onboard LST with a LS/TACAN command load and also synch the TrS LST.*

### **If no landing site exists in the DAE footprint, perform Step A7.**

A7) \_\_\_\_\_ Note Impact Point LATD and LONG on CRNT DAE OUTPUT display. *Coordinates are located in the NO DMP section of the display's middle column under the label NOM LANDING PT. See Figure 3.9.7-3. These coordinates should be relayed to the SAR forces through DOD Cape and also to the SCC. See Emergency Landing Comm Checklist (Section 3.9.7.3.3) and Block E "OTHER COORDINATION" below for details on TRAJ duties in lieu of LSO.*

**Go to SYNC LANDING SITE TABLES (Step D3).**

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*This set of steps is required to ensure the landing site (or bailout point) is onboard so entry guidance will have coordinates to fly to. Trajectory processing tools also require landing site coordinates so FDO can evaluate the entry. Step D3 generates the command load to uplink NOW24 to the onboard LST. The first step of D3 should have already been completed by NAV from execution of Step A2.*

### **BLOCK B DEORBIT BURN REQUIRED ASAP (TIG WITHIN 20 MINUTES)**

*Since the burn has not yet begun, targets can be read up. There may not be sufficient time to generate and uplink targets, so existing PEG-4D targets are used (either current DMP solution output or generic targets based on altitude and inclination).*

NOTE: while doing Steps B2, B4, and B5, NAV can start working Step B6. If Step B3 is executed, NAV has to wait for targets before starting Step B6.

NOTE: depending on the failure scenario requiring this immediate deorbit, the crew will be working in the Contingency Deorbit Prep book, most likely Section 10 (Emergency Deorbit). The procedure in Section 10 is designed for 20 min < TIG < 2 hrs 40 min. With < 20 minutes available, some steps such as PLBD closure must be delayed while others are eliminated.

B1) \_\_\_\_\_ Have the crew manually maneuver to LVLH  $Y=0$ ,  $P=180^\circ$ ,  $R=0$ .  
*This will get the Orbiter maneuvering toward the approximate deorbit burn attitude while FDO is preparing the burn targets. If the Orbiter is already close to this tail-forward bay-to-Earth attitude, this step can be omitted.*

B2) \_\_\_\_\_ If in a near-circular orbit ( $H_a - H_p \leq 50$  nm), read up pseudo-Deorbit PAD to crew (thruster, TVR, current weight and trims, C1, C2,  $\theta_T$ , HT, and TIG). Use either B2a (DMP targets) or B2b (generic targets) as the source for C1/C2/ $\theta_T$  (DMP is preferred).

*The 50 nm "elliptical threshold" is unverified, but acceptable targeting using sources B2a/b has been demonstrated in specific cases with  $H_a - H_p$  up to and including 50 nm.*

a) \_\_\_\_\_ Obtain C1/C2/ $\theta_T$  from an existing DMP solution in same orbit (get C1, C2, and  $\theta_T$  from DOD display in lieu of DMT).

*The DMP solution used must be from the same orbit. Since a circular orbit is assumed, the difference in argument of latitude between the DMP solution and the actual deorbit position does not adversely impact deorbit targets.*

b) \_\_\_\_\_ Obtain C1/C2/ $\theta_T$  from altitude/inclination-dependent tables (see Figures 3.9.7-4a/b in Section 3.9.7.3.7).

*These targets are good for circular orbits. NAV has these targets on files, so they can initiate their NOW24 process (SOP 6.7 in their handbook) given just the Set ID from Figures 3.9.7-4a/b. Targets from a current DMP solution in this orbit are probably better (although to what degree is unknown).*

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c) \_\_\_ HT = 65.832 nm (400000 ft).

*This is the standard deorbit altitude target (E1 altitude).*

d) \_\_\_ TIG = current time + estimated time to maneuver to burn attitude.

*If TIG is needed this soon (within 20 min), GNC may need to increase the maneuver rate in order to achieve attitude before TIG.*

B3) \_\_\_\_\_ If in an elliptical orbit ( $H_a - H_p > 50$  nm) or generic targets are otherwise unacceptable, perform the following steps.

**CAUTION:** step B3 is currently a placeholder until DMP's validity in elliptical orbits is determined. Until this validity is known, generic deorbit targets from Step B2 are preferred, and Step B3 should not be performed.

*Analysis supporting Step B3 is ongoing. How elliptical must the orbit be before targets are unacceptable? How are invalid generic targets detected? Until elliptical orbit DMP dependencies are better known, the best course is to use generic targets as in Step B2.*

a) \_\_\_ Run DMP from current orbit to first available site (check ELS DOPS).

*Since this step assumes an elliptical orbit, a new DMP solution is required because argument of latitude differences could render any existing PEG-4D targets invalid for the emergency deorbit TIG. If the TIG argument of latitude happens to be nearly equal to the value for which the existing DMP solution was run, existing targets are acceptable. Depending on current LAN, the landing opportunity for which the existing DMP solution was run may be near the emergency TIG. Under less fortunate circumstances, this TIG may fall at a LAN for which no valid targets exist at the desired TIG argument of latitude. This scenario is currently unaddressable.*

b) \_\_\_ Read up pseudo-Deorbit PAD, providing thruster, TVR, current weight and trims,  $C1/C2/\theta_T$  from DOD, HT = 65.832 nm, and TIG = current time + estimated time to maneuver to burn attitude.

*Current trims should be good. Check this, time permitting.*

B4) \_\_\_\_\_ Have the crew load targets in OPS 3. Verify targets on MNVR Monitor, if possible.

*Per Cont. D/O Prep p. 10-14, target load must be in OPS 3. If NAV has input deorbit maneuver into E1 (part of Step B6), onboard targets can be compared to the DMT display.*

B5) \_\_\_\_\_ Give 'GO' for maneuver to deorbit burn attitude.

B6) \_\_\_\_\_ Have NAV run NAV CHB SOP 6.7, ANY TIME DEORBIT.

a) \_\_\_ Specify deorbit targets (use Figure 3.9.7-4a/b or DOD).

b) \_\_\_ Provide TIG and ephemeris to NAV.

**NOTE:** an example call would be "NAV, run Emergency Deorbit, use H7 targets, E1, and TIG at 1/03:27 MET".



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*Orbit Navigation Console Handbook (USA007512) SOP 6.7 is the NAV position console handbook procedure for emergency deorbit support. NAV inputs specified burn targets and runs DAE off the deorbit burnout. This action produces a predicted impact point and footprint showing approximate entry guidance capability. The Downrange Abort Evaluator (DAE) will only give a crude entry guidance capability estimate because DAE is a TAL support processor and it flies a ballistic trajectory down to 280 Kft. From this state, cubic equations define a range/crossrange footprint at Earth's surface. In summary, Step B6 accomplishes the following tasks.*

- 1) Direct input the deorbit maneuver to E1.*
- 2) Run DAE based on the burnout of the deorbit.*
- 3) Update EDS and TrS LSTs to include the NOW24 site at the DAE-predicted impact point.*
- 4) Run EDS Orb Normal to NOW24.*

B7) \_\_\_\_\_ Access 'OUTPLANE Plot' and 'CUR DAE Output' from the FDO DNAV's ASCENT menu.

*These displays allow FDO to view the footprint and impact point coordinates, respectively. See Figures 3.9.7-2 and 3.9.7-3.*

B8) \_\_\_\_\_ Check for a Landing Site within the DAE footprint on 'OUTPLANE PLOT' **NOTE:** to zoom plot, draw box around region using left mouse button. To unzoom plot, click right mouse button. To extend plot to show high/low latitudes, hold CNTRL key and draw small box in center of screen using left mouse button. Then draw box around entire region using left mouse button without holding CNTRL key.

*Even though this is most likely a bailout scenario, a landing site may be in or near the footprint. The note gives some info on how to navigate the DAE display. Extreme southern or northern latitudes are not displayed by default. In order to see a footprint in these regions, it is necessary to perform the extend plot step above. See Figures 3.9.7-2 and 3.9.7-3.*

**If a landing site exists in the DAE footprint, perform Steps B9 and B10.**

*Whether the landing site is onboard or not onboard, DOD or non-DOD, start checking weather, try to contact the site, and alert FD that a site is available to steer toward. Further instruction on this coordination effort can be found in Block E of this checklist.*

B9) \_\_\_\_\_ Choose best site based on WX, if available, and LSO Priority list. *A quick check of weather can be done using the SMG ELS Wx web site from the DNAV or PC ([www.srh.noaa.gov/smg/els\\_obs.txt](http://www.srh.noaa.gov/smg/els_obs.txt)). The ChronDOPS application's "Get ELS Wx" function can be employed to import Wx data from the SMG web. The LSO ELS priority list (link on FDO home page) can also be used to choose between sites of differing priority. The ChronDOPS application incorporates this check as well.*

B10) \_\_\_\_\_ Check ENT FS p. 3-2 through 3-4 to determine if site is in the O/B LST.

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- a) \_\_\_ If YES, no LST synch required. **Go to SYNC LANDING SITE TABLES (Step D5).**

*An onboard landing site is available. This step sends you to D5 so that an Orb Normal can be run to this site (NAV has only run Orb Normal for NOW24 up to this point).*

- b) \_\_\_ If NO, an LST synch is required. **Go to SYNC LANDING SITE TABLES (Step D1).**

*A landing site is available, but it needs to be uplinked to the onboard LST. This landing site will, by definition, already be in the TSA and EDS LSTs since the emergency deorbit ops concept is to only assess sites in the LSO list (DAE output will only show landing sites in the TSA and EDS LSTs). Step D1 will synch the onboard LST with a LS/TACAN command load and also synch the TrS LST.*

**If no landing site exists in the DAE footprint, perform Step B11.**

B11) \_\_\_\_\_ Note Impact Point LATD and LONG on CRNT DAE OUTPUT display. *Coordinates are located in the NO DMP section of the display's middle column under the label NOM LANDING PT. See Figure 3.9.7-3. These coordinates should be relayed to the SAR forces through DOD Cape and also to the SCC. See Emergency Landing Comm Checklist (Section 3.9.7.3.3) and Block E "OTHER COORDINATION" below for details on TRAJ duties in lieu of LSO.*

**Go to SYNC LANDING SITE TABLES (Step D3).**

*This set of steps is required to ensure the landing site (or bailout point) is onboard so entry guidance will have coordinates to fly to. Trajectory processing tools also require landing site coordinates so FDO can evaluate the entry. Step D3 generates the command load to uplink NOW24 to the onboard LST. The first step of D3 should have already been completed by NAV from execution of Step B6.*

**BLOCK C DEORBIT ASAP (TIG > 20 MINUTES AWAY)**

*This scenario covers cases where time is available to generate and uplink targets and PADs, but deorbit is required before next PLS. If a landing site is available within allotted time to deorbit, FDO will target the deorbit burn to that site. If no site is available, a NOW24 bailout will be performed, but time may be available to generate targets specific to the NOW24 impact point.*

NOTE: the crew will be working in the Contingency Deorbit Prep book, most likely Section 10 (Emergency Deorbit). The procedure in Section 10 is designed for 20 min < TIG < 2 hrs 40 min. Depending on time available, some steps may be delayed or eliminated.

C1) \_\_\_\_\_ Have the crew manually maneuver to LVLH Y=0, P=180°, R=0.

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*This will get the Orbiter maneuvering toward the approximate deorbit burn attitude while FDO is preparing the burn targets. If the Orbiter is already close to this tail-forward bay-to-Earth attitude, this step can be omitted.*

C2) \_\_\_\_\_ Check ELS DOPS for available sites or check Chron DOPS spreadsheet, if available, for sites, priorities, and common names.

*Evaluate priority based on LSO "ELS priority" link on FDO home page. If the Chron DOPS office PC application has been run, site priority evaluation is made much easier. Chron DOPS output is typically stored in a folder on the V drive each day by the Planning Team (see Section 3.12.17) and will include the LSO priority for each deorbit opportunity.*

**If no site is available within allotted time to deorbit (probable system failure scenario), perform Steps C3 through C12.**

*In this scenario, deorbit must occur prior to next PLS because a system failure requires landing in < X hours. Additionally, there is no ELS available within the next X hours. It is possible to be in this gap scenario during portions of any orbit. This case might arise if TIG was required in < 30 min, and the last ELS prior to a long gap had just been passed.*

C3) \_\_\_\_\_ Run DMP from current orbit to first available site (regardless of TIG). *This step generates deorbit targets. Optimization is not required. The 2OMS/1OMS crossover TIG is sufficient (use OBP/OL thrusters in DMP, typically the Column 1 configuration). Since no site is available, this DMP run just generates acceptable targets for the entry to the bailout point.*

C4) \_\_\_\_\_ Transfer the DMP solution into E1 and override/change TIG to the latest acceptable TIG per the system failure scenario. *This action corresponds to Steps B and C (Input P4D targets and Input M66) in NAV console handbook SOP 6.7, ANY TIME DEORBIT. Instead of generic targets, however, those from a DMP solution are used. If TIG is being driven by a NLT landing time, set TIG to this latest landing time minus one hour.*

C5) \_\_\_\_\_ Have NAV run DAE off E1 deorbit burnout (B70, START, NONE, MVE1XX\$), per NAV CHB SOP 6.7. *This step produces a predicted impact point and footprint showing approximate entry guidance capability and corresponds to Step D (Run the DAE) in NAV Console Handbook SOP 6.7, ANY TIME DEORBIT. The Downrange Abort Evaluator (DAE) will give a crude estimation of the entry guidance capability because it's a TAL support processor and is based on flying a ballistic trajectory down to 280 Kft, followed by cubic equations which define a range/crossrange footprint at Earth's surface. "B70" is the DAE command (old MED name), "START" enables DAE processing, "NONE" is the dump option, and MVE1XX\$ is the vector to fetch (burnout vector of maneuver XX). This step corresponds to Step D (Run the Downrange Abort Evaluator) in SOP 6.7.*

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C6) \_\_\_\_\_ Have NAV update NOW24 per NAV CHB SOP 6.7.  
*This step updates TrS and EDS LSTs with the impact point (NOW24) coordinates and corresponds to step E (Update NOW24) in SOP 6.7. NOW24 will be in TrS LST Slot 3.*

C7) \_\_\_\_\_ Access 'OUTPLANE Plot' and 'CUR DAE Output' from the FDO DNAV's ASCENT menu.

*These displays allow FDO to view the footprint and impact point coordinates, respectively. See Figures 3.9.7-2 and 3.9.7-3.*

C8) \_\_\_\_\_ Note Impact Point LATD and LONG on CRNT DAE OUTPUT display. Coordinates are located in the NO DMP section of the display's middle column under the label NOM LANDING PT. See Figure 3.9.7-3. These coordinates should be relayed to the SAR forces through DOD Cape and also to the SCC. See Emergency Landing Comm Checklist (Section 3.9.7.3) and Block E "OTHER COORDINATION" below for details on TRAJ duties in lieu of LSO.

### **Execute Steps C9/C10/C11 only if time allows.**

*These steps would only be performed if time allowed further refinement in deorbit targets to NOW24. In this case, a DMP run is made to the actual predicted impact point. These steps are mainly included here to illustrate this capability exists. Even with sufficient time, extra refinement in the targets probably doesn't buy enough to warrant performing these steps.*

C9) \_\_\_\_\_ Update TSA LST manually with NOW24 (Impact Point coordinates).

C10) \_\_\_\_\_ Run DMP to NOW24 (fetch/search just prior E1 TIG).

C11) \_\_\_\_\_ Transfer DMP solution to E1, replacing previous deorbit maneuver.

C12) \_\_\_\_\_ **Go to Step C16.**

### **If one or more sites are available within allotted time to deorbit, perform Steps C13 through C23.**

*If a landing site is available, advise FD of landing opportunity; check site weather, and try contacting traffic control tower to clear airspace. Crew will be directed to select site prior to MM304.*

C13) \_\_\_\_\_ Verify acceptable weather prior to selecting site. Obtain ELS Wx from Chron DOPS output or SMG ELS Wx website (PC or DNAV).

**CAUTION:** surface wind direction on the SMG ELS Wx web site is TRUE; not MAGNETIC. When inputting winds into QuAC for assessing runways, select 'T' under the REF column.

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*Flight Rule requirements for selecting and targeting a landing site for are summarized below.*

- 1) *Crossrange < undispersed limit*
- 2) *Operational TACAN or DME within 50 nm*
- 3) *Runway in LST or uplinkable*
- 4) *Acceptable weather*
  - a) *Ceiling/Visibility > 0/0 if MLS; > 8000/5 if no MLS*
  - b) *Crosswind ≤ 15 knots*
  - c) *No thunderstorms or lightning at landing site*
- 5) *If night landing, xenon lights or edge lights and ≥ 1 operational HUD*

C14) \_\_\_\_\_ If SMG on console, request upper wind forecast for landing site. When winds data arrive, have NAV run their CHB SOP 6.12 Part A as time permits.

*FDO provides Wx Sheet obtained in Step C13 to NAV and specifies altitudes at which winds data are to be entered. The 50K, 38K, 20K, 7K, 3K, and 1K DEL PAD altitudes are considered minimal. A density altitude is also provided to NAV. The winds file is saved to path /users/trjcom/ASA01/SSPXXX\_YYY/Global/Winds/.*

C15) \_\_\_\_\_ Run DMP to site with appropriate thrusters and transfer solution to ephemeris. Advise FD of landing site selection.

*This step generates deorbit targets. Optimization is not required. The 2OMS/1OMS crossover TIG is sufficient (use OBP/OL thrusters in DMP, typically the Column 1 configuration). At this point, FD should be made aware of the landing site being targeted.*

C16) \_\_\_\_\_ Run Orb Normal to landing site or NOW24. Check Drag vs. VE and Groundtrack for acceptable entry profile.

*The Orb Normal generates entry ephemeris, groundtrack, and digital entry performance data. This action corresponds to NAV SOP 6.7 Step F. Check the entry data to ensure a successful capture and entry into the atmosphere are predicted (including thermal) based on the targeted deorbit burn.*

C17) \_\_\_\_\_ Build PEG-4D command load (411XX) and uplink (see DM-CH-05, Flight Dynamics Command Procedures).

**Perform Steps C18 - C20 as time permits.**

C18) \_\_\_\_\_ Have TRAJ build and display deorbit TIG wall clock or ensure OIGN is queued.

*Perform this step as time allows, providing situational awareness for the Flight Control Team.*

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C19) \_\_\_\_\_ Time permitting, build MNVR PAD. Otherwise, voice up TIG, TGO, and Notes.

*Maneuver PAD generation is not necessary in a time crunch since the targets have been uplinked. The TIG, TGO, and notes should be read up to give the crew a check for the TIG and because TGO on the command load is different from that calculated onboard (command load is correct). The notes are not on the command load, so those must be read up.*

C20) \_\_\_\_\_ Fill out top part of DEL PAD (set L, R OMS fail HPs = 80). Include TIG slip, if possible.

*Time permitting, the DEL PAD should be generated. The top deorbit section can be completed first and read to the crew. This contains deorbit burn Hp cues and TIG slip data. The Entry/Landing section can be read up later (prior to EI).*

C21) \_\_\_\_\_ Have the crew load targets in OPS 3 and verify them on MNVR Monitor, if possible.

*Per Cont. D/O Prep p. 10-14, target load must be in OPS 3. If NAV has input deorbit maneuver into E1 (part of Step B5), onboard targets can be compared to the DMT display.*

C22) \_\_\_\_\_ Give 'GO' for maneuver to attitude.

C23) \_\_\_\_\_ **Go to BLOCK D, SYNC LANDING SITE TABLES, as follows.**

- a) \_\_\_ Step D1 if landing site is not in onboard LST.
- b) \_\_\_ Step D3 if landing site is the Impact Point (NOW24).
- c) \_\_\_ Step D4 if landing site is in the onboard LST.

*Block D steps are required to ensure the landing site (or bailout point) is onboard so entry guidance will have a site to fly to. These actions also ensure trajectory processing tools support FDO entry evaluation.*

### **BLOCK D SYNC LANDING SITE TABLES (Onboard, TrS, EDS, TSA)**

NOTE: the following steps require landing site and TACAN command loads to be built and uplinked. Reference DM-CH-05, Flight Dynamics Command Procedures, and Section 3.9.7.3.4, Emergency Landing Site Uplink Notes.

CAUTION: Steps D1 and D3 use the standard LS/TACAN command manager application found on FDO DNAV path Gen Traj : Command Loads Sub-menu : Landing Site TACAN.

CAUTION: Step D2 uses the Emergency LS/TACAN command manager application, found on FDO DNAV path Gen Traj : Command Loads Sub-menu : Landing Site TACAN w/GLOBE (Emergency Tool).

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*On the FDO DNAV, there are two instances of the LS/TACAN command manager application. The standard application contains all landing sites/TACANs in NAVO-16B, while the emergency tool contains all landing sites/TACANs in the GLOBE database file. GLOBE is a worldwide set of non-approved landing sites managed by the AEGPO discipline.*

D1) \_\_\_\_\_ If the landing site is not onboard, but is resident in EDS and TSA LSTs, perform the following actions.

*This site will be on the LSO Sites list. An example runway would be RCA16 at Ellsworth AFB, SD.*

- a) \_\_\_ Build LS/TACAN command load (41203/41303) for landing site using LS/TACAN command manager (replace slot 3) and uplink to Onboard (must be in OPS 3).

*Refer to Section 3.9.7.3.4, Emergency Landing Site Uplink Notes.*

- b) \_\_\_ Update TrS LST using LS/TACAN command manager "Update TRS" button.

- c) \_\_\_ **Go to Step D5.**

D2) \_\_\_\_\_ If the landing site is not resident in EDS and TSA LSTs, access the GLOBE database for uplink with the following actions.

*An example site would be Christchurch, New Zealand. Per the current LST Ops Concept, this scenario is a post-burn "redes" from NOW24. It is best effort only for the Orbit FDO. In this case, the DAE footprint contained no LSO list site, so the NOW24 bailout steps have been executed (see Step D3 below). Should a GPO or LSO be available early enough to identify a GLOBE site in or near the DAE footprint, it can be evaluated with EDS and uplinked for crew selection. These steps should be delegated to GPO if possible.*

- a) \_\_\_ Request NAV load site into EDS using NOW24 script with manual override of site coordinates to specified ELS location.

*NAV will use the NOW24 option in EDS and override landing site lat/lon with specified ELS coordinates from the GLOBE database.*

- b) \_\_\_ Build LS/TACAN command load (41203/41303) for landing site using LS/TACAN w/GLOBE (Emergency Tool) command manager (replace slot 3) and uplink to Onboard (must be in OPS 3)

- c) \_\_\_ Update TrS LST using LS/TACAN command manager "Update TRS" button.

*Refer to Section 3.9.7.3.4, Emergency Landing Site Uplink Notes.*

- d) \_\_\_ **Go to Step D5.**

D3) \_\_\_\_\_ If the landing site remains NOW24 (no site in DAE footprint), perform the following actions.

**CAUTION:** if neither Step A2 nor Step B6 has been performed, first have NAV update TrS and EDS LSTs with NOW24.

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*This action corresponds to Step E (Update NOW24) in NAV Console Handbook SOP 6.7. NAV will run the NOW24 option in EDS to update EDS and TrS LSTs with NOW24. Steps A2 and B6 of this procedure have NAV execute SOP 6.7. Therefore, if D3 is being performed from Block A or B, the NOW24 LST synch is already complete.*

- a) \_\_\_ Build LS command load (41203) for NOW24 in Slot 3 using LS/TACAN command manager (use manual option in command manager and input NOW24 data from CUR DAE Output display) and uplink in OPS 3.

*Refer to Section 3.9.7.3.4, Emergency Landing Site Uplink Notes.*

- b) \_\_\_ **Go to Step D6.**

*No need to perform Step D5 because the Orb Normal targeting NOW24 has already been run.*

D4) \_\_\_\_\_ If landing site is onboard, no LST synch is required. **Go to Step D5.**

D5) \_\_\_\_\_ Re-run Orb Normal only if Block A or B steps have been executed. *A new Orb Normal is necessary if Block A or Block B was executed and the site of interest is not NOW24. Steps A2 and B6 execute the Orb Normal to NOW24. To get to Step D5 from either Block A or B entails actually finding a site in the footprint. Therefore, the Orb Normal must be run to this site. If Block C was executed, this step is unnecessary since the Orb Normal is run in Step C16 to either NOW24 or the site in the footprint.*

- a) \_\_\_ Run Orb Normal to landing site in DAE footprint using burnout vector in E1 or V53, as applicable.

*This action updates entry ephemeris and performance data for the landing site of interest. This is the site in the DAE footprint, and assumes the FDO has checked for acceptable weather. See ELS weather limits in Section 3.9.7.3.6.*

- b) \_\_\_ **Go to Step D6.**

D6) \_\_\_\_\_ Post-deorbit, direct crew to select landing site for entry per one of the following actions.

*Runway selection enables Entry Guidance steering to the expected landing location. The ITEM 41 should be executed prior to entering MM304 (Entry Guidance), nominally at EI -5 min.*

- a) \_\_\_ If NOW24 or ELS is loaded into slot 3, expect ITEM 41 + 2 on SPEC 50.

*On SPEC50 (HORIZ SIT), ITEM 41 selects the AREA from the onboard LST. AREA 2 contains runways in slots 3 and 4. Doing the ITEM 41 + 2 selects the runway in slot 3 by default.*

- b) \_\_\_ If landing site already existed onboard, expect ITEM 41 + X on SPEC 50, then ITEM 4 EXEC if necessary to select secondary runway. Get AREA number X from ENT FS, pp. 3-2 through 3-4.



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*On SPEC50 (HORIZ SIT), ITEM 41 selects the AREA from the onboard LST. Each AREA contains two runways, primary and secondary. If the site number is the primary runway in the AREA (an odd number), then it's selected by default when ITEM 41 is executed. If the secondary runway is desired (site number is even), the crew must do ITEM 4 EXEC after the ITEM 41 + X to select it. An ITEM 3 EXEC would reselect the primary runway in AREA X.*

c) \_\_\_ **Go to Block E.**

### **BLOCK E OTHER COORDINATION (TRAJ duties if LSO not present)**

NOTE: LSO will perform these actions after being contacted, even if still en route to MCC. When paging LSO, supply landing site/impact coordinates and landing GMT.

References: 1) FDO Console Handbook Sections 3.12.11.2 and 4.9.22

2) Example dialogue in Section 3.9.7.3.5

CAUTION: Block E actions rely heavily on the foregoing references. These documents should be used to achieve clear and concise communication.

E1) \_\_\_\_\_ Communicate with SAR forces through DOD Cape on DOD COORD (see Section 3.9.7.3.5 example) and supply the following information.

*Refer to Section 3.9.7.3.3, Emergency Landing Comm Checklist. The example dialogue in Section 3.9.7.3.5 provides comm loop setup instructions as well as guidelines for communicating with DOD Cape, SAR forces, and landing site personnel.*

a) \_\_\_ Projected Impact Point or Landing Site (runway #, if available)

b) \_\_\_ Projected landing GMT

E2) \_\_\_\_\_ Contact the landing site airfield per the following interfaces.

*Contact with the airfield is required to land at the site (see FR A2-205E). The following are the contacts depending on the type of site.*

a) \_\_\_ If CONUS landing site, phone "LRD" for KSC, "GOM" for EDW, and "WGM" for NOR. Transition to LANDING FIELD PRIME 1.

b) \_\_\_ If DOD landing site, contact "DOD Cape" on DOD COORD.

c) \_\_\_ If non-DOD landing site in US, contact FAA HQ ATC System Comm Center Duty Officer and request the site be alerted. Also attempt direct site contact.

d) \_\_\_ If non-DOD landing site outside US, contact State Department Watch Officer at Ops Center via NASA liaison - State Department loop. See Section 3.9.7.3.3, Emergency Landing Comm Checklist.

E3) \_\_\_\_\_ Exchange the following information with airfield personnel (see Section 3.9.7.3.5 example).

a) \_\_\_ Provide projected landing GMT and runway.

b) \_\_\_ Declare spacecraft emergency.

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- c) \_\_\_ Request immediate airspace and runway clearance.
- d) \_\_\_ Obtain current Wx observations.

*Flight Rule requirements for attempting a landing at any runway are cleared airspace and runway clear, together with crew or MCC voice contact with airfield for confirmation.*

E4) \_\_\_\_\_ **Go to Block F.**

### **BLOCK F ENTRY PLANNING**

F1) \_\_\_\_\_ Monitor and confirm deorbit burn.

*Standard task. If Block A was executed, a post-burn state can be obtained by grabbing the onboard vector.*

F2) \_\_\_\_\_ Build EI clock (TRAJ)

*This action supports FCR situational awareness.*

F3) \_\_\_\_\_ Direct crew to ENT FS p. 3-34 (starred block) for MM303 ATTITUDE (also located in Cont. D/O Prep p. 10-16).

*This is needed if burn targets were not uplinked. All uplinked burn targets will have the EI-5 Inertial attitude included. FD will want a post-burn attitude maneuver procedure and page number reference for the crew. This page gives the post-burn attitude (INRTL) to attain for a proper entry attitude at EI-5. The starred block specifies roll and yaw. The table provides pitch as a function of time to EI. The crew has an EI countdown based on the Mnvr Exec display's CRT timer. In MM302, this timer counts down to TIG when ITEM 23 is executed, and it then counts up from TIG. Upon transition to MM303, the timer starts counting down to EI based on the PEG-4D TFF target.*

F4) \_\_\_\_\_ Have NAV run Orb Normal off burnout vector (V53 or confirmed burn) to landing site or NOW24. If upper level winds data available (see Step C14), turn Approach/Land ON to access file.

*This Orb Normal re-run off the actual burnout vector updates the Entry ephemeris with the most accurate data, including upper level winds if available, for TAEM and approach & landing analysis. NAV retrieves upper level winds by executing Part B of NAV CHB SOP 6.12, Manual Entry of Wind Data.*

F5) \_\_\_\_\_ Evaluate Drag vs. VE, Groundtrack, etc.

F6) \_\_\_\_\_ Fill out Entry portion of DEL PAD. Annotate with "N/A" for upper winds if data are not available.

*See DEL PAD procedures in FDO Console Handbook Sections 4.5.4 and 4.9.8.*

F7) \_\_\_\_\_ At EI -5 min, project Entry plots on front screens and workstation with the following actions. Monitor entry (or bailout).

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- a) \_\_\_ For display on front screens, invoke Applications : Auto Display  
Configs : Large Screen Entry Displays : Entry Displays from FDO  
DNAV.
- b) \_\_\_ For display on workstation, invoke Applications : Auto Display  
Configs : HiSpeed Entry (FDO) from FDO DNAV.
- c) \_\_\_ Invoke Ascent : Bailout display from FDO DNAV to monitor bailout  
events.

*Coordinate with GC prior to projecting on front screens. Orbit Team responsibilities officially end at EI. By this time, the Entry Team should have arrived to assume console duties. If not, Entry monitoring, energy evaluation, and calls are on a best effort basis.*

### **3.9.7.3 Supporting Documentation**

The following pages contain charts, displays, and other information referenced in the Emergency Deorbit procedure.

## FDO Console Handbook Section 3.9: Contingency Maneuvers

### 3.9.7.3.1 Emergency Deorbit PEG-7 Targets

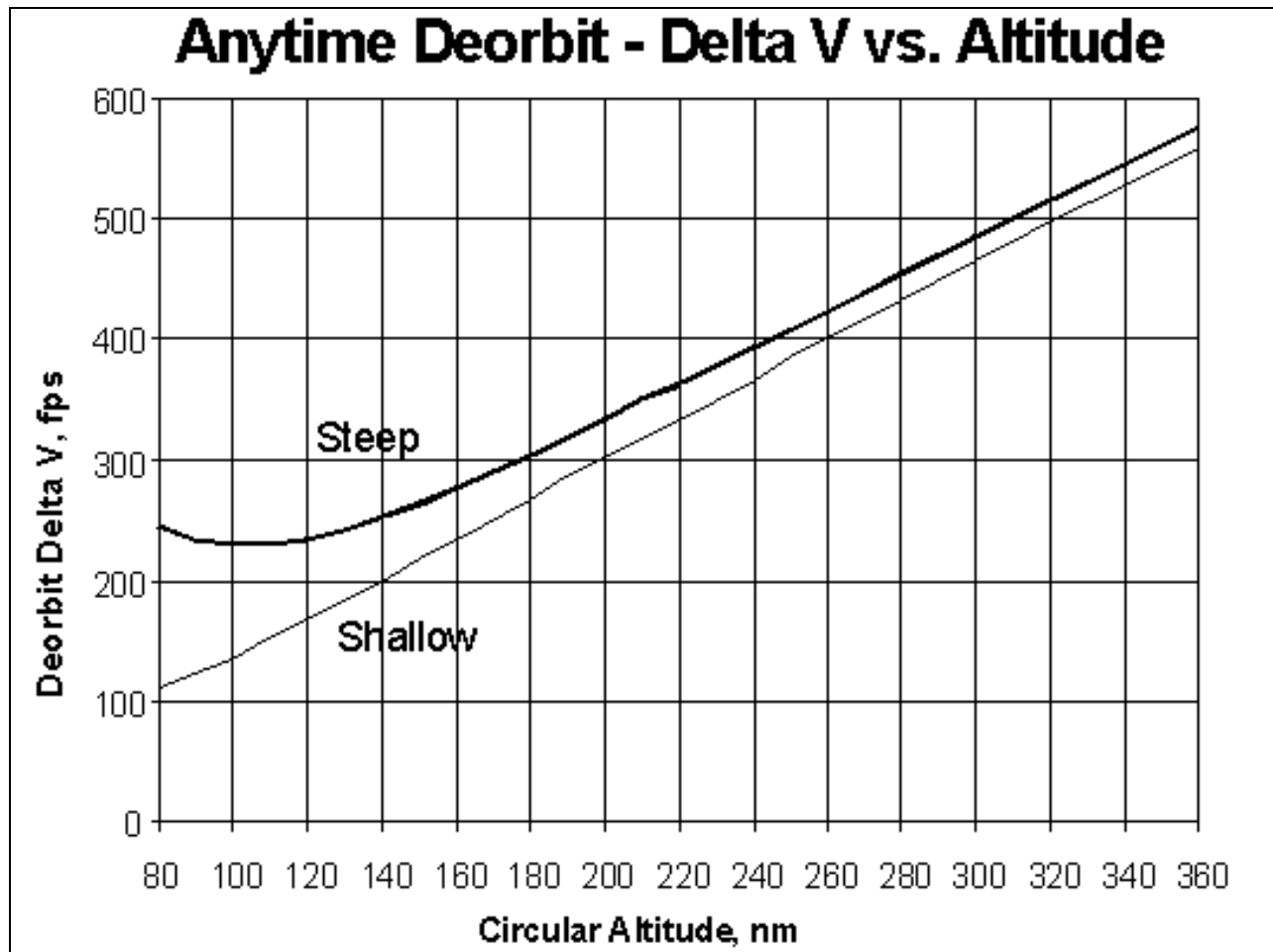


Figure 3.9.7-1: Generic  $\Delta VTOT$  Versus Orbit Height

Estimate appropriate PEG-7 components as follows after obtaining  $\Delta VTOT$  from chart.

$$\Delta V_x = -\Delta VTOT * \cos 30^\circ$$

$$\Delta V_y = 0$$

$$\Delta V_z = -\Delta VTOT * \sin 30^\circ$$

# FDO Console Handbook Section 3.9: Contingency Maneuvers

## 3.9.7.3.2 DAE Displays

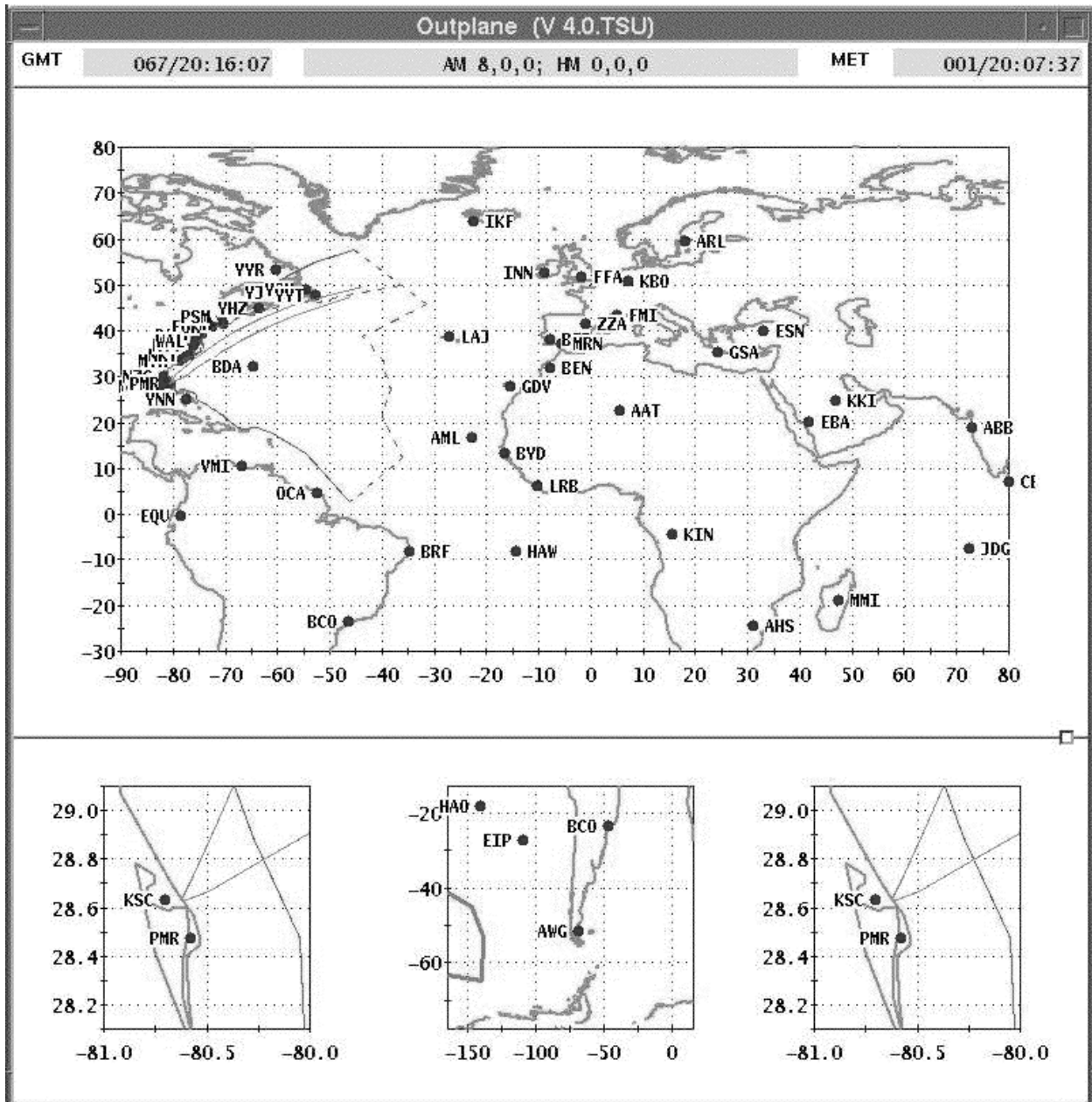


Figure 3.9.7-2a: DAE Plot Before Global Unzoom

**NOTE:** to zoom plot, draw box around region using left mouse button. To unzoom plot, click right mouse button. To extend plot to show high/low latitudes, hold CNTRL key and draw small box in center of screen using left mouse button. Then draw box around entire region using left mouse button without holding CNTRL key.

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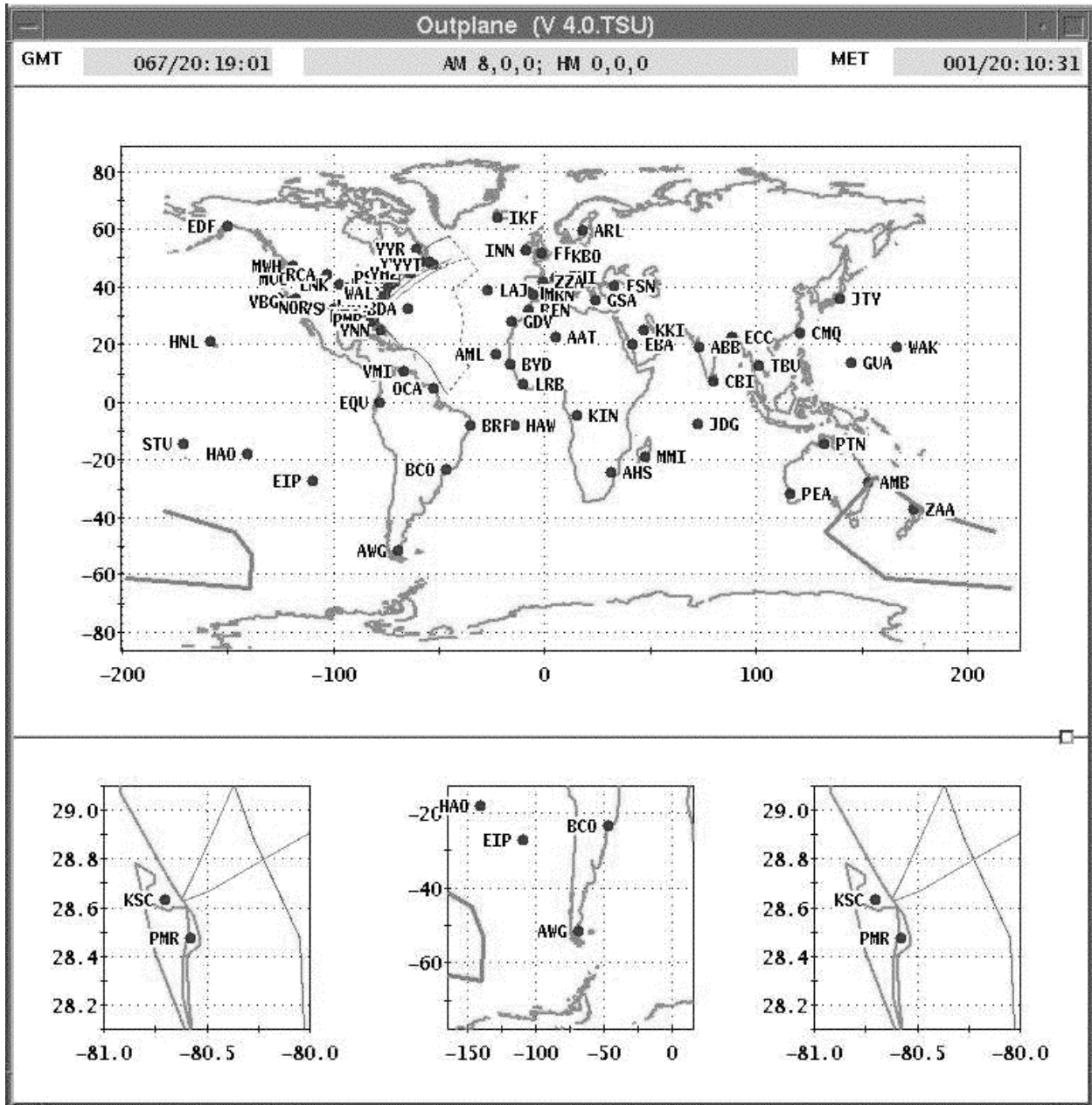


Figure 3.9.7-2b: DAE Plot After Global Unzoom

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DAE_CUR:(DAE_CUR):										
F/V 114 /103					CRNT DAE OUTPUT					A
SITE	NZ	1.50	NO DUMP	NZ	OMS&RCS	NZ	OMS			
	GO	DRNG	XRNG	GO	DRNG	XRNG	GO	DRNG	XRNG	
ZZA		*****	222R							
MRN		*****	345R							
FMI		*****	240R							
LZA		*****	222R							
LMN		*****	345R							
LBN		*****	537R							
BEN		*****	537R							
DUMP Δ T					DUMP Δ T					
TRAJECTORY SS FLTR					CONTROL PARAMETERS					
067:20:03:18.88 GMT					VI FTPRT 18000					
001:19:54:48.88 MET					VI PMECO 12000					
067:20:08:37 OGMT					SPASS 1 VID EST 29					
067:20:08:40 MGMT					DUMP OPT 0					
VI	24974			ICT φ	ORB WT 256123					
VI	0.050	L	0%	ENA λ	OMS WT 18695					
hD	191	C	0%	ICT φ	STRETCH COEF					
d	2070	R	0%	INH λ	DRIVER VI					
					NAME					
H <sub>A</sub>	188			PRED IMPACT PT						
H <sub>P</sub>	29			φIP	NOM FTPRT COEF 2					
φ <sub>D</sub>	32:50:49N			λIP	1=LOW 2=MID 3=HI					
λ	23:00:50W			ψIP						
ψTEI	47.52			dIP						

**Figure 3.9.7-3: DAE Landing Site Lat/Lon Output**

### 3.9.7.3.3 Emergency Landing Comm Checklist

In lieu of LSO, TRAJ performs the following procedure. See Section 3.9.7.3.5 for an example of TRAJ dialog with a landing site.

- 1) \_\_\_\_\_ Establish communication with the landing site.

**NOTE:** site contacts and phone numbers are under the glass at the FDO Console.

- a) \_\_\_\_\_ If this is a ConUS site, contact "LRD" for KSC, "WGM" for NOR, or "GOM" for EDW via phone and transition to LANDING FIELD PRIME 1.

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- b) \_\_\_ If this is a DOD site, contact "DOD CAPE" on DOD COORD or via phone and have them notify the site.  
CAUTION: DOD CAPE has capability to communicate on LANDING FIELD PRIME 1 if necessary but does not usually monitor this loop.  
NOTE: site facilities status can be accessed from the LSO homepage.
- c) \_\_\_ If this is a non-DOD site in the US, call Duty Officer at the FAA HQ ATC System Comm Center. Advise of landing site and Orbiter touchdown time and request assistance in obtaining airspace clearance.
- d) \_\_\_ If this is a non-DOD site outside the US, contact State Department Watch Officer at Operations Center. Request notification of the NASA Liaison from Advanced Technology. When the NASA Liaison arrives, have Houston Voice on VOICE CTRL activate STATE DEPT loop.
  - i) \_\_\_ Advise NASA Liaison of landing site and Orbiter touchdown time.
  - ii) \_\_\_ Have NASA Liaison request airspace and runway clearance.
  - iii) \_\_\_ Perform best effort comm with site as listed on the phone list. Personnel may not speak English.

- 2) \_\_\_\_\_ After comm is established with the site, provide the following landing information.
  - a) \_\_\_ Request airspace and runway clearance.
    - i) \_\_\_ Provide time and coordinates for Orbiter @ 60 Kft ("Flight Level 600"). Obtain these from ENTRY ELAPSED TIME (EET, MSK 505) at  $M = 1.5$ .
    - ii) \_\_\_ Provide touchdown time and runway.
    - iii) \_\_\_ Provide approach direction ("from the southwest").
  - b) \_\_\_ Advise that the Orbiter has no go-around or taxi capability.
  - c) \_\_\_ Advise that hypergolics ("hazardous materials") are on board. Recommend a 1250-ft (400-meter) corridor around the Orbiter be maintained post-rollout.
  - d) \_\_\_ Recommend no approach to the Orbiter unless requested by crew.
- 3) \_\_\_\_\_ Try to establish the runways and nav aids status.
  - a) \_\_\_ Are MLS (augmented sites) and TACAN nav aids operable?
  - b) \_\_\_ Are visual landing aids (PAPIs and BallBar) operable at augmented sites?
  - c) \_\_\_ What are surface conditions on the runway or lakebed (wet, dry, ice, debris)?
  - d) \_\_\_ What is the weather status (surface winds, ceiling, visibility, and altimeter setting)?



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NOTE: because tower wind readings are magnetic, normal QuAC procedures apply.

- e) \_\_\_ In the case of a night landing, are Xenon lights (at augmented sites) or approach/edge lights on?
- f) \_\_\_ What is the status of fire, crash, and rescue forces?

### 3.9.7.3.4 Emergency Landing Site Uplink Notes

NOTE: reference *Flight Dynamics Command Procedures* (DM-CH-05) Section 1.5.18, Runway, for officially published uplink procedures.

First, activate Landing Site/TACAN application via FDO DNAV.

**To uplink an existing runway**, perform either of the following two options to free up Slot 3 for the command load build. Then perform the ensuing steps.

Option A: under the File : Open menu, select the navo16b\_zero file & click ok.

Option B: click to select BEN36 R/W & associated TACAN in lower window, set slot & sequence = 0 for both R/W & TACAN, and deselect BEN36.

- a) Using the Search menu, scan for desired landing site (type in 3 letter RNWY ID).
- b) Click to select R/W & TACAN, then set slot & sequence = 3 for both.
- c) In upper left window, click "Selected" under both R/W & TACAN Selection.
- d) Ensure desired R/W & TACAN is still selected.
- e) Click "Generate" to build command loads.
- f) View and verify DSM 41203 & 41303 command loads (get TRAJ concurrence).
- g) Select "Update MOC" to ship landing site if required.

**To build a new runway/landing point**, perform the following steps.

- a) Obtain landing point location from CRNT DAE OUTPUT (see Figure 3.9.7-3).
- b) In upper left window, click "Manual" under R/W Selection.

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- c) Enter inputs using manual entry window as shown below (DAE IP from MSK 564 "DAE OUTPUT" or nearby R/W location).

Inputs	Emergency D/O Input	Units	Notes
Sequence	3		
Slot	3	nd	Normally same as LST slot number
Name	NOW24	nd	Max 5 chars
Latitude	NOM LANDING PT $\phi$	deg	
Longitude	NOM LANDING PT $\lambda$	deg	W long is negative
R/W Azimuth	240	deg	
Mag Variation	0	deg	
Altitude	0	ft	
Geodetic Sep.	0	ft	
R/W Length	10000	ft	
MSBLS Index	0	nd	
Command Title		nd	Max 21 characters

- d) Click "OK" then "Generate" to build command load.
- e) View and verify DSM 41203 command (get TRAJ concurrence).
- f) Select "Update MOC" to ship landing site if required.
- g) Obtain GO for Landing site/TACAN U/L from FD.
- h) Perform U/L (GNC/BFS OPS 1/6, 3 only).
- i) Have crew select Landing Site 2 on SPEC 50.
- j) Verify proper landing site selected (High Speed Entry FDO display).

### 3.9.7.3.5 Example Dialog Between TRAJ And A Landing Site

In this example, milestones are bold-faced and \_\_\_\_\_ signifies a variable. Where appropriate, the variable's identity or possible non-numeric values it may assume are enclosed in square brackets following its occurrence.

#### A) Initial Phone Call

- 1) Hello, I'm \_\_\_\_\_ [name], acting Landing Support Officer at NASA's Johnson Space Center. Space Shuttle \_\_\_\_\_ [*Discovery, Atlantis, Endeavour*] is experiencing a spacecraft emergency and needs to make an emergency landing as soon as possible due to \_\_\_\_\_ [nature of emergency]. The optimal landing opportunity is at your airport.
- 2) Expected landing time is \_\_\_\_\_ [hrs:min] Zulu.
- 3) We are targeting touchdown on Runway \_\_\_\_\_.
- 4) We will need clearance to land and landing weather updates.

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- 5) As soon as possible, we would like the following approach and landing conditions verified.
- a) Runway \_\_\_\_\_ is clear.
  - b) Airspace within a 15 nm (28 km) radius of Runway \_\_\_\_\_ is clear.
  - c) Barriers, cables, and arresting gear on Runway \_\_\_\_\_ are removed.
  - d) Runway lights are \_\_\_\_\_ [Bright (daylight), Step 3 (night)].
  - e) Threshold strobes are off.
  - f) VASIs are off.  
NOTE: VASIs are approach/slope indicator lights for conventional aircraft using shallow glideslopes (about 4°).
  - g) Sequential approach strobes are \_\_\_\_\_ [Off (dusk, night, or day with vis  $\geq$  10 mi), On (day with vis  $<$  10 mi)].
- 6) We are going to patch you in to one of our voice loops. Hang up this line and keep it clear. Houston Voice will call you shortly. When they connect you to our patch, stay on and do not hang up.

### **B) Following DVIS Patch Establishment**

- 7) We are planning to use TACAN/DME Channel \_\_\_\_\_. Please provide status on this equipment.
- 8) Please provide observed surface winds, ceiling, temperature, and altimeter setting at your location.
- 9) Be advised we have \_\_\_\_\_ crewmembers aboard. Of these, \_\_\_\_\_ are de-conditioned and in a recumbent position.
- 10) Crew health is \_\_\_\_\_ [good, debilitated, incapacitated, describe as necessary].
- 11) There are \_\_\_\_\_ [no toxic leaks, describe nature/amount/location of leak(s)].

### **C) Landing -25 min**

- 12) Current altitude is \_\_\_\_\_ ft, range is \_\_\_\_\_ nm, expected landing time is \_\_\_\_\_, and crew health is \_\_\_\_\_.
- 13) Arrival overhead will be from the \_\_\_\_\_ [north, east, south, west] on a heading of \_\_\_\_\_ deg at an altitude near 40,000 ft.
- 14) During approach, expect a \_\_\_\_\_ deg \_\_\_\_\_ [right, left] turn to final approach at about 12,000 ft altitude 7 to 15 nm from the runway.

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15) Approach will be unpowered without go-around or wave-off capability.

### D) Landing -20 min

16) Current altitude is \_\_\_\_\_ ft, range is \_\_\_\_\_ nm, expected landing time is \_\_\_\_\_, and crew health is \_\_\_\_\_.

17) Expect landing gear deploy at 300 ft altitude with an approach speed of 300 kts.

18) Touchdown is predicted \_\_\_\_\_ ft from the runway threshold at \_\_\_\_\_ [195, 205] kts.

19) A drag chute will be deployed at pitch over and will be jettisoned on the runway during rollout.

### E) Landing -15 min

20) At DoD sites, establish communication with the On-Scene Commander (OSC) at this time and provide situation briefing. Otherwise, continue to communicate with the control tower.

21) Current altitude is \_\_\_\_\_ ft, range is \_\_\_\_\_ nm, expected landing time is \_\_\_\_\_, and crew health is \_\_\_\_\_.

22) Maintain unprotected personnel > 1250 ft (400 m) from Orbiter post-rollout until toxic vapor levels verified safe.

23) A tire fire may occur up to 45 min after landing and can be contained with a water spray.

24) There are \_\_\_\_\_ [no toxic leaks, update nature/amount/location of leak(s)].

25) We are expecting residual toxic materials aboard following rollout.

a) \_\_\_\_\_ pounds of Monomethyl Hydrazine (MMH) and nitrogen tetroxide in forward propellant tanks.

b) \_\_\_\_\_ pounds of propellant in aft left pod.

c) \_\_\_\_\_ pounds of propellant in aft right pod.

d) \_\_\_\_\_ pounds of hydrazine in the aft fuselage APUs.

26) Be advised the crew is equipped with PRC-112 radios on National Guard frequencies 243.0 Mhz (UHF) and 121.5 Mhz (VHF) for use in the event of communications loss post-rollout.

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### F) Landing -10 min

- 27) Current altitude is \_\_\_\_\_ ft, range is \_\_\_\_\_ nm, expected landing time is \_\_\_\_\_, and crew health is \_\_\_\_\_.
- 28) Expect 2 sonic booms as Orbiter passes overhead.
- 29) Please provide any final updates on observed winds and weather conditions.

### G) Landing -5 min

- 30) Current altitude is \_\_\_\_\_ ft, range is \_\_\_\_\_ nm, expected landing time is \_\_\_\_\_, and crew health is \_\_\_\_\_.

#### 3.9.7.3.6 Flight Rules Governing ELS Weather Criteria

The following data are excerpted from Flight Rule A2-6, Landing Site Weather Criteria, Table A2-6-I.

<b>Ceiling/Visibility</b>	0/0 if MLS	8000/5 if no MLS
<b>Crosswind</b>	≤ 15 knots	
<b>Headwind/Tailwind</b>	N/A	
<b>Thunderstorms/Lightning</b>	None at site	

Flight Rule A2-6, Paragraph C.2, provides the following direction and rationale.

FOR ACLS/ECAL/ELS, PRECIPITATION IS ACCEPTABLE. NO THUNDERSTORMS (INCLUDING ATTACHED NONTRANSPARENT ANVIL) OR LIGHTNING AT THE SITE. ©[020196-1808A] ©[111298-6734] ©[022604-6167A]

*Weather at the site must be acceptable to provide good visibility during final approach, since lateral and longitudinal margins are minimal at ECAL/ELS sites. As long as visibility and ceiling limits are met, there is no constraint for precipitation. Additional constraints to avoid thunderstorms and lightning apply only to the landing site. The definition for "none at site" used in the Shuttle Program will mean that no thunderstorm is over the landing airfield. Note that operational meteorological reporting standards for weather occurring at a site differs slightly from the definition applied for shuttle landings. For thunderstorm and lightning observations (METAR) and forecasts (TAF) used to evaluate the GO/NO-GO status of an ACLS/ECAL/ELS site prior to launch, meteorological reporting standards define "none at site" as: no thunderstorms or lightning within 5 statute miles of the observing (landing) site. ©[111298-6734]*

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Flight Rule Rule A4-56, Performance Boundaries (Paragraph I.3), specifies use of an ACLS for abort gap closure. It is therefore reasonable to attempt landing at an ACLS with ceiling/visibility = 0/0 if the attempt carries a reasonable probability of success and the only alternative is a bailout.

FOR ACLS/ECAL/ELS, PRECIPITATION IS ACCEPTABLE. NO THUNDERSTORMS (INCLUDING ATTACHED NONTRANSPARENT ANVIL) OR LIGHTNING AT THE SITE. ©[020196-1808A] ©[111298-6734 ] ©[022604-6167A]

*Weather at the site must be acceptable to provide good visibility during final approach, since lateral and longitudinal margins are minimal at ECAL/ELS sites. As long as visibility and ceiling limits are met, there is no constraint for precipitation. Additional constraints to avoid thunderstorms and lightning apply only to the landing site. The definition for "none at site" used in the Shuttle Program will mean that no thunderstorm is over the landing airfield. Note that operational meteorological reporting standards for weather occurring at a site differs slightly from the definition applied for shuttle landings. For thunderstorm and lightning observations (METAR) and forecasts (TAF) used to evaluate the GO/NO-GO status of an ACLS/ECAL/ELS site prior to launch, meteorological reporting standards define "none at site" as: no thunderstorms or lightning within 5 statute miles of the observing (landing) site. ©[111298-6734 ]*

## FDO Console Handbook Section 3.9: Contingency Maneuvers

### 3.9.7.3.7 Generic PEG-4D Targets

**WARNING:** the following data are known to result in a flyable entry only for near-circular orbits. The applicability criterion in use is  $H_a - H_p \leq 50$  nm, but this threshold is not fully verified.

Target Set ID	Height (nm)	C1 (fps)	C2	Theta (deg)
L1	90-110	16764	-0.6708	73.8
L2	110-130	16009	-0.6419	91.5
L3	130-150	15533	-0.6238	104.2
L4	150-170	15157	-0.6093	113.8
L5	170-190	14908	-0.6000	121.3
L6	190-210	14664	-0.5905	127.5
L7	210-230	14443	-0.5820	132.4
L8	230-250	14503	-0.5844	136.4
L9	250-270	14226	-0.5738	139.8
L10	270-290	14210	-0.5732	142.6
L11	290-310	14042	-0.5666	145.6
L12	310-330	14246	-0.5746	147.5
L13	330-350	13819	-0.5579	150.0
L14	350-370	14301	-0.5766	151.6

Figure 3.9.7-4a: Emergency Deorbit Targets (Low Or Mid Inclination)

Target Set ID	Height (nm)	C1 (fps)	C2	Theta (deg)
H1	90-110	17233	-0.6890	79.6
H2	110-130	16403	-0.6572	95.2
H3	130-150	15827	-0.6351	107.0
H4	150-170	15383	-0.6181	115.6
H5	170-190	15057	-0.6056	122.6
H6	190-210	14774	-0.5948	128.2
H7	210-230	14537	-0.5857	132.9
H8	230-250	14236	-0.5740	136.9
H9	250-270	14088	-0.5684	140.2
H10	270-290	13786	-0.5569	143.0
H11	290-310	13621	-0.5505	145.7
H12	310-330	13473	-0.5449	147.8
H13	330-350	13465	-0.5446	149.8
H14	350-370	13231	-0.5355	151.7

Figure 3.9.7-4b: Emergency Deorbit Targets (High Inclination)

# **FDO Console Handbook Section 3.9: Contingency Maneuvers**

**Section 3.9 Concludes On This Page**



## **FDO Console Handbook Section 3.10: Rendezvous Operations**

### **3.10 Rendezvous Operations**

Rendezvous missions are among the most technically complex flights to plan and execute. This would be true even if rendezvous were the only mission objective. Frequently, rendezvous missions include other objectives of equal or greater priority, resulting in tight propellant budgets, and often mutually incompatible payload requirements. The rendezvous FDO for a mission is commonly assigned to be lead FDO. As such, the FDO plays a major role in the development of the rendezvous profile and mission timeline to ensure an operationally feasible plan, thus maximizing chances of mission success. The other Orbit FDOs on a rendezvous mission ("non-execute FDOs") have the equally important responsibility to correctly perform pre-day of rendezvous (DOR) burns and set up acceptable conditions for the final rendezvous phase. Rendezvous missions pose the challenge of routinely placing responsibility for mission success or failure in the hands of each FDO.

A rendezvous, as used in the Shuttle program, consists of a series of maneuvers performed by a chaser and/or target vehicle such that the chaser actively intercepts the target. The Space Shuttle Program (SSP) currently offers three different types of rendezvous missions. The "ground-up" profile is for a passive satellite already on-orbit prior to Shuttle liftoff. The Shuttle launches, intercepts the satellite, grapples or docks with it, then either re-deploys the satellite or brings it back to Earth in the payload bay. Another type of rendezvous profile is the "deploy/retrieve" profile. The Shuttle launches into orbit with the satellite in the payload bay, deploys the satellite, and subsequently retrieves the satellite prior to deorbit. As before, the satellite is normally passive, and the Shuttle performs all burns. The "control-box" profile is for satellites with active translation control. In general, the satellite is on-orbit prior to Shuttle liftoff. The satellite is then responsible for placing itself in an orbit that is within the rendezvous capability of the Shuttle.

This section of the Flight Dynamics Officer's Console Handbook introduces the fundamentals of designing, computing, and executing a rendezvous from launch to docking. First some background material and definitions are presented, followed by roles and responsibilities of the Rendezvous FDO before and during rendezvous missions. Then the processors and standard console procedures (SCP) are documented to provide the baseline for all real-time rendezvous console operations. A selection of historic rendezvous profiles will be provided for background. Contingency procedures will then be documented, followed by operations specific to ISS rendezvous and undocking.

It is assumed the reader has some basic understanding of orbit mechanics and is either a qualified Orbit Flight Dynamics Officer or is in training for that position. This document is not intended to provide the user with an exhaustive resource for rendezvous analysis, design and procedures. Additional details and background information may be found in the following documents and training materials.

## FDO Console Handbook Section 3.10: Rendezvous Operations

- 1) Rendezvous/Proximity Operations Workbook, RNDZ 2102
- 2) Rendezvous and Proximity Operations Handbook, JSC-10589
- 3) Rendezvous/Proximity Operations Crew Training Handbook

### 3.10.1 Rendezvous Fundamentals

The following subsections detail basic concepts, terminology, systems, and players relevant to rendezvous operations.

#### 3.10.1.1 Local Vertical Local Horizontal (LVLH) Coordinate System

The LVLH Coordinate system is a vehicle centered, rotating, reference system (Figure 3.10.1.1-1). The origin is fixed at the vehicle's center of mass. The +Z-axis always points toward the Earth's center of mass, thus it lies in the orbit plane. Both the X and Y axes lie in the plane perpendicular to the Z axis, therefore they lie in the "local horizontal" plane relative to the point on Earth directly below the satellite. +Y points in the opposite direction of the angular momentum vector of the orbit, thus it is perpendicular to the orbit plane. The +X-axis completes the right handed coordinate system and is also in the orbit plane. If the orbit of the vehicle is circular, the +X-axis will be coincident with the velocity vector of the vehicle. The X and Z axes of the LVLH system are often referred to as the +Vbar and +Rbar vectors respectively (Figure 3.10.1.1-2). This coordinate system is utilized for PEG-7 burn targets.

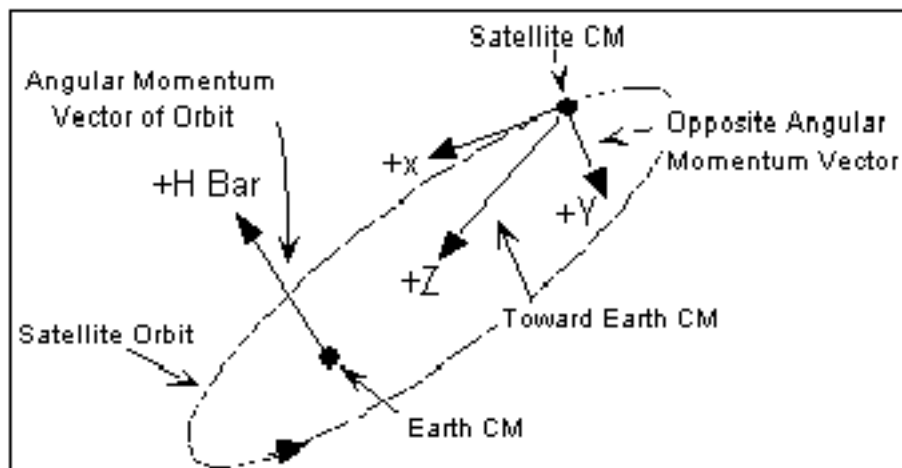


Figure 3.10.1.1-1: General Definition

## FDO Console Handbook Section 3.10: Rendezvous Operations

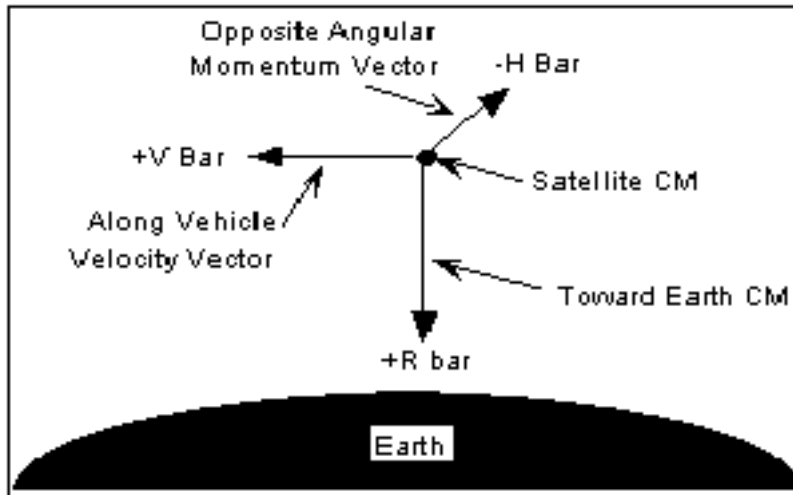


Figure 3.10.1.1-2: For Circular Orbits

### 3.10.1.2 Local Vertical Curvilinear (LVC) Coordinate System

A *relative coordinate system* is one that is used to represent the position of one orbiting vehicle with respect to another. A reasonably accurate representation of this relative position is provided by using a curvilinear coordinate system where the downtrack axis is curved to approximate the shape of the target vehicle's orbit. This is referred to as the Local Vertical Curvilinear (LVC), which is the coordinate frame used in TSA real-time Relative Motion application (a.k.a. "R/T RELMO"), and in onboard Orbit Maneuver Targeting (SPEC 34). (Ref. On-Orbit Guidance FSSR, STS83-0003H, Section 4.6.11 REL\_COMP). This coordinate frame is very similar to the LVLH frame, but here the x-axis bends to follow the orbit's curvature (see Figure 3.10.1.2-1).

The LVC system exhibits the following properties:

1. The +Z-axis always points toward the Earth's center of mass and lies in the orbit plane.
2. The +Y-axis points in the opposite direction of the target's angular momentum vector, thus it is perpendicular to the orbit plane.
3. The +X-axis completes the right handed coordinate system and is the curvilinear downtrack distance from target to chaser measured along a hypothetical circular orbit of radius equal to the magnitude of the target's radius vector. X is positive when the chaser is ahead of the target.

## FDO Console Handbook Section 3.10: Rendezvous Operations

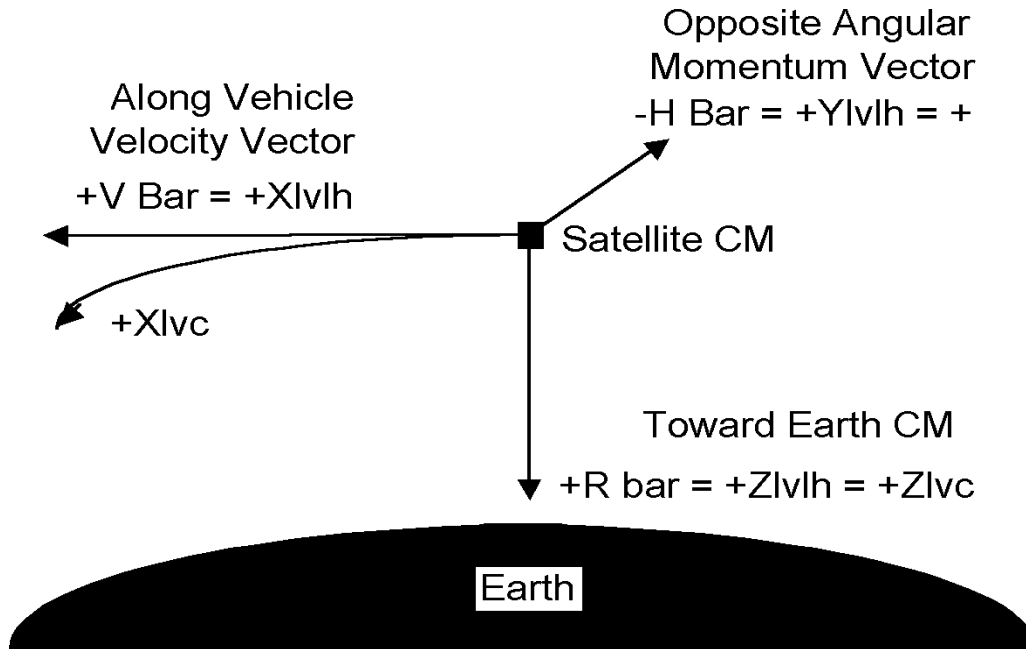


Figure 3.10.1.2-1

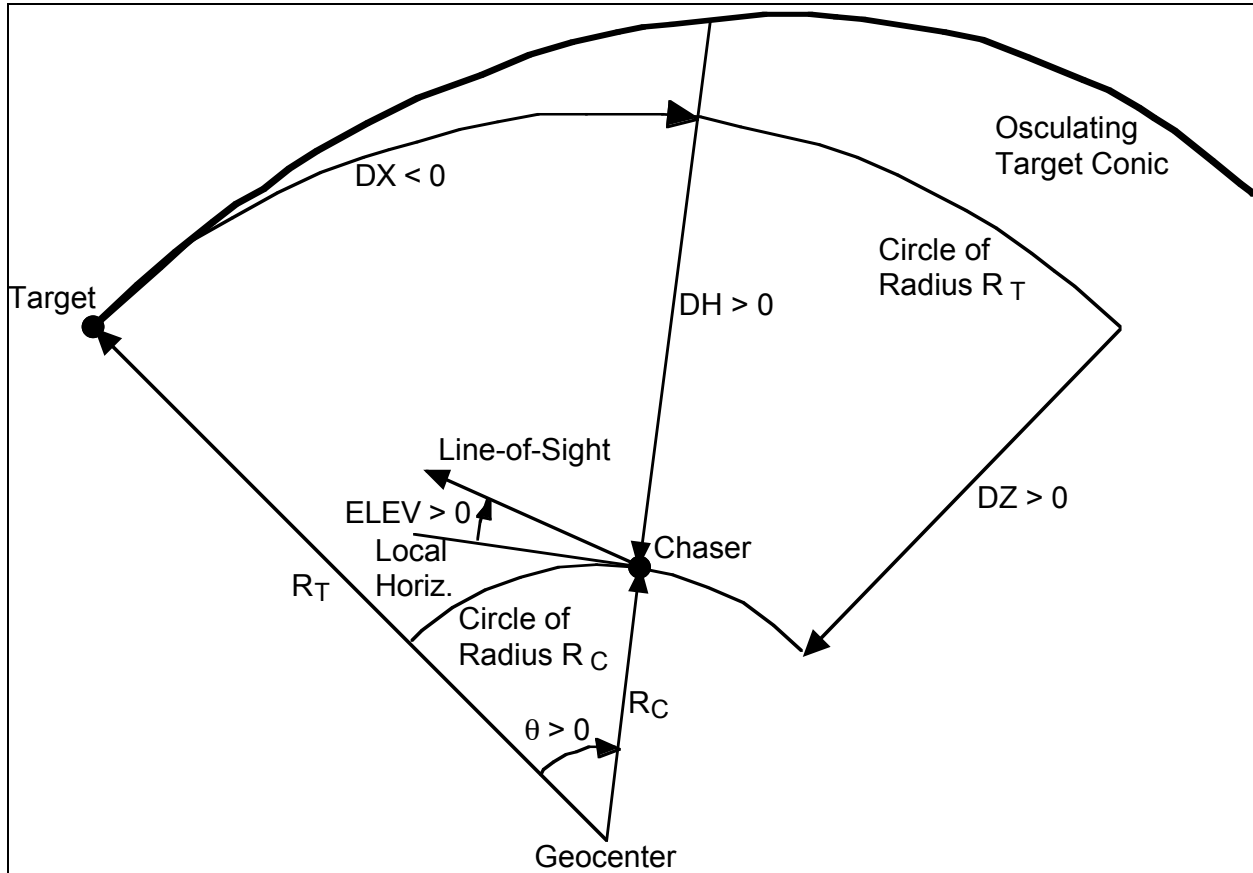
It is helpful to visualize the LVC coordinate system as a cylindrical tube curved around the Earth at the target satellite's altitude in the direction of flight, and with the long axis of the cylinder sticking out perpendicular to the orbit plane.

### 3.10.1.3 Relative Motion Parameter Definition

The phase angle ( $\theta$ , theta) is defined as the angle between the target position vector and the projection of the chaser's position vector projected into the target vehicle's orbit plane. Theta is positive when the chaser is trailing (opposite of the LVC and LVLH downtrack coordinates.)

DX, related to phase angle, is the curvilinear downtrack distance (measured in miles, for example). DZ is the height difference for a propagated circular target orbit (see Section 3.10.1.2). That is, DZ is simply the difference between target and chaser radius magnitudes.

## FDO Console Handbook Section 3.10: Rendezvous Operations



**Figure 3.10.1.3-1: CLV Coordinates, Targeting Offsets, and ELEV Angle**

Elevation angle (ELEV) is the angle between the chaser local horizon and line of sight angle to the target. Positive values indicate the target is above the chaser vehicle. Local horizon is defined as the plane perpendicular to the  $+R$  bar radius vector (see Section 3.10.1.2). Delta height (DH) is the radius difference between the Orbiter and target position vectors *at phase match*. The target radius is analytically computed at the same phase angle as the chaser to provide a phase-matched radius difference (measured in the target plane). This calculation utilizes the polar equation of a conic section as shown here (DH positive when the chaser is below the target).

$$DH = R_{\text{tgt @ phase}} - R_{\text{chaser}} = \frac{p}{1 + e \cos(\nu - \Delta\theta)_{\text{tgt}}} - R_{\text{chaser}}$$

The wedge angle (not shown on the figure above) is the angular difference between angular momentum vectors, and describes planar error, which could include inclination difference as well as right ascension of ascending node difference. Wedge angle is computed using the following equation.

## FDO Console Handbook Section 3.10: Rendezvous Operations

$$\text{wedge} = \arccos \left[ \frac{\vec{H}_{\text{tgt}} \cdot \vec{H}_{\text{chaser}}}{\left| \vec{H}_{\text{tgt}} \right| \left| \vec{H}_{\text{chaser}} \right|} \right]$$

### 3.10.1.4 Relative Motion Plots

Relative motion plots are a good visual aid for quick evaluation of rendezvous profiles both in pre-flight mission design, as well as real-time operations. Relative motion may be depicted from three different views on a curvilinear coordinate system (typically, the target is located at the origin). Examples in Fig. 3.10.1.4-1 through -3 are for generic 1-2-3 sep maneuver starting in a -ZLV attitude (payload bay to the Earth), with no drag (i.e. 1 fps radial up, 2 fps out-of-plane, 3 fps posigrade).

**View Along the +Y-Axis** (Figure 3.10.1.4-1). Both axes lie in the orbit plane. The vertical axis is delta height and the horizontal axis is delta range in the minus downtrack direction. The direction of orbital motion is to the left, while for this example the chaser is heading away from the target to the right. The two "humps" represent two revs worth of travel, with each hump spaced about 8 nm apart, as would be expected from a 3 fps posigrade SEP-3. This is the most commonly used perspective. It provides a clear view of the effects of the in-plane maneuvers.

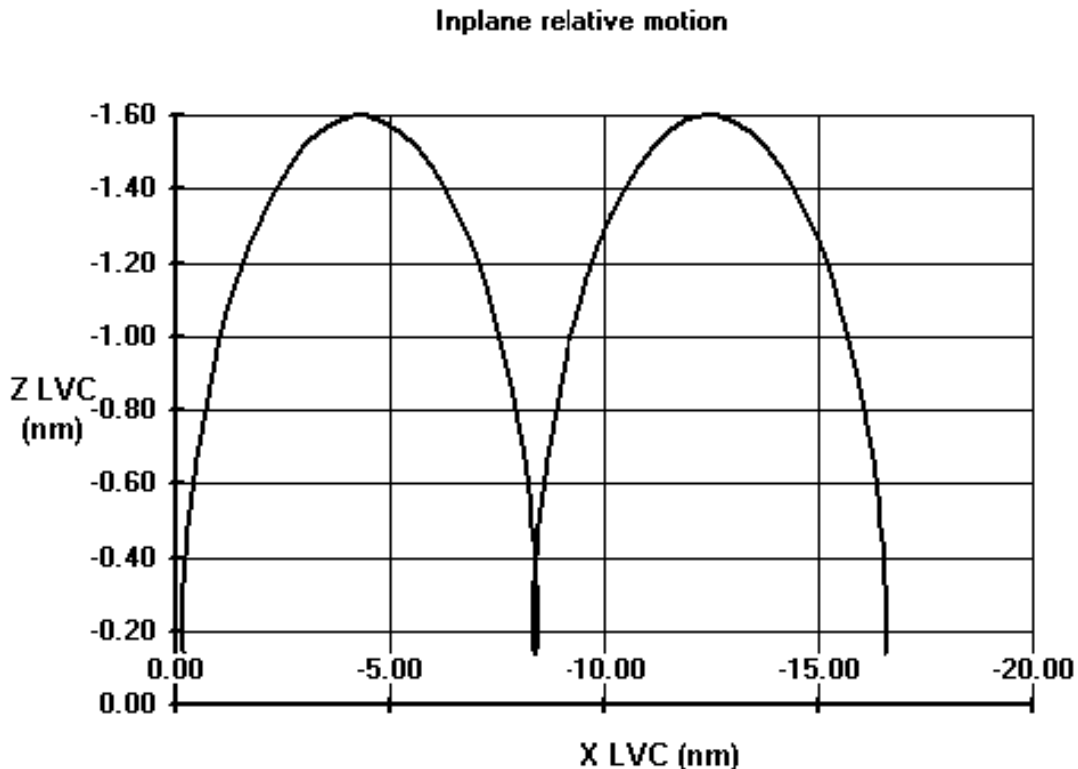
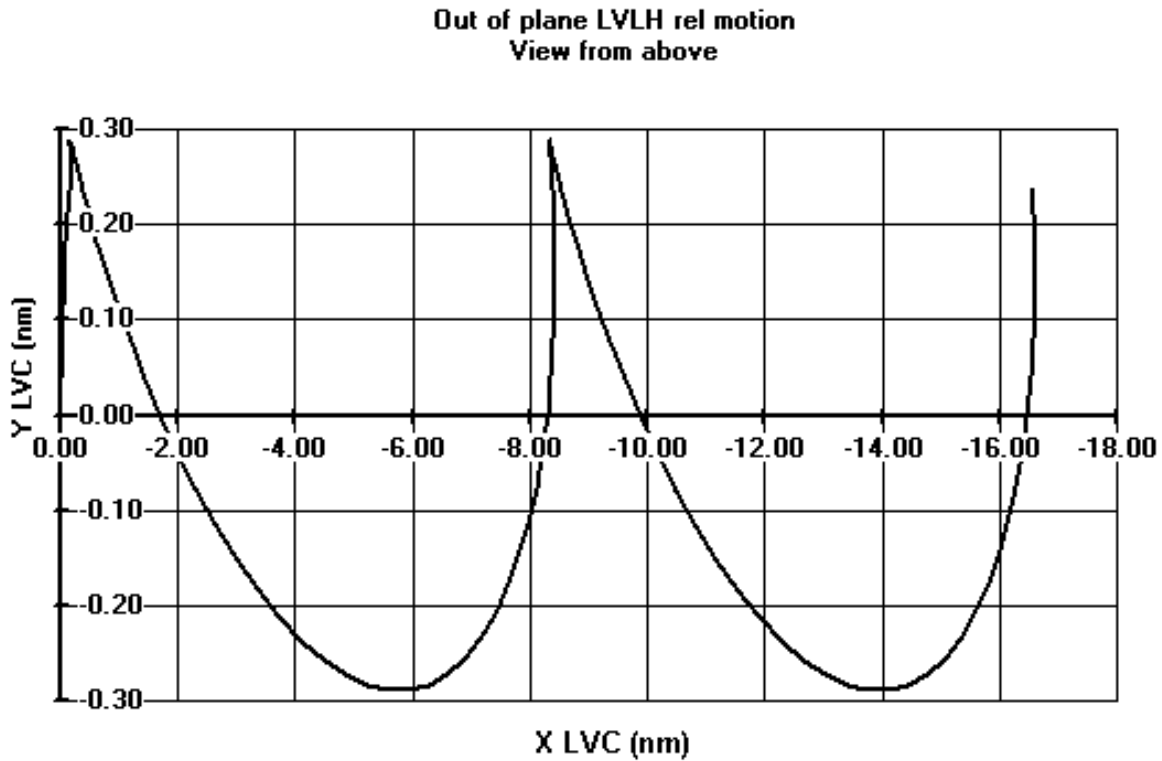


Figure 3.10.1.4-1

## FDO Console Handbook Section 3.10: Rendezvous Operations

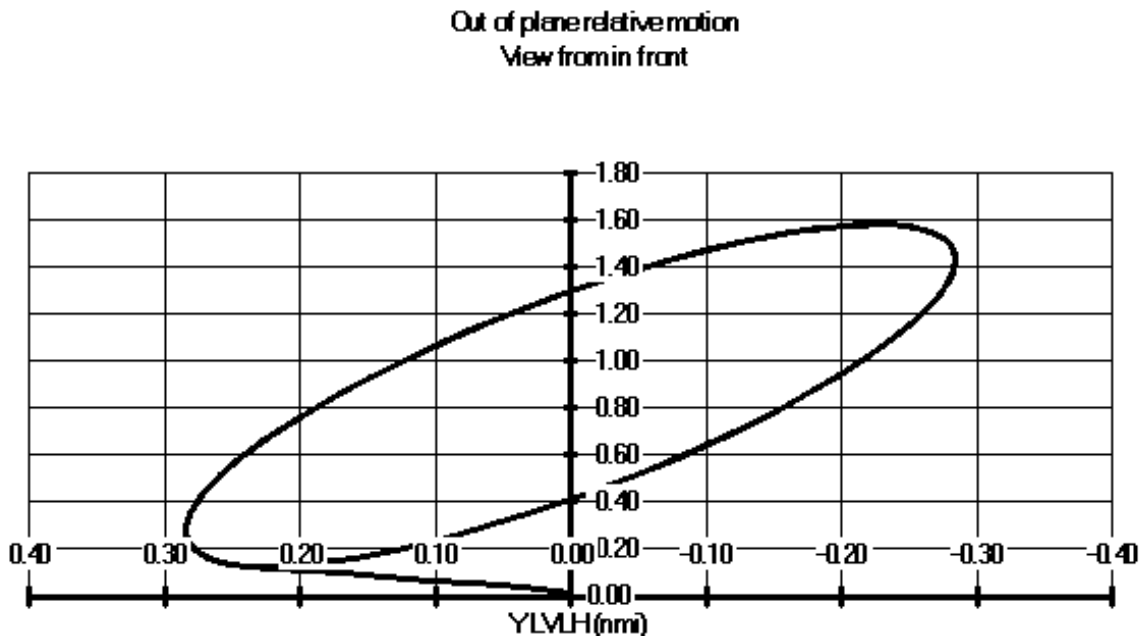
**View Along the Target Rbar** (Figure 3.10.1.4-2). The center of the Earth is into the paper. The vertical axis is out-of-plane distance. Up on the plot is in the +Y, or -H-bar, direction. The horizontal axis is range in the minus downtrack direction.



**Figure 3.10.1.4-2**

**View Along the Target -Vbar** (Figure 3.10.1.4-3). The direction of orbital motion is out of the paper. The vertical axis is delta altitude and the horizontal axis is out-of-plane distance with +Y to the left. This perspective view is rarely used.

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**Figure 3.10.1.4-3**

**Deploy-Retrieve Relative Motion** - Typical relative motion for a deploy-retrieve profile is depicted in the next relative motion plot (Figure 3.10.1.4-4). This plot shows the entire SPARTAN 201-5 deploy and rendezvous profile for STS-95. This plan is typical of rendezvous with a passive satellite that the Shuttle has deployed earlier in the same mission. Note however that the Orbiter may stationkeep in front of or behind the target, depending on payload requirements. Deploy-retrieve rendezvous profiles begin after the Shuttle has safely achieved orbit. The payload/target vehicle is carried on-orbit by the Shuttle, and is typically released via the RMS, but could also be released by a spring ejection mechanism or EVA crewmembers. After the payload has been released, the Shuttle performs a sequence of separation maneuvers to establish a safe opening rate (SEP-1 and SEP-2 in Figure 3.10.1.4-4). Subsequent phasing maneuvers are executed to increase and/or maintain the Shuttle-to-target range over the scheduled period of target free-flight (NC-1 in Figure 3.10.1.4-4 temporarily halted the opening rate to maintain 5 nm for a few revs, then NC-2 re-established the desired opening rate).

Generally, two phasing maneuvers are planned per day to maintain the desired stationkeeping distance with the target. The first burn is typically scheduled for crew morning, and may seek to resolve any long-term trajectory errors incurred during crew sleep, or may provide a significant adjustment pursuant with the planned stationkeeping strategy. The second maneuver is typically scheduled at the end of the crew day with similar goals. This burn will correct any perturbations that may have occurred during the crew activities that day (attitude maneuvers, water dumps, IMU aligns, etc). In Figure 3.10.1.4-4, NC-3 stopped the opening rate at the desired max range, and targeted the desired range for NC-4 the next morning, which was on Day of



## **FDO Console Handbook Section 3.10: Rendezvous Operations**

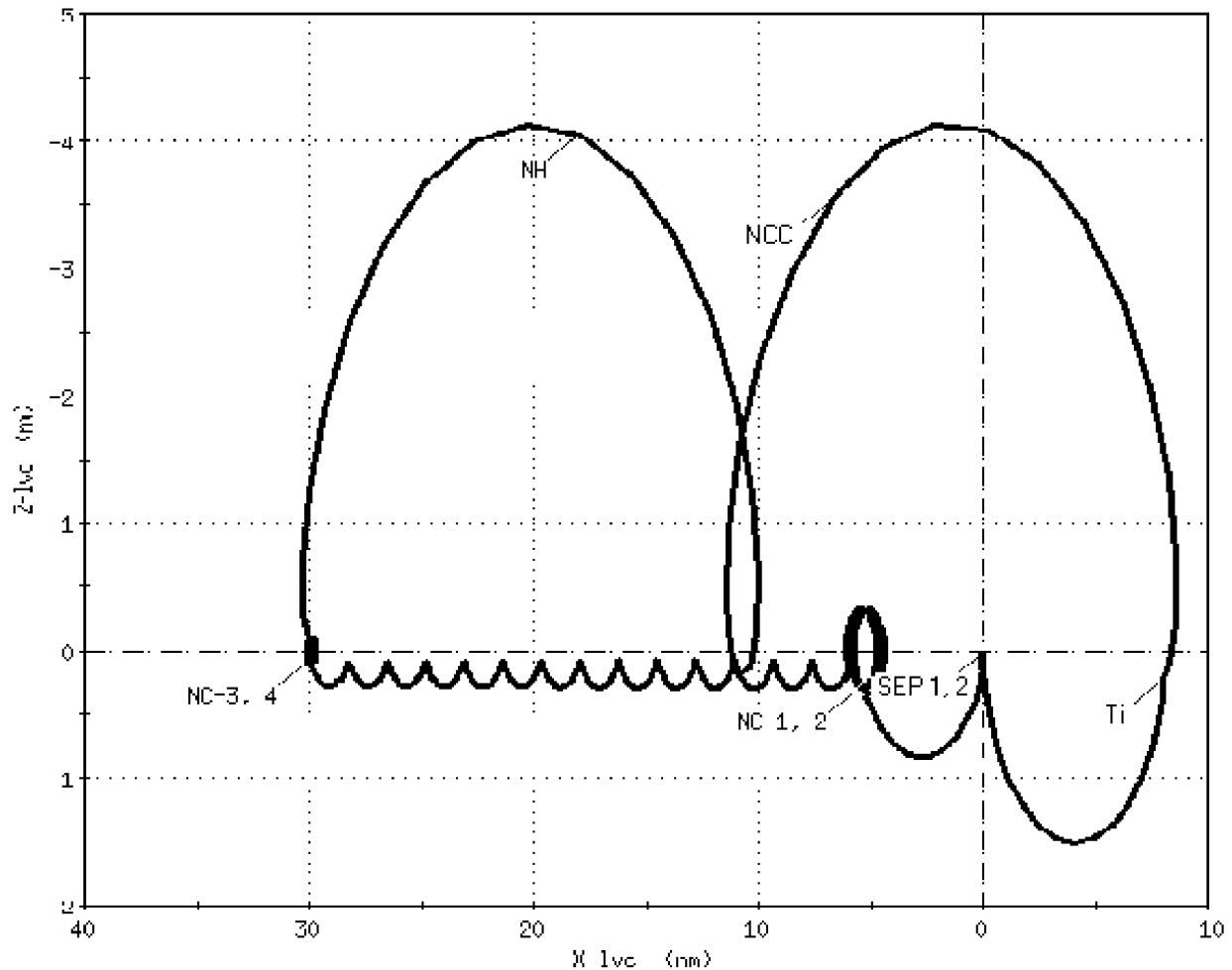
Rendezvous (DOR). Phasing maneuvers for profiles such as this can either be posigrade or retrograde, depending on the desired relative motion effect.

Plane change maneuvers are typically not required for these deploy-retrieve missions, unless the separation sequence introduced a significant out-of-plane velocity. If this is the case, a plane change maneuver will be required and will typically be targeted to occur at the crossing of the two vehicle's orbit planes. For some satellites a planar correction burn could be required due to perturbative effects of uncoupled control jet firings over large numbers of attitude maneuvers, or out-gassing of spacecraft consumables. The ability to achieve a propellant savings by combining the plane change maneuver with a regularly scheduled phasing maneuver is dubious in these profiles given the generally small magnitude of phasing maneuvers.

For deploy-retrieve rendezvous missions, DOR typically begins with an initial ground targeted phasing maneuver (NC-4 in Figure 3.10.1.4-4). This modifies the phasing rate to allow the rendezvous terminal phase initiation point (Ti) to occur within one or two orbits. It also sets up acceptable relative motion for the use of onboard navigation and targeting systems.

All translation maneuvers from SEP-1 through grapple are considered rendezvous maneuvers. The FDO is responsible for planning, execution, and confirmation of all rendezvous maneuvers other than when sufficient onboard navigation accuracy exists to allow transition of these duties to the flight crew. This occurs during the separation sequence, where the initial SEP maneuvers are generally fixed in the Flight Crew's deploy procedures, and at the very end when the crew is prime for targeting final rendezvous burns.

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**Figure 3.10.1.4-4: STS-95 SPARTAN Deploy-Retrieve Rendezvous**

**Ground Up Rendezvous** - Typical relative motion for a Ground Up Rendezvous (GUR) is depicted in Figure 3.10.1.4-5. GUR missions begin prior to launch, with the target/payload already on-orbit. The Shuttle launch window for these missions must be determined based on the target vehicle's orbit. The Rendezvous FDO along with the Ascent FDO must be intimately aware of the launch window/launch targeting process required for computing the Shuttle's launch window. The Shuttle ascent is typically targeted for an altitude lower than the target's orbit. OMS-2 is targeted as the first of a sequence of phasing maneuvers employed to gradually slow the phasing rates between the two vehicles. OMS-2 altitude targets can vary significantly, placing perigee as low as 85 nm for maximum phasing rate, to an effective circularization maneuver (or higher) for minimum phasing rates. In order to protect for any posigrade Shuttle dispersions from launch until DOR, the maximum apogee post-OMS-2 is 7 nm below the target altitude.

Prior to DOR, two phasing maneuvers are planned per day to maintain the desired closure strategy on the target. The first burn is typically scheduled for crew morning,

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and may seek to resolve any long term trajectory errors incurred during crew sleep, or may provide a significant adjustment pursuant with the planned phasing strategy. The second maneuver is typically scheduled at the end of the crew day with the similar goals, but also corrects for perturbations that occurred during crew activities that day.

At least one plane change maneuver is scheduled to recover planar errors introduced by Launch Window/Targeting, or from ascent dispersions. These maneuvers are executed at the crossing of the two vehicle's orbit planes (common node). This point cannot be fixed with certainty in pre-mission design, therefore, a plane change is scheduled as a separate and distinct maneuver in the mission plan. In real-time, conditions may be favorable for execution of the plane change in coincidence with a required phasing maneuver. This may result in an overall propellant savings by combining the two maneuvers.

For GUR missions, the day of rendezvous typically begins with an initial height adjust maneuver and phasing maneuver sequence, raising the Shuttle's orbit energy to within ~3 nm of the target's. This decreases the phasing rate to allow the rendezvous terminal phase initiate point to occur within one or two orbits. It also provides acceptable relative motion for the use of onboard navigation and targeting systems.

As stated above, all translation maneuvers from OMS-2 through grapple or docking are considered rendezvous maneuvers. The FDO is responsible for planning, execution and confirmation of all rendezvous maneuvers until such time that sufficient onboard navigation accuracy exists to allow transition of these duties to the flight crew. This occurs at the very end, when the range between the two vehicles is less than 40 nautical miles.

# FDO Console Handbook Section 3.10: Rendezvous Operations

## STS-96 FRR CYCLE RENDEZVOUS FRR CHARTS

B. E. Yarbrough/USH-423E  
T. D. Stitt/USH-423E

### TARGET-CENTERED RELATIVE MOTION -- ISS FD3 RENDEZVOUS

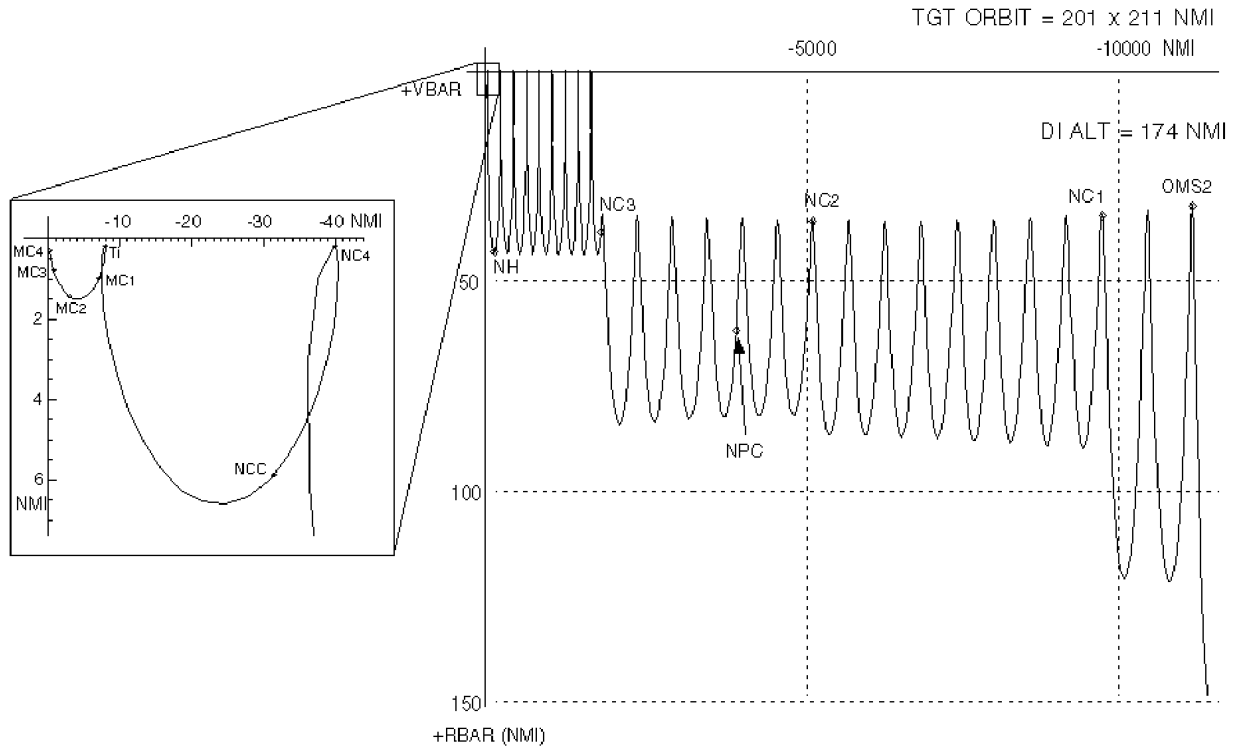


Figure 3.10.1.4-5: Ground Up Rendezvous

#### 3.10.1.5 Rendezvous Maneuver Definitions

Rendezvous missions require the use of many different types of translational maneuvers. Over the years, the maneuvers used to plan and execute rendezvous during the Gemini, Apollo, Skylab and now Shuttle programs have evolved to a very specific (and somewhat esoteric) nomenclature. This section details some of the more commonly used maneuvers.

**Phasing Maneuvers (NC)** - Phasing maneuvers, designated NC for "n<sup>th</sup> closing burn", control the LVC X-axis distance between the target and chaser, allowing the chaser to catch up with the target at the proper rate. In Shuttle rendezvous missions, the Orbiter is injected into an orbit, which is lower than the target's orbit, with the Orbiter trailing the target by some phase angle. This altitude differential causes the chaser to have a higher orbital velocity than the target, resulting in a closing rate. Posigrade NC burns increase the chaser vehicle's semi-major axis, or energy, and slow the closing rate so that rendezvous is achieved at the proper time. Most rendezvous plans contain several posigrade phasing maneuvers, the first of which may be OMS-2. Typically, the FDO will schedule two phasing maneuvers per flight day, one in the crew's morning and one in

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the evening. The X-axis distance, or downtrack, is most effected by perturbations caused by water dumps, attitude maneuvers, mismodeled drag, and propagation errors. Thus, daily phasing burns are required to control the closing rate. The phasing profile has a great effect on the available launch window, as will be discussed in more detail later.

**Height Adjust Maneuvers (NH)** - There is normally at least one height adjust maneuver (NH for "n<sup>th</sup> height correction") in a rendezvous plan. Its purpose is to control the Orbiter's height with respect to the target's  $V_{bar}$  at the Terminal Phase Initiate (Ti) maneuver. More complex flights may require more than one NH maneuver if there are multiple altitudes that must be achieved. An additional NH placeholder may be reserved on DOR in case height error is re-introduced by dispersions.

**Coelliptic Maneuvers (NSR)** - Some Shuttle GUR profiles use an NSR, or "n<sup>th</sup> slow rendezvous" burn to divorce lighting control from phasing. This coelliptic maneuver aligns the line of apsides of the chaser vehicle's orbit with that of the target's orbit. The differential height between the two orbits is then roughly constant. Assuming the target is in an approximate circular orbit, it is desirable to go coelliptic with the target so that phasing may be initiated based upon lighting requirements for terminal phase rather than upon placement of the line of apsides. Placement of the NSR maneuver is normally at relative apogee to minimize its radial  $\Delta v$  component, but TIG may be anywhere in the orbit. Note that an NSR maneuver does not target a future position or condition. NSR burns are rarely used anymore. Procedures to eliminate need for an NSR are covered later in this chapter. Figure 3.10.4.1-31 shows an STS-82 relative motion plot typical of HST missions and includes an NSR.

**Plane Change Maneuvers (NPC)** - The NPC maneuver ("n<sup>th</sup> plane change") puts the chaser in the same orbital plane with the target at a desired time. This applies mostly to ground-up rendezvous plans, where ascent dispersions may produce significant planar error. There is normally only one NPC maneuver in a rendezvous plan, and its placement in the timeline is somewhat arbitrary. In ground-up rendezvous missions, every effort is made to insert the Orbiter as accurately as possible into the desired orbital plane. At insertion, the desired plane is not the target plane, but a "phantom plane." The phantom plane is designed such that regression of the line of nodes will rotate the chaser plane into the target plane at intercept. The plane change maneuver is targeted take out planar errors at some future time, usually Ti, since differential nodal regression ceases to be a factor once the two satellite's altitudes are close. It is crucial to minimize planar errors during ascent and insertion because of the high cost of plane change maneuvers. To change the plane by only one degree would cost about 400 feet per second  $\Delta v$ . Currently, no more than 17 fps of aft propellant is budgeted for planar correction.

**Corrective Combination Maneuvers (NCC)** - There is only one NCC (n<sup>th</sup> corrective combination) maneuver in a rendezvous plan. It is the first onboard-targeted burn

## FDO Console Handbook Section 3.10: Rendezvous Operations

performed during a rendezvous, and typically incorporates star tracker or rendezvous radar data that has been previously acquired on the target, giving the Shuttle an accurate relative nav state. NCC is executed about 1 hr prior to the terminal phase initiate (Ti) burn, and its purpose is to position Ti in the right place. NCC is a *Lambert* burn that applies a correction to all three curvilinear axes simultaneously—it targets the desired downtrack, out of plane position, and height at a future point (e.g. Ti) with one burn.

**Terminal Initiate (Ti).** - Ti is a Lambert burn that targets a point below and slightly behind the target almost one rev later. Because this is the first burn in a rendezvous profile that targets the Orbiter for a near-intercept trajectory, it is referred to as the terminal phase initiate burn. This places the Orbiter on a fuel-optimal trajectory so that manual takeover may be commenced at a close range the target.

**Midcourse Corrections (MC)** - The MC burns are small, onboard-targeted Lambert burns executed between Ti and manual phase. There are typically 4, plus a manual planar null burn. Midcourse burns MC-1 through -3 all target to hit the MC-4 position below and slightly behind the target. MC-4 then targets a point 600 feet below the target on the Rbar.

**Manual Takeover** - While not a discrete maneuver, a brief introduction to manual phase is included to round out the discussion of rendezvous burns. After MC-4 the crew begins following braking gates specified as desired closing rate ("Rdot") versus range. The crew maintains the target in the center of the Crew Optical Alignment Sight (COAS) out the overhead window, and transitions from a -Z target track to a +Z Earth track attitude. In this manner, the Orbiter proceeds up the Rbar in a propellant efficient manner to grapple or dock with the target. This technique minimizes the amount of close-in braking firings required (up firing jets) that could disturb target solar arrays or sensors. This "natural braking" is a result of orbital mechanics which causes the chaser, below the target and traveling at the same speed, to drop away and speed up.

**External Delta-V Maneuvers (EXDV)** - These maneuvers are not targeted to any future trajectory constraints, but simply apply LVLH delta-velocity components at the time of ignition (TIG). "Canned" Orbiter separation maneuvers from deployed payloads are modeled using EXDVs. Also, "posigrade bias" burns in a ground up rendezvous are targeted as EXDVs. Where applicable, these burns force the profile to include posigrade tweak burns of 3-10 fps once or twice per day prior to rendezvous. If orbit perturbations due to attitude maneuvers, water dumps, etc prompt uphill energy changes, then the posigrade bias burns will shrink. Their purpose is to prevent subsequent NC's and/or NH's from going retrograde later in the profile in the event of uphill energy dispersions. Retrograde burns waste propellant twice, once for the original "overburn", and the second time to take out the "overburn". Therefore, the plans include these small burns to prevent over-phasing.

## FDO Console Handbook Section 3.10: Rendezvous Operations

### 3.10.1.6 SSP Rendezvous Design Constraints

This section presents the Optimized Rbar Targeting (ORBT) rendezvous design methodology currently in use for Shuttle missions<sup>1</sup>. ORBT provides specific data used onboard in the Lambert targeting scheme, as well as on console for burn planning and execution. ORBT, as its name implies, is a profile optimized for Rbar approaches (i.e. the Orbiter approaches the target from below). This type of approach is favored for the International Space Station (ISS), since it minimizes loads on plume-sensitive solar arrays. Rbar approaches provide natural braking by orbital mechanics, and if performed correctly, result in only downward jet firings (away from the station) to continue the approach. As the Orbiter passes through relative apogee coming up the Rbar, it will start dropping back down the Rbar and moving forward, relative to the target. To counteract this, downward-firing jets are used to continue closing along the Rbar. Forward/aft jets and side firing jets are fired as necessary to maintain the approach corridor (i.e. keep the target centered in the COAS out the overhead window). In this way, the Orbiter approaches the target with a minimum of pluming. The previous targeting scheme, sometimes referred to as Stable Orbit Rendezvous, was more appropriate for Vbar approaches, which used to be the norm in Shuttle rendezvous operations.

Since ORBT was created to provide an approach geometry optimized for Rbar terminal approaches, it results in minimum propellant usage as well as minimum plume loads. An ORBT rendezvous terminates at manual phase (the MC-4 position at about 2000 ft range) on a low energy coast coming up tangent to the Rbar at a range of 600 ft. Prior to this, the Ti burn and mid-course burns MC-1 through MC-3 are all targeted for the MC-4/manual takeover point, allowing several opportunities to correct the trajectory, thus reducing the effects of dispersions on the MC-4 position. The following table documents ORBT targeting constraints that are used to develop altitude-specific I-Loads for SPEC 34 ORB TGT as well as ground Orbital Maneuver Processor (OMP) constraints tables. The I-Loads themselves can be found in Section 6 of the Rendezvous Checklist. The following two pages illustrate DOR relative motion using ORBT.

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<sup>1</sup> ORBT was first used on STS-86 Shuttle/Mir rendezvous. On missions prior to this, rendezvous ILOADs were based on the "Stable Orbit Rendezvous" design philosophy which provided for faster closing rates at the manual takeover point. This was better suited for Vbar approaches, which were the standard earlier in the Shuttle program.

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Mnvr	Constraints	Rationale
NCC	<ul style="list-style-type: none"> <li>• 225 deg transfer to Ti</li> <li>• Targets Ti position 8 nm behind target, 1200 ft below Vbar</li> </ul>	<ul style="list-style-type: none"> <li>• Occurs after sunset to allow acquisition of ST data during lit portion prior to final targeting.</li> <li>• 225 deg transfer provides 45 deg pad between nominal NCC TIG &amp; 180 deg Lambert singularity.</li> </ul>
Ti	<ul style="list-style-type: none"> <li>• 300 deg transfer to MC-4</li> <li>• Targets MC-4 at 900 ft behind target, 1800 ft below</li> <li>• TIG is 28 min prior to sunset (SS) for target. For ISS missions, if <math>\beta &lt; 15</math> deg, then TIG is set to SS-38.5 min to avoid sun in crew's eyes during TORVA maneuver.</li> </ul>	<ul style="list-style-type: none"> <li>• Downtrack position is compromise between ground tracking uncertainties (about 2-4 nm) &amp; RR capability (max spec range 10 nm for 1 m<sup>2</sup> object).</li> <li>• Ti height chosen to make MC-4 primarily a +X burn</li> <li>• Lighting constraint protects day ST pass post-Ti to track out burn dispersions, plus allows night ST passes prior to MC-2*, &amp; results in sunrise no later than MC-3 +3 min, which is the last time to get visual acq prior to having to breakout if no sensors available.</li> </ul>
MC-1	<ul style="list-style-type: none"> <li>• TIG 8 min prior to sunset</li> <li>• Targets MC-4 at 900 ft behind target, 1800 ft below</li> </ul>	<ul style="list-style-type: none"> <li>• Allows incorporation of day ST data prior to MC-1</li> <li>• Provides opportunity for about 40 marks day ST after MC-1 to track out burn dispersions</li> </ul>
MC-2	<ul style="list-style-type: none"> <li>• Executed on elevation angle which occurs 27 min prior to MC-4 (about 28 deg)</li> <li>• Targets MC-4 at 900 ft behind target, 1800 ft below</li> </ul>	<ul style="list-style-type: none"> <li>• TIG on elevation angle maintains same geometry &amp; crew timeline from MC-2 to MC-4</li> </ul>
MC-3	<ul style="list-style-type: none"> <li>• Executed 17 min after MC-2</li> <li>• Targets MC-4 at 900 ft behind target, 1800 ft below</li> </ul>	<ul style="list-style-type: none"> <li>• Sunrise should be no later than MC-3 + 2 min**. This provides last opportunity for visual acquisition before breakout is required for no-sensor case.</li> </ul>
MC-4	<ul style="list-style-type: none"> <li>• Executed 10 min after MC-3</li> <li>• Targets end of terminal phase at 600 ft below target in 13 min</li> </ul>	<ul style="list-style-type: none"> <li>• Propellant optimal trajectory to acquire Rbar &amp; begin approach</li> </ul>

\*ISS post 4A is too big to track during day ST pass following Ti. Therefore night ST pass using tracking light prior to MC-2 is preserved with Ti being 28 min prior to sunset.

\*\*Assumes 0 deg beta and 3 min early MC-2 TIG.



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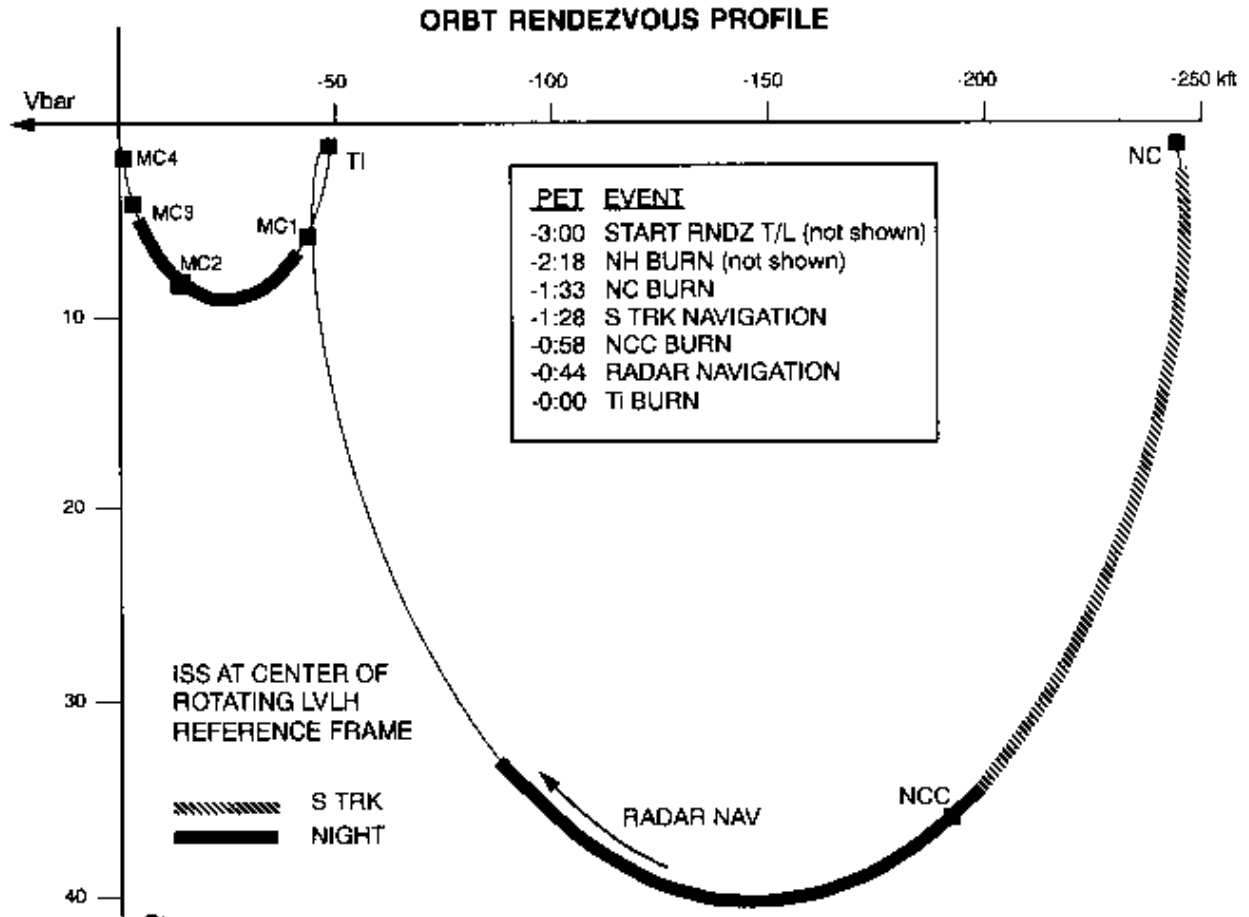


Figure 3.10.1.6-1

# FDO Console Handbook Section 3.10: Rendezvous Operations

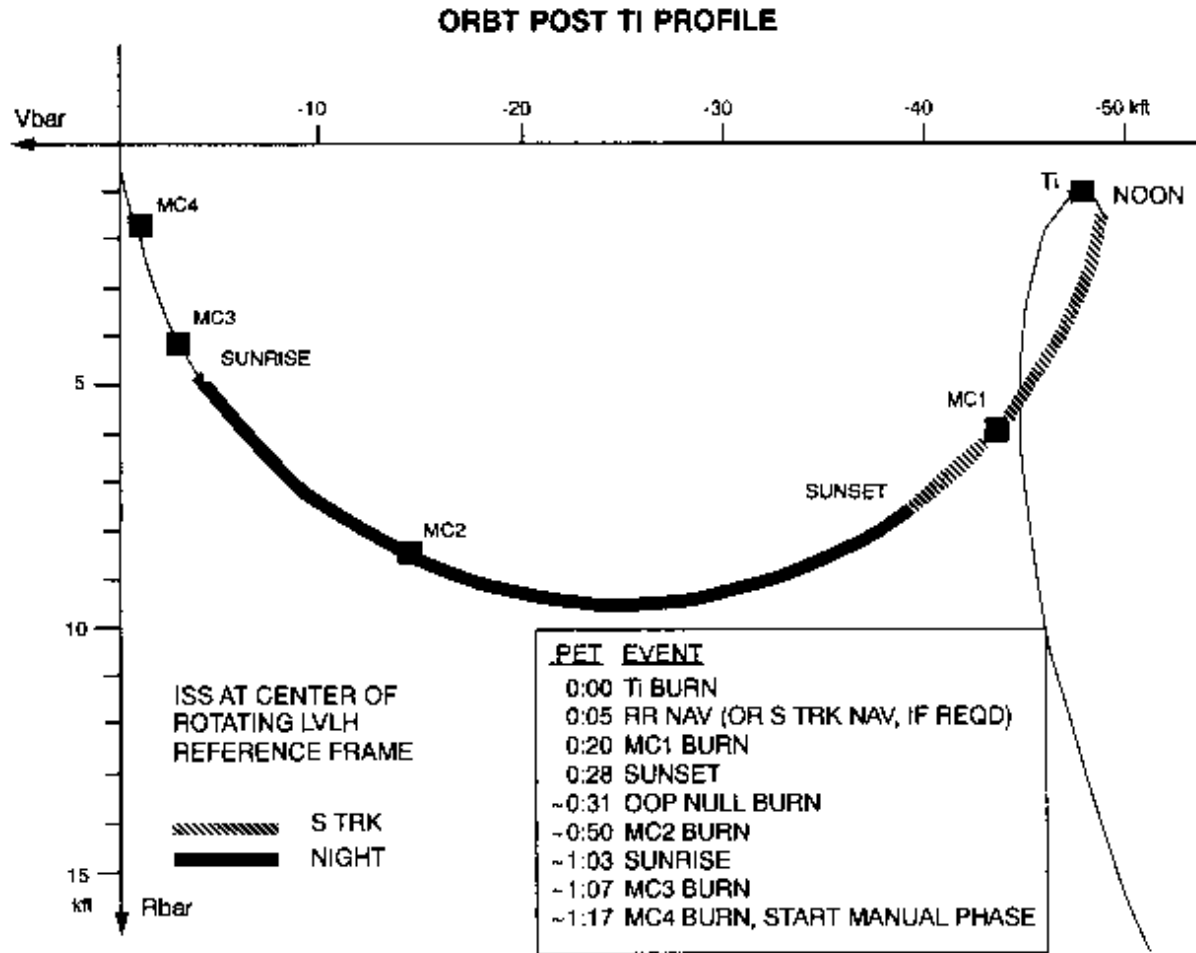


Figure 3.10.1.6-2

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## ORBIT TERMINAL PHASE AND RBAR APPROACH

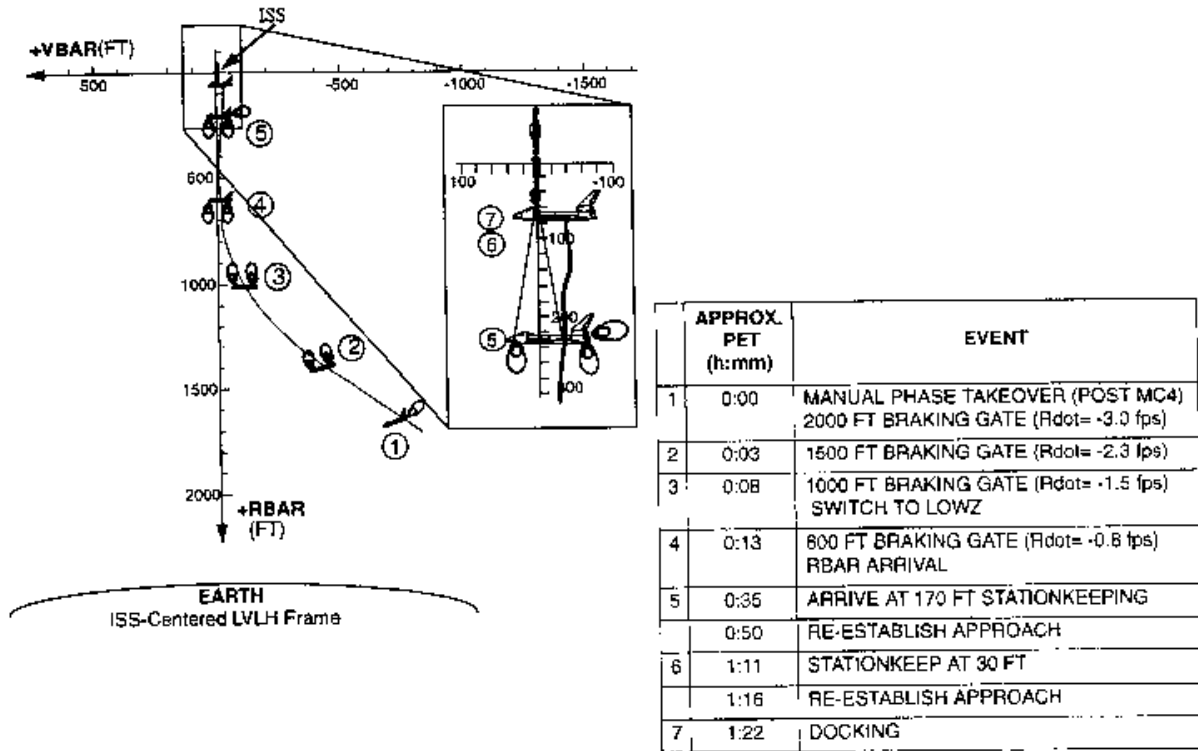


Figure 3.10.1.6-3

### 3.10.1.7 Onboard Sensors

The Shuttle has the capability to track rendezvous targets using onboard sensors, and to update the Orbiter-target relative nav state and the Orbiter/target covariance matrix resident in the Guidance, Navigation and Control (GN&C) computer. When valid sensor data is available, the onboard solution for the relative position and velocity of the Orbiter and target is more accurate than the ground's. Therefore the onboard state is used close-in for burn targeting. This section gives a brief explanation of the nature, use, and control of the onboard sensors, introduces selection criteria for the source of maneuver solutions, and explains typical sensor pass geometry.

#### 3.10.1.7.1 The Rendezvous Radar (RR)

The Orbiter is equipped with one parabolic dish antenna on a two-axis gimbal mount. The antenna can function as a communications dish, through the Tracking and Data Relay Satellites (TDRS), or as a KU-Band radar capable of skin tracking rendezvous targets. The RR can also track transponder-equipped "cooperative" targets out to a

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range of about 300 nm, but all targets to date have been passive objects requiring skin tracking. Max RR range for skin tracking is about 27 nm, however the maximum allowable range to incorporate RR data into nav is constrained to approximately 22 nm (135,000 ft to be exact). This limit was put in place after STS-32 to avoid an "eclipsing" problem that occurred during the LDEF rendezvous. This anomaly was caused by the pulse frequency being exceeded by the round-trip time between pulse transmission and echo return due to excessive range. Receipt of return pulse outside its pulse window resulted in erroneous range output. Limits in the Rendezvous Checklist should prevent this from recurring. The minimum RR range is 80 feet, but large targets like the ISS have a minimum *usable* range of about 600 ft. Inside this range, radar signals reflect off different locations on the target, resulting in noisy data.

The RR is mounted on the starboard side of the payload bay just aft of the crew compartment, and typically "looks" roughly in the direction of the Orbiter's -Z axis, although it has freedom of movement through 162 degrees in pitch, and 360 degrees in roll about its "polar" gimbal (see pictures of deployed RR in Figure 3.10.1.7-1). The RR provides angle data (azimuth and elevation), range, and range rate to nav. The coordinate system for RR angles is shown in Figure 3.10.1.7-2.



Figure 3.10.1.7-1

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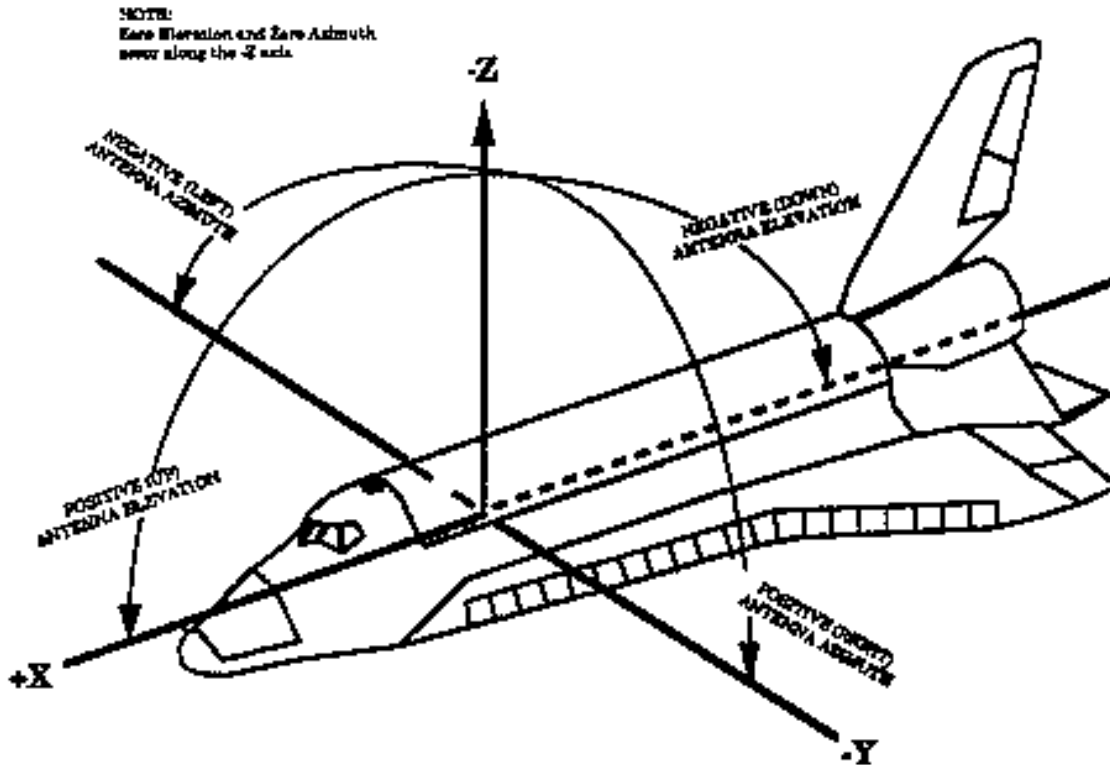


Figure 3.10.1.7-2

To set up for a RR pass, the crew normally performs an attitude maneuver to point the  $-Z$  axis at the GPC-predicted position of the rendezvous target. Item 2 on SPEC 33 "KU ANT" is turned on so that Orbiter and target vectors are passed from GNC GPCs to the SM GPC to enable the SM to calculate antenna pointing angles. There are four antenna steering modes the crew can select to search for, acquire, and track the target. These modes are:

GPC - Completely automatic control of search, acquisition, and tracking by SM using Orbiter and target vectors from the GNC GPC. If the RR breaks track, then a search is performed automatically. This is the mode normally used during RR nav.

AUTO TRACK - Similar to GPC mode, but the antenna must be pointed manually using the RR slew switches on the aft panel. Also, a spiral search can be initiated manually once the antenna has been manually positioned in the approximate direction of the target. Angle tracking is automatic once the RR locks on to the target. If the RR breaks track, a search is not commanded automatically, instead the antenna remains in an inertial track.

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GPC DESIGNATE - Automatic pointing, but no closed loop angle tracking or search capability. Range/rate data is provided if the state vector estimate provided to the RR was accurate enough to get a sufficiently strong signal return.

MANUAL SLEW - Similar to GPC Designate, but manual pointing is required. This mode is used to break track by manually slewing the RR away from the object it's locked onto.

The KU-Band antenna search pattern is a spiral centered about a GPC or manually designated point. The antenna bore sight can spiral out to an angle of 30 degrees away from the expected target location, but in GPC mode, the maximum spiral angle changes with range, being a maximum at minimum range. The smallest spiral angle is 16.2 degrees. Hardware damage can occur if the RR performs an auto search when pointed more than 30 deg from the -Z axis due to gimbal limitations. In GPC mode, the auto-search feature will exceed this limit if a break track occurs while the target is greater than 30 deg from the -Z axis. Therefore whenever the Orbiter leaves the -Z target track attitude (e.g. maneuver to Ti burn attitude), the RR mode is switched from GPC to AUTO TRACK. If a break track occurs, then a search will not be commanded. GPC mode can be resumed after the -Z axis is within 30 deg of the target in order to get an automatic search. Closed-loop tracking while greater than 30 deg from the -Z axis is permissible to within limitations of the mounting hardware; frequently the radar stays locked-on in AUTO TRACK mode during burns performed out of the target track attitude.

Normally ITEM 13 (RR) on SPEC 33 REL NAV display is selected during a RR pass. This routes RR angles to nav in order to update the FLTR state, as long as the selection filter is set to AUTO and ratios are  $< 1$ , or if FORCE is selected (ITEMs 17-25). Range and range-rate information are also incorporated into nav during a RR pass, but this is not controlled by ITEM 13 since the RR is the only sensor that provides this information. Therefore, it is possible to select ITEM 12 (S TRK) to incorporate ST angles while range and range-rate is being incorporated from the RR. This is not normally done during rendezvous operations.

### **3.10.1.7.2 The Star Trackers (ST)**

The star trackers are electro-optical sensors, which are part of the Orbiter's onboard navigation system. They are used to make star sightings to align the Inertial Measurement Units (IMU's), and to acquire and track rendezvous targets. Two ST's are fixed to the "nav base" upon which the IMU's are mounted. One points roughly along the Orbiter's -Z axis (3 degrees off), and the other points approximately along the -Y axis (10.5 degrees off). Figure 3.10.1.7-3 shows the location and orientation of the ST's.

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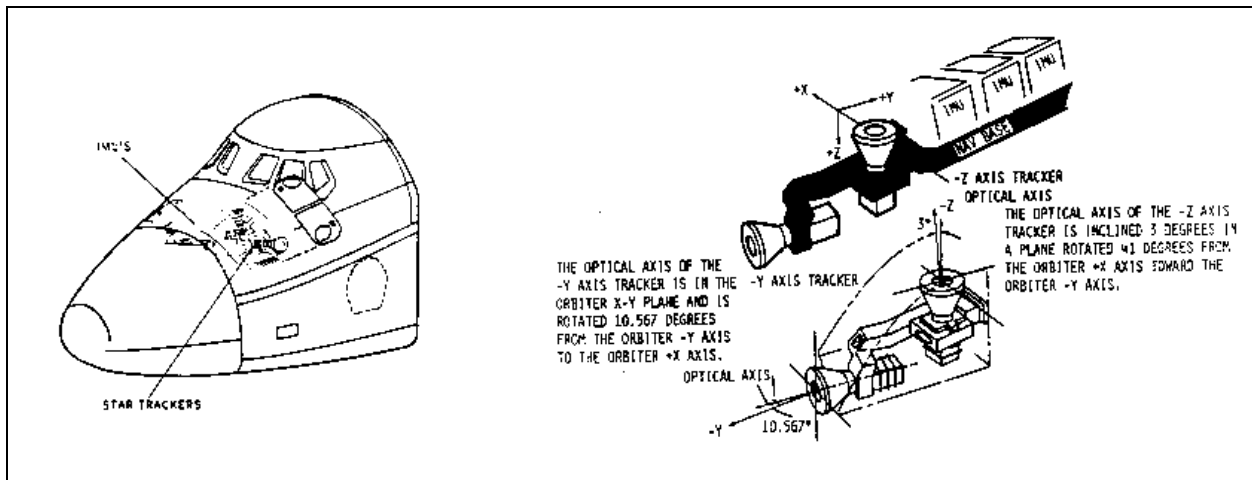


Figure 3.10.1-7-3

The star trackers use the astronomical magnitude scale to measure the brightness of objects. In this system, brighter objects have smaller magnitudes. The dimmest objects the ST's can detect have a magnitude of +3. The star trackers cannot track anything brighter than magnitude -7, to prevent damage to the sensors. Bright Object Sensors (BOS) will automatically close shutters if bright objects approach the line-of-sight. Shutters will close if the sun is within 30 deg, or the moon is within 8 deg, or the lit Earth horizon is within 12 deg of the line-of-sight, or the Earth's dark horizon is within 2 deg. In order for the ST to detect an object, it must either be in sunlight, or have running lights powerful enough to be detected by the ST. These considerations have had a strong influence on standard sensor pass geometry.

When a ST is used to track an object, the Orbiter is maneuvered to point the appropriate axis along the GPC computed line-of-sight to the target. The ST begins by searching a 1 by 1 degree field of view. If it fails to find the target, it will open the search field to 10 x 10 degrees and search for 20 seconds before quitting. If the target is acquired, it is kept at the center of a cruciform scan pattern until the target is lost, or the crew commands it to stop. Since the ST's are optical sensors, they provide angle data, but no range or range rate. Star tracker angles are more accurate than those obtainable from the rendezvous radar.

Unlike the RR, the star trackers are not limited by range alone. Their ability to track an object depends entirely on the brightness of sunlight reflected from the target's surface, and the proximity of the line-of-sight to the Earth's horizon. Critical factors are the target's size, shape, reflectivity, orientation, range, and viewing geometry, or "phase." Here we use the term phase in the astronomical sense, meaning the percentage of the target's surface, which is illuminated with respect to the sensor. These factors have also greatly influenced sensor pass geometry. Target visibility is also a crucial consideration for the manual phase of a rendezvous, when the crew must be able to see the target after orbital sunrise. Note that the ST may also track an object in orbital

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darkness if it is illuminated by artificial means. The ISS will have a running light that will be turned on during rendezvous operations so that day *and* night star tracker passes may be performed in the event of failure of the RR. This will also be an aid to the crew in maintaining visual contact during orbital darkness. The ST can (and has) tracked stars that appear in the field of view along with the target. In this case, data from the ST should be inhibited and the target re-acquired before data can again be accepted into nav.

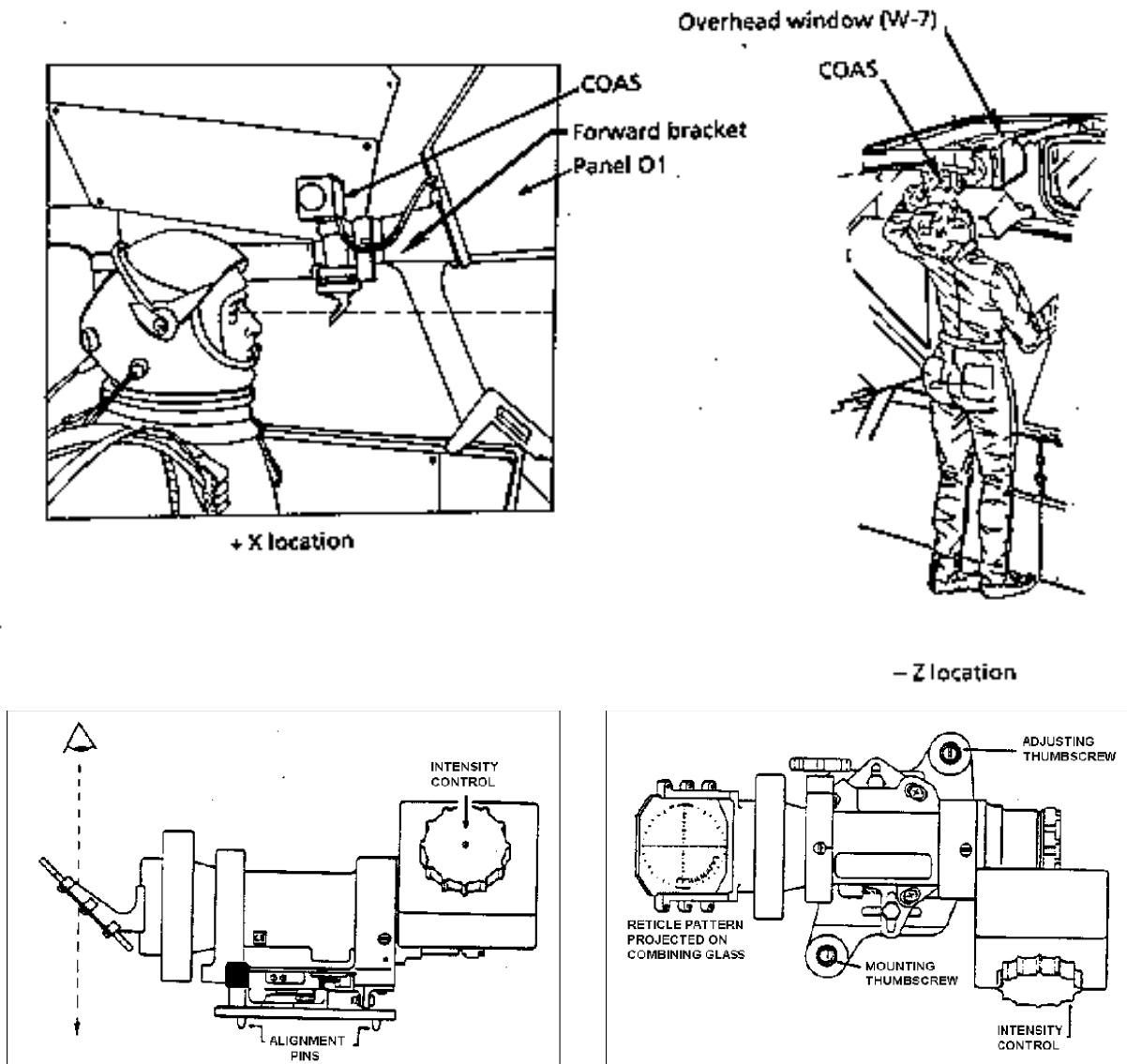
### **3.10.1.7.3 The Crew Optical Alignment Sight (COAS)**

The COAS is a backup to the star trackers for IMU alignment and rendezvous target tracking. As its name implies, it is a simple sighting device, which allows a crewmember to take visual star sightings. The COAS consists of a small projector with variable intensity control, which projects a reticle pattern focused at infinity, onto a transparent plate called the "combining glass." The combining glass is set at a 45 degree angle to the observer's line-of-sight, to allow simultaneous viewing of both the target or nav star, and the reticle pattern. See Figure 3.10.7.1-4 for views of the COAS and its mounting positions.

The Orbiter has two COAS mounting plates, one over the Commander's (CDR) front window, which aligns the COAS with the Orbiter's +X axis, and one at the starboard overhead window, which aligns the COAS with the Orbiter's -Z axis. The COAS and mounts are designed to allow repeated mountings and de-mountings without seriously changing the instrument's alignment. Because the COAS is not fixed to the nav base, but to the external structure of the Orbiter, it must be calibrated on-orbit. This is due to structural stresses that can actually change the shape of the crew cabin when the force of gravity is removed. The alignment is performed by taking star sightings after a good IMU alignment, so the GPC can determine the correct angle bias to apply to future COAS marks.



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**Figure 3.10.1.7-4**

To take COAS marks, the crew member must be able to see the target through the window (normally aft overhead). The Orbiter is maneuvered using the Rotational Hand Controller (RHC) until the target is centered in the reticle. The crewmember takes a mark by depressing the ADI attitude reference PBI. The crewmember then accepts or rejects a mark based on a subjective evaluation of how well the target was centered. Operating the COAS obviously takes much longer than either the RR or the ST, and results in greater trajectory perturbations due to the manual jet firings used to center the object in the COAS. For this reason, Flight Rule A2-123, requiring 40 marks for nav convergence, does not apply to the COAS.

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For rendezvous, the COAS can provide only angle data, but in PROX OPS, when the target appears as an extended object, it is useful for optical ranging. A crew member can observe the angle the target subtends using the scale on the COAS reticle and, if target size is known, this can be converted to a range using basic trigonometry.

$$R = \frac{d}{2 \tan\left(\frac{\theta}{2}\right)}, \text{ where } d \text{ is the dimension of the target, and } \theta \text{ is the angle it subtends.}$$

If the angle subtended by the target is changing, the crewmember can also determine whether or not there is an opening or closing rate. The Rendezvous Checklist contains tables of range vs. subtended angle to aid in performing these calculations. This provides a backup to RR range measurements.

### 3.10.1.7.4 Other Sensors

Independent range and range-rate information can be provided via a hand held LiDAR (HHL) device. "LiDAR" stands for Light Detection and Ranging--it's an infrared semiconductor pulsed laser. Manually pointed out the Orbiter windows, the HHL provides line-of-sight range by measuring the round-trip light time for the laser pulse to be reflected off the target. The crewman depresses the HHL trigger to initiate a rapid series of range measurements, and the average value is output on a built-in display. The HHL provides range readings accurate to 0.5 ft from as close as 12 ft, to as far as 1500 ft, or 5000 ft for targets equipped with a retroreflector. Slope of the range measurements is also computed to provide range-rate. HHL output can be incorporated into the Rendezvous Proximity Operations Program (RPOP), which resides on a laptop Payload and General Support Computer (PGSC) to provide graphical relative motion information to the crew. The HHL is used primarily during manual phase/prox ops in order to supplement range and range-rate information provided by other sensors.

Another LiDAR tool utilized during ISS missions is the Trajectory Control Sensor (TCS). This unit is mounted on the payload bay sill, and can automatically locate and track a target vehicle equipped with an optical retroreflector. TCS provides line-of-sight range, azimuth, and elevation, as well as rate data. It does this through the use of two lasers, which are scanned over a 20 deg cone field of view. The retroreflector returns coaxial laser energy back to the TCS to permit range determination through either phase shift or light round-trip time of flight (depending on range). Azimuth and elevation data is determined by position of the optical scanners at the time the retroreflector was detected. Rate data is computed by back-differencing, which is simply the difference between the previous and current values divided by elapsed time interval. TCS is controlled via a laptop PGSC, and is data-linked to the RPOP processor. TCS's raison d'être is to provide accurate relative state information during final approach to ISS. Inside about 600 ft, RR output becomes degraded due to the large size of ISS--the RR

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lock-on point tends to wander over the structure, resulting in spurious readings. So TCS is a necessary tool for providing steady measurements to support approach and docking. Normal TCS lock-on range is approximately 4000 ft. FDO can view TCS output (range, range-rate) on the V-POP display using picture-in-picture video.

### 3.10.1.8 Onboard Targeting Software

It would be impractical for the crew to rely exclusively on the MCC for burn solutions during rendezvous. It's just too dynamic a timeframe for the ground to compute all the required burns and uplink targets to the crew, particularly during final phase in which midcourse corrections occur as close as 10 min apart. Also it's desirable to target burns using the onboard relative nav state once accurate sensor data becomes available. Therefore the ability to target some rendezvous burns (from NCC on in) has been provided in the onboard Flight Software (FSW). Two algorithms are available, Lambert and Clohessy-Wiltshire (mercifully designated "C-W"); use of either of these algorithms is controlled by ILOADed flags in the onboard target sets. Both algorithms work in a similar fashion: given desired time of ignition ( $T_1$ ), transfer time ( $\Delta T$ ), and desired relative position after  $\Delta T$  ( $R_2$  at time  $T_2$ ), compute the change in velocity ( $\Delta v$ ) at  $T_1$  to effect the desired transfer orbit. Note that the position at  $T_1$  is determined simply by propagating the current orbit to  $T_1$ , and desired position at  $T_2$  is determined by applying desired relative offsets (specified with the burn target set) to the target's propagated position at  $T_2$ . In a simplified view, rendezvous can be achieved by performing the computed burn at  $T_1$  which was targeted for intercept (zero offsets), and then nulling rates with the target at  $T_2$ . For more detailed discussions below, refer to Figure 3.10.1.8-1, which is a flowchart of the onboard Lambert algorithm from USA/J. Goodman's Intro to Rendezvous GN&C presentation.

At the current time, Lambert is used exclusively for Shuttle rendezvous operations. Therefore, it will be the focus of the remainder of this section<sup>2</sup>. There are some important assumptions and limitations to this algorithm. First of all, it assumes that  $R_1$  and  $R_2$  uniquely define the plane of the transfer orbit, which is quite valid under most circumstances. However, this presents a problem when  $\Delta T$  is an integer number of half revs ( $180^\circ$ ,  $360^\circ$ ,  $540^\circ$ , . . .). In this case, the transfer orbit plane is not uniquely defined. In fact, there are an infinite number of transfer orbits with different planes between the two points. So Lambert breaks down for  $n \times 180^\circ$  transfer angles ( $\pm 8^\circ$  or so), and generates a "TGT T" alarm". For this reason, all Lambert-targeted burns stay

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<sup>2</sup> Although Lambert is of primary importance, C-W is nonetheless an algorithm worthy of some attention. A subset of the onboard targeting ILOADs are delivered with the C-W flag set "on" in order to provide a backup should Lambert fail. Also, C-W equations are coded into several useful ground programs: the spreadsheet cwspace.xls which is an excellent relative motion tool for a PC, and the RGPO's cyclical targeting ROSS alarm which continuously generates and plots burn targets based on onboard vectors.

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well away from 180° and 360° transfer angles (which can be seen with a quick review of Section 3.10.1.6).

Another limitation is that Lambert assumes conic motion with only the central gravity force field. To get around this, the conic  $\Delta v$  solution output by Lambert is propagated using the Shuttle's On-Orbit Precision Predictor. This provides a "real-world" (drag, 4x4 geopotential) prediction of exactly where the Lambert solution will take the Orbiter. The resultant position at T2 is then compared to the desired position R2, and a vector R\_MISS is computed. If R\_MISS is greater than some tolerance (R\_TOL, 250 ft), the desired "aimpoint" is biased by -R\_MISS, and this new "aimpoint" R\_OFFSET is targeted by Lambert. This process is repeated cyclically until R\_MISS satisfies the tolerance criteria. R\_OFFSET represents the accumulation of R\_MISS in order to correct Lambert limitations in the presence of "real-world" dispersions. If for some reason the onboard FSW cannot converge to a solution that satisfies R\_TOL within a certain number of iterations, then a "TGT ITER" alarm will be generated.

Another Lambert feature is capability to "float" T1 TIG in order to satisfy a target elevation angle constraint. This option is controlled by an ILOADed flag in the burn target set, and in practice is used for MC-2 targeting in order to better fix the geometry from MC-2 to MC-4. Failure to find the desired elevation angle during targeting (say the trajectory is too shallow) will generate a "MC2 EL ANG" alarm.

To perform an onboard targeted burn, the crew calls up GNC SPEC 34 ORBIT TGT on the CRT. Then a target set is loaded with an ITEM 1 input. Assuming a BASE TIME has been specified in ITEM 21, T1 will be computed onboard by applying a relative time associated with the target set to the basetime. In practice, BASE TIME is initially set to Ti TIG, then the target sets apply an ILOADed delta-time in order to compute T1 TIG. The target set has all other required information, including transfer time, desired relative offsets from the target at T2, Lambert/C-W flags, and elevation flag. Target set ILOADs for an actual mission can be viewed in the Rendezvous Checklist "Reference Data" chapter. Once a target set has been loaded into SPEC 34, all that's required to compute the first burn is an ITEM 28 COMPUTE T1.

NOTE: an ITEM 29 COMPUTE T2 could be used at the end of a transfer to null relative rates. However, this feature is not used in Shuttle ops since the crew transitions to manual phase prior to intercept.

When a Lambert burn is computed onboard, it may take several iterations to get a converged solution. Once computed, the "LAMB" flag will be turned on and PRED MATCH output to show how well R\_TOL was met. Most importantly, PEG-7  $\Delta v$  targets will be automatically shipped to MNVR EXEC for burn execution. All the crew has to do is mode to MM202, load the burn targets, and perform the burn at TIG.

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The FSW provides closed-loop feedback from Lambert to MNVR EXEC for improved burn accuracy. This is different from conventional PEG-7 external  $\Delta v$  targeting which is open loop (the VGOs simply update based on integrated sensed acceleration). Starting at TIG -15 sec, Lambert is cyclically executed once each guidance cycle, and the MNVR EXEC VGOs are updated accordingly. This feature provides for updates to the burn solution even after final targeting, if, for example, IMU accelerations are sensed due to RCS jet firings between final targeting and TIG. There is one drawback to this capability: burns must be completed within 90 sec of the TIG transferred to MNVR EXEC. This is due to the fact that R\_OFFSET is not updated after the initial burn targeting is completed. Accuracy of R\_OFFSET degrades with time if the burn is not performed at T1, the nominal TIG. After TIG+90 sec, inaccuracies in R\_OFFSET can degrade the entire Lambert solution above 0.2 fps (trim error threshold) and associated VGO output on MNVR EXEC. For this reason, if a burn is expected to continue past TIG+90 sec, the crew should stop and re-target the burn on SPEC 34 (doing so will automatically increment the TIG to current time plus 1 min). Then the burn will be executed at the new TIG. Again, if the crew is unable to complete this leg of the burn by TIG+90 sec, the entire process must be repeated.

Closed loop feedback from Lambert to MNVR EXEC only occurs when the LAMB flag is set in the FSW. This happens whenever Lambert targeting is executed with an ITEM 28 COMPUTE T1 on SPEC 34. However, if any item is changed on MNVR EXEC prior to TIG (the crew changes thruster selection, for example), then the FSW will downmode from LAMB to EXDV, and burn targets will be conventional open loop PEG-7s. Therefore, it's prudent to monitor the crew as they load targets such that no inadvertent MNVR EXEC entries are performed that could downmode guidance to EXDV. The LAMB/EXDV flags are displayed on both Rndz ONAV Status and the Orbit FDO DDD ROSS alarm panel.

For additional information on onboard targeting, the Rendezvous/Proximity Operations Workbook (RNDZ 2102) is a good source. More adventurous souls can consult the FSSR.

Lambert Targeting Summary

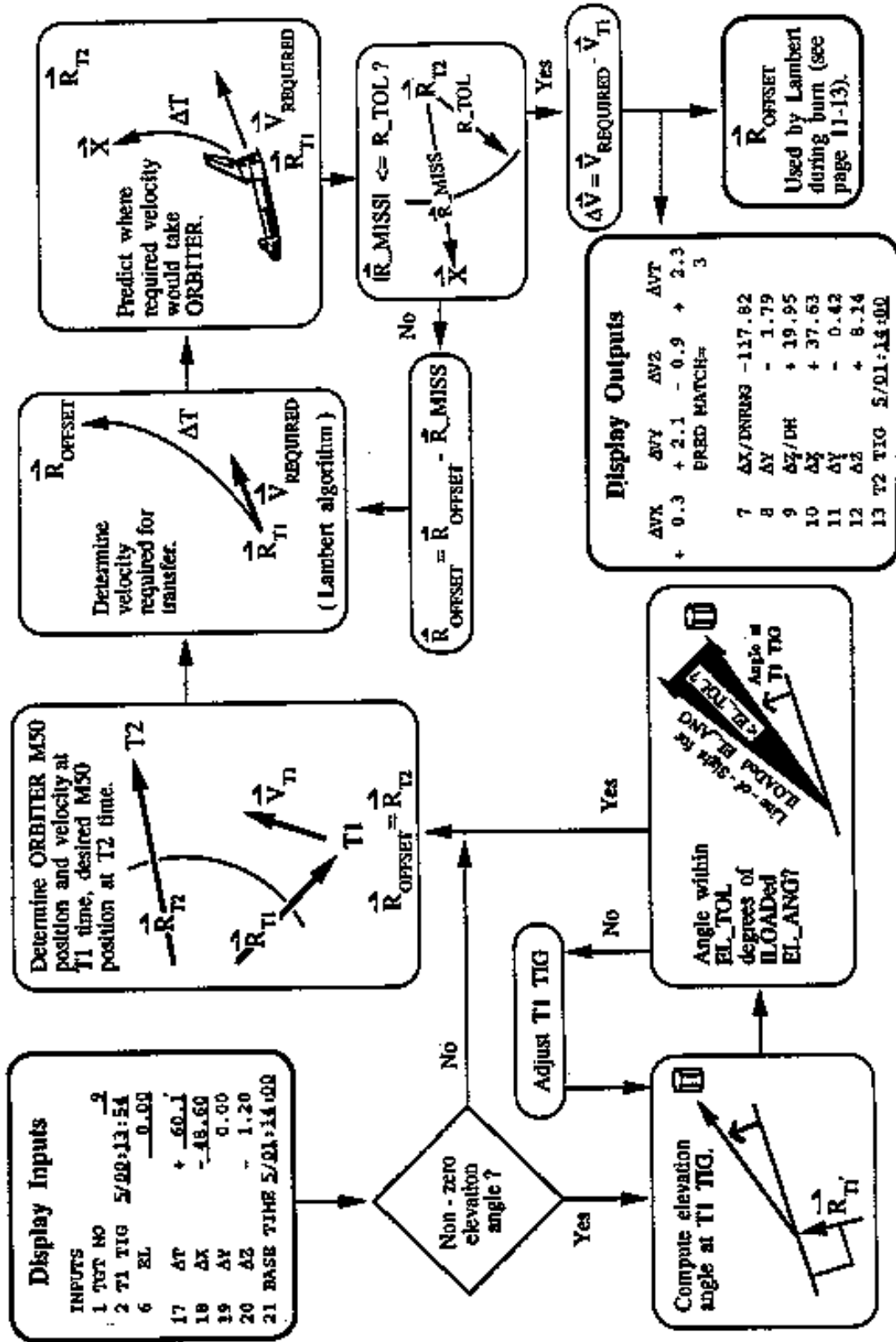


Figure 3.10.1.8-1

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### 3.10.1.9 Rendezvous Team Responsibilities and Interfaces

The following subsections detail Flight Dynamics Team duties associated with rendezvous.

#### 3.10.1.9.1 FDO

##### Pre-mission

- 1) Define Flight Rules for maneuver execution.
- 2) Participate in working groups and Flight Techniques for definition of flight specific procedures and crew timeline, as they affect rendezvous.
- 3) Work with Flight Design to select an appropriate rendezvous profile based on predicted phase angle. Update this as necessary for launch delays. This may include multiple plans for rendezvous on different flight days.
- 4) Prepare all other flight specific FDO console data as described in Section 2 below and the Lead FDO Handbook.

##### Day of launch

- 1) Ascent FDO initializes and executes Launch Window/Launch Targeting (LW/LT) processor to compute launch window and appropriate uplink command loads.
- 2) Rendezvous FDO initializes and executes OMP to select post-OMS-2 Ha x Hp that satisfies rendezvous plan phasing requirements.

##### On-orbit

- 1) Evaluate and maintain a rendezvous profile with maneuvers required to achieve the desired rendezvous within propellant and crew timeline constraints.
- 2) Re-plan the rendezvous maneuver profile as required to reflect confirmed maneuvers, Orbiter state vector updates, and target state vector updates.
- 3) Insure maneuver scheduling is compatible with crew timeline and ground tracking limitations.
- 4) Maintain contingency plans for safe separation during final phases of rendezvous and proximity operations.
- 5) Generate and coordinate uplinks of orbital maneuver targets and state vectors for timely execution of burns.

##### Post-landing

- 1) Generate Post-Flight Rendezvous Trajectory Summary

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### **3.10.1.9.2 Trajectory (FCR)**

- 1) Support FDO trajectory processing.
- 2) Build maneuver PADs.
- 3) Confirm Orbiter burns.
- 4) Maintain accurate ground estimate of Orbiter mass properties.

### **3.10.1.9.3 Profile Support (RFDO MPSR)**

- 1) Source of detailed rendezvous profile design expertise.
- 2) Advise RFDO on rendezvous profile techniques and options.
- 3) Advise RFDO on current/proper breakout procedures.
- 4) Provide Contingency profile design assessments.
- 5) Provide rendezvous TIG slip analyses.

### **3.10.1.9.4 Maneuver and Rendezvous Specialist (RFDO MPSR)**

- 1) Configure TSA OMP Mnvr Constraints Table (MCT) and Mnvr Transfer Table (MTT) for upcoming burns.
- 2) Run OMP for all planned dual vehicle burns and perform plan optimization.
- 3) Transfer OMP maneuver plan to TrS ephemeris.
- 4) Perform OMP iterations to achieve desired range and height offset in TrS ephemeris.
- 5) Provide Rendezvous Flight Design expertise to flight control team.
- 6) Assess/update TIG slip analyses as necessary if no Profile Support on console.

### **3.10.1.9.5 Dynamics (RFDO MPSR)**

- 1) Primary source of expertise in TrS software applications.
- 2) Perform MED inputs to support trajectory processing.
- 3) Coordinate MCC computing facilities as required to support RFDO/Trajectory Operations through GC, TAO, and FSM.

### **3.10.1.9.6 Trajectory Applications Officer (RFDO MPSR)**

- 1) Pre-sim verification of software release level & recon configuration; initialization of TSA Global & TrS
- 2) Single point of contact for management, control, & status of TrS
- 3) Create/turn around to checkpoints of the TrS & TSA Global



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- 4) Monitor data flow details, GDR statistics, ROSS events, process statistics, & on-line monitor
- 5) Perform TrS error identification & recovery

### **3.10.1.9.7 Navigation (RFDO MPSR)**

- 1) Primary source of expertise in MCC Orbit Determination applications.
- 2) Provide RFDO with state vector data based on OD processes.
- 3) Coordinate state vector generation and OD requirements with RFDO pre-mission and in real-time.
- 4) Provide pre-mission Tracking Matrix. Maintain Tracking Matrix/Site Selection in real-time.
- 5) Advises RFDO on best state vector source(s) during Rndz operations.
- 6) Maintain the Vent Timeline (VTL) and associated Vent Initialization Table (VIT) used in TrS Ephemerides.
- 7) Compute and maintain running semi-major axis errors and recommends updates to Ephemeris KCON/KVAR values to compensate.

### **3.10.1.9.8 Rndz GPO (FCR)**

- 1) Retains primary FCR expertise in Rendezvous Crew Procedures.
- 2) Is primary trajectory control operator during proximity operations. Primary trajectory control shifts from RFDO to RGPO after Ti during Day of Rendezvous Operations. RFDO continues to maintain "inertial" trajectory control in the event of a breakout, OMS Tank Fail or Emergency Deorbit.
- 3) Develops, verifies and maintains rendezvous crew procedures and Rendezvous Checklist FDF article.
- 4) Maintains primary responsibility for onboard Relative Navigation (SPEC 33), and Targeting (SPEC34).
- 5) Maintains primary responsibility for Rendezvous related sensors and tools including Ku Radar, Star Trackers, COAS, TCS, HHL, and RPOP.

### **3.10.1.9.9 RPS (RGPO MPSR)**

- 1) Provides RGPO with detailed Crew Procedure monitoring and support.
- 2) Is generally a certified RGPO or RGPO trainee and therefore generally retains the same Rendezvous systems knowledge as the FCR RGPO.

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### 3.10.1.9.10 Target (RGPO MPSR)

- 1) Maintains detailed expertise in Onboard Maneuver Targeting (SPEC 34) software and associated FSW alarms.
- 2) Monitors SPEC34 performance through shadow execution of SPEC 34 emulation software using onboard state vector data.
- 3) Provides recommendations of corrective course of action in the event of off-nominal SPEC 34 targeting.

### 3.10.1.9.11 Prox Ops (RGPO MPSR)

- 1) Maintains detailed expertise in Proximity Operations and associated tools.
- 2) Operates ground-based versions of RPOP using onboard telemetry data.
- 3) Operates the Silicon Graphics based VPOP application.

### 3.10.1.9.12 ONAV (RGPO MPSR)

- 1) Provides expertise in all aspects of RELNAV operation.
- 2) Builds commands pertinent to RELNAV management for uplink by RGPO and FDO.
- 3) Snapshots downlisted RELNAV chaser/target state vector pairs in TrS V1/2, V3/4, V5/6.

Beginning with OI-30 (STS-114/LF-1), ONAV performs command operations with FDO early on day-of-rendezvous. These are required for the flight software to properly model drag acceleration on the target after RELNAV is enabled. Without this Kfactor (DSM 400xx) uplink, the following default KLOAD values are in effect.

$A \equiv$  target cross-section area = 1.0 ft<sup>2</sup>

$M \equiv$  target mass = 1.0 slug

$C_{DT} \equiv$  target drag coefficient = 2.0

$K \equiv$  uplinkable target Kfactor = 1.0

After Earth-relative target velocity  $\mathbf{v}_R$  in fps and atmospheric density at the target  $\rho$  in slug/ft<sup>3</sup> are computed, flight software performs the following computations<sup>3</sup> to obtain drag acceleration  $\mathbf{d}$  in ft/sec<sup>2</sup>.

$$C_D = C_{DT} K$$

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<sup>3</sup> Reference STS-83-0006, *On-Orbit Navigation FSSR*, Section 4.2.4.1.1, Acceleration Models (ACCEL\_ONORBIT).

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$$\mathbf{d} = -\frac{C_D A \rho |\mathbf{v}_R| \mathbf{v}_R}{2 M}$$

To make the ballistic number  $B \equiv \frac{C_{DT} K A}{2 M}$  attain the proper value in ft<sup>2</sup>/slug, it's necessary to uplink a K whose value is B's in ft<sup>2</sup>/slug because the foregoing quotient would otherwise be unity with default KLOAD values. The source for B in ft<sup>2</sup>/slug is Flight Design's RNDZ-02 product.

**NOTE:** the foregoing B definition is consistent with that adopted by RNDZ-02 and its published ballistic number value. By convention, however, generally accepted aerodynamic theory confines B's 0.5 factor to the drag equation and does not include it in any ballistic number formula. The RNDZ-02 ballistic number definition should therefore be considered peculiar to SSP.

A 400xx command actually includes *two* Kfactor values, one each for the Orbiter and target. Because the default Orbiter value is correctly set at 1, the uplinked value is also unity.

After building and verifying a 400xx command, ONAV requests FDO perform the uplink. Detailed 400xx actions are found in DM-CH-05, *Flight Dynamics Command Procedures*. Prior to the uplink, ONAV and FDO work with DPS, who uplinks the two variable parameters (VPs) required to verify Orbiter and target Kfactors are modified as desired. Once this verification is accomplished post-uplink, VPs can be modified as necessary for other purposes.

**NOTE:** during the post-*Columbia* stand down, a typical ISS B consistent with RNDZ-02 would have a value ~0.5 ft<sup>2</sup>/slug. Thus, the KLOADed default B value results in ISS drag acceleration ~50% in excess of its real world value, assuming accurate  $\rho$ . At ~200 nm altitude, this deviation would result in ~4000 ft of target downtrack position error with respect to the real world during a typical 4-rev period with RELNAV enabled.

**CAUTION:** like the target state vector, the uplinked target Kfactor value will not survive a transition out of OPS 2 and reverts to its KLOAD default. Consequently, a 400xx uplink is a highly desirable component of RELNAV Recovery procedures following a transition out of OPS 2.

### 3.10.2 Orbital Maneuver Processor (OMP) User's Guide

Since the advent of orbital rendezvous in the Gemini program, flight controllers have relied on sophisticated computational tools to assist in the burn targeting process. Tools currently used in the MCC for rendezvous targeting are the descendants of these earlier applications. Today, the same rendezvous targeting program is used for both

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pre-mission flight design and for real-time maneuver planning. It can be used to model one or more maneuvers for a *single* vehicle, or can be used to model one or more maneuvers for a vehicle that is trying to rendezvous with *another* orbiting vehicle. The maneuvering vehicle is called the chaser and the passive vehicle (if present) is called the target.

The Orbital Maneuver Processor Bench Program (OMPBP) was developed for the Space Shuttle Program. It was derived from the Docking Initiation (DKI) program that was used during Gemini, Apollo, and Skylab. OMPBP is run by rendezvous mission designers and is used for the majority of the pre-mission rendezvous design work for the Space Shuttle Program (SSP). OMPBP is hosted on the Flight Analysis and Design System (FADS). The Rendezvous Targeting Processor (RTP) was developed from OMPBP in the early 1980s to run on the Mission Operations Computer (MOC) mainframe computer for real-time rendezvous maneuver planning and execution. This was the prime rendezvous targeting tool used in the MCC until its retirement on STS-110, the first flight on the Trajectory Server (TrS). Different versions of OMPBP and RTP have been developed continuously since 1970 from work done at the Charles Stark Draper Laboratory, the Johnson Space Center (JSC) and the McDonnell Douglas Astronautics Company-Houston Division.

In the TrS Era, a Trajectory Software Applications (TSA) version of the OMPBP is used for real-time maneuver targeting as well as pre-mission planning. This implementation of the OMPBP, known simply as OMP, provides the same capability as the FADS version of the OMPBP, with only a change in the user interface. This section is intended to instruct the reader in how to run the OMP. For instructions on running the OMPBP, refer to the "OMPBP User's Guide", TM# 1.5-TM-DM86T03-17, dated March 20, 1986. The OMPBP is a direct descendant of the original versions of the program.

OMP needs several inputs to run. It requires initial chaser and target state vectors along with propagation data (weights, areas, and coefficients of drag). Vector inputs may come from an ephemeris (specified with a vector fetch time), Vector Administration Table (VAT, simply a vector storage location), or telemetry downlist. Propagation data is set based on the vector source, but frequently must be manually overridden. OMP also requires a valid Maneuver Constraints Table (MCT). This provides the targeting constraints that the user would like OMP to satisfy with its output. The MCT defines the maneuver type (e.g. phasing burn), a primary constraint for determining earliest TIG, and optional secondary constraints that allow TIG to float, and/or specify burn target parameters to achieve. OMP is executed using the OMP Execution Menu, and output is shown on the Maneuver Evaluation Table (MET). If a rendezvous plan is to be transferred to an ephemeris (either TSA or TrS), the ephemeris and a Maneuver Transfer Table (MTT) must be set up. Refer to Section 3.3 "Ephemeris Maintenance" for more information on ephemeris operations.

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Once a plan has been transferred to an ephemeris, the user may notice that the relative motion the ephemeris yields is different than the OMP predicted. There are several reasons for this. First, OMP models all maneuvers impulsively, while the ephemeris models all maneuvers with the Powered Flight Numeric Integrator (PFNI). OMP does not access the weight gain/loss tables, Attitude Timeline (ATL) and Vent Timeline (VTL) as the ephemeris does, instead it uses constant area drag with no vents. Finally, OMP uses the lower-fidelity Analytical Ephemeris Generator (AEG), while the TrS ephemeris uses numerical-based Encke for propagation. The procedure to resolve these differences is covered in Section 3.10.4.1.5.

### 3.10.2.1 Maneuvers and Constraints

The OMP is capable of computing many different types of maneuvers, for example it can target a desired orbit height for a Hohmann transfer, or downtrack distance from another spacecraft after a period of time. For all maneuver types, the user must specify a *primary constraint*, for example TIG of the burn in MET, or number of revs since a previous burn. Most maneuver types also require one or more *secondary constraints*; these are normally of a lighting or geometric nature. For the height adjust (HA) burn example mentioned above, a valid secondary constraint would be APO=1 in order to force TIG to occur at the next apsis. In other words, the OMP would begin searching for the next apsidal crossing, starting at the threshold time specified as the primary constraint. Another secondary constraint could be HD=160, which tells the OMP what height to target for the burn (160 nm in this example). Some secondary constraints define desired chaser-target relative position at a future time (downrange distance, or DR, for example). This is the heart of rendezvous profile planning.

The following text is a complete list of all maneuvers and constraints supported by TSA v5.0 OMP.

#### 3.10.2.1.1 Single Vehicle Maneuvers

Table 3.10.2.1-2 and the following list the ten maneuvers, which are supported in OMP for use with only a single vehicle. In other words, they are target independent. "A single vehicle" means that the OMP is queued on the same vector for both the chaser and target.

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### Single Vehicle Maneuvers

OMP
APSO
CIRC
DVPY
DVYP
EXDV
HA
HASH
LSDV
NOSH
PC

**Table 3.10.2.1-2**

#### **APSO (Apsidal Shift)**

This is a maneuver targeted to shift the chaser's line of apsides with a purely radial maneuver done halfway between the current and desired line of apsides. This maneuver is normally used with the A or P secondary constraints and has no unique rendezvous constraints.

#### **CIRC (Circularization)**

This maneuver is targeted to circularize the chaser's orbit at the maneuver time. This maneuver has no unique rendezvous constraints.

#### **DVPY (Delta Velocity with Pitch and Yaw)**

This maneuver is a Powered Explicit Guidance (PEG) 7 targeted maneuver, similar to the EXDV maneuver, defined by a delta velocity magnitude and a Local Vertical/Local Horizontal (LVLH) pitch and yaw thrust direction. These parameters are indicated by the DV, PIT, and YAW secondary constraints. This is a useful tool for TIG slip analysis, as will be shown in Section 3.10.3.2. This maneuver has no unique rendezvous constraints.

#### **DVYP (Delta Velocity with Yaw and Pitch)**

This maneuver is a PEG 7 targeted maneuver, similar to the EXDV maneuver, defined by a delta velocity magnitude and a LVLH yaw and pitch thrust direction. These parameters are indicated by the DV, YAW, and PIT secondary constraints. This maneuver has no unique rendezvous constraints.

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### **EXDV (External Delta Velocity)**

This is a PEG 7 targeted maneuver defined by LVLH velocity components as specified with DVLV secondary constraints in X, Y, and Z order. This maneuver has no unique rendezvous constraints.

### **HA (Height Adjust)**

This is a horizontally executed maneuver targeted to achieve desired orbital altitude 180° from the maneuver point. Thus, this maneuver is targeted as a Hohmann transfer. The desired orbital altitude is indicated by the HD "height desired" secondary constraint. This maneuver has no unique rendezvous constraints.

### **HASH (Height Adjust and Apsidal Shift)**

This is a maneuver targeted to achieve a desired orbital altitude 180 degrees from the maneuver point and to simultaneously move the line of apsides to the maneuver point. The desired altitude is indicated by the HD secondary constraint. This maneuver has no unique rendezvous constraints.

### **LSDV (Line of Sight Delta Velocity)**

This maneuver is a PEG 7 targeted maneuver, similar to the EXDV maneuver, defined by velocity components in the line of sight coordinate system. The X axis is along the line of sight vector, the Y axis perpendicular to the line of sight vector in the direction of the negative angular momentum vector, and the Z axis completes the right handed system. The velocity components are indicated using the DVLS secondary constraints.

### **NOSH (Node Shift)**

This maneuver is targeted to shift the ascending or descending node location. The angle to be shifted is indicated using the DNOD secondary constraint. This maneuver has no unique rendezvous constraints.

### **PC (Plane Change)**

This maneuver is targeted to change the orbital plane of the chaser. The amount of plane change is indicated by the DPC secondary constraint. When this maneuver is located at an ascending or descending node using the ASC or DSC secondary constraints, the plane change will be only in orbital inclination. This maneuver has no unique rendezvous constraints.

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### 3.10.2.1.2 Dual Vehicle Maneuvers

Table 3.10.2.1-3 and the following list the thirteen maneuvers which are supported in OMP using two vehicles, a chaser and a target. These maneuvers require both state vectors for their computation.

**Dual Vehicle Maneuvers**

OMP
NC
NCC
NH
NHRD
NPC
NS
NSR
SOI
SOM
SOR
TPF
TPI
TPM

**Table 3.10.2.1-3**

#### **NC (n<sup>th</sup> Closing Maneuver)**

This is a horizontally executed maneuver targeted to obtain the desired offset position from the target (phase angle) at a future time. This maneuver controls the X axis curvilinear distance. The offset position is indicated using the PHA or DR secondary constraint.

#### **NCC (n<sup>th</sup> Corrective Combination)**

This is a Lambert targeted maneuver correcting the chaser's trajectory to achieve the desired offset position relative to the target. The desired curvilinear LVLH offset position is indicated by CXYZ secondary constraints in X, Y, Z order. This maneuver controls all curvilinear axes. It is a combination of three maneuvers: NC, NH, and NPC. Typically, Y-offset is set to zero, creating a common node at the subsequent maneuver<sup>4</sup>.

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<sup>4</sup> Because prior maneuver types (typically NH and NC) cannot use CXYZ offsets, MARS procedures call for NCC to target DR, DH, and WEDG constraints at T<sub>i</sub>. This is a technique equally valid to one using CXYZ constraints, and it minimizes modifications as earlier constraints tables evolve to the NCC table on day of rendezvous.



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### **NH (n<sup>th</sup> Height Adjust)**

This is a horizontally executed maneuver targeted to a differential height from the target at some future time. It controls the Z axis curvilinear distance. The differential height is indicated using the DH secondary constraint.

### **NHRD (Height Adjust with Radial Component)**

This maneuver is similar to the NH maneuver except it contains a radial component to null the radial velocity at the time of the maneuver. The differential height is indicated using the DH secondary constraint.

### **NPC (n<sup>th</sup> Plane Change)**

This is an out-of-plane maneuver placing the chaser in the target's phantom plane. The phantom plane is the target's actual plane offset by the amount of differential nodal regression calculated to occur between the NPC maneuver and the desired in-plane time (function of height difference). The in-plane time is indicated by the WEDG=0 secondary constraint, placed on a future maneuver. In addition, the maneuver should be placed at a common node between the chaser and phantom target planes which is indicated by the CN=1 secondary constraint. If this is not done, the chaser and target will remain in separate planes. The NPC maneuver controls the Y axis curvilinear distance.

If the WEDG secondary constraint is not used, the maneuver will place the chaser in the target's actual plane at the time of the maneuver.

### **NS (Node Shift)**

This maneuver is targeted to place a common node approximately 90 degrees from the maneuver point.

### **NSR (n<sup>th</sup> Slow Rate Maneuver)**

This maneuver is targeted to put the chaser in an orbit coelliptic to the target. Coelliptic is defined as a condition where there are coincident lines of apsides. This maneuver is often executed alone, allowing the next maneuver to set up lighting for intercept.

### **SOI (Stable Orbit Initiation)**

This is a Lambert targeted maneuver correcting the chaser's trajectory to achieve the desired offset position relative to the target at the subsequent SOR maneuver. The offset position is indicated with the CXYZ secondary constraints. The SOI maneuver

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must be followed by an SOR, with only the SOM maneuver allowed in between the SOI and SOR.

### **SOM (Stable Orbit Midcourse)**

This is a Lambert targeted midcourse correction maneuver to be used between SOI and SOR.

### **SOR (Stable Orbit Rendezvous)**

This is the second maneuver of the Lambert pair SOI/SOR. This maneuver is Lambert targeted to re-intercept the SOR offset position after 270° of orbital travel, essentially stabilizing the chaser in the same orbit as the target, assuming offsets are small.

SOR can also be a stand-alone maneuver. The maneuver computed will be the same as an NCC maneuver in a NCC/NSR combination when the primary constraint for the NSR is  $WT=270$  ( $M=0.75$ ) and the secondary constraint offsets are the same as the SOR maneuver.

Typically, with  $CXYZ=0$ , this maneuver yields the same relative motion between the target and chaser vehicles as would the TPF maneuver. However, if a large drag differential between the target and chaser exists, these relative motion differences could become significant.

### **TPI (Terminal Phase Initiation)**

This is a Lambert targeted maneuver placing the chaser on an intercept trajectory with the target (zero offsets). This maneuver must be followed by a TPF, with only the TPM maneuver allowed in between the TPI and TPF.

### **TPF (Terminal Phase Final)**

This is the second maneuver of the Lambert pair TPI/TPF. It is designed to null the relative rates between the target and chaser at the intercept point, i.e. zero position offset, as opposed to SOR which has uses variable offsets defined by  $CXYZ$ .

TPF is also a stand-alone maneuver. When used as such, the relative rates between the chaser and target will be instantaneously nulled. This is the same as the T2 compute (Item 29 Exec) of Orbit Targeting in the Orbiter software.

### **TPM (Terminal Phase Midcourse)**

This is a Lambert targeted midcourse correction maneuver to be used between TPI and TPF.

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### 3.10.2.1.3 Threshold (Primary) Constraints

Table 3.10.2.1-4 and the following descriptions reference fifteen threshold constraints (referred to as "primary constraints") supported by OMP. These constraints are used to define the Time of Ignition (TIG) of the maneuver if no secondary constraint is specified. If a geometric or lighting secondary constraint exists for the maneuver, the threshold constraint defines the threshold, or the time at which the OMP starts to search for the geometric or lighting constraint's value.

**Threshold (Primary) Constraints**

<b>OMP</b>
APS
CAN
DLT
DT
DTL
M
N
REV
T
WT

**Table 3.10.2.1-4**

#### **APS (Delta Apsides)**

This specifies the number of chaser half orbits from the previous maneuver. For example, APS=2.0 would yield the same result as M=1.0.

#### **CAN (Central Travel Angle)**

This specifies that the maneuver will occur when the chaser has flown through the central travel angle specified in degrees.

#### **DLT (Delta Time)**

This specifies the delta time from the previous maneuver's impulsive ignition time to the current maneuver's impulsive ignition time. The OMP expects this delta time in a DD:HH:MM:SS.SS format.

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### **DT (Delta Time)**

This specifies the delta time from the previous maneuver's impulsive ignition time to the current maneuver's impulsive ignition time. The OMP expects this delta time in a DDD:HH:MM:SS.SSS format.

### **DTL (Delta Time)**

This specifies the delta time from the previous maneuver's impulsive ignition time to the current maneuver's impulsive ignition time. The OMP expects this delta time in a DDD:HH:MM:SS.SSS format.

### **M (Delta Orbits)**

This specifies the number of chaser orbits from the previous maneuver. The value may be a decimal fraction.

### **N (Delta Apsides)**

This specifies the number of chaser half orbits from the previous maneuver.

### **REV (Delta Revolutions)**

This specifies the number of chaser orbits from the previous maneuver in orbits. This value may be a decimal fraction.

### **T (Time)**

The maneuver's impulsive ignition time will occur at the specified time. The OMP expects MET in DDD:HH:MM:SS.SSS format.

### **WT (Central Travel Angle)**

This specifies that the maneuver will occur when the chaser has flown through the central travel angle specified in degrees.

#### **3.10.2.1.4 Geometric (Secondary) Constraints**

Table 3.10.2.1-5 and the following documentation reference geometric (secondary) constraints supported by OMP. These constraints are used to alter the maneuver's TIG to meet the geometric constraint in relation to the Earth, inertial space, the chaser or target orbit, or the target. Care should be taken since the TIG is free to change as needed. For more on this, refer to Section 3.10.2.2.8, Operational Notes.

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### Geometric (Secondary) Constraints

<b>OMP</b>
A
ALT
APO
APS
ARG
ASC
CN
DEC
DSC
EL
LAT
LON
N
NA
NP
OPT
P
PER
RAS
TGTA
TGTP
U

**Table 3.10.2.1-5**

#### **A (Angle from Apogee)**

The maneuver is executed at a desired central travel angle from the chaser's apogee. The angle is input in degrees.

#### **ALT (Altitude)**

The maneuver is executed at a desired altitude above the surface of the Earth. The altitude is input in nautical miles.

#### **APO (n<sup>th</sup> Apogee)**

The maneuver is executed at the n<sup>th</sup> apogee of the chaser's orbit after the threshold constraint, where N is the constraint's value.

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### **APS (n<sup>th</sup> Apsidal Crossing)**

The maneuver is executed at the n<sup>th</sup> chaser apsidal crossing after the threshold constraint.

CAUTION: to insure OMP convergence, minimum delta-height between the chaser's apogee and perigee must be > 10 nm.

### **ARG (Argument of Latitude)**

The maneuver is executed when the specified argument of latitude is first encountered following the primary constraint's threshold epoch. Argument of latitude is the angle, measured in the plane of the chaser's orbit, from the ascending node to the chaser position. This angle is specified in degrees.

### **ASC (n<sup>th</sup> Ascending Node)**

The maneuver is executed at the n<sup>th</sup> ascending node of the chaser's orbit after the threshold time where N is the constraint's value.

### **CN (Common Node)**

The maneuver is executed at a common nodal crossing of the target and chaser orbit planes. OMP assumes the nth nodal crossing as specified by the value associated with CN. When used in conjunction with the WEDG secondary constraint, the chaser maneuver will be executed at a phantom common nodal crossing such that the two vehicles will be coplanar at the WEDG specified time.

### **DEC (Declination)**

The maneuver is executed at the specified latitude of the chaser's orbit. The angle is input in degrees.

### **DSC (n<sup>th</sup> Descending Node)**

The maneuver is executed at the n<sup>th</sup> descending node of the chaser's orbit after the threshold time, where n is the constraint's value.

### **EL (Elevation Angle)**

The maneuver is executed at the specified elevation angle. The elevation angle is the line of sight angle from the chaser's local horizontal to the target at the chaser maneuver time. The angle is input in degrees. Positive angles are when the chaser is

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behind and below the target. When this constraint is used on a TPI maneuver, the maneuver must be the first one in the constraints table.

### **LAT (Latitude)**

The maneuver is executed at the specified latitude of the chaser's orbit. The angle is input in degrees.

### **LON (Longitude)**

The maneuver is executed at the specified longitude of the chaser's orbit. The angle is input in degrees.

### **N (n<sup>th</sup> Apical Crossing)**

The maneuver is executed at the n<sup>th</sup> chaser apical crossing after the threshold constraint.

CAUTION: to insure OMP convergence, minimum delta-height between the chaser's apogee and perigee must be > 10 nm.

### **NA (n<sup>th</sup> Apogee)**

The maneuver is executed at the n<sup>th</sup> apogee of the chaser's orbit after the threshold constraint, where n is the constraint's value.

### **NP (n<sup>th</sup> Perigee)**

The maneuver is executed at the n<sup>th</sup> perigee of the chaser's orbit after the threshold constraint, where n is the constraint's value.

### **OPT (Optimum Node Shift)**

The maneuver is executed at the optimum node shift point. This secondary constraint has no particular numeric value.

### **P (Angle from Perigee)**

The maneuver is executed at a desired central travel angle from the chaser's perigee. The angle is input in degrees.

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### **PER (n<sup>th</sup> Perigee)**

The maneuver is executed at the n<sup>th</sup> perigee of the chaser's orbit after the threshold constraint, where n is the constraint's value.

### **RAS (Right Ascension)**

The maneuver is executed at a desired Mean of 1950 right ascension of the ascending node. The angle is input in degrees.

### **TGTA (Target Apogee)**

The maneuver is executed at the n<sup>th</sup> target apogee after the threshold constraint, where N is the constraint's value.

### **TGTP (Target Perigee)**

The maneuver is executed at the n<sup>th</sup> target perigee after the threshold constraint, where N is the constraint's value.

### **U (Argument of Latitude)**

The maneuver is executed at the specified argument of latitude from the chaser's next ascending node. The angle is input in degrees.

#### **3.10.2.1.5 Lighting (Secondary) Constraints**

Table 3.10.2.1-6 and the following descriptions reference lighting (secondary) constraints supported by OMP. These constraints allow maneuver times to be based on lighting events. All constraint values are input in minutes from the event, where positive values are after the event. The rule of thumb is that dual vehicle maneuvers refer to target lighting while single vehicle maneuvers refer to chaser lighting. The exception is the first maneuver in a plan, which always refers to chaser lighting.



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### Lighting (Secondary) Constraints

<b>OMP</b>
LITI
LITM
LITO
NITI
NITM
NITO

**Table 3.10.2.1-6**

#### **LITI (Time from Sunrise)**

The maneuver is executed at a time relative to orbital sunrise. This is similar to the NITO lighting constraint.

#### **LITM (Time from Noon)**

The maneuver is executed at a time relative to orbital noon.

#### **LITO (Time from Sunset)**

The maneuver is executed at a time relative to orbital sunset. This is similar to the NITI lighting constraint.

#### **NITI (Time from Sunset)**

The maneuver is executed at a time relative to orbital sunset. This is similar to the LITO lighting constraint.

#### **NITM (Time from Midnight)**

The maneuver is executed at a time relative to orbital midnight.

#### **NITO (Time from Sunrise)**

The maneuver is executed at a time relative to orbital sunrise. This is similar to the LITI lighting constraint.

### **3.10.2.1.6 Other Secondary Constraints**

Table 3.10.2.2-8 and the following descriptions reference remaining secondary constraints supported by OMP. These constraints are used to modify maneuver solutions or to provide the OMP with desired relative state information.

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### Other Secondary Constraints

<b>OMP</b>
CXYZ
DH
DNOD
DPC
DR
DV
DVLS
DVLV
HD
ITSR
MREV
NULL
PHA
PIT
VFIL
WEDG
YAW

**Table 3.10.2.1-8**

#### **CXYZ (Curvilinear Offsets)**

This specifies the chaser relative X, Y and Z position in the target centered local vertical curvilinear coordinate system. The distances are input in nm. Positive distances are when the chaser is leading, below and to the right of the target. OMP expects these to be input in an X, Y, Z ordered triplet (e.g. CXYZ= -8.0, CXYZ=0.0, CXYZ=0.2 for Ti position when targeting an NCC maneuver).

#### **DH (Delta Altitude)**

This specifies a desired differential height at the chaser maneuver time with the target propagated along its actual orbit to a condition of phase match. The distance is input in nautical miles. Positive distances are when the chaser is below the target.

#### **DNOD (Delta Node)**

This specifies the amount of node shift desired when the NOSH maneuver is executed. The angle is input in degrees.

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### **DPC (Delta Plane Change)**

This specifies the amount of plane change desired when the PC maneuver is executed. The angle is input in degrees.

### **DR (Down Range Offset)**

This specifies the downrange position that is desired at the maneuver's TIG in nautical miles. Positive distances are when the chaser is leading the target.

### **DV (First Guess Delta Velocity)**

This supplies an initial guess of a minimum  $\Delta v$  magnitude for the chaser maneuver's NC and NH, in fps. This secondary constraint gives orbital wrap around capability for phasing. DV is used for NC maneuvers to insure convergence since OMP uses 0 fps for the default initial guess. DV is usually required for Orbital Maneuvering System (OMS) 2 phasing maneuvers since the default value of 0 fps for OMS-2 maneuvers will have the Orbiter re-enter the atmosphere during the OMP first iteration cycle, and hence, will "bomb" the rendezvous plan.

When used in conjunction with either the DVPY or DVYP maneuvers, this secondary constraint defines the total  $\Delta v$  magnitude of the maneuver.

### **DVLS (Line of sight Delta Velocity)**

This specifies the external delta velocity component in the line of sight X, Y and Z direction, in fps. OMP expects these to be input in an X, Y, Z ordered triplet.

### **DVLV (Local Vertical Delta Velocity)**

This specifies the external delta velocity component in the LVLH X, Y and Z direction for the EXDV maneuver, in fps. OMP expects these to be input in an X, Y, Z ordered triplet (e.g. DVLV=3.0, DVLV=0.0, DVLV=0.0 for a posigrade 3 fps maneuver).

### **HD (Height Desired)**

This specifies the desired chaser altitude to be achieved after 180 degrees of orbital travel from a HA or HASH maneuver, in nautical miles. Positive altitudes are when the chaser is above the surface of the Earth.

### **ITSR (Iterate on NSR)**

This is used to iterate on the NSR ignition time to achieve the desired elevation angle at TPI. This secondary constraint has no particular numeric value.

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### **MREV (Multiple Rev Lambert Targeting)**

This specifies the desired number of orbits between two Lambert targeted maneuvers. The sign of this secondary constraint allows the user to choose between the two possible Lambert solutions. In general,  $\text{sign}(\text{MREV}) = \text{sign}(\sin \Delta\nu)$ , where  $\Delta\nu$  is the delta-true-anomaly during the Lambert time-of-flight. Thus,  $\text{MREV} > 0$  produces a "short way" trajectory that may or may not be posigrade.

### **NULL (Null Y-dot)**

This specifies that the out-of-plane relative velocity between the chaser and target be nulled at the time of the chaser's maneuver. This secondary constraint has no particular numeric value.

### **PHA (Phase Angle)**

This specifies a phase angle, the angle from the target's position to the chaser's position from the center of the Earth, at the chaser maneuver time. The angle is input in degrees. Positive angles are when the chaser is behind the target.

### **PIT (Pitch)**

This specifies the pitch value for the DVPY or DVYP maneuvers in degrees.

### **VFIL (Maneuvering Vehicle Flag)**

This specifies which vehicle is maneuvering and which thrust profile it is using. The constraint value is input as  $xy$  where  $x$  is either 1 (chaser is maneuvering) or 2 (target is maneuvering) and  $y$  can be 1 through 5 to specify which of the five possible thrust profiles is to be used. The default is  $xy=11$ . The normal usage for target maneuvering is  $\text{VFIL}=21$ .

### **WEDG (Wedge Angle)**

This specifies wedge angle for the NPC maneuver to target at some future maneuver. This secondary constraint should be placed on the maneuver for which the desired wedge angle is to be achieved. For example, in order to target an NPC maneuver to put the chaser in the target's plane at  $T_i$ , a secondary constraint of  $\text{WEDG}=0.0$  should be placed on the SOI maneuver in the plan.

### **YAW (Yaw)**

This specifies the yaw value for the DVPY or DVYP maneuvers, in degrees.

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### **3.10.2.2 OMP Displays**

There are several displays that OMP uses for data input, execution, and viewing. Once a plan has been transferred to an ephemeris, other displays may be used to evaluate the ephemeris with the rendezvous plan in it. There is a section for each of the displays. A copy of the display along with a parameter definition will be given in each of these sections. The format for the parameter definitions will give the parameter on the left side of the page and the description on the right. After each description, the units of the parameter will be given in parenthesis, if applicable.

#### **3.10.2.2.1 Maneuver Constraints Table (MCT)**

The MCT is used to input maneuver constraints for the OMP to process when generating a rendezvous plan. A static version of this display can be accessed from the TSA menu under "Rendezvous Processors : Orbital Maneuver Processor" pull-down. This should be used for stand-alone processing on the user's local machine (no one else can view the data). A dynamic version of the MCT is located under the FDO DNAV under the "Mnvr/Rndz" menu. This defaults to TSA global system, which is utilized in real-time to permit FDO and other users to view inputs MARS is making. Three columns are provided to allow the user to specify maneuver type, primary constraint, and secondary constraints for each maneuver. The display is broken into forty rows, for the forty possible maneuvers in an MCT. The display definition of each of these forty slots is identical. When all inputs are complete, the user must press "Execute" (F2) to save the data. This stores a constraints file in the TSA/OMP/MCT sub-directory. Several other functions keys are available for online help, constraints verification, and inserting/deleting rows. Previously-stored constraints tables may be displayed by entering the plan name and pressing "Load File" (F1).

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**MCT – Maneuver Constraints Table (Static) v4.0**

LOCAL MANEUVER CONSTRAINTS TABLE D3\_FIX  
COMMENT: (null) MNVRS: 9 / 40 CURRENT

MANEUVER	THRESHOLD	SECONDARIES		
1 RA OMS-2	T 000:00:20:00.000	APD =1.0	HD =85.0	=
2 NC NC-1	M 2.0	DV =100	=	=
3 EXDV NC-2	M 9.0	DVLV =8.0	DVLV =0.0	DVLV =0.0
4 NPC NPC	M 2.0	CN =1.0	=	=
5 EXDV NC-3	M 3.0	DVLV =3.0	DVLV =0.0	DVLV =0.0
6 NH NH	T 001:14:49:35.000	=	=	=
7 NC NC-4	T 001:15:33:56.000	DR =-40.0	=	=

ACTION: D (D/C) RANGE: 1 COMPRESS: Y (Y/N)

LOAD FILE (F1)   EXECUTE (F2)   SAVE MENU (F3)   EXIT MENU (F4)   OVR & COPY/DEL (F6)   VERIFY CONSTRNT (F7)   INSERT MNVR (F8)   OMP EXECUTE (F9)

**Figure 3.10.2.2-1**

The following is a parametric description of the display.

Parameter	Description	Units
MCT Plan Name	Name associated with OMP plan	10 characters max.
MANEUVER	Maneuver ID	4 characters max.
THRESHOLD	Threshold constraint and associated value	4 characters max., plus XXX.XXX or DD:HH:MM:SS.SSS
SECONDARIES	Secondary constraint and associated values	4 characters max., plus XXX.XXX or DD:HH:MM:SS.SS

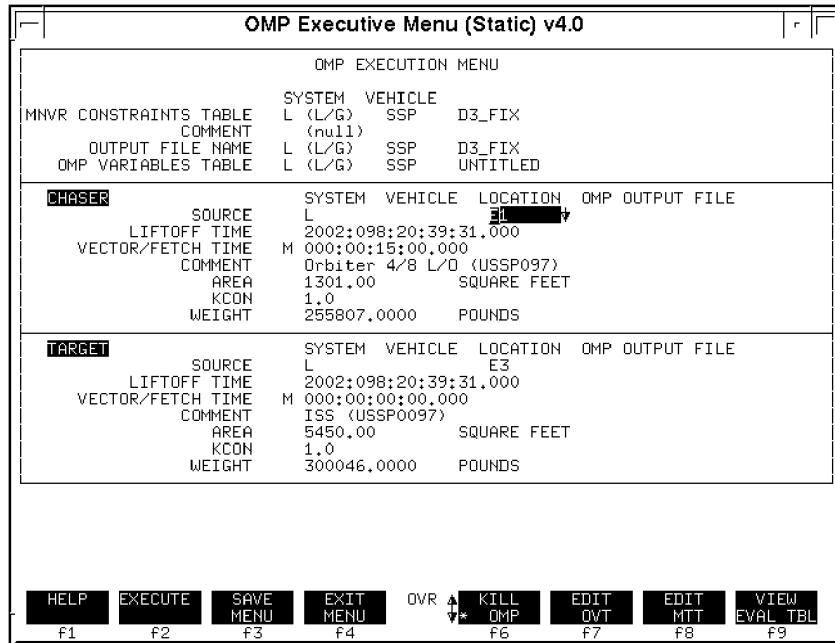
**NOTE:** foregoing time formats are in MET. A THRESHOLD time may optionally be entered in GMT using a yyyy:ddd:hh:mm:ss.sss format.

### 3.10.2.2.2 OMP Execution Menu

The OMP Execution Menu allows the user to run the OMP. It may be found under the TSA menu. The user must enter a constraints table name (including system designation). The output name will default to this name, but may be overridden. OMP variables filename, the "I-Loads" the OMP uses, may also be specified, but will default

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to the standard file if left blank ("UNTITLED"). Finally, chaser and target vectors and ballistic data are entered before the plan is processed by pressing "Execute" (F2).



**Figure 3.10.2.2-2**

The following is a parametric description of the display.

<u>Parameter</u>	<u>Description</u>	<u>Units</u>
MANEUVER CONSTRAINTS TABLE	System, vehicle, and MCT filename	
COMMENT	Comment associated w/MCT	
OUTPUT FILENAME	System, vehicle, and OMP output filename	
OMP VARIABLES TABLE	OMP variables being used for execution	
SOURCE	System, vehicle, and vector source	V## or E##
LIFTOFF TIME	GMTLO of source vector	YYYY:DDD:HH:MM:SS.SSS
VECTOR/FETCH TIME	Time-tag of source vector	GMT or MET
COMMENT	Comment string associated w/source vector or ephemeris	n.d.
AREA	Area to use in AEG propagation	square ft
KCON	Drag multiplier	n.d.
WEIGHT	weight to use in AEG propagation	lbs

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## 3.10.2.2.3 Maneuver Evaluation Table (MET)

After a plan is run, the output may be viewed on the Maneuver Evaluation Table (MET). A static version of the display can be accessed from the TSA main menu for stand-alone ops. Selecting "global" or "local" on the DNAV determines which TSA system this display accesses (normally "local" for stand-alone pre-mission work). A dynamic version of the MET can be found under the "FDO : Mnvr/Rndz" DNAV for real-time usage. This display shows plans stored in the global system, and updates whenever the plan is re-run. The user must enter the plan name and press "Load File" (F1).

MET - Maneuver Evaluation Table (Static) v4.0																																	
<b>LOCAL</b>		MANEUVER EVALUATION TABLE <b>D3_FIX</b>																															
COMMENT: (null)																																	
L SSP L SSP																																	
MCT : D3_FIX OVT : UNTITLED																																	
GMTR : 2002:098:20:39:31.000																																	
VECTOR TIME COMMENT																																	
CHASER L E1	M	000:00:15:00.000	Orbiter 4/8 L/O (USSP097)																														
TARGET L E3	M	000:00:00:00.000	ISS (USSP0097)																														
CHASER	$\Delta V_{tot}$ =	480.85	$\Delta V_x$ =	476.95	$\Delta V_y$ =	3.38 $\Delta V_z$ = 2.85																											
TARGET	$\Delta V_{tot}$ =	0.00	$\Delta V_x$ =	0.00	$\Delta V_y$ =	0.00 $\Delta V_z$ = 0.00																											
9 MNVRS																																	
MNVR	NAME	GMTIG	IMP	$\Delta V_x$	HA	RANGE																											
COMMENT		METIG		$\Delta V_y$	HP	PHASE																											
$\Delta V_{Mag}$		$\Delta T$		$\Delta V_z$	$\Delta H$	Noon/Mid -	Ydot SR/SS -																										
1	HA	098:21:17:58.982		97.34	123.26	1787.8215	-236829.9																										
	OMS-2	000:00:38:27.982		0.00	84.93	28.6229	-27.9																										
	97.3	000:02:56:40.103		0.00	86.84	N-00:38:06	SR-00:09:28																										
2	NC	099:00:14:39.085		15.25	122.72	174.6647	-224692.4																										
	NC-1	000:03:35:08.085		0.00	93.40	-2.3278	-25.9																										
	15.2	000:13:16:20.438		0.00	87.33	N-00:46:06	SR-00:17:25																										
3	EXDV	099:13:30:59.523		8.00	121.71	6716.3653	-131349.6																										
	NC-2	000:16:51:28.523		0.00	96.99	-137.1284	0.4																										
	8.0	000:03:22:42.009		0.00	88.68	M-00:34:13	SS-00:16:27																										
4	NPC	099:16:53:41.533		0.00	121.38	7172.5519	22632.4																										
	NPC	000:20:14:10.533		3.32	96.80	-170.3282	142.4																										
	3.3	000:03:59:55.312		0.00	106.84	M-00:16:08	SR-00:33:54																										
5	EXDV	099:20:53:36.845		3.00	120.93	6959.0116	-101624.3																										
	NC-3	001:00:14:05.845		0.00	98.34	149.1586	2.0																										
	3.0	000:14:35:29.155		0.00	89.33	N-00:07:02	SS-00:35:23																										
6	NH	100:11:29:06.000		195.14	210.27	254.1720	-864.7																										
	NH	001:14:49:35.000		0.00	116.63	3.7740	-2.2																										
	195.1	000:00:44:21.000		0.00	90.26	M-00:08:20	SR-00:26:10																										
<table border="0" style="width: 100%; text-align: center;"> <tr> <td>LOAD</td> <td>HELP</td> <td>HARDCOPY</td> <td>EXIT</td> <td>OVR</td> <td>EDIT</td> <td>OMP</td> <td>MNVR</td> <td>EDIT</td> </tr> <tr> <td>FILE</td> <td></td> <td></td> <td>MENU</td> <td>*</td> <td>MCT</td> <td>EXECUTE</td> <td>SUMMARY</td> <td>MTT</td> </tr> <tr> <td>F1</td> <td>F2</td> <td>F3</td> <td>F4</td> <td></td> <td>F6</td> <td>F7</td> <td>F8</td> <td>F9</td> </tr> </table>							LOAD	HELP	HARDCOPY	EXIT	OVR	EDIT	OMP	MNVR	EDIT	FILE			MENU	*	MCT	EXECUTE	SUMMARY	MTT	F1	F2	F3	F4		F6	F7	F8	F9
LOAD	HELP	HARDCOPY	EXIT	OVR	EDIT	OMP	MNVR	EDIT																									
FILE			MENU	*	MCT	EXECUTE	SUMMARY	MTT																									
F1	F2	F3	F4		F6	F7	F8	F9																									

Figure 3.10.2.2-3



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The following is a parametric description of the display.

<u>Parameter</u>	<u>Description</u>	<u>Units</u>
MANEUVER EVALUATION TABLE COMMENT	OMP output filename	
MCT	System, vehicle, and MCT filename	
OVT	System, vehicle, and OMP Variables filename	
GMTR	GMTLO of source vectors	
VECTOR	System, vehicle, and vector source	V## or E##
TIME	Time-tag of vector source	MET
COMMENT	Comment string associated w/source vector or ephemeris	
$\Delta V_{tot}$	Total plan $\Delta v$ magnitude	fps
$\Delta V_{x, y, z}$	Sum of the LVLH $\Delta V_{x, y, z}$ magnitudes	fps
MNVR NAME, COMMENT	Maneuver type & comment from MCT	
$\Delta VMAG$	$\Delta v$ RSS of LVLH burn components	fps
GMTIG, METIG	Impulsive GMT, MET of ignition	DDD:HH:MM:SS.SSS
$\Delta T$	Time until next mnvr	DDD:HH:MM:SS.SSS
$\Delta V_{x, y, z}$	Cartesian components of $\Delta v$ in Orbiter-centered LVLH coordinates	fps
HA, HP	Chaser apsis altitude above a spherical Earth at the maneuver's burnout	nm
$\Delta H$	Chaser altitude minus target altitude at phase match with the chaser at the maneuver's TIG	nm
RNG	Distance between the chaser and target at the maneuver's TIG	nm
PHASE	Phase angle between the chaser and target at the maneuver's TIG. + if chaser is trailing the target	deg
NOON/MID	Time from TIG until next orbital noon or midnight for target	HH:MM:SS
Y	Distance of the chaser from the target's orbital plane at the maneuver's TIG. Plus indicates displacement in the minus H-bar direction.	feet

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YDOT	Chaser's out-of-plane velocity at the maneuver's burnout (+ if Y is increasing)	fps
SR/SS -	Time from TIG until next orbital sunrise or sunset for target	HH:MM:SS

### 3.10.2.2.4 Maneuver Transfer Table (MTT)

A rendezvous plan may be transferred to an ephemeris after it has been generated. The OMP computes an impulsive TIG and LVLH  $\Delta v$  components, but the ephemeris, which uses PFNI, the finite burn processor, needs more information about the burn. PFNI requires the chaser vehicle's thruster selection and thrust vector roll angle (TVR) in order to compute burn attitude, plus guidance mode. The Maneuver Transfer Table (MTT) is used to define this information before a plan is transferred to an ephemeris—it essentially allows the burn to be converted from impulsive to finite. Figure 3.10.2.2-4 is a copy of the MTT. As with other TSA displays, local and global versions are available on the TSA main menu. A dynamic version slaved to global is available on the FDO DNAV, and should be used in real-time.

At the bottom of the MTT are ten slots where different configurations may be defined. A standard SSP configuration is provided when the display is first called, but this may be altered. At the top of the display are forty rows for maneuver definitions, one for each potential maneuver in the plan. To fill in the maneuvers, the user must enter the plan name and press "Load File" (F1). Transfer characteristics for each maneuver are then specified by entering a slot ID from the bottom of the display. The user may override any of these manually for a particular maneuver. When all transfer characteristics have been defined for all maneuvers, "Execute" (F2) is pressed to save the file.

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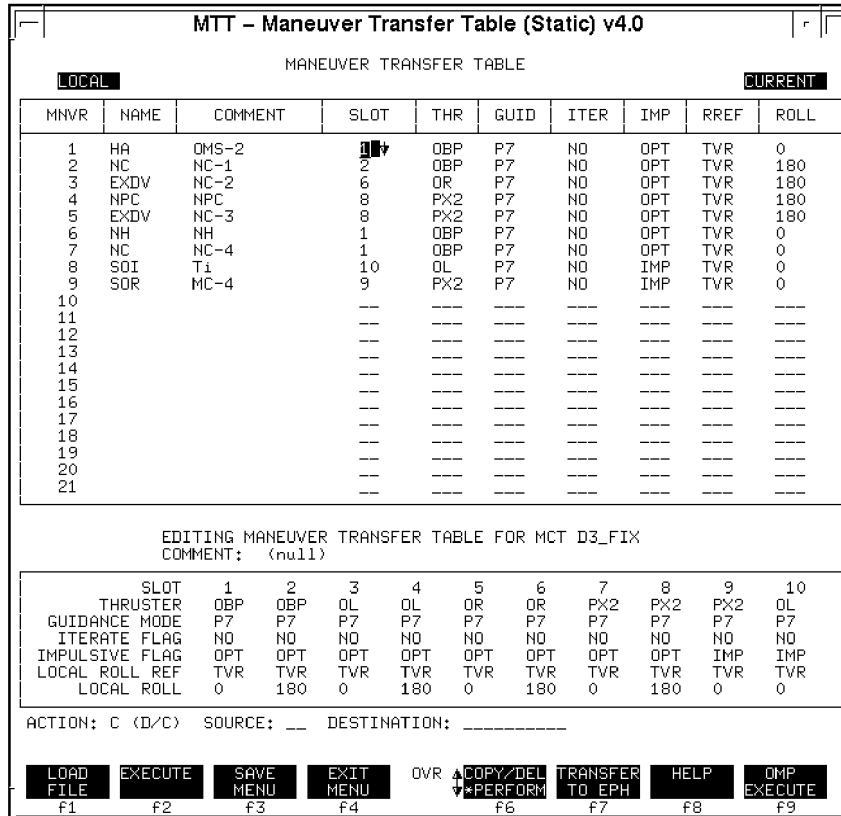


Figure 3.10.2.2-4

The following is a parametric description of the display.

Parameter	Description	Units
MNVR	Maneuver number	1-40
NAME	Maneuver type	4 characters
COMMENT	Comment associated w/mnvr	10 characters max.
SLOT	Slot number to reference characteristics from table below	
THRUSTERS	Thruster selection for the maneuver	PX4, PX3, PX2, MXL, YL, MYL, ZH, ZL, MZH, MZL, M1, M2, OL, OR, OBP, LOZ, PXA, MEP
GUID	Guidance mode for the maneuver	M50 or P7
ITER	Iteration flag	YES, NO*
IMP	Impulsive/Optimize flag	IMP, OPT**
RREF	Local roll reference for the maneuver	ADI or TVR
ROLL	Local roll angle for the maneuver	deg

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Multiple iterate and impulsive flag combinations can be confusing. To understand them, it is best to first know how the OMP models maneuvers. It determines the change in velocity that is required and then adds these velocity changes instantaneously. This is not very realistic, especially for large maneuvers. These two flags are used to define how the maneuvers calculated by the OMP are to be modeled in the ephemeris. The following table summarizes the flag combinations and the resultant post-burn orbital elements comparison when transferring an OMP maneuver plan to an ephemeris.

<b>OMP-ephem COMPARISON</b>	<b>ITERATE</b>	<b>IMPULSIVE</b>	<b>MODIFIES</b>
BEST	YES	OPT	DV and TIG
	YES	IMP	DV
	NO	OPT	TIG
WORST	NO	IMP	nothing

\*The iterate flag may be set to either iterate (YES) or do not iterate (NO). If NO is selected, the maneuver will be transferred as is, taking into account the impulsive flag below. If YES is chosen, the maneuver's attitude and delta velocity will be altered such that the post-burn orbital elements match the OMP post-burn elements to within specified tolerances. For dual vehicle targeting, the iterate flag is normally set to NO, since MARS manually iterates on the OMP solution to account for propagation differences. (Recall that OMP uses Analytical Ephemeris Generator (AEG) with constant area, while the TrS uses a higher-fidelity Encke with variable area drag normally turned on and possibly vents present in the Vent Timeline (VTL)). The manual-iteration solution converges faster if the OMP iterate feature is disabled, so as not to interfere with MARS' manual iteration on relative position offsets. For single-vehicle operations such as a height-adjust/circularization plan, it is appropriate to turn on this flag since it is desirable in this case for the post-burn orbit in the TrS ephemeris to closely match that of the OMP Eval Table.

\*\*The impulsive flag may be set to either IMPulsive (IMP) or OPTimize (OPT) to control TIG selection during the transfer to the ephemeris. If OPT is chosen, the maneuver's burn arc is taken into account by "splitting the TIG". That is, the transferred TIG is set equal to the OMP TIG minus one-half of the length of the burn. The OMP's impulsive delta velocities, converted to the inertial frame, are then applied to the burn. When IMP is chosen, the transferred TIG is the same as the OMP-computed TIG, resulting in a net TrS-OMP difference in LVLH burn components due to the finite burn arc (a radial component shows up in the DMT PEG-7  $\Delta v$  components). In normal practice, the impulsive flag is set to OPT for any non-Lambert burns in order to center the burn arc about the impulsive TIG. This is extremely important for big burns (> 50 fps) that have a significant burn arc. On day of rendezvous, NCC, Ti, and all mid-course burns are transferred as IMP so that the same TIG is used consistently between ground and onboard, to assure that the timeline in the Rendezvous Checklist is adhered to.



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The following is a parametric description of the display.

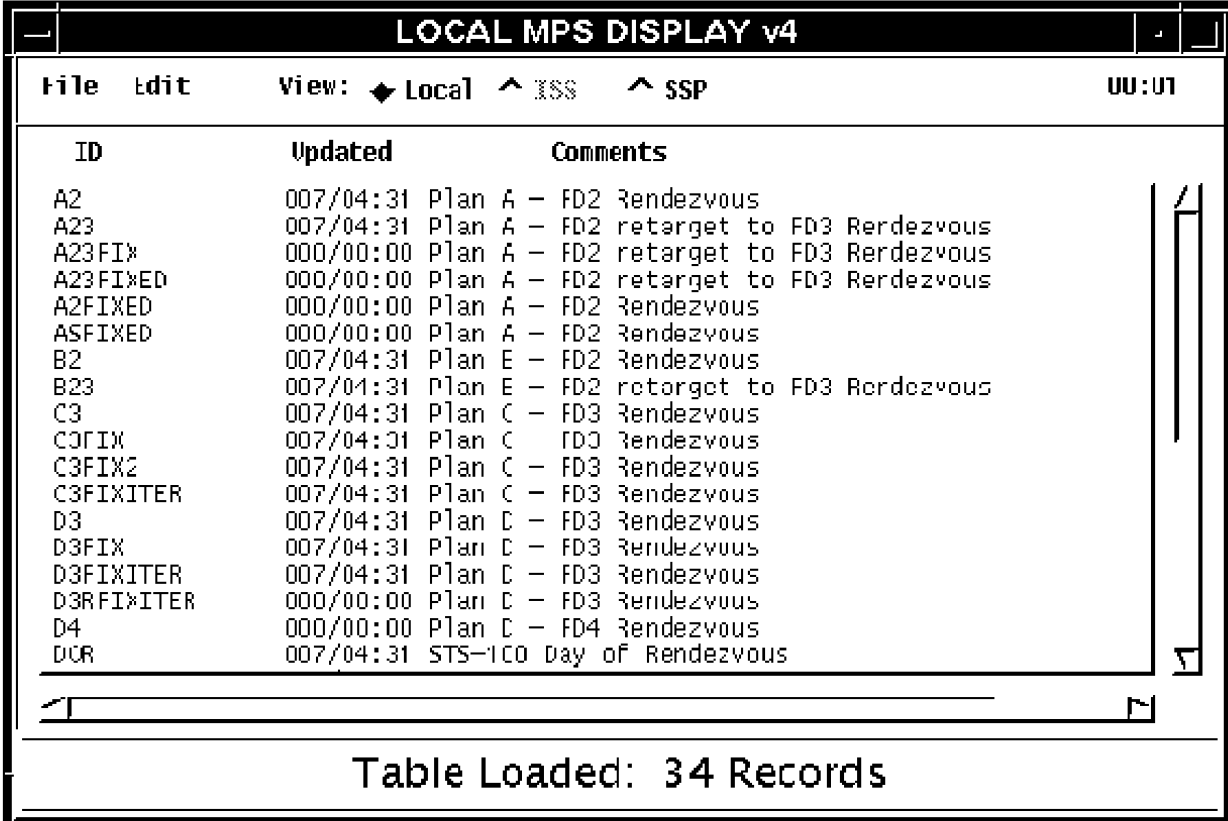
<u>Parameter</u>	<u>Description</u>	<u>Units</u>
OMP OUTPUT FILE	OMP output filename	
COMMENT	Comment associated with MCT	
MCT	System, vehicle, and MCT filename	
OVT	System, vehicle, and OMP Variables filename	
GMTR	GMTLO of source vectors	
VECTOR	System, vehicle, and vector source	V## or E##
TIME	Time-tag of vector source	MET
COMMENT	Comment string associated w/source vector or ephemeris	
CHASER EPH	Chaser ephemeris for transfer; system and number	L, G, M, ##
TARGET EPH	Target ephemeris for transfer; system and number	L, G, M, ##
DELETE FROM MNVR #	Mnvr number from which to delete from (xfer replaces mnvrs)	##
NAME	Maneuver type	4 characters
CHAR	MTT characteristics defined?	Yes/No
TRANSFER?	Transfer mnvr to eph?	Y/N
COMMENT	Comment associated w/mnvr	10 characters max.

### 3.10.2.2.6 Maneuver Plan Status (MPS) Display

The Maneuver Plan Status (MPS) display provides an overview of the maneuver plans created by executing the Maneuver Constraints Table (MCT) program. It is handy for identifying what plan names are available. It is also a user interface for copying, pasting and deleting of plans from global to local, as well as launching the other OMP processors editing and executing a particular plan. MPS is a dynamically updated display that shows the name of each plan, the elapsed time since it was last modified, and its associated comment text. The source of the display is the MCT summary file which is checked every five seconds for changes. See Figure 3.10.2.2-6.

The user can highlight one or more plans on the display with a left mouse click, then either click the Edit Pulldown or right-click to get the popup menu to perform operations on the highlighted plan(s). Operations include cut, copy, delete, paste and launch an instance of a particular OMP processor for each of the highlighted plans. Copy/paste or cut/paste operations can be performed between different views (Global SSP, Global ISS, Local) and between different instances of MPS. OMP programs launched from MPS will be executed in dynamic mode and will use the highlighted plan at startup.

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The screenshot shows a terminal window titled "LOCAL MPS DISPLAY v4". The menu bar includes "File", "Edit", "View: Local", "ISS", "SSP", and "UU:01". The main area contains a table with three columns: "ID", "Updated", and "Comments". The table lists various rendezvous plans (A2, A23, B2, C3, D3, D4) and their associated dates, times, and plan identifiers. A status bar at the bottom of the window reads "Table Loaded: 34 Records".

ID	Updated	Comments
A2	007/04:31	Plan A - FD2 rendezvous
A23	007/04:31	Plan A - FD2 retarget to FD3 Rendezvous
A23FIX	000/00:00	Plan A - FD2 retarget to FD3 Rendezvous
A23FIXED	000/00:00	Plan A - FD2 retarget to FD3 Rendezvous
A2FIXED	000/00:00	Plan A - FD2 rendezvous
ASFIXED	000/00:00	Plan A - FD2 rendezvous
B2	007/04:31	Plan E - FD2 rendezvous
B23	007/01:31	Plan E - FD2 retarget to FD3 Rendezvous
C3	007/04:31	Plan C - FD3 rendezvous
C3FIX	007/04:31	Plan C - FD3 rendezvous
C3FIX2	007/04:31	Plan C - FD3 rendezvous
C3FIXITER	007/04:31	Plan C - FD3 rendezvous
D3	007/04:31	Plan C - FD3 rendezvous
D3FIX	007/04:31	Plan C - FD3 rendezvous
D3FIXITER	007/04:31	Plan C - FD3 rendezvous
D3RFIXITER	000/00:00	Plan C - FD3 rendezvous
D4	000/00:00	Plan C - FD4 rendezvous
DCR	007/04:31	STS-100 Day of Rendezvous

Table Loaded: 34 Records

Figure 3.10.2.2-6

### 3.10.2.2.7 Errors and Advisories

The various OMP menu output advisory messages to the TSA advisory line located just above the function key line. If a plan fails to run and no reason is output, then the OMP Execute menu offers some assistance in troubleshooting. The F6 function key kills a plan that may be hung up. Another function key is available to view the OMP log file, which may contain further messages. Finally, TSA pop-up messages provide other feedback, such as plan completed, or maneuver transfer failed.

### 3.10.2.2.8 Operational Notes

Several operational notes should be mentioned which are due to either bugs in the software or OMP design considerations which may not be completely obvious. Software errors described in this section have not been fixed because simple work-arounds have been implemented to avoid the problem. The rest of this section lists the operational notes.

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- 1) Only one phasing (NC) maneuver may be targeted for the same phase constraint. OMP achieves the proper phasing from the first phasing maneuver, so a second is not required. Two work-arounds are commonly used for this problem. One is to model all but one phasing maneuver as EXDV maneuvers, manually assigning the desired delta velocities required for those phasing maneuvers. Another is to have one phasing constraint for each phasing maneuver. For example, if three phasing maneuvers are planned in a row, then a phasing constraint is put on the second phasing maneuver to satisfy the first phasing maneuver. Do likewise on the third maneuver. To satisfy the third phasing maneuver, put the ultimate phasing constraint desired on some maneuver after the third phasing maneuver.
- 2) The lighting condition logic is supposed to search forward from the threshold time. However, this is not the case for the OMP, as it may search in either direction. The location of the maneuver could be in error by one orbit which the user must be able to identify. The only fix is to change the threshold time until the desired condition is found.
- 3) The common node search logic and the zero wedge angle constraint logic have difficulty for orbits that are close to coplanar (4000 feet out of plane separation or 0.01 degrees wedge angle). The user should not target an NPC maneuver for a node or use the WEDG constraint if the chaser and target are in near coplanar orbits. The Lambert maneuver pairs do not have this problem and should be used for final corrections.
- 4) For Lambert maneuvers, a singularity exists for transfers of 0, 180 and 360 degrees. 180 degree transfers are acceptable, but there will be no planar control, and  $\Delta V_y$  will be set equal to zero. A multi-rev Lambert targeting capability exists for SOI/SOR and NCC in OMP.
- 5) The maneuver transfer logic occasionally breaks down when transferring a plan into an ephemeris when a maneuver being transferred has the ITERATE FLAG in the Maneuver Transfer Table set to YES. If this happens, the ITERATE FLAG can be set to NO and the problem should not occur again.
- 6) The sign of the out-of-plane value displayed on the MET is positive in the direction of the orbital angular momentum vector. This is reversed from the positive direction of the curvilinear coordinate system used in the Relative Motion Digitals.
- 7) The OMP uses a zero delta velocity for all maneuvers on the first iteration. This will cause errors on some orbits, such as a Main Engine Cutoff (MECO) orbit where OMS-2 is being computed as a phasing burn, and a re-entering trajectory is obtained as a result of the zero  $\Delta v$  assumption. A fix is to use the DV secondary constraint on the maneuver causing the problem, which specifies the initial guess at  $\Delta v$  for the burn.



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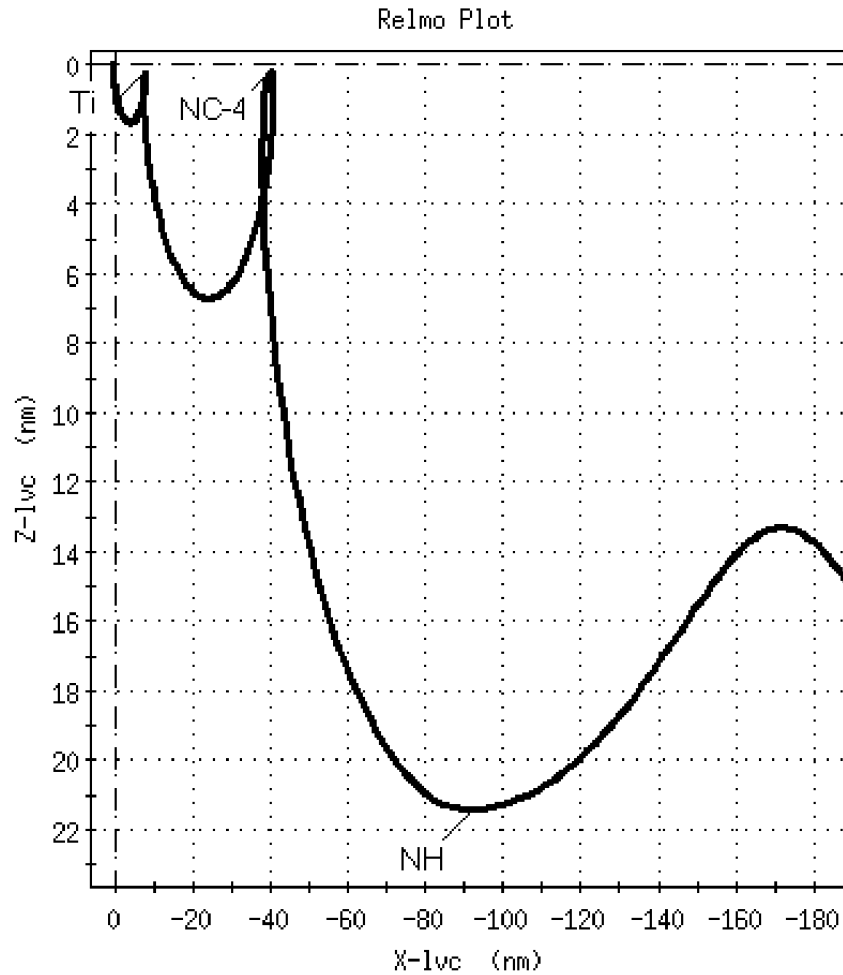
- 8) An elevation angle constraint on the first maneuver is illegal if the chaser and target states are identical.
- 9) A secondary constraint of APS will sometimes cause a max iterations error message to appear on the MET and the returned TIG to be incorrect. This is a permanent limitation. It is caused by attempting to find an apsis in a nearly circular orbit (eccentricity less than or equal to 0.005). A possible work around is to obtain the time of apsis crossing with TSA Checkout Monitor. This time can then be used in the MCT without an APS constraint. One consideration is that any change to the trajectory before the maneuver in question will cause the time of apsis to change, making an iteration process necessary.

### 3.10.2.3 Running the OMP

Up to this point, you have been provided with lists of maneuver constraints and descriptions of displays. This section will illustrate how to put it all together to actually generate a rendezvous plan. A generic ISS-type profile will be used in this example.

An example of relative motion of the Shuttle with respect to the target is presented in Figure 3.10.2.4-1. This shows a typical "1 rev to Ti" DOR profile. It is so-named since one orbit takes place between the final phasing burn on the morning of rendezvous and the Ti burn. Other profiles, particularly deploy-retrieves, often use 2 rev transfers when crew timeline constraints permit. The resultant plan consists of four maneuvers. The maneuvers are:

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**Figure 3.10.2.4-1**

- **NH** is a height adjust burn executed on the morning of rendezvous to place Ti 1200 feet below the Vbar
- **NC-4** is a phasing maneuver executed 0.5 rev after NH to place Ti at 8 nautical miles behind the target. On the evening before rendezvous, NC-3 (not included here) targets this burn to be 40 nm behind the target.
- **Ti** is a Lambert burn executed 1 rev after NC-4 to place the chaser on a near-intercept trajectory with the target. This is modeled as SOI in the OMP.
- **SOR** (not shown) is second maneuver of the Lambert pair to place the chaser on a stable trajectory about the target.

The trajectory problem will be solved one step at a time. First, a constraints table must be built to uniquely define the plan. The MCT must be set up with the correct sequence of maneuvers and constraints in order to provide valid data to the OMP. One important requirement is that the primary constraint of maneuver 1 be *time*. For stand-alone ops

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(e.g. pre-flight planning), the Lead FDO will normally generate the plan in the TSA local area using the MCT display. For real-time ops, MARS will prepare the MCT in the global area so that FDO and others can view the output. The following descriptions correspond to the maneuvers in Figure 3.10.2.4-2.

### Maneuver 1 (NH):

Used to adjust the height of the chaser relative to the Vbar at  $T_i$ . It will be modeled as an **NH** with a primary constraint of time (**T**) so that it will occur 1.5 revs prior to the planned  $T_i$  time (which is based on lighting). The desired height to be achieved is 1200 feet below the target's minus velocity vector, commonly called the "minus Vbar". This corresponds to a secondary constraint **DH** of 0.2 nm which must be placed on maneuver 3 (**SOI**). The sign convention for DH is the same as LVLH, therefore below the Vbar is positive.

### Maneuver 2 (NC):

Used to phase the chaser to 8 nm behind the target at  $T_i$ . It is modeled as an **NC** with a primary constraint of **M** so that it will occur 0.5 rev after NH. The downrange constraint that NC targets is a **DR** of -8 on maneuver 3 (**SOI**). Sign convention for DR corresponds to the direction on the Vbar.

### Maneuver 3 (SOI, "Ti"):

Used to place the chaser on a near-intercept trajectory with the target. It is modeled as an **SOI** with a primary constraint of **M** so that it will occur 1 rev after NC-4. Remember that **SOI** is the first maneuver in a Lambert pair and must be followed by an **SOR**. **SOI** targets the curvilinear offset constraints on the **SOR** maneuver, which should comply with ORBT rendezvous ILOADs. Therefore, maneuver 4 ("intercept") must have three secondary constraints for this offset: **CXYZ**= -0.1481, **CXYZ**= 0.0 and **CXYZ**= 0.2962. CXYZ secondary constraints are an "ordered triplet" for X, Y, and Z location in target-centered local vertical curvilinear coordinate system. The distances are input in nm, with positive distances for chaser leading, to the right of, and below the target. In this case, the **CXYZ** secondaries represent the MC-4 position with the chaser 900 ft behind and 1800 ft below the target.

### Maneuver 4 (SOR) :

This maneuver is used to achieve a stable orbit with the target. It is modeled as an **SOR** with a primary constraint of **DT** so that it will occur 1 hr 16 min 54 sec minutes after  $T_i$ , again based on ORBT ILOADs. This results in SOR TIG matching MC-4 TIG. **DT** can be found in the Reference Data section of the Rendezvous Checklist along with the other Lambert ILOADs. **SOR** does not allow the user to enter any future constraints for it to target. Recall that **SOR** is Lambert-targeted to re-intercept the same SOR offset position after 270 degrees of orbital travel, effectively setting up a very small football around the MC-4 position. **SOR** approximates the  $\Delta v$  of MC-4 to target for 600 ft below the Vbar and is the start of manual phase.

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**MCT - Maneuver Constraints Table (Static) v4.0**

LOCAL MANEUVER CONSTRAINTS TABLE DOR

COMMENT: Sample DOR plan MNVRS: 4 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 NH DOR NH	T 001:13:48:22,000	---	---	---
2 NC NC-4	M 0,5	---	---	---
3 SOI Ti	M 1,0	DR =-8,0	DH =0,2	---
4 SOR MC-4	DT 000:01:16:54,000	CXYZ =-0,1481	CXYZ =0,0	CXYZ =0,2962
5 -----	-----	---	---	---
6 -----	-----	---	---	---
7 -----	-----	---	---	---

ACTION: D (D/C) RANGE: 1-5 COMPRESS: Y (Y/N)

LOAD FILE EXECUTE SAVE MENU OVR COPY/DEL VERIFY INSERT OMP  
 F1 F2 F3 F4 \*PERFORM CONSTNT MNVR EXECUTE  
 F6 F7 F8 F9

**Figure 3.10.2.4-2**

Note that each maneuver in the MCT above has a comment below each maneuver type specifying the "common name" of the maneuver. This is a good practice, since it makes the MCT and MET output more readable for external customers. When all updates to the MCT are complete, the table must be saved (F2).

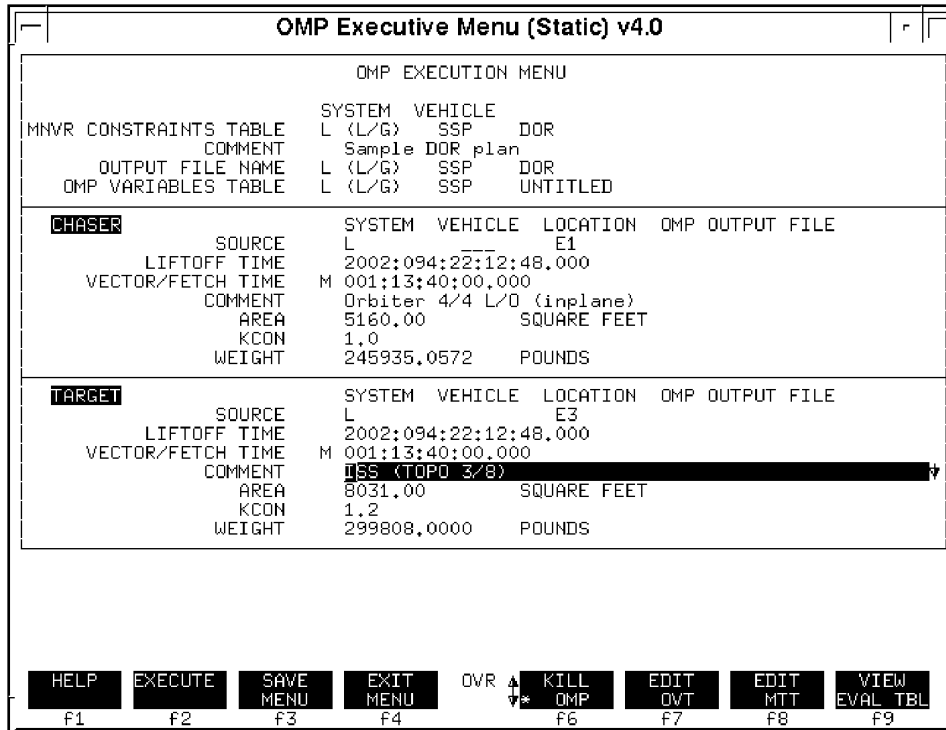
The OMP Execution menu is used to run a plan. First verify ephemeris configuration for Orbiter and target on Traj Profile Status display (valid vector, area, weight, KCON, ATL, VTL). This is of vital importance since a plan is only as good as the vectors that were used to initialize it. Similarly, if running off vectors instead of ephemerides, verify they are valid. The chaser and target vectors/ephemerides must have identical liftoff times in order for the OMP to run. On a related note, the global liftoff time must be set correctly in order to run off onboard vectors. Otherwise, the vector time-tags will be in error and invalid  $\Delta v$  output will be obtained. Then the OMP may be run from the Execute menu using the following inputs (Figure 3.10.2.5-3).

- 1) MCT system (global or local) and name (standard console procedure is to use same output filename as MCT filename in order to avoid confusion)
- 2) Chaser system, location (V# or E#), fetch time, and drag characteristics
- 3) Target system, location (V# or E#), fetch time, and drag characteristics

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**NOTE:** vector time-tag or fetch time from ephemeris should be > 5 min prior to first maneuver TIG in the MCT.

**WARNING:** you must press <return> after typing in vector location into the OMP menu in order to fetch the latest vector or ephemeris. Failure to do so may result in old source data being used for the OMP run.



**Figure 3.10.2.5-3**

Note that MARS performs all of these inputs during real-time ops, based simply on the que from FDO to "run plan DOR using eph 1 and 3". The OMP is executed with an F2. Other buttons are available to grab onboard vectors and run the plan. For our example, the resultant MET is shown Figure 3.10.2.5-4. Note the achieved range and delta-height at Ti.

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**MET - Maneuver Evaluation Table (Static) v4.0**

**LOCAL** MANEUVER EVALUATION TABLE **DOR**  
 COMMENT: Sample DOR plan  
 L SSP L SSP  
 MCT : DOR OVT : UNTITLED

GMTR : 2002:094:22:12:48,000

VECTOR TIME COMMENT  
 CHASER L E1 M 001:13:40:00,000 Orbiter 4/4 L/O (inplane)  
 TARGET L E3 M 001:13:40:00,000 ISS (TOPO 3/8)

CHASER  $\Delta V_{tot}$  = 60.24  $\Delta V_x$  = 59.76  $\Delta V_y$  = 0.20  $\Delta V_z$  = 1.90  
 TARGET  $\Delta V_{tot}$  = 0.00  $\Delta V_x$  = 0.00  $\Delta V_y$  = 0.00  $\Delta V_z$  = 0.00 **4** MNVRS

MNVR NAME COMMENT $\Delta V_{Mag}$	GMTIG IMP METIG $\Delta T$	$\Delta V_x$ $\Delta V_y$ $\Delta V_z$	HA HP $\Delta H$	RANGE PHASE Noon/Mid -	Y Ydot SR/SS -
1 NH DOR NH 22.9	096:12:01:10.000 001:13:48:22.000 000:00:46:55.000	22.94 0.00 0.00	208.52 185.70 21.32	96.0833 1.4740 21.32 N-00:45:55	-579.6 -0.5 SR-00:16:41
2 NC NC-4 24.8	096:12:48:05.000 001:14:35:17.000 000:01:32:16.000	24.85 0.00 0.00	208.90 198.77 0.20	41.7768 0.6554 M-00:45:05	336.4 0.2 SS-00:28:01
3 SOI Ti 9.5	096:14:20:21.000 001:16:07:33.000 000:01:16:54.000	9.50 0.05 -0.31	209.89 202.71 0.20	8.0020 0.1255 M-00:45:06	153.3 0.1 SS-00:28:00
4 SOR MC-4 2.9	096:15:37:15.000 001:17:24:27.000 000:00:00:00.000	2.47 -0.14 1.58	210.00 204.00 0.30	0.3293 0.0023 N-00:14:19	3.8 0.0 SS-00:43:10

**LOAD FILE** **HELP** **HARDCOPY** **EXIT MENU** **OVR** **EDIT MCT** **OMP EXECUTE** **MNVR SUMMARY** **EDIT MTT**  
 F1 F2 F3 F4 F6 F7 F8 F9

**Figure 3.10.2.5-4**

The next step in plan development is to configure the MTT. A definition for each maneuver in the plan must exist before the plan can be transferred. An MTT can be brought up by pressing F9 on the MET display. The plan name is typed in and loaded (F1). Then each maneuver can be assigned characteristics from the 10 standard slots at the bottom of the display, or specified individually. F2 is pressed to create the MTT file. The resultant MTT is shown in Figure 3.10.2.5-5.

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**MTT – Maneuver Transfer Table (Static) v4.0**

MANEUVER TRANSFER TABLE

**LOCAL****CURRENT**

MNVR	NAME	COMMENT	SLOT	THR	GUID	ITER	IMP	RREF	ROLL
1	NH	DOR NH	1	OBP	P7	NO	OPT	TVR	0
2	NC	NC-4	1	OBP	P7	NO	OPT	TVR	0
3	SOI	Ti	10	OL	P7	NO	IMP	TVR	0
4	SOR	MC-4	9	PX2	P7	NO	IMP	TVR	0
5			---	---	---	---	---	---	---
6			---	---	---	---	---	---	---
7			---	---	---	---	---	---	---
8			---	---	---	---	---	---	---
9			---	---	---	---	---	---	---
10			---	---	---	---	---	---	---
11			---	---	---	---	---	---	---
12			---	---	---	---	---	---	---
13			---	---	---	---	---	---	---
14			---	---	---	---	---	---	---
15			---	---	---	---	---	---	---
16			---	---	---	---	---	---	---
17			---	---	---	---	---	---	---
18			---	---	---	---	---	---	---
19			---	---	---	---	---	---	---
20			---	---	---	---	---	---	---
21			---	---	---	---	---	---	---

EDITING MANEUVER TRANSFER TABLE FOR MCT DOR  
COMMENT: Sample DOR plan

SLOT	1	2	3	4	5	6	7	8	9	10
THRUSTER	OBP	OBP	OL	OL	OR	OR	PX2	PX2	PX2	OL
GUIDANCE MODE	P7	P7	P7	P7	P7	P7	P7	P7	P7	P7
ITERATE FLAG	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
IMPULSIVE FLAG	OPT	OPT	OPT	OPT	OPT	OPT	OPT	OPT	IMP	IMP
LOCAL ROLL REF	TVR	TVR	TVR	TVR	TVR	TVR	TVR	TVR	TVR	TVR
LOCAL ROLL	0	180	0	180	0	180	0	180	0	0

ACTION: C (D/C) SOURCE: \_\_ DESTINATION: \_\_\_\_\_

LOAD FILE

EXECUTE

SAVE MENU

EXIT MENU

OVR

COPY/DEL

TRANSFER TO EPH

HELP

OMP EXECUTE

f1
f2
f3
f4
f6
f7
f8
f9

**Figure 3.10.2.5-5**

Now the plan is ready to be transferred to either a TSA or TrS ephemeris. To do this, press F7 on the MTT display to bring up the Transfer to Ephemeris menu (Figure 3.10.2.5-6). Then load the plan (F1), fill in the appropriate destination data (normally chaser only, although target is allowed if appropriate secondary constraints are utilized). "Delete from Mnvr #" should be left blank if it is desired to insert the maneuvers, rather than replace. Press F2 to execute the transfer. Note that system M refers to TrS (leftover from MOC days).





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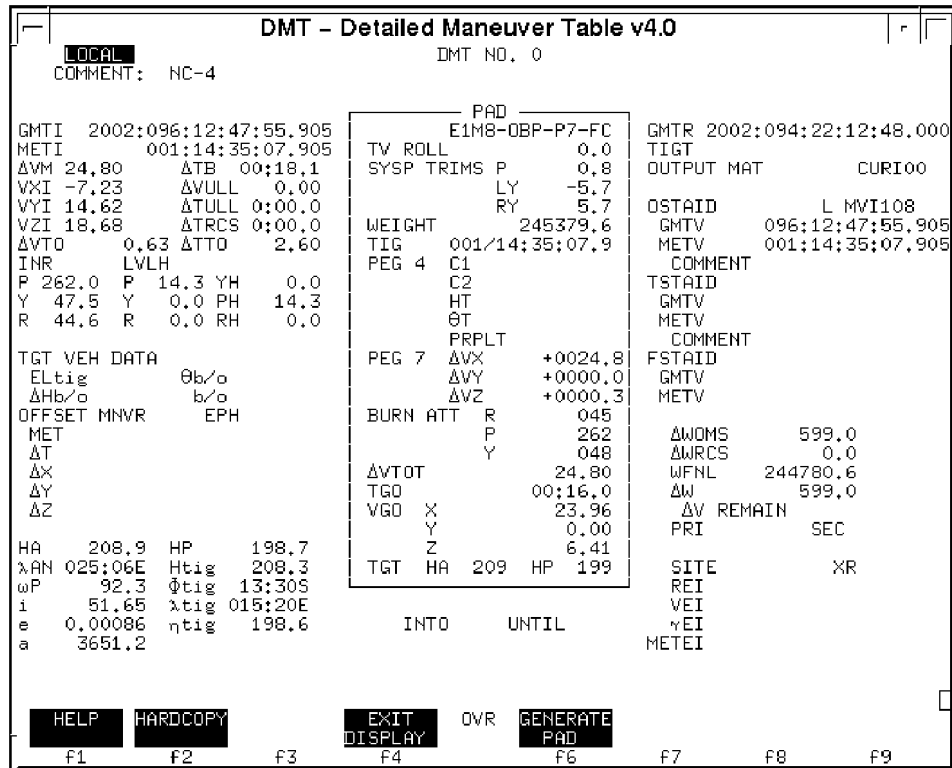


Figure 3.10.2.5-7

### 3.10.3 Pre-mission Planning

This section is intended to provide details on the work that the rendezvous FDO (RFDO) is responsible for during the mission design phase. In order to complete many of the tasks outlined below, it is important for the RFDO to configure a TSA save area for his or her mission. This is necessary to perform TIG slip analyses, provide vectors to DT, post data to the FDO website, and fill up the FDO Console Databook with required information. An early start at building the TSA save area will put RFDO ahead of the curve. By approximately L-9 months (Flight Operations Panel (FOP) timeframe), ONOR-29 is completed by Flight Design. This contains post-MPS dump vectors for both the Orbiter and target that can be used to initialize the TSA trajectory. RNDZ-02 contains area and weight information on the target to configure the TSA constant-area drag ephemeris for the target. Using the FOP Flight Design overview, rendezvous constraints tables can be input into TSA to allow generation of a rendezvous plan closely matching what flight design has. Now the RFDO is ready to begin the gradual process of transitioning responsibility for the trajectory from Flight Design to the FDO console. Since the RFDO for a rendezvous mission is usually the Lead FDO, some of the tasks below are also documented in the Lead FDO Handbook.

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### 3.10.3.1 Navigation, Tracking, and Crew Timeline

At approximately L-3 months, the lead NAV will lay out a preliminary tracking plan for the entire mission. This plan will specify which ground radars will be used to track the Shuttle and target each orbit. For the Shuttle, ground radars will supplement TDRS tracking; for non-transponder equipped target vehicles, ground radars will be the only available source of tracking information<sup>5</sup>. Of particular importance to the RFDO is the pre-day of rendezvous (DOR) and DOR ground radar availability and scheduling. DOR itself is classified as a "complex" timeframe, requiring state vector quality of the highest level to ensure (a) accurate initialization of onboard relative navigation via ground uplink, and (b) accurate ground-targeted burn solutions. "Complex" scheduling guidelines dictate that it is desirable to have two radars each rev in addition to the TDRS network. This level of support begins two revs prior to the first burn in the rendezvous sequence until Ti. From Ti until two revs later, "critical" scheduling guidelines are followed, with one ground radar scheduled per rev in addition to TDRS tracking. Deploy and undock are also considered "critical" phases for the purposes of tracking scheduling. Remember that groundtrack will ultimately dictate whether the spacecraft is in range of any radars during the timeframe of interest, for example no radars may end up being scheduled for a complex period if the spacecraft is "off range". C-band radars normally scheduled, in order of preference for cost<sup>6</sup>, are:

FRCC - Dryden Flight Research Center, California

WLPC - Wallops Flight Research Center, Virginia

ANTC - Antiqua Island in the Caribbean

KPTC - Kiana Point, Hawaii

ASCC or ASTC - Ascension Island in the Atlantic, south of the horn of Africa

PTPC - Point Pillar, California

VDDB or VDHC - Vandenberg Air Force Base, California

KMAC, KMTC, or KMRC - Kwajalein Island Air Force Station in the south Pacific

Ground S-band comm sites are not normally scheduled by NAV for tracking. They may be used in real-time, however, if INCO calls up a site and the Orbiter downlinks through

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<sup>5</sup> HST is the only target currently equipped with an S-band transponder that enables TDRS target tracking. USSPACECOM target vectors are technically an alternate substitute for dedicated NASA C-band tracking, assuming a "quiet" satellite (i.e. small semi-major axis changes over time). Current SOP utilizes USSPACECOM target vectors for some pre-mission planning, but not usually during real-time operations.

<sup>6</sup> Air Force implementation of "full cost accounting" has significantly increased the cost of tracking at Kwajalein. By approximately FY '01, a single pass at Kwaj will cost approximately \$50,000. This will force Kwaj to be placed lowest on the priority list of sites, and indeed limit its use to only times when it is absolutely required for mission success or crew safety. As other DoD sites switch to full cost accounting over the next few years, this priority list will have to be revised.

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the site. High speed C-band radars are not normally scheduled for on-orbit use due to cost. For the remaining low speed radars, low inclination missions provide the best geometry for frequent tracking opportunities. For high inclination missions, only a couple radar passes may be available during DOR. Although it may be tempting in these cases to assign the sole ground radar to the target each rev, remember that most targets remain stable (ISS included so far), requiring less tracking than the Orbiter which is maneuvering and thrusting during DOR. Therefore it is sometimes appropriate to track the Orbiter instead if there is some merit, such as providing an updated vector with which to target an upcoming burn. One exception to this is the CRISTA SPAS spacecraft (STS-66 & -85), which had a cryostat vent and attitude profile that resulted in much greater semi-major updates than are typically seen for "quiet" targets. Other target spacecraft in the future may pose similar problems. A pre-flight tagup between the RFDO and lead NAV can allow these and other issues to be discussed, and a plan developed for prioritizing the precious C-band resources.

It is important that the RFDO review the tracking plan for deploy/undock timeframe, DOR, and any stationkeeping or phasing burns. Concerns of insufficient (or excess) tracking should be communicated to the lead NAV. The final tracking plan for a rendezvous mission should be finalized by L-6 weeks. For ISS flights, however, it may be L-7 days before final target vector receipt allows re-generation of the launch window, rendezvous profile, and tracking plan data. The tracking plan is officially submitted to the Network with the Tracking Scheduling Message which is completed by L - 2 weeks, and is internally distributed with a SOC Transmittal Form (STF). At this time the final tracking matrix, which goes in the FDO Console Databook, is provided to the lead FDO by the lead NAV either by STF or hand delivery. For GUR missions, the pre-launch FDO is responsible for sending out predicted burnout vectors to Sunnyvale in order to schedule remote tracking sites (RTS). This process is performed at approximately L-12 hrs, and is documented in Section 3.12.14.

As the overall rendezvous burn profile takes shape, it is important to coordinate this with the lead Flight Activities Officer (FAO). The Flight Plan published by FAO will include TIGs from Flight Design's RNDZ-01 Rendezvous/Prox Ops Maneuver Summary product. The lead FAO will develop a crew shift schedule that provides for the burns to be performed during the crew's workday. If necessary, however, some burns can be performed late in post-sleep or early into pre-sleep. The RFDO should assure that an adequate tracking arc is available prior to each burn. No perturbative activity (water dump, attitude maneuver, COAS calibration, cabin depress, IMU alignment, PRCS jet hotfire, DAP deadband collapse, etc) should be scheduled within two revs of a burn, if possible. This is to provide FDO with the highest quality state vector to use in targeting the upcoming burn. Due to compressed timelines and payload requirements, it may not always be possible to guarantee a quiet period prior to a burn. In this case the FDO should be aware of the degraded accuracy with which the burn will be targeted.

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Another timeline concern to look out for is scheduling of any perturbative activity following a burn. Even though a burn may be targeted and performed perfectly, following it up with a water dump or several attitude maneuvers may introduce unwanted semi-major axis dispersions. This is of special concern for the final NC burn executed the evening before rendezvous. If a perturbative activity is scheduled post-burn, then no opportunity is available during crew sleep to fix the dispersion until the NC or NH burn on morning of rendezvous. By then, the energy effects of the perturbative activity may have resulted in large range dispersions. For example, 1500 ft  $\Delta a$  introduced by an attitude maneuver and water dump following NC-3, and propagated over 7 revs during crew sleep, could cut the NC-4 range in half (23 nm instead of the desired 40 nm).

**CAUTION:** it is imperative to assure a clean timeline following the last phasing burn the evening before rendezvous until crew wakeup. If a water dump or IMU align must be performed prior to rendezvous, it is preferred to place them just after crew wakeup on morning of rendezvous. This way any energy effects will not have time to propagate into downtrack dispersions. One or two revs of ground tracking following the event will permit an updated state vector to be obtained for start of rendezvous.

### 3.10.3.2 TIG Slip Analysis

It is possible that systems failures and/or procedural errors can prevent a burn from being executed on time. This could arise from GPC failures, getting into burn attitude late, or PAD/burn targets uplinked late due to comm problems, to name just a few examples. Burns that cannot be performed at the planned time of ignition (TIG) must either be performed as soon as possible after the original TIG, or rescheduled for a later time. Certain burns are considered "critical" in that they *cannot* be rescheduled without significant crew safety or mission success implications. "Non-critical" burns, on the other hand, *may* be rescheduled without serious impacts (a formal burn criticality definition is documented in Flight Rule A2-114). For critical burns, FDO is responsible for providing TIG slip information on the burn PAD, specifying how long the burn can be delayed. FDO will also include directions to burn either the original inertial  $\Delta v$  components by not updating the TIG, or to re-load PEG-7s with the delayed TIG. These options are referred to as "inertial TIG slip" and "LVLH TIG slip", respectively, and will be described in more detail below. The crew and flight control team will use the TIG slip time to recover from systems failures, if required, and get the burn off rather than impact crew safety or mission objectives.

An example of a critical burn is the DOR NC burn (usually NC-4) on a ground-up rendezvous for a large phase angle case. The Orbiter may be closing in rapidly at hundreds of miles per revolution until NC-4 slows the closing rate to allow a one rev transfer from 40 to 8 nm where Ti occurs. If NC-4 is not performed on time, the Orbiter

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will phase so far in front of the target within one revolution that propellant margins and crew timeline may not support recovery. Thus, in this case, it is vitally important to have as much TIG slip available as possible, and Orbiter systems are configured to a high level of redundancy so that single failures may be absorbed without impacting the burn. DPS and GNC will typically maintain 2 or 3 GNC GPCs and 2 or 3 IMUs, respectively. The Propulsion Officer will also contribute to systems redundancy by specifying a thruster downmode option for critical burns (a "1 OMS to RCS" downmode, for example).

Prior to every rendezvous mission, RFDO should determine burn criticality for every burn, and then perform a TIG slip analysis for every critical maneuver in the profile. The TIG slip analysis determines whether inertial or LVLH attitude hold is more economical for slips, and what the TIG slip limits actually are. These limits will be determined by (1) growth in propellant costs to correct the rendezvous profile after a slipped burn, and (2) relative motion considerations—i.e. is the Orbiter on a collision course with the target after a certain amount of TIG slip. It will be necessary to tag up with PROP prior to a critical burn in order to review propellant costs as a function of TIG slip and pick the maximum TIG slip permissible. An important concept to remember when communicating with PROP is that the  $\Delta v$  of the upcoming burn is fixed, whether slipped or not—it is the *subsequent* burns that will increase in cost. Profile Support will provide updated TIG slip analysis in real-time showing propellant costs versus TIG slip and resultant relative motion. The first step in a TIG slip assessment is to determine if a burn can be slipped an entire rev without significant propellant penalty. Small phasing maneuvers and posigrade bias burns can usually be slipped at least one orbit. If so, the burn is non-critical, and TIG slip limits aren't required on the burn PAD. Big DOR burns, however, are usually limited to a couple minutes' TIG slip, and are the focus of the remainder of this section.

NOTE: trajectory and propellant implications aren't the only criteria influencing burn criticality. Timeline considerations (impending crew sleep or a high priority activity critical to mission success) may also conspire to render burn postponement impractical. These considerations may only become apparent when FAO or ACO/PAYLOADS are consulted.

### 3.10.3.2.1 LVLH TIG Slip Analysis

LVLH TIG slip, as its name implies, preserves the original LVLH burn targets. To do this, the crew must input the new (slipped) TIG into the Maneuver Exec display and re-load the targets. That way, onboard guidance will re-compute a new inertial burn solution to satisfy the input PEG-7 targets at the new TIG. To model LVLH TIG slips in rendezvous constraints tables, first run the on-time plan for the maneuver in question to generate nominal LVLH (PEG-7)  $\Delta v$  components in the maneuver evaluation table (MET). Next, replace the maneuver of interest with two burns: (1) a zero fps external  $\Delta v$

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(EXDV) maneuver at the nominal TIG, and (2) another EXDV with primary constraint  $DT=TIG$  slip time, using LVLH  $\Delta v$  components from the nominal MET as secondary constraints. You may want to specify a fixed-TIG (primary constraint "T") for the subsequent burn in the plan in order to prevent its TIG from slipping past its original time. The plan can be re-executed, and the MET will show *total plan*  $\Delta v$  increase as TIG slip is increased. Figure 3.10.3.2-1 shows an NC-4 TIG slip MCT for STS-95 (SPARTAN rendezvous from 30 nm in front of the target). In Figure 3.10.3.2-2, note the  $\sim 2$  fps  $\Delta v$  increase of the cost of an 8 min LVLH TIG slip for NC-4 compared to the nominal STS-95 DOR plan of 19.4 fps. This is primarily a function of NCC  $\Delta v$  (it's zero for the nominal plan). This shows the importance of including an NCC in any TIG slip study, since this burn will perform a large part of the trajectory correction.

If an EXDV maneuver is not compatible with the rest of the rendezvous plan, you can simply model the desired TIG slipped maneuver in a TrS or TSA ephemeris using the direct input technique. Then use the ephemeris as the source to re-run the remainder of the rendezvous plan for the burn following the one you modeled. Obtain the total  $\Delta v$  cost of the plan from the MET plus the burn modeled in the DMT. Repeat this for different TIG slips and record the results.

Of primary interest is how the total  $\Delta v$  for the plan varies with TIG slip. Another concern is how TIG slip effects relative motion. To assess this, use R/T Relmo or Genplot with a curve for each TIG slip case. To facilitate this, it is helpful to have individual plans for each increment of TIG slip. Each plan must use an OMP Variables Table that has the plot flag turned "on" (otherwise, the plan must be transferred to an ephemeris before it may be plotted). Then relative motion for multiple plans can be plotted, clearly showing the effects of TIG slip on relmo. An example of this is shown later in Figure 3.10.3.2-5.

**CAUTION:** running Global OMP plans with the plot flag "on" in OMP Variables tables is inadvisable. Excessive execution time will result due to writing large plot files on the HA server. Use Local-based plans to obtain Genplot output.

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MANEUVER CONSTRAINTS TABLE NC-4SLIP8

COMMENT: DOR MCT - NC-4 TIG slip study

CURRENT  
MNVRS: 6 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 EXDV NOM NC-4	T 004:18:55:00.000	DVLV=0 = =	DVLV=0 = =	DVLV=0 = =
2 EXDV Late NC-4	DT 000:00:08:00.000	DVLV=6.92 = =	DVLV=0 = =	DVLV=0 = =
3 NH NH	T 004:19:42:56.000	= = =	= = =	= = =
4 NC NCC	T 004:21:04:51.000	= = =	= = =	= = =
5 SOI Ti	T 004:22:04:57.000	DR =-8.0 = =	DH =0.2 = =	= = =
6 SOR MC-4	DT 000:01:20:06.000	CXYZ=-.148 = =	CXYZ=0.0 = =	CXYZ=.2962 = =

**Figure 3.10.3.2-1**

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MANEUVER EVALUATION TABLE NC-4SLIP8  
COMMENT: NC-4SLIP8

MCT : NC-4SLIP8    OVT : PLOTON

GMTR : 1998:302:19:00:00.000

VECTOR	TIME	COMMENT
CHASER E2	M 004:18:45:00.000	Orbiter SEP-1 thru Grapple
TARGET E4	M 004:18:45:00.000	SPARTAN

CHASER	DVtot =	21.15	DVx =	20.00	DVy =	0.02	DVz =	5.04	
TARGET	DVtot =	0.00	DVx =	0.00	DVy =	0.00	DVz =	0.00	6 MNVRS

MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
	COMMENT	METIG		DVy	HP	PHASE	Ydot
	DVMag	DT		DVz	DH	Noon/Mid -	SR/SS -
1	EXDV	307:13:55:00.000		0.00	302.95	29.9329	76.2
	NOM NC-4	004:18:55:00.000		0.00	295.47	-0.4586	0.3
	0.0	000:00:08:00.000		0.00	-0.05	M-00:41:39	SS-00:26:24
2	EXDV	307:14:03:00.000		6.92	306.74	29.8695	122.6
	Late NC-4	004:19:03:00.000		0.00	295.98	-0.4575	0.2
	6.9	000:00:39:56.000		0.00	-0.06	M-00:33:39	SS-00:18:24
3	NH	307:14:42:56.000		0.50	306.71	23.9046	-48.7
	NH	004:19:42:56.000		0.00	296.36	-0.3606	-0.2
	0.5	000:01:21:55.000		0.00	-3.85	N-00:41:37	SR-00:08:57
4	NC	307:16:04:51.000		-1.88	306.49	7.6676	14.1
	NCC	004:21:04:51.000		0.00	295.26	-0.1112	-0.1
	1.9	000:01:00:06.000		0.00	-2.43	M-00:07:32	SR-00:22:46
5	SOI	307:17:04:57.000		-8.31	301.46	8.0035	-15.6
	Ti	004:22:04:57.000		0.01	295.22	0.1226	-0.1
	9.0	000:01:20:06.000		-3.56	0.20	M-00:43:15	SS-00:28:00
6	SOR	307:18:25:03.000		2.39	302.80	0.3299	-5.9
	MC-4	004:23:25:03.000		-0.01	295.23	0.0023	0.0
	2.8	000:00:00:00.000		1.48	0.29	N-00:11:00	SS-00:43:42

**Figure 3.10.3.2-2**

### 3.10.3.2.2 Inertial Hold TIG Slip Analysis

Procedurally, inertial TIG slip is easier for the crew to perform than LVLH slip, and this option should therefore be used whenever possible. When targets are initially loaded, MM202 guidance converts LVLH  $\Delta v$  to inertial M50 components for the input TIG.

These inertial targets are held constant, even after the nominal TIG, until they are burned out. To slip a burn inertially, the crew simply burns out the body VGOs at any time after TIG for RCS, or presses the EXEC key to light up the OMS.

**CAUTION:** provided that targets have been loaded previously, no onboard software inhibit exists to performing a burn after any delay. An illegal entry will result if a load is attempted more than 12 hrs before or 5 min after the associated TIG, however.

To perform an inertial TIG slip analysis, first run the nominal rendezvous plan and obtain PEG-7  $\Delta v$  components for the burn from the MET. Then anchor the nominal TIG



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with a zero fps EXDV maneuver in the MCT. Next, insert the slipped burn into the MCT using DVPY maneuver type and a zero TIG slip DT as the primary constraint. Secondary constraints will be DV=total  $\Delta v$ , PIT=LVLH thrust pitch angle (0 deg for pure posigrade, 180 for pure retrograde, etc), and YAW=LVLH thrust yaw angle (normally 0). Run this plan and make sure the DVPY resultant PEG-7  $\Delta v$  components match the original result at the planned TIG. Once configured correctly, DVPY can easily be used to model the effect of the inertial thrust vector rotating in the LVLH frame as the burn is slipped. Simply type in the TIG slip DT as the primary constraint, and increment PIT to match orb rate x TIG slip (orb rate = 4 deg/min for a 90 min period orbit). For example, to inertially slip a pure posigrade burn 4 min, the PIT value would be changed from 0 to 16 deg. Remember that PIT always increases so that for posigrade burns the resultant  $\Delta V_z$  on the MET goes more negative over time, while for retrograde burns  $\Delta V_z$  gets more positive over time. Figures 3.10.3.2-3 and 3.10.3.2-4 show STS-95 NC-4 with an 8 min inertial TIG slip. Note that this is significantly more expensive than the LVLH option shown above. An example relative motion is shown in Figure 3.10.3.2-5, which shows there are no relmo concerns for any of the inertial TIG slip cases analyzed.

MANEUVER CONSTRAINTS TABLE NC-4SLIP8

COMMENT: DOR MCT - NC-4 TIG slip study

CURRENT  
MNVRS: 6 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 EXDV NOM NC-4	T 004:18:55:00.000	DVLV=0 = =	DVLV=0 = =	DVLV=0 = =
2 DVPY Late NC-4	DT 000:00:08:00.000	DV =6.92 = =	PIT =32 = =	YAW =0 = =
3 NH NH	T 004:19:42:56.000	= = =	= = =	= = =
4 NC NCC	T 004:21:04:51.000	= = =	= = =	= = =
5 SOI Ti	T 004:22:04:57.000	DR ==-8.0 = =	DH =0.2 = =	= = =
6 SOR MC-4	DT 000:01:20:06.000	CXYZ=-.148 = =	CXYZ=0.0 = =	CXYZ=.2962 = =

**Figure 3.10.3.2-3**

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## MANEUVER EVALUATION TABLE NC-4SLIP8

COMMENT: NC-4SLIP8

MCT : NC-4SLIP8    OVT : PLOTON

GMTR : 1998:302:19:00:00.000

VECTOR	TIME	COMMENT
CHASER E2	M 004:18:45:00.000	Orbiter SEP-1 thru Grapple
TARGET E4	M 004:18:45:00.000	SPARTAN

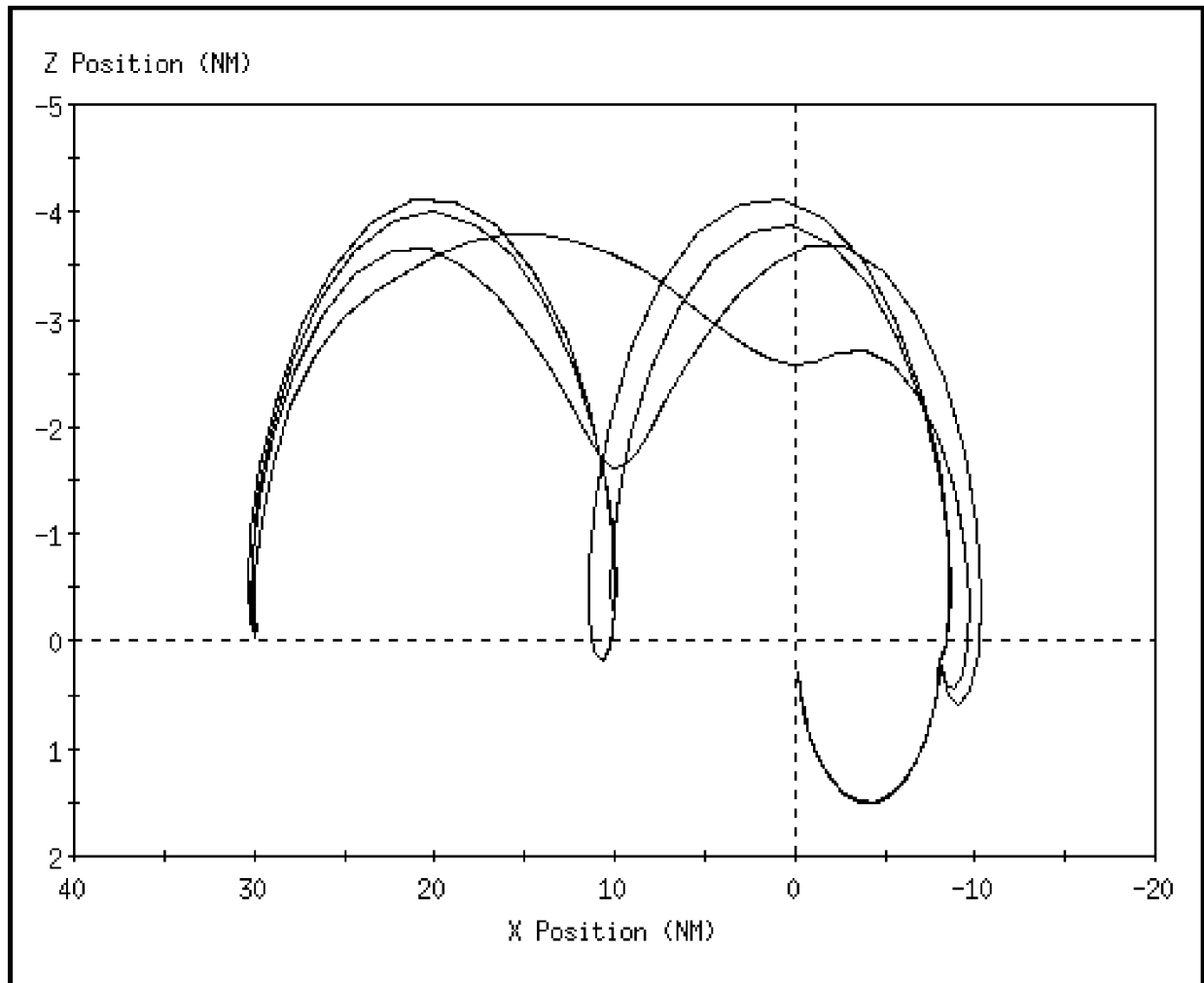
CHASER	DVtot =	26.00	DVx =	23.22	DVy =	0.02	DVz =	9.78	
TARGET	DVtot =	0.00	DVx =	0.00	DVy =	0.00	DVz =	0.00	6 MNVRS

MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
	COMMENT	METIG		DVy	HP	PHASE	Ydot
	DVMag	DT		DVz	DH	Noon/Mid -	SR/SS -
1	EXDV	307:13:55:00.000		0.00	302.95	29.9329	76.2
	NOM NC-4	004:18:55:00.000		0.00	295.47	-0.4586	0.3
	0.0	000:00:08:00.000		0.00	-0.05	M-00:41:39	SS-00:26:24
2	DVPY	307:14:03:00.000		5.87	306.42	29.8695	122.6
	Late NC-4	004:19:03:00.000		0.00	295.59	-0.4575	0.2
	6.9	000:00:39:56.000		-3.67	-0.06	M-00:33:39	SS-00:18:24
3	NH	307:14:42:56.000		3.17	306.39	22.7348	-49.4
	NH	004:19:42:56.000		0.00	297.56	-0.3433	-0.2
	3.2	000:01:21:55.000		0.00	-3.54	N-00:41:37	SR-00:08:57
4	NC	307:16:04:51.000		-4.23	306.08	3.2700	9.5
	NCC	004:21:04:51.000		0.00	295.10	-0.0221	0.0
	4.2	000:01:00:06.000		0.00	-2.93	M-00:07:32	SR-00:22:46
5	SOI	307:17:04:57.000		-7.56	301.46	7.9983	-16.6
	Ti	004:22:04:57.000		0.01	295.22	0.1225	-0.1
	8.9	000:01:20:06.000		4.62	0.20	M-00:43:15	SS-00:28:00
6	SOR	307:18:25:03.000		2.39	302.80	0.3299	-5.9
	MC-4	004:23:25:03.000		-0.01	295.23	0.0023	0.0
	2.8	000:00:00:00.000		1.50	0.29	N-00:11:00	SS-00:43:42

**Figure 3.10.3.2-4**

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### STS-95 NC-4 Inertial TIG Slip



**Figure 3.10.3.2-5**

To conduct an inertial TIG slip analysis on the TrS, model the nominal maneuver as a direct input PEG-7 in an ephemeris. Using a DMT, obtain inertial  $\Delta v$  components for an on-time TIG. Then re-input the maneuver in M50 guidance mode using these inertial values. The TIG can be slipped on the MED menu as desired while holding M50  $\Delta v$  components constant. Replace the nominal maneuver in the ephemeris, and then run OMP for the remainder of the plan. Use the constraints table starting with the maneuver after the one you modeled in the DMT. Again, record the resulting residual (slipped – nominal)  $\Delta v$  components from the MET for each TIG slip case, and resultant relative motion.

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### 3.10.3.2.3 Lambert TIG Slip

Onboard-targeted burns are computed using a Lambert algorithm that determines the change in velocity required to arrive at a specified position in space after a specified transfer time. The onboard Lambert solution is automatically transferred to the MNVR EXEC display so the crew can load and burn the targets. Also, Lambert mode provides closed-loop targeting where the body VGOs to be burned are updated every guidance cycle starting at TIG-15 sec. If a Lambert burn is not performed on time, the closed-loop algorithm takes this into account and *decrements the transfer time to maintain the same future target point in time*. As the burn is slipped, the VGOs continue to update to reflect the latest solution. To model this in ground processors, it is necessary to (1) slip the TIG of the Lambert burn, and (2) decrement the  $\Delta t$  to the second burn in the Lambert pair accordingly. For example, to check  $T_i$  TIG slip capability for 10 minutes, move the primary constraint  $T$  10 minutes later than planned for maneuver SOI. Then decrease the DT primary constraint by 10 min for the SOR burn.

### 3.10.3.3 Propellant Budgets

Rendezvous missions frequently have tight propellant margins. Besides the propellant needed for rendezvous maneuvers themselves, any burns necessary to satisfy other mission objectives, such as ISS attitude control, post-deploy separation maneuvers, and deorbit all must be budgeted. Other payload activities that require attitude maneuvers must also be included in the prop budget. For rendezvous, typically the Forward Reaction Control System (FRCS) propellant has the smallest margins, since in the aft, OMS and RCS propellant may be interconnected.

RNDZ-03 product contains rendezvous  $\Delta v$  and prox ops propellant usage predictions, and is used by the Propulsion Officer to build the prop budget. RNDZ-03 contains mean and 1 sigma prop cost for each burn in the rendezvous plan, as well as a failed radar prop bias and re-rendezvous costs. Mean  $\Delta v$  values are derived from the nominal plan. The sigmas are determined by Monte Carlos analysis assuming dispersions for: Ground NAV accuracy for burn planning, onboard nav accuracy for onboard targeted burns, burn trim error, manual piloting, and attitude maneuvers. Any special DTOs, if they affect prop usage, will be included in RNDZ-03 as well. Undock and flyaround, or payload deploy and separation burns, are also included in the product. From the Lead FDO, PROP obtains  $\Delta v$  for all other on-orbit burns not included in the product, such as orbit adjust trim burns that were not part of the flight design. Also, PROP requires planned OMS-2  $\Delta v$ , EOM D/O  $\Delta v$ , and required ballast quantities to complete the budget. If a launch slip occurs for ground-up rendezvous mission, the Lead FDO must send PROP a new burn plan so that engine selection and propellant impacts can be assessed.

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When the propellant budget is complete, it is used to compute bingo quantities for the propellant PAD in the Rendezvous Checklist. "Bingo" is a fighter-jock term for terminating a mission when just enough fuel remains to get home, plus reserves. Similarly, "bingo" in our case refers to terminating rendezvous activities when quantities fall below the amount required to (a) break out of the rendezvous, (b) perform attitude maintenance for 1 day, (c) protect deorbit redlines and deorbit prep usage, (d) provide ballast for c.g. control, and (d) perform higher priority mission objectives. PROP also uses the propellant budget to make the "go for Ti" and/or "go for Ti Delay" calls. In the case of a deploy-retrieve mission, the prop budget is also used to determine whether sufficient quantities are available to be "go for deploy". Refer to the flight specific Flight Rules Annex to find what level of dispersion protection is provided for a given mission (mean to mean+3 sigma).

Pre-mission budgets for ground-up rendezvous must also contain some margin for planar errors. In the past, it was assumed that yaw steering during ascent would place the Orbiter in the correct plane. This was a bad assumption. Three sources of error could occur, and if they are all additive it could result in as much as about 20 fps planar error. The error sources are 1) MECO dispersions (Monte Carlo results), 2) MECO errors due to guidance and navigation limitations (most flights have experienced 2-15 fps planar errors), and 3) Launch Window/Launch Targeting errors (planar rotations due to launch slips). Specific ground procedures have been developed by the ascent FDOs to reduce these errors to less than 10 fps, but that is probably the best we can do. Specific ground-up launch window constraints and general use of the Launch Window/Launch Targeting Processor (LWLT) will be discussed in Section 3.10.4.5.

Figure 3.10.3.3-1 provides a "back of the envelope" assessment of DVX changes due to switching planned docking day, along with variable altitude. Use the top table if the prop budget assumed FD3 rendezvous, and you are asked about the additional costs of performing a FD4 rendezvous. Flight Design may not have budgeted enough prop for a FD4 rendezvous and this will let you know right away. As an example, assume FD3 was budgeted for an altitude of 205 nm, but due to large phase angle on launch day, only FD4 can be supported. The table shows a DV cost of 6 fps of drag penalty to go from max FD3 to max FD4 phase angle. The lower table contains the same information, but assumes FD4 was planned and budgeted, but now only FD3 is required.

**CAUTION:** Figure 3.10.3.3-1 should only be used for "quick assessment", and should not be used for formal console products. This table shows only change in rendezvous cost—it does not include any increase or decrease in deorbit propellant requirements.

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<b>Planned Altitude</b>		<b>Actual Altitude</b>								
		<b>FD3 MAX - FD4 MAX - you were FD3 and now they want FD4</b>								
		Altitude(⊕)	FD4	215 (695)	213 (682)	211 (670)	209 (658)	207 (645)	205 (633)	203 (620)
FD3	TOT DVX	501	494	487	480	473	466	459	452	
215 (442)	495	6	-1	-8	-15	-22	-29	-36	-43	
213 (434)	488	13	6	-1	-8	-15	-22	-29	-36	
211 (426)	481	20	13	6	-1	-8	-15	-22	-29	
209 (418)	474	27	20	13	6	-1	-8	-15	-22	
207 (410)	467	34	27	20	13	6	-1	-8	-15	
205 (403)	460	41	34	27	20	13	6	-1	-8	
203 (395)	453	48	41	34	27	20	13	6	-1	
201 (387)	446	55	48	41	34	27	20	13	6	

<b>Planned Altitude</b>		<b>Actual Altitude</b>								
		<b>FD4 MAX - FD3 MAX - you were FD4 and now they want FD3</b>								
		Altitude(⊕)	FD3	215 (442)	213 (434)	211 (426)	209 (418)	207 (410)	205 (403)	203 (395)
FD4	TOT DVX	495	488	481	474	467	460	453	446	
215 (695)	501	-6	-13	-20	-27	-34	-41	-48	-55	
213 (682)	494	1	-6	-13	-20	-27	-34	-41	-48	
211 (670)	487	8	1	-6	-13	-20	-27	-34	-41	
209 (658)	480	15	8	1	-6	-13	-20	-27	-34	
207 (645)	473	22	15	8	1	-6	-13	-20	-27	
205 (633)	466	29	22	15	8	1	-6	-13	-20	
203 (620)	459	36	29	22	15	8	1	-6	-13	
201 (608)	452	43	36	29	22	15	8	1	-6	

(-) means cost savings, baseline is with a F10 approx. 168.1, YKP approx. 2.82, 85 min perigee, DI = 122 nmi  
 Ti at 1:18:56:7 in nominal plan, MAX FD3 is Plan D, MAX FD4 is Plan F per STF No. OFD-01-48300-024  
 Orbiter mass = 257674.6 lbm, Cd = 2.0, area = 1208.48 ft sq  
 Target mass = 284369.9 lbm, Cd = 2.35, area = 6896.44 ft sq  
 built from 105 FRR vectors with BGF14 propagator  
 F10 and Kp differences can cause a difference in total DV costs of up to as much as 9.5 fps for a plan F with a F10 change from 242 to 70. A14 See tables below for more details.

**Figure 3.10.3.3-1: Rendezvous  $\Delta\Delta v$  (fps) Versus  $\Delta DOR$  and  $\Delta H$**

### 3.10.3.4 Flight Design Support

It is imperative that the Rendezvous FDO/lead be involved with the pre-mission flight design for a rendezvous mission. The FDO's job is not to design missions, but to ensure that the flight, as designed, can be successfully executed in real time with the limited MCC tools and manpower available. The FDO should ensure that all required flight design products are available on time, and should begin evaluating the mission from an operational perspective as soon as possible. The sooner the FDO is able to identify areas that can be improved, or unworkable points in the design, the easier it is to implement changes. This way the FDO has the opportunity to affect the trajectory design if it may be of operational benefit. The FDO should become well acquainted with the Flight Design Manager. A good FDO/FDM relationship will be of mutual benefit-- FDM handles programmatic issues and oversees the flight design process, while FDO provides operational expertise and assures that Flight Rules, procedures, and console tools and personnel are in place to support the mission. To maintain close ties with Flight Design, FDO should try to attend flight design planning meetings to keep abreast of flight-specific design issues. Specific Flight Design products that are required to build the FDO Console Databook are summarized in the Lead FDO Handbook.

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### 3.10.3.5 Rendezvous Launch Windows

Planning ground-up rendezvous missions is complicated by several unique launch window constraints, especially when the mission includes deployable payloads. This section explains the factors that determine the launch window, and the RFDO's preflight responsibility in launch window/launch targeting processing.

#### 3.10.3.5.1 Planar Window

Rotation of the Earth causes the launch site to pass under the target orbit plane once or twice per day (assuming the spacecraft's inclination is  $\geq$  the launch site latitude). These times are called in-plane times. Since orbital plane changes are very propellant expensive (442 fps  $\Delta v$  for 1 deg inclination change at 160 nm altitude), launch is performed at or close to the in-plane time to minimize any planar difference on-orbit. Thus the Earth's rotation is utilized to control initial orbit plane at no propellant cost. For high inclination flights, two launch opportunities are theoretically available each day, one ascending and the other descending. The descending pass, however, is unacceptable since this would require a south-easterly launch azimuth from KSC over populated islands in the Caribbean Sea. If the target's inclination is 28.5 deg, there is only one in-plane time per day as KSC just grazes the extreme northern part of the orbit plane.

The Orbiter can actually launch within a window on either side of the in-plane time, and still achieve the desired plane, by means of yaw steering during ascent. Yaw steering is closed-loop targeting of the desired insertion plane as defined by the  $I_y$  vector, which is a unitized M50 angular momentum vector computed prior to launch by the Ascent FDO. Duration of the planar window depends on the amount of ascent performance allocated to yaw steering--usually a few thousand pounds of MPS propellant. For a 51.6 deg inclination, this MPS availability allows only about 5 min on either side of the in-plane time for usable launch window. This is because the Earth's rotation direction is nearly perpendicular to the orbit plane. For a 28.5 deg inclination, the same MPS allotment for yaw steering may yield a launch window over 1 hr long, since the Earth's rotation is parallel with the orbit plane at the in-plane time. The planar window may also be limited by ET beta--the maximum allowable sideslip angle in second stage which limits heating on the ET. Guidelines which prevent ET disposal near populated islands in the Pacific Ocean can also limit the planar window. The Level B Groundrules and Constraints state that the ET will not impact within 200 nm of a foreign land mass, or within 25 nm of the U.S.A., Antarctica or the permanent ice shelf. Ascent Flight Design converts the beta and ET disposal constraints to more usable quantities "longitudes of descending node" as inputs to the TrS's Launch Window/Launch Targeting program (LW/LT), and TSA's Rendezvous Launch Window (RLW) processor.

## FDO Console Handbook Section 3.10: Rendezvous Operations

The desired insertion plane is actually slightly different from the target plane. Since the chaser will be at a lower altitude while catching up to the target until rendezvous, the chaser's line of nodes will regress slightly more than the target's, since nodal regression is more pronounced at lower altitudes. The *phantom plane* is the target plane biased eastward to account for this differential nodal regression, so that at rendezvous time the chaser's nodes will match the target's. MECO  $I_y$  targets actually aim for this phantom plane. The optimum liftoff time should theoretically be when the phantom plane lies directly over the launch site, allowing the chaser to insert without any performance penalty for yaw steering. However, since the Orbiter does not instantly accelerate to orbital velocity, the optimum liftoff time is biased backwards by about 5 min for a 51.6 deg inclination (" $\Delta t$  optimum" or OPT in RLW). This allows the Orbiter to be near insertion velocity as the Earth rotates eastward into the phantom plane. At window open (earlier than optimum), the Orbiter steers significantly farther eastward during ascent; at window close (later than optimum), the phantom plane is almost directly above the launch site, and as the Earth rotates eastward during ascent, the Shuttle must overcome this and steer back westward to hit the phantom plane. This is illustrated for a 51.6 deg inclination in Figures 3.10.3.5-1 through -3 in the out-of-plane (OOP) distance scale on the right hand side for curves without time ticks on each plot. Figure 3.10.3.5-4 shows the planar window open and close groundtracks.



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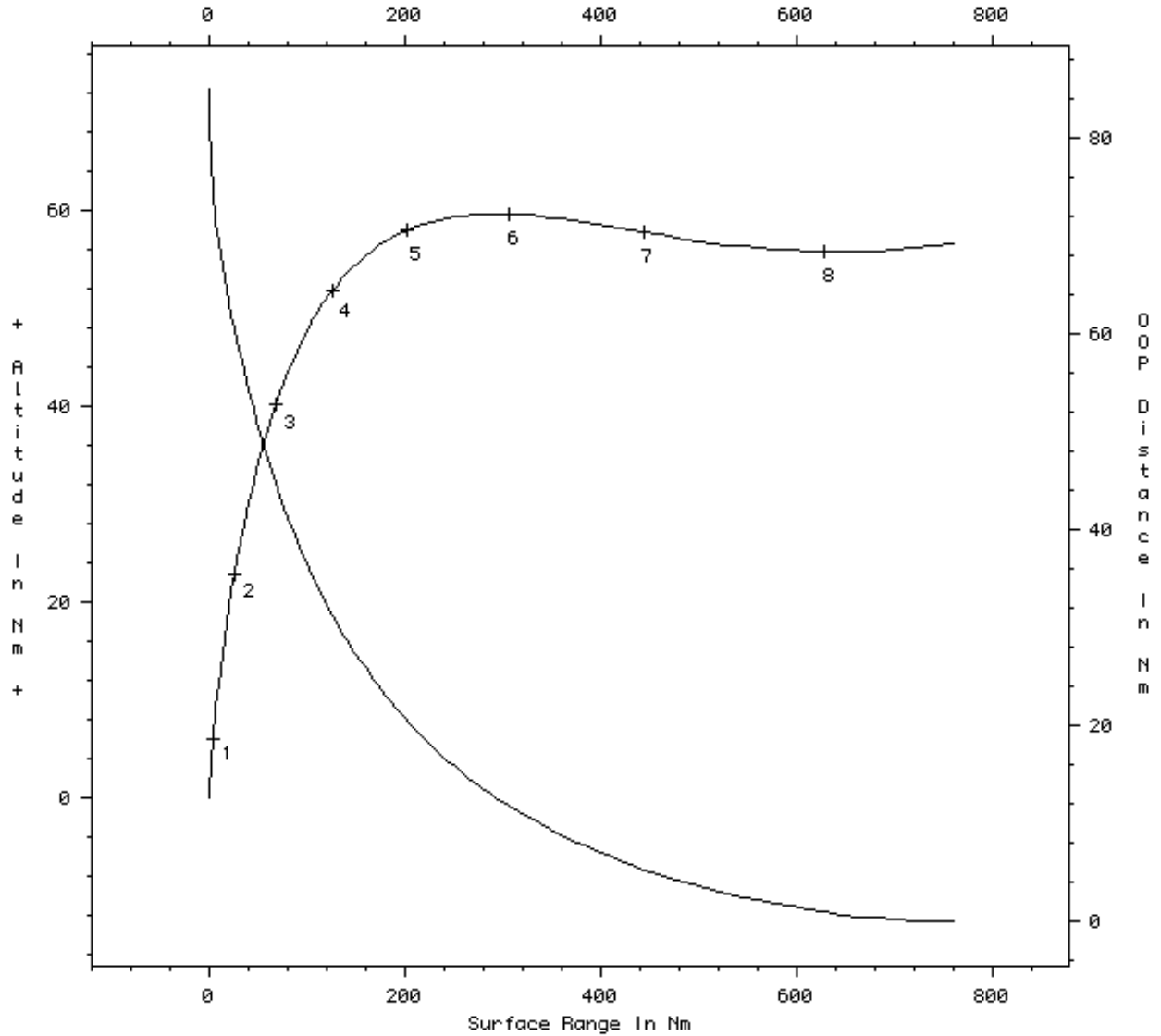


Figure 3.10.3.5-1: Launch at Planar Window Open

# FDO Console Handbook Section 3.10: Rendezvous Operations

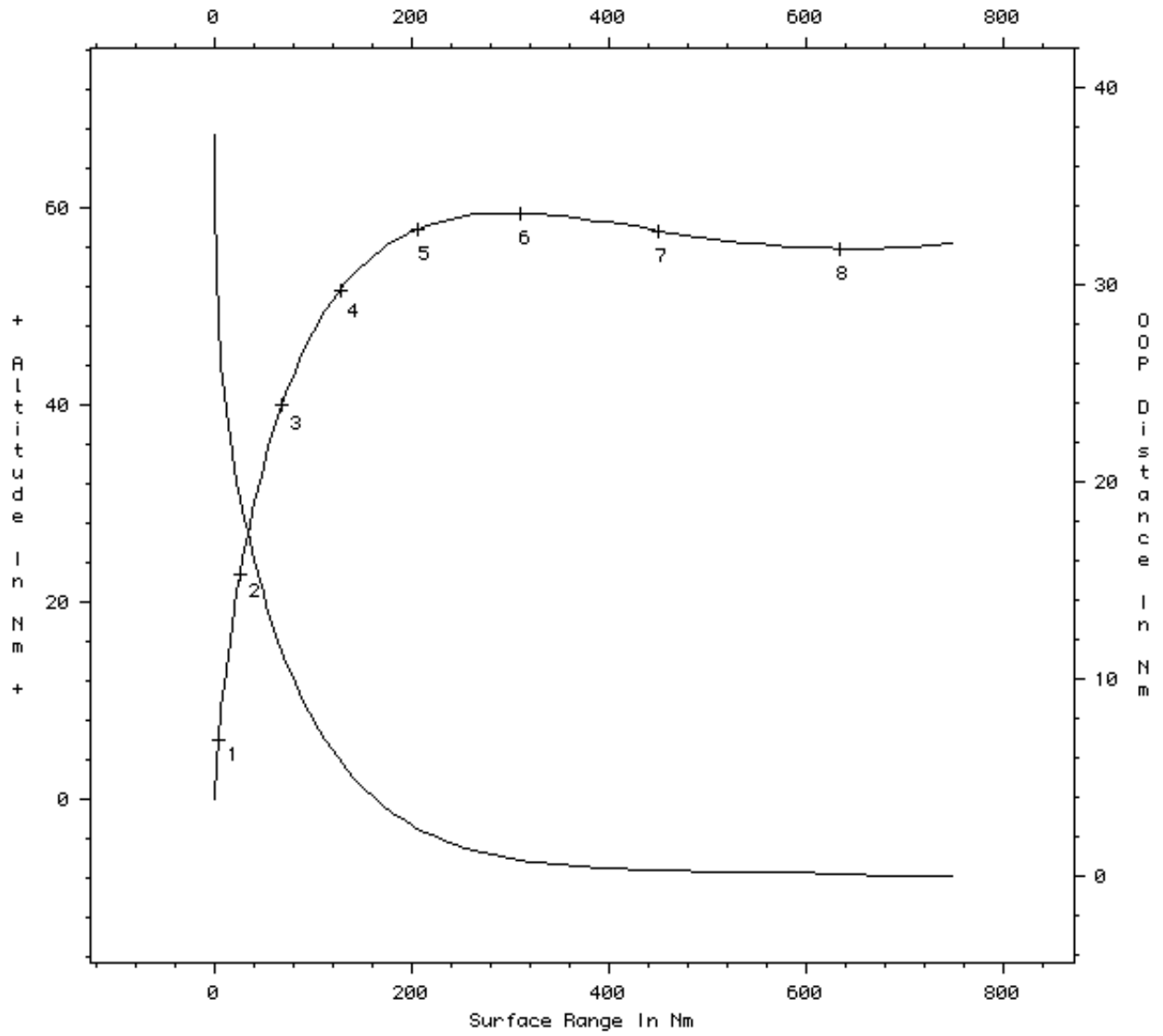
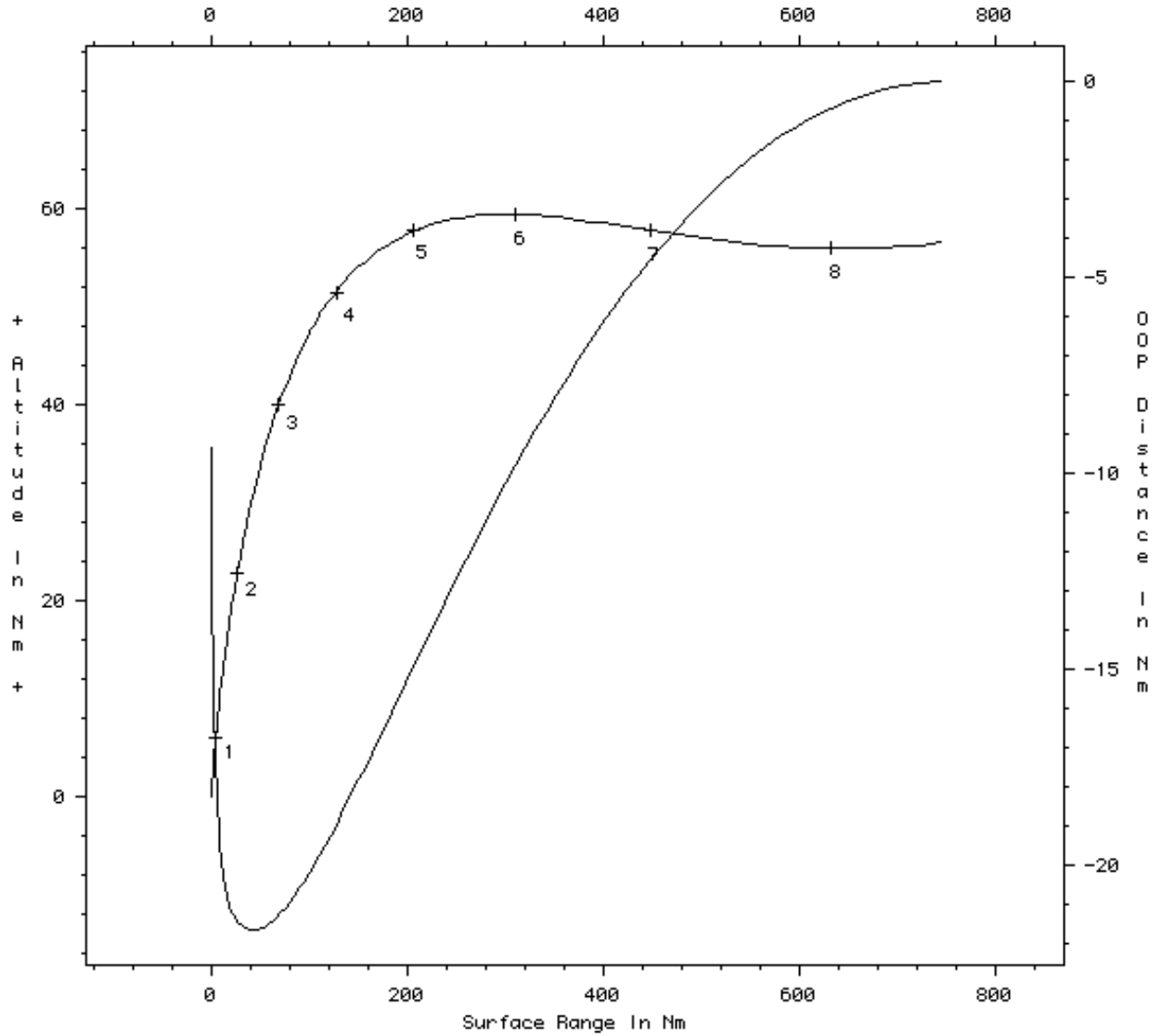


Figure 3.10.3.5-2: Launch at Optimum Time

# FDO Console Handbook Section 3.10: Rendezvous Operations



**Figure 3.10.3.5-3: Launch at Planar Window Close**

## FDO Console Handbook Section 3.10: Rendezvous Operations

51.6 deg Inclination Planar Window Ground Tracks

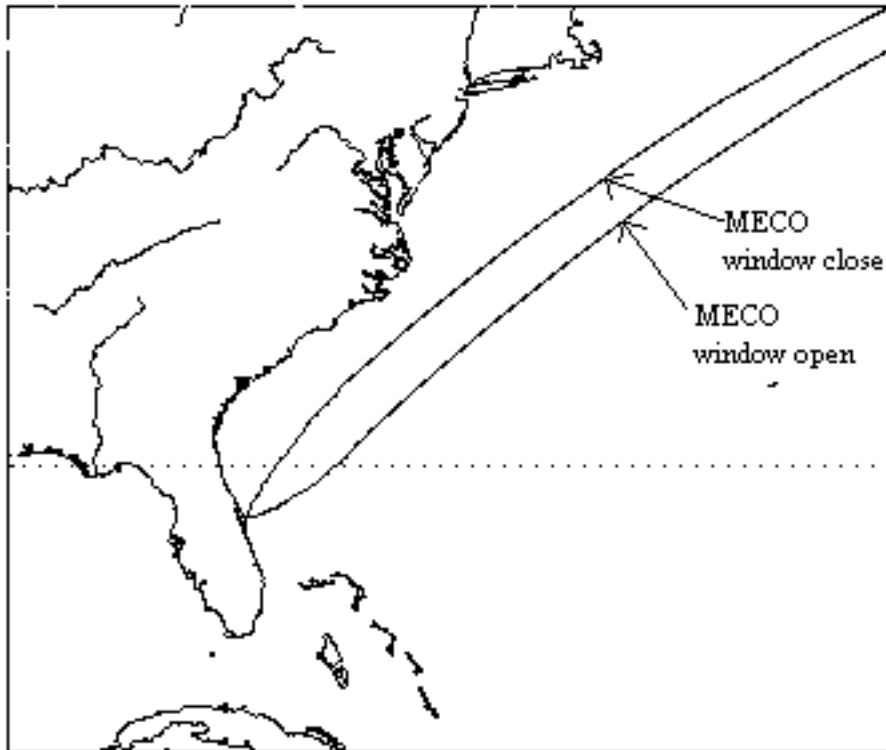


Figure 3.10.3.5-4

### 3.10.3.5.2 Phase Window

As mentioned above, the planar window controls the *lateral* trajectory so that the target's orbit plane may be achieved. The phase window, on the other hand, limits the *longitudinal* trajectory so that the chaser can reach the target's in-plane position within mission time and propellant constraints. As mentioned previously, phase angle ( $\theta$ ) is the angle between the target and chaser radius vectors at a particular time. Phasing capability refers to the ability of the chaser to "catch up" to the target within some specified time. In the Shuttle program, insertion targets always place the Orbiter in a lower altitude than the target, so that the Orbiter catches up from behind. The phase window denotes the range of phase angles over which the chaser can catch the target within the above-mentioned constraints. Orbital mechanics drives the phase window, since chaser-target semi-major axis difference produces a velocity difference that results in the chaser's closing rate. Time of rendezvous is also a big player since this specifies how much time the chaser has available to apply the velocity difference in order to close in on the target.

The minimum allowable phase angle is limited by the earliest MET that rendezvous can be executed. Obviously, a FD1 rendezvous profile would correspond to extremely small phase angles at launch, with MECO and OMS-2 designed to take the Orbiter up to the

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target altitude quickly to prevent over-phasing (chaser passing in front of the target). In the Shuttle program this is not done, in order to limit workload on FD1, and to allow crew acclimation to the weightless environment prior to performing the rendezvous. Normally FD3 is the preferred DOR, with FD2 rendezvous sometimes useable in case of MDF. Since this forces several days of phasing prior to rendezvous, posigrade bias burns (3 to 10 fps at least once/day) are built into the profile to guarantee that uphill semi-major axis Ground NAV updates won't cause any burns to go retrograde. This saves propellant by preventing the earlier burns from being "over-targeted", but unfortunately limits the minimum phase angle since it forces the Orbiter into a lower orbit that "steps up" in altitude at each posigrade burn. Flight design protects for a minimum phase window so that, with the posigrade biases included, no phasing burns are retrograde. As an example, the minimum OMS-2 phase angle for STS-110/8A with a FD3 rendezvous was 40 deg as a result of these factors.

Maximum phasing capability is limited by the maximum altitude difference between the chaser and target, and how long the chaser has to catch up to the target (MET of rendezvous). For STS-110/8A the MECO targets were designed for a 122 nm apogee in order to maximize phasing capability. This required a full OMS load in order to raise the orbit during rendezvous plus perform the deorbit burn. Since MECO targets (which drive apogee) are not changeable in real-time, the best phasing capability can be achieved by leaving the post-OMS-2 *perigee* as low as possible without encountering an excess of atmospheric drag. The lowest allowable perigee for STS-110 was 85 nm, which provided up to 399 deg phase capability for a FD3 rendezvous with the ISS.

### 3.10.3.5.3 Additional Launch Window Constraints

Different payloads may impose additional constraints on a ground-up rendezvous launch window. For example, thermal or solar array power limits on a payload may dictate that the beta angle at launch not exceed a certain value. These type constraints will be specified in the Payload Integration Plan (PIP), and flight design will account for them in designing the launch window. In the past, the Shuttle program co-manifested communication satellites on ground-up rendezvous missions (the last time was STS-32). This added significant operational complexity to the launch window design, so a discussion is included here in case this knowledge is needed for future missions. The basic target orbit requirements for deployable payloads and rendezvous are fundamentally different, so harmonizing the two when a deployable flies on a rendezvous mission can be difficult. The rendezvous target orbit is an "inertial" plane defined by the target object's orbit at intercept. The deployable's orbit planes for the transfer and final orbits are earth-referenced. The transfer orbit needs to maintain ground station coverage for command and telemetry, and the final orbit is usually geosynchronous or semi-synchronous. Launch times are driven by payload thermal and earth horizon sensor requirements at the injection node. As a result, the deployable launch window constrains the rendezvous launch window and vice versa.

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### 3.10.3.5.3.1 Right Ascension

An acceptable right ascension of the injection node for a typical spin-stabilized Hughes geosynchronous communications satellite (HS-376) is determined by the position of the sun at injection. The design of the HS-376 is responsible for this. Thermal limitations confine the sun to a band 25 degrees on either side of a perpendicular to the spin axis (Figure 3.10.3.5-5). For thermal purposes, the sun must lie in this band during the transfer orbit. Since the satellite is deployed and injected at a node, the line of nodes of the post perigee kick motor (PKM) firing transfer orbit will be approximately in the direction of the sun. The right ascension of the injection node (RAIN) could therefore be near zero or 180 degrees from the right ascension of the sun, so injection could occur near orbital noon or midnight. From a groundtrack map of a 28.5 degree inclination launch from KSC, one sees that the first descending node occurs close to zero degrees longitude. If nodes occur near orbital noon or midnight, and injection is at a node, injection occurs near noon or midnight in GMT (0600 and 1800 CST). Launch times are therefore within 20 to 25 minutes of these times.

The HS-376 charges its batteries in sunlight and it can only tolerate about 30 minutes in earth shadow due to battery depletion rates. This eclipse constraint further limits injection opportunities, because eclipses are this short only on the perigee side of the transfer orbit. If the eclipse were on the apogee side, it would last about 140 minutes near the vernal or autumnal equinoxes. If perigee occurs near orbital midnight, the eclipse only lasts around 23 minutes year round. Therefore, injection should occur near orbital midnight. If injection will be on a descending node, a launch near midnight GMT is required, and if injection will occur on an ascending node, a noon GMT launch is required. This geometry is shown in fig. 3.10.3.5-6.

The two narrow sun exclusion bands on Figure 3.10.3.5-5 are for the north and south earth horizon sensor (EHS) cutouts. The EHS are used during the transfer orbit to calibrate the attitude control system. The sun can temporarily blind the sensors, causing degradation in attitude control system accuracy, which shortens on-orbit lifetime due to excessive use of the reaction control system (RCS) to compensate for attitude errors.

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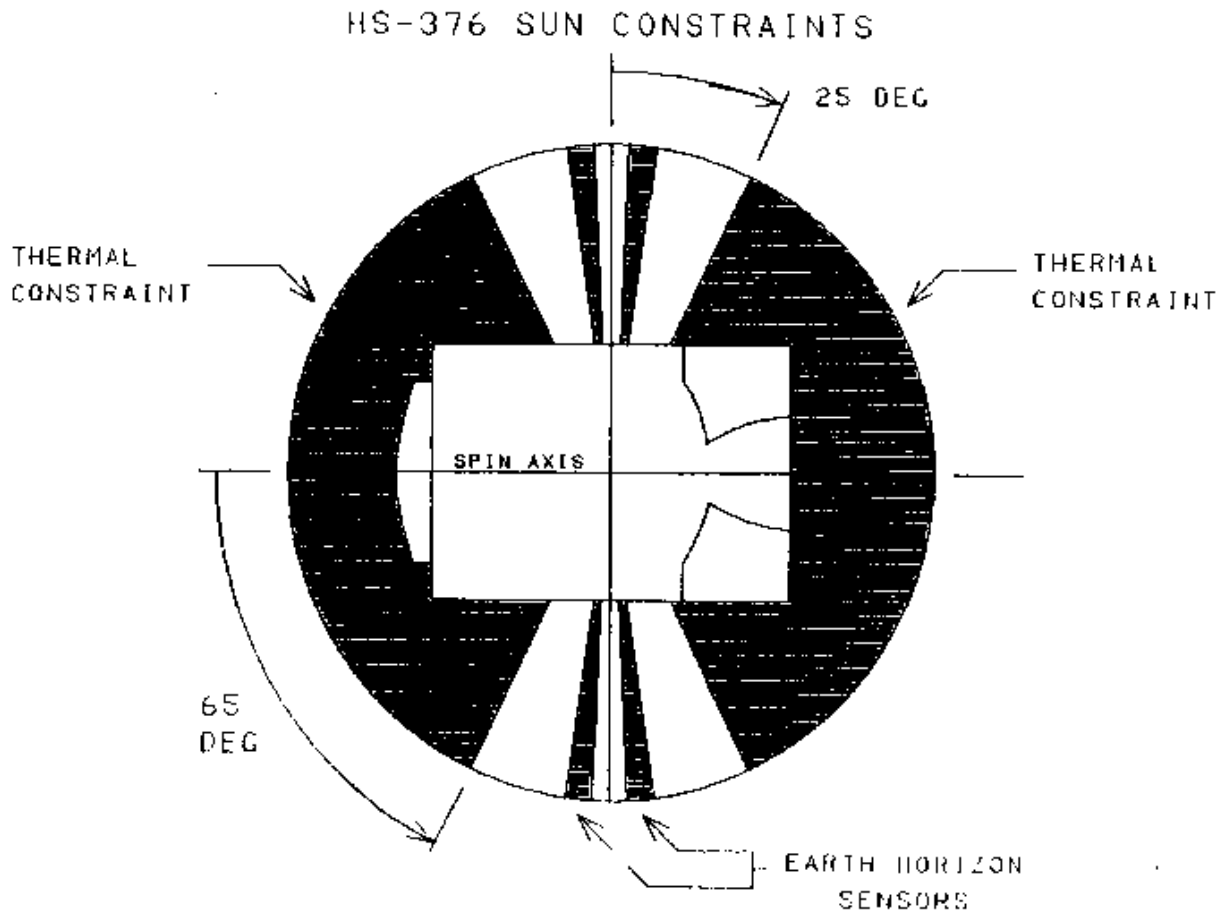
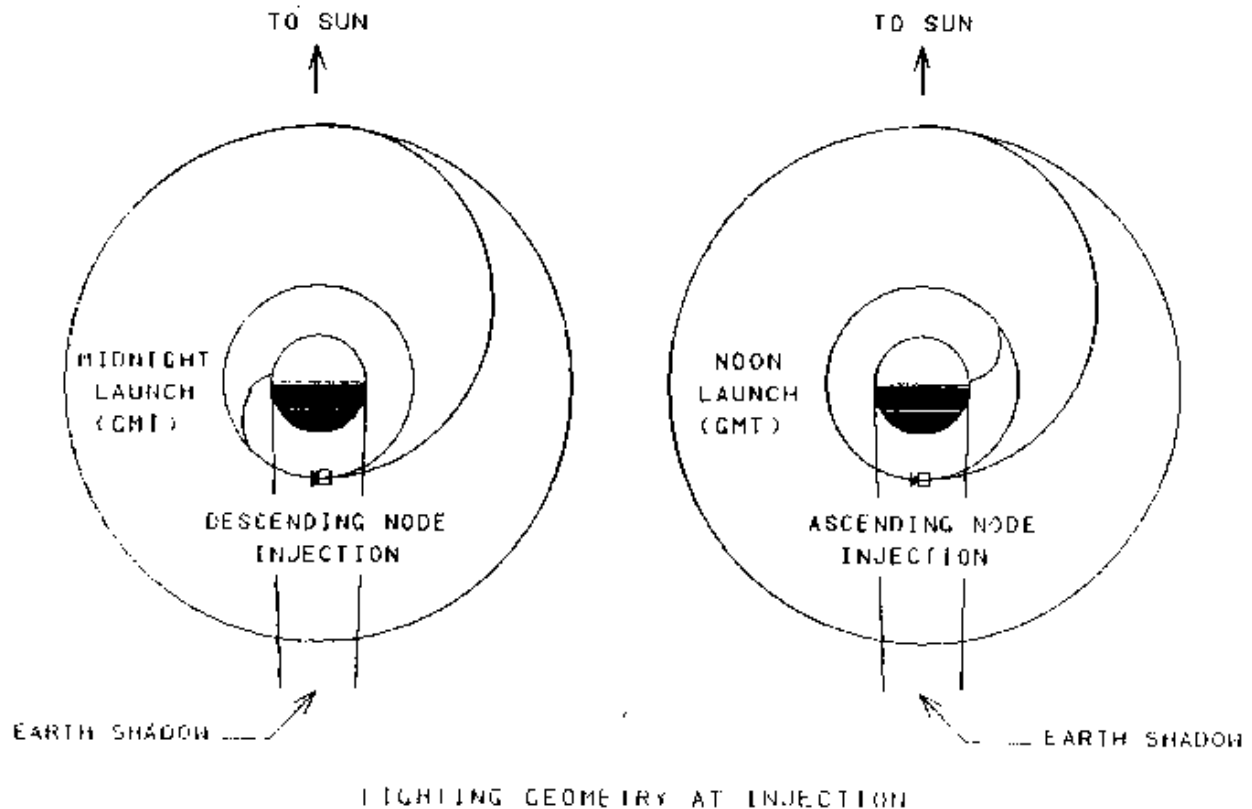


Figure 3.10.3.5-5

## FDO Console Handbook Section 3.10: Rendezvous Operations



**Figure 3.10.3.5-6**

Fig 3.10.3.5-7 shows RAAN vs. launch month. The stippled bands identify acceptable RAANs for injection. Note that the sun position stays about 180 degrees from the RAAN. PIP Annex 2 contains deployable launch window plots as a function of launch date/time and RAAN for each deployable. To determine which deploy opportunities are acceptable to both the payload and the rendezvous, superimpose a diagonal line representing the target's inertial orbit plane over this graph. To achieve rendezvous, the Orbiter must be somewhere on the diagonal line. Various injection nodes occur on the diagonal line at a horizontal distance from the launch time equal to the mission elapsed time (MET) of the node. Marking the primary and backup injection nodes on the diagonal line assures the customer that the RAAN constraints have been satisfied.



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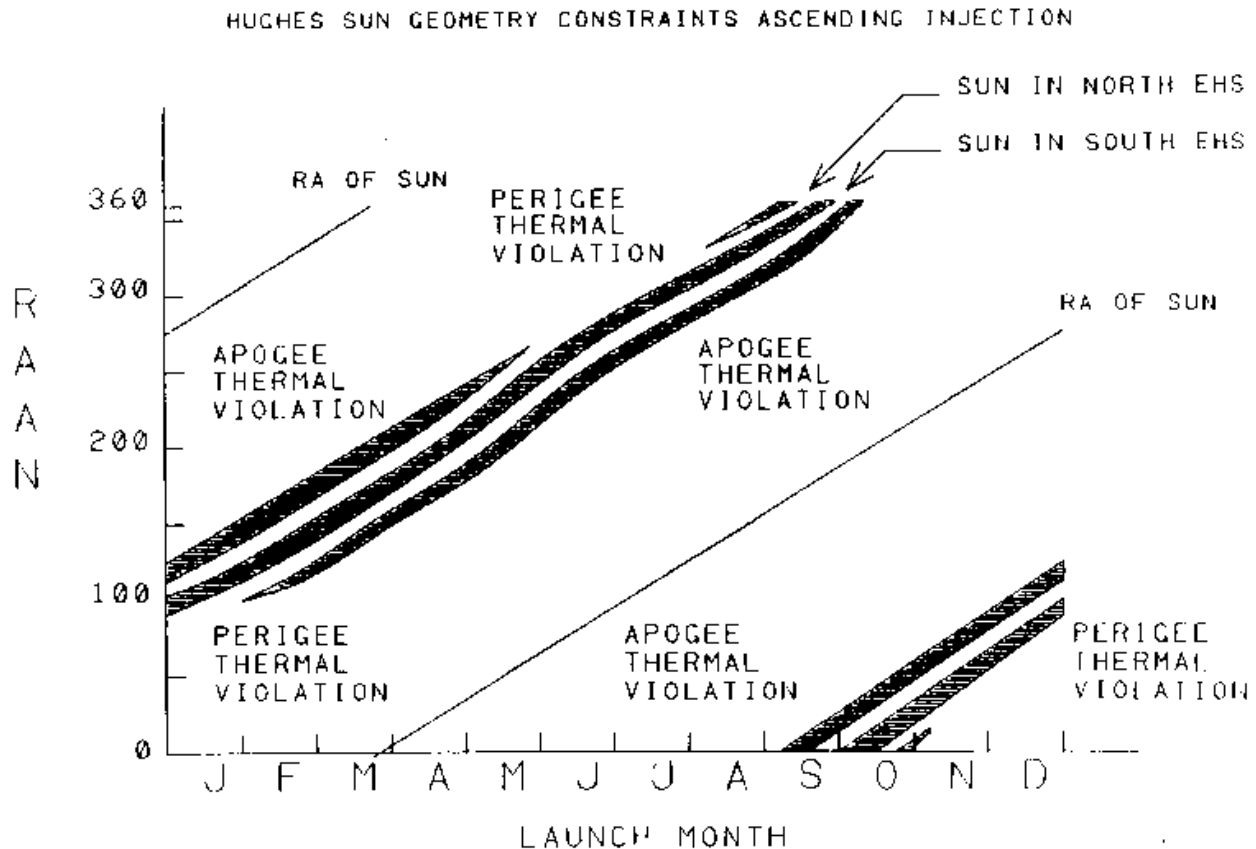


Figure 3.10.3.5-7

### 3.10.3.5.3.2 Longitude

In addition to RAAN constraints, the customers supply acceptable longitude bands for injection. As long as the injection node lies within these bands, the payload will have adequate ground station coverage for command and telemetry during the transfer orbit. The longitude of nodes depends on launch azimuth and ascent yaw steering. Yaw steering is used to achieve the target plane when launch occurs within the planar window, but not at the in-plane time. Therefore, given acceptable longitude bands for the deployable, a plot can be generated showing the acceptable injection opportunities as a function of when launch occurs in the planar window.

### 3.10.3.5.4 Composite Launch Window

When all constraints are combined together, and the most limiting selected, a composite launch window emerges. Figure 3.10.3.5-8 shows the STS-88 planar launch window from ONOR-37, with FGB beta limits superimposed. Note that for a 51.6 deg inclination, 210 nm launch, the in-plane time moves earlier by about 23 min per day due

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to nodal regression. The  $\beta \geq 60$  deg window cutout can result in no launch opportunities available for approximately 16 days in a row, when the planar window passes through this band. Note also that in order to satisfy the planar window, launch time may be any time of day or night. It is for this reason that ground-up rendezvous crews must be trained in night landings, since EOM lighting is not protected.

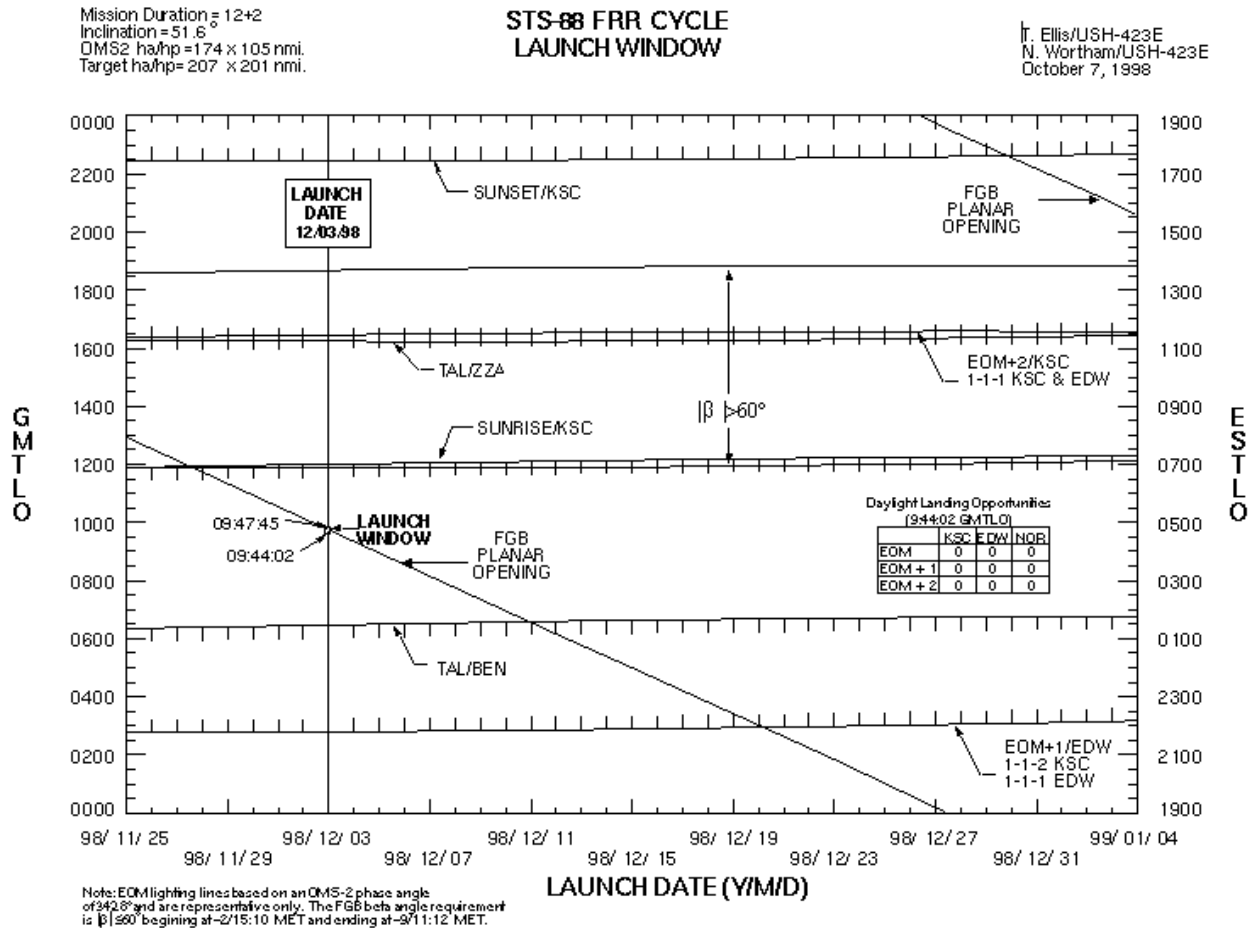


Figure 3.10.3.5-9 shows the phase window superimposed on the planar window. For certain launch days, some of the planar window may be unusable if the phase window limits are exceeded. For example, on Dec 3, the maximum OMS-2 phase angle of 356.7 deg is reached prior to the end of the planar window. Therefore on this date, the usable launch window is only 3 min 43 sec. The intersection of the planar and phase window, considering any additional payload constraints, defines the composite launch window.

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Mission Duration = 12+2  
 Inclination = 51.6  
 OMS2 ha/hp = 174 x 105 nmi.  
 Target ha/hp = 207 x 201 nmi.

## STS-88 FRR CYCLE DAILY PLANAR/PHASE WINDOW

T. Ellis/USH-423E  
 N. Wortham/USH-423E  
 October 7, 1998

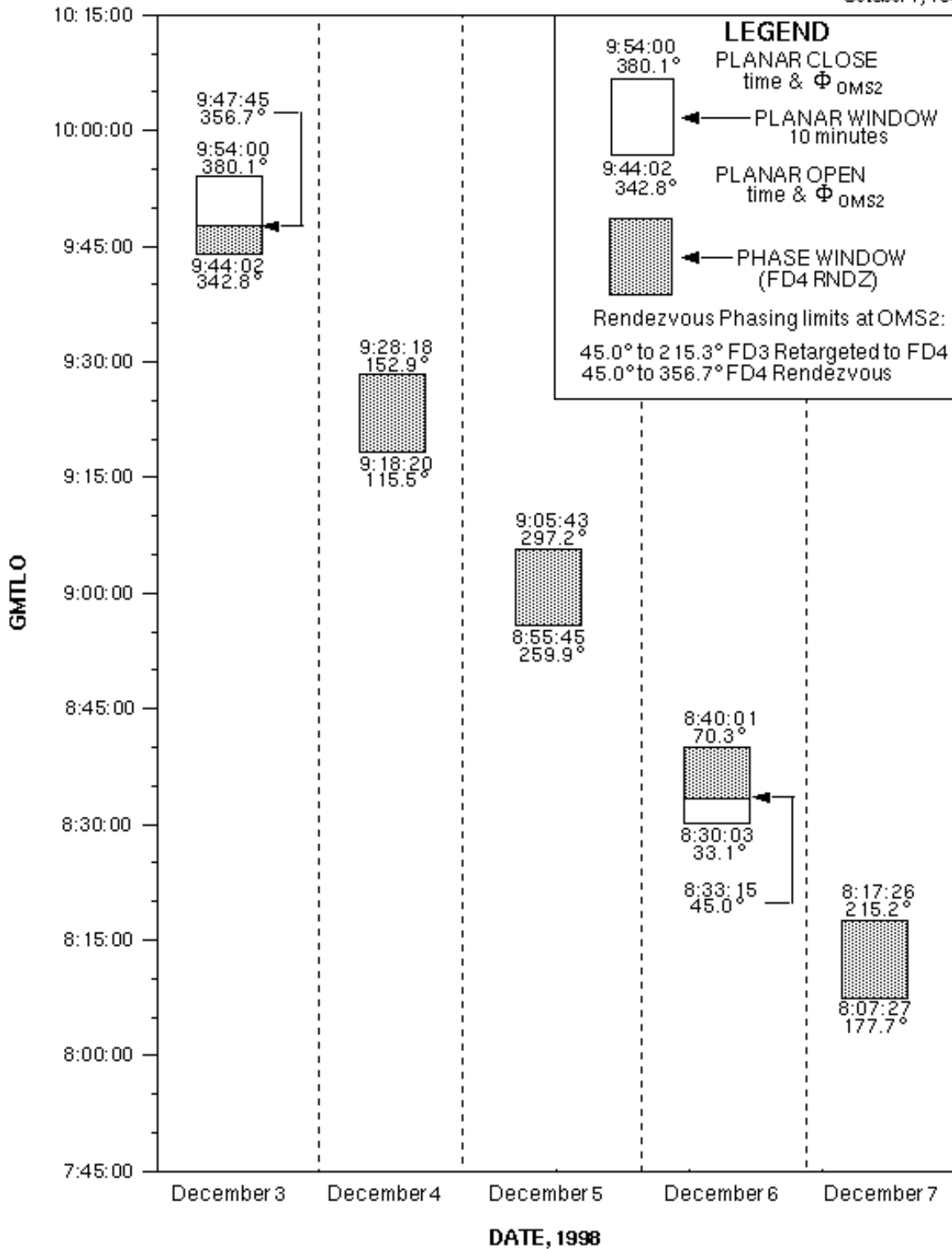


Figure 3.10.3.5-9: Launch Window "barchart"

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STS-88 rendezvous was planned for FD4. The legend in Figure 3.10.3.5-9 states that FD3 rendezvous may be retargeted to FD4 for phase angles between 45 to 215 deg. This is referring to the capability to start off post OMS-2 with a large enough phasing rate to support an early rendezvous if MDF is declared. In the event of failure of some Orbiter system that requires an early landing, a rendezvous for this range of phase angles may be conducted 1 day early in order to salvage some mission success. To do this, the Orbiter must remain at a much lower altitude than the nominal plan in order to rapidly make up the phase angle. Alternately, if all systems are running smoothly during post-insertion, the phasing rate will have to be slowed down to switch back to the nominal rendezvous day. Usually by NC-1 early on FD1 it is necessary to commit to a rendezvous day by either raising the altitude to slow the phase rate for a nominal timeline, or staying low to phase in fast for an early rendezvous.

A key factor to remember for retargeted rendezvous profiles is that the same phase angle is flown regardless of which day the rendezvous occurs. This allows both plans to have identical *planar* targets, since nodal regression is the same. On some missions where the nominal day of rendezvous is flexible, two rendezvous plans and planar windows may be available in which the phase angle differs by 360 deg. For example, STS-86 Mir mission could support a nominal rendezvous on FD3 or 4 (in addition to MDF FD2 rendezvous retargeted to FD3, similar to what was discussed above). The availability of these options depends on phase angle, as shown in Figure 3.10.3.5-10. Examining Sept. 20, it can be seen that the first launch window opens and closes on planar capability, is 10 min in duration, and its phase angles support FD3 rendezvous. Another 10 min planar window is available, slightly later in time, whose phase angles are wrapped an additional 360 deg to support a FD4 rendezvous. This planar window is different because the extra phasing required for the  $\Phi+360$  case forces the chaser to remain lower for much longer than the  $\Phi$  case, resulting in a phantom plane biased further eastward (later in time) to make up for the additional nodal regression. Note that since the second window opens about 3 min later than the first, the composite launch window is 13 min long rather than the usual 10 min. When the timeline can support a nominal rendezvous on different days, it is preferred to carry two planar windows since the increased time improves launch probability. The drawback to this is a corresponding increase in operational complexity in providing multiple  $I_V$  targets, maintaining a launch window cutout at the pane switch time, and carrying multiple rendezvous plans.

# FDO Console Handbook Section 3.10: Rendezvous Operations

July 25, 1997

## STS-86 FRR

### DAILY PLANAR WINDOW

Mission Duration = 10+(1)+2  
 Inclination = 51.6°  
 Insertion ha/hp = 161 x 85 nmi.  
 Target ha/hp = 216 x 207 nmi.

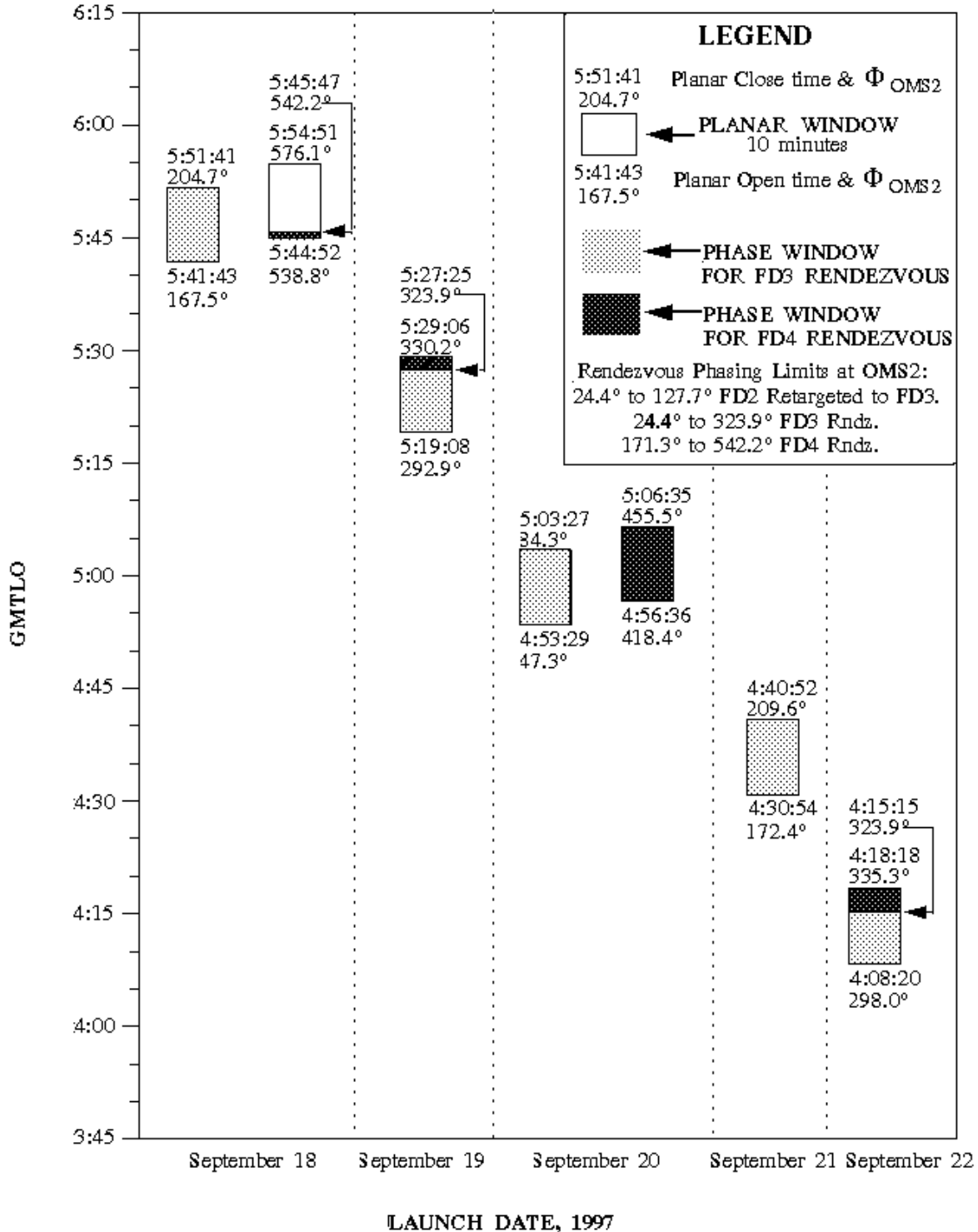


Figure 3.10.3.5-10: STS-86 Launch Window "Barchart"

# FDO Console Handbook Section 3.10: Rendezvous Operations

## 3.10.3.5.5 RFDO Launch Window Operations

While the Ascent FDO is ultimately responsible for generating launch window times and guidance targets, the Rendezvous FDO must also be able to perform similar launch window calculations in order to adequately fulfill lead FDO duties. During each design cycle, Flight Design generates a rendezvous burn plan "sequence of events" (ONOR-03) and launch window (ONOR-37) for the targeted launch date. However, in the event of launch slips not picked up by flight design as part of the standard flight design template, launch scrubs, or SMS launch date "jump aheads", the RFDO bears responsibility for re-generating the rendezvous burn plan and preparing preliminary launch window information. This section describes the tools and procedures for performing these functions.

The Rendezvous Launch Window (RLW) processor resident in TSA is the primary off-line tool for generating launch windows. It is closely related to the Launch Window/Launch Targeting (LW/LT) processor on the TrS that is used by the Ascent FDO for day-of-launch calculations. Data necessary to initialize RLW consists of the following items.

- 1) Target state vector - for ISS, TOPO can provide a predicted vector, otherwise use a USSPACECOM vector. Time-tag of the vector should be prior to estimated planar window open time; normally midnight of launch date is used to initialize RLW.
- 2) DATA-22B LWLT table - this contains MED inputs for LW/LT, many of which are also required for RLW initialization.
- 3) ET Sep Parameters - these depend on ET photo procedures used, which can be found in the Level A Groundrules and Constraints. If orbital darkness is present at ET sep, then the +X translation will not be performed (unless the Lead FDO has coordinated otherwise). Consult with Ascent FDO to determine lighting if the planned launch date is different from the Level A G & C's.

ET Sep LVLH $\Delta v^*$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$ (heads down)	$\Delta V_z$ (heads up)
+X translation	5	0	4	-4
None or pitch mnvr	0	0	4	-4

\* Make sure that ET photo  $\Delta v$  has not been included in MPS Dump  $\Delta v$  to avoid double-bookkeeping.

- 4) Nominal 51.6 deg inclination MPS Dump LVLH  $\Delta V_x$  9.2,  $\Delta V_y$  -2.6,  $\Delta V_z$  -4.2 fps (heads down), or  $\Delta V_x$  9.7,  $\Delta V_y$  0.2,  $\Delta V_z$  -1.0 fps (heads up). These numbers are averages from flight data, and the latest values can be obtained from DM46/E. Gonzalez.

## FDO Console Handbook Section 3.10: Rendezvous Operations

- 5) Phase and wrap flags - these control phase angle calculations. Can be determined from the following table if initial estimate of in-plane OMS-2 phase angle is known:

Expected OMS-2 $\Phi$	-90 to 90°	90 to 270°	270 to 450°	450 to 630°	630 to 720°
Phase Control	2	0	2	0	2
Wrap	0	0	1	1	2

- 6) MET Rendezvous - set to 3/00:00 if  $i = 51.6^\circ$  and phase angle  $\leq 430^\circ$   
5/12:00 if  $i = 51.6^\circ$  and phase angle  $> 430^\circ$   
~2/00:00 if low inclination
- 7) Launch Reference Target Sets - OMS-1 & -2 and  $I_V$  reference data from DATA-22B LTT; remainder from LWLT table.

It is easiest to start off with RLW inputs from a previous ground up rendezvous mission. Use the Xdir program to copy the previous mission's entire RLW directory into your TSA ASA. Then using inputs described above, update items in the LAUNCH W/T INIT menu that have changed (Fig 3.10.3.5-10). The target vector can be easily loaded in with the FILE/OPEN VECTOR menu pull-down. Next, the CONSTANTS menu (under the OPTIONS pulldown) should be checked to assure that appropriate data files will be accessed as shown in Figure 3.10.3.5-11. And finally the LNCH REF TGT SETS menu should be filled out using DATA-22B as shown in Figure 3.10.3.5-12. For T-LO-REF, use the value shown on cover of DATA-22B, or simply use midnight of launch date. Also, the  $I_V$  vectors do not have to be typed in--any unit vector will do (e.g. 1, 0, 0) to get a valid RLW run.

**NOTE:** currently, target vectors must be fetched from a TSA Local VAT slot or Local ephemeris.

**NOTE:** a large "core" file in the Local/RLW/ directory frequently results from RLW execution. To save storage in your home directory, it's advisable to exclude the core file from Local archives you create therein. In fact, only ".sel" files need be archived from the Local/RLW/ directory.

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Launch W/T Init			
File	Edit	View	Options Operations Help
<p>TGT STATE M50</p> <p>TGT VECTOR SOURCE</p> <p>A1.3/RLW/Cool_hand.sel</p> <p>GMTV 1998:337:07:00:00.000</p> <p>X 756591.3 ft</p> <p>Y -21725995.0 ft</p> <p>Z 4495091.0 ft</p> <p>VX 16009.890150 fps</p> <p>VY -3406.877560 fps</p> <p>VZ -19152.067195 fps</p> <p>TGT CD 2.0</p> <p>TGT AREA 520 ft2</p> <p>TGT WT 43475 lbm</p>		<p>LAUNCH W/T INIT</p> <p>MPS Dump Data</p> <p>PEG 7</p> <p>DVX 8.1</p> <p>DVY 0.5</p> <p>DVZ 1.6</p> <p>DTIG 0:00:01:54</p> <p>MPS DUMP FLAG <input checked="" type="checkbox"/> Y</p> <p>F10 134.0</p> <p>KP 2.8</p>	
<p>YS 14.0 deg</p> <p>MET RNDZ 0:12:00:00</p> <p>INSERTION MODE <input type="checkbox"/> DI</p>		<p>ET DATA</p> <p>AREA 598.0 ft2</p> <p>CD 2.0</p> <p>WT 75000.0 lbm</p>	
<p>CHASER VEHICLE DATA</p> <p>EPH</p> <p>CD 2.0</p> <p>AREA 2500.0 ft2</p> <p>WT AT</p> <p>OMS-2 TIG 251679 lbm</p>		<p>MISC PARAMETERS</p> <p>DT PANE EVAL</p> <p>PHASE CNTRL FLAG 0</p> <p>SSHE H-DOT</p> <p>WRAP FLAG 0</p> <p>LAUNCH AZ DIR FLAG <input type="checkbox"/> N</p> <p>IP/OOP FLAG <input checked="" type="checkbox"/> IP</p> <p>HE EX VEL</p> <p>OMS EX VEL</p>	
<p>LAUNCH SITE 39A</p> <p>LATD 28:36:30 deg</p> <p>LONG 279:23:45 deg</p>		<p>PFA 14.4 deg</p> <p>PFT 0:00:08:39.0</p> <p>RAD 21241700.0 ft</p> <p>VEL 25928.0 fps</p> <p>FPA 0.6 deg</p> <p>OPT 0:00:05:40.0</p> <p>DTO 0:00:05:00.0</p> <p>DTC 0:00:05:00.0</p>	
		<p>ET SEP PARAMETERS</p> <p>DELTA VX 5.0 fps</p> <p>DELTA VY 0.0 fps</p> <p>DELTA VZ 5.0 fps</p> <p>DTIG FROM</p> <p>MECO 0:00:00:12.0</p>	
		<p>NET SEP</p> <p>STG VEH WT lbm</p> <p>STAGING VECTOR &lt;DIR&gt;</p> <p>X-STG ft</p> <p>Y-STG ft</p> <p>Z-STG ft</p> <p>VX-STG fps</p> <p>VY-STG fps</p> <p>VZ-STG fps</p>	
		<p>LWT TGT SET <input type="checkbox"/></p> <p>SRB SEP PARNs</p>	
<p>HARDCOPY</p>			

Figure 3.10.3.5-10: Launch W/T Init



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Constants	
State Vector Manual Input?	<input checked="" type="checkbox"/> YES
Use Drag?	<input checked="" type="checkbox"/> YES
Phase Angle Tolerance	<input type="text" value="0.00001"/> deg
Phase Angle Iteration Limit	<input type="text" value="9"/>
Geophysical constants	<input type="text" value="geocon.mdf"/>
Physical constants	<input type="text" value="phycon.mdf"/>
Atmospheric density model	<input type="text" value="jac171.mdf"/>
Solar flux model	<input type="text" value="mbe0895.mdf"/>
Geopotential model	<input type="text" value="geo4x4.mdf"/>
RLW state vector filename	<input type="text" value="bvec.df"/>
MECO state vector filename	<input type="text" value="meco.do"/>
PRE-ET SEP state vector filename	<input type="text" value="pre-etsep.do"/>
POST-ET SEP state vector filename	<input type="text" value="post-etsep.do"/>
MPS state vector filename	<input type="text" value="mps.do"/>
OMS-1 state vector filename	<input type="text" value="oms1.do"/>
OMS-1 BURNOUT state vector filename	<input type="text" value="oms2_bo.do"/>
OMS-2 state vector filename	<input type="text" value="oms2.do"/>
OMS-2 BURNOUT state vector filename	<input type="text" value="oms2_bo.do"/>
Launch Window data object filename	<input type="text" value="lwp.do"/>
Launch Targeting data object filename	<input type="text" value="rlt.do"/>
<input type="button" value="ACCEPT"/> <input type="button" value="CANCEL"/>	

Figure 3.10.3.5-11 Constants

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LNCH REF TGT SETS				
LNCH REF TGT SETS				
	REF SET 1	REF SET 2	REF SET 3	REF SET 4
T-LO-REF	1998:338:08:35:34.000	I	I	I
DEL PSI (RAD)	0.0	0.0	0.0	0.0
IYD-NOM X	-0.780975676	0.0	0.0	0.0
(M50) Y	-0.093098985	0.0	0.0	0.0
Z	-0.617583657	0.0	0.0	0.0
<b>OMS-1 TGT S</b>				
DTIG-	0:00:02:00.000	I	I	I
C1	0.0	0.0	0.0	0.0
C2	0.0	0.0	0.0	0.0
HT	158.0	0.0	0.0	0.0
THETA-T	154.0	0.0	0.0	0.0
IYD-OMS-1 X	-0.780928148	0.0	0.0	0.0
(M50) Y	-0.092934422	0.0	0.0	0.0
Z	-0.617668537	0.0	0.0	0.0
<b>OMS-2 TGT S</b>				
DTIG-	0:00:35:01.000	I	I	I
C1	0.0	0.0	0.0	0.0
C2	0.0	0.0	0.0	0.0
HT	110.8	0.0	0.0	0.0
THETA-T	338.0	0.0	0.0	0.0
IYD-OMS-2 X	-0.781461342	0.0	0.0	0.0
(M50) Y	-0.091069392	0.0	0.0	0.0
Z	-0.617271851	0.0	0.0	0.0
MPS PROP REF	0.0	0.0	0.0	0.0
OMS-1 DELTA-V REF	0.0	0.0	0.0	0.0
OMS-2 DELTA-V REF	212.44877427	0.0	0.0	0.0
MET SRB JET	I	I	I	I
WT SRB JET	0.0	0.0	0.0	0.0
DELROP	0.0	0.0	0.0	0.0
DELVOP	0.0	0.0	0.0	0.0
HARDCOPY				
CLOSE				

Figure 3.10.3.5-12: Launch Ref Target Sets

After all of the above inputs have been verified, the Launch Window Processor (LWP) is cued via the OPERATIONS pull down menu (Fig 3.10.3.5-13). It requires either the desired OMS-2 phase angle(s) for a window constrained by phase angle, or the

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longitudes of descending node ( $\lambda_{DN}$ ) for computation of the planar window. Normally the planar window is computed first using  $\lambda_{DN}$  inputs from Flight Design for the expected window duration, which is usually 10 min for a 51.6 deg inclination. Obtain  $\lambda_{DN}$  constraints from the latest Flight Design STF (consult Ascent FDO), and choose the appropriate table based on earth-relative target inclination (Iteg). The table below shows constraints for a 51.63 deg inclination for various launch window lengths centered on in-plane time. The following table is for illustrative purposes and contains values published by STF ADFD-2003-48220-030 on July 30, 2003.

Planar Window Size (min)	$\lambda_{DN}$ open (deg)	$\lambda_{DN}$ close (deg)
0 (Inplane)	65.087	65.087
5	65.676	64.496
6	65.795	64.378
7	65.913	64.260
8	66.031	64.142
9	66.149	64.024
10	66.267	63.905

```

LWP EXECUTION

REF SET ID 1

The following are all optional inputs for LWP:

DESIRED OMS-2 PHASE ANGLE(S)
  (DEG, D:M:S, OR D.D)

LONGITUDE(S) OF THE DESCENDING NODE
  (PLANER WINDOW) (DEG, D:M:S, OR D.D) 66.205
                                          63.850

EXECUTE  CLOSE
  
```

Figure 3.10.3.5-13 LWP Execution

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LAUNCH WINDOW PROCESSOR OUTPUT			
LAUNCH WINDOW PROCESSOR OUTPUT			
TXT SOURCE	Manual Input	REF SET	1
		CLOSE APP FLAG	0
OPTIMUM L/O	337:08:58:44.3		
PHASE	251.1 deg		
PFT	0:00:08:39.0		
PFA	14.4 deg		
DT0	0:00:05:00.0		
DTC	0:00:05:00.0		
OPT	0:00:05:40.0		
PHASE CNTL	0		
WRAP FLAG	0		
PLANAR OPEN		PLANAR CLOSE	
L/O	337:08:53:44.3	L/O	337:09:03:44.3
PHASE	232.5 deg	PHASE	269.9 deg
DESIRED OMS-2 PHASE ANGLES(S)		L/O TO ACHIEVE DESIRED PHASE	
	deg		
	deg		
DESIRED LONG OF DESC NODE		L/O FOR DESIRED NODE	
	66.205 deg		337:08:54:17.1
	63.850 deg		337:09:04:16.0
HARDCOPY			CLOSE

**Figure 3.10.3.5-14 LWP Output**

The LAUNCH WINDOW PROCESSOR OUTPUT menu (Figure 3.10.3.5-14) shows launch times to achieve the input constraints. Data under "L/O FOR DESIRED NODE" at the bottom should be used when  $\lambda$ DN inputs have been used to queue the program; "L/O TO ACHIEVE DESIRED PHASE ANGLE" output should be used when phase angle is input. Data at the top of the display is not quite as accurate as running with  $\lambda$ DN or phase angle. Next, the Launch Window program is executed using  $\lambda$ DN corresponding to 0 DT in order to find the optimum (i.e. in-plane) liftoff time. Hardcopies of all of these cases should be made.

Next the Launch Targeting Processor (LTP) should be executed with GMT L/O corresponding to planar window open, close, and optimum cases found above. Input and output menus are shown in Figures 3.10.3.5-15 and -16. Each time the LTP is executed, the post-OMS-2 phase angle should be checked against its expected value as well as the limits shown on the launch window barchart. If the phase angle falls outside the limits, then the Launch Window Program should be re-executed with the limiting phase angle in order to compute the window open and/or close time constrained by phase angle rather than plane. Each time the LTP is run, a post-MPS dump state vector should be stored off in the TSA VAT using the FILE / SAVE VECTORS pulldown

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menu (don't include "V" with the VAT slot designator—it won't accept this input. Just type in the number. Once this is done, you are ready to build an OMP plan for the launch window and run it off of the vectors you've just stored in the VAT. This process will be described in the Real-time.

### LTP EXECUTION

GMT L/O 1998:337:08:54:17.100

REF SET ID 1

SOLUTION SET 1

EXECUTE LTP?:  YES

EXECUTE
CLOSE

Figure 3.10.3.5-15 LTP Execution

### LAUNCH TARGETING PROCESSOR OUTPUT

LAUNCH TARGETING PROCESSOR OUTPUT

LTP OPT 2      GMT L/O 1998:337:08:54:17.100      SELECTED REF SET 1

CHASER MECO	MPS DUMP	OMS-2	TGT (AT ASCN)
MECO <span style="border: 1px solid black; padding: 2px;">8:39.0</span>	TIG <span style="border: 1px solid black; padding: 2px;">10:33.0</span>	TIG <span style="border: 1px solid black; padding: 2px;">43:52.0</span>	HA <span style="border: 1px solid black; padding: 2px;">211.6 nm</span>
VMECO <span style="border: 1px solid black; padding: 2px;">25928.0 fps</span>	DELTA V <span style="border: 1px solid black; padding: 2px;">8.3 fps</span>	DELTA V <span style="border: 1px solid black; padding: 2px;">118.2 fps</span>	HP <span style="border: 1px solid black; padding: 2px;">209.2 nm</span>
RMECO <span style="border: 1px solid black; padding: 2px;">3495.9342 nm</span>	HA <span style="border: 1px solid black; padding: 2px;">169.3 nm</span>	HA <span style="border: 1px solid black; padding: 2px;">178.1 nm</span>	LONG <span style="border: 1px solid black; padding: 2px;">86.1 deg</span>
GMECO <span style="border: 1px solid black; padding: 2px;">0.6000 deg</span>	HP <span style="border: 1px solid black; padding: 2px;">40.0 nm</span>	HP <span style="border: 1px solid black; padding: 2px;">105.4 nm</span>	DELN <span style="border: 1px solid black; padding: 2px;">0.472677 deg</span>
IMECO <span style="border: 1px solid black; padding: 2px;">51.594 deg</span>		NODE <span style="border: 1px solid black; padding: 2px;">-125.2 deg</span>	PERIOD <span style="border: 1px solid black; padding: 2px;">1:32:20.9</span>
PHASE <span style="border: 1px solid black; padding: 2px;">234.5 deg</span>		PHASE <span style="border: 1px solid black; padding: 2px;">229.2 deg</span>	
HA <span style="border: 1px solid black; padding: 2px;">166.6 nm</span>		PERIOD <span style="border: 1px solid black; padding: 2px;">1:29:45.6</span>	
HP <span style="border: 1px solid black; padding: 2px;">40.0 nm</span>			
LONG <span style="border: 1px solid black; padding: 2px;">-69.0 deg</span>			

HARDCOPY
VIEW SOLN SET
PRINT IYD VECTORS
VIEW IYD VECTORS
XFER DATA
CLOSE

Figure 3.10.3.5-16 LTP Output

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### **3.10.3.6 Console Data**

The lead FDO must insure that all FDOs and TRAJECTORYs who will be working mission simulations and the actual flight have all the data they need to do the job. Periodically, the lead should update the FDOs on the progress of mission planning, and the development of rules and procedures. Before simulations begin, the lead FDO can hold a Trench Tagup to brief the section on the rendezvous profile and flight specific procedures. Also, the FDO Console Databook should be compiled and available on console prior to the first integrated sim. One to two weeks before launch, the preflight Trench Tagup should be held and final console data distributed. The following is a list of rendezvous-specific items to include in the Console Databook. This list includes only those things pertaining to rendezvous and is not meant to be definitive. Depending on the mission, items could be added to or subtracted from this list.

#### **3.10.3.6.1 Launch Window Data**

ONOR-37 presents graphical depictions of launch time vs. launch date with window opening and closing constraints superimposed, including a description of the impact of launch date/time on science objectives. For a ground-up mission, launch window is shown as a function of date with respect to in-plane time, ascent performance limits and ET impact limits. At approximately L-21 days Flight Design produces ONOR-37B, which shows launch window phase angle versus date (the so-called "FDO barchart" format). This better depicts location of the launch window with respect to phase limits. This product is re-generated at L-6 days as ONOR-37C using a more recent target vector.

#### **3.10.3.6.2 TIG Slip Analysis**

The results of any pre-flight TIG slip analysis should be included in the FDO data book. This analysis provides the basis for evaluating the effects on the propellant budget of missed TIGs for any critical rendezvous maneuver, and for deciding whether a late maneuver should be performed in LVLH or inertial attitude hold.

#### **3.10.3.6.3 Monte Carlo Dispersion Analysis**

This analysis is done by the Flight Design as part of the RNDZ-03 product. Using estimates of ground tracking uncertainty, maneuver execution trim errors, sources of unmodeled orbital perturbations (i.e. attitude maneuvers), and onboard sensor errors, the analysis predicts 3 sigma dispersions and the associated cost in delta-V and pounds

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of propellant for each maneuver. The analysis is done for the nominal and various sensors failed cases.

### **3.10.3.6.4 Rendezvous PSAT**

Use TSA to generate a Predicted Site Acquisition Table (PSAT) off the target vector for the day of rendezvous. Then, using the PSAT Timeline output, mark up tracking passes for both the Orbiter and target. Also note the times of all FDO actions, such as maneuver TIGs, and vector and PAD uplink times, etc. This provides a good situational awareness tool to be aware of state vector deliveries from NAV, and to generally stay ahead of the curve in real-time.

### **3.10.3.6.5 Contingency Rendezvous Timelines**

It is impossible to come up with a timeline for all possible contingencies, but when predictable problems still leave room for a limited rendezvous mission, such as a shortened deploy/retrieval case, developing a timeline saves a lot of work in real-time if the situation occurs. Any such timeline must be thoroughly coordinated with the payload community, the flight directors, and flight activities officers. Among the possible causes for changes to nominal deploy/ retrieval missions are Orbiter systems anomalies causing a day late deploy, or remote manipulator system (RMS) joint failures which could cause non-nominal deploy attitudes and separation sequences. The lead FDO develops these timelines.

### **3.10.3.6.6 Maneuver Constraints Tables**

MARS will generate a complete set of maneuver constraints tables. These will be based on standard templates. FDO should verify each table in Global prior to use.

### **3.10.3.6.7 Relative Motion Plots**

As a minimum, include in-plane relative motion plots for the mission as a whole, separation sequences, and terminal phase. Terminal phase plots should indicate sensor passes, orbital sunrise/sunset, and approximate location of midcourse correction burns. Whole mission plots should label the rendezvous maneuvers, showing post burn perigee and apogee heights and other notes as appropriate. Marking off crew sleep periods is helpful.

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### **3.10.3.6.8 Rendezvous Target Characteristics Summary**

The FDO needs accurate target characteristics in order to configure the target ground ephemeris. Minimal data required for the ephemeris are weight in pounds, average cross-sectional area in square feet, and coefficient of drag ( $C_D$ ). Flight Design formally delivers these data in the RNDZ-02 product. This product also contains the target ballistic number uplinked as a Kfactor scalar used in target drag acceleration modeling during rendezvous nav operations (see Section 3.10.1.9.12). The target KCON in TSA and TrS ephemerides should be set equal to target  $C_D/2$  since both the TrS and TSA  $C_D$  values are hardcoded to 2.0. The NAV controllers may update the value of KCON by analyzing tracking data prior to launch. Usually, however, most targets (ISS, HST) are stable.

Some cautions are in order regarding payload weight for deployable rendezvous objects. The weight that appears in the PMP Cargo Buildup display may include the weight of the pallet structure used to mount the payload in the cargo bay. Make sure the payload ephemeris reflects only the deployed weight. For payloads with active attitude control systems, weight at deploy may be significantly more than weight at retrieval.

Other important information for terminal phase and grapple operations includes predicted target attitude and attitude rates, optical reflective characteristics, and estimates of the probability of sensor acquisition as a function of range and relative position and lighting, for the rendezvous radar, star tracker and Crew Optical Alignment Sight (COAS).

For general information, include engineering drawings of the target, if available, and a descriptive payload mission summary, including science objectives.

### **3.10.4 Realtime Operations**

Section 3.10.2 introduced you to the details of the OMP and the mechanics of using it. TSA input menus were described, output displays were explained, and all the maneuver types with their associated primary and secondary constraints were defined. This section goes into more operational detail on how to run a typical sequence of ground-up rendezvous plans, and shows what the resulting output looks like. This section covers the timeframe from pre-launch (following launch window determination), through the phasing portion of the mission, plus all DOR operations as well. Nominal procedures are covered first, followed by off-nominal procedures. An additional sub-section documenting special considerations for deploy-retrieve/stationkeeping profiles is also included. Following this section, MCC displays for monitoring onboard data will be covered.



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### **3.10.4.1 Pre-Day of Rendezvous**

A mature rendezvous plan must be prepared prior to liftoff, because immediately after main engine cutoff, the pre-rendezvous phase of a GUR mission will have begun. OMS-2 will be the first of several phasing burns conducted over the next few days to control the closing rate of the Orbiter and target. Targeting and executing the various phasing, planar, and height control burns is a "team effort", with the Planning team setting up each day's burn plan, Orbit 1 team performing the burns after crew wakeup, and the Orbit 2 team executing the evening burns prior to crew sleep period. The rendezvous-execute FDO is heavily dependent on the Planning team to provide a mature and stable plan on the morning of rendezvous, along with updated and verified trajectory data on console. The execute FDO is also dependent on the Orbit 2 FDO to accurately target the final pre-DOR phasing burn the evening before rendezvous in order to place the Orbiter at the correct range when the rendezvous phase begins. All teams contribute to a successful rendezvous during the pre-DOR timeframe, not just the execute FDO.

#### **3.10.4.1.1 Prelaunch Operations and FDO Support Duties**

The FDO SUPPORT flight control position serves Ascent FDO as rendezvous operations expert. The Lead FDO (reference DM-WI-3201) of a ground-up rendezvous mission generally staffs this position. The Lead FDO may delegate this duty if required. However, a rendezvous FDO certification must have been previously obtained (reference JSC-27645) before executing FDO SUPPORT procedures in real time.

In general, FDO SUPPORT responsibilities fall into the following categories.

- 1) Compare TrS launch window computations against results from RLW.
- 2) Provide target vehicle drag characteristics.
- 3) Work with MARS and PROFILE to provide OMP Maneuver Constraints Tables to support OMS-2 and NC-1 targeting.
- 4) Provide post-OMS-2 perigee (or apogee) height.
- 5) Work with MARS and Profile Support to run OMP post-MECO and provide updates to OMS-2 targets if required.
- 6) Work with MARS and Profile Support post-OMS-2 with a confirmed post-OMS-2 state vector to evaluate planar error and NPC combination with another maneuver.

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- 7) Support resolution of off-nominal cases (underspeed, pre-OMS-2 state vector uplink, etc.).

The most important FDO SUPPORT task is to serve as rendezvous expert for the launch team. The Orbit 1 MARS and PROFILE Support will also be on console to assist in this duty. Prior to the ascent shift or simulation, it is imperative to have constraints tables built and ready for all possible FD1 scenarios. For short phase cases, this means having plans ready to support both FD2 and 3 rendezvous. On two-pane days, this will mean having plans available for both panes (FD3 and FD4 rendezvous options). The Ascent FDO will provide predicted post-MPS dump vectors from LWLT for launch window open, close, and in-plane. These vectors can be used to run the various cases on OMP. FDO SUPPORT is responsible for finding an optimum OMS-2 target height that satisfies phase constraints for each plan. For short phase angles, this means finding an OMS-2 target height that allows FD2 or FD3 rendezvous. Otherwise, it's more straightforward. The Ascent Team will bias this height slightly when building actual targets in order to account for limitations in PEG-4A guidance<sup>7</sup>.

NOTE: if Ascent FDO or TrS is unavailable to generate LWLT post-MPS dump state vectors, FDO SUPPORT can supply acceptable equivalents using RLW.

Phase angle will also influence whether an ET photo translation (5 fps +X) should be performed or not. For long phase cases, the translation should be canceled in order to maximize phase capability. For short cases, the translation should be performed, regardless of lighting, in order to slow the phase rate.

NOTE: the importance of Method 1 ET photography, facilitated by +X translation after ET sep, may dictate this maneuver be performed even after launch into a marginally long phasing case. Assuming adequate lighting during separation, obtaining Method 1 imagery may even justify the propellant expense of a retrograde NC-1.

An ascent underspeed case requires quick thinking by the flight control team to assess rendezvous capability, and then re-plan OMS-2 if rendezvous looks possible. MARS should have a constraints table available with OMS-2 modeled as an NC burn (as opposed to HA) to support this. A quick first guess to determine new OMS-2 target height following an underspeed uses the sum of nominal post-MECO Ha + OMS-2 target height. This sum provides a total height to set up desired phasing in the nominal case. Then the actual Ha is subtracted from this sum to obtain a new OMS-2 target height preserving the same phase rate in the underspeed case. Once the new OMS-2

---

<sup>7</sup> PEG-4A utilizes a simple spherical geopotential model. Due to real-world geopotential (J2 and higher order terms), actual post-OMS-2 burnout perigee (or apogee, as the case may be) will not match the input height target. Consequently, a bias is applied to the desired height target in order to account for this effect. The resulting DMT will display biased height in association with the H<sub>T</sub> parameter. The DMT's HP (or HA, as the case may be) parameter should match OMP targeting to within a couple tenths of a nm.

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If it is determined, PROP should be provided total rendezvous  $\Delta v$  from the MET in order to assess rendezvous capability.

### 3.10.4.1.1.1 Target Vector Generation

For GUR missions, the Lead FDO should begin monitoring target vehicle drag trends several weeks before launch. For ISS, TOPO can provide predicted vectors for midnight of launch date to be used in RLW launch window determination. Current target vectors should also be obtained from USSTRATCOM at least once per week. A drag fit is performed between the weekly vectors to determine drag characteristics (area or KCON), and this in turn can be used to propagate out to midnight of launch date. For ISS, these results should agree fairly well with the drag characteristics being used in TOPO's orbit prediction. If not, inform TOPO of the discrepancy and seek an explanation. Beware any target vehicle maneuvers and/or attitude changes that may interfere with conducting a drag fit. For best results, the drag fit should be conducted over a quiescent period of several days.

CAUTION: Jacchia atmosphere solar flux F10 and geomagnetic index Kp values in use by TOPO possess a pedigree differing from those NAV will compute immediately prior to launch. Whereas the TOPO values are computed from data distributed equally in the past and future with respect to their epoch, NAV determines an average using historic data ending at the computation epoch. Consequently, ISS drag fits should utilize TOPO's F10/Kp values until the NAV values become available. A drag fit using NAV's values will generally not match a corresponding fit with TOPO's Jacchia values.

For integrated ascent simulations, FDO SUPPORT has the option of using either the target vector used for the pertinent Flight Design cycle or providing one to the Ascent FDO. Using the specific cycle's target vector is always acceptable, but it limits rendezvous cases to that single phase angle for all simulations. Exercising the flight control team on a variety of target vectors and phase angles helps prepare everyone for actual flight conditions as phase angles change from launch day to launch day.

A variation in phase angles will prepare the flight control team for a variety of rendezvous maneuvers not just on rendezvous day but also on FD1. For example, a small phase angle ( $< 90^\circ$ ) may have a critical OMS-3 maneuver prior to NC-1 so that the chaser does not over-phase the target. Conversely, a larger phase angle is better suited for rendezvous recovery operations involving JURE. In general though, small phase angles are tougher to recover from with MECO underspeeds and promise some challenging scenarios to work. Smaller phase angles also lead to multiple planar windows, again challenging the Ascent Team more than single-pane cases. FDO SUPPORT can choose whatever phase angle is appropriate but should always coordinate the effort with the Ascent FDO and the Training Division FDO-GPO Monitor (FIGMO).

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No matter what state vector is chosen, the constraint of having the same launch time as the time associated with the Flight Design cycle is always in effect. Note that Flight Design chooses the planar window open time as their launch time. This procedure is inconsistent with real time operations, where flight rules select the in-plane time as the preferred launch time. All SMS ascent data stores are built to Flight Design's planar open time, so any changes to the target vector must be made such that the in-plane time is within a few seconds of the original Flight Design launch time.

### **3.10.4.1.1.2 Obtain Flight Design Target Vector**

The original target vector associated with the Flight Design cycle is located in the ONOR-29A Flight Design product (Rendezvous Init State Vectors). Typically, this vector has an epoch of midnight day of launch. As an example, Figure 3.10.4.1-1 shows the target vector for the OCF cycle of STS-114. The phase angle for this vector can be gathered from the ONOR-37 Flight Design product (Launch Window) or from the Level A Groundrules and Constraints. Figure 3.10.4.1-2 shows the launch window for the STS-114 OCF Cycle.

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/fads/msn/mas/mastdyn/fltcyc/114ocf/onor29a.tsvdogmt.asc.01

```

-----
                STS-114 OCF TARGET VECTOR AT MIDNIGHT
SSVD / ollivier   DATE 12/14/ 1   TIME 08/37/15   PAGE 1 of 1

LAUNCH DATE= 01/17/2003  LAUNCH TIME= 00:00:00.000  GMT H:M:S

SOURCE: trgt_29A.de
RECORD NUMBER: 1
OUTPUT: DATA/ssvd_dump.de

STATE:  TARGET ISS
VEHICLE: ISS

BASE DATE      = JAN 17, 2003

VECTOR TIME    = 0:00:00:00.000 IET  TIME =0.00000000000000D+00 SEC  IET
                0:00:00:00.000 MET  MASS =0.37156643530000D+06 LBM
                0:00:00:00.000 PET  ORBIT= 1 REF = ASCN
                17:00:00:00.000 GMT  RRAD =0.20925721784776D+08 FT
                                   AREA = 0.780599E+04 FT2
                                   CD   = 0.235000E+01

                CARTESIAN (M50)
X   =-.85511969944595D+07 FT
Y   =0.11625624259833D+08 FT
Z   =0.16788633527607D+08 FT
XDOT =-.15604002444701D+05 FT/S
YDOT =-.19104547400627D+05 FT/S
ZDOT =0.52780920350647D+04 FT/S

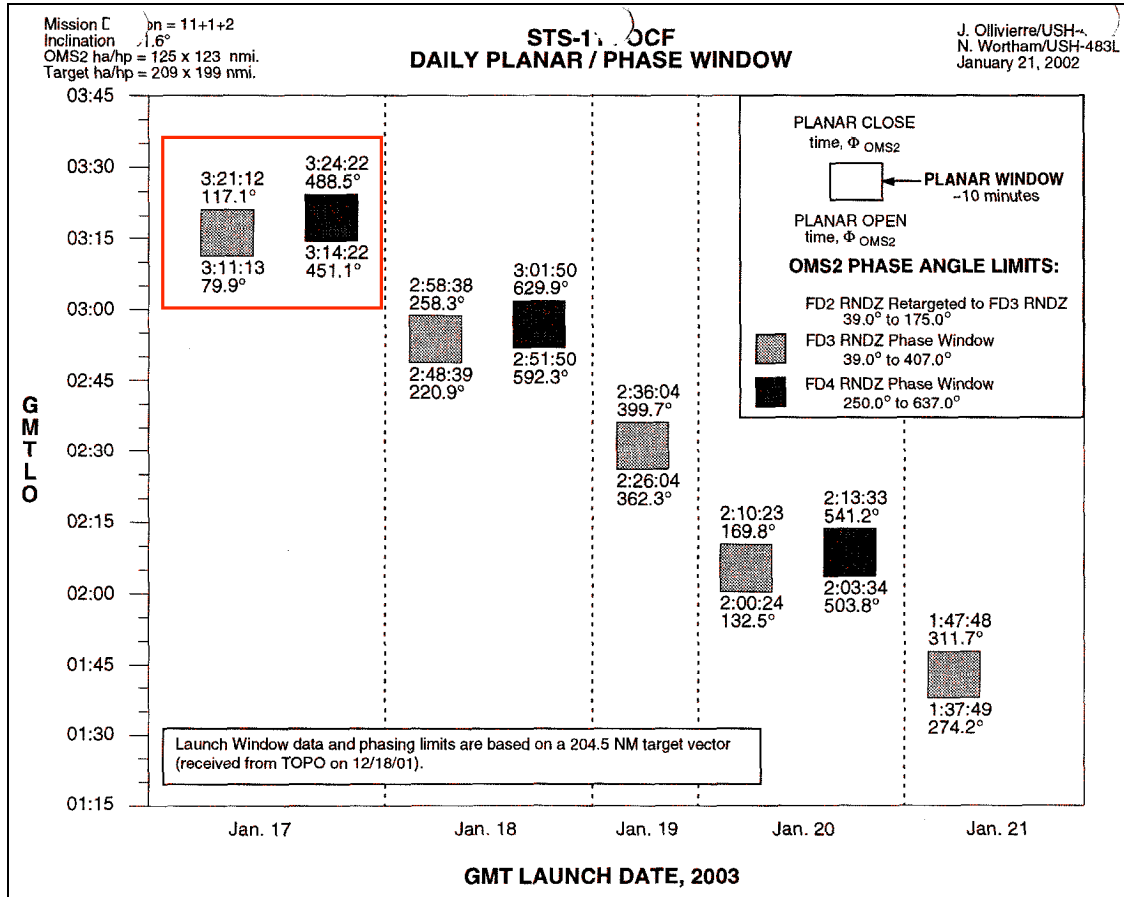
                POLAR (TEG)
V   =0.25225520395180D+05 FT/S
GAMC =-.58928251611399D-02 DEG
AZC   =0.71631683067044D+02 DEG
R     =0.22139022679268D+08 FT
LONG  =0.11281604195772D+02 DEG
LATC  =0.49130997165186D+02 DEG
LATD  =0.49321304116058D+02 DEG
GAMD  =0.50682004401017D-01 DEG
AZD   =0.71631749663642D+02 DEG
RDOT  =-.25944246206021D+01 FT/S
DECL  =0.49141772135931D+02 DEG
RASC  =0.11281604195772D+02 DEG

                ORBITAL ELEMENTS (M50)
A   =0.22156630723506D+08 FT
ECC  =0.80133527470351D-03
INCL =0.51876789889641D+02 DEG
ARGP =0.81949379760239D+02 DEG
RAN  =0.60425779148837D+02 DEG
MA   =0.35263179691460D+03 DEG
TA   =0.35262000892461D+03 DEG
EA   =0.35262590409131D+03 DEG
ARGL =0.74569388684845D+02 DEG
PER  =0.55290019259215D+04 SEC
TMTP =0.54101282469423D+04 SEC
GDOT =0.42759296196192D-04 DEG/S
HDOT =-.58317270188710D-04 DEG/S
LDOT =0.65186710730877D-01 DEG/S
DECL =0.49316990123733D+02 DEG
RASC =0.12633624192632D+03 DEG
ALTC =0.19968364613462D+03 NM (TEG)
ALTD =0.20629783536655D+03 NM (TEG)
HA   = 209.32 NM (TEG)
HP   = 199.67 NM (TEG)
-----

```

Figure 3.10.4.1-1: ONOR-29A Target Vector at Midnight Day of Launch

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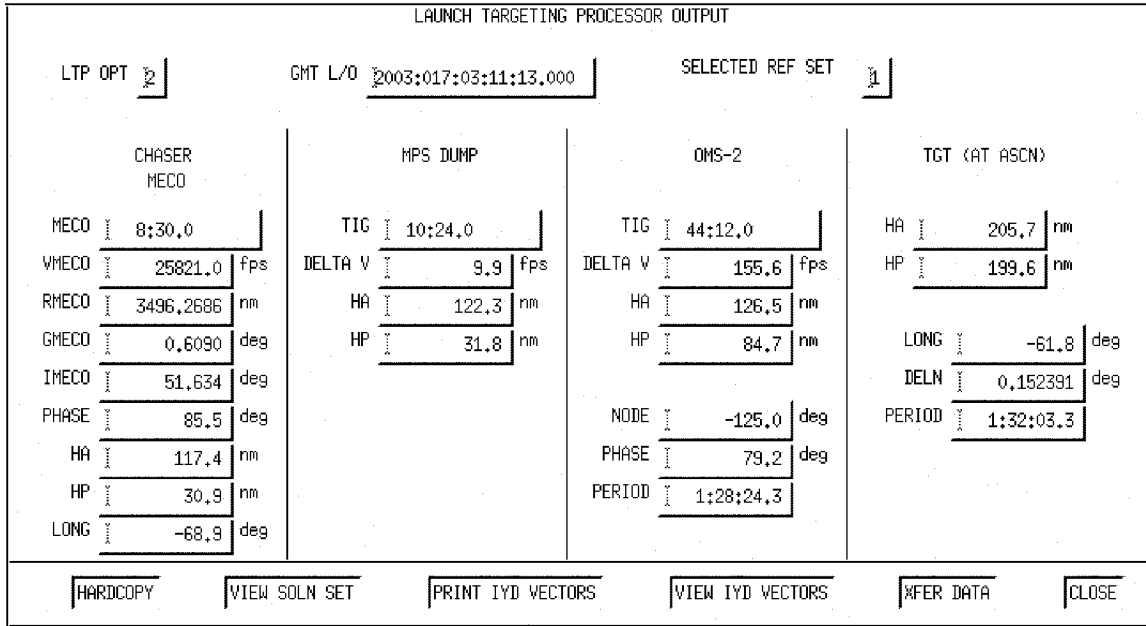


**Figure 3.10.4.1-2: STS-114 OCF Launch Window**

### 3.10.4.1.1.3 Verify the Phase Angle

Begin by verifying the phase angle for window open of the original target vector using the procedures in Section 3.10.3.5.5 (RFDO Launch Window Operations). The resultant phase angle at OMS-2 should be within 1° of the Flight Design predicted phase angle. Figure 3.10.4.1-3 illustrates the RLW results based on the target vector in Figure 3.10.4.1-1. The window open phase angle RLW computes is 0.7° from the value appearing in Figure 3.10.4.1-2. This is due to orbit prediction internal to RLW and the OMS-2 TIG, both of which can be slightly different than applications used by Flight Design.

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**Figure 3.10.4.1-3: RLW Results for Original Target Vector**

### 3.10.4.1.1.4 Generic Data

If the Flight Design vector won't be used, generic ascent data may also be acceptable. Generic data also enjoy the benefit of having all pre-launch FDO data (reference Section 3.10.4.1.1.17) already completed. Four different target vectors, corresponding to phase angles of 71°, 134°, 261°, and 340°, were used circa 2005. These data are used for generic ascent sims but can support for flight-specific training as well. Use the TSA Vector Rotation application to "rotate" the target state vector from its old GMTLO to that of the new ascent simulation. All other generic data can be used "as is" for the simulation.

**CAUTION:** it may be inadvisable to use target state vectors from generic sims in flight-specific training. This is certainly the case for significant inclination changes, and it may also apply to changes in target orbit height amounting to as small as 5 nm.

### 3.10.4.1.1.5 Launch Window/Launch Targeting Inputs

There are a large variety of required inputs on the RLW menu, and correct configuration of the software for execution seems a daunting task. However, many inputs remain the same for all ISS flights, and the rest of the inputs come from standard sources. Inputs for RLW processing come from "Selection" files. RLW will recognize any file that has a ".sel" appended to it. Choosing the "File : Open Selections" RLW menu item will immediately give the user a way to select any .sel files in TSA Local's RLW directory.

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Once all parameters have been input to RLW menus, be sure to save them in a selections file by using "File : Save...". As with many computer input menus, beginning with previously archived RLW data saves time. Use XDIR to archive and restore selections files in your personal directory tree.

NOTE: particularly when saving selections files to `/users/fdo/` directories, where storage capacity is limited, only save those files; not the entire RLW directory. Voluminous RLW core dump files frequently populate an RLW directory after any processing is performed. Other than an optional selections file to supply menu inputs in place of tedious manual entry, RLW requires no files in its directory prior to execution.

As shown in Figure 3.10.4.1-4, the DATA-22B product contains most of the flight-specific inputs RLW requires. It has quite a bit of other TrS inputs as well. However, the inputs are difficult to decipher since they are given in the form of MEDCVs that are input into the TrS. Searching through the product for launch window inputs (MEDs K11 through K19) gives inputs pertinent to RLW. These are the same inputs to be used for actual launch window determination by the Ascent FDO.

The K11 MED contains launch window processor parameters, none of which are required by RLW.

The K12 MED contains Launch Window/Launch Targeting common parameters.

- 1) Display LWT TGT\*
- 2) TGT Vector Source\*
- 3) TGT vector fetch time\*
- 4) TGT TRJ profile\*
- 5) Chaser TRJ profile\*
- 6) Chaser Weight at OMS-1 TIG
- 7) Launch Site Name
- 8) Launch Site Geodetic Latitude
- 9) Launch Site Longitude
- 10) ET Sep DVX (PEG-7)
- 11) ET Sep DVY (PEG-7)
- 12) ET Sep DVZ (PEG-7)
- 13) DTIG from MECO for ET Sep

\* Not used by RLW



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```

/fads/msn/mds/mastdyn/fltcyc/114ocf/data22b.lwlt.asc.01
1
MEDCV,,,K11, -05:00, 05:00, -5:25.0, N$
MEDCV,,,K12,,,,, 256236.6, 39B, 28.627, 279.379, 5.0, 0.0, -4.0, C
0:12.0$
MEDCV,,,K13, 21244764.0, 25819.0, 0.608, 14.400, 08:30, 14.000, 0, C
14586.51, 10138.04, 100.5313, DI, YES, 9.8, 0.5, -0.9, 1:55.0, C
8:12:00:00, -1.34875e-06, 365:00:00:00, -0.7750$
MEDCV,,,K17, 1, 1, 120.00, 133.00, 0.0, 0.0, 01:54$
MEDCV,,,K17, 1, 2, 111.00, 315.00, 0.0, 0.0, 29:12$
MEDCV,,,K17, 2, 1, 120.00, 133.00, 0.0, 0.0, 01:54$
MEDCV,,,K17, 2, 2, 111.00, 315.00, 0.0, 0.0, 29:12$
MEDCV,,,K17, 3, 1, 120.00, 133.00, 0.0, 0.0, 01:54$
MEDCV,,,K17, 3, 2, 111.00, 315.00, 0.0, 0.0, 29:12$
MEDCV,,,K17, 4, 1, 120.00, 133.00, 0.0, 0.0, 01:54$
MEDCV,,,K17, 4, 2, 111.00, 315.00, 0.0, 0.0, 29:12$
MEDCV,,,K18, 1,1589167.9, 0.0, 133.5, 17:03:16:13, 0.0, 3125442.8, C
-18192120.0, 10149934.0, 2661.19, -39.30, 3477.25, 02:05.28, C
1529535.0, 0.0, 0.0, IP, 0$
MEDCV,,,K18, 2,1589167.9, 0.0, 133.5, 17:03:16:13, 0.0, 3125442.8, C
-18192120.0, 10149934.0, 2661.19, -39.30, 3477.25, 02:05.28, C
1529535.0, 0.0, 0.0, IP, 0$
MEDCV,,,K18, 3,1589167.9, 0.0, 133.5, 17:03:16:13, 0.0, 3125442.8, C
-18192120.0, 10149934.0, 2661.19, -39.30, 3477.25, 02:05.28, C
1529535.0, 0.0, 0.0, IP, 0$
MEDCV,,,K18, 4,1589167.9, 0.0, 133.5, 17:03:16:13, 0.0, 3125442.8, C
-18192120.0, 10149934.0, 2661.19, -39.30, 3477.25, 02:05.28, C
1529535.0, 0.0, 0.0, IP, 0$
MEDCV,,,K19, 1, NOM50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 1, MIN50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 1, ABT50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 1, O1M50, -0.68084520, 0.39422397, -0.61728218$
MEDCV,,,K19, 1, O2M50, -0.68015527, 0.39605117, -0.61687292$
MEDCV,,,K19, 2, NOM50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 2, MIN50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 2, ABT50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 2, O1M50, -0.68084520, 0.39422397, -0.61728218$
MEDCV,,,K19, 2, O2M50, -0.68015527, 0.39605117, -0.61687292$
MEDCV,,,K19, 3, NOM50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 3, MIN50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 3, ABT50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 3, O1M50, -0.68084520, 0.39422397, -0.61728218$
MEDCV,,,K19, 3, O2M50, -0.68015527, 0.39605117, -0.61687292$
MEDCV,,,K19, 4, NOM50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 4, MIN50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 4, ABT50, -0.68098240, 0.39412110, -0.61719648$
MEDCV,,,K19, 4, O1M50, -0.68084520, 0.39422397, -0.61728218$
MEDCV,,,K19, 4, O2M50, -0.68015527, 0.39605117, -0.61687292$

```

**Figure 3.10.4.1-4: DATA-22B Launch Window Information**

The K13 MED also contains launch window/launch targeting common parameters.

- 1) MECO Radius Magnitude (ft)
- 2) MECO Velocity Magnitude (fps)
- 3) MECO Flight Path Angle (deg)
- 4) Powered Flight Arc to MECO (deg)
- 5) Powered Flight Time to MECO
- 6) Maximum Yaw Steering (deg)
- 7) Phase Control Flag
- 8) Main Engine Exhaust Velocity (fps)
- 9) OMS Engine Exhaust Velocity (fps)

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- 10) Main Engine Flow Rate (slug/sec)
- 11) Insertion Mode Flag
- 12) MPS Dump Flag
- 13) MPS Dump DVX (fps)
- 14) MPS Dump DVY (fps)
- 15) MPS Dump DVZ (fps)
- 16) MPS DTIG
- 17) Rendezvous MET
- 18) Node Slope
- 19) Pane Switch Time
- 20) Delta Node Phase

The K17 MED contains launch window target sets.

- 1) LWT TGT set ID
- 2) OMS ID
- 3) Target Height
- 4) Target Theta
- 5) Target C1
- 6) Target C2
- 7) Target DTIG

The K18 MED contains launch targeting and performance predictor inputs, none of which are required by RLW.

The K19 MED contains launch target pre-mission IY vector inputs, none of which are required by RLW.

### **3.10.4.1.1.6 Nominal Rendezvous Constraints Tables**

The phase angle at OMS-2 will drive rendezvous plan selection. Therefore, prior to the ILC or the beginning of integrated simulations, FDO SUPPORT and MARS should prepare rendezvous constraints tables for the full spectrum of phase angles that will be used by OMP. These tables will almost certainly undergo changes over the course of all pre-flight work, but a baseline set of tables makes changes easier. Also, a full set of completed and tested tables is required to support generic ascent simulations where a wide variety of phase angles can be encountered.

There are two sets of constraints tables to be prepared. First, the seven tables corresponding to the seven rendezvous plans entered for ascent support. Many aspects of plan generation and refinement are detailed in Sections 3.10.4.1.2 through 3.10.4.1.5. However, baseline tables for all rendezvous plans are included here for completeness.

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The second set is the Joint Underspeed Recovery (JURe) plan(s). While only one constraints table is required for JURe, FDO SUPPORT may want to establish one plan dedicated to FD4 and one to FD5 rendezvous.

### 3.10.4.1.1.7 Ascent Rendezvous Constraint Tables

Ascent constraint tables are used to define phasing strategies beginning with OMS-2. There are seven distinct plans developed as a function of phase angle at OMS-2. The plans are presented in STF #OFD-01-48300-024 (USA/Tim Stuit) and are summarized here. Note that these plans are "TIGs-Free" and should be customized for mission-specific conditions. Refining maneuver TIGs is essential in developing a final plan with the correct lighting and Ti conditions.

Ascent plans are used to produce three results. First, a post-OMS-2 perigee is determined based on the target vector and the post-MPS dump vector provided by the Ascent FDO. The Ascent FDO will use this altitude when the OMS-2 targets are built and uplinked prior to launch. Second, the plans are used to verify the actual post-OMS-2 altitude post-MECO as well as to assess planar error incurred during ascent. Finally, the plans are used as a starting point for NC-1 and subsequent maneuver plans since the day of rendezvous times and positions do not need to be updated. For all TIGs-fixed plans, it is recommended FDO SUPPORT specify a primary constraint of time ("T") for the second maneuver. This enables the plan to correctly run off a post-OMS-2 vector once the OMS-2 first maneuver is deleted. Capability to quickly run an OMP plan with a post-OMS-2 vector can be useful in a case where the Ascent Team is considering a pre-OMS-2 state vector update due to planar errors. Here the Ascent Team will model both "no-update" and "w/update" OMS-2 maneuvers in separate ground ephemerides. Then the OMP can be run off each of these to determine NPC savings, and whether a pre-OMS-2 state vector update is warranted (update performed if  $\geq 6$  fps NPC savings; see Ascent FDO Console Handbook). It is for this scenario that all constraints tables should include an NPC burn as well.

NOTE: the standard plans documented on the following pages were developed during an era in which NH burns on morning of rendezvous were undesirable from a crew timeline perspective. Because extreme crew sleep-shifting to achieve docking over Russian ground sites is no longer a timeline constraint, large NH burns on rendezvous day have become desirable in support of robust trajectory operations. In the presence of dispersions prior to morning of rendezvous, final NC range at 40 nm can be achieved through iterating NH and final NC TIGs earlier (perturbations impose insufficient range) or later (perturbations impose excessive range). Particularly in support of the latter case, it's advisable to bias final NC TIG at least 5 min before orbit noon prior to launch. In this manner, slipping TIG later will not tend to conflict with post-NC ST operations. Placing an effective ( $\Delta v > \sim 50$  fps) dispersion-controlling NH on rendezvous day isn't

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possible for launch into small phase angles. At intermediate ( $> \sim 150^\circ$  for FD3 rendezvous) phase angles, the following steps can be used to effectively create a rendezvous day NH in a baseline plan targeting NH on FD2 (Plan C, for example).

- 1) Run the baseline plan without rendezvous day NH and note final NC  $\Delta v$ , along with total plan  $\Delta v$ .
- 2) Insert a posigrade EXDV into the baseline plan with  $\Delta v$  equal the final NC's baseline value and TIG half a rev before final NC. The EXDV will become the rendezvous day NH when it's the first burn in the rendezvous plan.
- 3) Run the modified plan. If it can be iterated such that its total  $\Delta v$  is equivalent to the baseline plan's, rendezvous day NH capability is possible.
- 4) Check the modified plan for the following conditions.
  - a) Final NC is at least 5 min before orbit noon.
  - b) The sum of inserted EXDV and final NC  $\Delta v \geq 140 \text{ fps}^8$ .
  - c) Inserted EXDV and final NC  $\Delta v$  are approximately equal. This assists PROP's consumables management. Iterate on EXDV posigrade  $\Delta v$  to achieve this desirable condition if the other conditions can be satisfied.

---

<sup>8</sup> This condition guarantees pre-NH phase rate exceeds 370 nm/rev on rendezvous morning. At lower phase rates, slipping NH and final NC TIGs by 5 min cannot shift final NC range by more than 20 nm. Particularly if TIG slips much more than 5 min aren't possible without ST operations conflicts, range shifts considerably less than 20 nm aren't operationally significant.

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### Plan A

Plan A is a short phase angle case resulting in a FD2 rendezvous. It is possible to back out of the FD2 rendezvous case and into a FD3 case (see Plan C in this section) without propellant penalty. The decision point to move from a FD2 to FD3 rendezvous must be made no later than the OMS-2 TIG. The NC-1 burn is nominally scheduled 1.5 orbits after OMS-2 but can vary from 1.0 to 2.0 orbits depending on lighting conditions, the FD1 timeline, and control of the radial  $\Delta v$  costs at Ti. For STS-114, Plan A was valid at phase angles between 39° and 93°.

MANEUVER	THRESHOLD	SECONDARIES			
1 NC OMS-2	T 000:00:20:00.000	APO =1 = =	DV =150.0 = =	= = =	= = =
2 NH NC-1	M 1.5	= = =	= = =	= = =	= = =
3 NPC NPC	DT 000:00:00:01.000	CN =1.0 = =	= = =	= = =	= = =
4 NC NC-2	M 8.5	DR =-40.0 = =	NITI =-28.0 = =	= = =	= = =
5 NCC Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =	= = =
6 SOI MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =	= = =
7 SOR +Rbar	DT 000:00:13:00.000	CXYZ =0.0 = =	CXYZ =0.0 = =	CXYZ =0.0987 = =	= = =

**Figure 3.10.4.1-5: Plan A Rendezvous Constraints**

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### Plan B

Plan B (like Plan A) is also used for FD2 rendezvous and can be converted to FD3 rendezvous cases (see Plan C in this section) without propellant penalty. Unlike Plan A though, height control can be postponed until FD2 and NC-1 becomes a posigrade-biased EXDV. The NC-1 burn is used to target FD2 (or FD3 with Plan C) and is nominally 2 orbits after OMS-2. Plan B is the preferred FD2/3 option because it requires less  $\Delta v$  on FD1 than does Plan A. Therefore, the switchover point from Plan A to Plan B is the Plan B minimum phase angle. For STS-114, Plan B was valid at phase angles between  $93^\circ$  and  $175^\circ$ .

MANEUVER	THRESHOLD	SECONDARIES			
1 NC OMS-2	T 000:00:20:00.000	APO =1.0 = =	DV =50 = =	= = =	= = =
2 EXDV NC-1	M 2.0	DVLV =8.0 = =	DVLV =0.0 = =	DVLV =0.0 = =	= = =
3 NPC NPC	DT 000:00:00:01.000	CN =1.0 = =	= = =	= = =	= = =
4 NH NC-2	M 7.5	= = =	= = =	= = =	= = =
4 NC NC-3	M 0.5	NITI =-28.0 = =	DR =-40.0 = =	= = =	= = =
6 NCC Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =	= = =
7 SOI MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =	= = =
8 SOR +Rbar	DT 000:00:13:00.000	CXYZ =0.0 = =	CXYZ =0.0 = =	CXYZ =0.0987 = =	= = =

**Figure 3.10.4.1-6: Plan B Rendezvous Constraints**

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## Plan C

Plan C is a mid-phase angle plan that is used for the FD3 rendezvous case only. In this plan, OMS-2 is targeted as an HA burn to the minimum perigee altitude. This results in a “flat line” on the post-OMS-2 perigee vs. phase angle plot (see Figure 3.10.4.1-12), which greatly simplifies OMS-2 targeting. For STS-114, Plan C was valid at phase angles between 175° and 327°.

MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-2	T 000:00:30:00.000	APO =1.0 = =	HD =85.0 = =	DV =200.0 = =
2 NC NC-1	M 2.0	DV =100 = =	= = =	= = =
3 EXDV NC-2	M 8.0	DVLV =8.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
4 NPC NPC	M 3.5	CN =1.0 = =	= = =	= = =
5 NH NC-3	M 2.0	= = =	= = =	= = =
6 EXDV DOR NH	M 8.0	DVLV =0.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
7 NC NC-4	M 0.5	DR =-40 = =	NITI =-28.0 = =	= = =
8 SOI Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =
9 SOR MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =

**Figure 3.10.4.1-7: Plan C Rendezvous Constraints**

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## Plan D

Plan D is also a mid-phase angle plan that is used for the FD3 rendezvous case only. The only difference between a Plan C rendezvous and a Plan D rendezvous is the placement of the NH burn. A Plan C rendezvous places the NH burn on FD2, while Plan D places the NH burn on FD3. For STS-114, Plan D was valid at phase angles between 327° and 407°.

MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-2	T 000:00:20:00.000	APO =1.0 = =	HD =85.0 = =	= = =
2 NC NC-1	M 2.0	DV =100.0 = =	= = =	= = =
3 EXDV NC-2	M 8.0	DVLV =8.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
4 NPC NPC	M 2.0	CN =1.0 = =	= = =	= = =
5 EXDV NC-3	M 3.0	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
6 NH NH	M 8.5	= = =	= = =	= = =
7 NC NC-4	M 0.5	DR =-40.0 = =	NITI =-28.0 = =	= = =
8 SOI Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =
9 SOR MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =

**Figure 3.10.4.1-8: Plan D Rendezvous Constraints**



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## Plan E

Plan E is a large phase angle FD4-only rendezvous plan. As with Plans C and D, OMS-2 is targeted as an HA to the minimum perigee altitude. This plan has two extra maneuvers on FD3, one in the morning and another in the afternoon to control phasing on FD3 and the beginning of FD4. For STS-114, Plan E was valid at phase angles between 407° and 556°.

MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-2	T 000:00:20:00.000	APO =1.0 = =	HD =85.0 = =	DV =200.0 = =
2 NC NC-1	M 2.0	= = =	= = =	= = =
3 EXDV NC-2	M 8.0	DVLV =8.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
4 NPC NPC	M 2.0	CN =1 = =	= = =	= = =
5 EXDV NC-3	M 4.0	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
6 EXDV NC-4	M 10.0	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
7 NH NC-5	M 6.5	= = =	= = =	= = =
8 NC NC-6	M 9.5	NITI =-28.0 = =	DR =-40.0 = =	= = =
9 SOI Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =
10 SOR MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =

**Figure 3.10.4.1-9: Plan E Rendezvous Constraints**

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## Plan F

Plan F is the rendezvous plan that covers the largest expected phase angles. Like Plan E, it is exclusively a FD4 rendezvous plan. The only difference between Plan E and Plan F is that the NH maneuver is placed on FD4 to maximize the phase rate as long as possible. For STS-114, Plan F was valid at phase angles between 556° and 637°.

MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-2	T 000:00:20:00.000	APO =1.0 = =	HD =85.0 = =	DV =200.0 = =
2 NC NC-1	M 2.0	= = =	= = =	= = =
3 EXDV NC-2	M 8.0	DVLV =8.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
4 NPC NPC	M 2.0	CN =1 = =	= = =	= = =
5 EXDV NC-3	M 4.0	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
6 EXDV NC-4	M 10.0	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
7 EXDV NC-5	M 6.0	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
8 NH NH	M 9.5	= = =	= = =	= = =
9 NC NC-6	M 0.5	NITI =-28.0 = =	DR =-40.0 = =	= = =
10 NCC Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =
11 SOI MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =
12 SOR +Rbar	DT 000:00:13:00.000	CXYZ =0.0 = =	CXYZ =0.0 = =	CXYZ =0.0987 = =

**Figure 3.10.4.1-10: Plan F Rendezvous Constraints**

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## Plan G

Plan A often does not work for flights with a direct insertion altitude of 122 nm. The large difference in altitude between chaser and target does not allow retargeting between a FD2 and FD3 rendezvous after already having performed OMS-2. A FD3-only rendezvous plan, Plan G, was developed for these cases in order to extend the phase angle capability as low as possible. This sacrifices FD2 rendezvous capability. Plan G targets OMS-2 for NC-4 on FD3. NC-1 is targeted as an NH 1.5 orbits after OMS-2. As with Plan A, the switchover between Plan G and Plan B is chosen to be the Plan B minimum phase angle.

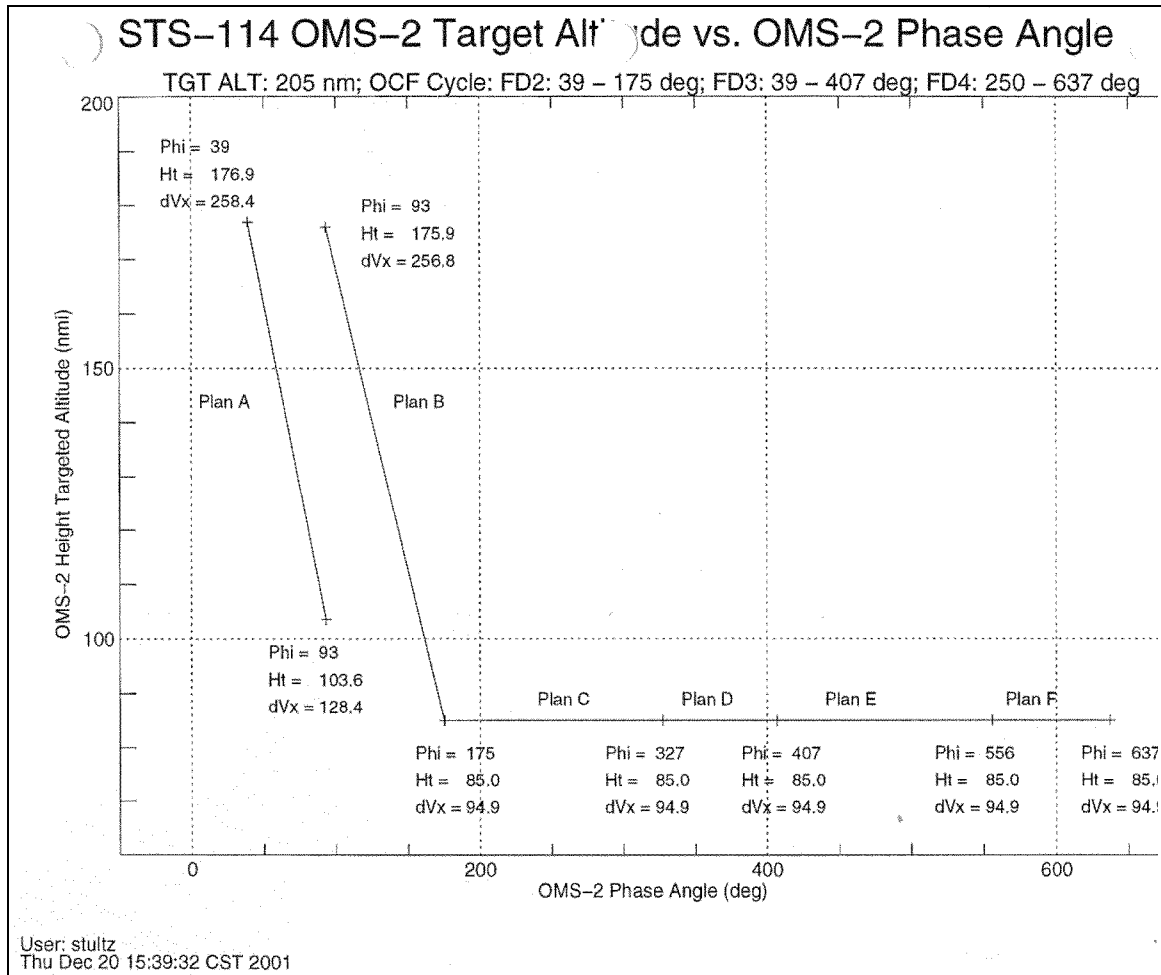
MANEUVER	THRESHOLD	SECONDARIES		
1 NC OMS-2	T 000:00:20:00.000	APO =1 = =	DV =150.0 = =	= = =
2 NH NC-1	M 1.5	= = =	= = =	= = =
3 NC NC-2	M 8.5	DVLV =8.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
4 NPC NPC	M 2.0	CN =1 = =	= = =	= = =
5 NC NC-3	M 3.5	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
6 NC NC-4	M 9.0	DR =-40.0 = =	NITI =-28.0 = =	= = =
7 NCC Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =
8 SOI MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =
9 SOR +Rbar	DT 000:00:13:00.000	CXYZ =0.0 = =	CXYZ =0.0 = =	CXYZ =0.0987 = =

Figure 3.10.4.1-11: Plan G Rendezvous Constraints

# FDO Console Handbook Section 3.10: Rendezvous Operations

## 3.10.4.1.1.8 Post-OMS-2 Altitude Plan

Figure 3.10.4.1-12 shows the nominal post-OMS-2 perigee versus phase angle for STS-114. This plot is target altitude-dependant and is therefore flight-specific. The RNDZ-02 product contains this plot.



**Figure 3.10.4.1-12: Rendezvous Plans vs. Phase Angle**

Operationally, a constant OMS-2 perigee is easier to work with than one that varies as a function of launch time within a launch window. FDO SUPPORT should make every effort to determine a constant OMS-2 perigee for the duration of the launch window.

## **FDO Console Handbook Section 3.10: Rendezvous Operations**

The following objectives, listed in order of descending priority, should be used in planning post-OMS-2 perigee.

- 1) Achieve minimum propellant during rendezvous.
- 2) Protect FD2 rendezvous (if phase angle permits).
- 3) Eliminate maneuvers on FD1 other than OMS-2 and NC-1.
- 4) Target constant (though different) post-OMS-2 apsis heights in each launch window pane.
- 5) Target constant (same) post-OMS-2 apsis heights in both launch window panes.
- 6) Target post-OMS-2 perigee of 85 nm for both panes.

### **3.10.4.1.1.9 JURE Preparation (ISS Missions Only)**

JURE procedures are detailed in Section 3.10.6.

One JURE rendezvous constraints table (Figure 3.10.4.1-13) is required that accounts for four JURE maneuvers performed by the ISS and a resulting FD5 rendezvous. While it is fairly easy to modify the FD5 JURE table to account for a lesser underspeed that only requires 1 or 2 JURE maneuvers by ISS and a resulting FD4 rendezvous, it may be advantageous to set up a second JURE table for this case as well (Figure 3.10.4.1-14).

## FDO Console Handbook Section 3.10: Rendezvous Operations

MANEUVER	THRESHOLD	SECONDARIES			
1 HA OMS-2	T 000:00:30:00.000	HD =85.0 = =	APO =1.0 = =	=	=
2 NC NC-1A	T 000:02:25:00.000	APO =1.0 = =	DV =50.0 = =	=	=
3 NSR NC-1b	DT 000:00:00:00.000	ARG =9.0 = =	=	=	=
4 NPC NPC	DT 000:00:00:01.000	CN =1.0 = =	=	=	=
5 NH NC-2	T 003:00:55:30.000	=	=	=	=
6 NC NC-3	T 003:17:00:00.000	DR =-40.0 = =	LITO =-36.0 = =	=	=
7 NCC Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =	=
8 SOI MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =	=
9 SOR +Rbar	DT 000:00:13:00.000	CXYZ =0.0 = =	CXYZ =0.0 = =	CXYZ =0.0987 = =	=

**Figure 3.10.4.1-13: Standard JURE Rendezvous Constraints**

## FDO Console Handbook Section 3.10: Rendezvous Operations

MANEUVER	THRESHOLD	SECONDARIES			
1 HA OMS-2	T 000:00:30:00.000	HD =163.0 = =	APO =1.0 = =	= = =	= = =
2 NC NC-1A	T 000:02:25:00.000	APO =1.0 = =	DV =150.0 = =	= = =	= = =
3 NSR NC-1b	DT 000:00:00:00.000	ARG =-255.0 = =	= = =	= = =	= = =
4 NPC NPC	DT 000:00:00:01.000	CN =1.0 = =	= = =	= = =	= = =
5 NH NC-2	T 002:00:48:00.000	= = =	= = =	= = =	= = =
6 NC NC-3	T 002:15:21:00.000	DR =-40.0 = =	LITO =-36.0 = =	= = =	= = =
7 NCC Ti	M 1.0	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =	= = =
8 SOI MC-4	DT 000:01:16:54.000	CXYZ =-0.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =	= = =
9 SOR +Rbar	DT 000:00:13:00.000	CXYZ =0.0 = =	CXYZ =0.0 = =	CXYZ =0.0987 = =	= = =

**Figure 3.10.4.1-14: Optional FD4 JURE Rendezvous Constraints**

Workload for FDO SUPPORT during JURE operations (see Section 3.10.6) can be challenging. In addition to normal rendezvous support, coordinating with TOPOs and informing the rest of the flight control team of JURE rendezvous ramifications, there will be critical coordination with the Mission Management Team (MMT). This is not a manageable situation for one individual, so the role of “JURE FDO” has been created to perform those tasks pertaining to a JURE rendezvous.

The JURE FDO is responsible for pre-flight preparation of all JURE products. These include the JURE spreadsheet and confidence run, JURE OMP constraints tables with proven OMP evaluation tables, a Global TSA ISS ephemeris with four full ISS orbit-lowering burns, and the pre-flight JURE flight note. The JURE products are all completed prior to launch so that by the time of an actual JURE declaration, the JURE FDO’s role will be that of a liaison between MOD management, the MMT, and the FDO Console. In the first few hours after a JURE declaration, the JURE FDO will relieve FDO SUPPORT from supporting any meeting or other forms of coordination regarding rendezvous specifics. FDO SUPPORT can then focus on rendezvous plan development. Since the JURE FDO will be briefing the MMT on the JURE ops concept, a generic set of presentation charts should also be prepared pre-flight.

## FDO Console Handbook Section 3.10: Rendezvous Operations

### 3.10.4.1.1.10 MECO Underspeed Gates

Meaningful MECO underspeed “gates” give FDO SUPPORT and Ascent FDO an indication of what type of rendezvous trajectory recovery, if any, is possible. While these gates are highly simplistic in nature, they can give early indications of how best to direct recovery.

FDO SUPPORT computes three performance gates prior to launch. The first is the “Maximum Underspeed (No JURE)” scenario. In this case, no JURE is performed and any MECO underspeed is compensated with Orbiter propellant margin alone. To compute the maximum underspeed without a JURE, the maximum amount of propellant to be used for rendezvous and deorbit is obtained from the Lead PROP. The propellant for this case is referred to as “Raise the Orbit” (RTO), and PROP will provide RTO values in lbm.

**CAUTION:** RTO does not include propellant required by the attitude timeline. Neither does RTO include mean rendezvous propellant consumed during translations from NCC to docking. A prelaunch RTO value must therefore support all translations from OMS-2 through final NC, together with steep ConUS deorbit<sup>9</sup> including resupply/assembly payload return.

Once RTO is obtained, FDO SUPPORT will determine the total amount of “uphill”  $\Delta v_U$  required for the nominal rendezvous plan from OMS-2 up to and including final NC. From the JURE Spreadsheet (see Section 3.10.6.3), a corresponding “downhill” steep deorbit  $\Delta v_D$  estimate can be obtained for the nominal ISS orbit height. Using the 25 lbm/fps conversion, Maximum Underspeed (no JURE) is  $RTO/25 - \Delta v_U - \Delta v_D$ .

The second performance gate is the “Maximum Underspeed (Max JURE)” case. In this scenario, a maximum-effort JURE is performed. Unless over-phasing is a concern due to an OMS-2 phase angle  $< \sim 200^\circ$ , a “Max JURE” implies four retrograde ISS burns of maximum duration will be performed to recover the rendezvous. In practice, the number of ISS burns associated with a maximum-effort JURE replaces the parenthetical “Max”. Thus, a performance gate associated with a  $130^\circ$  OMS-2 phase angle might be called “Maximum Underspeed (2 JURE)”. To compute Maximum Underspeed (Max JURE), determine the reduced  $\Delta v_U$  and  $\Delta v_D$  resulting from lower ISS orbit height at docking and subtract each from  $RTO/25$ . Because the number of ISS JURE burns is a function of phase angle, four full JURE burns may not be possible on all launch days.

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<sup>9</sup> PROP assumes this deorbit occurs the day after planned docking, simulating a worst-case failed docking



## **FDO Console Handbook Section 3.10: Rendezvous Operations**

The third performance gate is the “Maximum Underspeed No Deorbit (Max JURE)” case. In this scenario,  $\Delta v_D$  is assumed to be zero. This, of course, means the Orbiter will remain attached to ISS after docking. The scenario is only invoked if there is no possibility of a safe entry. To obtain Maximum Underspeed No Deorbit (Max JURE), subtract the previously computed Max JURE  $\Delta v_U$  from RTO/25.

These three performance gates are not hard-and-fast thresholds because each is subject to a variety of real time conditions. They should be used only as initial guesses leading to possible courses of action and should be thoroughly assessed based on real time events. In practice, gates are computed and recorded using the FDO SUPPORT Data Sheet, to which the Ascent FDO Data Sheet is appended (see Section 3.10.4.1.1.17). The latter is transmitted to the Ascent FDO pre-launch.

### **3.10.4.1.1.11 Rendezvous Plan Flight Note Generation**

As soon as practical once real time operations begin at L-1 day, FDO SUPPORT should compose and publish an internal flight note for Ascent FDO, TRAJ, RNDZ, and PROP documenting the projected rendezvous plan. The flight note should include the rendezvous plan as a whole (an OMP Eval Table is excellent for this purpose), ET photography +X translation recommendations, and any other information relevant to the rendezvous.

# FDO Console Handbook Section 3.10: Rendezvous Operations

An example note follows.

MCC FLIGHT NOTE - FOIN001																																																																																																																																																								
To	FDO				Date	01/28/2003	MET	11/19:23																																																																																																																																																
From	FDO-WTRACY				Status	Info_Only	Req'd	N/A																																																																																																																																																
Vehicle				Flight ID	Sim		EFN#	FOIN001																																																																																																																																																
Title	STS-114 Projected Rendezvous Plan (January 17, 2003 Launch at 13:11:13 GMT)																																																																																																																																																							
<p>For an on-time launch of STS-114, the following rendezvous plan is expected:</p> <p>NOTE: The ET will be in darkness for viewing and photography for the entire window duration.</p> <p style="text-align: center;">GMTR : 2003:017:03:11:13.000</p> <p>CHASER L E1                    M 000:00:11:25.000                    STS-114 Orbiter</p> <p>TARGET L E3                    M 000:00:00:00.000                    ISS</p> <p>CHASER DVtot = 452.44    DVx = 450.58    DVy = 1.70    DVz = 1.21</p> <p>TARGET DVtot = 0.00    DVx = 0.00    DVy = 0.00    DVz = 0.00    10 MNVRS</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>MNVR</th> <th>NAME</th> <th>GMTIG</th> <th>IMP</th> <th>DVx</th> <th>HA</th> <th>RANGE</th> <th>Y</th> </tr> <tr> <th>COMMENT</th> <th></th> <th>METIG</th> <th></th> <th>DVy</th> <th>HP</th> <th>PHASE</th> <th>Ydot</th> </tr> <tr> <th>DVMag</th> <th></th> <th>DT</th> <th></th> <th>DVz</th> <th>DH</th> <th>Noon/Mid -</th> <th>SR/SS -</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>EXDV</td> <td>017:03:50:05.000</td> <td></td> <td>166.16</td> <td>123.92</td> <td>4635.4800</td> <td>-45204.1</td> </tr> <tr> <td></td> <td>OMS-2</td> <td>000:00:38:52.000</td> <td></td> <td>0.00</td> <td>123.41</td> <td>79.8585</td> <td>13.1</td> </tr> <tr> <td></td> <td>166.2</td> <td>000:02:31:16.000</td> <td></td> <td>0.00</td> <td>81.95</td> <td>M-00:41:48</td> <td>SS-00:24:12</td> </tr> <tr> <td>2</td> <td>NH</td> <td>017:06:21:21.000</td> <td></td> <td>151.03</td> <td>209.01</td> <td>3591.3545</td> <td>21672.6</td> </tr> <tr> <td></td> <td>OMS-3</td> <td>000:03:10:08.000</td> <td></td> <td>0.00</td> <td>123.72</td> <td>59.7081</td> <td>-52.9</td> </tr> <tr> <td></td> <td>151.0</td> <td>000:00:45:21.133</td> <td></td> <td>0.00</td> <td>76.10</td> <td>N-00:28:50</td> <td>SR-00:00:23</td> </tr> <tr> <td>3</td> <td>NC</td> <td>017:07:06:42.133</td> <td></td> <td>72.32</td> <td>209.07</td> <td>3466.3129</td> <td>-20365.7</td> </tr> <tr> <td></td> <td>NC-1</td> <td>000:03:55:29.133</td> <td></td> <td>0.00</td> <td>164.75</td> <td>56.6563</td> <td>49.9</td> </tr> <tr> <td></td> <td>72.3</td> <td>000:13:43:18.937</td> <td></td> <td>0.00</td> <td>0.21</td> <td>M-00:29:36</td> <td>SS-00:12:01</td> </tr> <tr> <td>4</td> <td>EXDV</td> <td>017:20:50:01.070</td> <td></td> <td>8.00</td> <td>209.13</td> <td>2090.6391</td> <td>-8194.4</td> </tr> <tr> <td></td> <td>NC-2</td> <td>000:17:38:48.070</td> <td></td> <td>0.00</td> <td>169.07</td> <td>33.2572</td> <td>31.8</td> </tr> <tr> <td></td> <td>8.0</td> <td>000:03:25:49.767</td> <td></td> <td>0.00</td> <td>0.22</td> <td>M-00:35:50</td> <td>SS-00:18:19</td> </tr> <tr> <td>5</td> <td>NPC</td> <td>018:00:15:50.836</td> <td></td> <td>0.00</td> <td>209.08</td> <td>1806.1731</td> <td>9277.1</td> </tr> <tr> <td></td> <td>NPC</td> <td>000:21:04:37.836</td> <td></td> <td>1.60</td> <td>169.16</td> <td>28.7234</td> <td>6.9</td> </tr> <tr> <td></td> <td>1.6</td> <td>000:04:11:21.794</td> <td></td> <td>0.00</td> <td>15.71</td> <td>M-00:14:23</td> <td>SR-00:31:51</td> </tr> </tbody> </table>									MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y	COMMENT		METIG		DVy	HP	PHASE	Ydot	DVMag		DT		DVz	DH	Noon/Mid -	SR/SS -	1	EXDV	017:03:50:05.000		166.16	123.92	4635.4800	-45204.1		OMS-2	000:00:38:52.000		0.00	123.41	79.8585	13.1		166.2	000:02:31:16.000		0.00	81.95	M-00:41:48	SS-00:24:12	2	NH	017:06:21:21.000		151.03	209.01	3591.3545	21672.6		OMS-3	000:03:10:08.000		0.00	123.72	59.7081	-52.9		151.0	000:00:45:21.133		0.00	76.10	N-00:28:50	SR-00:00:23	3	NC	017:07:06:42.133		72.32	209.07	3466.3129	-20365.7		NC-1	000:03:55:29.133		0.00	164.75	56.6563	49.9		72.3	000:13:43:18.937		0.00	0.21	M-00:29:36	SS-00:12:01	4	EXDV	017:20:50:01.070		8.00	209.13	2090.6391	-8194.4		NC-2	000:17:38:48.070		0.00	169.07	33.2572	31.8		8.0	000:03:25:49.767		0.00	0.22	M-00:35:50	SS-00:18:19	5	NPC	018:00:15:50.836		0.00	209.08	1806.1731	9277.1		NPC	000:21:04:37.836		1.60	169.16	28.7234	6.9		1.6	000:04:11:21.794		0.00	15.71	M-00:14:23	SR-00:31:51
MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y																																																																																																																																																	
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	1.6	000:04:11:21.794		0.00	15.71	M-00:14:23	SR-00:31:51																																																																																																																																																	

## 3.10.4.1.12 Post-MECO Helium Leak Ht

The scenario of an OMS helium tank leak in the post-MECO timeframe is a condition that does not necessarily mean loss of rendezvous capability. While the resulting rendezvous might be difficult, it may not be impossible if the Ascent FDO makes the correct call to burn the leaking OMS engine to blowdown in the correct direction. Depending on the size of the leak, the blowdown burn will be performed as soon as practical after leak detection, possibly before OMS-2. If the leak is small and manageable, OMS-2 becomes the blowdown burn and rendezvous capability is re-evaluated thereafter. If the leak is large and the blowdown burn must be performed pre-OMS-2, burn direction is critical to preserving rendezvous capability.

Typically, blowdown burns in the post-MECO timeframe require about 200 fps  $\Delta v$ . This is a large amount of energy to put into the orbit, and managing it while preserving rendezvous capability is challenging. Pre-mission planning is the best way to address this scenario. In the past, blowdown burn  $\Delta v$  was placed entirely in the PEG-7 DVx component. Technically, this would be acceptable for impulsive burns as long as the

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post-blowdown burn apogee was still at least 7 nm below the target's perigee<sup>10</sup>. However, with such a large amount of propellant to burn, finite effects must be accounted for in the radial direction in order not to exceed this threshold, especially with blowdown TIG soon after MECO. Generally, if the blowdown burn is executed after about 0/00:20 MET, almost all the propellant to be burned can go exclusively in the positive DVx direction. If the burn is before this time, positive radial  $\Delta v$  must be included so as not to raise apogee too high. FDO SUPPORT must determine what  $\Delta v$  can be allocated to the blowdown burn's DVx component and what the radial component should be.

The OMS helium leak scenario is also addressable before MECO. If the leak is detected pre-MECO, PROP and FDO will determine if performance loss due to the leak by ~0/00:20 MET justifies an additional dump beyond nominal OMS assist during powered flight. If the performance loss is manageable until approximately 0/00:20 MET, an additional OMS dump is not performed and the blowdown burn TIG is planned as soon as possible after MECO.

Generally, a post-MECO blowdown burn cannot occur any sooner than 0/00:15 MET. The earlier the blowdown burn is accomplished, the better for current usable prop, but such is not necessarily the case for rendezvous prop consumption. A relatively early burn may entail propellant wasting in the radial direction so apogee is maintained no higher than 7 nm below the target's perigee. Burning earlier is also advantageous since it means less propellant will be trapped on one side, thus avoiding a potential YCG problem imposing ballast requirements. These conflicting TIG drivers have given rise to the concept of an "optimum" blowdown performed purely posigrade at the earliest time resulting in Orbiter apogee at least 7 nm below target perigee. Burning at or after the optimum TIG means max blowdown can be achieved without wasting current  $\Delta v$  capability.

There are two key pieces of information required in determining optimum blowdown TIG. The first is target perigee height, and the second is  $\Delta v$  required to reach a max blowdown condition. In order not to waste further propellant in the rendezvous plan, future retrograde maneuvers must be eliminated. To accomplish this, Orbiter apogee is maintained no higher than 7 nm below target perigee. Higher altitudes may be possible, but retrograde maneuvers may arise if the relative line of apsides is not cooperating with the rendezvous plan. During STS-114 sims, ISS Hp was 185.0 nm. Therefore, post-burn Orbiter apogee height is constrained to values no higher than 178.0 nm.

---

<sup>10</sup> The worst case, in which an Orbiter's apogee is 7 nm below a target's perigee, will guarantee an NH targeting delta-height at  $T_i$  can be planned with posigrade  $\Delta v$  above 3 fps. In a marginal phasing case, it may be necessary to achieve a sufficiently co-elliptic condition prior to this NH by adding one or more burns to the rendezvous plan.

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The amount of propellant to be expended in reaching max blowdown is heavily dependent on flight-specific OMS loading and may exceed 200 fps. For STS-114, the value provided by Ascent PROP was 176 fps. The analysis proceeds in TSA as follows.

- 1) Anchor an Orbiter ephemeris off a nominal post-MPS dump state vector and TUP with 2-hour length.
- 2) Determine finite burn PEG-7 DVX/DVZ corresponding to a "horizontal" blowdown burn with null radial propellant wasting.
  - a) Run a single-burn "Pure Posi" OMP plan to generate an EXDV maneuver with DVx = blowdown  $\Delta v$  and DVy/DVz = 0. Set TIG = 0/01:00 MET so the horizontal burn will not interfere with ephemeris fetches in the post-MECO timeframe. The resulting eval table will resemble Figure 3.10.4.1-15a.

```

LOCAL          MANEUVER EVALUATION TABLE MAXBD
                COMMENT: (null)
                L          L
                MCT : MAXBD          OVT : UNTITLED

                GMTR : 2005:066:00:08:30.000
                VECTOR          TIME          COMMENT
CHASER L E8      M 000:01:00:00.000          LT1 MPS  pane 1 inplane
TARGET L E8      M 000:01:00:00.000          LT1 MPS  pane 1 inplane

CHASER DVtot = 176.00  DVx = 176.00  DVy = 0.00  DVz = 0.00
TARGET DVtot = 0.00   DVx = 0.00   DVy = 0.00  DVz = 0.00  1 MNVRS
    
```

MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
COMMENT		METIG		DVy	HP	PHASE	Ydot
DVMag		DT		DVz	DH	Noon/Mid -	SR/SS -
1	EXDV	066:01:08:30.000		176.00	192.38	0.0000	0.0
	Pure Posi	000:01:00:00.000		0.00	56.80	0.0000	0.0
	176.0	000:00:00:00.000		0.00	0.00	N-00:07:31	SS-00:31:35

**Figure 3.10.4.1-15a: Horizontal Max Blowdown Burn In OMP**

- b) Edit the Pure Posi plan's MTT to transfer the EXDV to an ephemeris using OBP thrusters, impulsive TIG, and no iteration. The MTT will resemble Figure 3.10.4.1-15b.

```

                MANEUVER TRANSFER TABLE
LOCAL          CURRENT
-----
| MNVR | NAME | COMMENT | SLOT | THR | GUID | ITER | IMP | RREF | ROLL |
-----
| 1    | EXDV | Pure Posi |      | OBP | P7   | NO   | IMP | TVR  | 180  |
    
```

**Figure 3.10.4.1-15b: Horizontal Max Blowdown Burn Ephemeris Transfer**

**NOTE:** unless additional systems failures dictate otherwise, the burn is performed with both OMS engines fed off the leaking pod to achieve max blowdown sooner and with greater redundancy vice one engine.

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c) After ephemeris transfer, display the horizontal blowdown burn in a DMT (see Figure 3.10.4.1-15c), noting its PEG-7 DVX and DVZ values.

```

LOCAL                                DMT NO. 0                                ENGLISH
COMMENT:  Pure Posi

----- PAD -----
GMTI 2005:066:01:08:30.000 |           E8M1-OBP-P7-FC | GMTR 2005:066:00:08:30.000
METI      000:01:00:00.000 | TV ROLL           180.0 | TIGT
DVM 176.00 DTB 01:56.50 | SYSP TRIMS P       1.0 | OUTPUT MAT           CURI00
VXI 92.95 DVULL 0.00 | LY -5.7 |
VYI 148.86 DTULL 0:00.0 | RY 5.7 | OSTAID           L MVI801
VZI -13.30 DTRCS 0:00.0 | WEIGHT           256122.9 | GMTV           066:01:08:30.000
DVTO 0.61 DTTO 2.60 | TIG 000/01:00:00.0 | METV           000:01:00:00.000
INR      LVLH | PEG 4 C1 | COMMENT
P 341.3 P 341.0 YH 0.0 | C2 | TSTAID
Y 66.2 Y 0.0 PH -19.0 | HT | GMTV
R 158.7 R 180.0 RH 180.0 | GT | METV
| PRPLT | COMMENT
TGT VEH DATA | PEG 7 DVX +0175.6 | FSTAID
  ELtig Gb/o | DVY +0000.0 | GMTV
  DHb/o 0b/o | DVZ +0012.3 | METV
OFFSET MNVR EPH | BURN ATT R 159 |
MET | P 341 | DWOMS 4404.4
DT | Y 066 | DWRCS 0.0
DX | DVTOT 176.00 | WFNL 251718.5
DY | TGO 01:54.0 | DW 4404.4
DZ | VGO X 170.01 | DV REMAIN
| Y 0.00 | PRI SEC
HA 194.7 HP 54.6 | Z 45.52 |
LAN 126:01W Htig 74.9 | TGT HA 195 HP 55 | SITE XR
zP 308.0 Vtig 50:51S |
i 51.62 ltig 135:12E |
e 0.01910 htig 266.8 | INTO UNTIL cEI
a 3565.7 | METEI
  
```

**Figure 3.10.4.1-15c: Transferred Horizontal Max Blowdown Burn**

**NOTE:** even though the Figure 3.10.4.1-15a DVz component is exactly zero and the blowdown burn is transferred with impulsive TIG and no iterations, Figure 3.10.4.1-15c still shows a DVZ > 0. This is because the transfer computes PEG-7 targets at TIG corresponding to an inertial attitude for the entire finite burn arc. This attitude directs thrust such that it's aligned with OMP's impulsive  $\Delta v$  at the burn arc centroid or midpoint about 1 min after TIG. In this "horizontal" case, TIG attitude is pitched down 4° from the local horizontal. With DVM = 176 fps, a DVZ =  $176 \cdot \sin 4^\circ = 12.3$  fps can be expected.

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- 3) Beginning at TIG = 0/00:15 MET, use Maneuver Edit (ME) to fetch an Orbiter ephemeris vector and model a blowdown burn with OBP thrusters and BFI targets per the Figure 3.10.4.1-16 example.

```

MANEUVER EDIT INPUT MENU

MANEUVER SOURCE      SYSTEM      VEHICLE      LOCATION
                     I (L,G,M,I)                      (E##M##,M##)

DESTINATION DMT      L (L,G)                      1 (1,2,3,4)

VECTOR SOURCE        SYSTEM      VEHICLE      LOCATION
                     L                               E8
LIFTOFF TIME          2005:066:00:08:30.000
VECTOR/FETCH TIME    (G,M,C) M 000:00:15:00.000
SOURCE COMMENT        LT1 MPS   pane 1 inplane
WEIGHT                256122.90          LBS

THRUSTER SELECTION    OBP (Thruster name or BT##)
GUIDANCE MODE         BFI (P7,M50,P4D,IMP,BFI)
MANEUVER COMMENT      Max Blowdown
UNITS TYPE            E ((E)NGLISH,(M)ETRIC)

BODY-FIXED INERTIAL INPUTS:
TIG                   (G,M,C,D) M 000:00:15:00.000
ATTITUDE REFERENCE    L                               (A = ADI, L = LVLH)
ATTITUDE HOLD REFERENCE I                               (I = INERTIAL, L = LVLH)
PITCH                 -12.8                          DEGREES
YAW                   0                               DEGREES
ROLL                  0                               DEGREES
DV                    176                          FPS
DT                    SECONDS
DT ULLAGE             SECONDS

```

**Figure 3.10.4.1-16: Blowdown Burn BFI Targeting in Maneuver Edit**

**NOTE:** BFI targeting in ME permits burnout apogee to be controlled with the only degree of freedom available in this scenario: LVLH pitch angle at TIG. Targeting could also be accomplished in PEG-7, but it would entail iterating on DVX and DVZ while preserving their RSS equal to the specified max blowdown  $\Delta v$ .

**NOTE:** if this analysis is performed for one OMS engine, doing so with OL or OR thrusters will generally result in PEG-7 DVY  $\neq$  0. This can be corrected in the ECT by temporarily zeroing the corresponding Yaw CG trim or by configuring a miscellaneous thruster with single-OMS thrust/flow rate and zero Body Yaw.

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- 4) Iterate on the ME LVLH pitch angle at blowdown TIG until the resulting DMT displays HA at the maximum permissible value (see Figure 3.10.4.1-17).

```

LOCAL                                DMT NO. 1                                ENGLISH
COMMENT:  Max Blowdown

----- PAD -----
GMTI 2005:066:00:23:30.000 | I-OBP-BLI-FC | GMTR 2005:066:00:08:30.000
METI 000:00:15:00.000 | TV ROLL 0.0 | TIGT
DVM 176.00 DTB 01:56.50 | SYSP TRIMS P 1.0 | OUTPUT MAT CURI00
VXI -54.96 DVULL 0.00 | LY -5.7 |
VYI -163.01 DTULL 0:00.0 | RY 5.7 | OSTAID L E8
VZI -37.19 DTRCS 0:00.0 | WEIGHT 256122.9 | GMTV 066:00:23:30.000
DVTO 0.61 DTTO 2.60 | TIG 000/00:15:00.0 | METV 000:00:15:00.000
INR LVLH | PEG 4 C1 | COMMENT LT1 MPS pane
P 179.0 P 347.2 YH 0.0 | C2 | TSTAID
Y 298.0 Y 0.0 PH -12.8 | HT | GMTV
R 37.2 R 0.0 RH 0.0 | GT | METV
| PRPLT | COMMENT
TGT VEH DATA | PEG 7 DVX +0155.7 | FSTAID
Eltig Gb/o | DVY +0000.0 | GMTV
DHb/o 0b/o | DVZ +0082.1 | METV
OFFSET MNVR EPH | BURN ATT R 037 |
MET | P 179 | DWOMS 4403.9
DT | Y 298 | DWRCS 0.0
DX | DVTOT 176.00 | WFNL 251719.0
DY | TGO 01:54.0 | DW 4403.9
DZ | VGO X 170.01 | DV REMAIN
| Y 0.00 | PRI SEC
HA 178.0 HP 62.9 | Z 45.52 |
LAN 126:23W Htig 72.3 | TGT HA 178 HP 63 | SITE XR
zP 40.2 Vtig 50:14N | REI
i 51.62 ltig 037:27W | VEI
e 0.01563 htig 89.7 | INTO UNTIL | CEI
a 3561.4 | METEI

```

**Figure 3.10.4.1-17: Max Blowdown Burn Iterated To Maximum Permissible HA**

- 5) Record the DMT's displayed METI, LVLH PH, HA, HP, and PEG-7 DVX/DVZ per the example table at the end of Section 3.10.4.1.1.17. Do *not* transfer the iterated blowdown burn to the Orbiter ephemeris, as it will invalidate results at later TIGs.
- 6) Increment TIG by one min and return to Step 3. Cease further analysis when the iterated PEG-7 DVZ in Step 5 is less than the horizontal burn DVZ noted in Step 2c. Reiterate LVLH pitch for this final TIG to achieve the horizontal burn DVZ and record corresponding DMT values with inequalities per the example table at the end of Section 3.10.4.1.1.17. These data should be provided to the Ascent FDO and filed in the FDO SUPPORT Data Book for easy access.

**NOTE:** the Section 3.10.4.1.1.17 Ascent FDO Data Sheet, on which max blowdown burn data are recorded, primarily contains data specific to a single launch day. However, this is not the case for max blowdown data. They need be updated only when target perigee height or OMS propellant loading changes.

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### 3.10.4.1.1.13 FD2 Rendezvous Assessment

For short phase angles at OMS-2 ( $< \sim 180^\circ$ ), a FD2 rendezvous may be possible in the event of a declared MDF prior to NC-1. FDO SUPPORT should determine the phase angle, if possible, where the transition from FD2 capability to FD3-only capability occurs. If a FD2 rendezvous is possible anywhere in the window, the FD2 Ti TIG should be determined.

This analysis is only required if the phase angle at OMS-2 approaches the upper limit of FD2 rendezvous capability on the given launch day. The goal is to find the transition from a FD2 Plan B rendezvous to a FD3 Plan C rendezvous. The Flight Design product RNDZ-01B provides a graphic representation of the rendezvous plans versus the phase angle at OMS-2 (Figure 3.10.4.1-12). This chart is an excellent starting point to determine the exact upper limit of the phase angle that will support a FD2 rendezvous.

**CAUTION:** flight experience at altitudes below  $\sim 140$  nm (most recently during STS-110) demonstrates MCC's Jacchia-Lineberry atmosphere models excessively high densities in this region. Some attitudes, such as YVV, further aggravate this error because RCS deadbanding impulses tend to impart a net postgrade acceleration to the Orbiter CG. Consequently, an Orbiter drag profile computed only from Orbiter aero cross-section considerations tends to over-model energy losses during a long phasing case. This tendency will then result in an overly optimistic assessment of maximum FD2 phasing capability. Experience during STS-110 indicates low-altitude phasing in a -ZLV -XVV attitude is best modeled with an Orbiter ballistic drag area =  $910 \text{ ft}^2$  and  $KCON = 1$ .

From RLW, select a time when the phase angle approaches the perceived upper limit of FD2 rendezvous capability. Use the rule of thumb phase angle rate of  $4^\circ/\text{min}$  to determine a good launch time. For example, if the phase angle at OMS-2 at the window open is  $160^\circ$  and the expected upper limit on phase angle to support FD2 rendezvous is  $176^\circ$ , then a launch time  $\{176 - 160\}/4 = 4$  min later than the window open is a good place to start searching for the exact limit.

The upper phase angle limit at OMS-2 to reliably target a FD2 rendezvous is that resulting in a post-OMS-2 perigee of 85 nm for a FD2 rendezvous plan. Using the post-MPS dump vector obtained from RLW at the selected launch time, a Plan B FD2 rendezvous is generated. Lighting constraints and radial  $\Delta v$  iterations at Ti are included to produce a viable plan. If the OMS-2 perigee height is 85 nm or more, the phase angle on the OMP Evaluation Table is short enough to safely support a FD2 rendezvous. If the perigee is less than 85 nm, the phase angle is too large to accommodate the FD2 rendezvous. Iterate on the phase angle at OMS-2 until Plan B's post-OMS-2 perigee height equals 85 nm. Note the launch time corresponding to this phase angle and provide this information to the Ascent FDO.



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It is also possible that an extremely short phase angle at OMS-2 ( $< 45^\circ$ ) cannot support a FD2 rendezvous in parallel with a FD3 rendezvous. FDO SUPPORT should also determine the minimum phase angle that a FD2 rendezvous can be carried without compromise to FD3 capability.

This procedure is similar to that computing a maximum FD2 phase angle and is only required if phase angle  $< \sim 45^\circ$  exists in a planar window on a given launch day. The goal is to determine the phase angle (and launch time) below which a FD2 rendezvous Plan A OMS-2 causes unacceptably small posigrade or retrograde maneuvers (usually NC-4) in a FD3 rendezvous Plan C. If the phase angle is below this limit, rendezvous Plan G will be used, and FD2 rendezvous capability will be abandoned.

Again use RLW to generate a post-MPS dump vector at various phase angles assessing the minimum value supporting both FD2 and FD3 rendezvous. The RNDZ-01B chart is again an excellent source to begin this assessment. After a viable Plan A rendezvous is developed with the post-MPS dump state vector, a Plan C FD3 rendezvous is developed using Plan A's OMS-2  $\Delta v$ . If any Plan C rendezvous maneuvers result in maneuvers less than 3.0 fps posigrade, the phase angle at OMS-2 is increased. Otherwise, the phase angle can be reduced. Iterate on the phase angle until NC-4 is 3.0 fps posigrade. Below this phase angle (and before this launch time), FD2 rendezvous is not possible, and Plan G will be utilized.

NOTE: aggressive FD3-only rendezvous plans may be developed to provide the smallest possible phasing capability. These plans entail adding an OMS-3 burn to FD1, as on STS-96, further reducing phase rate and possibly providing co-elliptic relative motion. This strategy significantly increases FD1 workloads. If justified, a minimum-phase plan with additional FD1 burns must be carefully coordinated with the flight control team and crew.

### 3.10.4.1.14 Large Phase Angle Assessment

FDO SUPPORT should examine the case of a very large phase angle at OMS-2 if one can be encountered on the given launch day. Specifically, FDO SUPPORT should determine the maximum phase angles for which a FD3 rendezvous Plan D and a FD4 rendezvous Plan F are viable. At near-maximum phase angles, impacts posed by the Method 1 ET photography translation should be made. An assessment of introducing retrograde maneuvers into the rendezvous plan may also be necessary.

CAUTION: flight experience at altitudes below  $\sim 140$  nm (most recently during STS-110) demonstrates MCC's Jacchia-Lineberry atmosphere models excessively high densities in this region. Some attitudes, such as YVV, further aggravate this error because RCS deadbanding impulses tend to impart a net posigrade acceleration to the Orbiter CG.

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Consequently, an Orbiter drag profile computed only from Orbiter aero cross-section considerations will tend to over-model energy losses during a long phasing case. This tendency will then result in an overly optimistic assessment of maximum FD2 phasing capability. Experience during STS-110 indicates low-altitude phasing in a -ZLV -XVV attitude is best modeled with an Orbiter ballistic drag area = 910 ft<sup>2</sup> and KCON = 1.

Like the maximum FD2 rendezvous capability, the goal here is to determine the maximum phase angle that can be encountered and still perform a FD3 rendezvous Plan D (see Section 3.10.4.1.1.7). The procedures are virtually identical, except the plan to be used is Plan D. This plan supports the largest phase angles within FD3 rendezvous capability.

Again, RLW is used to generate a post-MPS dump vector for a specific launch time that is close to the limit found in the RNDZ-01B chart. Once a viable Plan D rendezvous is iterated, check OMP's estimate of NC-1  $\Delta v$ . If NC-1  $\Delta v$  is greater than 6 fps posigrade, an increase in phase angle should be made. Otherwise, a decrease in phase angle is required. Iteration on NC-1  $\Delta v$  until posigrade 6 fps is achieved results in the phase angle (and launch time) for maximum FD3 capability.

Like the maximum FD2 and FD3 rendezvous cases, FDO SUPPORT should determine the maximum phase angle providing a FD4 rendezvous if that case can be encountered on a given launch day.

RLW is once again used to generate a post-MPS dump vector to evaluate the rendezvous plan. The difference here is that rendezvous Plan F (see Section 3.10.4.1.1.7) is used. If NC-1  $\Delta v$  is greater than 6 fps posigrade, an increase in phase angle should be made. Otherwise, a decrease in phase angle is required. Iteration on NC-1  $\Delta v$  until posigrade 6 fps is achieved results in the phase angle (and launch time) for maximum FD4 capability.

### **3.10.4.1.1.15 Extending Phasing Capability**

It is always preferable to keep FD2 capability over FD3-only capability. Also, it is better to rendezvous on FD3 instead of on FD4. In those cases where OMS-2 phase angle is at or near the transition from one flight day to another, extending phasing capability a little may make the difference.

Extended phasing capability may be achieved using multiple possible techniques. In general, these techniques are not mutually exclusive. First, Method 1 ET photography can be deleted and the +X translation removed from the trajectory. The +X translation is 5 fps posigrade and reduces phase rate accordingly. Adding this energy into the orbit decreases total rendezvous phasing capability. Deleting it can buy back several degrees of maximum phasing potential.

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Second, FDO SUPPORT should look at the possibility of extending maximum phasing limits with the addition of retrograde maneuvers in the rendezvous plan. Propellant margins may permit this. A retrograde maneuver at NC-1 or the earliest practical time near perigee will serve to reduce the apogee and increase the phase rate. This results in extending maximum phasing capability by several degrees.

Third, moving the launch time earlier (or later) will decrease (or increase) the phase angle by approximately  $4^\circ$  per minute. Flight rules usually dictate a preferred launch time at the in-plane time<sup>11</sup>. However, moving the preferred launch time to the planar window open time is possible via a flight-specific rule exception. A decrease of approximately  $20^\circ$  in phase angle can result if the launch time is moved 5 min earlier. During the final minutes of STS-105's countdown, preferred launch time was moved to planar window open not to decrease phasing, but to launch before adverse weather arrived at the launch complex.

Fourth, rendezvous propellant penalties associated with a marginally excessive phase angle can often see dramatic reduction when the planned Ti TIG is delayed one to three revs. With maximum phase rate approaching 900 nm per rev in these cases, just a one-rev slip increases phasing capability by nearly  $14^\circ$ . Given a FD3 rendezvous plan would otherwise be unacceptable, delaying docking a few hours (as opposed to an entire day) may be an attractive option.

### **3.10.4.1.1.16 Propellant Increases Due to Low Orbits**

If propellant margins are small or unknown, the increase in required rendezvous propellant due to low orbit altitude atmospheric drag should be assessed and passed along to PROP. In terms of  $\Delta v$ , rendezvous cost can be obtained directly from OMP's MET display. If PROP requires propellant consumption expressed in lbm, transferring the OMP plan into an ephemeris is necessary. In this case, it's essential to verify relative motion offsets at NC-4 and Ti. Iterate on OMP chaser area until these offsets are acceptable. Any increase in propellant usage should be forwarded to PROP. This can be accomplished via the internal flight note documented in Section 3.10.4.1.1.11.

### **3.10.4.1.1.17 FDO SUPPORT Data Delivery to the Ascent FDO**

The culmination of all the described pre-launch tasks for FDO SUPPORT should be briefed and presented to the Ascent FDO prior to launch. The FDO SUPPORT Data Sheet serves as a detailed worksheet with which to prepare data for this briefing.

---

<sup>11</sup> This inplane preference applies to launches targeting  $51.6^\circ$  inclination. Range safety considerations tend to place preferred launch time near planar open when  $28.5^\circ$  inclination is targeted.

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These data are summarized in the Ascent FDO Data Sheet. Detailed procedures for computing data on these sheets are found in Section 3.10.4.1.1.10, Section 3.10.4.1.1.12, and Section 3.10.6.8. Typical data sheet examples appear as follows. Unique flight-specific scenarios may require format and content deviations from examples provided here.

### FDO SUPPORT DATA SHEET

#### STS-121 Training (12103 Load)

**Panes = 2**

#### TSA Save Area

/users/fdo/drafdo/STS121/AscentSims/

#### JURe Spreadsheet Save Area

\\JSC-MOD-FS3\World\Divisions\DM\Private\DM32\FLIGHTS\STS-121\FDO Support\JURel30deg.xls

**Nominal OMS Assist = 5556 lbm**

**Nominal OMS Assist RTO = 19000 lbm**

**ISS Propellant = 3000 kg**

Pane 1 (IP = 130°)	Pane 2 (Switch Point = ~503°)
Plan C to FD3 Post OMS 2 Hp = 85 nm	Plan F to FD4 Post OMS 2 Hp = 85 nm
Nominal Rendezvous: 376 fps Nominal Deorbit: 290 fps Total $\Delta v$ : 666 fps	Nominal Rendezvous: 389 fps Nominal Deorbit: 290 fps Total $\Delta v$ : 679 fps
Max JURe $\Delta v_U$ : 320 fps Max JURe Deorbit $\Delta v_D$ : 244 fps Max JURe Phase-Limited Dock Hp = 154 nm	Max JURe $\Delta v_U$ : 273 fps Max JURe Deorbit $\Delta v_D$ : 195 fps Max JURe Dock Hp = 123 nm
Max Underspeed (No JURe) = RTO/25 - Total $\Delta v$ = 94 fps Max Underspeed (2 JURe) = RTO/25 - $\Delta v_U$ - $\Delta v_D$ = 196 fps Max Underspeed No Deorbit (2 JURe) = RTO/25 - $\Delta v_U$ = 440 fps Max ITEM 9 = 43%	Max Underspeed (No JURe) = RTO/25 - Total $\Delta v$ = 81 fps Max Underspeed (4 JURe) = RTO/25 - $\Delta v_U$ - $\Delta v_D$ = 292 fps Max Underspeed No Deorbit (4 JURe) = RTO/25 - $\Delta v_U$ = 487 fps Max ITEM 9 = 53%

#### Max JURe Burns

Burn	TIG GMT	$\Delta v$ (fps)	Ha (nm)	Hp (nm)
ISS-1	193/13:48	29.55	183.1	168.9
ISS-2	193/15:20	29.65	181.3	153.6
ISS-3	194/12:29	29.76	179.6	138.3
ISS-4	194/13:59	29.86	177.9	123.2

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### ASCENT FDO DATA SHEET (12103 Load)

#### Pane 1 (IP = 130°)

1. Post OMS 2 HP = 85 nm
2. Max Underspeed (No JURE) = 94 fps
3. Max Underspeed (2 JURE) = 196 fps
4. Max Underspeed No Deorbit (2 JURE) = 440 fps
5. Max ITEM 9 = 43%

#### Pane 2 (Switch Point = ~503°)

1. Post OMS 2 HP = 85 nm
2. Max Underspeed (No JURE) = 81 fps
3. Max Underspeed (4 JURE) = 292 fps
4. Max Underspeed No Deorbit (4 JURE) = 487 fps
5. Max ITEM 9 = 53%

#### Post-MECO Max Blowdown Burns

1. Max Ha = 177.4 nm (ISS Hp - 7 nm)
2. Blowdown  $\Delta v$  = 176 fps

TIG MET (h:mm)	OBP LVLH Pitch (deg)	Ha (nm)	Hp (nm)	PEG-7 $\Delta V_X$ (fps)	PEG-7 $\Delta V_Z$ (fps)
0:15	-13.7	177.4	63.1	154.4	84.5
0:16	-10.6	177.4	65.1	158.7	76.0
0:17	-7.2	177.4	67.1	163.0	66.5
0:18	-3.2	177.4	68.9	167.2	54.9
0:19	+1.4	177.4	70.5	171.1	41.4
0:20	+7.0	177.4	71.7	174.3	24.5
≥ 0:21	+10.98	≤ 176.1	≥ 73.2	175.6	12.3

#### Target Drag Modeling

1. F10 = 80.0 Jansky\*10<sup>4</sup>
2. Kp = 2.40
3. Weight = 423000.0 lbm
4. Area = 4000.0 ft<sup>2</sup>
5. KCON = 1

Compiled by DM32/Dan Adamo 3/27/06

#### 3.10.4.1.1.18 TrS Ephemeris/VAT Mirror Management

FDO SUPPORT is required to manage certain ephemeris mirrors during the course of launch and post-insertion activities. Specifically, FDO SUPPORT will manage M3 and M7 at the very least. M3 will reflect the target trajectory, and M7 will reflect the Orbiter

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trajectory, most likely out until the end of FD3 (or FD4 if a FD4 rendezvous is expected). The Ascent FDO/TRAJ will mirror E1, E2, E4, and perhaps E5.

Post-launch, FDO SUPPORT has the added responsibility to monitor VAT mirror health. Ordinarily, TRAJ will operate this mirror. Shortly after STS-114 launch, however, the VAT mirror automatically terminated due to excessive system loading and latency. Therefore, if the VAT mirror terminates any time prior to OMS-2, FDO SUPPORT should immediately turn it back on without FDO or TRAJ coordination. As soon as practical, FDO SUPPORT should contact FDO or TRAJ to report the VAT mirror was off and was turned back on. FDO SUPPORT should then coordinate with TRAJ on transferring VAT mirror control back to the TRAJ workstation.

With the advent of 2D DEMOS World Map display events annotation capability, FDO SUPPORT is also responsible for driving OMS-2 and subsequent events as they become available in E1 post-MECO. See Section 3.3.6 for details on driving World Map events annotation. To ensure data from a previous checkpoint do not drive incorrect ascent events on the World Map, FDO SUPPORT should purge any `Events.txt` file residing in the M1 directory prior to launch.

### 3.10.4.1.2 Rendezvous Plan Setup

The previous section emphasized that all necessary MCTs be available on console prior to the pre-launch shift. This section, and several that follow, will describe in detail how to set up rendezvous plans. Separate constraints tables may be required if more than one phasing plan is required for the range of phase angles encountered on launch day. These plans should be based on generic maneuver profiles developed by Flight Design, which are documented in STF OFD-01-48300-024. This STF contains standard burn plans for ISS rendezvous missions, and should be used as a starting point for building constraints tables. Seven plans are included in the memo (labeled A-G), each valid over a particular range of phase angles and rendezvous day. Another resource for profile planning is the Flight Design burn plan presented in the Groundrules and Constraints document. This plan will be specific to whatever launch date and phase angle flight design used for a particular design cycle. Regardless of source, you should start with a TIG-free MCT for each phase plan at first—it will be fine-tuned later with fixed TIGs. Figure 3.10.4.1-19 shows a TIG-free MCT from STS-91 that was built based on plan B FD2 rendezvous. Post-MPS dump Orbiter vectors should be available from RLW for window open, close, and optimum liftoff times. These can be stored off in TSA VAT slots as described in Section 3.10.3.5.5. One final step remains before running the OMP: the target vector to be used must have a Tref (liftoff time) equal to the Orbiter vector. Build a TSA target ephemeris off the midnight of launch vector used to run RLW, then grab a vector out of the ephemeris corresponding to the desired liftoff time and store in the VAT. Next, use TSA Vector Edit menu to modify the target vector's liftoff time to correspond to the post-MPS dump Orbiter vector liftoff time.

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Repeat as necessary so that each post-MPS dump Orbiter vector has a corresponding target vector with the same liftoff time. The target vector can then be input into the OMP Execute menu along with propagation characteristics derived from the drag fit conducted earlier. After executing the plan, TIG-free output can be examined in the MET, Figure 3.10.4.1-20.

OMP output should be compared against a Flight Plan to assure the profile meets various timeline constraints. The plan should conform with crew sleep/wake cycles by keeping TIGs during the crew workday. Burns late in post-sleep or early in pre-sleep are usually acceptable, assuming this has been coordinated with FAO. Perturbing events such as water dumps and attitude maneuvers should be planned around burns to provide adequate tracking arcs prior to ignition. Finally, rendezvous and docking rev should be coordinated with FAO and RGPO. It is frequently necessary to modify the MCT burn sequence in order to make the plan meet timeline constraints. Other flight-specific constraints may also affect design of the overall profile (e.g. docking over particular groundsites). Once a rendezvous plan has been transmitted to external customers, target drag changes may result in slight changes to lighting at Ti TIG. Do not update the Ti time unnecessarily (1-10 sec difference) since numerous external customers use Ti TIG as a baseline time for other events, and any change to Ti triggers a flurry of replanning.

MANEUVER CONSTRAINTS TABLE B2

COMMENT: Rendezvous Plan B FD2 Dock on D.O. 4 CURRENT  
MNVRs: 6 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 NC	T	APS =1.0	DV =200	=
OMS-2	000:00:20:00.000	=	=	=
2 EXDV	M	DVLV=8	DVLV=0	DVLV=0
NC-1	2.0	=	=	=
3 NH	M	=	=	=
NC-2	8.0	=	=	=
4 NC	M	DR =-40.0	=	=
NC-3	0.5	=	=	=
5 SOI	T	DR =-8.0	DH =0.2	=
Ti	1	=	=	=
6 SOR	DT	CXYZ=-.1481	CXYZ=0.0	CXYZ=0.2962
	000:01:16:54.000	=	=	=

**Figure 3.10.4.1-19: TIG Free MCT, Plan B, FD2 Rndz**

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MANEUVER EVALUATION TABLE B2  
MCT : B2                   OVT : PLOTON  
GMTR : 1998:153:22:15:04.000

VECTOR	TIME	COMMENT
CHASER V18	M 000:00:10:33.000	POST-MPS DUMP - planar window close
TARGET V19	M 000:00:00:00.000	ELSET 285 Propped to planar close
CHASER	DVtot = 365.64    DVx = 340.35    DVy = 3.06    DVz = 33.18	
TARGET	DVtot = 0.00    DVx = 0.00    DVy = 0.00    DVz = 0.00	6 MNVRS

MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
	COMMENT	METIG		DVy	HP	PHASE	Ydot
	DVMag	DT		DVz	DH	Noon/Mid -	SR/SS -
1	NC	153:22:59:23.762		87.02	174.47	5754.9935	-70935.2
	OMS-2	000:00:44:19.762		0.00	88.40	104.7148	36.5
	87.0	000:02:58:43.182		0.00	30.20	N-00:12:10	SS-00:42:58
2	EXDV	154:01:58:06.944		8.00	173.93	4854.1250	-52838.4
	NC-1	000:03:43:02.944		0.00	92.89	83.8048	35.4
	8.0	000:11:55:28.352		0.00	30.71	N-00:17:33	SS-00:48:08
3	NH	154:13:53:35.296		189.31	199.54	136.8965	1017.1
	NC-2	000:15:38:31.296		0.00	172.71	2.0978	1.2
	189.3	000:00:45:42.568		0.00	32.28	N-00:38:31	SR-00:07:51
4	NC	154:14:39:17.864		44.73	199.64	39.8931	-1524.5
	NC-3	000:16:24:13.864		0.00	198.56	0.6273	-0.6
	44.7	000:01:31:54.384		0.00	0.20	M-00:38:45	SS-00:23:10
5	SOI	154:16:11:12.248		8.80	205.69	8.0066	-1694.3
	Ti	000:17:56:08.248		-0.76	195.47	0.1258	-1.2
	32.9	000:01:16:54.000		31.65	0.20	M-00:38:54	SS-00:23:16
6	SOR	154:17:28:06.248		2.50	206.21	0.3306	0.8
		000:19:13:02.248		2.30	196.41	0.0023	0.0
	3.7	000:00:00:00.000		1.53	0.30	N-00:08:05	SS-00:38:24

**Figure 3.10.4.1-20 - MET for Plan B, FD2 Rndz, L/O at Window Close**



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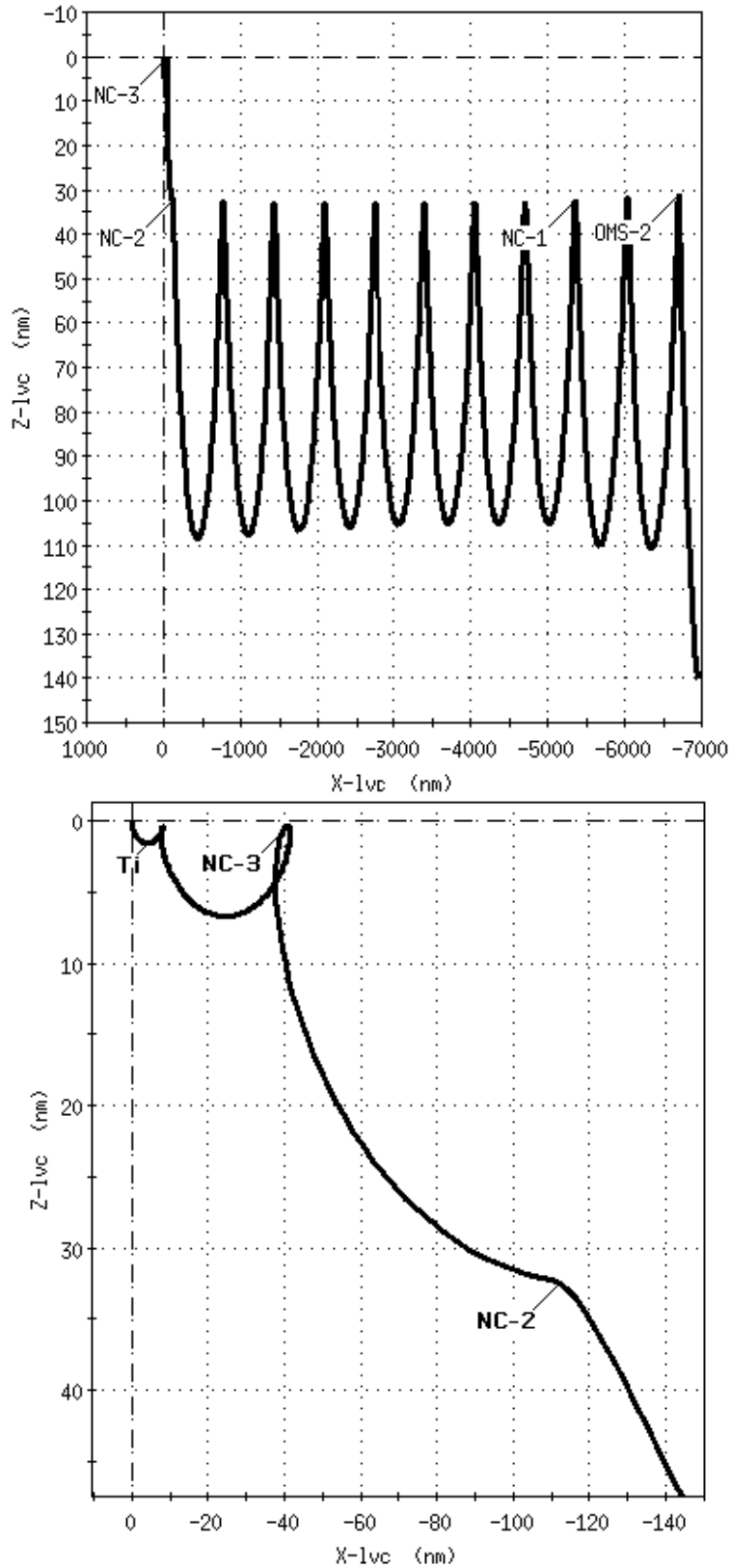


Figure 3.10.4.1-21: Relative Motion for FD2 Rendezvous

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Normally the max phase angle (window close) profile is run first to determine an OMS-2 target height that works for the entire window: OMS-2 is targeted as an NC (phasing) burn, with primary constraint T (time) using some threshold time soon after the MPS dump. An APS secondary constraint is used to force TIG at apogee, and an initial DV guess of about 100 fps is included to prevent the OMP from bombing if the first pass spits out a re-entering vector. Note that NC-1 is modeled as a fixed "posigrade bias" of about 8 fps. This is shown in Figure 3.10.4.1-19 above. After the output is displayed in the MET (Figure 3.10.4.1-20), the post OMS-2 phase angle should be checked against that provided by RLW. Also the planar error between the chaser and target should be checked, as indicated by SOI  $\Delta V_{\gamma}$  or NPC if it is explicitly modeled. Either of these should be less than 8 fps, otherwise the RLW phase and wrap flags are likely misconfigured, or RLW MET of rndz was misconfigured. All burns should be posigrade, and post-OMS-2 height > 105 nm (105 nm is a flight design constraint, but operationally we can go as low as 85 nm with SSP approval). For max phase case, the OMP's post-OMS-2 perigee, computed as an NC, will provide a low enough initial altitude to make up the required phasing. And as will be described next, this OMS-2 altitude should also work for the rest of the launch window.

The OMP's output OMS-2 perigee (88 nm in our example above) will be used when preparing plans for the remaining launch times with smaller phase angles (window open and optimum). In these plans, OMS-2 will be modeled as a fixed HA (height adjust) burn targeting the height found previously for the window close case. Then the next phasing burn in the profile, NC-1, can be targeted as an NC. Due to the smaller phase angle (as compared to the window close case), the post-OMS-2 orbit will be "over-phasing". The subsequent NC burn will compensate for this and be larger than the posigrade bias used in the window close case. *Where possible*, this strategy can result in a constant OMS-2  $H_t$ , simplifying crew and ground procedures. This is frequently taken advantage of thanks to the short launch windows seen with high inclination GURs. However, one fixed value for OMS-2  $H_t$  may not be feasible if the range of phase angles forces different rendezvous burn profiles (e.g. NH required on DOR as opposed to evening before). This problem often occurs for due east GURs where the launch window may be one hour or more.

One more word on the use of max phasing case to determine a fixed OMS-2  $H_t$ . If any launch day phase angle permits FD2 rendezvous, then the option for FD2 rendezvous must be built into the plan. This protects for an MDF scenario in which Orbiter system failures force the mission to be shortened. Flight Design's STF referenced above generically documents FD2 availability as a function of phase angle. A couple weeks prior to launch, the lead Profile Support will generate actual phase limits based on the target altitude and Orbiter insertion targets. FD2 rendezvous requires much more rapid phasing than either the FD3 or 4 case since it must close the distance between the Orbiter and target over a shorter timeframe. For this reason, FD2 rendezvous plans feature much lower post-OMS-2 perigees. As described above, this altitude should be determined for the max phasing (window close) case and used as the OMS-2 HA target

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for all plans on launch day (if possible). Then NC-1 is targeted in the other plans as the first NC in the profile. Normally, this first NC burn around MET 3 hrs is the "fork in the road" for FD2 vs. FD3 or 4 rendezvous. In the event of a problem that forces a FD2 rendezvous, rapid phasing must be preserved and NC-1 stays small. Otherwise, if all systems are performing well, then NC-1 becomes a larger burn to raise perigee and slow the phasing rate to get back on track for a FD3 or 4 rendezvous. Figures 3.10.4.1-3 and 4 show plan B/FD3 rendezvous using the OMS-2 HA target height derived from plan B/FD2 MET shown in Figure 3.10.4.1-20. Note how for FD3 rendezvous, the first NC burn (maneuver 2 "NC-1") is 181 fps in order to slow the phasing rate to switch from FD2 to FD3 rendezvous. If MDF had been declared prior to NC-1, then it would have been around 8 fps. Compare relative motion for the two plans and see how NC-1 is drastically different depending on which day rendezvous is targeted.

MANEUVER CONSTRAINTS TABLE B23

COMMENT: Plan B retarget to FD3

CURRENT  
MNVRs: 8 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-2	T 000:00:20:00.000	HD =88.000 = =	APS =1 = =	= = =
2 NC NC-1	M 2.0	= = =	= = =	= = =
3 NH NC-2	M 8.0	= = =	= = =	= = =
4 EXDV NC-3	M 6.0	DVLV=3.0 = =	DVLV=0.0 = =	DVLV=0.0 = =
5 EXDV DOR NH	M 8.0	DVLV=0 = =	DVLV=0 = =	DVLV=0 = =
6 NC NC-4	M 0.5	DR =-40.0 = =	= = =	= = =
7 SOI Ti	M 1	DR =-8.0 = =	DH =0.2 = =	= = =
8 SOR	DT 000:01:16:54.000	CXYZ=-.1481 = =	CXYZ=0.0 = =	CXYZ=0.2962 = =

**Figure 3.10.4.1-22: MCT for Plan B; FD2 -> 3 Rndz**

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MANEUVER EVALUATION TABLE B23  
MCT : B23 OVT : PLOTON  
GMTR : 1998:153:22:09:05.000

VECTOR	TIME	COMMENT
CHASER V5	M 000:00:10:33.000	POST-MPS DUMP In-plane - 1 minute
TARGET V6	M 000:00:00:00.000	ELSET 285 at 6/2/98 Launch I.P. - 1 mi

CHASER	DVtot = 361.10	DVx = 338.06	DVy = 1.36	DVz = 31.44
TARGET	DVtot = 0.00	DVx = 0.00	DVy = 0.00	DVz = 0.00

8 MNVRS

MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
COMMENT		METIG		DVy	HP	PHASE	Ydot
DVMag		DT		DVz	DH	Noon/Mid -	SR/SS -
-----							
1	HA	153:22:53:24.236	236	80.82	174.29	4784.0613	-51716.9
OMS-2		000:00:44:19.236		0.00	88.92	82.3238	33.7
80.8		000:02:58:34.902		0.00	30.30	N-00:18:09	SS-00:48:50
-----							
2	NC	154:01:51:59.138	138	181.54	187.51	3682.0055	-33004.4
NC-1		000:03:42:54.138		0.00	173.61	60.8738	27.9
181.5		000:12:09:38.959		0.00	30.96	N-00:23:40	SS-00:54:16
-----							
3	NH	154:14:01:38.097	097	18.98	198.00	2187.2120	-14761.1
NC-2		000:15:52:33.097		0.00	173.90	35.0232	16.6
19.0		000:09:08:28.042		0.00	30.97	N-00:30:26	SS-01:00:46
-----							
4	EXDV	154:23:10:06.139	139	3.00	199.76	1290.8937	-7058.4
NC-3		001:01:01:01.139		0.00	173.73	20.4571	9.6
3.0		000:12:11:32.027		0.00	30.97	N-00:34:15	SR-00:03:54
-----							
5	EXDV	155:11:21:38.165	165	0.00	199.51	132.7934	305.1
DOR NH		001:13:12:33.165		0.00	173.98	2.0359	1.6
0.0		000:00:45:43.280		0.00	30.96	N-00:39:06	SR-00:09:01
-----							
6	NC	155:12:07:21.446	446	42.37	199.63	40.0610	-785.2
NC-4		001:13:58:16.446		0.00	198.24	0.6300	-1.0
42.4		000:01:31:54.140		0.00	0.20	M-00:39:19	SS-00:23:08
-----							
7	SOI	155:13:39:15.585	585	8.86	205.66	8.0019	-955.7
Ti		001:15:30:10.585		0.04	195.40	0.1258	-0.7
31.2		000:01:16:54.000		29.90	0.20	M-00:39:27	SS-00:23:15
-----							
8	SOR	155:14:56:09.585	585	2.49	206.20	0.3308	0.4
		001:16:47:04.585		1.32	196.33	0.0023	0.0
3.2		000:00:00:00.000		1.55	0.30	N-00:08:38	SS-00:38:23
-----							

**Figure 3.10.4.1-23: MET for plan B, FD2 -> 3 Rndz; L/O at In-Plane -1 min**

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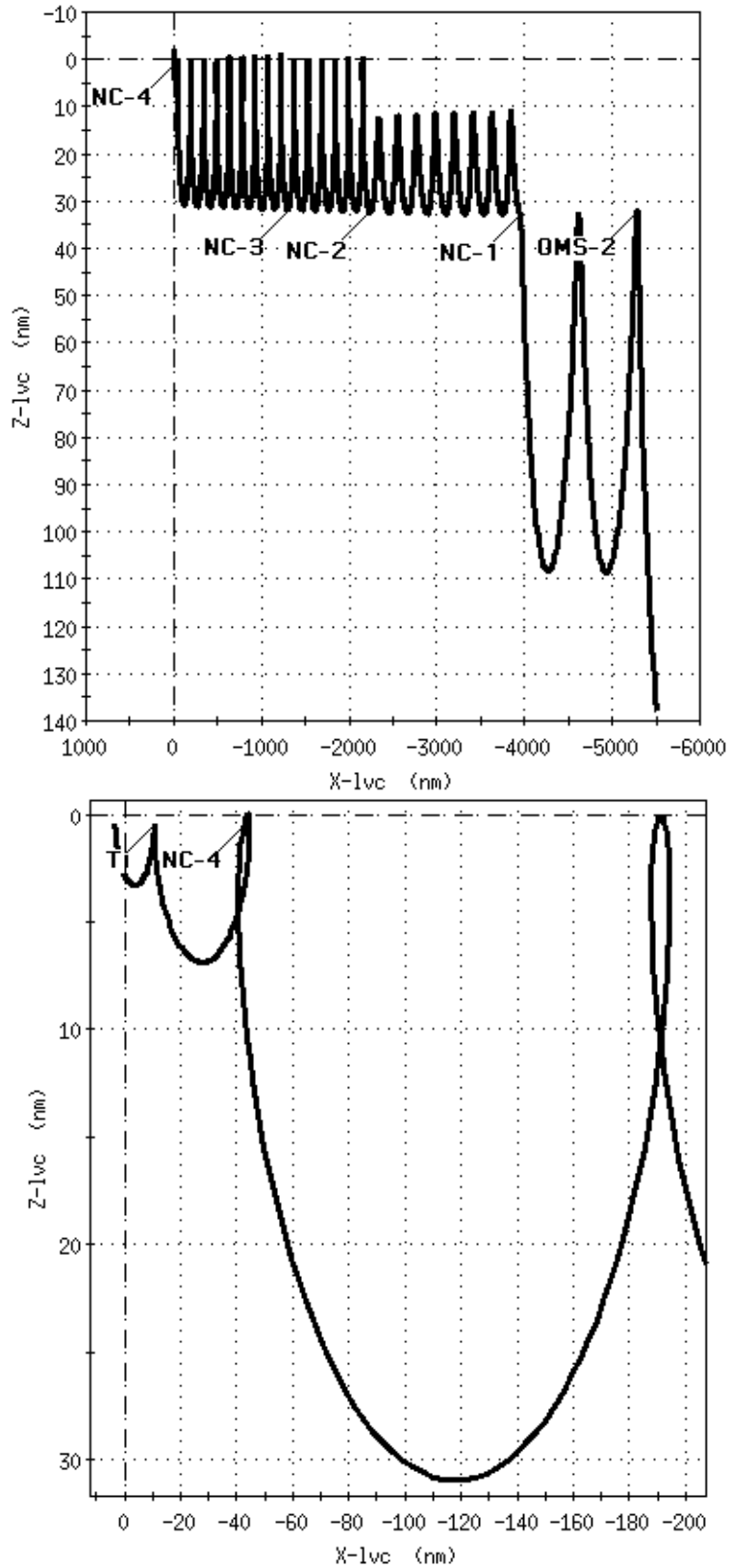


Figure 3.10.4.1-24: Relative Motion for FD2 -> 3 Rendezvous

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After the optimum OMS-2 target height has been found, it's time to turn our attention to the remainder of the profile. As mentioned above, the second maneuver is usually an NC burn targeting a range of 40 nm for the final phasing burn one or two revs prior to  $T_i$ <sup>12</sup>. This is done with the DR (downrange) secondary constraint.

It is worth noting that only one pre-DOR burn is targeted as an NC, since the OMP does not permit multiple burns to target the same DR or phase secondary constraint. Though the goal of all pre-DOR phasing burns is to achieve a range of 40 nm behind the target at the final NC burn before  $T_i$ , only one burn at a time may be explicitly targeted as such. The remaining phasing burns must be carried as fixed EXDVs since the first phasing burn achieves the desired range. These EXDVs serve another purpose as "posigrade biases" that build non-zero burns into the plan. This prevents uphill energy updates from forcing subsequent burns to go retrograde. The size of the posigrade biases is based on how much energy growth could occur between burns. FD1 biases are larger, around 8 fps due to the large tracking updates that are frequently seen during the post insertion phase. Biases for burns on FD2 or 3 are smaller, around 3 fps, since the trajectory is tracked out better by then and energy updates are smaller. Maneuver 4 in Figure 3.10.4.1-22 is a posigrade bias. In real-time, after NC-1 is executed, this burn will be switched in the constraints table from an EXDV to an NC since it will now take over the job of targeting 40 nm for the final NC burn before  $T_i$ . The output  $\Delta v$  should be similar to the posigrade bias  $\Delta v$  that was modeled previously. As the burn approaches, vector updates from Ground NAV may cause some fluctuation in the output  $\Delta v$ , or even make the burn go away. This procedure will be repeated with each external  $\Delta v$  maneuver as its turn comes up. Deployable payload separation burns may be built into the profile in a similar manner as EXDV maneuvers.

As mentioned previously, all phasing burns prior to DOR target the desired range/phase angle for the final phasing burn on DOR. This burn, in turn, targets  $T_i$  to be 8 nm behind the target, but does nothing to guarantee the correct relative height between the chaser and target. An NH (height adjust) burn must be included in the profile to fix this. A  $T_i$  secondary constraint of  $DH=0.2$  assures that  $T_i$  occurs 1200 ft below the  $V_{bar}$ . Since the OMP targets NH as a horizontal burn, the height constraint must be applied at a position 180 deg from the burn (i.e.  $n + 0.5$  revs earlier) in order to assure the desired height coincides with apogee (assuming conventional GUR approach from behind). In our FD3 rendezvous example in Figure 3.10.4.1-22,  $T_i$  (modeled as SOI) occurs 15.5 orbits after the FD2 NH burn. NH remains in the MCT as an NH through burn execution, except when it's the last maneuver to be performed the evening before rendezvous. If the phase angle is such that NH is the final burn prior to NC-4 at 40 nm on DOR, *it is switched to an NC* for final targeting, and is re-targeted as a phasing burn. The reason for this is that the previous burns have set up an approach profile assuming NH would eventually be burned of sufficient magnitude to meet the relative height

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<sup>12</sup> Some phase angles require the second burn to be an NH (height adjust) rather than NC (phase control). This is specified in the Flight Design STF.

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requirements for  $T_i$ . Since NH  $\Delta v$  also affects the phasing plan, the previous and subsequent NC burns have already taken into account the phasing effects of NH. Thus when NH is the next burn in the profile, it can be switched to an NC and its  $\Delta v$  solution will not change appreciably (assuming the phasing burns previously executed were done correctly and no large navigation updates have occurred). Switching NH to NC puts the emphasis on controlling downtrack position, since this component is more sensitive to semi-major axis dispersions than is height. When the switch is made, a final NH burn should be added to the plan, typically on morning of rendezvous 0.5 rev prior to the final NC burn. (In Figure 3.10.4.1-22, a placeholder DOR NH was included as a zero fps EXDV). If all goes well, the DOR NH burn will not be required, and NCC will make up for any small height errors at  $T_i$ . Note that plans with large phase angles (plans D and F) place a mandatory NH burn on DOR in order to stay low for rapid phasing. Flight plan burn naming convention usually reserves the name "NH" for the DOR height adjust burn, whether it's required or optional. Any burns prior to DOR targeted as an NH are customarily named "NC-x", even though their true purpose is height *and* phase control.

### 3.10.4.1.3 Iteration to Correct $T_i$ Lighting and Radial $\Delta v$

After the TIG-free plan has been run and verified to be a good "ballpark" estimate of the actual rendezvous, the next step is to "freeze" TIGs and perform fine-tuning of the profile. This includes: fixing  $T_i$  lighting, eliminating radial  $\Delta v$ , and assuring proper downtrack position at  $T_i$  as well as the final NC burn. The first step is to re-save the TIG-free plan to another name in order to begin working with a new plan name. Next, use the TIG-free MET (Figure 3.10.4.1-23) to determine  $T_i$  lighting under the "SR/SS" column. The desired TIG is generally near orbit noon and conforms to a mission-specific offset from sunset. This TIG can also be computed from the target ephemeris using AcqMon in Sun mode. For an ISS rendezvous, the  $T_i$  TIG sunset bias is also dependent on solar beta angle. If the absolute value of beta from a near-docking target ephemeris Checkout Monitor is greater than 15 deg, the desired  $T_i$  TIG will be SS -36 min. Otherwise,  $T_i$  will need to be at SS -38.5 min in order to avoid having the Sun in the crew's line of sight during the Twice Orb Rate Vbar Approach (TORVA). This is only applicable to targets with an active light source since it will likely require the failed radar procedure to be executed in darkness.

Now using the Maneuver Evaluation Table and desired time of  $T_i$ , you can compute how many minutes the lighting is off, and then move the TIG of the final NC burn as necessary to nail  $T_i$  lighting. The best way to change  $T_i$  TIG is to switch the TIG of the first burn on DOR (NC or NH) to a primary constraint of T (time). That time will be equal to its TIG-free MET output plus  $T_i$  error computed above. Re-run the plan and iterate on NH or NC's TIG as necessary to achieve the correct lighting at  $T_i$ . When  $T_i$  has the right lighting conditions, you can fix the remainder of DOR TIGs. This is an easier technique than fixing  $T_i$  first and then working backwards to determine fixed TIGs for NC and NH.

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Next check the TIG of the final NC burn prior to Ti in relation to orbital noon. In order to avoid interfering with the post-NC star tracker (ST) pass which starts at orbital noon, it is important to complete the burn ASAP and maneuver to a target track attitude to point either the -Z or -Y ST tracker at the target. Since the ST relies on reflected sunlight to detect the target at this range, the length of the pass is the amount of time from noon to sunset, when approaching the target from behind. Therefore it is desired to perform the final NC burn no later than about 3 min before noon in order to get a full ST pass. Under the "Noon/Mid" column on the MET, determine NC time relative to noon, and move the TIG backwards as required to get a minimum of 3 min prior to noon. When you do this, leave Ti TIG alone since it is already anchored on its lighting constraint. Of course, if the plan already has NC TIG more than 3 min before noon, leave it alone. Re-run the plan and verify that the TIGs for the final NC and Ti look good. Even though the final NC and Ti should be an integer orbit period apart for optimum geometry, it is possible to move the NC TIG a few minutes either way without messing up the plan. If the DOR NH TIG has not been fixed yet, go ahead and set it 0.5 rev prior to the final NC burn. Figures 3.10.4.1-7 and 8 show our plan B/FD3 rendezvous with NH, NC-4, and Ti TIGs fixed on lighting.

MANEUVER CONSTRAINTS TABLE B23\_FIXED

COMMENT: Plan B retarget to FD3 - TIGs Fixed      CURRENT  
 MNVRS: 8 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-2	T 000:00:20:00.000	HD =88.000 = =	APS =1 = =	= = =
2 NC NC-1	M 2.0	= = =	= = =	= = =
3 NH NC-2	M 8.0	= = =	= = =	= = =
4 EXDV NC-3	M 6.0	DVLV=3.0 = =	DVLV=0.0 = =	DVLV=0.0 = =
5 EXDV DOR NH	T 001:13:03:00.000	DVLV=0 = =	DVLV=0 = =	DVLV=0 = =
6 NC NC-4	T 001:13:48:00.000	DR =-40.0 = =	= = =	= = =
7 SOI Ti	T 001:15:25:29.000	DR =-8.0 = =	DH =0.2 = =	= = =
8 SOR	DT 000:01:16:54.000	CXYZ=-.1481 = =	CXYZ=0.0 = =	CXYZ=0.2962 = =

**Figure 3.10.4.1-25: MCT for Plan B, FD2 -> 3 Rndz; DOR TIGs Fixed**



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MANEUVER EVALUATION TABLE B23\_FIXED  
MCT : B23\_FIXED OVT : PLOTON

GMTR : 1998:153:22:09:05.000

VECTOR	TIME	COMMENT
CHASER V5	M 000:00:10:33.000	POST-MPS DUMP In-plane - 1 minute
TARGET V6	M 000:00:00:00.000	ELSET 285 at 6/2/98 Launch I.P. - 1 mi

CHASER	DVtot = 424.65	DVx = 338.09	DVy = 1.50	DVz = 95.45	
TARGET	DVtot = 0.00	DVx = 0.00	DVy = 0.00	DVz = 0.00	8 MNVRS

MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
COMMENT		METIG		DVy	HP	PHASE	Ydot
DVMag		DT		DVz	DH	Noon/Mid -	SR/SS -
-----							
1	HA	153:22:53:24.236		80.82	174.29	4784.0613	-51716.9
OMS-2		000:00:44:19.236		0.00	88.92	82.3238	33.7
80.8		000:02:58:34.902		0.00	30.30	N-00:18:09	SS-00:48:50
-----							
2	NC	154:01:51:59.138		177.69	185.31	3682.0055	-33004.4
NC-1		000:03:42:54.138		0.00	173.61	60.8738	27.9
177.7		000:12:09:18.913		0.00	30.96	N-00:23:40	SS-00:54:16
-----							
3	NH	154:14:01:18.050		25.02	199.26	2108.1455	-13991.7
NC-2		000:15:52:13.050		0.00	173.90	33.7184	15.9
25.0		000:09:08:36.617		0.00	30.97	N-00:30:46	SR-00:00:08
-----							
4	EXDV	154:23:09:54.668		3.00	201.02	1244.2408	-6711.8
NC-3		001:01:00:49.668		0.00	173.73	19.7099	9.2
3.0		000:12:11:43.477		0.00	30.97	N-00:34:27	SR-00:04:05
-----							
5	EXDV	155:11:12:05.000		0.00	200.78	132.6918	309.0
DOR NH		001:13:03:00.000		0.00	173.98	2.0343	1.6
0.0		000:00:45:00.000		0.00	30.97	N-00:39:06	SR-00:09:01
-----							
6	NC	155:11:57:05.000		40.76	206.64	40.1871	-127.8
NC-4		001:13:48:00.000		0.00	189.72	0.6262	-1.1
40.8		000:01:37:29.000		0.00	5.37	N-00:03:38	SS-00:33:30
-----							
7	SOI	155:13:34:34.000		8.31	205.88	8.0034	-681.5
Ti		001:15:25:29.000		0.54	195.19	0.1258	-0.5
94.3		000:01:16:54.000		93.91	0.20	M-00:44:11	SS-00:28:00
-----							
8	SOR	155:14:51:28.000		2.50	206.18	0.3291	3.7
		001:16:42:23.000		0.96	196.33	0.0023	0.0
3.1		000:00:00:00.000		1.54	0.30	N-00:13:19	SS-00:42:59
-----							

**Figure 3.10.4.1-26: MET for Plan B, FD2 -> 3 Rndz; DOR TIGs Fixed**

When the plan is re-generated, it is likely that Ti will have a non-zero radial component. In fact, in the figure above, SOI  $\Delta V_z$  is 94 fps! This is because Ti is not located on the line of apsides. This is the "maneuver line" connecting apogee and perigee. (For the case of rendezvous with a target in a non-circular orbit, we are actually referring to *relative* apsides, where the chaser-target height differences are minimum and maximum. In this case, the chaser-target "line of *relative* apsides" may not necessarily coincide with the geocentric line of apsides. Subsequent terminology will not make this distinction, and it will be referred to simply as the "line of apsides"). In order for Ti to be purely horizontal/most prop efficient, it must be performed very close to the line of apsides, and it must be located at the correct relative height, which is assured by NH. If either of these is not met, a radial component will be added to SOI in order to simultaneously satisfy downtrack, height, and time-of-flight constraints for SOR. An

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example of this is shown in the relmo plot in Figure 3.10.4.1-27, on the top, which shows where Ti TIG is located when its solution includes a radial  $\Delta v$  component of 12 fps (coasted trajectory pre-SOI). The bottom plot shows the transfer orbit (SOI modeled), and how the radial  $\Delta v$  forced the line of apsides to SOI (got rid of the extra height above SOI). Note: same scale for both plots.

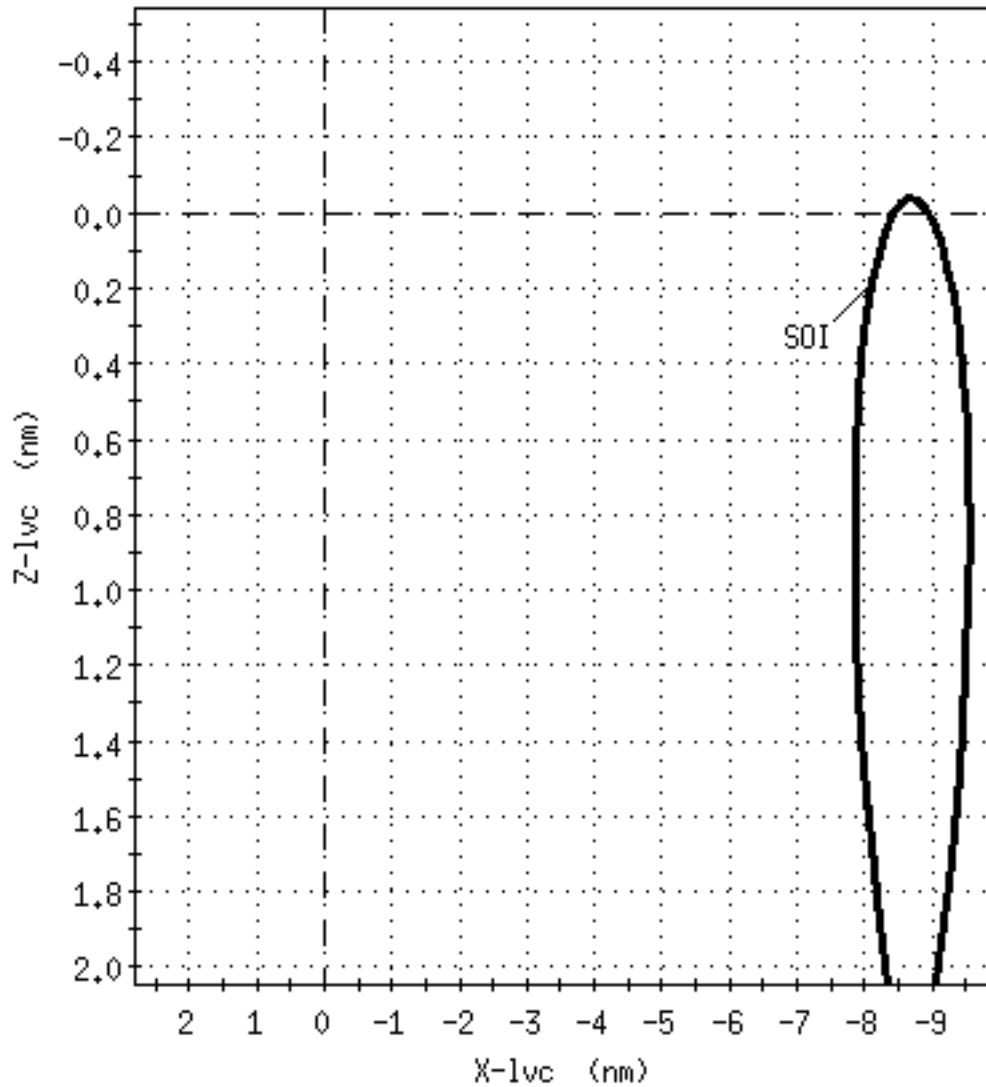


Figure 3.10.4.1-27a: Ti Position with 12 fps  $\Delta V_z$  SOI Solution

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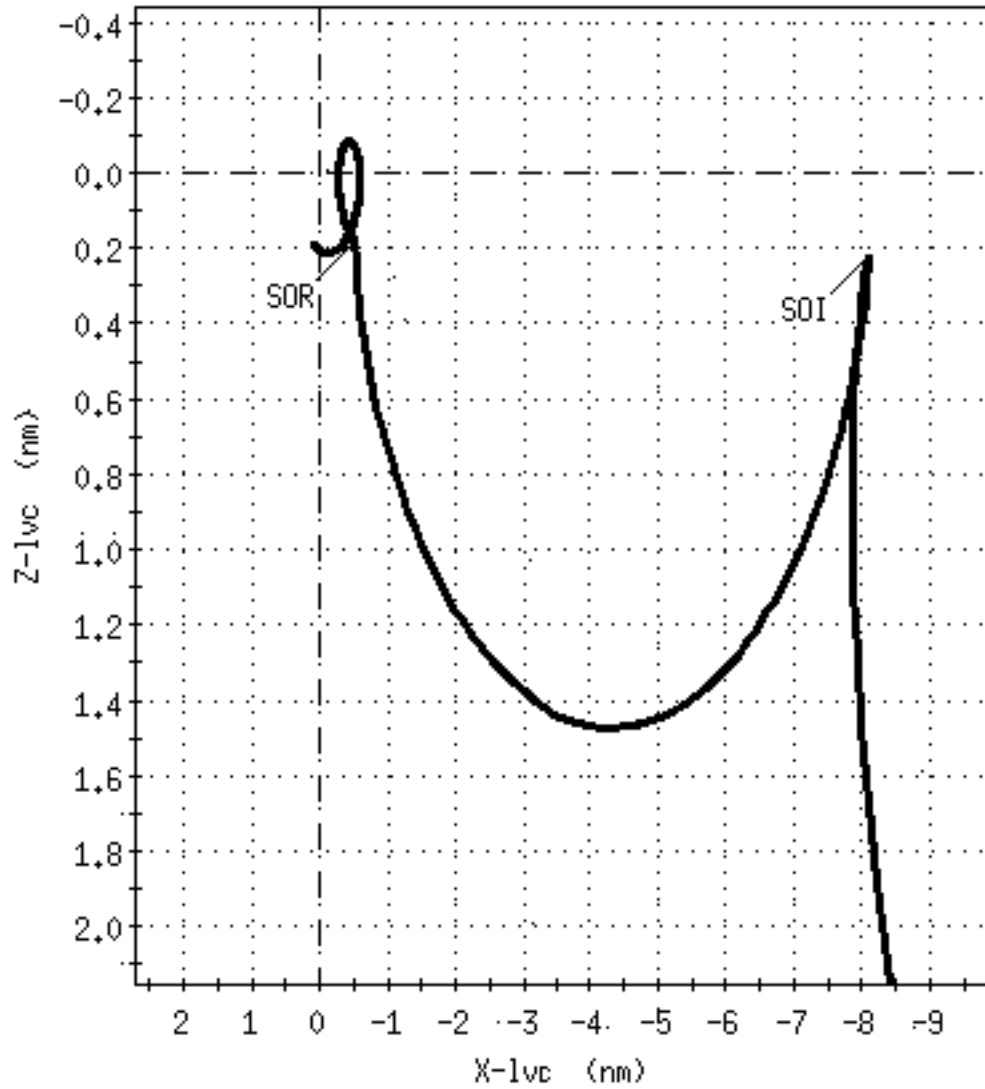


Figure 3.10.4.1-27b: Resultant Post-Ti Trajectory

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The next figure illustrates correct orientation of SOI. The left hand side shows a no-radial  $\Delta v$  SOI located very close to the line of apsides (SOI burn not modeled), and the right side shows the resultant transfer orbit with SOI modeled.

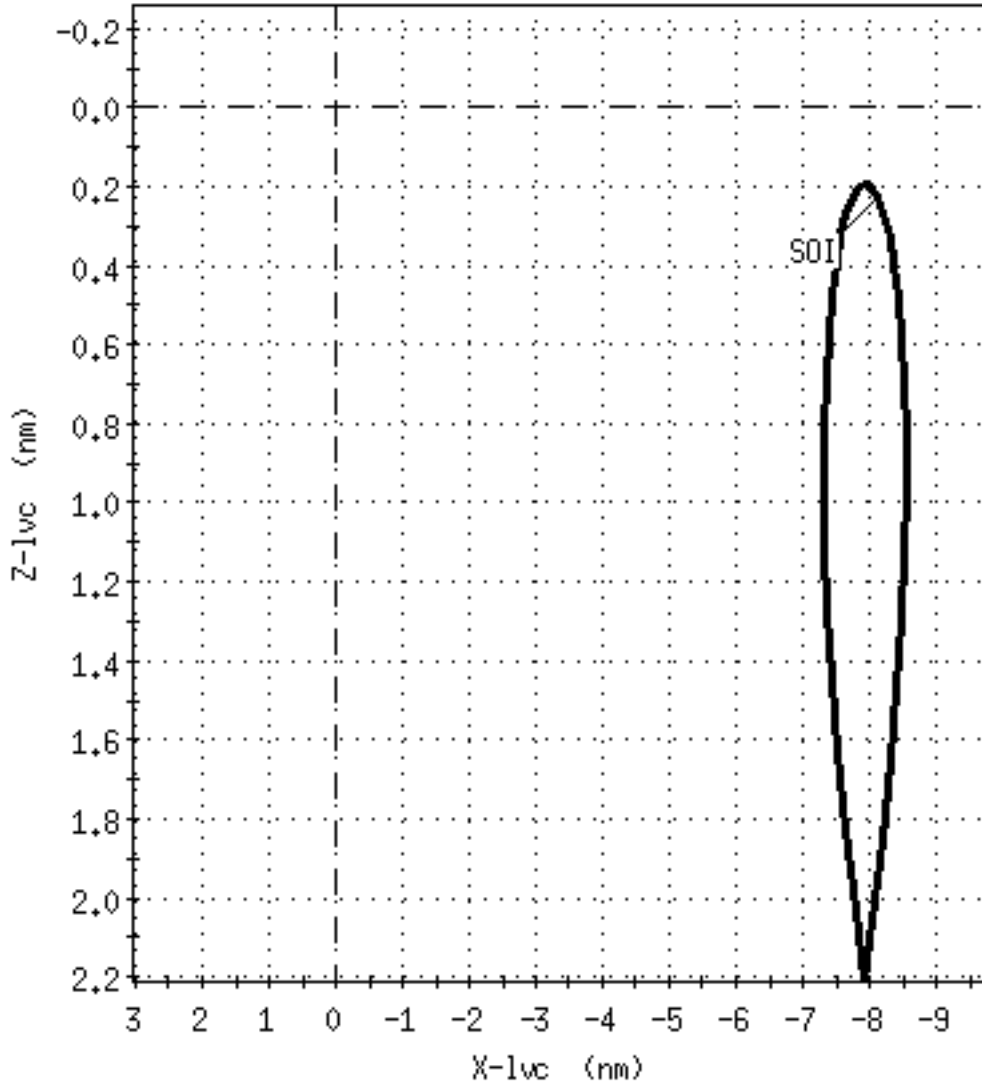
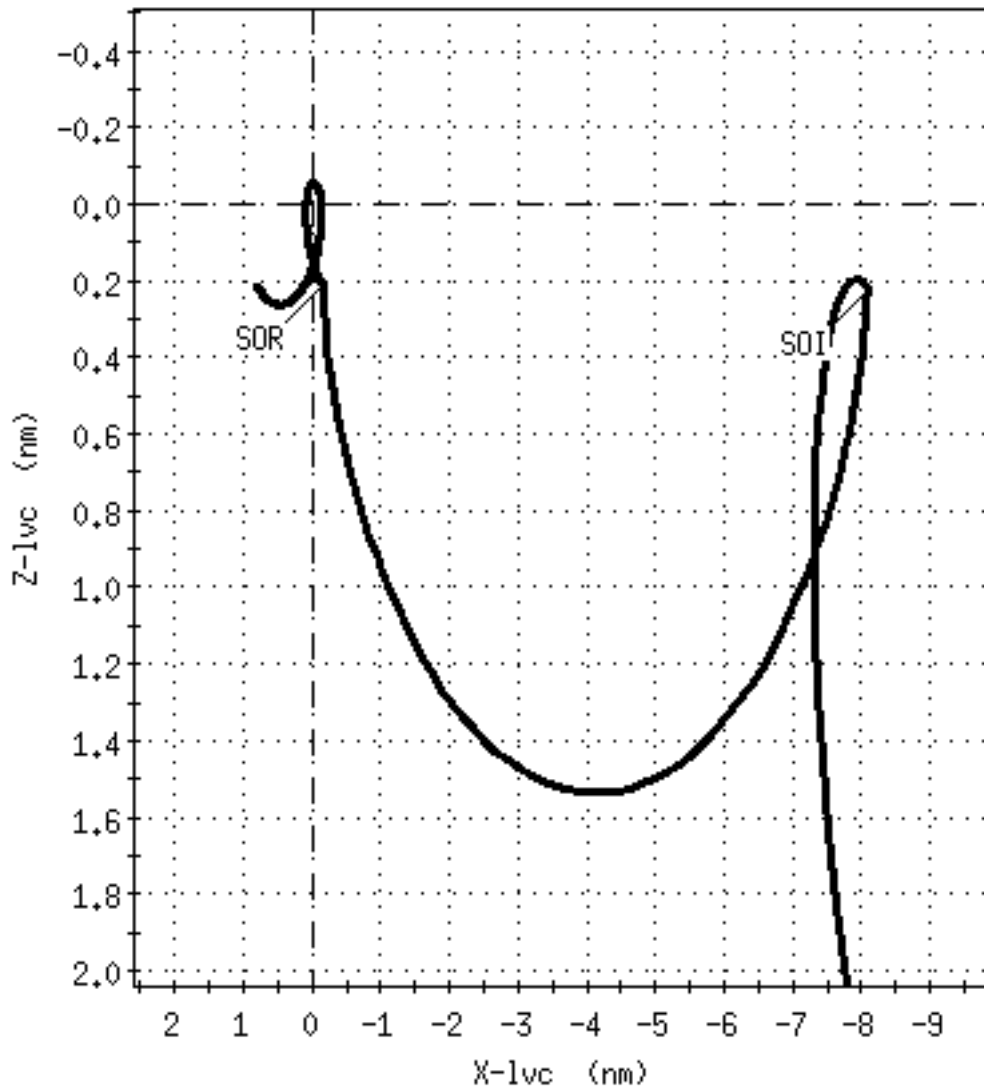


Figure 3.10.4.1-28a: Ti Position with 0 fps  $\Delta V_z$  SOI Solution

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**Figure 3.10.4.1-28b: Resultant Post-Ti Trajectory**

The preferred technique to place Ti on the line of apsides (and thus eliminate  $\Delta V_z$ ) is to move the TIG of one of the prior large phasing burns. This rotates the line of apsides so that Ti falls on the line. To do this, locate a prior NC or NH maneuver in the profile that starts from as nearly a circular orbit as possible. It must be a large burn ( $\Delta v >$  about 20 fps) in order to have enough "muscle" to move the line of apsides. There may be one or two candidate burns that can be used; pick one to start with and see if you get a satisfactory result. By modifying the TIG of this burn, the orientation of the line of apsides is moved without significant  $\Delta v$  penalty to the plan<sup>13</sup>. In the OMP, this is done by changing the primary constraint to T for one of the candidate burns, and fixing the time based on previous MET output. Add a small bias to the TIG in order to see if it

<sup>13</sup> Recall that a horizontal burn executed from a circular orbit creates the line of nodes along a line from the maneuver position to a position 180 deg away. A horizontal burn executed off-apsis from an elliptical orbit rotates the line of nodes.

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improves  $T_i \Delta V_z$ . Continue tweaking TIG until  $T_i \Delta V_z$  is less than 1 fps. This was performed with maneuver 2 (NC-1) in Figures 3.10.4.1-11 and 12 by moving its TIG forward by about 3.5 minutes. Once iteration is complete, fix the TIGs for all maneuvers based on the MET output. What you should have is all burns horizontal (other than SOR), planar component on SOI/SOR or NPC < 8 fps,  $T_i$  at sunset -28 (generic) or -36 min (ISS  $|\beta| > 15^\circ$ ) or 38.5min (ISS  $|\beta| < 15^\circ$ ), and the final NC burn on DOR no later than noon -5 min. The total  $\Delta v$  for the plan will be a minimum in this configuration.

MANEUVER CONSTRAINTS TABLE B23\_FIXED

COMMENT: Plan B retarget to FD3 - TIGs Fixed      CURRENT  
 MNVRS: 8 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 HA OMS-2	T 000:00:20:00.000	HD =88.000 = =	APS =1 = =	= = =
2 NC NC-1	T 000:03:39:25.000	DV =100 = =	= = =	= = =
3 NH NC-2	M 8.0	= = =	= = =	= = =
4 EXDV NC-3	M 6.0	DVLV=3.0 = =	DVLV=0.0 = =	DVLV=0.0 = =
5 EXDV DOR NH	T 001:13:03:00.000	DVLV=0 = =	DVLV=0 = =	DVLV=0 = =
6 NC NC-4	T 001:13:48:00.000	DR =-40.0 = =	= = =	= = =
7 SOI Ti	T 001:15:25:29.000	DR =-8.0 = =	DH =0.2 = =	= = =
8 SOR	DT 000:01:16:54.000	CXYZ=-.1481 = =	CXYZ=0.0 = =	CXYZ=0.2962 = =

**Figure 3.10.4.1-29: Plan B MCT, FD2 -> 3 Rndz; NC-1 & DOR TIGs Fixed**

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MANEUVER EVALUATION TABLE B23\_FIXED  
MCT : B23\_FIXED OVT : PLOTON

GMTR : 1998:153:22:09:05.000

VECTOR	TIME	COMMENT					
CHASER V5	M 000:00:10:33.000	POST-MPS DUMP In-plane - 1 minute					
TARGET V6	M 000:00:00:00.000	ELSET 285 at 6/2/98 Launch I.P. - 1 mi					
CHASER	DVtot = 338.75	DVx = 338.08	DVy = 1.59	DVz = 1.64			
TARGET	DVtot = 0.00	DVx = 0.00	DVy = 0.00	DVz = 0.00	8 MNVRS		

MNVR	NAME	GMTIG	IMP	DVx	HA	RANGE	Y
COMMENT	METIG	DVy	HP	PHASE	Ydot		
DVMag	DT	DVz	DH	Noon/Mid -	SR/SS -		
1	HA	153:22:53:24.236		80.82	174.29	4784.0613	-51716.9
OMS-2		000:00:44:19.236		0.00	88.92	82.3238	33.7
80.8		000:02:55:05.764		0.00	30.30	N-00:18:09	SS-00:48:50
2	NC	154:01:48:30.000		184.51	195.41	3687.9747	-31594.5
NC-1		000:03:39:25.000		0.00	166.30	60.9960	16.3
184.5		000:12:09:55.016		0.00	31.23	N-00:27:09	SS-00:57:49
3	NH	154:13:58:25.016		13.14	201.74	2255.8574	-15013.1
NC-2		000:15:49:20.016		0.00	167.89	36.1685	9.5
13.1		000:09:08:17.243		0.00	31.23	N-00:33:39	SR-00:03:01
4	EXDV	154:23:06:42.259		3.00	203.31	1317.1601	-7344.4
NC-3		001:00:57:37.259		0.00	168.04	20.8837	5.2
3.0		000:12:11:17.389		0.00	31.23	N-00:37:40	SR-00:07:17
5	EXDV	155:11:12:05.000		0.00	200.78	132.6918	309.0
DOR NH		001:13:03:00.000		0.00	173.98	2.0343	1.6
0.0		000:00:45:00.000		0.00	31.23	N-00:42:46	SR-00:12:39
6	NC	155:11:57:05.000		45.04	203.84	40.0659	-239.3
NC-4		001:13:48:00.000		0.00	192.34	0.6295	-1.1
45.0		000:01:37:29.000		0.00	0.34	N-00:03:38	SS-00:33:30
7	SOI	155:13:34:34.000		9.08	205.88	8.0010	-813.8
Ti		001:15:25:29.000		0.45	195.19	0.1257	-0.6
9.1		000:01:16:54.000		-0.09	0.20	M-00:44:11	SS-00:28:00
8	SOR	155:14:51:28.000		2.50	206.18	0.3291	3.7
		001:16:42:23.000		1.14	196.33	0.0023	0.0
3.2		000:00:00:00.000		1.55	0.30	N-00:13:19	SS-00:42:59

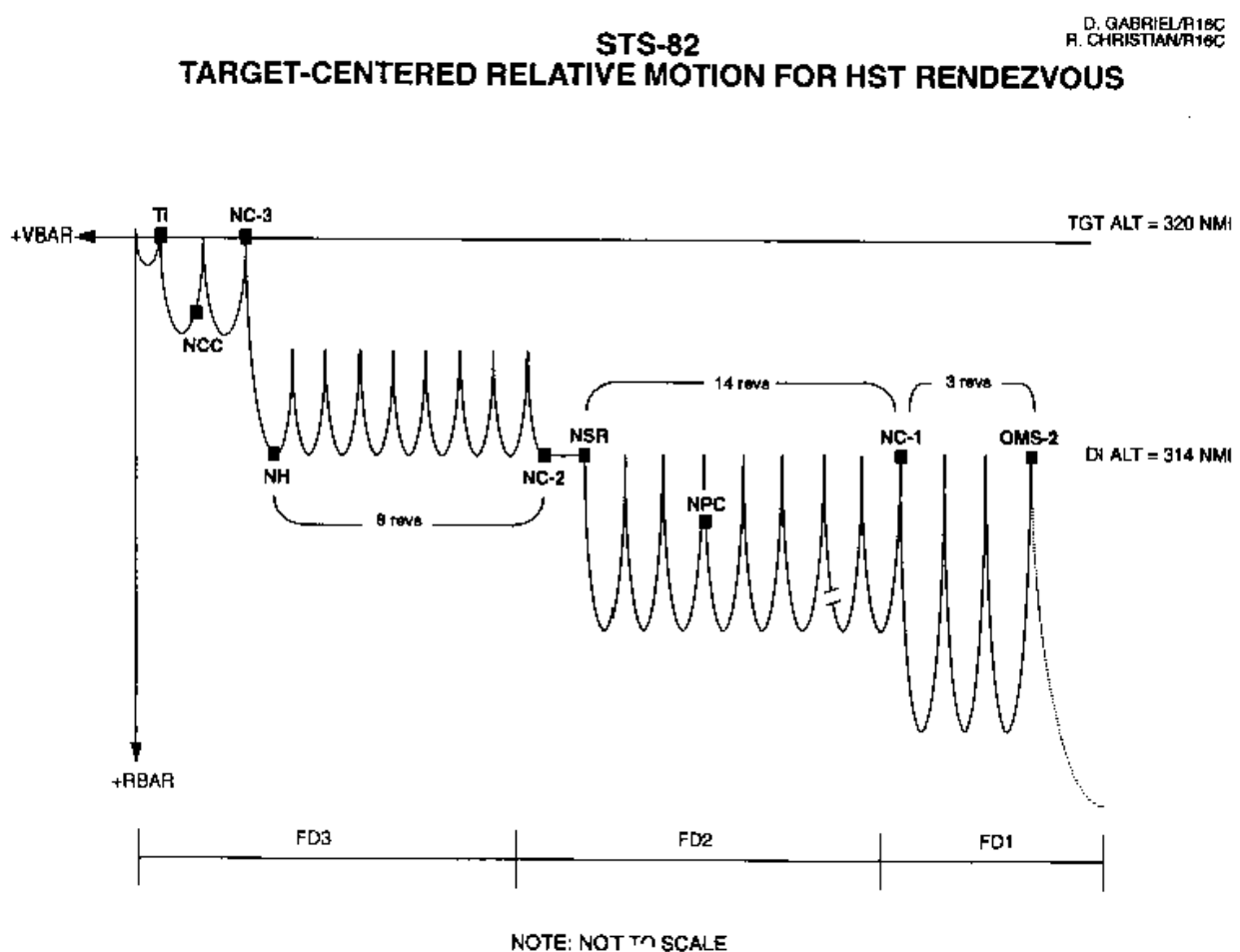
**Figure 3.10.4.1-30: Plan B MCT, FD2 -> 3 Rndz; NC-1 & DOR TIGs Fixed**

**CAUTION:** when transferring an iterated burn plan to a TrS or TSA ephemeris, failure to properly configure the MTT will re-introduce radial  $\Delta v$  at Ti. To guarantee TrS/TSA finite burn results are consistent with OMP impulsive burn modeling, the MTT impulsive flag must be set to *optimize* for all large OMS burns (except Ti). This will center the finite burn arc about the impulsive TIG, ensuring similar OMP iteration results are obtained on the TrS/TSA ephemeris.

In some cases it will not be possible to find a burn large enough to eliminate Ti radial  $\Delta v$  by moving its TIG. This is frequently the case for high altitude missions where MECO conditions do not allow sufficient "maneuvering room" to change the line of apsides. In this case launch time determines orientation of the line. For example, on STS-82 Hubble Space Telescope servicing mission #2, the insertion altitude was placed only 7

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nm below the target altitude in order to maximize post-MECO performance. This effectively fixed the maneuver line in space at an orientation dependent on launch time within the 1 hr launch window. Any attempt to move TIGs of subsequent burns to eliminate radial  $\Delta v$  at Ti had little effect on the pre-established maneuver line. Therefore to divorce Ti TIG placement from the post-insertion line of apsides, an NSR burn was inserted at relative apogee to place the Shuttle into a coelliptic orbit with HST. This appears as a horizontal line on a relative motion plot (see Figure 3.10.4.1-31). This profile allowed subsequent NC-2 TIG placement to be driven purely by *desired* location of line of apsides, which was in turn driven by the requirement that Ti occur at apogee with the desired lighting conditions. Although an extra burn had to be used in the profile, it minimized prop usage by eliminating radial  $\Delta v$  at Ti. Other missions may also require an NSR burn to be included if iteration steps are unsuccessful at removing radial  $\Delta v$  at Ti.



**Figure 3.10.4.1-31: STS-82 Coelliptic Rendezvous Plan**



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### 3.10.4.1.4 Planar Correction Burn

If an NPC (planar correction) has not already been included in a GUR burn plan, it should be added once TIGs have been fixed. Prior to this, the  $\Delta V_y$  solution for SOI and SOR indicate how much planar error is present. NPC can be placed in the profile wherever it is convenient from a crew timeline perspective (usually mid-day FD2), and where there is a quiet tracking arc for about two revs prior to the burn. In the constraints table, this burn should have a CN secondary constraint to force the OMP to place TIG on a common node where the orbit planes intercept<sup>14</sup>. A WEDG=0 secondary constraint is placed on SOI to specify when a zero wedge angle is desired. This is the *future time* that the planar error is desired to be nulled. OMP calculations will take into account differential nodal regression due to height difference between the target and chaser between when NPC is executed and when the WEDG constraint is specified so that planar error is nulled at the time that WEDG=0 is specified.

**WARNING:** failure to place a zero wedge angle secondary constraint on Ti will result in zero wedge angle being applied *at the NPC TIG* rather than Ti. In this case, differential nodal regression due to chaser-target height difference will re-introduce planar error to the profile, wasting propellant and possibly resulting in loss of mission.

As NPC TIG approaches, if the predicted  $\Delta v$  is below about 1-2 fps, it is appropriate to cancel the burn due to uncertainty in Ground NAV's planar solution. The star tracker pass on DOR will provide a more accurate planar solution, and it is smarter to wait until you have better data than burn a solution within the noise level of Ground NAV. If the star tracker pass confirms a 2 fps or so planar error, then the NCC solution will include a  $\Delta V_y$  component to force a common node at Ti, after which Ti will zero out the planar velocity error with its own  $\Delta V_y$  component. Since Ti is around 9 fps to start with, RSSing a 2 fps OOP component will not appreciably add to the total  $\Delta v$  (in this example Ti would grow to 9.2 fps).

In the case where NPC is required, sometimes it is possible to combine it with another burn in the rendezvous profile. Although console procedures are complicated, it is well worth the effort since, not only is a burn and associated attitude maneuvers eliminated, but propellant is saved by RSSing as described above. For example, a 10 fps NPC combined with a 90 fps NH results in a total  $\Delta v$  of 90.6 fps. Combining burns here saves 9.4 fps! Obviously, the biggest savings occur when NPC is combined with a much larger burn. Feasibility of combining burns is evaluated as follows: in the MCT, immediately after a candidate large burn, insert an NPC with primary constraint DT

---

<sup>14</sup> It is for this reason that including NPC in a *TIG-free* plan is somewhat inconvenient—the subsequent TIGs float with NPC since they are all tied together via the M (orbit) primary constraint. This means that burns post-NPC may be execute off-apsis. A workaround for this is to include an APS=1 secondary constraint on the burn following NPC in order to keep subsequent burns on apsis.

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(delta-time) of 1 sec, and secondary constraint CN. Don't forget to put a WEDGE secondary constraint on Ti. Run this, and in the MET check NPC  $\Delta v$  and the delta-time between it and the prior burn. Then copy the plan to another MCT, delete the NPC, and move the "big burn" TIG to the NPC common node time. The "big burn" should be input as an EXDV with  $DV_x=NC$  or NH solution from the previous run,  $DV_y=NPC$  solution from the previous run, and  $DV_z=0$ . Run this, then in the eval table, check Ti radial  $\Delta v$ , and if required, jump back into procedures in Section 3.10.4.1.3 to zero this out by moving the TIG of a different burn.

In our example plan, the biggest burn in the profile is maneuver 2, NC-1. However, we can't move NC-1 TIG to a common node since it's already placed to zero out Ti radial  $\Delta v$ . There are no other sufficiently large burns available to control Ti radial  $\Delta v$ , thus, NC-1 is not a good candidate for combining with NPC (unless, of course, a node happens to fall right on top of TIG—which is worth checking out). The next best burn to try would be maneuver 3, which is the NH. This is illustrated in Figure 3.10.4.1-32, which shows the NPC burn inserted just after NH with a DT of 1 sec. Since NH is a smaller burn, the payback from combining with NPC is less, but this also means the plan may be able to handle significant movement of the NH TIG without introducing radial  $\Delta v$  at Ti.

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LOCAL

MANEUVER CONSTRAINTS TABLE NPC

COMMENT: Plan B retarget to FD3 w/NPC - TIG fixed MODIFIED  
MNVRS: 9 / 40

MANEUVER	THRESHOLD	SECONDARIES			
1 HA OMS-2	T 000:00:20:00.000	HD =88 = =	APS =1 = =	= = =	= = =
2 NC NC-1	T 000:03:39:25.000	DV =100 = =	= = =	= = =	= = =
3 NH NC-2	T 000:15:49:20.000	= = =	= = =	= = =	= = =
4 NPC NPC	DT 000:00:00:01.000	CN = = =	= = =	= = =	= = =
5 EXDV NC-3	M 6.0	DVLV =3.0 = =	DVLV =0.0 = =	DVLV =0.0 = =	= = =
6 EXDV DOR NH	M 8.0	DVLV =0.0 = =	DVLV =0.0 = =	DVLV =0.0 = =	= = =
7 NC NC-4	T 005:17:48:00.000	DR =-40 = =	= = =	= = =	= = =
8 SOI Ti	T 001:15:25:29.000	DR =-8 = =	DH =0.2 = =	WEDG =0.0 = =	= = =
9 SOR	DT 000:01:16:54.000	CXYZ =-.1481 = =	CXYZ =0.0 = =	CXYZ =0.2962 = =	= = =

**Figure 3.10.4.1-32: Plan B MCT, FD2 -> 3 Rndz; NPC After NC-2**

Combining NPC with another burn is an exercise in trial-and-error. It may be necessary to try combining NPC with several different burns before an acceptable solution is found. Obviously, the more burns that are available in a rendezvous plan, the higher likelihood of being able to combine NPC and simultaneously eliminate  $T_i \Delta V_z$ . Thus it is important to identify *early on* whether NPC is required, and if so, to begin examining combination strategies. This process should be started soon after ascent when the orbit team takes over. If a satisfactory combination plan cannot be found, then a dedicated NPC burn will have to be included in the profile. Notify FAO. In this case, it may be useful to experiment with NULL secondary constraints on any large burns prior to NPC. This would zero out the current y-dot at burn execution, and while not eliminating the need for a subsequent NPC, might at least reduce its size.

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### 3.10.4.1.5 Iteration for Desired Downtrack/Height Position

Rendezvous planning is computationally intensive work where both accuracy *and* speed are important. To satisfy these conflicting requirements, OMP uses a fast propagator known as Analytic Ephemeris Generator, or AEG. As its name implies, AEG analytically propagates the orbital elements (using variation of parameters), rather than numerically integrating the trajectory. Higher order gravity terms through J4 are utilized, along with constant area drag. This technique results in reasonable accuracy with quick execution time. However, once an OMP plan is transferred to an ephemeris, differences do arise due to the higher-fidelity ENCKE propagator in the TrS (or Nystrom-Cowell propagator in TSA), and higher order gravity terms through J7 that are modeled in both of these propagators. The TrS typically models time-varying drag in the form of vents and attitude timeline entries, further exacerbating propagation differences. And finally, both the TrS and TSA use finite burn modeling (defined by the Maneuver Transfer Table) as opposed to simplified impulsive burns with OMP. The bottom line of all this is that, whenever an OMP plan is transferred to an ephemeris, the resulting profile may not quite meet all of the specified constraints (range, phase angle, height offset, etc). Therefore, in order to achieve desired post maneuver conditions, FDO must alter the MCT secondary constraints (or chaser area), run the plan, and transfer the plan to the ephemeris, repeating this until the desired accuracy is achieved in the DMT offsets.

AEG-ENCKE propagation differences are assessed on the TrS using the DMT displays. For example, in Figure 3.10.4.1-30 maneuver 6 is the DOR NC-4 burn at 40 nm. The MET shows the OMP was successful in meeting this range target. To evaluate how well it does with higher-fidelity ENCKE propagation, the plan must be transferred to an ephemeris, and the burn immediately prior to the maneuver of interest placed in the DMT (maneuver 5 in this case). Then the proper target ephemeris is selected using Sammi controls on the DMT. Orbiter/target curvilinear offsets in kilofeet are shown for the *next* maneuver (6 in our case) in the left hand side, halfway down. Note that the time of this maneuver is also shown. See Figure 3.10.4.1-33. The ephemeris-computed DX is -85.570 kft rather than the desired -243.040 kft. Therefore, the AEG needs to be calibrated so that the desired range target is achieved when propagated on the TrS. This can be done one of two ways.

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088		DMT NO. 1			
VEH EPH   1	TGT EPH   3	MNVR   5	EXECUTE	CANCEL	
----- PAD -----					
GMTI 192:05:47:27.0		I-PX2-P7-FC		GMTR 1998:190:16:44:27.0	
METI 001:13:03:00.0		TV ROLL 0.0		TIGT	
DVM 0.00 DTB 00:00.0		SYSP TRIMS P		OUTPUT MAT	CURI00
VXI 0.00 DVULL 0.00		LY			
VYI 0.00 DTULL 0:00.0		RY		OSTAID	L E1
VZI 0.00 DTRCS 0:00.0		WEIGHT 213000.0		GMTV	192:05:53:21.6
DVTO 0.00 DTT0 0.00		TIG 001/13:03:00.0		METV	001:13:08:54.6
INR LVLH		PEG 4 C1		COMMENT ORB 101	
P 90.0 P 90.0 YH -90.0		C2		TSTAID	
Y 0.0 Y 0.0 PH 90.0		HT		GMTV	
R 90.0 R 90.0 RH 0.0		GT		METV	
		PRPLT		COMMENT	
TGT VEH DATA		PEG 7 DVX +0000.0		FSTAID	
ELtig 46.49 Gb/o 0.6775		DVY +0000.0		GMTV	
DHb/o 41.63 Ob/o 0.0033		DVZ +0000.0		METV	
OFFSET MNVR 5 EPH 3		BURN ATT R 090			
MET 001:13:47:45.000		P 090		DWOMS	0.0
DT 000:00:45:00.000		Y 000		DWRCS	0.0
DX -85.570		DVTOT 0.0		WFNL	213000.0
DY 0.067		TGO 00:00		DW	0.0
DZ 1.277		VGO X 0.00		DV REMAIN	
		Y 0.00		PRI	SEC
HA 210.5 HP 168.2		Z 0.00			
LAN 028:29E Htig 169.8		TGT HA 211 HP 209		SITE	XR
zP 2.30 Vtig 29:52N				REI	
i 51.62 ltig 076:17E				VEI	
e 0.00134 htig 335.8		INTO UNTIL		cEI	
a 3654.8				METEI	

**Figure 3.10.4.1-33: DMT for DOR NH Placeholder Showing NC-4 Offsets**

**Area Method** - Early in the rendezvous, when chaser altitude is relatively low, it is convenient to iterate on the chaser area in OMP Execute menu. Doing this changes the average chaser drag amount in the OMP such that a match with the average ephemeris drag level can be achieved. The direction of area change can be determined as follows: if the actual downtrack position on the DMT was behind the aimpoint LVLH-wise, then it will be necessary to model less drag with AEG to match what the TrS is seeing, so decrease the area. Do the opposite if the actual downtrack position was in front of the desired position. Make the area change, re-run the OMP, and re-transfer the plan to the ephemeris. Then compare the DMT offsets again and repeat the process until an acceptable miss distance is achieved. A table of results can be built to improve the area guess, as shown in Table 3.10.4.1-1. The area method is good for plans covering multiple days. The iterated ephemeris area incorporates the effects of TrS vents, ATL, and propagator differences into the rendezvous plan. Any changes to these quantities will necessitate an update to chaser area in OMP. In fact, every time OMP is run in real-time, DMT offsets should be verified and area tweaked correspondingly. The main drawback to this method is that it is not effective at high altitudes (above  $\approx 200$  nm), since there's so little drag to work with. The primary advantage, however, is that MET range output will agree closely with the DMT offsets, since no secondary constraints were changed during iteration. In other words, the MCT secondary constraints remain intact and "make sense". The next method, as you shall see, does not preserve either the MCT secondaries or the MET output ranges.

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**Table 3.10.4.1-1: Example of Downtrack Iterations**

Area	DMT DX	Desired DX
2750	-85.570	-243.040
4500	-251.780	
4410	-242.870	

$$\text{Trade Factor} = \frac{DX_1 - DX_2}{\text{Area}_1 - \text{Area}_2} = \frac{-85.57 - (-251.78)}{2750 - 4500} = -0.095 \text{ kft/ft}^2$$

$$\text{New area} = \text{last area} + (DX_{\text{tgt}} - DX_{\text{last}}) / \text{T.F.} = 4500 + (-243.04 - (-251.78)) / -0.095 = 4408$$

**Secondary Constraint Method** - As its name implies, this method involves alteration of the secondary constraints that OMP is using in order to achieve the desired offsets in the ephemeris. It is useful when area iterations alone are not sufficient to provide accurate offsets, or when multiple maneuvers must be fixed. Downrange distance DX on the DMT is controlled by DR or CXYZ with OMP. This method can also be used to improve an NH solution when Delta Height, DH, is iterated to control height offset DZ on the DMT. The iteration algorithm can be generally stated as (assuming consistent units):

$$\text{New constraint} = \text{Old constraint} + \text{error} = \text{Old constraint} + (\text{desired value} - \text{actual value})$$

For example, a typical NC-4 maneuver targets a DX offset of -48.600 kilofeet at SOI using DR = -8 secondary. When the plan is run and transferred to an ephemeris, the NC maneuver can be viewed in a DMT, and offsets will show the relative position for the next maneuver, SOI. If the DMT DX value is -54.000, then the ephemeris-predicted downtrack position is 5.4 kft behind the AEG-predicted position. Using the above formula, the new DR constraint for SOI becomes:

$$\text{New constraint} = -8.0 + (-48.600 - (-54.000)) / 6.076 = -7.1$$

This makes sense if thought of in terms of the AEG miss distance. In this example, the ephemeris result was 5.4 kft behind the aimpoint. Thus the OMP aimpoint must be biased forward by the same amount, so instead of shooting for 8 nm behind the target, the new aimpoint is biased toward the target by 5.400 kft. This type of iteration is typically used on DOR when the area method is not as responsive due to high altitude. A similar methodology can be employed to iterate on height offsets using DZ on the DMT and DH in the MCT.

MARS is responsible for OMP iterations in real-time, with FDO verifying results. RFDO will have to perform iterations during off-line planning whenever accurate relative states are desired in ephemerides. For example, when preparing DOR vectors for DT to use in generating simulation datastores it is necessary to iterate on relative offsets using R/T Relmo. This is to assure the training load comes up with NC-4 at 40 nm, Ti at 8 nm,

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etc. Regardless of the setting, the iteration process is ceased whenever the residual downtrack or height error results in a  $\Delta v$  change of less than 0.05 fps. This corresponds to onboard MNVR EXEC's single decimal place precision in the PEG-7  $\Delta v$  fields. Since the crew has no insight into  $\Delta v$  changes below this threshold, it is unproductive to iterate beyond this point. However, since an NC-1  $\Delta v$  uncertainty of 0.05 fps results in a downtrack uncertainty of about 3 nm at  $T_i$ , this criteria alone is insufficient. (A downtrack error of this magnitude is undesirable when generating DOR relative motion plots). An additional success criteria therefore is specified where downtrack error < 0.5 nm must always be assured. These guidelines have been transformed to DX and DZ constraints, and are summarized below in Table 3.10.4.1-2.

**Table 3.10.4.1-2: Rndz Burn Iteration Success Criteria**

Goal: Halt iteration when  $\Delta v$  changes by < 0.05 fps  
or when downtrack error > 0.5 nm

Transfer Time (revs)	Iterate downtrack error to within $\pm$ (kft)
>3	3.0
3	2.3
2	1.5
1	0.7

Always iterate DZ to within  $\pm 0.2$  kft

This concludes the section on rendezvous plan generation and optimization. Once the plan is finalized, a labeled MET copy should be provided to PROP in order to keep him or her apprised of  $\Delta v$  cost of each of the burns for budgeting and thruster selection. The Rendezvous GPO should also be given a copy, with  $T_i$  time noted. At this point, RGPO may access ephemeris PSAT data to determine lighting and groundstation events during the rendezvous.

### 3.10.4.1.6 Pre-DOR Planning Team Duties

Several important tasks must be performed by the planning team before the execute team takes over on DOR to perform the rendezvous. These principally involve preparation of MCC data products and verification of trajectory processor configuration. The tasks are as follows.

- 1) Final rendezvous plan iteration - Obtain the latest and greatest state vector from Ground NAV after any pre-sleep perturbative activities have been tracked out. Verify TrS VTL and ATL configuration. Run the DOR burn plan and verify  $T_i$  position and lighting are correct, and eliminate any  $T_i$  radial  $\Delta v$  (< 1 fps). Don't update  $T_i$  TIG for lighting changes smaller than about 30 seconds. Try to maintain

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at least 3 min from the final NC burn TIG until orbital noon in order to avoid interfering with the pre-Ti ST pass (this applies only to rendezvous from behind on a one-rev to Ti profile); check with RGPO if it is difficult to maintain this. Determine whether a DOR NH burn is likely to be required, if so include it with preliminary PADs prepared below.

- 2) Rendezvous Constraint Tables - MARS will prepare all necessary DOR RCTs based on standard templates. TIGs and/or secondary constraints should be updated as appropriate (based on item 1 above). FDO will independently verify the tables, including Lambert secondary constraints which should be checked against the Rendezvous Checklist reference data ILOADs table.
- 3) Maneuver Transfer Tables - MARS will pre-configure the MTT for each plan generated above. All DOR Lambert burns should have the impulsive flag set to "IMP" in order to keep TIGs constant with the onboard. Since Lambert TIGs are referenced to a basetime (Ti, then MC-2), the ground TIGs should be kept fixed to avoid getting the ground and onboard times out of synch. The impulsive flag should be set to "OPT" for all other burns. The iterate option should be set to NO when manually iterating on a rendezvous profile. On a GUR rendezvous profile from behind, TVR for all posigrade DOR burns should be 0 in order to provide an approximate 90 deg pitch maneuver from -Z target track to burn attitude and back. This helps minimize prop usage and maneuver time. (If the -Z ST is failed, then the -Y ST will be used for the first ST pass following NC, so set TVR=90 for posigrade NH and NC. Unless the RR is also broken, the Orbiter will return to the -Z target track attitude following NCC, so stick with TVR=0 for posigrade Ti). For Ti, OMS-L is the preferred thruster for posigrade burns in order to keep the radar locked onto the target throughout the burn, but verify all thruster selections with your PROP Officer.
- 4) MET and state vectors to external customers - Deliver any required data to external customers as documented in the flight rules and/or Joint Operations Integrated Procedures (JOIP). For example, send TOPO a copy of the final iterated MET and post-burn vectors.
- 5) TIGs Flight Note - Using the iterated rendezvous plan, TRAJ should generate a TIG Flight Note on TSA Rendezvous Maneuver Monitor (RMM) application. This should list all planned burns for DOR, and should be distributed to the flight control team and uplinked to the crew. Include a placeholder for NH with the notation "if required" if there is any doubt as to whether NH will be performed or not. Also include the planned docking time, which can be obtained from RGPO. In addition, a single copy "throw-down" TIG flight note should be generated for a one-rev late rendezvous, starting at Ti delay. This will aid FDO in updating RCTs for the one-rev late scenario should this arise. Keep this flight note separate from the nominal



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TIGs note to avoid confusion. See Section 3.10.4.2.8 for further details on how to do this.

- 6) Tracking Plan - Review DOR tracking plan with NAV. Be sure that appropriate ground radar support is scheduled and assigned. Review the updated Flight Plan and look for any perturbing events that may have crept into the timeline. If necessary, request that FAO move or eliminate offending activities to minimize trajectory perturbations.
- 7) Relmo - Have Profile Support prepare a DOR relative motion plot for uplink to the crew with the morning mail. Note burns as well as crew wakeup on the plot.
- 8) Predicted burnout vectors to USSPACECOM - After an up-to-date ground NAV vector has been used to anchor the ephemeris, and the final rendezvous plan has been iterated, TRAJ should send predicted post-burn vectors to USSPACECOM. Send vectors for all major burns (NC, NH, Ti), as well as a target vector epoched at approximately Ti time to "screen" the arrival space. These should be sent early enough so that results can be obtained in time for the execute team to have sufficient time to act upon it.
- 9) Preliminary Maneuver PADs - PADs for should be prepared using the final iterated rendezvous plan, including all ground targeted burns plus Ti. The PADs should include all standard inputs except Notes and TIG slip information, which the crew will expect with the final PAD (if prompted by PROP, GNC, or Rendezvous, it is permissible to provide early "heads-up" systems information on the preliminary PAD, but be sure and fill in *all* notes completely on the final PAD). The preliminary PADs should be uplinked to the crew with the morning Execute Package to provide (a) capability to perform burns in a loss of comm situation, and (b) "heads-up" on burn  $\Delta v$ , thruster selection, etc. In the event of loss of comm, having the preliminary PADs onboard is an implied "go" for the burn using the preliminary solution for ground-computed burns. Figure 3.10.4.1-34 shows a preliminary Ti PAD generated using the Auto-Maneuver PAD (AMP) application.
- 10) Check communication with TDRS to determine if any DOR maneuvers are near the ZOE. If so, the RFDO can be alerted to put PADs and/or command loads onboard at an earlier time than would otherwise be the case.

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**Figure 3.10.4.1-34: Preliminary Ti PAD**

- 11) Ephemeris Config - Set up the ephemerides as specified by the Rendezvous FDO. The standard config is documented in Table 3.10.4.2-1. The prime maneuver plan should be in ephemeris 1 so that the ignition clock and acquisition data are correct.
- 12) Re-boot workstations - At the end of the Planning Team shift, reboot both FDO and TRAJ workstations (one at a time!) to reduce the likelihood of workstation problems for the oncoming team.
- 13) PET Clock - A global count-down/count-up clock should be configured counting down to Ti (PET=0). This is for use in keeping up with crew activities in the Rendezvous Checklist. This clock should be displayed on the front timer display along with the burn ignition clock from ephemeris 1.

The above-list is presented in checklist form in Section 3.10.4.2.12.1. Other standard planning team tasks should be performed as well, such as RADAR message, PADJ

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runs (more than one may be required if the DOR profile includes big burns such that tank fail capability is altered), standard mission summary message, and updated current mass properties just before handover.

### **3.10.4.2 Nominal Rendezvous Operations**

The following sections detail console operations on a nominal rendezvous flight day.

#### **3.10.4.2.1 Console Setup**

Once handover from planning team to the execute team is finished, all of the above tasks should be complete<sup>15</sup>. A thorough handover briefing is essential to review what's been done, plus any unfinished work that must be closed out by the execute team prior to the start of rendezvous. Once handover is complete, RFDO should confirm proper ephemeris config (vents, weights, area, integration options, etc). Ground ephemerides are normally configured per Table 3.10.4.2-1 below. The nominal rendezvous plan should be verified by having MARS re-run it. If the plan needs more tweaking and tuning, repeat any necessary steps from Section 3.10.4.1. Also make sure required data and tools are available on console (FDF, calculator, etc). A console checklist is provided in Section 3.10.4.2.12.3 that concisely lists each of these pre-rendezvous activities, as well as summarizes the real time steps that will be discussed in detail below. The remainder of this section will cover rendezvous execution procedures assuming a typical one-rev to Ti ground-up rendezvous from behind, using actual STS-110 DOR constraints tables as examples. These MCTs were built from the same standard templates that MARS utilizes to support sims and missions. These are intended to be a general guide on how to configure DOR constraints tables, not "gospel". Flight specific MCT content is always up to the RFDO and MARS on-console (however, MARS should not depart from the standard without first gaining FDO's concurrence). It is customary to name each plan after the upcoming burn that is being targeted. FDO functions during DOR will be presented first in this section, followed by a separate section on TRAJ, MARS, and Profile Support responsibilities.

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<sup>15</sup> If working a rendezvous integrated simulation, the rendezvous team must complete preceding tasks prior to sim start. The team should therefore be on console at least 1.5 hrs prior to sim start time.

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**Table 3.10.4.2-1: Standard Rendezvous Ephemeris Configuration**

Eph #	Contents	Anchor	Intgr Option	PSAT STDN	Length (hrs)	Golden?
1	Short term Orbiter	V39	VAM	Y	48	Y
2	Long term Orbiter	<24 hrs old	VAM	N	thru EOM+2	Y
3	Prime target	V38	DM	Y	48	Y
4	Secondary P/L, debris	as req'd	DM	N	as req'd	Y/N
5	O/B Orbiter	V56	VAM	N	12	Y
6	O/B target	V54	DM	N	12	Y
7	Rndz planning*	V39	VAM	N	12	N
8	Rndz cont. planning†	V39	VAM	N	48	N

\*Prime MARS planning ephemeris

†Prime Profile Support planning ephemeris

### 3.10.4.2.2 Navigation

The navigation philosophy for rendezvous is to go into any maneuver with the best possible state vector, especially on the night before and the day of rendezvous. Typically, *FDO will update the ground ephemeris on every state vector NAV thinks is better than the ephemeris 1 anchor.* Every additional tracking site provides more data to the ground's knowledge and should be used, even if it is the first pass after a maneuver. After the onboard state has been updated and RELNAV enabled, the FDO is not so much concerned with position error because it usually remains small assuming frequent ephemeris updates (around 500 feet). FDO is more concerned with energy error, since this directly affects the ability to predict the Orbiter's future position. Energy error appears as a difference in semi-major axis on the Vector Compare display, and governs the rate of increase of downtrack position error. A rough rule of thumb for estimating the downtrack error per revolution is to multiply the indicated semi-major axis error by -10.

OMP provides the ability to target burns off ground or onboard vectors. All burns prior to the first onboard sensor pass must be targeted using ground vectors. Once valid sensor data is available, it makes sense to target burns (e.g. Ti Delay) with onboard vectors since usually the onboard will have a more accurate relative state than the ground. Exceptions to this are NCC ground and Ti ground solutions targeted with ground vectors for use as a comparison with the onboard solution in the absence of RELNAV sensor data.

The onboard nav state must be as accurate as possible prior to the start of rendezvous. The standard procedure is to uplink an Orbiter/target state vector pair using the latest Ground NAV solution about the time the crew enters the Rendezvous Checklist. That way a target vector will be available to PASS when RELNAV is enabled, since a target vector less than 15 hrs from current time must be resident in the GNC GPC in order for RELNAV to be enabled. *This state vector uplink is extremely important since it sets up*

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*the initial Orbiter-target relative navigation state that will be used for sensor acquisition and filtering.* This is another reason for minimizing perturbations prior to the start of rendezvous activities so that the most accurate relative state may be uplinked. Of nearly equal importance to these uplinks is the target Kfactor used to accurately scale onboard target drag acceleration modeling. Ideally, this uplink is also performed prior to enabling RELNAV (see Section 3.10.1.9.2).

Ground versus onboard vector differences, as well as Orbiter-target relative position can be monitored in real-time using TSA R/T Relmo. TrS ephemerides 1 and 3 should be used to drive the ground curve. Just after RELNAV enable, the filter and prop bugs can be displayed. Initially, they will both be coincident with the ground curve. Then as the first sensor pass progresses, the filter bug may move away from the ground and prop bugs. The magnitude of position difference shows the difference between the filter and prop, as well as filter and ground relative state. Predictor bugs can also be enabled for the filter to show the predicted position up to 1 rev in the future in 4 min increments. R/T RELMO is an important situational awareness tool that provides a large amount of relative motion and navigation information "at a glance". It is the equivalent of an aircraft window to a pilot. Profile Support should work with GC to display a R/T RELMO video stream on the right front big screen of the MCC to maintain good FCT situational awareness.

### 3.10.4.2.3 NH

If a height adjust maneuver (NH) is required on DOR, it is typically the first burn of the day. Recall that an NH may be required either due to large phase angle (i.e. DOR NH was planned from the beginning to make the phasing plan work), or navigation updates. The STS-91 example above included an NH burn on FD2 so that FD3 DOR NH should not normally be required. However, large navigation updates introducing height error at Ti could cause a DOR NH burn to have to be re-inserted into the profile. For this reason, a "placeholder" NH burn is carried on DOR plans even when it is not expected to be required. NH TIG is normally planned for 0.5 rev before the final phasing burn (NC) for a one-rev transfer to Ti. For a two-rev transfer, NH is placed 0.5 rev *after* the final NC burn since this provides a half-rev relief for the crew prior to the first burn of the day. Regardless of its exact placement, Rendezvous FDO must either prepare for a nominal NH that will definitely be performed, or determine if a placeholder NH must be executed. If NH is required due to phasing constraints, then targeting the burn is rather straightforward<sup>16</sup>. For smaller phase angles where NH may or may not be required, several steps must be taken to make the final determination.

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<sup>16</sup> A good rule of thumb is that a DOR NH will be required for OMS-2 phase angles > 320 deg for a typical ISS rendezvous (122 nm DI with ISS at 210 nm).

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A good estimate of height error in the rendezvous profile can be found on the MET by looking under the DH column for SOI. The desired value is +0.2 nm for 1200 ft below the target. The DMT DZ offset offers the best indication of height error; in this case the units are kilofeet, and the desired value is +1.200. Any height error not fixed with an NH burn must be corrected by the NCC maneuver, which is a Lambert burn that targets  $T_i$  position in all three axes—downtrack (8 nm behind the target), wedge angle with the target plane (0 deg), and height (1200 ft below the target). Since NCC is performed 225 deg before  $T_i$ , it is not in an optimum position for controlling height. NCC burn targets will contain radial and/or downtrack  $\Delta v$  in order to simultaneously satisfy downtrack and height constraints. Excessive height error in the profile will drive up the cost of NCC. Flight rule A2-121 directs the crew to maneuver to burn attitude for any rendezvous burn (prior to and including  $T_i$ ) that is targeted to use more than 2 fps from the forward RCS. The intent of this Flight Rule is to preserve forward RCS propellant for manual phase and subsequent deploy or undocking. An attitude maneuver for NCC is highly undesirable, because up to two sensor passes may have been incorporated into the nav filter state by this time. Perturbations introduced by the attitude maneuver would not be incorporated into the nav state in time for NCC to correct them, because the maneuver would occur *after* the last sensor pass. Therefore, the relative state between the chaser and target would not be as good as if there had been no attitude maneuver. As a result, NCC would be performed without knowledge of the perturbations due to the attitude maneuver, and the desired offsets at  $T_i$  would not necessarily be achieved. Post-burn, the maneuver back to target track attitude may cause further dispersions in the relative state. If no additional sensor data is acquired before  $T_i$ , then it would also be computed on a degraded relative state vector, further compounding the problem. Thus when the choice is between performing an NCC that requires an attitude maneuver, or inserting an NH earlier into the profile to avoid the NCC attitude maneuver, the decision is usually made in favor of performing NH.

In addition to the concern of maneuvering for NCC, propellant-critical missions may dictate performing NH if doing so will reduce the total  $\Delta v$  cost of the rendezvous. That is, if it is cheaper to perform an NH and subsequently smaller NCC, than it is to perform a larger NCC alone, then the NH/NCC option may be chosen to save propellant. This scenario is usually encountered with high altitude rendezvous flights like the Hubble Space Telescope servicing missions where the Shuttle is at the edge of its performance capability and prop margins are small or negative.

An example NH constraints table is shown in Figure 3.10.4.2-1. Note that SOI and SOR secondary constraints have been iterated to accurately hit  $T_i$  and MC-4 positions. To evaluate the need for a dedicated NH, first check with Ground NAV to see if any state vector updates for the Orbiter or target are available. The first onboard sensor pass will not have occurred yet for a one-rev to  $T_i$  GUR profile, so have MARS run the NH plan off ground vectors. Now note the NH and NC  $\Delta v$  values. NCC is not modeled in this plan since NH is already targeting height and NC is targeting downtrack at  $T_i$  (NCC in-plane  $\Delta v$  would be 0 fps in this plan; the only additional piece of information an NCC

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plan would add would be the out-of-plane  $\Delta v$ , which is not of concern yet since you can get an idea of the planar error by looking at  $\Delta V_y$  for SOI and SOR). Next have MARS run plan NC4, which has the upcoming NC burn, plus *NCC modeled as an NH* for height control<sup>17</sup> (Figure 3.10.4.2-2). Again, a Lambert NCC is not specifically targeted, so planar solution will not be available, but in this "apples to apples" comparison, it will be possible to compare height control performed at the NH position for the first plan, versus height control at the NCC position for the second plan. A direct comparison between the plans may be made using a table such as follows.

1) Target NH w/NCC not modeled: Run NH

DVtot	DVx	DVy	DVz	Burn
				NH
				NC

2) Check NCC without NH: Run NC4 (\*w/NCC modeled as NH)

DVtot	DVx	DVy	DVz	Burn
				NC
				NCC*

```

LOCAL                MANEUVER CONSTRAINTS TABLE NH
COMMENT: (null)
CURRENT
MNVRS:  4 / 40
-----
| MANEUVER | THRESHOLD | SECONDARIES |
|-----|-----|-----|
| 1 NH | T | = = = |
| NH | 001:14:45:04.000 | = = = |
|-----|-----|-----|
| 2 NC | T | = = = |
| NC-4 | 001:15:28:17.000 | = = = |
|-----|-----|-----|
| 3 SOI | T | DR ==-8.4 DH =0.135 |
| Ti | 001:17:01:19.000 | = = = |
|-----|-----|-----|
| 4 SOR | DT | CXYZ ==-0.8980 CXYZ =0.0 CXYZ =0.2401 |
| MC-4 | 000:01:16:54.000 | = = = |
|-----|-----|-----|

```

**Figure 3.10.4.2-1: DOR NH Targeting**

<sup>17</sup> Here NCC cannot be explicitly modeled in the plan since NC is targeting SOI range for 8 nm. NCC, if included in the MCT, would also be targeting this range for SOI. The OMP generally does not allow two or more maneuvers to target the same secondary constraint on a subsequent maneuver (SOM is an exception for Lambert burns).

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LOCAL

MANEUVER CONSTRAINTS TABLE NC4

COMMENT: (null)

CURRENT  
MNVRS: 4 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 NC NC-4	T 001:15:28:17.000	=	=	=
2 NH NCC	T 001:16:03:37.000	=	=	=
3 SOI Ti	T 001:17:01:19.000	DR ==-8.2	DH =0.2	=
4 SOR MC-4	DT 000:01:16:54.000	CXYZ ==-.51687	CXYZ =0.0	CXYZ =.29624

**Figure 3.10.4.2-2: NC Targeting**

Using the results from NC4 plan, TRAJ should compute the body VGOs for NCC and pass these to PROP. If the FRCS usage is above 2 fps, then NH will usually be performed to avoid the attitude maneuver for NCC. Or, if propellant margins are low, the NH plan may be elected if it saves overall  $\Delta v$ . The determination should be made between FDO, PROP, and RGPO as to the proper course of action. If NH is to be executed, that plan should be transferred to the ephemeris, then plan NCC run to check that NH did its job. When plan NCC is run, be sure MARS uses a fetch time that is after *both* NH and NC so the  $\Delta v$  comes out reasonable (should be close to 0 fps in-plane if NH and NC are working correctly).

In the Maneuver Transfer Table, NH TIG should be optimized to "split the TIG" since it's not a Lambert burn. TVR should be set to 0 for posigrade burns from behind. Once the plan is transferred, check the DMT relative offsets for SOI and SOR, and verify good Ti lighting and radial  $\Delta v < 1$  fps. MARS will iterate as necessary to correct these items. After targeting is complete, build a PEG7 target command load and have TRAJ prepare the maneuver PAD. If the crew already has a preliminary PAD for NH onboard, then have TRAJ include only changes from the preliminary PAD on the final PAD. All of this must be complete prior to the time in the Rendezvous Checklist where MCC uplink of final NH PAD & targets is noted (typically TIG minus 30-40 min). If PADs will be late for any reason (e.g. more time is needed to process late tracking data), the FD should be informed ASAP.

If DOR NH was designed into the profile due to a large phase angle at launch, then it's probably going to be a critical burn with little TIG slip capability. In this case it's paramount that FDO have the burn PAD and targets ready on-time, and assure that the crew loads the targets and begins the maneuver to burn attitude on schedule. Also, Profile Support should have TIG slip analysis results ready in time to be included on the PAD (more on this in Section 3.10.4.2.9). Try to bump up PAD delivery time if a ZOE or



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period of ratty comm is expected at the normal PAD read-up time. Regardless of criticality, CAPCOM should read all *changed* items on a final PAD (noted with a box on Auto-Maneuver PAD (AMP)), as opposed to "blue box" items on a standard PAD. This is to prevent confusion on stale versus updated data. Standard burn execution and monitoring procedures should be used for NH. Like all rendezvous burns (pre-DOR and DOR), the VGOs should be trimmed to  $\pm 0.2$  fps. If NC is to be executed  $\_$  rev later, the Rendezvous Checklist will direct the crew to select DAP LVLH post-burn in order to stay in a nose forward, heads up attitude. NC will also be executed heads-up (TVR=0), so this step will eliminate an unnecessary attitude maneuver<sup>18</sup>. After NC, a simple 90 deg pitch maneuver will be all that's required to get into a -Z target track attitude for the star tracker pass.

### 3.10.4.2.4 NC and 1<sup>st</sup> Star Tracker Pass

Following NH, or the decision that NH is not required, NC will be the next burn on a typical one-rev to Ti GUR profile. For a mission with a large phase angle at launch, rapid closing rate at NC will make this a critical burn with little TIG slip capability. In this case it's paramount that FDO have the burn PAD and targets ready on-time, and assure that the crew loads the targets and begins the maneuver to burn attitude on schedule. NC is usually targeted with an MCT as shown above in Figure 3.10.4.2-2. A ground vector update should be performed if available, and the plan run off ground vectors. If NH has just been executed, make sure it is confirmed in the ephemeris before targeting NC. Transfer the resultant plan to the ephemeris, making sure the MTT is configured for TVR=0 (assuming posigrade NC from behind and operational -Z ST), and the optimize flag=OPT. After the plan is transferred, verify good offsets for SOI and SOR in the DMT. Iterate on either vehicle area or secondary offsets to achieve the desired range and height (the planning team should already have done this; Figure 3.10.4.2-2 has been iterated). Also check to make sure  $\Delta V_z$  at Ti is less than 1 fps—significant vector updates could introduce radial component even if the planning team had eliminated it previously. If there is excessive radial  $\Delta v$ , move NC TIG to eliminate it, as described in Section 3.10.4.1.2. Be careful not to move NC TIG later in time such that it interferes with the post-burn ST pass; consult with RGPO if necessary. When targeting is complete, display the burn in a DMT, build the PEG 7 command load and have TRAJ prepare a final burn PAD. Profile Support should provide TIG slip capability for the PAD if NC is a critical burn. Use standard burn execution/confirmation procedures.

Post-burn, it is imperative that the crew immediately begins the maneuver from burn attitude to target track attitude in order to be in the proper position for the first star tracker pass. If NC TIG is NLT 3 minutes before noon, then a 0.5 deg/sec maneuver

---

<sup>18</sup> This assumes both NH and NC will be executed with the +X RCS or OMS. If FRCS will be used for either of these burns, then DAP INRTL should be selected post-NH in order to perform a "free" 180 deg flip prior to the next burn.

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rate should get the Orbiter into attitude by orbital noon, which is the beginning of the ST pass. For a typical GUR, this will be the first and only sensor pass prior to NCC, since range is too great at this point for the RR. Since the purpose of NCC is to correct the predicted Ti position, it is very important to get a valid sensor pass in prior to the burn, otherwise the NCC solution is only as good as the current ground nav solution. Beware systems failures during or after NC, such as post-burn gimbal checks or other propulsion system anomalies, which could distract the crew and ground team and delay the maneuver to ST attitude. If possible, initiate the attitude maneuver prior to, or in parallel with, trouble-shooting steps. While assuring a successful sensor pass is primarily a RGPO responsibility, FDO should be cognizant of the timeline pressures, and be willing to speak to RGPO and/or Flight if necessary to assure a successful sensor pass so that the trajectory stays on track.

As the ST pass begins, ONAV will notify FDO that downlisted chaser/target state vector snapshots have been initiated in TrS V1/2, V3/4, and V5/6. These snaps will continue in cyclic fashion at periodic intervals throughout RELNAV's ST and RR passes. The VAT then serves as an uplinkable archive should RELNAV become degraded beyond the capability of simple recovery procedures such as a PROP-to-FILT state vector transfer (see Section 3.10.4.3.2). After the crew enters manual phase, FDO can expect a call from ONAV indicating snapshots have ceased.

Once the ST has detected an object ("DET" on Rndz ONAV Status), the RGPO team will monitor the residuals, which are nav predicted minus measured angles from the ST. These residuals can also be found on Rndz ONAV Status. Large residuals or rapidly changing angles indicate the ST has locked onto a star or possibly a piece of co-orbiting debris rather than the target. Alternately, if residuals are small, this indicates the ST has probably locked onto the target. At this point the crew will AUTO the angles, which allows the filter state vector to be updated based on ST angle measurements. Keep in mind during all sensor passes that the *Orbiter filter* vector is being updated, not the target. The rationale for this is that target spacecraft are expected to remain stable, whereas the Orbiter is performing attitude maneuvers, burns, venting, etc, therefore it makes more sense to assume that measurement residuals apply to the Orbiter position rather than the well-tracked out target. Refer to a Rendezvous Checklist to see the actual crew procedures for performing a star tracker pass.

At the beginning of a ST pass (or RR pass for that matter), an important parameter to note is the 1<sup>st</sup> state vector update to the filter based on the incoming sensor data (U/D on Rndz ONAV Status). The size of the update gives FDO an immediate indication of the difference between ground and onboard nav. After about 40 marks (5.3 min since ST data comes in at 1 mark every other nav cycle, or 1 mark/8 sec), the filter vector will normally stabilize to a fairly constant offset from the prop position (FLTR-PROP column on Rndz ONAV Status). TSA R/T Relmo FILT and PROP bugs can be turned on to graphically display this offset in curvilinear coordinates. The difference between the ground bug (an Orbiter symbol) and the FILT bug (an F) is the ground-FILT difference,

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from which radial and downtrack components can be "eye-balled" from the plot (assuming in-plane motion is being displayed). During the actual ST pass, FDO should monitor RGPO's backroom loop, MPSR DYN-B, to be aware of the general health of the sensor pass.

As mentioned above, 40 marks is the rule-of-thumb frequently used to specify the minimum number of ST marks required to converge the nav state, but in reality the solution may not completely converge until later. Cross-track (out-of-plane) is the quickest component to converge, followed by line-of-sight (mostly downtrack), and in-plane normal (mostly radial). Of all the sensors, the ST provides the best estimate of planar error between the target and chaser. It is also useful for downtrack error, but to a lesser degree. Downtrack and energy errors are more difficult to measure with the ST since angles are being used to determine range via triangulation. It requires some variation in target elevation (i.e. delta-height) over time in order to get a converged range solution with the ST. In other words, if the Orbiter were coelliptic on the target's minus  $V_{bar}$  at some fixed range, there would be no change in the Orbiter pitch angle required to keep the target centered in the ST FOV during the pass. This would provide no useful range information—only planar. Typical rendezvous profiles do provide sufficient elevation variation to get a fair range solution. The usual signature seen during ST passes is for an excessive downtrack position update to creep in early while the Orbiter is close to the target's minus  $V_{bar}$ . As the pass continues and the Orbiter falls below the  $V_{bar}$ , the FILT downtrack position moves back towards the Ground NAV estimate. For shallow ST passes (little elevation change), regard with suspicion large downtrack updates, especially if Ground NAV disagrees with the onboard results.

### 3.10.4.2.5 NCC

As stated previously, NCC is an important trajectory correction burn during rendezvous. It provides a chance to fix prior perturbations and assure  $T_i$  occurs at the right position relative to the target. In fact, NCC simultaneously corrects downtrack, radial, and planar position at  $T_i$ . It is the first "onboard targeted" burn where FDO's ground solution is not prime. In spite of this, there are several important supporting tasks for FDO to do during NCC timeframe.

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LOCAL

MANEUVER CONSTRAINTS TABLE NCC

COMMENT: (null)

CURRENT

MNVRS: 3 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 NCC NCC	T 001:16:03:37.000	=	=	=
2 SOI Ti	T 001:17:01:19.000	DR ==-8.0	DH =0.2	WEDG =0
3 SOR MC-4	DT 000:01:16:54.000	CXYZ ==-.14812	CXYZ =0.0	CXYZ =.29624

**Figure 3.10.4.2-3: NCC Targeting**

Figure 3.10.4.2-3 shows a typical NCC constraints table with NCC modeled as a true 3-axis Lambert burn. Immediately following execution of the NC burn, MARS runs this plan with onboard filter (V56) and target (V54) vectors. FDO should note the solution based on the onboards. After NC is confirmed in the ground ephemeris, NCC is evaluated using ground vectors. At this point (pre-ST pass) there should be good agreement between ground and onboard solutions, otherwise ground vector updates post-uplink are likely responsible for the differences. Once ST data starts coming in, NCC should be periodically re-targeted using onboard vectors. Planar error will manifest itself as a  $\Delta V_y$  component for NCC and SOI, while downtrack, energy, and height errors will be corrected with NCC  $\Delta V_x$  and  $\Delta V_z$ . In parallel, the crew will perform onboard targeting of the NCC solution prior to and during the ST pass. These times are noted in the Rendezvous Checklist. Whenever the crew performs onboard targeting (as evidenced by SPEC 34 inputs on the front screen "scratchpad"), MARS will simultaneously re-target using onboard vectors for comparison purposes. Any significant difference ( $> 0.2$  fps) between ground and onboard solutions is indicative of either a ground configuration error (e.g. bad MCT constraints), onboard ILOAD error, or Lambert problem. Should this occur, notify RGPO and begin trouble-shooting immediately. Ground configuration should be suspect first since it is not controlled as stringently as onboard ILOADs and Lambert FSW.

Following NCC onboard targeting, TRAJ should provide body VGOs to PROP so that propellant requirements from the forward and aft RCS can be determined. Based on Intermediate targeting VGOs, a decision can be made whether to maneuver to +X burn attitude for NCC, or burn in target track attitude using the multi-axis technique. FDO should confer with PROP and RGPO regarding any decision to maneuver to attitude for NCC. As mentioned previously, if NCC requires less than 2 fps from the FRCS, then it will be performed multi-axis. Otherwise, PROP may call for an attitude maneuver so it can be burned +X. In the checklist, the crew is directed to perform NCC as a +X burn if  $\Delta V_{tot}$  is between 4-6 fps. This assumes that NCC  $\Delta v$  is evenly split between forward and aft RCS, which may not be accurate. This is why TRAJ computes the actual VGOs for

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PROP. If the decision is made to burn NCC multi-axis even though  $\Delta V_{tot}$  is  $> 4$  fps, the crew must be notified.

Also leading up to NCC TIG, FDO is required to provide an NCC ground solution as a backup to onboard Lambert targeting. FDO's targets may be burned onboard if for some reason the filter and prop states become unusable, or if Lambert targeting errors occur, or if both the onboard filter and prop solutions fall outside the ground-onboard limits specified in the Rendezvous Checklist. Best Ground NAV vectors should be used to generate the ground NCC solution, so update the corresponding ephemeris if a better target or Orbiter vector is available from NAV. Have MARS re-run the plan from the updated ephemerides. The resulting MET output can be passed to TRAJ, who will use AMP to manually generate an electronic NCC Ground Solution Flight Note. FD can then be notified and CAPCOM will read up the  $\Delta v$  components directly from the workstation display. This product should be ready by the time noted in the Rendezvous Checklist "MCC UPDATE Ground NCC Burn Solution" which is about NCC TIG-25 min. The NCC ground solution should be transferred to the Orbiter ground-based ephemeris. At this point, it is inappropriate to iterate on Lambert secondaries to make DMT offsets match the desired position. Iteration is abandoned in order to insure NCC targeting constraints in the MCC always match onboard ILOADs.

Final onboard targeting of NCC will occur about 5 minutes prior to TIG (assuming an attitude maneuver is not required). At this time, the crew will compare onboard  $\Delta v$  components against those from the ground NCC PAD. Differences between the final solution and the ground solution are computed for each component and compared against  $3\sigma$  limits provided in the checklist. These limits are generated by Flight Design using Monte Carlo sims that model the effects of attitude maneuvers, state vector uncertainty, and other dispersions on the trajectory. The limits are transmitted to the RGPOs via a flight specific STF so they can be incorporated into the checklist. If the crew finds that any  $\Delta v$  component has differences greater than the  $3\sigma$  "final minus ground" limits, the following decision tree will be executed (from FR A2-123).

- 1) Burn onboard FLTR solution if ST or RR NAV is converged (at least 40 marks accepted with less than 0.5 kft position update for last 4 marks, or if state vector updates are small and stable). If COAS NAV is being used, go to step 2.
- 2) Burn onboard FLTR solution if it is within final-ground limits.
- 3) Burn onboard PROP solution if it is within final-ground limits.
- 4) Burn ground solution.

It should be apparent from this list that the ground solution will rarely be burned. In order to get to this point, the sensor pass has to be invalidated as well as the PROP state vector. However, there are scenarios that lead to this (IMU accelerometer spike

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during ST pass is one), so FDO should always maintain an accurate ground solution and monitor onboard targeting closely.

Standard burn monitoring procedures should be used for NCC, with a couple additions. First, make sure the onboard guidance mode is Lambert "LAMB" rather than external  $\Delta v$  "EXDV". This can be viewed on one of several FDO ROSS Alarms (e.g. "Orbit FDO DDDs"). Lambert will provide closed-loop burn targeting beginning at TIG-15 sec (as evidenced by cycling VGOs). An inadvertent item entry on MM202 MNVR EXEC could downmode the software to EXDV, so keep an eye on this flag. If the crew accidentally downmodes to EXDV, they should return to SPEC 34 and re-target. Also, remember that NCC (and any other onboard-targeted burn) must be completed prior to TIG+90 sec due to the limitations of the onboard Lambert implementation (covered in Section 3.10.1.8). If it appears the burn will not be complete by this time, RGPO should have the crew re-target the burn on SPEC 34, which will bump the TIG 1 min into the future. Lambert will decrease the transfer time to take into account the late TIG, so that the final end conditions are preserved. Beware that if NCC is slipped more than approximately 10 min, it will approach the 180 deg transfer singularity and generate a "TGT  $\Delta T$ " alarm.

### 3.10.4.2.6 Ti and Ti Delay

Ti is an important burn. As its name implies, it initiates the terminal phase of the rendezvous by putting the chaser on a *near-intercept* trajectory. Any burn that puts the Orbiter on a "collision course" is by its very nature "critical". Accurate placement and execution of Ti will ensure acceptable approach geometry, and minimize subsequent midcourse propellant costs and MC-2 TIG slip. Prior to Ti, the rendezvous can easily be aborted by either doing nothing--phasing safely below and in front of the target, or by performing a Ti Delay. After Ti however, active breakout measures must be taken to abort a rendezvous. The onboard is considered prime for targeting Ti when valid sensor data is available, but, as with NCC, a ground solution is prepared for backup purposes. Ti Delay is computed exclusively by the ground, and, like Ti, is considered critical due to the fact that it cannot be delayed beyond a certain point or the day's rendezvous attempt is likely lost. Accurate targeting of Ti Delay is essential because it places the Orbiter in a football-shaped holding pattern that can vary from about 8 to 4 nm in range (depending on Ti arrival conditions). Close-in stationkeeping of this sort must be performed accurately to avoid collision.

Console procedures for Ti ground solution and Ti Delay are complementary, but are usually performed serially. Ti ground solution is normally attacked first since the limited time between NCC and Ti will not allow a well-converged ground NAV update, even if one waited right up until Ti TIG to grab vectors and compute. Also, this strategy puts off Ti Delay targeting awhile, which allows some RR data to be incorporated into the onboard state. So, immediately after NCC is executed, MARS will grab onboard vectors

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and run the Ti plan (shown in Figure 3.10.4.2-4). FDO should note Ti location (range and DH) from the MET. This will provide a "heads-up" on how dispersed the trajectory is. If NCC was executed accurately, then Ti should be within a few tenths of a nautical mile of the targeted position. If for some reason NCC was not executed successfully and Ti is significantly dispersed in location and cost, then the team should look at MC-2 TIG slip and  $\Delta v$  with the current trajectory. It may make more sense to perform a Ti Delay and incur the associated timeline and propellant hit in order to get the trajectory back on track to the nominal Ti position, rather than pressing into Ti and the midcourses with a severely dispersed trajectory.

To generate the Ti ground solution, FDO should first verify with TRAJ that NCC has been confirmed in the ephemeris. NAV should be allowed about 5 min tracking post-NCC (just to get a few points), and then should EOT the batch and provide a vector. The ephemeris should be updated on this new Orbiter vector, and the target ephemeris updated if any C-band tracking is available. Ti is then re-run with the ground vectors and transferred the Orbiter ephemeris. Good relative motion should be verified with R/T Relmo and DMT offsets. TRAJ will prepare the Ti ground solution PAD about the time FDO and MARS begin tackling Ti Delay targeting. All the while, the crew will be performing onboard targeting of Ti as well. Each time this is done, MARS will re-run the Ti plan using onboard vectors to check for good agreement. Also the ground solution should be compared to the latest onboard solution to determine if the components are within the  $3\sigma$  ground-minus onboard limits. If not, then every effort should be made to determine the source of the state vector differences.

```

LOCAL                MANEUVER CONSTRAINTS TABLE TI
COMMENT: (null)
CURRENT
MNVRS: 3 / 40
-----
| MANEUVER | THRESHOLD | SECONDARIES | | |
|---|---|---|---|---|
| 1 SOI | T | DR ==-8.0 | DH =0.2 | = |
| Ti | 001:17:01:19.000 | = | = | = |
|-----|-----|-----|
| 2 SOM | DT | = | = | = |
| MC-2 | 000:00:49:54.000 | EL =29.07 | = | = |
|-----|-----|-----|
| 3 SOR | DT | CXYZ ==-.14812 | CXYZ =0.0 | CXYZ =.29624 |
| MC-4 | 000:00:27:00.000 | = | = | = |
|-----|-----|-----|

```

**Figure 3.10.4.2-4: Ti Targeting**

Once Ti ground solution is published, Ti Delay can be tackled. If RGPO is "go" with the onboard relative state, then it is appropriate to target using onboard vectors. This is because the onboard is assumed to have the best relative state as long as no problems were encountered during sensor passes. If time permits, it's preferable to wait until at least 40 marks of RR data have been incorporated in order to improve upon the post-NC ST pass. The crew will configure for RR target acquisition at a range of 150 kft ( $\approx 25$

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nm). Then, if a good lock-on is obtained, they'll incorporate RR data into nav when inside 135 kft ( $\approx 22$  nm). Although RGPO is prime for monitoring onboard nav procedures, FDO should pay attention to the radar data—noting the first state vector update, watching trends in the onboard filter-prop position, etc in order to be aware of any trajectory problems uncovered by the RR.

After about 40 marks, FDO should check with RGPO to determine the best nav state. Unless there are problems with the RR, then the onboards will likely be the best source. If this is the case, FDO should TUP ephemerides 5 and 6 on the onboard filter and target vectors, and DMT2 target offsets should be set to ephemeris 6 for the target so that DMT2 can be used for Ti Delay evaluation. If RGPO recommends sticking with ground tracking, then TUP E5 out of E1 using an anchor time approximately 15 min prior to Ti. Next, have MARS run plan TID off the best source (Figure 3.10.4.2-5). In the place of Ti, this plan generates an NC solution to return the chaser to the nominal Ti position 1 rev later. Then MARS can modify plan TID2 maneuver 1, an EXDV, to include the TID NC output  $\Delta V_x$ , and 1-rev late SOI  $\Delta V_y$  and  $\Delta V_z$  from TID as well. By doing so, the 1-rev late SOI burn will be minimized (around 3 fps), and all the correction components (planar, radial) will be RSSed with the larger Ti Delay burn (around 12 fps for a standard one-rev to Ti GUR profile). TID2 is shown in Figure 3.10.4.2-6. After TID2 constraints are updated and the plan run, FDO should check the MET to assure that Ti one rev late occurs at the nominal Ti position. For some extremely long trajectories, this will result in a closing rate between Ti Delay and the one rev late Ti burn. Remember in this case that a subsequent Ti Delay #2 burn may be required to stop the closing rate if a second rev of delay is required.

```

LOCAL                MANEUVER CONSTRAINTS TABLE TID

COMMENT: (null)

CURRENT
MNVRs:  4 / 40
-----
| MANEUVER | THRESHOLD | SECONDARIES |
|-----|-----|-----|
| 1  NC    | T         | =           |
| Ti-delay | 001:17:01:19.000 | =           |
|-----|-----|-----|
| 2  NH    | T         | =           |
| NCC     | 001:17:35:51.000 | =           |
|-----|-----|-----|
| 3  SOI   | T         | =           |
| Ti      | 001:18:33:33.000 | DR ==-8    DH =0.2 |
|-----|-----|-----|
| 4  SOR   | DT        | CXYZ ==-.14812  CXYZ =0.0  CXYZ =.29624 |
| MC-4    | 000:01:16:54.000 | =           |
|-----|-----|-----|

```

**Figure 3.10.4.2-5: Ti Delay as NC**



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LOCAL

MANEUVER CONSTRAINTS TABLE TID2

COMMENT: (null)

CURRENT  
MNVRS: 4 / 40

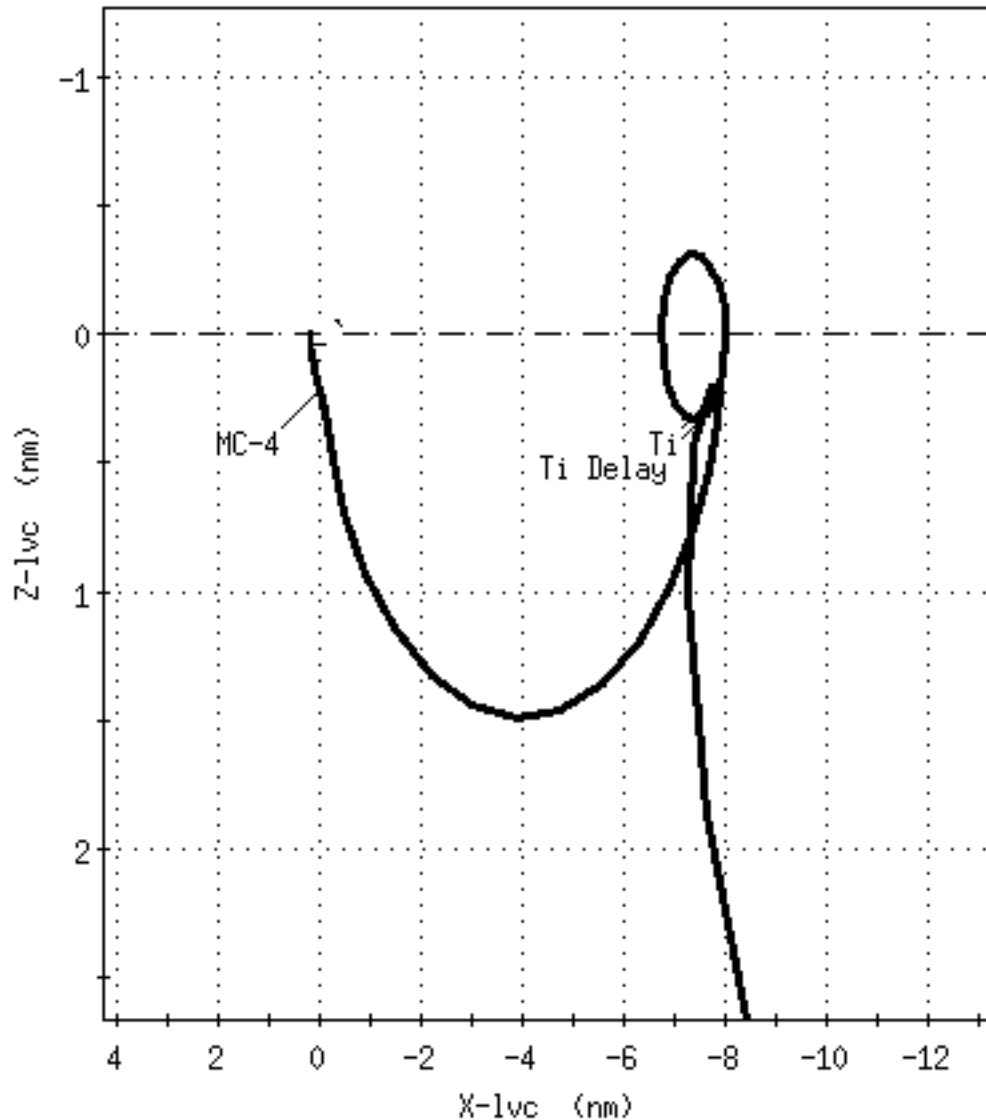
MANEUVER	THRESHOLD	SECONDARIES		
1 EXDV Ti-delay	T 001:17:01:19.000	DVLV =13.37 = =	DVLV =.45 = =	DVLV =2.58 = =
2 NCC NCC	T 001:17:35:51.000	= = =	= = =	= = =
3 SOI Ti	T 001:18:33:33.000	= = DR =-8	= = DH =0.2	= = WEDG =0
4 SOR MC-4	DT 000:01:16:54.000	CXYZ =-.14812 = =	CXYZ =0.0 = =	CXYZ =.29624 = =

**Figure 3.10.4.2-6: Ti Delay as EXDV**

The next step in Ti Delay targeting is to transfer TID2 to ephemeris 5 for relative motion assessment. Prior to this, the MTT for plan TID2 must be configured so that the thruster for EXDV is set to the planned Ti config. This is typically LOMS, TVR 0, and IMP. After the transfer, Relmo can be run off ephemerides 5 and 6 for onboards, or 5 and 3 for ground vectors. An example Ti Delay relmo plot is shown in Figure 3.10.4.2-7. The Ti Delay loop should come no closer than 4 nm to the target, in order to satisfy the "rule of halves" from Level B Groundrules and Constraints). Check offsets for the subsequent Ti and MC-4 burns in DMT2. When a good solution is found, have Profile Support determine Ti Delay TIG slip capability. Then pass Ti Delay  $\Delta v$  to PROP and verify the thruster is the same as for Ti. Meanwhile, TRAJ can be PADING the burn, and a PEG-7 command load can be generated as well.

While Ti Delay is being targeted, additional Rendezvous Radar (RR) data will continue to be incorporated into the onboard nav state. The Ti Delay solution can be re-verified by grabbing onboard vectors and updating ephemerides 5 and 6, and then re-checking R/T Relmo and DMT2 offsets for the plan. If RR updates have invalidated the previous ST-derived Ti Delay solution, then FDO and Profile Support will have to generate new Ti Delay targets posthaste. Refer to the Rendezvous Checklist to find out when Ti and Ti Delay PADs are due to the crew.

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**Figure 3.10.4.2-7: Ti Delay Relmo**

Ti ground solution and Ti Delay PADs must be provided by the time specified in the Rendezvous Checklist. Allow yourself about 10 min to PAD the burns prior to the specified time.

It is important to make sure the PADs are read up in a timely manner (Ti Delay is highest priority if onboard nav is converged, or if Ti solution is inside ground-onboard limits). Command loads should be built for both Ti and Ti Delay (normally 40601 and 40602 respectively), even though if things go nominally, neither will be uplinked. It is also important to start the maneuver to burn attitude in time in order to get there before TIG. If systems failures or other distractions take place, it is imperative that FDO and RGPO keep the Flight Control Team focused to make sure that events leading up to Ti are performed in time to support Ti TIG. Upon burn execution, a log entry should be made recording actual Ti position for post-flight purposes (range and  $\Delta$ height). As a

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Lambert burn, the same burn execution constraints apply to Ti as described earlier for NCC—the "LAMB" flag should be on, and the burn must be completed by TIG+90 sec, else re-target.

### 3.10.4.2.7 Midcourse Corrections and Prox Ops

Between Ti and manual phase, up to 4 midcourse correction burns may be performed. They are all onboard-targeted Lambert burns, of which the first three target for the MC-4 position (900 ft behind, 1800 ft below target; the same end point that Ti was targeting), and the last burn targets 600 ft below the target on the +Rbar. If Ti is executed flawlessly, and no perturbations take place during terminal phase, then midcourses MC-1 through 3 will be zero. In the real world, however, dispersions frequently take place that require non-zero  $\Delta v$  to get the trajectory back on track. Midcourse burns fulfill this important function in steering the trajectory down an increasingly narrower corridor towards the manual takeover point.

The midcourse tables are all similar in that they are SOI/SOR plans as follows.

- 1) Maneuver 1 is SOI with primary constraint T equal to the midcourse TIG (determined relative to Ti or MC-2 basetime using ILOADs in Rendezvous Checklist Ref Data). The TIGs Flight Note generated with TSA RMM is useful for computing these TIGs.
- 2) Maneuver 2 is SOR with primary constraint DT equal to the transfer time specified in Rendezvous Checklist Ref Data. Secondary constraints are position offsets from Rendezvous Checklist Ref Data.

MC-1 is computed on the ground by running plan MC1 with onboard vectors. This solution should compare well against the crew's preliminary solution. Immediately after initial targeting, FDO should have MARS transfer the solution to Eph 1 in order to keep the OIGN clock counting and to keep the ground caught up with actual trajectory. In this case, it's ok to have a "mixed bag" of ground-tracking based ephemeris with onboard solutions, since ground-targeting of the midcourse maneuvers is not required. The main purpose at this point is to monitor onboard targeting and burn execution.

Post-Ti, the crew should be maneuvering back to the -Z target track attitude in order to get more RR data. Frequently the RR stays locked onto the target throughout Ti, even though RR data to nav is inhibited while in MM202. That is why it is desirable to satisfy RGPO's OMS engine selection preference for Ti since this speeds up the process of incorporating RR data post-Ti after the attitude maneuver is complete. If the RR is down, then an appropriate ST attitude should be selected and maneuvered to ASAP, since orbital sunset is less than 28 to 36.5 min away. It is important to get post-Ti sensor data prior to MC-1 so that any Ti-related dispersions (e.g. attitude maneuver,

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trim error) can be detected and incorporated into the MC-1 solution. Remember that the later a dispersion is detected, the more expensive it is to fix it. Usually the midcourses will be well below 4 fps, so expect them all to be multi-axis. TRAJ should continue providing VGOs to PROP based on onboard targeting to support burn attitude determination. Burn execution technique is identical to NCC and Ti. It is important that the crew trim all VGOs during each midcourse burn. Any residual error on an earlier midcourse will drive up  $\Delta v$  costs for later burns.

MC-2 is a slightly different story from the other midcourses. It is executed on an elevation angle constraint rather than time. This is done to maintain the same approach timeline and geometry from MC-2 until manual takeover. The way this works in Lambert is that, at the T1 time relative to basetime (i.e. nominal MC-2 TIG), the algorithm searches for the desired elevation angle from the chaser to the target. This may result in a TIG earlier or later than the nominal T1 time. The transfer time  $\Delta t$  is *not* adjusted for the variation in MC-2 TIG (i.e. the transfer time remains *fixed*), so subsequent burns are referenced to the new basetime, MC-2 TIG. This entire process is automated onboard. The MC-2 target set contains a non-zero elevation angle, which tells the FSW that TIG is to be based on this elevation angle. When the burn is targeted on SPEC 34, the TIG that matches the elevation constraint is displayed and copied to MNVR EXEC. If this output TIG exceeds "TIG slip limits" (more than 3 min early or 7 min late compared to the expected TIG), then a new target set must be loaded that does not contain an elevation constraint. The crew will enter a new TIG either 3 min early or 7 min late, as appropriate, and burn fixed-TIG using target set 19. On a nominal day, however, MC-2 is performed at the TIG that satisfies the elevation angle.

Ground procedures are to target MC-2 with MC2, which contains an ELEV secondary constraint for SOI (get the angle from the Rendezvous Checklist Ref data). In this plan, normally maneuver 1 is a zero  $\Delta v$  EXDV that provides a handy  $\Delta T$  reference in the MET to the MC-2 TIG based on elevation. This  $\Delta T$  can be easily compared against the crew's TIG slip, which is read down over the air-to-ground each time MC-2 is targeted onboard. It is not a good idea to transfer MC2 to the TrS ephemeris, since the zero  $\Delta v$  EXDV maneuver may cause problems and mess up OIGN. Rather, plan MC2FIX should be set up as a fixed-TIG MC-2 SOI/SOR sequence, and the SOI TIG should be updated to the latest value from plan 2. Then this plan can be transferred. TRAJ should update the elapsed time "ET" clock based on the MC-2 TIG slip, and have GC display it underneath "PET" on the front clock panel. The actual MC-2 TIG becomes the new basetime for subsequent midcourses. After MC-2 is executed, MARS will have to correct MC-3 and -4 TIGs in the MCT if MC-2 TIG slip was non-zero.

During terminal phase, a planar null burn will also be performed when the out-of-plane (Y) position is zero relative to the target's plane. This normally occurs at  $T_i + 32$  min for a 210 nm rendezvous with good onboard nav and a clean  $T_i$  execution. The reason is that any planar error at  $T_i$  resulted in a  $\Delta V_y$  component to force a node at MC-4. With a zero planar position targeted for MC-4, there must be a corresponding node  $\_ rev$

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earlier, which happens to be  $T_i + 120$  deg of orbital travel. At this node, the crew will deflect the THC in order to null out the Y-dot (out-of-plane rate). This can be confirmed in the ground ephemeris if desired. Y and Y-dot are displayed on SPEC 34 onboard, and a RGPO ROSS alarm on the ground.

Orbital sunrise should occur sometime between MC-2 and MC-3 (depends on beta angle), but no later than MC-2 + 19 min (or 2 min after MC-3 since this TIG is fixed at 17 min after MC-2). By MC-2 +20 min the crew needs to have visual contact with the target in order to continue the approach. If the target is not acquired visually or with the RR, FR A2-126 states that a breakout must be performed here. An exception is that if valid sensor data (RR, ST, or COAS) has been incorporated into nav and utilized for burn execution earlier during the rendezvous, then the crew may proceed MC-2 + 24 min without visual contact. Normally the crew will make a "tally-ho" call on A/G loop at sunrise to inform the ground that they have the "bogey" in sight. If this call is not made, RGPO or FDO should request that CAPCOM query the crew. Normally RR will also be tracking the target during this timeframe regardless of lighting.

MC-4 is usually the largest of the midcourses since it's aiming for a different end condition than the previous burns. It is designed to nominally be a +X burn in order to preserve FRCS. Immediately after MC-4, the crew initiates a slow maneuver to +ZLV Earth track in anticipation of arrival at the Rbar. 1000 ft is generally considered the point at which rendezvous phase ends and proximity operations begin. After MC-4 the crew begins following manual braking gates to control closing rate (Rdot) versus range. ORBT ILOADs will nominally put the chaser on a trajectory requiring a minimum of jet firings. After arrival on the Rbar, the crew will use the THC to fly up the Rbar towards the target, keeping it centered in the COAS. Here is where target-specific approach techniques may be initiated, such as +Rbar approach corridor restrictions for ISS, or a fly-around to the +Vbar. These are highly flight-specific, and can be determined from the flight specific Groundrules and Constraints document, Rendezvous Checklist, or RGPO.

After docking with, or grapple of, the target, the ephemeris weights should be updated to reflect the new configuration. Also, USSPACECOM should be notified so they can update their catalogue. The Orbiter ephemeris may be updated on the target ephemeris, if Ground NAV is having trouble catching up with all the maneuvers (recall that most targets are extremely stable, and therefore have a more consistent tracking solution). RELNAV will be disabled onboard when the crew executes the "Rendezvous Nav Safing" procedure. It is important to assure that a target track attitude is not being performed on UNIV PNTG when this is done, otherwise large rates could result when the onboard target state is no longer propagated each cycle. The onboard filter state may be significantly in error by this time, especially if the ground processing of the target state took significant updates (recall that all onboard target updates are applied to the filter during sensor passes). This can easily be fixed with a 401xx Orbiter state vector uplink after the ground ephemeris is correctly configured.

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### 3.10.4.2.8 Trajectory Officer Duties on Day of Rendezvous

There are several "standard" duties that TRAJ is responsible for during a rendezvous execute shift. Among these are PADing and confirming burns, maintaining MCC clocks, and evaluating propellant usage for onboard-computed burns. In addition, TRAJ is expected to be able to handle off-nominal FDO-type functions "solo" if the FDO's workload is excessive. An example of this is conjunction assessment and collision avoidance maneuver recommendation during the heat of rendezvous. Finally, TRAJ should also serve as a "second set of eyes and ears" for FDO, double-checking every product that leaves the console for accuracy, listening to the FD and A/G loops for calls that FDO may have missed, keeping a close eye on the TrS configuration including its mirrored data, and pointing out anything that looks amiss.

#### 3.10.4.2.8.1 Initialization

Prior to the start of a rendezvous sim, TRAJ should perform normal console initialization duties documented in Section 3.2.3. For shift handover during a mission, TRAJ should perform a standard handover with the off-going TRAJ. In addition to standard work, TRAJ should verify the tasks below have been completed. It is very important to get a thorough handover from the off-going TRAJ to determine what pre-rendezvous work has been completed, and what remains. Included in this briefing should be a status of vectors transmitted to USSPACECOM for collision analysis, and any results received back. Workstation/MCC status should also be reviewed to point out ground problems and verify that the FDO/TRAJ workstations were rebooted.

- 1) TSA Rendezvous Maneuver Monitor (RMM) - First input the target altitude and check RMM ILOADs against the Rendezvous Checklist ILOADs located in the Ref Data chapter. These ILOADs define the TIGs relative to Ti TIG for on-board targeted burns. Also at this time configure the RMM ATT REF correctly so that valid attitudes will be computed for VGO comps. Get the nominal and 1-rev late Ti TIGs from FDO. Input the 1-rev late Ti TIG into RMM and print out a TIG flight note (be sure and include a title that clearly states that these are 1 rev-late TIGs). RMM will determine NCC and midcourse TIGs based on your input Ti TIG. Keep the 1-rev late copy handy in case there is a Ti Delay, but don't get it confused with the nominal plan. Next, prepare a TIGs Flight Note on RMM for the nominal plan. Also type in any ground-targeted burn TIGs (NH, NSR, and/or NC-n), which you get from FDO. Finally, get the MET of docking or grapple from RGPO and manually type this onto the note as a handy reference. Have FDO review what you've done, then pass it out to the operators on the distribution list at the top of the note (you may need to include preliminary burn PADs with this; see step 3 below).

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- 2) Clocks - Create a global count-down/count-up clock labeled "PET" (see clock procedures in Appendix 3F). The time reference for this will be  $T_i$ . Have GC put the clock up on one of the front displays. This clock will be used by the flight control team to monitor execution of steps in the Rendezvous Checklist. Also discuss with FDO the plan for maneuver clocks. The simplest option is to use OIGN which is automatically driven by the next burn in TrS ephemeris 1. The drawback to this is that OIGN does not count up from TIG, therefore it is useless for TIG slip cases, also it does not identify the name of the upcoming burn. Determining accurate TIG slip during a late burn is absolutely critical during onboard executed burns since there is a 90 sec limit on burning Lambert. Also, FDO includes on PADs the maximum permissible TIG slip for critical burns based on propellant costs and relative motion. A workaround to OIGN that provides TIG slip and the name of the burn is to manually create count-down/count-up clocks for each burn, and have the clocks available on your workstation so FDO can refer to these, and GC can display it if a TIG slip situation arises.
- 3) Burn PADs - For actual missions, the planning team will prepare and uplink preliminary PADs with the morning mail. For sims, the lead FDO will prepare preliminary PADs prior to the start of integrated training, and put a copy in the FDO Databook. For both sims and actual missions, TRAJ should work with FDO to make sure that a set of preliminary PADs is a) available on console, b) has been provided to the crew (either uplinked via FAO or faxed to the SMS by Rendezvous Monitor), and c) is provided to the flight control team either through hardcopies or the Auto Maneuver PAD (AMP) application.
- 4) Pointing Tagup - You will need the time to maneuver to attitude for any in-attitude burn. Work with FDO to get Pointing the DMT attitudes for these "big burns". Record the 0.2 and 0.5 deg/sec maneuver times and have them handy for later. The two different rates represent the slow A/AUTO/ALT and faster B/AUTO/ALT DAPs respectively. Also get from Pointing the LVLH attitude for NCC and any other multi-axis burns to use in RMM, which will be discussed later. RMM automatically computes mid-course burn attitudes, so don't worry about getting these from Pointing.
- 5) TSA R/T Relmo - FDO will want Profile Support or TRAJ to publish a relmo plot on the right front projector for team situational awareness. Reference Orbit Flight Design Console Handbook, Section 2.2.1.8, for relmo projection procedures. Make sure DOR burns are defined in the Events menu, and that a reasonable Orbiter attitude is selected for the plot bug. When rendezvous nav is enabled, the plot should show filter and prop digital data as well as filter predictor bugs. A neat trick is to place a ROSS 3-D Attitude window in the lower right corner of the relmo window, so that the team can easily visualize the Orbiter's current attitude (this may block the filter & prop digital data output on Relmo, so check with FDO before doing this).

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- 6) Mass Properties - For a mission, the off-going TRAJ should have completed a current set of mass props and transferred door open trims to the Engine Characteristics Table and updated the TrS ephemeris weights. Verify this is done. For a sim, the Rendezvous TRAJ will have to do a quick set of mass props right after the sim goes to run. Reference procedures in Section 3.6.

### 3.10.4.2.8.2 Rendezvous Execution

The following is a timeline of rendezvous execution with descriptions of Trajly duties.

- 1) Rendezvous Nav Enable - In preparation for this event, work with FDO to build and verify Orbiter and target state vector command loads. These procedures are documented in Sections 3.5.6. After Relnav is enabled, have Dynamics ship a G55\$ MED to enable ground-based ranging comps on Rndz ONAV Status.
- 2) NH and/or NC Burns - Prior to these burns, prepare a final maneuver PAD that shows *changes only* to the preliminary PAD. Below is an example of both types of PADs. Get notes from GNC and PROP. Query FDO for TIG slip notes. Have as much data filled in as possible prior to FDO performing final targeting and giving you a "GO" to PAD. When creating the final PAD based on changes to the preliminary PAD, don't bother to include an updated value if it has changed only slightly ( $\leq 2$  deg for burn attitude and  $\leq 0.2$  fps for VGOs). The exception to this is that *any item on the burn command load should be PADed exactly*, no matter how small the change. This consists of TIG, weight, TVR, trims, and PEG-7  $\Delta v$  components. Note that AMP will automatically perform this function. Have FDO look over your work, then copy and distribute paper PADs, or publish AMP. In this timeframe, provide FDO with the times to maneuver to attitude that you obtained from Pointing. After burn confirmation, coordinate with GC to get the next burn's countdown clock displayed if manual clocks are being used.



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**STS-096 Simulation 2000:096:17:58:02 GMT**

PRELIMINARY ORBITAL MANEUVER PAD FOR NH

OMS BOTH <input checked="" type="checkbox"/> L 2 R 3 RCS SEL 4	BURN ATT R 24 312 DEG P 26 058 DEG Y 26 336 DEG	ΔVTOT 134.8 FPS TGO 01:25 MM:SS VGO X +130.00 FPS VGO Y +000.00 FPS VGO Z +035.68 FPS	HA HP TGT 204 +173 NM
TV ROLL 5 000 DEG TRIM LOAD P 6 +0.5 DEG LY 7 -5.7 DEG RY 8 +5.7 DEG	NOTES		
WT 9 248580 LBS TIG 1001/13:13:56.8 TGT PEG 7 ΔVX 19 +134.6 FPS ΔVY 20 +000.0 FPS ΔVZ 21 +006.7 FPS	OMS GMBL CK: PRE POST-BURN L PRI L SEC R PRI R SEC NONE	RCS FCNCT: L OMS→RCS R OMS→RCS NONE	DOWN MODE OPTIONS: 2 OMS→1 OMS→RCS 2 OMS→1 OMS 1 OMS→RCS SEE FLIGHT NOTES NONE
OMS HE REG TEST: L,R OMS HE P/VAP ISOL NONE LEFT RIGHT		-X RCS BURNS:  N/A	
FLIGHT NOTES:			
FDO: James C. Edelen			

**STS-096 Simulation 2000:096:20:09:26 GMT**

FINAL ORBITAL MANEUVER PAD FOR NH  
DELTA'S HIGHLIGHTED

OMS BOTH <input checked="" type="checkbox"/> L 2 R 3 RCS SEL 4	BURN ATT R 24 312 DEG P 26 058 DEG Y 26 337 DEG	ΔVTOT 135.0 FPS TGO 01:26 MM:SS VGO X +130.28 FPS VGO Y +000.00 FPS VGO Z +035.74 FPS	HA HP TGT 203 +173 NM
TV ROLL 6 000 DEG TRIM LOAD P 6 +0.5 DEG LY 7 -5.7 DEG RY 8 +5.7 DEG	NOTES		
WT 9 248595 LBS TIG 1001/13:13:56.7 TGT PEG 7 ΔVX 19 +134.9 FPS ΔVY 20 +000.0 FPS ΔVZ 21 +006.7 FPS	OMS GMBL CK: PRE POST-BURN L PRI L SEC R PRI R SEC NONE	RCS FCNCT: L OMS→RCS ✓ R OMS→RCS NONE	DOWN MODE OPTIONS: 2 OMS→1 OMS→RCS ✓ 2 OMS→1 OMS 1 OMS→RCS SEE FLIGHT NOTES NONE
OMS HE REG TEST: L,R OMS HE P/VAP ISOL NONE ✓LEFT ✓RIGHT		-X RCS BURNS:  N/A	
FLIGHT NOTES:			
MAX TIG SLIP 4 MIN.			
FDO: James C. Edelen			

**Figure 3.10.4.2-8: Preliminary and Final Maneuver PADs**

1. Star Tracker or RADAR Pass - Monitor sensor residuals and the RGPO backroom loop (MPSR DYN-B) during initial sensor acquisition. Alert FDO if problems with the sensors develop or if large residuals are observed (ratio > approximately 0.2). When angles are "AUTOed", record the first state vector update in the log.
2. NCC - This is the first onboard targeted burn, and is performed multi-axis in the target track attitude if it costs less than 2 fps out of the FRCS. Multi-axis is preferred since this reduces trajectory perturbations due to attitude maneuvers to

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and from the burn attitude. To make this determination, TRAJ enters the LVLH attitude for the burn (from Pointing) into the NCC page on RMM (scroll down through the displays with <CNTRL> F D, and back up with <CNTRL> F U). Next, enter the onboard burn solution in the preliminary, intermediate, and final columns as appropriate ( $\Delta v$  components are displayed on Rndz ONAV Status). RMM will compute the body VGOs—pass these to PROP for the preliminary solution, and then subsequently only for significant updates (> about 0.2 fps). PROP and FDO will use this information to determine whether an attitude maneuver will be required, or if NCC can be burned multi-axis. During this timeframe, FDO will compute a "ground NCC solution" using OMP and Ground NAV state vectors. When these data are ready, enter FDO's  $\Delta v$  components into AMP's "NCC PAD" menu, and electronically publish the "Ground NCC Flight Note". Include the Rendezvous Checklist page number on which the crew will write the data. Also in RMM, check differences between the ground and onboard  $\Delta v$  components. If they are greater than the "ground-onboard" limits shown in the Rendezvous Checklist NCC BURN SOLUTION block, notify FDO immediately, as this affects the determination of which solution to burn.

3. Ti/Ti Delay - Immediately after NCC is confirmed, FDO will begin computing a final Ti ground solution, and a Ti Delay solution based on the best relative navigation source. While FDO is doing this, TRAJ should get as much of the two PADs filled out as possible (notes from PROP & GNC, checklist page number, title, etc). When FDO's targeting is complete, TRAJ should PAD changes only for the final Ti PAD. For the Ti Delay PAD, only the left side of the sheet is filled out (see example Ti-Delay PAD below in Figure 3.10.4.2-9). Be sure to include TIG slip notes from FDO on the Ti PAD. As for NCC above, use RMM to compute ground-onboard  $\Delta v$  differences and notify FDO if they exceed the limits shown in the Rendezvous Checklist (listed on the page where the crew records Ti solutions). If Ti Delay is executed, pull out the 1-rev late TIG Flight Note, copy, and distribute (give FDO a copy first). Reset the PET clock to the new Ti time, then proceed with NCC steps above.

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STS-096 Simulation 2000:096:19:57:24 GMT

Ti-DELAY			
OMS BOTH 1			
L	2		✓
R	3		
RCS SEL 4			
TV ROLL 5 000 DEG			
TRIM LOAD			
P	6	+0.5	DEG
LY	7	+4.8	DEG
RY	8	-4.9	DEG
WT 9 244.143 LBS			
TIG 10 01/15:32:17.8			
TGT PEG 7			
$\Delta V_X$	19	+012.0	FPS
$\Delta V_Y$	20	-001.2	FPS
$\Delta V_Z$	21	+000.9	FPS
FLIGHT NOTES:			
FDO: James C. Edelen			

**Figure 3.10.4.2-9: Ti Delay PAD**

- Midcourse Burns - For each midcourse burn, provide PROP with body VGOs based on the onboard Lambert solution. RMM will correctly compute the LVLH attitude for each burn if the target track attitude reference is set correctly, so you won't have to worry about this input—just enter the onboard PEG 7  $\Delta v$  components when the crew targets. MC-1 TIG is always fixed relative to Ti. MC-2 is burned on an elevation angle, and the TIG is therefore variable. Whenever the crew targets MC-2, this will be reported on the A/G loop along with TIG slip. Another way to get this data is from Target on MPSR DYN-B. Prior to MC-2, an MC-2 Elapsed Time "ET" count-down/count-up clock must be created referenced to the latest onboard-computed MC-2 TIG. This should be displayed on the front display until docking or grappling phase begins. Once MC-2 is executed, this will fix the TIGs for MC-3 and -4, which are referenced to MC-2 ET. Therefore, any manual MC-3 and -4 clocks will need to be adjusted accordingly. Each midcourse burn should be confirmed with DV Sensor. Some FDOs also like to confirm the planar null burn, which occurs sometime between Ti and MC-4, so listen up on the FD loop for RGPO's call of when the crew will perform this and check with FDO.

Some miscellaneous notes are included next.

- Whenever a thruster change is required (e.g. switch from left to right OMS for Ti), help FDO make sure that the following adjustments are made on the ground: appropriate Maneuver Transfer Table updated, command load re-built after the plan is re-transferred to the TrS ephemeris, PAD thruster corrected if time permits, and PROP and GNC should be consulted for any changes to NOTES on the PAD.
- For non-rendezvous maneuvers, in-attitude burns using the PX2 jets or OMS engines are usually performed in a heads-down attitude (TVR 180 deg). On DOR, however, it is beneficial to minimize attitude maneuvers in order to maximize star tracker or radar data passes. Therefore, TVR is selected to provide the minimum single-axis maneuver from the target-track attitude to burn attitude and back again.

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The -Z target track attitude is preferred since both the -Z Star Tracker (ST) and Rendezvous RADAR (RR) are directed along the -Z axis. The TVR to minimize attitude maneuvers for burns that correspond to the -Z target track attitude is TVR 0 for posigrade burns and 180 for retrograde, assuming rendezvous from behind. MARS should have this set up correctly in the MTT, but it is helpful if TRAJ gives these numbers a sanity check. If a problem is encountered with the -Z ST, then a switch to the -Y ST will be necessary. This could impact burn TVR selection if the RR also fails, in which case, all sensor passes prior to MC-3 would be conducted in the -Y target track attitude. Using the same logic as above, all in-attitude burns would be conducted with TVR 90 deg (posigrade), or 270 deg (retrograde). TRAJ should help coordinate this change to the burn PADs, if necessary. Also don't forget to change the target track attitude reference in RMM so the midcourse burn Body VGOs are computed correctly, and adjust the areas in ephemerides 1 & 2 to reflect the -Y ST attitude.

- 3) Prior to rendezvous execute shift, the planning team will send USSPACECOM a set of predicted post-burn vectors for NH (if required), NC, and Ti. Also a target vector will be sent. USSPACECOM will perform CAV runs off these vectors and notify the Flight Dynamics team of any possible collision hazards. Results based on these predicted vectors will be used by FDO for determining any alternate course of action to stay clear of any space debris. During rendezvous execution, there is insufficient time to send actual burnout vectors, since burns are occurring so frequently as to make any post-burn CAV results obsolete. The only exception to this is if an off-nominal burn has occurred, and no other burns will be performed for the next few hours (extremely unlikely). Once docking or grapple is complete and Ground NAV is converged, a current Orbiter state should be transmitted.

### 3.10.4.2.8.3 Checklist

The following actions and supporting tables have proven to be an effective means of conducting TRAJ duties during a rendezvous execute shift.

#### Sim Initialization

- 1) \_\_\_\_\_ Perform normal initialization procedures.
- 2) \_\_\_\_\_ Obtain and verify Orbiter/target state vectors as required.
- 3) \_\_\_\_\_ Start RMM.
  - a) \_\_\_\_\_ Input target altitude (usually ILOAD Set 5).
  - b) \_\_\_\_\_ Check RMM ILOADs against Rndz C/L ILOADs (Ref data chapter); ILOADs define TIGs relative to Ti TIG for O/B targeted burns.

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- c) \_\_\_\_\_ Configure ATT REF correctly so valid attitudes will be computed for VGO comps.
- d) \_\_\_\_\_ Ask FDO for nominal and 1-rev late Ti TIGs.  
NOTE: for ORBT, Ti TIG may range from SS -28 to -38.5 min and other values depending on target, RPM, beta angle, etc.
- e) \_\_\_\_\_ Input 1-rev late Ti TIG into RMM and print out a TIGs Flight Note, including a title clearly stating these are 1-rev-late TIGs. Keep copy in case of Ti Delay.
- f) \_\_\_\_\_ Prepare nominal plan TIGs Flight Note on RMM for nominal plan.
  - i) \_\_\_\_\_ Type in any ground-targeted burn TIGs (NH, NSR, and/or NC-n) FDO is carrying in the nominal DOR plan.
  - ii) \_\_\_\_\_ Type in MET of docking or grapple from RGPO.
  - iii) \_\_\_\_\_ Give to FDO for review. Distribute with preliminary burn PADs as required.
- 4) \_\_\_\_\_ Build clocks.
  - a) \_\_\_\_\_ PET-/PET+ (Reference Time = Ti TIG)
  - b) \_\_\_\_\_ DOCK-/DOCK+
- 5) \_\_\_\_\_ After sim in RUN, have DYN ship a G55\$ MED to enable E1/3 range comps on Rndz ONAV Status display.
- 6) \_\_\_\_\_ Configure RelMo as required. Turn on FILT and PROP digital data and FILT bugs after RNAV enabled.
- 7) \_\_\_\_\_ Verify burn confirmation ephemerides with FDO.

### NH Burn (If Required)

- 1) \_\_\_\_\_ Prepare final maneuver PAD showing preliminary PAD changes only.
- 2) \_\_\_\_\_ Get latest maneuver times from POINTING.
- 3) \_\_\_\_\_ Build or verify 406xx command.
- 4) \_\_\_\_\_ Confirm burn.

### Final NC Burn

- 1) \_\_\_\_\_ Prepare final maneuver PAD showing preliminary PAD changes only.
- 2) \_\_\_\_\_ Get latest maneuver times from POINTING.
- 3) \_\_\_\_\_ Build or verify 406xx command.

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- 4) \_\_\_\_\_ Confirm burn.

### Star Tracker or RADAR Pass

- 1) \_\_\_\_\_ Verify ONAV has initiated FILT/TGT vector storage in TrS VAT.
- 2) \_\_\_\_\_ Monitor TrS VAT to verify ONAV stores in V1/2, V3/4, and V5/6.
- 3) \_\_\_\_\_ Verify ONAV has terminated FILT/TGT vector storage in TrS VAT.

### NCC

- 1) \_\_\_\_\_ Perform RMM actions.
  - a) \_\_\_\_\_ Enter LVLH burn attitude from POINTING into the NCC page or compute in RMM after after setting REF ATT to ST in use.
  - b) \_\_\_\_\_ Enter O/B solution in the Preliminary, Intermediate, and Final columns
  - c) \_\_\_\_\_ Pass Preliminary VGOs to PROP (update as PROP requires).
  - d) \_\_\_\_\_ Check Ground/Onboard  $\Delta v$  differences within tolerances.
- 2) Publish Ground NCC PAD after FDO is GO.
- 3) \_\_\_\_\_ Confirm burn.

### After RR Converged

- 1) \_\_\_\_\_ TUP E5 from E1 and E6 from E3 at current time with transfer options.
- 2) \_\_\_\_\_ Have DYN anchor E5 off onboard FILT; E6 off onboard TGT.

### Ti/Ti Delay

- 1) \_\_\_\_\_ Prepare final maneuver PAD showing preliminary PAD changes only.
- 2) \_\_\_\_\_ Get latest maneuver times from POINTING.
- 3) \_\_\_\_\_ Build or verify Ti Delay command.
- 4) \_\_\_\_\_ Perform RMM actions.
  - a) \_\_\_\_\_ Enter LVLH burn attitude from POINTING into the NCC page or compute in RMM after after setting REF ATT to ST in use.
  - b) \_\_\_\_\_ Enter O/B solution in the Preliminary, Intermediate, and Final columns
  - c) \_\_\_\_\_ Pass Preliminary VGOs to PROP (update as PROP requires).
  - d) \_\_\_\_\_ Check Ground/Onboard  $\Delta v$  differences within tolerances.

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- 5) \_\_\_\_\_ Remind FDO to transfer MC1 plan into E1 to drive OIGN clock post-Ti.
- 6) \_\_\_\_\_ Confirm burn.

### If Ti Delay Executed

- 1) \_\_\_\_\_ Distribute 1-rev late TIGs Flight Note.
- 2) \_\_\_\_\_ Reset PET clock to the delayed Ti TIG.
- 3) \_\_\_\_\_ Confirm burn.

### Midcourse Burns

- 1) \_\_\_\_\_ Perform RMM actions for each burn.
  - a) \_\_\_\_\_ Enter LVLH burn attitude from POINTING into the NCC page or compute in RMM after after setting REF ATT to ST in use.
  - b) \_\_\_\_\_ Enter O/B solution in the Preliminary, Intermediate, and Final columns
  - c) \_\_\_\_\_ Pass Preliminary VGOs to PROP (update as PROP requires).
  - d) \_\_\_\_\_ Check Ground/Onboard  $\Delta v$  differences within tolerances.
- 2) \_\_\_\_\_ Confirm MC-1 burn (TIG fixed in PETi).
- 3) \_\_\_\_\_ By MC-2 TIG -10 min, create ET-/ET+ count-down/count-up clock from RMM MC-2 TIG comp (early/late slip based on elevation angle reported by ONAV and crew).
- 4) \_\_\_\_\_ Confirm MC-2 burn.
- 5) \_\_\_\_\_ Confirm MC-3 (TIG fixed in ET)
- 6) \_\_\_\_\_ Confirm MC-4 (TIG fixed in ET)

### Prox Ops / Docking

- 1) \_\_\_\_\_ Adjust DOCK clock per RENDEZVOUS input.
- 2) \_\_\_\_\_ Delete DOCK clock with RENDEZVOUS concurrence when "capture" confirmed.

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### REFERENCE INFO

Nominal Ti (PET) \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (GMT or MET)  
 1-rev Late Ti \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (GMT or MET)  
 Plan MC-2 TIG (ET) \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (GMT or MET)  
 DOCK Time: \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (GMT or MET)

PLS: Site \_\_\_\_\_ Rev \_\_\_\_\_ TIG \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (MET) (Light / Dark)  
 Site \_\_\_\_\_ Rev \_\_\_\_\_ TIG \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (MET) (Light / Dark)  
 NPLS: Site \_\_\_\_\_ Rev \_\_\_\_\_ TIG \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (MET) (Light / Dark)  
 Site \_\_\_\_\_ Rev \_\_\_\_\_ TIG \_\_\_\_\_ / \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ (MET) (Light / Dark)

Current Weight \_\_\_\_\_ X / Y / Z CGs \_\_\_\_\_ Ballast: *None* / \_\_\_\_\_

**Post-NH** OMP St / Sh = \_\_\_\_\_ / \_\_\_\_\_ PX4St / Sh = \_\_\_\_\_ / \_\_\_\_\_  
**Post-NC** OMP St / Sh = \_\_\_\_\_ / \_\_\_\_\_ PX4St / Sh = \_\_\_\_\_ / \_\_\_\_\_  
**Post-Dock** OMP St / Sh = \_\_\_\_\_ / \_\_\_\_\_ PX4St / Sh = \_\_\_\_\_ / \_\_\_\_\_

PADS		NH Rendz 3-5	Final NC Rendz 3-3	Ti Rendz 3-7
FDO	TIG?			
	Thruster?			
	Critical?			
GNC	OMS Gimbal Check	Pre- Post-		
	GPC Fill In	( )	( )	( )
PROP	Interconnect		->	->
	He Reg	Left	A: B:	A: B:
	Test	Right	A: B:	A: B:
	Downmode		->	->
Notes:				
TIG Slip (min)		<i>LVLH / Inertial</i>	<i>LVLH / Inertial</i>	Ti: _____ Ti Delay: _____ <i>LVLH / Inertial</i>
Maneuver Times	0.2			
	0.5			



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**NH and Final NC**      Actual NH TIG      = ontime or \_\_\_\_ / \_\_\_\_ [MET/GMT]  
 Actual NC TIG      = ontime or \_\_\_\_ / \_\_\_\_ [MET/GMT]

	Pre- M50	Post- M50	Cfd P7	Pre M50-	Post M50-	Cfd P7
DV Count						
DVx						
DVy						
DVz						

**NCC**      Actual TIG      = ontime or \_\_\_\_ / \_\_\_\_ [MET/GMT]

	Tol	Ground	O/B			Confirmed M50s / P7			
			Prelim	Inter	Fin	Pre-M50	Post-M50	Cfd M50	Cfd P7
DV Count									
DVx	( )								
DVy	( )								
DVz	( )								

**Ti/Ti Delay**      Actual TIG      = ontime or \_\_\_\_ / \_\_\_\_ [MET/GMT]

	Tol	Ground	O/B			Confirmed M50s / P7			
			Prelim	Inter	Fin	Pre-M50	Post-M50	Cfd M50	Cfd P7
DV Count									
DVx	( )								
DVy	( )								
DVz	( )								

### Midcourses

		Tol	Ground	O/B			Confirmed M50s			
				Prelim	Inter	Fin	Pre-M50	Pst-M50	CfdM50	Cfd P7
MC-1	DV Count									
	DVx	( )								
	DVy	( )								
	DVz	( )								
MC-2	TIG / DV Count									
	DVx	( )								
	DVy	( )								
	DVz	( )								
MC-3	DV Count									
	DVx	( )								
	DVy	( )								
	DVz	( )								
MC-4	DV Count									
	DVx	( )								
	DVy	( )								
	DVz	( )								

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### 3.10.4.2.9 Profile Support

Profile Support provides valuable assistance to the FDO during rendezvous missions. Profile Support (call sign "PROFILE") is a *phase specialist* with expertise in rendezvous design and targeting, TIG slip analysis, and off-nominal plan recovery. The PROFILE position is staffed only during the execute shift (usually Orbit 1 Team) until rendezvous is complete. When PROFILE is not present, MARS fills in as necessary. The PROFILE for a mission is sometimes the same flight designer that developed the burn plan for the mission. Close to launch, this person will participate with the lead FDO in preparing launch window phase limits, plus burn plans for each launch opportunity. During real-time ops, PROFILE typically provides TIG slip data for critical burns, assessment of how dispersions will affect burn solutions and relative motion, evaluation of missed burn scenarios, and preparation of relative motion plots for the execute package. The other purpose of having flight design personnel support on console is to provide feedback from operations into the design process. Supporting actual missions provides more experience and knowledge to the designers, while supplying worthwhile assistance to the FDOs. During DOR, PROFILE is on console to perform all the duties outlined above as well as to provide expertise in choosing between breakout options. The remainder of this brief section will detail FDO-PROFILE interaction.

**TIG Slip** - Every critical burn must have TIG slip limits provided on the PAD. Since, by definition, a critical burn cannot be delayed by one or more revs, there must be a strategy for dealing with late burn execution. The lead FDO should have burn criticality and TIG slip information prepared pre-flight for *every* critical burn in a rendezvous profile (see Section 3.10.3.2). Then in real-time, PROFILE will update the calculations using the actual rendezvous plan and latest state vectors. Information is typically provided to FDO in the form of propellant costs versus time for both inertial and LVLH slips. Relative motion plots for both options is also provided. See Figures 3.10.4.2-10 and -11 for examples of PROFILE products. This data should be reviewed with FDO prior to final burn targeting, so as to allow timely incorporation into the burn PAD. In this example, NC-4 has been analyzed 1, 2, and 3 min late, and the increased propellant cost for NCC and Ti is represented in the hand-written data. Note that it is necessary to include NCC in the TIG slip plan when analyzing any DOR burn through Ti Delay. This is because, as the trajectory is dispersed, NCC will perform a significant portion of the correction to get Ti back into position. Therefore, NCC must be included.

The slip option that provides lowest propellant cost recovery, while preserving safe relative motion, is the preferred course of action. Since inertial TIG slip is procedurally easiest to implement, it is usually the default method chosen, until such point as LVLH slip saves more prop<sup>19</sup>. Absolute TIG slip limits will be constrained by

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<sup>19</sup> Recall that to perform an inertial TIG slip, the crew simply executes the burn when ready. MM202 guidance will perform an inertial attitude hold (assuming DAP AUTO and ITEM 27), and MNVR EXEC

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either relative motion, or by how much propellant PROP is willing to commit. For the GUR NC-4 example shown below, inertial slip is clearly better from both a propellant and relative motion perspective. After 2 min slip, the trajectory passes within about 4 nm of the target on the transfer to Ti. This violates the spirit of the "rule of halves", which seeks to provide protection against collision between the target and Orbiter. In the LVLH example, in addition to costing more propellant, a dangerous closing trajectory is achieved after 1 min of slip. Therefore it would be appropriate to utilize inertial TIG slip, setting max slip at 2 min. PROP should be consulted to see if the desired TIG slip limit can be supported from a propellant perspective. Assuming so for this example, proper burn PAD phraseology would be: "MAX TIG SLIP 2 MIN; DO NOT RE-LOAD TARGETS". Phraseological examples for different scenarios are: "MAX TIG SLIP 6 MIN, RE-LOAD TARGETS AFTER 4 MIN" and "MAX TIG SLIP 3 MIN; RE-LOAD TARGETS".

Maximum Ti TIG slip capability is based on how long Ti Delay may be safely delayed. Prior to the Ti PAD read-up time, PROFILE should compute Ti Delay TIG slip. Prop usage and relative motion will be the limiting factor here. The limit derived by PROFILE should be included on the Ti Delay PAD, e.g. "MAX TIG SLIP 6 MIN; DO NOT RE-LOAD TARGETS". Then on the Ti PAD include a note such as "IF TI NOT STARTED BY TIG+5 MIN, PERFORM TI DELAY". This reserves one minute for the crew to downmode from Ti to Ti Delay.

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VGOs will be rotated with time to hold the same inertial targets. So all the crew has to do is depress EXEC pushbutton for an OMS burn, or deflect the THC for a  $\pm X$  burn. LVLH TIG slip requires the crew to input a new TIG on MNVR EXEC, and then enter ITEM 22, 23, and 27 (if maneuver to burn attitude is desired).

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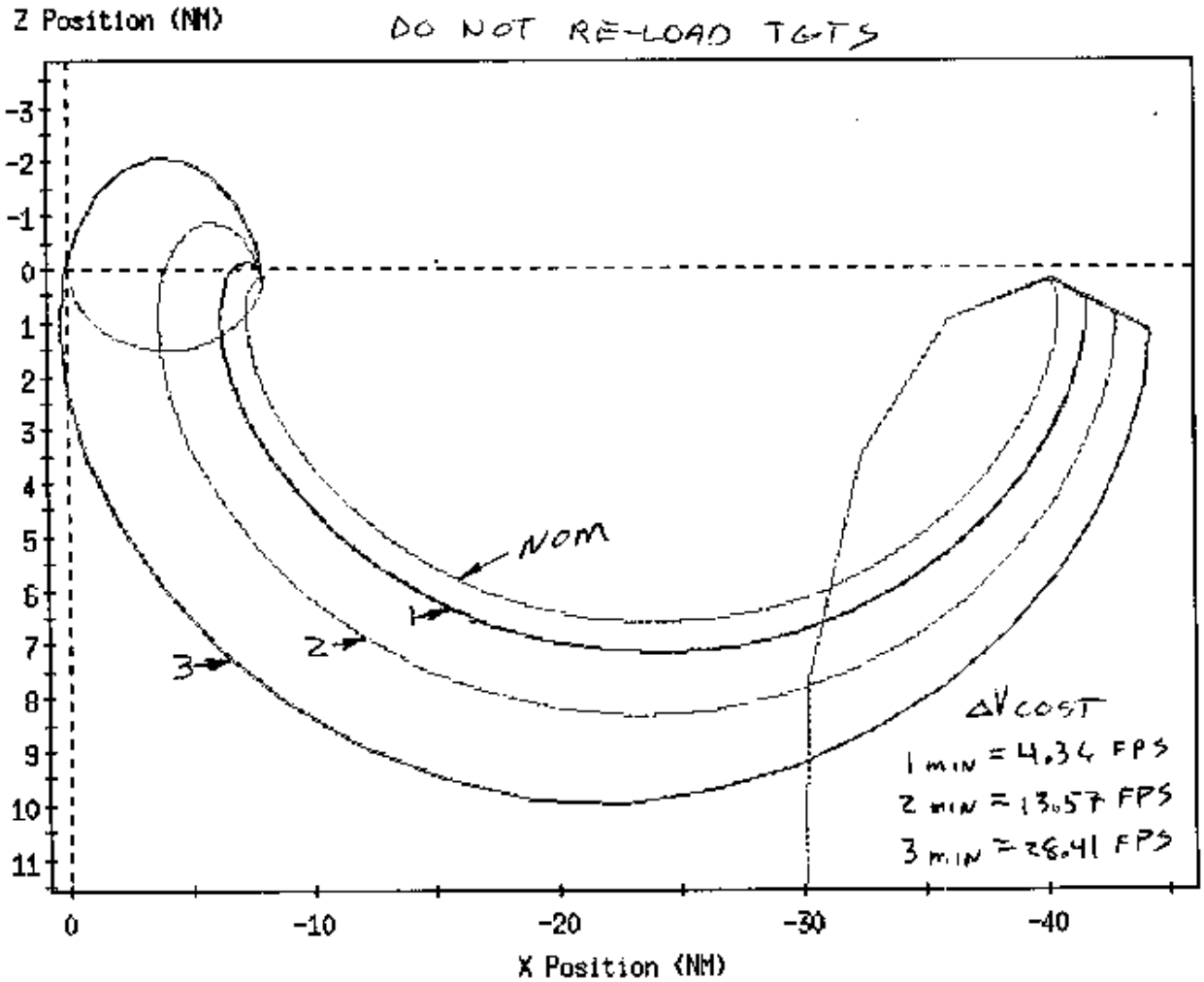


Figure 3.10.4.2-10: NC-4 Inertial TIG Slip

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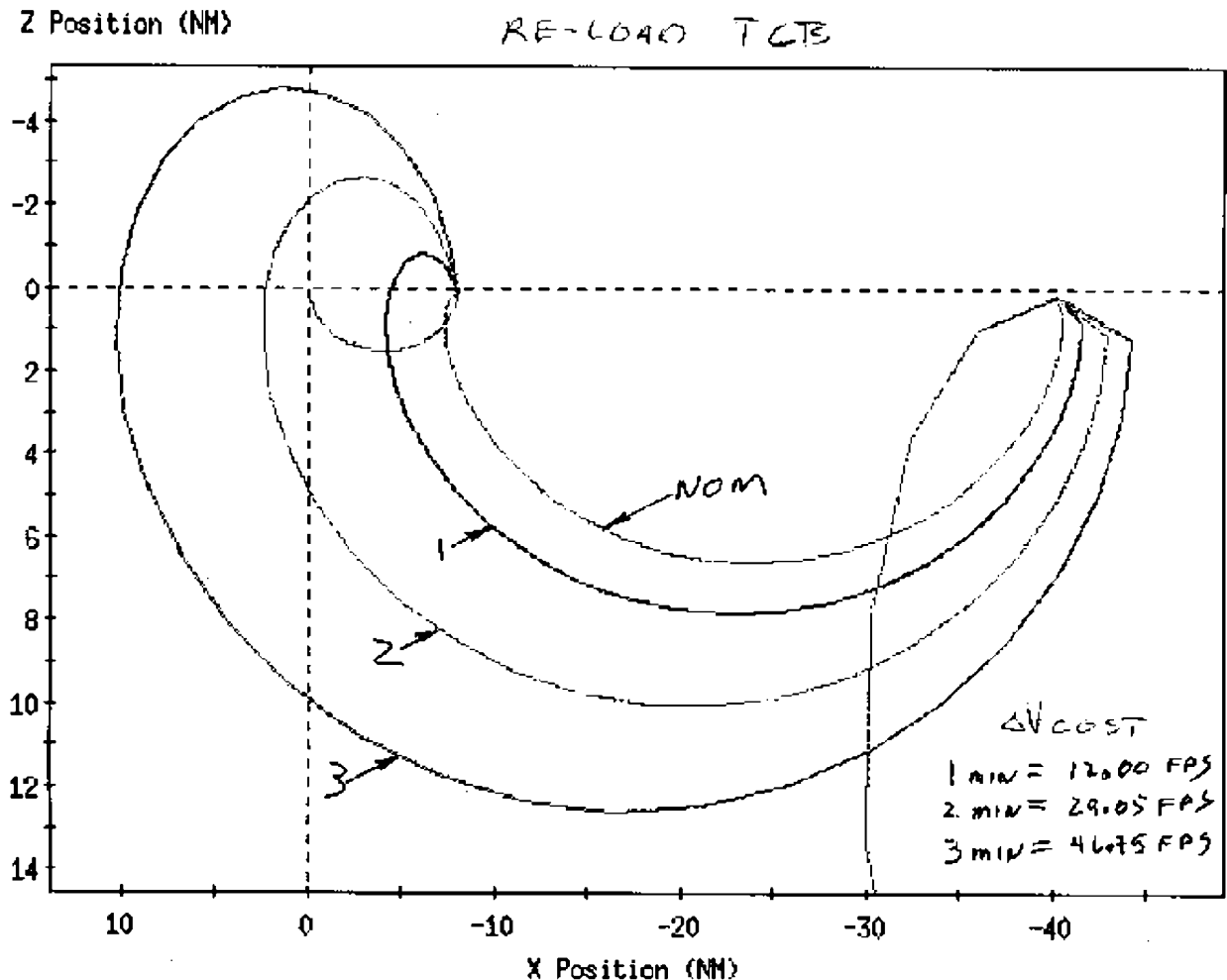


Figure 3.10.4.2-11: NC-4 LVLH TIG Slip

**Off-nominal Plan Recovery** - If a critical burn is missed, or any burn is abnormally terminated, PROFILE should be employed to determine an appropriate recovery strategy. This includes providing MET and R/T Relmo output to find a solution that meets propellant and timeline limitations. An experienced PROFILE can usually generate a recovery plan for a missed or off-nominal burn within 10-20 min, so FDO should utilize this resource to help out. Following generation of a contingency plan, PROFILE will have FDO look at the MET results. If desired, PROFILE can transfer the plan to Eph 8, which is dedicated for contingency rendezvous plans. Then range offsets and relative motion can be evaluated. Note that MARS assistance may be necessary to transfer the plan since PROFILE training flow does not include maneuver plan transfer to the TrS.

**Relative Motion** - It is customary on DOR to have PROFILE output R/T Relmo video feed from a MPSR workstation. PROFILE or TRAJ will coordinate with GC to have the video displayed on the right front-screen projector for the MCC. This prevents the FDO or TRAJ workstations from having to perform this CPU-intensive function.

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Since PROFILE is proficient in the use of R/T Relmo, they can also be called upon for any relative motion tasks, such as re-creating an actual station-keeping profile, or generating relmo plots for the crew's mission summary message on DOR.

### **3.10.4.2.10 Maneuver And Rendezvous Specialist (MARS)**

Maneuver and Rendezvous Specialist, or "MARS", is a position that was created as part of the Trajectory Sub-system Upgrade Project (TSUP). Since the RTP was not rehosted on the TrS, it was necessary to task a position that would assume the role of running the OMP in real-time. The MARS position was created from the ranks of Rendezvous Flight Design, which included existing Profile Support personnel, in order to combine flight design and console experience into one position. No net change to flight dynamics MPSR staffing resulted from this new position, since the 2nd Dynamics position that had previously run the RTP was replaced by the MARS. Basically, MARS is responsible for performing all OMP targeting at FDO's direction. This is done in the TSA global area so that all output is viewable by FDO and other operators. MARS interfaces with FDO on the MPSR DYN A voice loop. Specifically, MARS responsibilities are as follows.

- 1) Configure TSA OMP Mnvr Constraints Table (MCT) and Mnvr Transfer Table (MTT) for upcoming burns.
- 2) Run OMP for all planned dual vehicle burns and perform plan optimization.
- 3) Transfer OMP maneuver plans to TrS ephemeris.
- 4) Perform OMP iterations to achieve desired range and height offset in TrS ephemerides.
- 5) Provide Rendezvous Flight Design expertise to flight control team and a "second set of eyes" on rendezvous plan generation.
- 6) Assess/update TIG slip analyses as necessary if no Profile Support on console.

The general FDO-MARS rendezvous burn targeting process is described next. First, FDO should verify a valid Orbiter ephemeris is available, i.e. proper anchor vector, drag characteristics, solar flux, vents, etc. Normally TrS Eph 7 is delegated to MARS as the standard Orbiter ephemeris to be used for burn targeting and iterations. MARS is free to transfer and iterate rendezvous plans iteratively, but FDO is still responsible for configuring Eph 7 initially and keeping it up to date. (Post-launch, whenever MARS is supporting, FDO/TRAJ should keep Eph 7 anchor current, confirm mnvrs, and update init weight, etc). Eph 3 is the prime target ephemeris, and it should also be checked in a similar manner. Ephemeris mirrors must also be up and running, and caught up with

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latest TUP number on the server. FDO then passes burn-targeting requirements to MARS and specifies which ephemerides to use. MARS will provide the plan name to FDO, who in turn, checks targeting constraints on the Maneuver Constraint Table (MCT). The dynamic version of this display can be accessed from the FDO MnvR/Rndz DNAV. This display is slaved to Global TSA output, and updates automatically whenever the MCT is updated. The user has to type the plan name in the appropriate field and hit F1 to load. MARS runs OMP and notifies FDO "plan <plan name> complete". FDO then verifies output on the dynamic Maneuver Evaluation Table (MET) from the MnvR/Rndz DNAV.

After a satisfactory plan is obtained, FDO directs MARS to transfer the plan to Eph 7 and iterate (if necessary). MARS configures the Maneuver Transfer Table (MTT), has FDO verify it, then transfers the plan to the ephemeris. MARS uses delegated DMTs 7 and 8 to check range and height offsets. OMP area or MCT secondary constraints are modified as described in Section 3.10.4.1.5, and the OMP is re-que'd in order to obtain a match between OMP impulsive/AEG and TrS finite/Encke modeling. This activity takes place iteratively without FDO's direct involvement. After good DMT offsets are obtained, MARS notifies FDO the plan is iterated. FDO must verify that the MET and DMTs look good, then notify MARS to ship the final plan to Eph 1. MARS will execute the maneuver transfer protocol (described next) together with DYNAMICS, assuring a valid transfer to the prime Orbiter ephemeris. After the TUP is complete, MARS will compare the MPT against the MET, and check DMT offsets match Eph 7. FDO is notified "ephemeris 1 update complete...good offsets". FDO then may elect to have the plan transferred to E2 to update long-term acquisitions if significant changes have taken place.

Table 3.10.4.2-1 in a previous section showed standard DOR ephemeris configuration. It also identified so-called "golden ephemerides"--those from which flight critical calls/decisions are made, or from which commands loads are built. The MCC ephemeris operations concept does not allow MARS to transfer any OMP plan directly into a golden ephemeris (such as Eph 1) without first verifying a valid transfer into a "non-golden" ephemeris. To satisfy this, MARS will first transfer any OMP plan to their non-golden working ephemeris (Eph 7) to check DMT offsets, relative motion, etc. A couple of OMP executions and re-transfers may be required before satisfactory results are obtained. Then MARS notifies FDO the DMT offsets look good and the plan is ready to go to Eph 1 (or Eph2, or Eph 5 for Ti delay). Upon FDO's "go" to transfer, MARS initiates the protocol shown below with Dynamics. This is necessary since Dynamics is designated as the ephemeris "gatekeeper". No update to a golden ephemeris can occur without Dynamics approval. This discipline is responsible for logging all changes and error identification/troubleshooting associated with golden ephemerides.

### OMP Maneuver Transfer to Golden Ephemeris

MARS: obtain a clear GO from FDO to transfer plan to golden eph.

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MARS: "DYNAMICS, MARS...I'd like to transfer <plan name> to eph <number>, replacing <mnvr number, or 'no mnvrs'>."

DYNAMICS: check mnvr number matches next burn in eph; if not re-verify w/MARS. View online monitor; "MARS, DYNAMICS...you have a go to proceed."

MARS: execute Transfer to Ephemeris menu; monitor OMP for messages.

DYNAMICS: View online monitor. If mnvr specified to be replaced, verify M62 successfully sent. Monitor for other MED rejections; if none "MARS, DYNAMICS...transfer successful." Otherwise, notify MARS of error messages.

MARS: acknowledge DYNAMICS call of successful transfer or error messages, check MPT for correct mnvr content, check DMT for desired offsets, notify FDO of transfer results. If error encountered, notify FDO immediately.

Rigorous adherence to this protocol is essential for assuring the integrity of each golden ephemeris. Both MARS and Dynamics play an essential role in verifying good maneuver plan incorporation. During the process, several different malfunctions can occur due to human error and/or software limitations. These are listed in the table below, including error signatures and recovery steps. Note that Dynamics is prime for identifying errors on the Online Advisory, while MARS is prime for monitoring OMP messages and the MPT. Any troubleshooting should be preceded by notification of FDO, but the generic fix is to re-load the MTT, re-load the Transfer menu, check inputs, & re-transfer.



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**Table 3.10.4.2-2a: OMP Transfer Errors (continued)**

	Error	Result	Signature / Fix
1	Attempt to replace executed mnvr (future OMP mnvrs have same TIG as in MPT).	No mnvrs deleted. No eph update due to overlapping future mnvrs.	OMP: "Mnvr has been executed" Online: No M62 MED sent "MED M67 rejected: overlapping mnvrs" <b>Fix: Re-transfer w/correct mnvr replace no.</b>
2	Attempt to replace executed mnvr (future OMP mnvrs have different TIG from what's in MPT)	No mnvrs deleted. Future mnvrs duplicated in eph.	OMP: "Mnvr has been executed" Online: No M62 MED sent MPT shows extra mnvrs; AutoMPT out of synch <b>Fix: Re-transfer w/correct mnvr replace no.</b> <b>Cycle AutoMOC for affected eph.</b>
3	Replace wrong future mnvr in eph (TIGs same as in MPT)	Overlapping mnvr(s) not accepted; rest of plan transfers ok.	Online: M62 MED successful "MED M67 rejected: overlapping mnvrs" MPT shows some mnvr DVs not updated <b>Fix: Re-transfer w/correct mnvr replace no.</b>
4	Replace wrong future mnvr in eph (TIGs different from what's in MPT)	Mnvrs duplicated in eph up to mnvr no. specified to be replaced.	Online: M62 MED successful MPT shows extra burns up to mnvr no. specified to be replaced <b>Fix: Re-transfer w/correct mnvr replace no.</b>
5	Failure to specify mnvr no. to be replaced OR Attempt to replace non-existing mnvr (TIGs same as in MPT)	Overlapping mnvr(s) not accepted.	Online: No M62 sent "MED M67 rejected: overlapping mnvrs" MPT shows some mnvr DVs not updated <b>Fix: Re-transfer w/correct mnvr replace no.</b>
6	Failure to specify mnvr no. to be replaced OR Attempt to replace non-existing mnvr (TIGs diff. from what's in MPT)	Mnvrs duplicated in eph.	Online: No M62 sent MPT shows extra mnvrs <b>Fix: Re-transfer w/correct mnvr replace no.</b>
7	Latest plan not loaded into Transfer to Eph menu	Stale plan is transferred	MPT does not match MET <b>Fix: Load Transfer to Eph menu (F1) &amp; re-transfer.</b>
8	Transfer to Eph menu does not have 'Y' flag for "TUP MOC eph?"	No adverse effect. Eph TUPed w/final M51 MED.	

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**Table 3.10.4.2-2b: OMP Transfer Errors (concluded)**

9	Double-click 'Execute' button on Transfer to Eph menu, or hold down F2 too long (auto-repeat on)	OMP attempts to transfer plan twice; fails on 2nd transfer due to no M62.	Online: No M62 sent on 2nd transfer "MED M67 rejected: overlapping mnvrs" "cannot delete empty slots" <b>Fix: Re-transfer plan</b>
10	Plan transferred to wrong eph	MPT contains different plan than desired.	Online: MEDs sent to different eph than planned MPT: shows different mnvr plan <b>Fix: Re-transfer plan into correct eph</b>
11	Non-existent plan typed into Transfer to Eph menu	No adverse effects. Error msg on menu.	Transfer to Eph menu: "Plan does not exist"
12	Leading zero or space entered in eph field	OMP interprets eph input field as "0"; no mnvrs deleted.	Online: No M62 MED sent Additional errors per case 1 and 2 <b>Fix: Drop &amp; recall OMP transfer menu</b> Re-transfer w/valid eph no (no leading 0) Cycle AutoMOC for affected eph. if req'd

The MPSR staffing requirement for each mission is 3 MARS and 1 Profile Support. One MARS is staffed on each shift from launch to docking. Post-undock support is required only when dual-vehicle type burns are being targeted with OMP (must be requested by Lead FDO). A Profile Support is required only for the execute team (Orbit 1). Off-nominal situations may require additional support to be called in on a best-effort basis (must be initiated by FDO on console). MARS can be utilized during slow periods to verify TIG slip and other data for future burns when Profile is not present. Orbit 1 MARS, Profile Support, and FDO Support support the Ascent Team on L-1 day to initialize trajectory processors and generate latest rendezvous plan and one day launch scrub plans. The same team comes in again on launch day at L-4 hrs, supporting from final launch window determination through preliminary NC-1 targeting. Profile is required to stay on console past Orbit 2 handover in order to validate NC-1 TIG slip data on a tracked-out Ground NAV solution, and to assure Orbit 2 FDO has all necessary data to support FD1 contingency planning. The Orbit 1 Profile is not be required to stay on console past NC-1 burnout, unless the burn was not completed as planned. Orbit 1 Profile may be allowed to delay start of FD2 shift as necessary to ensure adequate off duty time (however, FD2 start of shift must allow sufficient time to perform NC-2 TIG slip analysis, if applicable).

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L-1 day			T-0	NC-1		NC-2	NC-3		DOR	
			↓	↓		↓	↓			
Asc		PIng	Asc	O2	PIng	O1	O2	PIng	O1	O2
FDO Supt MARS Profile			FDO Supt MARS Profile----	MARS --->	MARS	MARS Profile	MARS	MARS	MARS Profile	

**Figure 3.10.4.2-12: Rndz Team Console Staffing**

### 3.10.4.2.11 Deploy-Retrieve Profiles

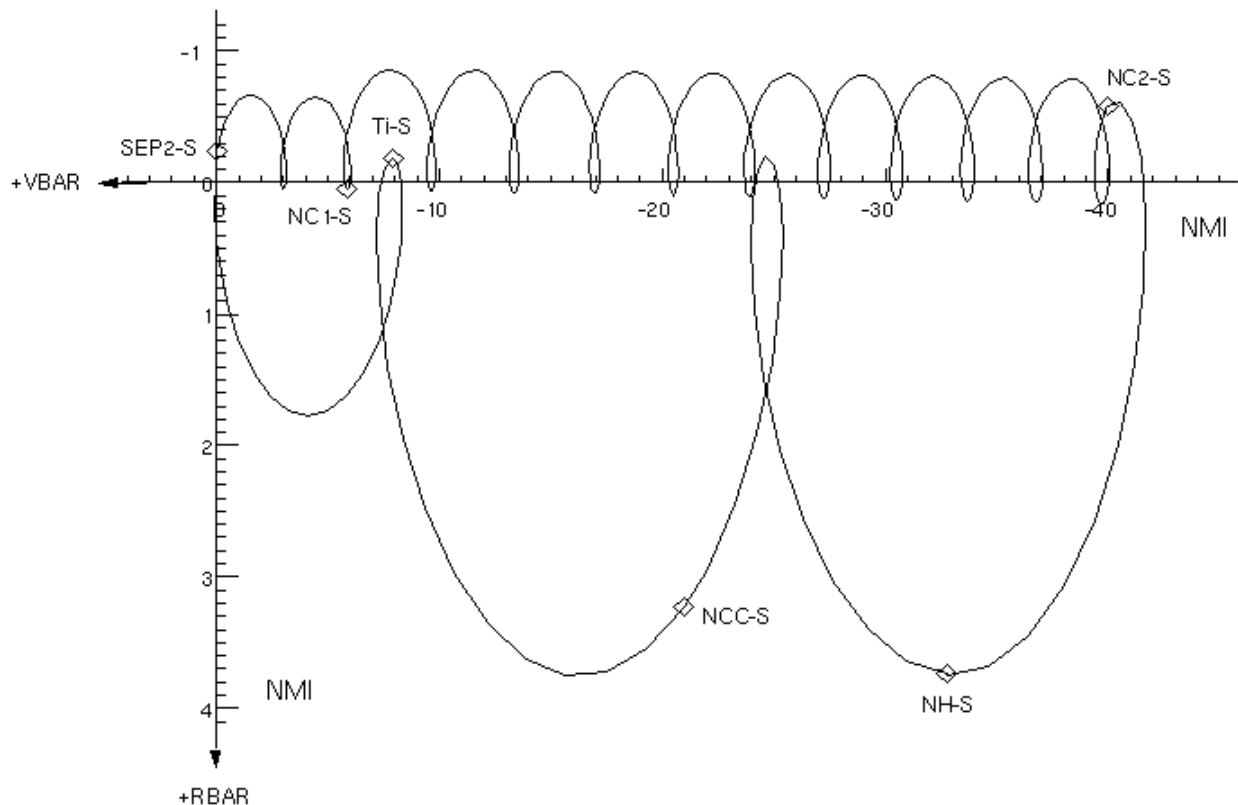
So far, this chapter has dwelt mostly with ground up rendezvous profiles and procedures. While many topics previously covered are generic in nature, some changes to standard operating procedures are required for deploy-retrieve profiles. This section will present those differences.

Deploy-retrieve profiles consist of three subparts: deploy, stationkeeping (optional), and rendezvous. Deployment is usually accomplished by the RMS, followed shortly thereafter by one or more separation burns. These are usually performed by the Orbiter, but sometimes are performed by the payload. The "SEP" burns provide safe opening rate between the Orbiter and target. Once a safe distance has been achieved, a series of stationkeeping burns may be employed to halt the opening rate and maintain the desired stationkeeping range. After the specified period of free-flight time has expired, the Orbiter performs a phasing burn to return to the target and complete the rendezvous. Sometimes a standard ISS-type rendezvous profile is flown, while other missions require deviation, such as a rendezvous from in front. All profiles eventually converge on the standard Ti position 8 nm behind the payload so that subsequent terminal phase operations can be conducted without extensive crew and FCT re-training, and development of new procedures and ILOADs. Rendezvous and prox ops ends with payload grapple and berthing. An "in front" deploy-retrieve profile was presented earlier in Figure 3.10.1.4-4. A rendezvous from behind is shown below in Figure 3.10.4.2-12. A more detailed description of the three subphases is presented next, along with operational considerations specific to deploy-retrieve missions.

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### STS-77 FRR Cycle Design

#### Target-Centered Orbiter Relative Motion for SPARTAN-207



**Figure 3.10.4.2-13: Deploy-Retrieve Relmo (Rendezvous From Behind)**

**Separation** - Prox Ops Flight Design will come up with a deploy window and Orbiter attitude that satisfies both payload and Orbiter constraints. Payload constraints are specified in the Payload Integration Plan (PIP), while generic Orbiter constraints are specified in the Level B Space Shuttle Operational Flight Design Standard Groundrules and Constraints Section 4.5.2. The composite deploy window is documented in the flight-specific Level A Groundrules and Constraints document. Considerations for a deploy window usually consist of lighting and pointing constraints (e.g. SPARTAN horizon sensor orientation), RMS position/crew visibility, comm requirements, and relative motion. The last item is of particular interest to FDO, since it will be FDO's responsibility in real-time to assure a safe separation profile even under off-nominal conditions. Many deployments require an inertial hold for satellite pointing, resulting in constantly-changing LVLH sep components over time. The deploy window design should factor this in, to maintain safe relative motion throughout. A thorough TIG slip analysis should be conducted pre-flight for all sep burns to understand how relative motion changes as the deploy time slips through the window.

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While the Orbiter usually performs the separation burns, some payloads perform their own (e.g. Wake Shield Facility). Direction of the separation burns is determined by the preferred location for stationkeeping. The most propellant efficient stationkeeping mode is along the  $\pm V$  bar, where the chaser and target velocities are the same. This enables long term stationkeeping capability with minimum prop usage. Some payloads require Orbiter Payload Interrogator (PI) comm link with the free-flyer for real-time monitoring and control. This antenna is mounted in the payload bay and must be pointed towards the payload. In this case, Orbiter in front of the payload on the +V bar is the preferred stationkeeping location since this results in Orbiter +ZVV attitude, which is better for orbital debris than -ZVV on the -V bar. Other payloads may not care where the Orbiter is if they have no comm requirements, so in that case the -V bar is usually chosen since it has slightly lower propellant cost for the rendezvous.

Most separation burns are in-plane in order to avoid a subsequent NPC, and usually only one or two are required. Following the sep burn(s), but prior to crew sleep, is an NC burn targeting the desired stationkeeping range at some future time (usually crew wakeup). Some profiles make SEP-2 a FDO-targeted phasing burn to do just this, so that the end-of-the-day NC burn is not required. It is important when targeting all separation and phasing burns that the TrS target characteristics, and attitude and vent timelines be properly configured in order to have accurate drag modeling.

**Stationkeeping** - Crew sleep occurs sometime after the sep burns, normally while the Orbiter is heading outbound. At some point during the next day another burn is performed to null the opening rate and stationkeep at the desired range. For payloads with short deployment periods, a phasing burn may be performed here to begin heading back in for rendezvous the following day. Stationkeeping gets tricky if there are stringent range requirements. For example, on STS-85, CRISTA SPAS required near-continuous PI comm link that limited the maximum acceptable range to 60 nm. The minimum range (constrained by SPAS science) was 11 nm. Numerous Orbiter attitude maneuvers for the International Extreme Ultraviolet Hitchhiker (IEH) experiment made the stationkeeping task difficult, even with twice-daily burns. On top of this, CRISTA SPAS vented cryogenic coolant, resulting in larger than normal KCON variation. All of these factors lead to the need for frequent C-band tracking on both the Orbiter and target, and vigilance on the part of the entire Flight Dynamics team to stay within range limits.

Normally two stationkeeping burns are planned each day—one for the crew morning and one for the evening. These are targeted as NC burns. The same tracking/timeline constraints apply for these as for other rendezvous phasing burns. That is, try to avoid attitude maneuvers, water dumps, IMU aligns, etc for 2 orbits prior to TIG, and resist these items being placed after the evening burn prior to crew

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sleep. The reason to avoid significant pre-sleep perturbations is that any energy hit will have all night to propagate into downtrack error before the next morning's burn. This could lead to unacceptable range and the need to wake the crew up to perform an unscheduled burn. Also for this reason, it is good practice to avoid a significant closing rate going into crew sleep. Rather, aim for the close-in range during the crew day and then allow the Orbiter to drift out at night. Frequently during missions, it is possible to observe repeatable effects of water dumps, attitude maneuvers, etc. By all means incorporate this knowledge into burn targeting if possible. In fact, water dumps have been modeled *pre-priori* as EXDVs on several missions, after a dependable trend was established.

As with GURs, there is some flexibility in the timeline for burn placement. Ideally, TIGs for daily phasing burns should be picked so that the burn occurs at relative apsis, and as close to the  $V_{bar}$  as possible. By burning at either relative apogee or perigee,  $\Delta v$  will be minimized, and "loops" will be kept as tight as possible. Burning close to the  $V_{bar}$  keeps the height error to a minimum and decreases the likelihood of having to perform NH on DOR. Relmo can be used to determine the time at which the Orbiter relative height ( $Z$ ) is a local minima or maxima as required, so that TIG can be placed here. For example, in Figure 3.10.4.2-12 above, NC-2S should be moved earlier by almost  $\frac{1}{2}$  rev in order to burn at relative perigee below the  $V_{bar}$ . Then the tops of the subsequent hops will reach just below the  $V_{bar}$  where they need to be for  $T_i$  (1200 ft below). Profile Support or MARS can provide assistance in TIG optimization during stationkeeping.

Towards the end of the stationkeeping phase, an NPC burn may be inserted if the sep sequence included an out-of-plane component, or if the payload experienced significant planar disturbances due to attitude maneuvers, venting, etc. However, an NPC is not normally required, and NCC is often adequate to correct any planar errors. Remember that some stationkeeping geometries allow onboard sensors to be utilized as a substitute or improvement over ground tracking. A ST pass could be used to assess planar error and target an NPC. Likewise, radar marks could be incorporated within 22 nm in order to fine-control the trajectory when close-in.

**Rendezvous** - At the appointed time, rendezvous is kicked off with a phasing burn designed to close the Orbiter to  $T_i$  at 8 nm behind the target. If the Orbiter was stationkeeping on the  $+V_{bar}$ , then the NC burn will have to be designed to "hop over" the target in order to get there<sup>20</sup>. Since deploy-retrieve rendezvous timelines

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<sup>20</sup> A two rev transfer from in front must provide a safe clearance for the middle hop, which restricts the range of acceptable starting positions. For example, in Figure 3.10.1.4-4, NC-4 occurs at 30 nm which provides a clearance of 11 nm at the middle hop. An unacceptable starting position would be 8 nm, which would result in near zero range at the middle hop. To protect for dispersions, it is prudent to provide a pad around the target depending on ground nav uncertainties. For example, to protect  $\pm 4$  nm around the target, don't start any closer than 16 nm for a two rev transfer from in front. An additional factor to consider is that if the Orbiter starts a two-rev to  $T_i$  transfer from within 22 nm, RR may be

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are usually more relaxed than for ISS docking, the luxury of a two-rev transfer to Ti is usually attainable (see Figure 3.10.4.2-12 above). This provides two ST passes prior to NCC, and smaller  $\Delta v$  for the NC burn initiating rendezvous. Another advantage of deploy-retrieve rendezvous profiles is that small phase rates prior to the start of rendezvous allow the final NC burn to be non-critical from a TIG slip standpoint. That is, the final phasing burn can be slipped a rev or two without penalty (of course at some point a phasing burn should be performed if to do nothing more than stabilize/correct the Orbiter's range). Also, FAO may have some timeline considerations that limit how late the rendezvous can start.

As with GURs, the need for NH is assessed by checking NCC  $\Delta v$  and seeing whether adding an NH significantly reduces NCC size. One unique property of the two rev transfer is that the middle hop (point closest to  $V_{bar}$  in-between NC and Ti) is an excellent place to correct any range error that may have crept into the profile. An NC burn may be inserted here in real-time to re-target Ti for 8 nm. This position is more efficient to correct range error than is NCC, since NCC requires a combination of horizontal and radial  $\Delta v$  to control range, while the inserted NC burn can do it with horizontal  $\Delta v$  alone. Use the OMP to compare  $\Delta v$  required at the middle hop with an NC against NCC alone and discuss with PROP the results to see if it is worth doing. Another burn that can be inserted on a two-rev transfer is an NPC. The first ST pass will determine the planar error to a high degree of accuracy. Run the NCC plan off of onboard vectors after RELNAV converges. If there is a significant  $\Delta V_y$  at NCC ( $> 2$  fps), then consider inserting an NPC at the next node in order to get rid of the planar error. It may be cheaper to do it at a node rather than at the NCC point. This can be done as a +X burn to avoid sloppy handling characteristics due to off-axis jet firings for a body  $\pm Y$  burn, but it incurs a penalty. A dedicated attitude maneuver must be performed. Also, the NPC TIG should be chosen to occur such that it doesn't interfere with the next ST pass (check TIG with RGPO).

It is handy to have a combined NPC/extra NC MCT included with the other DOR MCTs to streamline evaluation of these two cases. See Figure 3.10.4.2-14 for an example from STS-95 SPARTAN rendezvous. Maneuver 1 is a placeholder EXDV set on a time just after the DOR NC burn. Maneuver 2 is a NPC burn with a NODE secondary constraint. On the MET, the TIG for NPC will indicate when the common node occurs, and the lighting will also be indicated so that NPC can be slipped  $\_$  rev if it will interfere with a ST pass. Maneuver 3 is a "middle-hop" phasing burn that can be used to correct Ti downtrack position and possibly save prop for NCC (which is modeled as an NH in slot 4). This plan covers two dispersion scenarios, but it can be tailored for the case at hand by deleting maneuvers 1-2 to insert the extra NC burn, or get rid of 3 for just the NPC case. Note that maneuver 4 is really NCC.

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employed to achieve an extremely accurate relative nav state. In this case it may be safe to decrease the "buffer zone" around the target if onboard vectors are used to target the NC burn.

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LOCAL

MANEUVER CONSTRAINTS TABLE STS95

COMMENT: STS-95 DOR NPC TGT &/OR 1 REV LATE NC

CURRENT

MNVRs: 4 / 40

MANEUVER	THRESHOLD	SECONDARIES		
1 EXDV	T 004:18:55:00.000	DVLV =0.0 = =	DVLV =0.0 = =	DVLV =0.0 = =
2 NPC NPC	DT 000:00:00:01.000	CN = = =	= = =	= = =
2 NC NC-4A	T 004:20:30:00.000	= = =	= = =	= = =
2 NH NCC	T 004:21:04:51.000	= = =	= = =	= = =
3 SOI Ti	T 004:22:04:57.000	DR =-8.0 = =	DH =0.2 = =	WEDG =0.0 = =
4 SOR MC-4	DT 000:01:20:06.000	CXYZ =-.1481 = =	CXYZ =0.0 = =	CXYZ =.2962 = =

**Figure 3.10.4.2-14: NPC/Extra NC Plan**

## 3.10.4.2.12 Console Checklists

Checklists are presented on the following pages to assist in real-time console ops. Each checklist starts at the top of a page to facilitate photocopying.



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## 3.10.4.2.12.1 FDO Support Checklist

### Pre-launch

- 1) Verify ATL, VTL, MCTs.
- 2) Verify TIG-fixed plan contains primary constraint "T" for 2<sup>nd</sup> mnvr so that mnvr 1 (OMS-2) may be deleted in real-time to check ascent team's OMS-2 in eph.
- 3) TIG-fixed plan should contain NPC for planar error assessment.
- 4) Variable OMS-2 Hp plan (NC) should be included for MECO underspeed case.
- 5) Confirm ET photo +X translation GO/No-GO plan w/FDO.
- 6) Run OMP plans for window open and close to verify nominal OMS-2 Hp.
- 7) Develop hip-pocket OMS He leak burn plan (maximize uphill  $\Delta v$ ).

### Launch

- 8) If launch slip:
  - a) Verify new liftoff time in TSA Global System
  - b) Check SR/SS for Ti time & update plans if req'd
- 9) If underspeed post-MECO (ops phase):
  - a) Initial OMS-2 Hp guess (nm):
  - b) 
$$\frac{\text{Nom MPS dump Ha}}{\text{Nom OMS-2 tgt Ht}} + \frac{\text{Nom OMS-2 tgt Ht}}{\text{actual Ha}} = \frac{\text{Nom OMS-2 tgt Ht}}{\text{actual Ha}} + \frac{\text{Nom OMS-2 tgt Ht}}{\text{desired OMS-2 tgt Ht}}$$
  - c) Run plan w/OMS-2 as NC to compute desired OMS-2 Hp.
  - d) If FD2/3 capability: Run FD2 first for OMS-2 Hp, then verify for FD3.
  - e) If retro phasing burn, then delete all posi biases; consider Ti slip
  - f) Pass PROP following quantities:

$$\frac{\text{rndz } \Delta v \text{ (incl OMS-2)}}{\text{fps}}$$

$$\frac{\text{nom D/O } \Delta v}{\text{fps}}$$

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### 3.10.4.2.12.2 Pre-Day of Rendezvous Planning Team Tasks

- 1) Review Tracking Plan w/NAV
- 2) Verify all MCTs
- 3) Check target lighting for Ti TIG (use OMP MET lighting; don't update for lighting errors < 30 sec)
- 4) Perform final rendezvous plan iteration (Ti lighting &  $\Delta VZ$ , NC placement wrt orbital noon for ST pass, planar error, etc)
- 5) Configure MTTs (Impulsive flag=OPT for non-Lambert burns, TVR=0 for posigrade burns from behind. If -Z ST ↓, use TVR=90 for NH & NC).
- 6) Provide MET & state vectors to external customers
- 7) Generate TIGs flight note for FCT & morning mail (also generate Ti Delay note for FDO console).
- 8) DOR relmo plot for morning mail
- 9) Preliminary maneuver PADs for morning mail
- 10) Provide vectors to USSPACECOM (burnout of all major Orbiter burns plus one target vector to screen arrival space).
- 11) Set up TrS ephemerides as specified by Rndz FDO
- 12) Set PET clock
- 13) Re-boot workstations

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## 3.10.4.2.12.3 Rendezvous Prep

- 1) Verify proper tools avail (Rndz C/L, Flt Rules, Flt Plan, Prelim PADs, Calculator)
- 2) Work through CONSOLE INITIALIZATION checklist with following delta's:

- a) Verify TrS ephem config
- b) ✓ AutoMOC running E1, 3, 5-8
- c) ✓ ROSS Timing Services Active
- d) G55\$

E#	Contents	Anchor	Intgr	STDN	Length
E1	Short Term Orb	V39	VAM	Y	48 hrs
E2	Long Term Orb	<24 hrs	VAM	N	<480 hrs
E3	Prime Tgt	V38	(V)DM	Y	48 hrs
E4	Debris/Dply	VAT	DM	N	as req'd
E5	O/B Orb	FLTM	VAM	N	12 hrs
E6	O/B Tgt	TVTM	DM	N	12 hrs
E7	Rndz planning	V39	VAM	N	12 hrs
E8	Rndz cont. plan.	V39	VAM	N	48 hrs

- 3) ✓ USSTRATCOM clearance.
- 4) Rendezvous Initialization
  - a) Record SR/SS for target (nominal, 1 & 2 orbits late)
  - b) Verify Ti times (✓RGPO) → MARS/PROFILE
  - c) TRAJ: RMM (✓I-Loads), TIG flight note (nom & 1 rev late), ✓AMP prelim PADs
  - d) TRAJ: Start PET clock for Ti & DOCK clock (✓RGPO); O-IGN auto from E1

- 5) MARS Tag-Up
  - a) Verify all nominal MCT & MTT
  - b) ✓OMP variables vs. bench hardcopy  
✓PLOT flag: Global=OFF / Local=ON (60 s)
  - c) Purge old OMP data from OMP/Output
  - d) Verify preliminary plan
  - e) Transfer to E7 iterate on E7 offsets
  - f) Transfer plan to E1 & E2 (✓offsets)

<u>Iteration success criteria:</u>			
DX	≤ 3.0 kft	future mnvr	> 3 revs
"	≤ 2.3 kft	"	= 3 revs
"	≤ 1.5 kft	"	= 2 revs
"	≤ 0.7 kft	"	= 1 rev
DZ	≤ 0.2 kft always		

- 6) PROFILE Tag-up
  - a) Verify all contingency MCT & MTT
  - b) ✓OMP Vars (PLOT flag ON, Δt = 60 s)
  - c) Verify R/T Relmo ready for VTR project
  - d) Discuss TIG slip &/or special analysis [NH, NC (1 & 2 rev xfer), Ti Delay]

<u>MTT Guidelines:</u>	
Thruster	DV < 6 fps: PX2; SOI: OL; else OBP
Guidance	P7
Iterate	NO for all dual veh mnvrs
TIG	IMP for all Lambert burns, else OPT
TVR	0 for all posi DOR; else 180 (90 if -Y ST for posi NC/NH)

- 7) PROP Tag-Up
  - a) Provide copy of nominal plan
  - b) Verify nominal thruster selection & thruster sensitivity; talk prop margins
- 8) GNAV Tag-Up
  - a) Verify VTL configured; history data available (sim)
  - b) Review tracking timeline and negotiate vector delivery schedule
  - c) Review any ground station/TDRS anomalies

- 9) Checkpoint TrS & TSA Global.

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### 3.10.4.2.12.4 NH Maneuver (If Required)

- 1) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target. Uplink 400xx, 401xx, and 402xx prior to RELNAV enable.
- 2) MARS: if no NH planned, run NC4 on E7/E3.  
FDO: record NCC  $\Delta v$  w/out NH burn (NCC modeled as NH).

NCC $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	VID

TRAJ: compute VGOs. If FRCS usage @ NCC < 2 fps, NH not req'd (✓PROP), then go to **NC** page.

- 3) NH Maneuver Targeting
  - a) MARS: run NH on E7/E3.
    - ✓Ti lighting (SS -TBD per | $\beta$ | and RPM constraints).
    - ✓Ti  $\Delta V_y < 1$ fps, else consider inserting NPC prior to NC.
    - Time NH for 40 nm range @ NC; iterate NC TIG for Ti  $\Delta V_z < 1$ fps (NLT noon -5 min, if possible).
  - b) MARS: transfer to E7 & iterate on relative offsets as required.
  - c) MARS: transfer to E1 when complete (✓offsets).

NH $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	VID

If NH  $\Delta v$  is small, repeat NCC  $\Delta v$  check without NH above.

- 4) Prepare maneuver PAD & command load.
  - a) NH max TIG slip from PROFILE = \_\_\_\_\_ min LVLH or IAH
  - b) TRAJ: generate Final NH PAD ( $\Delta s$  only)
  - c) Generate PEG-7 command load (40601)
  - d) ✓PAD read-up time for bad comm, ZOE
  - e) Maneuver-to-attitude time (A/ALT @ 0.2°/sec) = \_\_\_\_\_ min  
 (B/ALT @ 0.5°/sec) = \_\_\_\_\_ min

- 5) Uplink NH PAD, Tgts; execute burn:

NH $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	
				Planned
				Confirmed

TRAJ: confirm in E1 & 7. Delete 40601.

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## 3.10.4.2.12.5 NC Maneuver

- 1) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
- 2) RELNAV ENA
  - a) U/L target vector prior to RELNAV ENA.
  - b) PROFILE: configure R/T Relmo with FILT/PROP and predictor bugs ON.
- 3) NC Maneuver Targeting
  - a) MARS: run NC on E7/E3.
    - ✓Ti lighting (SS -TBD per |β| and RPM constraints).
    - ✓Ti  $\Delta V_y < 1\text{fps}$ , else consider inserting NPC prior to NC.
    - Time NC for Ti  $\Delta V_z < 1\text{fps}$  (NLT noon -5 min, if possible).
  - b) MARS: transfer to E7 & iterate on relative offsets as required.
  - c) MARS: transfer to E1 when complete (✓offsets).

NC $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	VID

- 4) Prepare maneuver PAD & command load.
  - a) NC max TIG slip from PROFILE = \_\_\_\_\_ min LVLH or IAH
  - b) TRAJ: generate Final NC PAD ( $\Delta s$  only)
  - c) Generate PEG-7 command load (40601)
  - d) ✓PAD read-up time for bad comm, ZOE
  - e) Maneuver-to-attitude time (A/ALT @ 0.2°/sec) = \_\_\_\_\_ min  
 (B/ALT @ 0.5°/sec) = \_\_\_\_\_ min

- 5) Uplink NC PAD, Tgts; execute burn:

NC $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	
				Planned
				Confirmed

TRAJ: confirm in E1 & 7. Delete 40601.

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## 3.10.4.2.12.6 First Star Tracker Pass & NCC Maneuver

**CAUTION:** due to Lambert guidance during TIG slips, onboard FLTR/PROP solutions are preferred to a Ground downmode in the following sequence.

- A) Burn FLTR if converged sensor data incorporated or PEG-7s < 3σ limits.
- B) Burn PROP if corrupted data in FLTR and PEG-7s < 3σ limits.
- C) Burn Ground PEG-7s unless valid IMU data recently incorporated onboard.

- 1) MARS: immediately post-NC, grab onboards & run NCC.
- 2) ST Pass
  - a) First State Vector Update = \_\_\_\_\_ ft
  - b) MARS: grab onboards & run NCC during crew targeting and every 40 marks.
  - c) TRAJ: pass VGOs to PROP; inform crew if Δv > 4 fps, but GO for multi-axis.
  - d) ONAV: grab onboards every 40 marks and store in VAT slots 1-6.
  - e) FILT - PROP @ end of star tracker pass = \_\_\_\_\_ ft

- 3) NCC Onboard Solution (ground processing)

NCC ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	Marks

- 4) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.

- 5) Ground NCC Maneuver Targeting
  - a) MARS: run NCC on E7/E3.
  - b) MARS: transfer to E7 (✓offsets).
  - c) MARS: transfer to E1 (✓offsets).
  - d) TRAJ: generate Ground NCC PAD.

NCC ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	VID

- 6) Preliminary Ti Ground Solution: MARS runs Ti on E7/E3, fetching before/after NCC.

Ti ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	Range	ΔHeight	MC2 Slip	
							w/NCC
							No NCC
							Onboard

- 7) NCC Onboard Solution (onboard processing)

NCC ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	Sol'n/Marks
				Pre/
				Int/
				Final/
				Confirmed

TRAJ: confirm in E1 & 7.

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## 3.10.4.2.12.7 Ti Maneuver

**CAUTION:** due to Lambert guidance during TIG slips, onboard FLTR/PROP solutions are preferred to a Ground downmode in the following sequence.

- A) Burn FLTR if converged sensor data incorporated or PEG-7s < 3σ limits.
- B) Burn PROP if corrupted data in FLTR and PEG-7s < 3σ limits.
- C) Burn Ground PEG-7s unless valid IMU data recently incorporated onboard.

- 1) MARS: immediately post-NCC, grab onboards & tun Ti.
- 2) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
- 3) Ground Ti Maneuver Targeting
  - a) MARS: run Ti on E7/E3.
  - b) MARS: transfer to E7 (✓offsets).
  - c) MARS: transfer to E1 (✓offsets).
  - d) ✓Ti position & MC2 TIG slip. If dispersed or out-of-limits, consider Ti Delay.

Ti $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	MC2 Slip	VID

- 4) Prepare maneuver PAD & command load
  - a) Note on PAD "If Ti Not Started By TIG +x Min, Perform Ti Delay", where x = Ti Delay max TIG slip -1 min.
  - b) TRAJ: generate Ground Ti PAD ( $\Delta s$  only).
  - c) Generate PEG-7 command load (40601).
  - d) Maneuver-to-attitude time (A/ALT @ 0.2°/sec) = \_\_\_\_\_ min  
(B/ALT @ 0.5°/sec) = \_\_\_\_\_ min
- 5) RR Pass
  - a) First State Vector Update = \_\_\_\_\_ ft
  - b) MARS: grab onboards & run Ti during crew targeting and every 40 marks.
  - c) ONAV: grab onboards every 40 marks and store in VAT slots 1-6.

6) Ti Onboard Solution (ground processing)

Ti $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	MC2 Slip	Marks

7) Ti Onboard Solution (onboard processing)

Ti $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	Sol'n/Marks
				Pre/
				Int/
				Final/
				Confirmed

TRAJ: confirm in E1 & 7. Delete 40601 & 02.

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## 3.10.4.2.12.8 Ti Delay (TID) Maneuver

- 1) Determine best-source ephemeris for Ti Delay solution (✓RGPO for ONAV health).
- 2) If Best-Source = Onboard:
  - a) After RR converged, TUP E5 & 6 on onboards (Init weight = E1 Current weight).
  - b) ✓E5/E6 mirrors are ON.
  - c) Switch DMT 2 target ephemeris to E6.
  - d) MARS: run TID on E5/E6.

TID $\Delta V_{TOT}$	$\Delta V_x = NC \Delta V_x$	$\Delta V_x = SOI \Delta V_y$	$\Delta V_x = SOI \Delta V_z$	Marks

- 3) If Best-Source = Ground:
  - a) TUP E5 out of E1 @ ~Ti -15 min (Init weight = E1 Current weight).
  - b) ✓E5 mirror is ON.
  - c) MARS: run TID on E5/E3.

TID $\Delta V_{TOT}$	$\Delta V_x = NC \Delta V_x$	$\Delta V_y = SOI \Delta V_y$	$\Delta V_z = SOI \Delta V_z$	VID

- 4) Target Ti Delay.
  - a) MARS: configure TID2 based on TID results; run TID2 on best-source ephem.
  - b) MARS: transfer TID2 to E5 (✓offsets).
  - c) Verify relative motion on R/T Relmo.
  - d) Inform PROP of TID2  $\Delta V_{TOT}$ ; verify thruster selection.
- 5) Prepare maneuver PAD and command load.
  - a) TRAJ: PAD Ti Delay.
  - b) Generate PEG-7 command load (40602).
  - c) PROFILE: supply Ti Delay max TIG slip = \_\_\_\_\_ min LVLH/IAH.
  - d) Note on PAD, "Max TIG Slip = x Min; <Do NOT> Reload Targets", where x = Ti Delay max TIG slip.  
CAUTION: cannot load targets or EXEC an OMS burn w/TIG > 5 min in the past.

- 6) If Ti Delay declared:
  - a) U/L 40602; have MARS transfer TID2 to E7 & E1 (or confirm Ti w/Ti Delay  $\Delta v$ ).
  - b) Execute burn.

TID $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	
				Planned
				Confirmed



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## 3.10.4.2.12.9 Post-Ti-Delay NCC Maneuver

**CAUTION:** due to Lambert guidance during TIG slips, onboard FLTR/PROP solutions are preferred to a Ground downmode in the following sequence.

- A) Burn FLTR if converged sensor data incorporated or PEG-7s < 3σ limits.
  - B) Burn PROP if corrupted data in FLTR and PEG-7s < 3σ limits.
  - C) Burn Ground PEG-7s unless valid IMU data recently incorporated onboard.
- 1) New Base Time = \_\_\_\_\_.
  - 2) Distribute one-rev-late TIGs Flight Note ASAP. Crew loads new BaseTime as SPEC 33 ITEMS 21 through 24, followed by ITEM 26.
  - 3) PROFILE: reconfigure NCC through MC-4 MCTs to reflect new BaseTime.
  - 4) Submit second NCC Flight Note by required checklist PET.  
**NOTE:** ground ephemerides will likely be stale post-Ti-Delay. Expect large ground/onboard NCC Δv differences.
  - 5) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
  - 6) "No NCC Required" RelMo assessment
    - a) MARS: run Ti on E7/E3.
    - b) From R/T Relmo's Curves/ASCII menu, select Global to choose "nom sensors" or other applicable curves for this assessment.

Ti ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	Range	ΔHeight	MC2 Slip	
							Ground
							Onboard

c) If  $-3 \leq \text{MC2 Slip} \leq +7$  and Ti position within  $3\sigma$  ellipse, NCC not required this rev.

- 7) Ground NCC Maneuver Targeting
  - a) MARS: run NCC on E7/E3.
  - b) MARS: transfer to E7 (✓offsets).
  - c) MARS: transfer to E1 (✓offsets).
  - d) TRAJ: generate Ground NCC PAD.

NCC ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	VID

- 8) NCC Onboard Solution (ground processing)

NCC ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	Marks

- 9) NCC Onboard Solution (onboard processing)

NCC ΔV <sub>TOT</sub>	ΔV <sub>x</sub>	ΔV <sub>y</sub>	ΔV <sub>z</sub>	Sol'n/Marks
				Pre/
				Int/
				Final/
				Confirmed

TRAJ: confirm in E1 & 7.

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## 3.10.4.2.12.10 Delayed Ti Maneuver

**CAUTION:** due to Lambert guidance during TIG slips, onboard FLTR/PROP solutions are preferred to a Ground downmode in the following sequence.

- A) Burn FLTR if converged sensor data incorporated or PEG-7s < 3σ limits.
- B) Burn PROP if corrupted data in FLTR and PEG-7s < 3σ limits.
- C) Burn Ground PEG-7s unless valid IMU data recently incorporated onboard.

- 1) MARS: immediately post-NCC, grab onboards & run Ti.
- 2) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
- 3) Ground Delayed Ti or Ti Delay-2 Maneuver Targeting
  - a) PROFILE: verify safe relmo following Delayed Ti waveoff.
  - b) MARS: run Delayed Ti on E7/E3.
  - c) TRAJ: Delayed Ti target track attitude from PTG, VGOs to PROP - MA or +X.
  - d) MARS: reconfigure Delayed Ti MTT thruster/TVR (180° if retro & behind target).  
Transfer to E7 (✓offsets).  
MARS: transfer to E1 (✓offsets).
  - e) ✓Delayed Ti position & MC2 TIG slip. If dispersed or out-of-limits, consider Ti Delay-2.

Ti $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	MC2 Slip	VID

- 4) Prepare maneuver PAD & command load.  
**NOTE:** if safe relmo without Ti Delay-2, compute TIG slip assuming a Delayed Ti burn under Lambert guidance with retargeting every 90 sec.
  - a) PROFILE: supply Delayed Ti max TIG slip = \_\_\_\_\_ min Lambert/LVLH/IAH.
  - b) TRAJ: generate Ground Delayed Ti PAD ( $\Delta s$  only).
  - c) Generate PEG-7 command load (40601).
  - d) Maneuver-to-attitude time (A/ALT @ 0.2°/sec) = \_\_\_\_\_ min  
(B/ALT @ 0.5°/sec) = \_\_\_\_\_ min
- 5) Post-Ti-Delay-1 RR Pass
  - a) MARS: grab onboards & run Ti during crew targeting and every 40 marks.
  - b) ONAV: grab onboards every 40 marks and store in VAT slots 1-6.

- 6) Delayed Ti Onboard Solution (ground processing)

Ti $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	MC2 Slip	Marks

- 7) Delayed Ti Onboard Solution (onboard processing)

MC1 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	Sol'n/Marks
				Pre/
				Int/
				Final/
				Confirmed

TRAJ: confirm in E1 & 7. Delete 40601.

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### 3.10.4.2.12.11 MC1 Maneuver

- 1) MC1 Onboard Solution (ground processing):
  - a) MARS: immediately post-Ti, grab onboards and run MC1.
  - b) MARS: transfer to E7 (✓offsets).  
 Transfer to E1 when complete (✓offsets).

MC1 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	MC2 Slip	Mark

- 2) Post-Ti RR Pass
  - a) MARS: grab onboards & run MC1 during crew targeting and every 40 marks.
  - b) ONAV: grab onboards every 40 marks and store in VAT slots 1-6.
  - c) Inform crew if  $\Delta v > 4$  fps, but GO for multi-axis burn.
- 3) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
- 4) Optimum time for inplane breakout is SS to MC2.
- 5) ✓Planar Null  $\Delta v$  reasonable. Otherwise, consider maneuver to NPC attitude.
- 6) MC1 Onboard Solution (onboard processing)

MC1 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	Sol'n/Marks
				Pre/
				Int/
				Final/
				Confirmed

TRAJ: confirm in E1 & 7.

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## 3.10.4.2.12.12 MC2 & Planar Null Maneuvers

**WARNING:** MC3/4  $\Delta v$  sensitive to MC2 trim error. Trim MC2 VGOs  $\leq 0.2$  fps.

- 1) MC2 Onboard Solution (ground processing):
  - a) MARS: immediately post-MC1, grab onboards and run MC2.
  - b) MARS: update MC2 TIG in MC2FIX and run with onboards.  
 Transfer MC2FIX to E7 (✓offsets).  
 Transfer to E1 when complete (✓offsets).

MC2 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	MC2 Slip	Marks

- 2) Post-MC1 RR Pass
  - a) MARS: grab onboards & run MC2 during crew targeting and every 40 marks.
  - b) ONAV: grab onboards every 40 marks and store in VAT slots 1-6.
  - c) Inform crew if  $\Delta v > 4$  fps, but GO for multi-axis burn.
- 3) TRAJ: set ET countdown/countup timer to onboard MC2 TIG.
- 4) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
- 5) Optimum time for inplane breakout is SS to MC2.
- 6) ✓Planar Null  $\Delta v$  reasonable. Otherwise, consider maneuver to NPC attitude.
- 7) MC2 Onboard Solution (onboard processing)

MC2 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	TIG Slip	Sol'n/Marks
					Pre/
					Int/
					Final/
					Confirmed

TRAJ: Confirm in E1 & 7

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### 3.10.4.2.12.13 MC3 Maneuver

**WARNING:** MC4  $\Delta v$  sensitive to MC3 trim error. Trim MC3 VGOs  $\leq 0.2$  fps.

- 1) Verify TIG updated based on MC2 actual TIG.
- 2) MC3 O/B Solution (ground processing):
  - a) MARS: immediately post-MC2, grab onboards and run MC3.
  - b) MARS: transfer to E7 (✓offsets).

Transfer to E1 when complete (✓offsets).

MC3 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	Marks

- 3) Post-MC2 RR Pass
  - a) MARS: grab onboards & run MC3 during crew targeting and every 40 marks.
  - b) ONAV: grab onboards every 40 marks and store in VAT slots 1-6.
  - c) Inform crew if  $\Delta v > 4$  fps, but GO for multi-axis burn.
- 4) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
- 5) MC-3 Onboard Solution (onboard processing)

MC3 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	Sol'n/Marks
				Pre/
				Int/
				Final/
				Confirmed

TRAJ: confirm in E1 & 7.

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### 3.10.4.2.12.14 MC4 Maneuver

- 1) Verify TIG updated based on MC2 actual TIG.
- 2) MC4 O/B Solution (ground processing):
  - a) MARS: immediately post-MC3, grab onboards and run MC4.
  - b) MARS: transfer to E7 (✓offsets).

Transfer to E1 when complete (✓offsets).

MC4 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	Marks

- 3) Post-MC3 RR Pass
  - a) MARS: grab onboards & run MC4 during crew targeting and every 40 marks.
  - b) ONAV: grab onboards every 40 marks and store in VAT slots 1-6.
  - c) Inform crew if  $\Delta v > 4$  fps, but GO for multi-axis burn.
- 4) If applicable, update E1 & 7 on latest Orbiter tracking; E3 on latest target.
- 5) MC4 Onboard Solution (onboard processing)

MC4 $\Delta V_{TOT}$	$\Delta V_x$	$\Delta V_y$	$\Delta V_z$	Sol'n/Marks
				Pre/
				Int/
				Final/
				Confirmed

TRAJ: confirm in E1 & 7.

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### 3.10.4.3 Off-nominal Rendezvous Operations

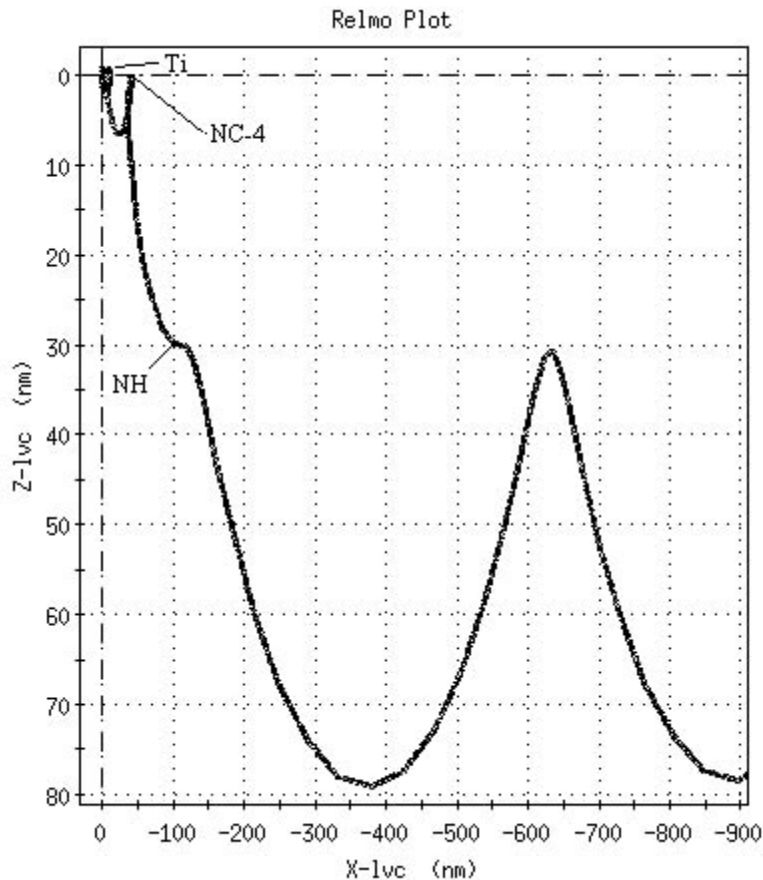
Rendezvous is *not* a highly automated flight phase, neither onboard nor in the MCC. While the crew is manually executing burns, controlling sensors, and flying the approach corridor, the ground is busy computing burn targets and preparing other console products to support the rendezvous. All of this manual effort takes place during even the most benign rendezvous. In addition to this, extra ground effort is expended to prepare for and protect against failure cases (e.g. Ti Delay targeting, TIG slip notes on burn PADs, monitoring of breakout options). The reason failure scenarios are prepared for ahead of time is that, once one occurs, a response plan must be readily available due to the time-critical nature of rendezvous. *Failure to correctly recover from an Orbiter anomaly in a timely manner could result in excessive propellant consumption, loss of rendezvous, and/or unsafe relative motion.* This section addresses Orbiter failures and outlines FDO responses in order to save the Orbiter, and then get the rendezvous back on track if possible.

#### 3.10.4.3.1 Trajectory Recovery

Onboard problems can quickly undo even the most well laid rendezvous plans—especially on DOR. This is particularly true for large phase angle cases in which the Orbiter is closing rapidly on the target. Figure 3.10.4.3-1 shows a large phase angle ISS rendezvous where a DOR NH is required. If either a critical NH or NC burn is not executed within its TIG slip window, then severe repercussions on the rendezvous profile will occur. In the Figure below, executing NH one rev late would place the Orbiter about 400 nm in front of the target rather than 40 nm behind. This would be very difficult, if not impossible, to recover from within normal propellant and timeline margins. Numerous problems could lead to a burn being missed, including ground failure to compute and uplink burn solution/PADs in a timely manner (assuming the crew fails to downmode to the preliminary solution), MCC-Orbiter communication problems, loss of multiple GNC GPCs, failure of the crew to maneuver to burn attitude in time, or failure of the crew to properly execute the burn or downmode in the event of a propulsion system failure. Even minor Orbiter systems problems can affect the trajectory if the crew or flight control team are allowed to become distracted with resolving a minor problem, to the point where no one is paying attention to an upcoming burn. *It is the responsibility of the FDO to prevent a loss of FCT situational awareness when a burn is approaching. Do not permit the team to lose its focus on what is most important!* This should underscore the importance of having burn targets and PADs ready on time. To facilitate this, during the burn planning process, check with INCO for comm predictions during the PAD/target uplink timeframe. Also check with Pointing for latest maneuver times. Advance preparation for critical burns will minimize your chances of making a special guest appearance before the MMT to explain how the rendezvous was blown.

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If a critical burn is not executed within its TIG slip limits, the crew must immediately be notified that they are NO-GO to burn. Expect severe propellant and timeline repercussions in this case. In general, rendezvous recovery from a missed or abnormally executed burn is accomplished via an NC/NH combination. Of course, actual recovery techniques must be tailored for the specific phase rate, failure mode, crew timeline, and propellant availability, but general techniques can be illustrated through the three examples to follow. The examples below assume a high phase rate in order to illustrate the worst-case scenario.



**Figure 3.10.4.3-1: Large Phase Angle DOR Trajectory (Nominal)**

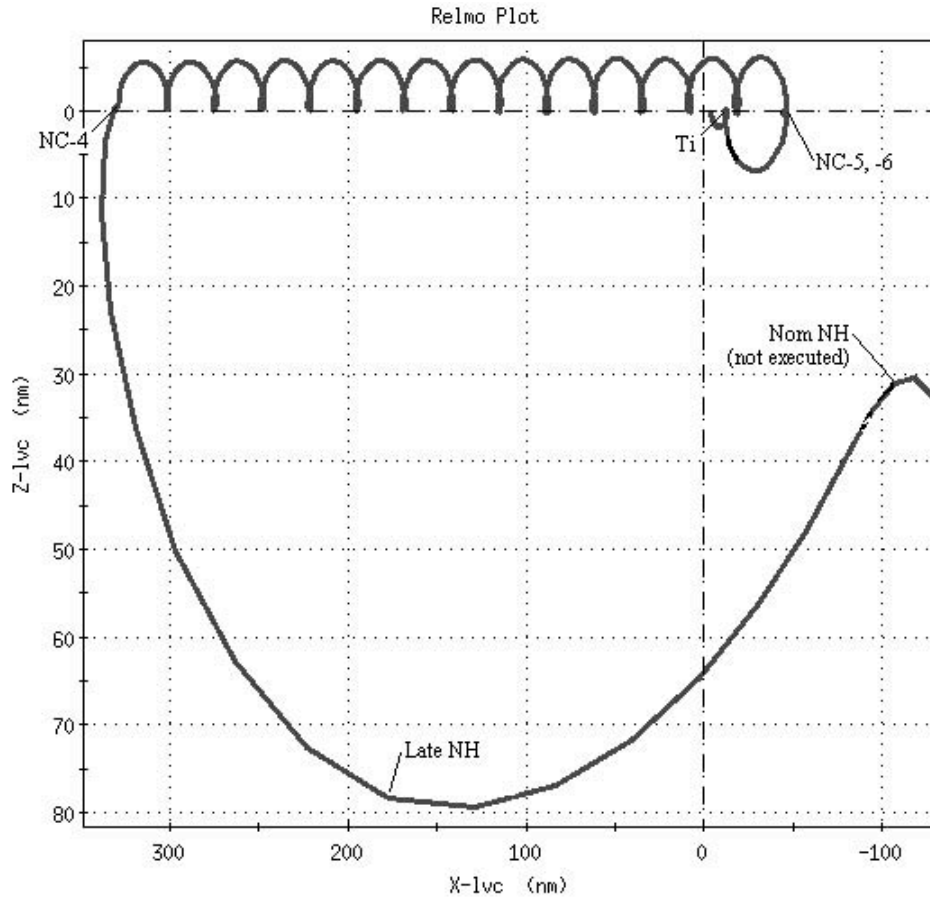
**Missed NH Burn** - Figure 3.10.4.3-2 shows a large phase angle DOR trajectory in which the nominal NH burn is missed. The plot shows that, even with a recovery burn executed N revs later, the Orbiter phases hundreds of miles in front of the target. This extreme phase rate makes it difficult to impossible to restore rendezvous capability. A recovery plan can be developed by modifying the nominal NH plan to be TIG free. Move NH to N revs after than the missed NH. The NC burn after the late NH will target for Ti at 8 nm behind the target in one rev.



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For our example case, this will be costly from a propellant standpoint (about 300 fps!). A more realistic option is to allow multiple revs from the NC burn (NC-4 in the figure) until Ti. To get a reasonable propellant impact, rendezvous must be delayed by a whole day. NC-4 targets an additional NC burn (NC-5) to stop at 40 nm behind the target on the morning of rendezvous the next day. This is followed one-half rev later by another phasing burn (NC-6) to kick off a one-rev transfer to Ti. The half-rev "pause" is necessary to restore proper lighting conditions at Ti. Targeting NC-5 for 40 nm has the benefit of restoring the trajectory to its nominal geometry, which minimizes procedural changes in the checklist (sensor pass times, lighting, etc), rather than having NC-4 target directly for Ti position. Even allowing an extra day to get back on track, the recovery plan shown in this example costs 44 fps above the nominal plan, or about 1,100 lbs of propellant. Plus it delays rendezvous by a whole day. Two options are available to trim off some of the  $\Delta v$  cost if PROP needs help. The first is going to a two-rev transfer from NC-6 to Ti. This saves about 12 fps from 40 nm, and is actually the nominal plan that Profile Support will recommend. Another technique is to move in the NC position to about 30 nm in order to shave off some  $\Delta v$ . Another important consideration is maintaining adequate clearance on the target when passing from in front to behind. Also, it may be necessary to insert an additional NH burn into the profile if height adjustment is necessary. Regardless of the techniques used, remember that the longer it takes to generate a recovery plan, the more prop and time it will take to get back on track. In these situations, FDO must work quickly with Profile Support, MARS, PROP, and FAO to come up with a contingency plan. In this case, the first burn of the recovery (NH) must be executed 45 min after the failed attempt.

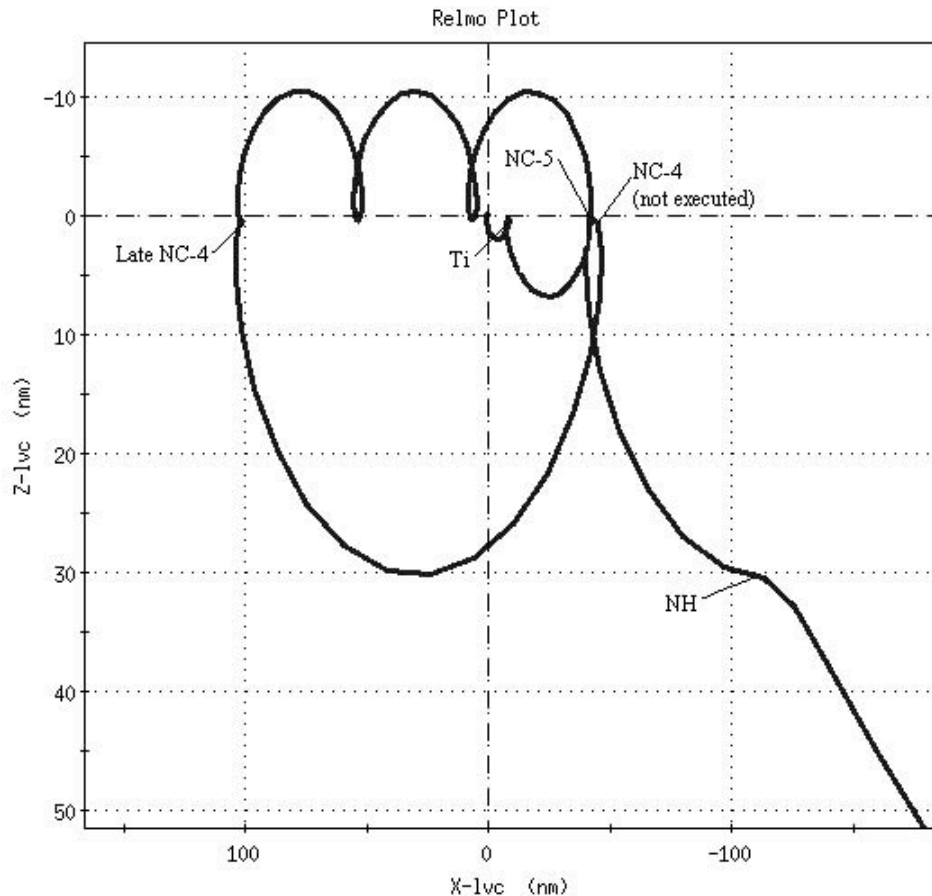
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**Figure 3.10.4.3-2: Missed NH Burn Recovery (Large Phase Angle)**

**Missed NC Burn** - This is a similar scenario to the previous one, but it assumes NH was performed successfully. In this case, the phase rate is slowed somewhat by NH, such that recovery from a failed NC-4 is more feasible than before. A one-rev late NC-4 is targeted to return to 40 nm behind the target after three revs rather than after a whole day (see Figure 3.10.4.3-3). The next burn, NC-5, targets for Ti at 8 nm. If necessary, a new NH burn can be added to one of the "humps" in order to fix any residual height error. This plan has the advantage of keeping rendezvous on the planned flight day, but the disadvantage of delaying docking or grapple by 4 revs, which makes for a very long crew day. FAO and Payloads should be consulted when making this decision. The prop cost is 58 fps more than the nominal plan. If PROP cannot support this, then the only alternative is to add more delay from NC-4 to NC-5. If necessary, delay rendezvous until the next day (as above), which would reduce the cost of this plan to 32 fps more than the nominal plan.

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**Figure 3.10.4.3-3: Missed NC Burn Recovery (Large Phase Angle)**

**NH Overburn** - A single GNC GPC failure can force an OMS engine to be stuck on, requiring manual shutdown (covered later in Section 3.10.4.3.5). If the crew fails to take the OMS ENG switch to OFF at the correct time, then either an overburn or underburn will result. An underburn is simple to fix—simply follow downmode instructions per the PAD and trim with +X jets. An overburn can be trimmed out with FRCS *if* there is sufficient gas there. In order to avoid decision delay in real-time, it is a good idea to pulse PROP prior to the start of rendezvous to get an estimate of how many fps of FRCS can be used for trimming an overburn. Unfortunately, forward margins are frequently low, such that PROP sometimes won't allow much FRCS gas to be used to trim out all of an overburn. If this is the case, trim the overburn with as much FRCS propellant as PROP will allow, then recover the rendezvous as follows. The example shown in Figure 3.10.4.3-4 assumes 10 fps residual excess  $\Delta v$  at NH. The first response would be to run the NC plan (NC targeting with NCC modeled as an NH) and see how much NCC would cost to fix the height error. In this example NCC would be 27 fps and Ti would be 22 fps! Also, the resulting relative motion would take the Orbiter too close to the target on the way to Ti (always check Relmo for any recovery plan). A better option is to add an NC/NH pair to the profile, as was done in the examples above, in order to get things under control before pressing in to Ti. Working with the TIG free MCT, make NC-4 the first

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burn in the constraints table at its nominal time and have it target 40 nm for NC-5, which will have to be added to the plan. Insert an NH burn one-half rev after NC-4 to fix the height error from the overburn. The NC-5 burn is one-half rev after NH, and targets Ti for 8 nm. For this particular example, the rendezvous is delayed by only one rev, but costs 22 fps more than the nominal plan (not including the 10 fps overburn itself). As always, check with PROP, MARS, and Profile Support when developing a recovery plan. The related case of an NC overburn can be handled simply by inserting an extra NC burn one rev after the overburn, which targets Ti for 8 nm. This would force the rendezvous to be delayed by one rev.

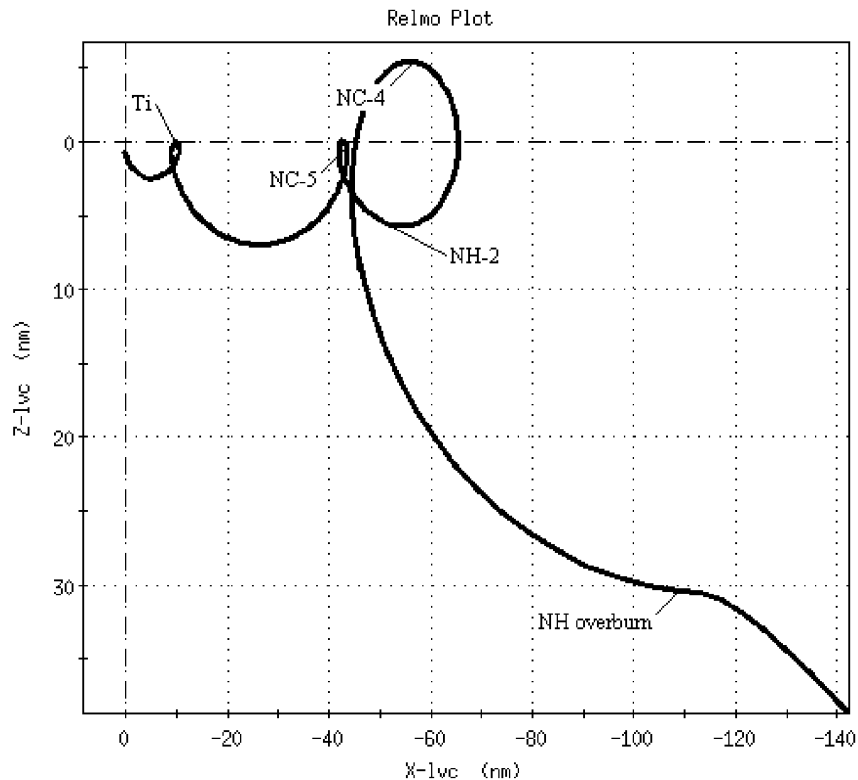


Figure 3.10.4.3-4: NH Overburn Recovery (Large Phase Angle)

### 3.10.4.3.2 Navigation Anomalies

Failure to maintain a valid onboard relative nav state will degrade Lambert targeting capability, and interfere with the ability to perform sensor target acquisitions, since ST and RR pointing are dependent on an accurate relative nav state. Therefore, prompt recovery from a failure is vital. RELNAV may be lost through one of several failure modes.

**Loss of GNC GPC redundancy** - At least two GNC GPCs ("G2") are required to commit to Ti and prox ops. In practice, two or even three GNC GPCs are configured

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prior to the first rendezvous burn on DOR. Loss of G2 redundancy (e.g. 1 of 2 G2s down) does not affect RELNAV, but it would be cause for either Ti Delay if the problem occurred near Ti, or a backout from close-in prox ops to 250 ft if close in to the target. In either case, the extra time and range would be used to safely restore dual GNC GPCs.

**Loss of all PASS GNC GPCs** - This failure would most likely occur during single G2 operations prior to DOR, or early on DOR prior to entering the Rendezvous Checklist. Recovery is straightforward. DPS would have the crew bring up a "freeze-dried" GNC GPC (reference "GNC Recovery via FDG2" in the Orbit Pocket Checklist). Its state vector would be more than 10 min old (resulting in GNC using the default state vector), so FDO would have to uplink a new Orbiter vector. Eventually the PASS redundant set would be configured from this machine for DOR or critical phasing burns, using a non-failed GPC of course. In this scenario, FDO must keep the FCT apprised of any upcoming burns. Recovery of the GPC(s) must occur early enough to support TIG for any critical burns.

Complete loss of the common or redundant set during terminal rendezvous ops is a much more serious failure because no freeze-dried GNC GPC is available for quick recovery. Typical DPS configuration for rendezvous is GPCs 1-3 running PASS GNC, GPC 4 PASS SM, and GPC 5 in halt mode with BFS. Normal pre-DOR config for critical burns is dual G2, so a PASS freeze-dried machine is usually available for easy recovery. With all the machines configured in this manner, no G2 software is freeze-dried in a GPC. Loss of the entire redundant set requires hardware failures of two or more GNC GPCs (very unlikely, although it has happened in flight), or a PASS software error (more likely). Loss of all PASS GNC GPCs renders the Orbiter essentially unflyable, and is cause to immediately terminate the rendezvous, at least for that day. Note that RHC and THC inputs are not received by the RCS jets without a DAP running on either a PASS or BFS GPC. For failures prior to Ti, a passive breakout is possible, but recovery burns will be required within a rev or two in order to halt the opening rate and set up for re-rendezvous the next day. For failures post-Ti, a crew safety concern exists due to the closing trajectory. Here, GPC recovery must be performed ASAP in order to execute the Rendezvous Breakout procedure and then set up for rendezvous recovery. Depending on the time-critical nature of the scenario, there are two options to recover vehicle control.

- 1) GNC Reassignment DPS SSR-3 (MAL): in this procedure, the SM machine is loaded with PASS GNC software. FDO would need to uplink a state vector once this is done. An IMU reference recovery would also be required in order to regain a valid REFSMAT. These are time-consuming and laborious procedures that must be executed prior to any burns. Therefore, this recovery method is not advised if critical burns are required in the near future (2-3 hours). However, this approach does avoid the lengthy FRP-4 PASS Recovery steps that are eventually required if the following Option 2 is executed.

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- 2) **BFS Engage (OPCL):** this is the quicker way to regain vehicle control. The crew powers up the BFS GPC (typically GPC 5), makes a couple quick switch reconfigurations, and then pushes the BFS engage button. The BFS software is then PROed to OPS 3 to support a breakout burn. The IMUs revert to the same REFSMAT that was stored when the BFS was put to sleep, so a reasonably good attitude reference should be available post-engage. After FDO uplinks a state vector, the crew may perform burns in MM 302. DSM 401xx is valid for state vector updates to the BFS, and DSM 410xx should be used to uplink PEG 7s to the BFS in OPS 3. After any critical burns are completed, the laborious GPC FRP-4 procedure must be executed to recover PASS.

**Transition to OPS 8 for APU leak** - For a leaking APU fuel tank or lines, the crew may have to power up the APU in order to burn off fuel to minimize leakage into the aft compartment (more in Section 3.10.4.3.6). Since OPS 2 does not allow APUs to be activated, the crew must mode to OPS 8. The target vector and uplinked target Kfactor are lost during this OPS transition, so FDO or ONAV must grab onboard vectors prior to OPS 8 PRO, and uplink a target vector and Kfactor upon return to OPS 2. Note that the filter vector will emerge intact, but the prop vector will be reinitialized to the filter upon return to OPS 2.

**Transition to OPS 3 for FRCS leak (null dump)** - The target vector and uplinked target Kfactor are lost during the transition to OPS 3, so FDO or ONAV must grab onboard vectors prior to OPS 3 PRO and uplink a target vector and Kfactor upon return to OPS 2.

**IMU spike during ST pass** - During DOR ops, three IMUs are usually up and running. Any bad angle data or accelerometer spikes on a single IMU are thrown out by the mid-value select (MVS) logic in Redundancy Management (RM). During ST passes, however, one of the IMUs is deselected in order to reduce angle noise in the ST data. This protocol is a result of the first Shuttle rendezvous mission, STS-41G Solar Maximum Mission repair. During this mission it was found that with three IMUs, the MVS logic was bouncing between different IMU pairs for angle data during the ST pass, introducing noise into the ST angle output. By deselecting one of three IMUs, RM prime selects one unit for angle data and averages the two remaining units for velocity data. Doing this smoothes angle data during a ST pass, but it increases the risk that an accelerometer spike, rather than being thrown out via MVS, will instead be averaged with the good IMU. Recall that IMU accelerometer data are incorporated into both the filter and prop state, so a spike has the effect of corrupting velocity of the onboard filter and prop states. The only guaranteed recovery from a spike is to uplink a new filter state after the bad IMU is deselected, and then perform a FILT TO PROP (ITEM 8 on SPEC 33). Otherwise, onboard burn targeting will be based on an invalid state vector, and a position error will also be introduced over time, leading to degraded accuracy of sensor measurements.

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Another recovery option is available if sufficient time remains during the ST pass. If at least 40 more marks can be incorporated following the IMU spike, the ST measurements may be able to correct the filter state *without* a vector uplink (assuming no more spikes). Then a FILT TO PROP can be performed at the conclusion of the pass to clean up the PROP state.

In any of the above cases where the target vector is lost, RGPO will assure appropriate safing steps are performed, such as inhibiting sensor data from nav, and de-selecting target track on UNIV PNTG (failure to do so could cause excessive vehicle rates as the Orbiter attempts to track a static vector). When it is necessary to uplink an Orbiter and/or target state vector, FDO should send a vector based on the last valid *onboard* state rather than a ground-based state. This is to maintain the most accurate relative state possible. The onboard filter will usually be better than the ground due to sensor data and IMU accelerations. It is for this reason that ONAV stores off filter and target vectors in the VAT every 40 marks during sensor passes. If for any reason the onboard filter and/or target vectors become corrupted, ephemerides can be updated with the most-recently stored vectors. Standard ephemeris allocation has TrS E5 and E6 reserved for onboard filter and target states, respectively, during DOR. Special procedures must be employed if state vectors from either of these ephemerides are to be uplinked. The COTM STVECT command load application cannot access TrS ephemerides 5-10. To build a command load from one of these ephemerides, the user must first put the desired vector in Checkout Monitor 1, then press the "Checkout" button on the command load application (see Figure 3.10.4.3-5). STVECT will fetch the vector from Checkout Monitor and display the Cartesian components and time tag. Then the user can build a command load from these data.

The screenshot displays the STVECT Command Load application interface. It is organized into several functional areas:

- Input Control:** Includes a GMT input field and buttons for Ephemeris 1, 2, 3, and 4.
- Checkout Monitor:**
  - Checkout 40101 (EPH-PASS (BFS)):**

GMT	020:23:10:13,000	020:23:10:13,000	
X	13869716,820	13869716,820	-8830,950 ( > )
Y	-8315840,495	-8315840,495	18202,379 ( > )
Z	-15280449,521	-15280449,521	1805,092 ( > )
X dot	3166,210	3166,210	-13,484 ( > )
Y dot	23006,296	23006,297	-3,641 ( > )
Z dot	-9600,934	-9600,934	20,007 ( > )
  - Source (EPH - TLM (BFS)):**

Delta GMT	10:13	Delta a	-2335,552 ( > )
HA	220,127	Delta U	-2616,128 ( > )
HP	207,393	Delta V	20138,376 ( > )
i	51,855	Delta W	-415,104 ( > )
e	0,002	Delta U dot	-24,324 ( > )
		Delta V dot	1,285 ( > )
		Delta W dot	1,429 ( > )
- Command Tracking:** A list of commands with time tags and parameters, such as '019:02:36:02,961 SM 4781 FM SYSTEM 1/2 - OFF SNGL'.
- Load Inventory:** A list of command loads with IDs, names, and parameters, such as '40101 No\_MF 23 Orbiter State 019:02:35:45'.

Figure 3.10.4.3-5: STVECT Command Load using Checkout Monitor Source

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### 3.10.4.3.3 Sensor Anomalies

Problems with the Star Trackers (ST) or Rendezvous Radar (RR) can degrade the ability to maintain an accurate relative nav state. This can lead to trajectory dispersions and increased propellant costs. However, since several levels of redundancy are built into these systems, failure in one or two components should nevertheless allow a fairly high probability of successful rendezvous. Indeed, the approach geometry timeline has been designed with sensor failures in mind, so the crew can easily recover from loss of a single sensor. Propellant budgets also contain a level of conservatism to protect for failed RR, so that trajectory dispersions should not result in "bingoing" out on prop. This section will briefly describe sensor anomalies and appropriate FDO response.

**ST lock onto star** - Since the ST is designed to search for a bright object in its FOV, it is quite possible for it to lock onto a star rather than the target. This could occur at the beginning of a pass if a star happened to be close by the target in the ST FOV, or during a pass if a star passed through the target position in the ST FOV. A star lock-on would be evidenced by vertical or horizontal residuals (difference between expected angles and measured angles) that change greater than 0.05 deg each cycle, as shown on SPEC 33. This apparent motion would be due to the star being inertially fixed, while the Orbiter rotates at approximately orb rate when in the target track mode at long ranges. It is for this reason that the crew has angle measurements INH on SPEC 33 prior to initiating a ST pass. Angle residuals are examined for stability prior to selecting AUTO. If V and H exceed the threshold above, then the crew will break track, wait briefly for the sensor to reacquire the target, and repeat the evaluation.

**ST large initial residuals** - When the ST locks onto a stable object, but outputs V or H residuals much larger than expected ( $> 0.6$  deg), the crew will break track and try to reacquire. This is to avoid tracking any co-orbiting debris that may be near the target or Orbiter (this actually happened during STS-82 HST rendezvous--the ST first locked onto a star, and then a piece of debris). If the subsequent re-acquisition yields similar large residuals, the crew will proceed to the procedure HIGH INITIAL RESID in the Contingency Ops section of the Rendezvous Checklist. This procedure will have the crew use the COAS or window to visually inspect the target region for debris. If debris is observed, the crew will repeat break track and reacquisition until a stable lock-on is achieved. If no debris is found, the crew will check IMUs for misalignment, since this could cause high residuals to be computed. Here they will try deselecting a different IMU for the pass in hopes of clearing up the problem.

**ST large updates** - Once ST angles are AUTOed into nav, the filter state is updated every 8 sec. The crew and ground should monitor FLTR MINUS PROP value on SPEC 33 to assure the value remains reasonable during the pass. If it changes by more than 8 kft during a ST pass, then the validity of the pass is called into question.



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The crew will proceed to the HIGH FLTR MINUS PROP procedure in the Contingency Ops section. This will have them inhibit angles and proceed to troubleshooting similar to that outlined above. If this anomaly occurs towards the end of a ST pass, proper lighting may expire before the problem is resolved. In this case, the entire pass would be lost, since the FLTR would have been corrupted by the large residuals. RGPO in this case would call for a PROP TO FLTR in order to restore a valid filter state from the uncorrupted propagation state. In this case the rendezvous would proceed without sensor data until within range for the RR.

**RR fail** - The RR is the most critical rendezvous sensor since it provides the most data (range, range rate, and angles), and is not restricted by lighting. One limiting factor of the RR is that it does not provide useable data outside 135,000 ft. However once inside this range, the RR is used to continuously track the target. Being an electro-mechanical system, the RR is susceptible to a number of malfunctions that could render it inoperative, such as failures in the gimbal systems, antenna electronics, or FF-3 MDM which provides output to the GPCs. Should the RR become unusable, the -Z ST (or -Y if -Z ST is failed) will be employed when acceptable lighting conditions are present. A typical scenario is as follows: the RR fails during its initial pass post-NCC. Ti is performed using the post-NC-4 ST pass relative nav state. Then immediately following Ti, the ST is used again to track the target until MC-1. After MC-1, there is just enough time (8 min) for 40 ST marks until sunset. Then special "radar fail" procedures are followed for the remainder of the profile. Located in the Rendezvous Checklist timeline just after the MC-2 callout, the RADAR FAIL block has the crew perform MC-3, then attempt to acquire the target visually through the COAS at sunrise. Based on ORBT design, sunrise should be no later than MC-3 + 2 min (i.e. MC-2 + 19 min). Since the Orbiter's relative nav state is used to compute -Z target track attitude, *target position error in the COAS will be proportional to nav state error*. Therefore, if the target is > 30 deg from the COAS horizontal, the trajectory is excessively dispersed, and a breakout must be performed<sup>21</sup>. If the target is within 30 deg of horizontal, target elevation in the COAS will be used to compute a small correction burn to move the trajectory back towards the nominal approach path. At MC-3 + 2, the crew will determine how many deg the target is from the COAS horizontal, then deflect the THC  $\pm X$  as follows:

If target is N deg high in COAS, perform  $2N + X$  pulses

If target is N deg low in COAS, perform  $N - X$  pulses

This technique has proven to be effective in correcting nav state errors during RR fail simulations. Following this correction, the crew will manually maintain the target in the center of the COAS and continue the approach manually using braking gates

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<sup>21</sup> An exception in FR A2.1.3-27 RNDZ/PROX OPS BREAKOUT allows the crew to continue the approach on a best-effort basis if propellant margins do not allow for a subsequent re-rendezvous attempt. In this case, the crew would manually attempt to correct the trajectory until successful, or until prop bingo limits were reached (breakout).

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prescribed in the procedure (MC-4 is not performed). As long as propellant quantities remain above the bingo level, the approach will continue. Failed RR procedures correct trajectory dispersions later in time compared to nominal since the human eye has to substitute for the radar. Therefore propellant costs are considerably higher. Failed radar procedures were used for the first time on STS-92/3A rendezvous with the ISS. Propellant costs were about  $5\sigma$  higher than predicted.

**Loss of all sensor capability** - Multiple failures would have to occur to prevent *any* sensor data from being obtained during a rendezvous. For example, some problem would no-opt the post-NC-4 -Z ST pass, then the RR would have to be unsuccessful between NCC and Ti, then following Ti there would be no-joy with the -Z or -Y ST pass. In the remote possibility that this sequence of failures should occur, Flight Rules do allow the rendezvous to proceed through MC-2 up to the RADAR FAIL procedures described above. In this case, all burns will be targeted using the relative nav state uplinked at the start of the rendezvous. Rather than uplinking ground PADs for every burn, it is still appropriate for the crew to target NCC, Ti, and the midcourses using onboard Lambert, since the Orbiter state will continue to update based on IMU-sensed DVs. In this dynamic timeframe, the Ground NAV solution will probably not be as accurate as the onboard. Of course, if Ground NAV is able to compute a "best source" vector off ground tracking, then this may be used to uplink the onboard state, and target subsequent burns. At sunrise following MC-3, the approach can continue as long as the target is within 30 deg of the COAS horizontal. But if the crew does not visually acquire the target by MC-2 plus 20 min (MC-3 plus 3 min), a breakout is required. These procedures belie the faith the Shuttle Program holds that FDO and Ground NAV alone can safely maneuver the Orbiter to within 7000 ft of another spacecraft.

### 3.10.4.3.4 Trajectory Dispersions

**Downtrack Dispersions** - It is quite common to have range errors at the commencement of a rendezvous. For example, the Orbit 2 shift typically executes the final phasing burn, NC-3, prior to crew sleep, aiming for 40 nm behind the target at NC-4 on DOR. Assuming 0.2 fps trim error and 200 ft energy error from the attitude maneuvers to and from burn attitude, all in the same direction and applied over 8 revs, this alone could result in downtrack errors of  $\pm 10$  nm. Sometimes greater dispersions are possible if secondary payloads require additional attitude maneuvers between NC-3 and -4, or if other perturbative events are scheduled. The final NH and NC burns will always attempt to return Ti to its nominal position at 8 nm behind and 1200 ft below the target. But even though Ti position may eventually be corrected, these above dispersions will result in Ti  $\Delta v$  being different from what was nominally planned, since a different closing rate is present. In the extreme case where safe relative motion cannot be assured prior to the first burn of the day, then

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the crew's morning timeline would have to be modified to insert an additional phasing burn one rev before NC-4.

For large phase angle cases where a DOR NH is required, the opportunity for additional range control at NC-4 presents itself. For example, say a DOR NH is required, and due to overnight drag dispersions the range at NC-4 is predicted to be 46 nm instead of the planned 40. Normally NC-4 TIG would be chosen to provide proper lighting at Ti 1 rev later, and NH TIG placed to minimize radial  $\Delta v$  at Ti. Since NH targets only height, no downtrack range control for NC-4 is provided. However, one may move the NH TIG a small amount to affect NC-4 range in the right direction. Subsequent Ti radial  $\Delta v$  can be eliminated by modifying NC-4 TIG. This should only be done in small amounts in order to avoid  $\Delta t$  between NH and NC-4  $< 30$  min, or NC-4 TIG slipping later than noon. In the example cited above, NH TIG would have to be moved later to bring NC-4 range back to 40 nm. The amount of TIG movement is a function of burn  $\Delta v$  (the smaller the burn, the more TIG movement required). Besides keeping the geometry "down the centerline", another advantage to this method is that it keeps DOR burn  $\Delta v$  values close to those planned, which makes PROP happy.

**Onboard Nav Uncertainty** - At the beginning of the rendezvous timeframe, RELNAV will be initialized with an Orbiter and target state vector pair based on ground tracking. Any uncertainties in those nav states will show up as measurement residuals during subsequent sensor passes. The Filter Flag specifies whether measurement residuals will update the filter state or target state. Normally this flag is set to ON, so that sensor data updates the filter state, which leaves the target state unchanged (TSS missions set the filter flag OFF so that RR data updated the target state continuously during deployed ops). This is based on the assumption that the target vehicle is not maneuvering, so therefore any nav state errors should be applied to the Orbiter, which is thrusting and maneuvering and likely experiencing more orbit perturbations. This feature can sometimes cause confusion during rendezvous ops with a noisy target satellite. For example, assume that the target vehicle experienced an energy hit after going off-range. The resultant downtrack error is detected during the first ST pass, but is corrected in RELNAV by updating the *Orbiter filter* position. This shows up as an inertial state vector error compared to incoming ground tracking on the Orbiter. As additional target ground tracking comes in, it will also show an inertial error as compared to the onboard target state. So even though both the onboard filter and target states have inertial downtrack errors compared to ground tracking, the onboard relative nav state remains valid. This confusing behavior should be kept in mind if ground tracking of the target shows significant dispersions.

**Ti Position Error** - Another topic that falls under the broad heading of "trajectory dispersions" is Ti position error. Recall that the final NC and NH burns attempt to place Ti 8 nm behind and 1200 ft below the target. NCC is the final chance to

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correct Ti position after onboard sensor data has been incorporated. This burn sequence is normally sufficient to place Ti within a  $3\sigma$  error ellipse shown in Figure 3.10.4.3-6. State vector error, attitude maneuver perturbations, pre-rendezvous water dump perturbations, and burn trim error are some of the potential dispersion sources that drive the size and shape of the Ti error ellipse. A nominal sensors and no-sensor error ellipse are computed by Flight Design for each mission using a series of Monte-Carlo runs with STAMPS. Figure 3.10.4.3-7 compares nominal sensor ellipse against actual Ti position for all ORBT missions as of this writing.

Typical Ti Position Error Ellipses (3 sigma)

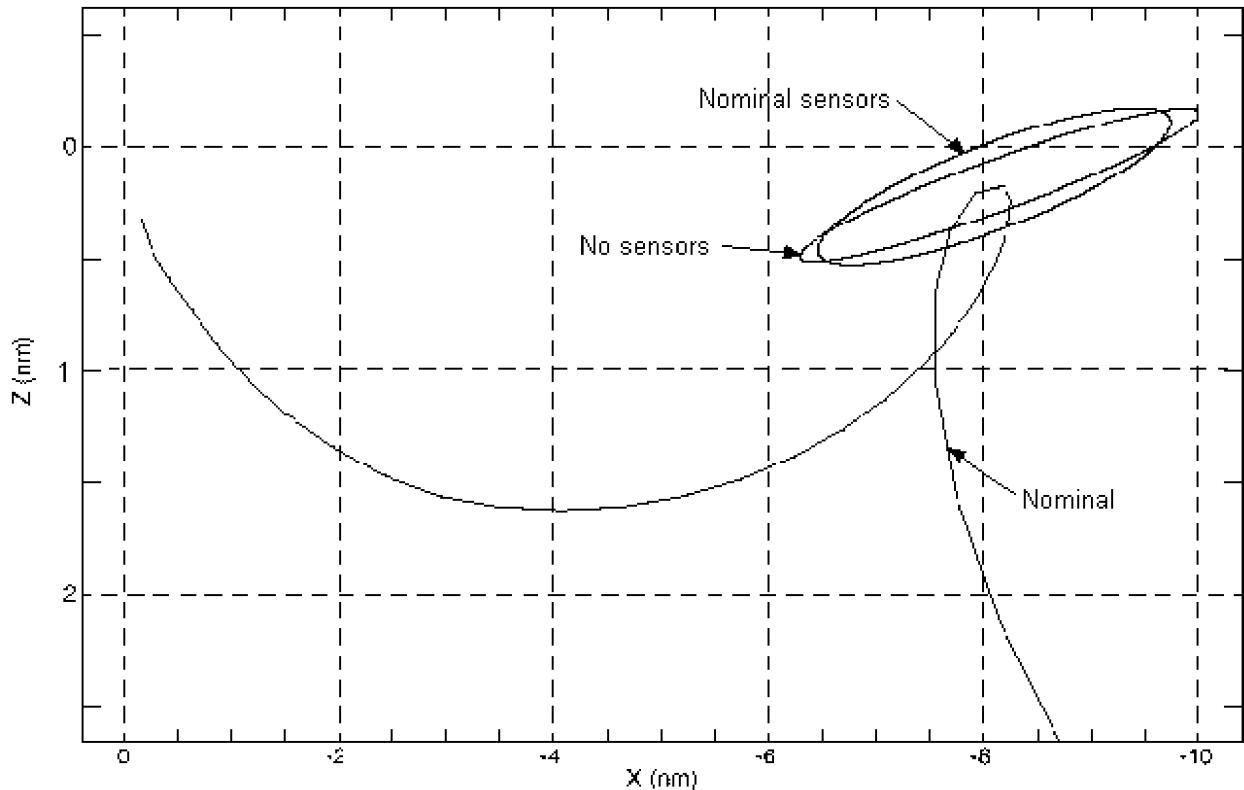
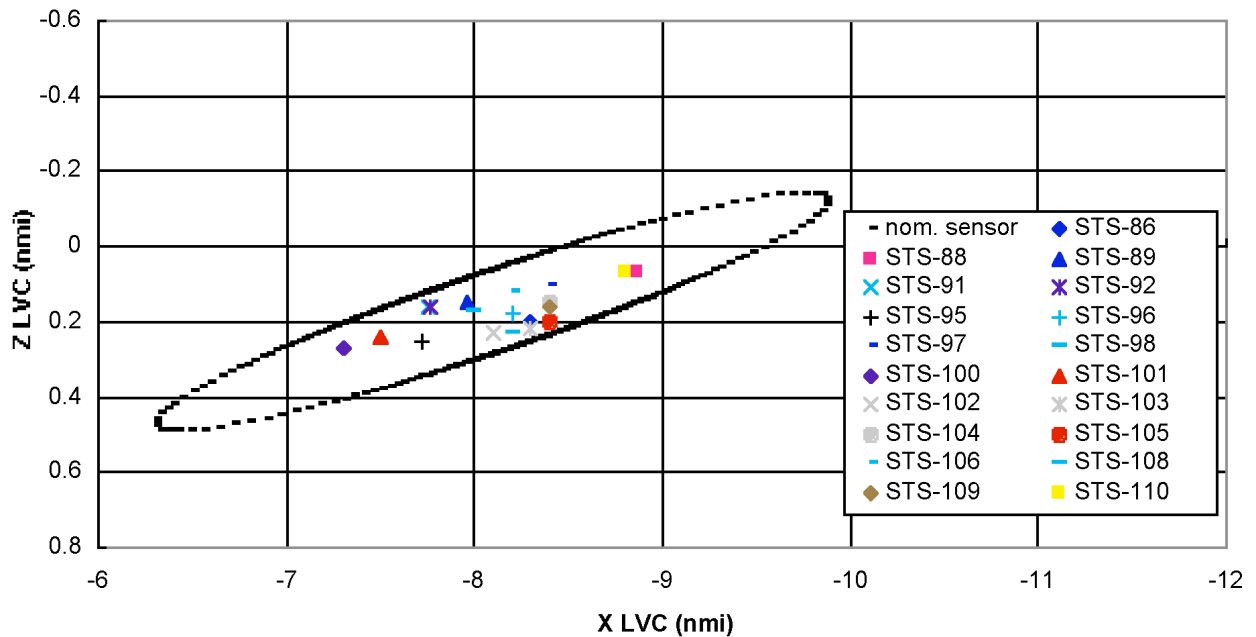


Figure 3.10.4.3-6

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## Ti Position Flight History (ORBT)



**Figure 3.10.4.3-7**

As long as Ti is located within either the nominal or no-sensors error ellipse, a safe post-Ti trajectory and reasonable midcourse  $\Delta v$  values are assured with ORBT ILOADs. That is, Lambert will take the chaser from Ti to MC-4 position following a path that does not loop above the  $V_{bar}$ , cross the  $R_{bar}$ , or pass too close to the target. A safe breakout using the RNDZ BREAKOUT procedure (3 fps retrograde) is also guaranteed. If Ti is performed outside the ellipses, then Lambert, in its attempt to solve the transfer problem over the fixed  $\Delta t$ , *may* generate an unsafe and/or propellant-costly solution. Also, MC-2 TIG slip limits may be exceeded. Approximate limits where an unsafe trajectory and/or invalid breakout occur are shown along with MC-2 TIG slip limits in Figure 3.10.4.3-8. Note that the  $3\sigma$  ellipse lies alarmingly close to the "bad trajectory" curve. Total propellant costs for MC-2 and -4 as a function of Ti position are illustrated in Figure 3.10.4.3-9. Be advised that these plots are for illustrative purposes only--actual limits vary somewhat based on altitude and possibly other factors.

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## Trajectory Envelopes for ISS & HST Altitudes

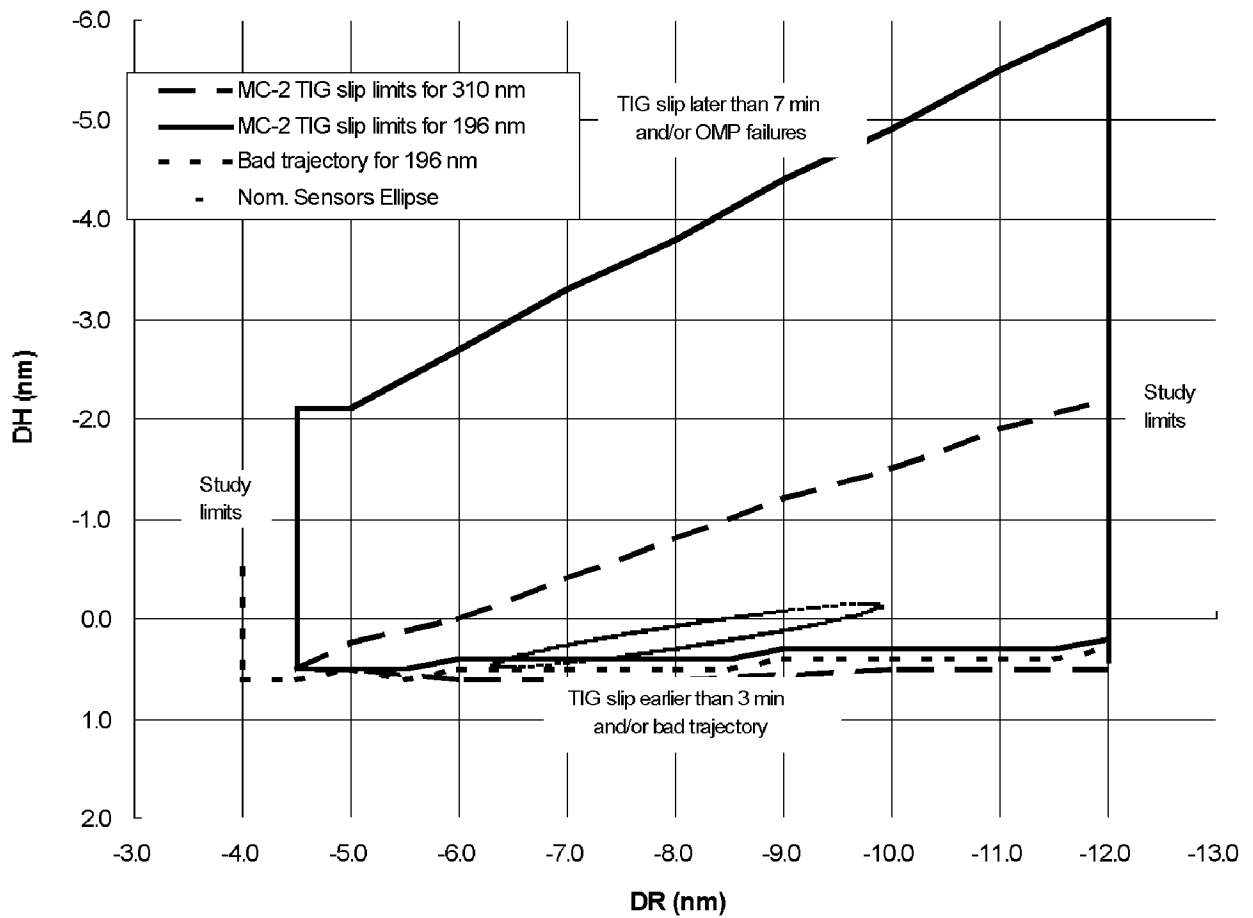
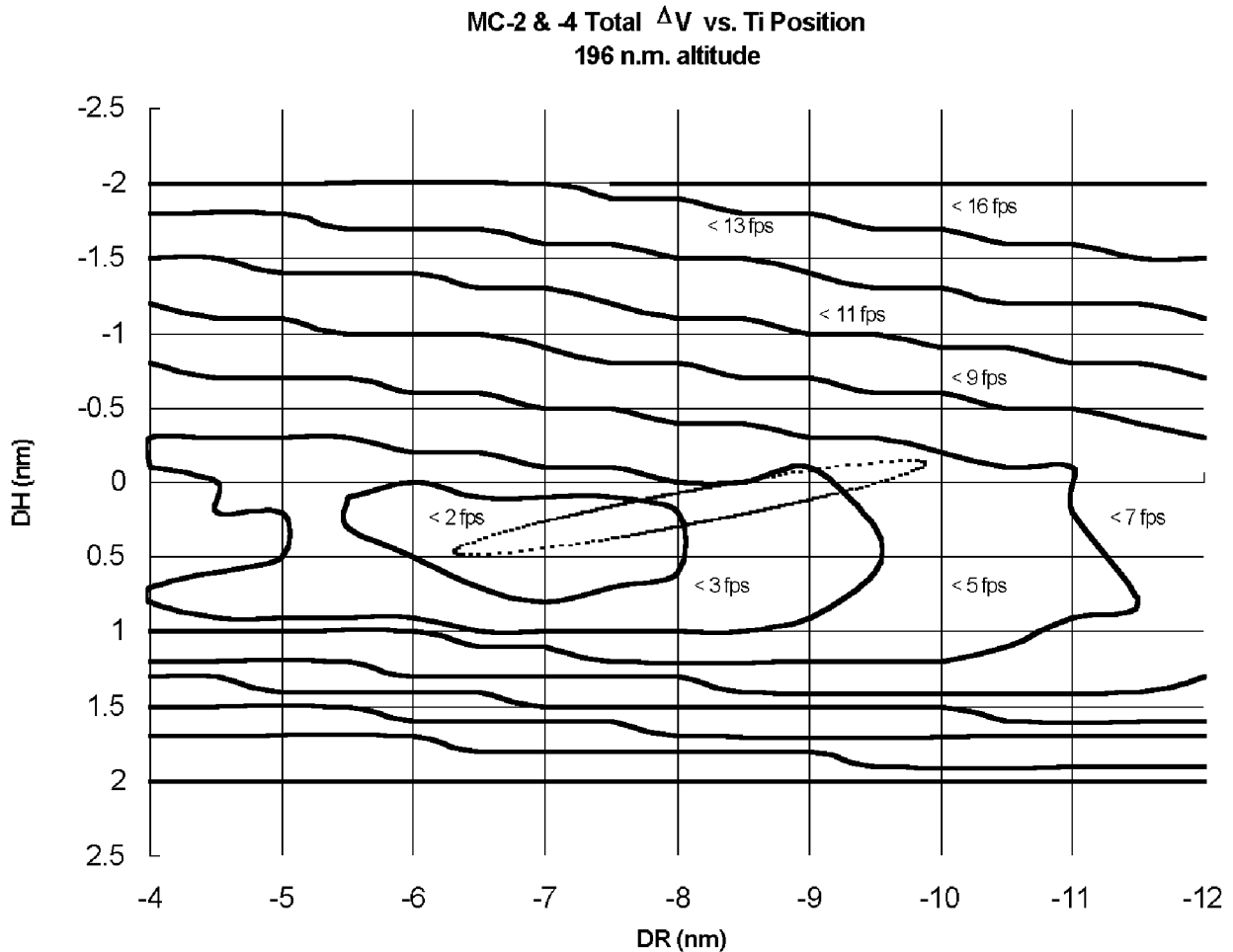


Figure 3.10.4.3-8

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**Figure 3.10.4.3-9**

**WARNING:** performing Ti outside its  $3\sigma$  position error ellipse may result in unsafe relative motion and/or excessive midcourse  $\Delta v$ . Sufficient clearances during a breakout maneuver are not guaranteed in this case.

Post-NCC, FDO should verify that Ti is predicted to be inside the nominal or no-sensors ellipse prior to giving a "go for Ti" call. This can be done using RT Relmo predictor bugs (if good onboard nav state), and/or ground curve if the Ground NAV state is good. *If Ti is predicted to be outside this region, caution should be exercised before proceeding with Ti.* It may be prudent to execute a Ti Delay burn, with a subsequent NCC to nail Ti position the next go-round. But if Ti Delay is unacceptable for any reason, or if the trajectory is just slightly outside limits, FDO can evaluate the on-time post-Ti relative motion on RT Relmo to determine if it's safe. OMP can be used to evaluate MC-2 TIG slip, and MC-2 and -4  $\Delta v$  (MARS and Target can help with these tasks). These predictions can then be passed to PROP in order to determine whether propellant margins can support the increased cost of the dispersed trajectory. If proceeding on this course of action, it must be

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remembered that the standard breakout maneuver may not guarantee safe clearances. So breakout  $\Delta v$  may have to be increased to provide adequate margins.

### 3.10.4.3.5 Propulsion System Failures

FDO should be cognizant of several OMS and RCS failures that can immediately impact the trajectory. This is not meant to be an exhaustive list of all possible prop failures, but rather a discussion of those that require the most immediate response during rendezvous timeframe.

**OMS manual shutdown** – Failure of a single GNC GPC during an OMS burn can result in the OMS engine (OME) being stuck on. This can occur even when configured dual or triple G2. Each OME contains two ball valves (BV) that operate serially. The GPC(s) must command at least one BV to the closed position in order to terminate a burn. Each BV, in turn, is interfaced to the GPC(s) by two flight-critical MDMs. A different string is used to command each of the four MDMs on an OME. If a single MDM fails during a burn, the BV open command stays latched on the MDM, and overrides the close command from the good MDM, resulting in that BV remaining open. In this single MDM failure case, the other BV should close on time assuming both its MDMs are working. If however, a GPC fails, then multiple MDMs will go down, depending on the stringing configuration. For example, if configured for dual G2 and strung 1212, then failure of GPC 2 will take down MDMs FA2 and FA4 on strings 2 and 4. This will force the left OME to be stuck on due to string arrangement for the left OME BVs. The right engine's BVs are controlled by a slightly different arrangement of MDMs, so it will shutdown properly. For another example, if configured triple G2 and strung 1233, then failure of GPC 3 will bring down strings 3 and 4, resulting in BOTH OMEs being stuck on, since FA3 and FA4 are connected to both BVs on both OMEs. This information can be found in an abbreviated form on the back of the OMS Burn Monitor in the Ascent Checklist, or can be explained by a PROP Officer.

The workaround for an OME stuck on is to take the OMS ENG switch to OFF, which will override the MDMs. Therefore, if GPC or multiple MDM failures during a burn necessitate manual shutdown on an engine, PROP will make the appropriate call on the Flight Loop including the words "manual shutdown required", and the crew should shutdown the engine when TGO=0. FDO should monitor closely as TGO counts to zero to assure that the crew does indeed shut down the affected engine. If not, FDO and/or PROP should call ASAP for OMS ENG OFF on the Flight Loop to avoid overburning. If an overburn does occur, then there are two choices, either trim out the VGOs (using FRCS propellant), or do nothing and correct the trajectory later. It is prudent to tag up with PROP prior to an OMS burn to determine approximately how much FRCS is available to trim out an overburn (typically PROP can commit some or all of the FRCS prop margins). Then if a manual shutdown occurs, a



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response is readily available. Section 3.10.4.3.1 above addressed trajectory recovery options if insufficient propellant is available to trim out an overburn.

**Engine failure during burn** – Flight Rule A2-114 states that a single downmode action will be taken in order to complete a burn that is critical for mission success. Therefore PROP must specify on the burn PAD which downmode option to use for any mission critical burn (e.g. 2 OMS→1 OMS or 1 OMS→RCS). Propulsion system downmode is inappropriate for non-critical burns since any failure should be cause to cease the burn and investigate the problem before re-planning a maneuver. In the non-critical case, by definition, there is time to delay the burn without adversely affecting mission success. Usually recovery is conducted one or more revs later.

**Non-isolatable propellant leak** – Leaking propellant creates a grave hazard to Orbiter safety, and also presents a contamination concern to any vehicle that would be docked with or grappled. The biggest concern is fuel or oxidizer freezing around RCS lines in the aft fuselage and leaving the Orbiter with no means of control. Therefore PROP will recommend that the propellant be burned off ASAP to minimize leakage into the Orbiter. Rendezvous is not an option following an OMS or RCS depletion burn for several reasons. First of all, prop margin on the remaining systems are usually insufficient to continue with rendezvous, and second, for OMS it is desired to minimize the number of restarts on the remaining system in order to preserve it for deorbit. Rendezvous is also not an option following a FRCS depletion burn since the Orbiter cannot translate in the  $\pm Z$  direction without the FRCS. The Flight Rules Annex will specify what action to take for a prop leak during DOR. Prior to arrival on the +R bar, a retrograde depletion burn will place the Orbiter on a safe departing trajectory. Once closer in, the crew will have to execute a breakout prior to performing the depletion burn.

**Non-isolatable helium leak** – For a helium leak, the concern is not contamination but rather loss of capability as the system goes into blowdown mode once the helium tank pressure decays below that of the prop tank. If the propellant tank is at or below max blowdown quantity, then maximum performance is already available, and nothing more can be done for the system. In this case PROP will determine whether proceeding with the rendezvous is feasible from a margins standpoint and overall systems redundancy. If, however, the propellant tank is *above* max blowdown, and the leak rate can support a burn to get the system into max blowdown, then PROP may recommend a burn. Note that for an ARCS He leak, Flight Rules specify NPLS, so this would have to be considered.

For a fast helium leak, an immediate depletion burn may be required. If so, FDO will have to assess its effects on the rendezvous and work with PROP to determine the feasibility of recovering. For a slow helium leak, there may be time to replan an upcoming burn to use the leaking system so as to maximize overall prop margins and not waste the gas. If the leak occurs during pre-DOR timeframe, then it will be a

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matter of luck whether the plan has an upcoming burn of the right size that can be used for the burn to max blowdown. If there is no good candidate burn in the plan, then it is best to waste the prop in a radial direction. This normally will not drive up the cost of subsequent burns, assuming one or more large burns remain until DOR. Usually the TIG of any large burn can be used to move the line of apsides back to the desired location following the radial burn. Burning either out-of-plane, posigrade, or retrograde are not as good of options, since it will cost the same amount of propellant to take out the  $\Delta v$  introduced by the burn to max blowdown.

On DOR it will not be possible to perform a burn much larger than 12 fps without severely impacting the rendezvous. The radial option should not be used in this timeframe without assessing relative motion and how much propellant it will take to recover the trajectory. It will generally be more benign to waste the propellant out-of-plane and then delay the rendezvous (either at NC-4 or Ti Delay) in order to evaluate whether capability exists to continue. If PROP can support a burn to max blowdown in the place of an upcoming rendezvous burn, FDO must assure that any thruster system changes are well understood with respect to the burn PAD, TIG slip procedures, burn attitude, etc. In particular, FDO should beware using FRCS to perform critical burns—the procedures are more complicated and likely less familiar to both crew and FCT. TIG slip for FRCS burns is much more difficult to perform as well, so FDO should consider the limitations of performing critical rendezvous burns on the FRCS prior to agreeing to the change. Another option for burning down the FRCS is to use the Mal Checklist to perform an OPS 3 null dump. In this case, side firing jets F1L, F3L, F2R, and F4R cancel each other out during the burn. This procedure is also not without peril, as RELNAV is lost during the transition to OPS 3 (refer back to Section 3.10.4.3.2), and no sensor tracking can be performed in OPS 3. The null dump is not strictly null, since the jets have a 2 deg downward cant that results in some perturbation to the trajectory. In the case of an ARCS or OMS burn to max blowdown post-Ti, no benign option exists--the burn should be performed retrograde (essentially "breaking-out" of the rendezvous), or a 3 fps breakout should be performed followed by a burn to max blowdown out-of-plane. The latter preserves the option of conducting the rendezvous the next day if propellant margins permit.

### **3.10.4.3.6 APU Leaks**

As mentioned previously, MMACS will recommend burning a leaking APU as soon as possible in order to minimize hydrazine leakage into the aft compartment. During rendezvous timeframe this will affect FDO in three ways: First, the crew must mode to either OPS 8 or 3 in order to start up an APU, and the onboard target vector will be lost. Second, no sensor data will be available during the time in OPS 8 while activating the APU. It takes 10-15 min to go to OPS 8 and turn on an APU, after which the crew may return to OPS 2 to continue taking sensor data while the APU is running. The downside

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to returning to OPS 2 during an APU run is that it takes longer to deplete the leaking system. Third and final, the trajectory will be dispersed by the APU vent force and Orbiter FCS response. APU plume is in a -Z direction, with net thrust in a +Z direction. In OPS 8 under max hydraulic load, the vent force is about 20-30 lbs per APU (including water spray boiler force). In OPS 2 there is no load on the APU and the thrust drops to 5-10 lbs, but the force acts over a longer time period. Due to the lower vent force, it is generally better from a trajectory standpoint to burn in OPS 2, however depending on the leak rate, MMACS may insist on OPS 8 to minimize contamination in the aft compartment.

**WARNING:** APU vent force during rendezvous may result in excess propellant consumption or unsafe relative motion. It is advisable to turn the Orbiter -Z axis (vent direction) out-of-plane to minimize downtrack effects.

FDO's first order of business following notification of an APU leak is to determine from MMACS when the APU burn needs to be performed, how long it will take to deplete the tank, and whether MMACS will allow a return to OPS 2 right after the APU is started. RGPO should also participate in this discussion. Then the team should come up with the following strategy for depleting the leaking system: what attitude to perform the APU burn, when to go to OPS 8, whether to stay there or return to OPS 2, and what impact the APU burn will have on the trajectory and upcoming sensor passes. It is essential to avoid OPS 8 transition close to any critical burns, since PEG burns cannot be performed in OPS 8<sup>22</sup>. APU runs during integrated sims have resulted in significant trajectory dispersions that warrant serious consideration of delaying the rendezvous. The following table lists preferred strategies for dealing with a leaking APU at various times during rendezvous. Actual response will vary if other factors are involved (e.g. no one rev late rendezvous capability). Be aware that FAO and ACO should be included in any discussions regarding Ti Delay (timeline constraints), or running the leaking system in prox ops (target contamination concerns).

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<sup>22</sup> If the APU must be started close to any critical burn, it may be advisable to do it in OPS 3 so that the burn may be performed in the event of a delay in getting back to OPS 2.

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**Table 3.10.4.3-1 APU Leak Strategy**

APU Leak Timeframe	Response
APU leak identified prior to NC-4; APU burn can be completed by NC-4	Perform OPS 2 APU burn in water dump attitude or other -Z radial attitude. Post-NC-4 ST pass will pick up traj dispersions.
APU leak identified prior to NC-4; APU burn cannot be completed by NC-4	Downmode to 2-rev transfer from NC-4 to Ti. Start APU burn before NC-4 only if time permits. Burn APU in OPS 2 using -Z south OOP attitude for -Y ST (use NC-4 TVR=90 deg). Traj dispersions will be picked up in 2 <sup>nd</sup> loop ST pass.
APU leak identified between NC-4 & Ti	Finish ST pass & NCC if possible. Burn APU in OPS 2 using -Z north OOP attitude to allow RR pass (no angles). Downmode to Ti Delay in order to identify traj dispersions prior to Ti.
APU leak identified between Ti & Rbar arrival	Delay APU burn until Rbar or Vbar if possible (Vbar is more prop efficient). Burn APU in OPS 8 using COAS and HHL to maintain Rbar or Vbar position. Delay docking/grapple until after APU burn is complete. If must burn prior to Rbar arrival, then burn in OPS 2 using -Z target track attitude to allow RR data.
APU leak identified between Rbar arrival & docking/grapple	Perform APU burn in OPS 8 on Vbar. Use COAS and HHL to maintain position. Delay docking/ grapple until after APU burn is complete

NOTE: "NC-4" in this table refers to final phasing burn prior to Ti. OPS 2 APU burns are generally preferred to OPS 8 due to sensor availability & lower thrust force. OPS 8 should be utilized for fastest tank depletion when the Orbiter is in a stable relative position where RR & ST data are not required.

### 3.10.4.3.7 Lambert Anomalies

A summary of the possible Lambert alarms is summarized next. For more information, refer back to Section 3.10.1.8, or to the RGPO Console Handbook, Section 5.13.

#### 3.10.4.3.7.1 TGT T (formerly TGT ΔT)

This alarm can be caused by the transfer time being negative, zero, or some multiple of 180°. This results in a Lambert planar singularity. The first troubleshooting step is for

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RGPO and the crew to check onboard ILOADs to make sure the transfer time is not negative or zero. If  $\Delta t$  was somehow corrupted, the crew will manually correct it. Otherwise, the most likely cause of a Target  $\Delta T$  alarm is a 180° transfer arising from TIG slip. In this case, proceed as for a TGT ITER alarm below. Don't burn the PEG-7  $\Delta VY$  component (VGO-Y in nominal -Z target track attitude) if it looks unreasonable.

### 3.10.4.3.7.2 TGT ITER

In this case, Lambert is having difficulty converging to an acceptable solution. If PRED MATCH is reasonable, and computed  $\Delta v$  components are within ground-onboard limits, then the crew should downmode to EXDV (e.g. go to MNVR EXEC, re-input thruster, and re-load targets) and burn the onboard solution. This is done to fix  $\Delta v$  components and avoid Lambert cyclic targeting during burn execution. Otherwise if the onboard solution exceeds the ground-onboard limits or if PRED MATCH is large, then burn the ground solution (see GCI below).

### 3.10.4.3.7.3 MC2 EL ANG

The first step is for RGPO to verify the onboard target set ILOADs. Assuming they are valid, then the alarm is likely due to the trajectory being short, and the desired elevation angle not converging within the maximum number of iterations allowed in Lambert. In this case, FDO should confirm with RGPO that a shallow trajectory is present. Then if the output TIG is within MC-2 TIG slip limits (-3 min to +7 min), go ahead and burn the onboard solution. If the output TIG is outside these limits, load target set 19 and burn on a fixed TIG (7 min late for shallow). In either case, FDO should confirm the onboard solution with OMP to make sure it's reasonable (OMP will also likely have trouble converging on desired elevation angle). If the trajectory is not shallow, then some unknown Lambert problem may be present (this can be identified by OMP output *not* matching the onboard); in this case proceed with a GCI by burning the ground solution.

CAUTION: for any Lambert alarm *during burn execution* (TGT  $\Delta T$  or TGT ITER), the burn should be completed.

### 3.10.4.3.7.4 Ground-Controlled Intercept (GCI)

A GCI is required in the event of complete Lambert targeting failure. A GCI scenario has the FDO continue to provide ground-computed OMP solutions to the crew for burns normally targeted onboard (NCC, Ti, and midcourse corrections). This downmode was

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invoked during STS-49 rendezvous #3 when an onboard software anomaly prevented successful execution of Lambert targeting<sup>23</sup>.

When Lambert has been declared failed, Rendezvous FDO must provide PEG-7 targets to the crew in the same time periods Lambert targeting would normally be performed. This keeps the crew in the rendezvous timeline just as would be the case if Lambert functioned normally. The only change during GCI is the crew doesn't execute targeting actions. Instead, FDO performs OMP targeting and uplinks PEG-7 results. FDO should compute OMP targets each time a callout for targeting (preliminary, intermediate, or final) is encountered in the checklist. The PEG-7 targets are then voiced to CAPCOM over the FD Loop so they can be read to the crew. The crew will then enter PEG-7 values in the spaces provided in the Rendezvous Checklist. This is an important step, providing the crew at least some preliminary targets in case communications are lost. Targets associated with the final OMP solution are also uplinked.

Normally, FDO computes PEG-7 targets using both onboard and ground state vectors for comparison purposes. The GCI process of computing PEG-7 targets and uplinking them to the Orbiter is somewhat more involved. By using the following procedure, FDO relieves the crew of burdensome PEG-7 ITEM entries in MNVR EXEC unless command capability is lost.

NOTE: the key to a smooth GCI is standard, consistent procedures executed for each burn. To this end, communicate with FLIGHT and CAPCOM in advance, relating what information will be sent to the crew and when it will be provided.

CAUTION: the following steps assume the best available rendezvous navigation sources are the onboard Orbiter (either PROP or FILT) and target vectors. For sensor anomalies prohibiting use of any onboard vector source, Steps 1 and 2 are not required and FDO should use M1 for the Orbiter and M3 for the target in Steps 3, 4, and 6. Additionally, since a specific attitude is not required for lost or failed onboard sensors, consider maneuvering the Orbiter to a +XVV heads up attitude (BV = 5, Pitch = 270, Yaw = 0, Omicron = 0) to reduce VRCS attitude hold perturbations.

- 1) After consultation with RNDZ, have NAV (re)anchor E4 with the best relative Orbiter state vector available (typically the onboard FILT vector). This process can also be performed by FDO or TRAJ using the ROSS Alarm PBI to fetch either

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<sup>23</sup> During Ti targeting, the onboard guidance system generated a series of TGT ITER alarms. The crew performed an OPS 8 transition and then returned to OPS 2 in hopes that re-setting rendezvous ILOADs would fix the problem, however Lambert failed again. A Ti Delay was performed in order to try additional troubleshooting. Onboard guidance was declared "failed" and FDO solutions were used for the remainder of the rendezvous. The cause was eventually traced to single precision assignment of double precision variables, as well as missing exit logic in an iteration step in the Flight Software. Also, on rendezvous #2, an unrelated problem occurred where the onboard MC-2 solution was > 500 fps due to Lambert ILOADs being corrupted by the previous rendezvous attempt. To work around this problem, the fixed-TIG (non-elevation angle) target set (#19) was burned using FDO's TIG from the RTP.

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PROP or FILT and TUP the requested ephemeris. Verify area and integration options are consistent with E1. Initial weight should be burnout weight from the previous maneuver.

- 2) Have NAV TUP E6 with the onboard target vector and verify E6 drag characteristics are consistent with E3.
- 3) Have MARS run the upcoming maneuver's OMP plan using E4 as chaser and E6 as target. Check thruster selection for the burn with PROP and verify the plan's MTT is configured appropriately. Transfer the plan to E4.
- 4) After the final targeting solution is transferred, FDO or TRAJ prepares a PEG-7 command load (40601) from E4 and uplinks it using standard procedures.  
NOTE: this step is not required for preliminary or intermediate solutions.
- 5) FDO voices maneuver TIG and targets to FLIGHT and CAPCOM via the FD Loop and monitors read up and read back on A/G Loops. FDO also provides the Rendezvous Checklist page number on which the crew will enter targets.
- 6) FDO and TRAJ will monitor burn execution and confirm the maneuver in E1, E4, and E7.

WARNING: when using PEG-7 targets and EDV onboard guidance, Lambert Guidance TIG slip capability is lost. Any TIG slip of the EDV maneuver is problematic due the rendezvous trajectory's high precision. There will probably not be sufficient time for MARS or PROFILE to determine TIG slip for each maneuver. Therefore, without any TIG slip analysis and knowledge of a post slip trajectory, GCI maneuvers should have zero TIG slip. If the GCI maneuver cannot be performed on time, the burn should not be performed at all. Conversely, if time permits PROFILE to generate TIG slip data, those data can (and should) be used to communicate TIG slip capability.

### **3.10.4.3.7.5 Multiple Rendezvous Attempts**

Early in the rendezvous, prior to loading the new Ti base time, RGPO will have the crew pull up the Lambert target sets on SPEC 34. Any corrupted data will be corrected and re-loaded. Then the crew will proceed with loading the new base time.

### **3.10.4.3.7.6 Rendezvous After MET Day 9**

Prior to OI-29 (first flown on STS-110/8A launched April 8, 2002), SPEC 34's BASE TIME field would only accept one digit in its MET days field. This field now accepts two

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digits, and special workarounds developed for rendezvous more than 10 days after launch are no longer required.

### 3.10.4.3.8 Ti Delay

The decision to execute a Ti Delay can be made in response to any number of system failures that make it advisable to put off the terminal phase for 1 or more revs. This allows time to understand failures, determine impacts, and come up with workarounds so the rendezvous may be continued. Either Orbiter or target problems could be cause for performing Ti Delay. During STS-49 Intelsat rendezvous, a Ti Delay was executed due to problems encountered with onboard Lambert targeting software. The extra time allowed the FCT to better understand the problem and assure that it was safe to proceed with terminal phase.

Upon declaration of Ti Delay, FDO should verify that the crew has Ti Delay PAD onboard, and should obtain FD approval to uplink PEG-7 targets (already built and standing by). As with any ground-targeted OMS or +X burn, the crew should load targets and maneuver to attitude in a timely manner (unless Ti is multi-axis). The burn attitude will likely be very close to that planned for Ti. If nominal Ti TIG has already passed and a decision whether to burn Ti or Ti Delay has not been made, then FDO should call for Ti Delay NLT one minute prior to the TIG slip limit. This is to provide the minimum time to get Ti Delay targets uplinked or typed in, and the burn executed. If the TIG slip limit is reached before the burn can be performed, then do not proceed with the burn. Rather, do nothing so the Orbiter phases out safely in front of the target.

WARNING: if Ti Delay is declared greater than 5 min after Ti TIG has expired, FDO will not be able to uplink the PEG-7 command load due to time limits on the onboard uplink software, nor will the crew be able to load the targets. Therefore, if inertial Ti Delay TIG slip is desired (i.e. "do not re-load targets"), Ti TIG slip should be limited to 4 min to avoid not being able to load targets after downmoding from Ti to Ti Delay. There is no onboard software time limit on executing a burn after it has been loaded.

After Ti Delay is complete, FDO should verify safe relative motion, then have TRAJ make copies and distribute the 1 rev late TIGs Flight Note ASAP. This note will contain the new Ti TIG that RGPO will have CAPCOM read up. RGPO will have the crew execute "Ti Delay Burn" in the contingency ops section of the Rendezvous Checklist. This will have the crew type in the new Ti TIG (basetime) on SPEC 34 for subsequent Lambert targeting. Then the rendezvous timeline will be rejoined at the appropriate PET time, picking up with RR nav and NCC targeting. TRAJ should update the PET clock on the front board. As before, NCC will target the nominal Ti position for 1 rev late. If a stable football has been achieved post Ti, and NCC  $\Delta v$  is predicted to be small (based on ground or onboard targeting of onboard vectors), then FDO and RGPO can consider waiving NCC if this is desired to free up crew time to work any systems



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problems that caused the Ti Delay. Of course, it's always best to perform NCC if practical, even if it's a small burn. The final step to recover from Ti Delay is to reconfigure TIGs in the MCTs for 1 rev late.

Post NCC, FDO and MARS should resume Ti and Ti Delay-2 targeting immediately. Ti  $\Delta v$  should be small (about 3 fps retro), therefore PROP may be agreeable to burning it multi-axis. Ti Delay-2 may be a "no burn" if a stable football at 8 nm is present, and safe relative motion can be assured for at least one rev. If so, then Ti TIG slip will be limited only by Lambert slip capability (prop and relative motion limited). Profile Support and MARS can assist with setting up plans to determine these limits.

### **3.10.4.3.9 Breakouts**

As can be inferred from their respective titles, "Ti Delay" puts the rendezvous in a holding pattern from which it can be continued, while a "breakout" is a more serious termination of the rendezvous in progress. Breakouts can be executed for a variety of reasons, including insufficient propellant margins, Orbiter systems failures making it unsafe to dock or grapple (e.g. loss of translation capability in any axis), or unsafe relative motion. Flight Rules A2-117 (RNDZ/PROX OPS GNC SYSTEMS MANAGEMENT), A2-121 (RNDZ/PROX OPS PROPULSION SYSTEMS MANAGEMENT), and A2-126 (RNDZ/PROX OPS BREAKOUT) document failures for which the Orbiter is no-GO to continue rendezvous. In the event a breakout is required, the proper response is a function of Orbiter location in the rendezvous timeline as described below. As always, Profile Support should be heavily involved in determining the optimal breakout strategy.

#### **3.10.4.3.9.1 Prior to Ti**

Most phase angles allow a passive breakout for which no burns are required to put the Orbiter on a safe trajectory. If Ti has not yet been executed, FDO should have the crew refrain from executing any upcoming burns. This will allow the Orbiter to phase safely in front of the target. This strategy is appropriate in cases where rendezvous was aborted early in the DOR burn sequence, and it also applies to cases in which PLS was declared prior to DOR. FDO's primary consideration in evaluating this course of action should be to guarantee a safe miss distance from the target (using R/T Relmo). If the predicted miss distance is not adequate, a ground-targeted burn should be computed to provide acceptable clearance.

Another possibility to be considered is reversal of the "breakout" decision. Flight Rules may be waived by the MMT such that a rendezvous attempt could be resurrected later in the mission. Therefore, if FLIGHT deems it worthwhile, FDO should evaluate a burn sequence that arrests the closing rate at some safe distance behind the target

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(assuming GUR from behind). Then the option will be available to continue at a later point in the mission with a minimal propellant penalty. Ideally, a "halt" burn would be performed at the NC-4 point 40 nm behind the target. Then two stationkeeping burns could be scheduled each day to maintain position until the problem is resolved or deorbit is performed. The subsequent re-rendezvous propellant penalty arises from performing a retrograde phasing burn to reestablish a closing rate (about 12 fps for a one-rev transfer to Ti), plus Ti itself (about 9 fps after a one-rev transfer), for a total of 525 lbm. In contrast to the "stationkeeping at 40" strategy, the passive breakout technique phases the Orbiter out in front of the target. If the decision to re-rendezvous is ultimately made in this case, a series of propellant-expensive and time-consuming burns will be required to maneuver the Orbiter back behind the target for Ti.

### **3.10.4.3.9.2 At Ti**

Another likely spot where a breakout could be declared is the Ti position. Assuming some failure prompted a Ti Delay, one or more revs would be spent troubleshooting near that location. If a time-intensive IFM or other Orbiter reconfiguration is required prior to continuing the rendezvous, FDO will be called on to get the Orbiter into a safe trajectory so the rendezvous can be attempted the following day. Again, 30-40 nm behind the target by crew wakeup is an acceptable region at which to aim. The main consideration is to provide  $> 2$  nm/rev opening rate from the target following the phasing burn. This criterion tolerates most energy hits that could null the opening rate and eventually drive the Orbiter back towards the target. More  $\Delta v$  would be prudent if the attitude timeline includes numerous attitude maneuvers or other perturbing events.

### **3.10.4.3.9.3 Between Ti and TORVA Init**

Breakouts during this timeframe are executed using "canned" crew procedures in the Rendezvous Checklist. The RNDZ BREAKOUT procedure in the contingency ops section has the crew simply perform a 3 fps retrograde multi-axis burn to phase out in front of the target. Flight Design Monte Carlo analysis has shown this maneuver has a high probability of providing safe clearances. Between Ti and manual takeover, it provides a chaser CG to target CG miss distance of at least 500 ft to a  $3.5\sigma$  confidence level. After the manual takeover point post-MC-4, the minimum miss distance decreases to 370 ft if breakout is commenced at a range of 500 ft. Time permitting, the ideal location to perform this type of breakout is between MC-1 and MC-2, since this maximizes delta-height clearance between the target and Orbiter. After confirming the burn, FDO should verify a safe miss distance is obtained using R/T Relmo. The next order of business would then be to determine if a second rendezvous option is to be preserved. If so, a phasing burn should be planned to halt Orbiter opening rate on the  $+V_{bar}$ , or to hop the Orbiter over the target back to a safe stationkeeping distance on the  $-V_{bar}$ . The earlier this is done, the lower the propellant cost.

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A 3 fps retro breakout is also the appropriate maneuver to perform if the crew is unable to visually locate the target at sunrise following MC-3. Flight rules require a breakout by MC-2 +20 min (no prior sensors) or 24 min (prior sensor data incorporated). This scenario is unlikely on a nominal day when all sensors are functioning, but it has a greater chance of occurring if the RR is failed or if some other dispersion has pushed the trajectory significantly out of limits. If the RR is failed, recall the target has to be within 30° of the COAS centerline at sunrise following MC-3. Otherwise, a breakout is required.

Specialized breakout procedures are required after Twice Orbit Rate Vbar Approach (TORVA) initiation at approximately 600 ft for a Vbar approach. The following "prox ops" breakouts are custom-designed for ISS operations. Other payloads may feature different procedures. Regardless, the Rendezvous Checklist will incorporate the appropriate technique(s) based on Prox Ops Flight Design analysis.

### **3.10.4.3.9.4 During RPM**

During the Rbar Pitch Maneuver, Orbiter attitude is not stable enough to define an active breakout. The CG-to-CG separation between ISS and Orbiter during this maneuver is enough to allow a passive or "hands-off" breakout. When a breakout is required in this scenario, the crew will simply cease control inputs and allow the two vehicles to drift apart. The Orbiter will remain in Free Drift until the range between the two vehicles has increased to 1000 ft. At this point, the Orbiter will be put back in target track attitude control. Opening rate resulting from this passive breakout should be about 4 nm/rev.

### **3.10.4.3.9.5 During Rbar Approach (Stable Inside 500 ft)**

By about MC-4 +15 min, the Orbiter is close enough to the target that a different breakout technique is warranted. For ISS plume impingement protection, a LO Z breakout sequence has been designed for use within 500 ft. It is documented in the Rendezvous Checklist RBAR BREAKOUT procedure. This assumes the Orbiter is in a stable approach on the Rbar. If the range is less than 75 ft, the crew will back out to at least 75 ft prior to proceeding. Once range is beyond 75 ft, the crew will perform a 3 fps retrograde (posigrade if re-rendezvous capability is to be preserved) separation burn. Rather than burning in MM202, the crew simply deflects the THC in the  $\pm X$  direction for a specified period of time to achieve desired  $\Delta v$ . Since the Orbiter is in a  $\pm XVV +ZLV$  attitude hold, nearly pure posigrade or retrograde  $\Delta v$  is achieved. Minimum ISS plume impingement occurs in this attitude since the +X jets are oriented nearly perpendicular to the ISS line of sight. Once outside 1000 ft range, NORM Z can be reselected. A

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possible scenario in which this breakout would be employed is a docking mechanism fail-to-capture following an Rbar approach.

NOTE: Rbar approach is no longer utilized for ISS missions. Consequently, the LO Z breakout is no longer carried in the Rendezvous Checklist. The procedure has been retained here as a basis for future breakout designs in similar scenarios.

### 3.10.4.3.9.6 During Vbar Approach (Stable on $\pm$ Vbar Inside 500 ft)

The VBAR BREAKOUT procedure in the Rendezvous Checklist assumes that a TORVA maneuver from the +Rbar to +Vbar has been completed. It also assumes the Orbiter is in stable position and approach attitude (target in -Z Body direction). The procedure has the crew back out to at least 150 ft and perform a 1.5 fps +X Body (radial up) burn in OPS 201. Twenty-eight minutes later, a 3 fps separation burn is performed from a position above and behind the target. Posigrade  $\Delta v$  is selected for the sep burn if a subsequent re-rendezvous is planned. Otherwise, retrograde  $\Delta v$  is utilized. This breakout would be invoked for a docking mechanism fail-to-capture scenario in which docking was attempted along the Vbar.

### 3.10.4.3.9.7 Shuttle Nose In Plane (SNIP)

The SHUTTLE NOSE IN-PLANE BREAKOUT procedure, otherwise known as SNIP, assumes the Orbiter is within 500 ft of the ISS with the X/Z Body plane lying in that of the ISS orbit. The Orbiter is not constrained to be on the Rbar or Vbar. For example, a SNIP breakout might be performed during an ISS flyaround after an Orbiter cabin leak occurs. If the Orbiter is closer than 75 ft to the ISS, the crew will back out to at least 75 ft prior to proceeding. The first sep burn is a 1.5 fps +X Body THC translation in LO Z. In order for the  $\Delta v$  to be perpendicular to the line of sight to the target, the crew must verify ISS is in the -Z Body direction ( $8^\circ$  corridor) prior to burning. Thirty minutes later, a combination OOP and retrograde/posigrade burn (PEG-7  $\pm 4.3$  fps DVX; +3.6 fps DVY) is performed using MM202 guidance with a maneuver to attitude. Posigrade direction should be selected if re-rendezvous capability is desired. Because the Shuttle nose is in plane, OOP direction can always be south (PEG-7 DVY is positive) without fear of the Z Body VGO being negative (toward ISS). The second burn's total  $\Delta v$  is 5.6 fps. Combined with the 1.5 fps SEP-1, this renders SNIP the most propellant-expensive breakout.

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### 3.10.4.3.9.8 Any Attitude

In this case, a generic 1-2-3 SEP MANEUVER is required in order to guarantee adequate clearance for any location relative to the target. The Orbit Ops Checklist contains this procedure. Make sure the crew has the -Z Body axis pointed at the target with no closing rate prior to executing SEP-1.

### 3.10.4.3.9.9 During Flyaround

Technically speaking, the SHUTTLE NOSE IN-PLANE BREAKOUT can provide a safe, rapid departure from all points during a nominal flyaround. This procedure is propellant inefficient, so some optimization is desired for situations without critical response times. In these cases, the crew should continue the flyaround to the next  $\pm$ Rbar. At Rbar crossing, a nominal multi-axis sep burn (3 fps posigrade or retrograde) is performed in LO Z. The SEP BURN block in the undocking timeline can be used to execute this burn. Posigrade or retrograde  $\Delta v$  will provide safe departure from either Rbar location at half the cost of a SHUTTLE NOSE IN-PLANE BREAKOUT. This technique was employed on STS-79 during the second rev of a *Mir* flyaround. Propellant bingo limits were reached while the crew was attempting to stationkeep on the +Vbar. Inaccurate HHL marks led to a closing rate inside 400 ft, which had to be countered with a LO Z backaway. This expended excessive prop, so the MCC directed the crew to coast to the next -Rbar crossing in order to perform a retrograde separation. This maximized clearances and minimized  $\Delta v$ .

## 3.10.5 MCC Displays for Rendezvous

Although RGPO is primarily responsible for monitoring the onboard navigation system and crew procedures, FDO must also stay up to speed on crew activities and nav state health. This section provides detailed information on the primary Sammi display containing telemetry-based data. This is the prime tool used to monitor onboard activities.

### 3.10.5.1 Rndz ONAV Status

During the terminal phase of rendezvous, RGPO's onboard nav monitoring task increases as the onboard system begins incorporating sensor measurements. Much of this information is contained on the Rndz ONAV Status display. FDOs also find this display quite useful. Some of the information on this display is computed by the Rendezvous Navigation Monitoring Processor (RNMP), and involves comparisons of onboard states versus ground states. The remaining data being displayed are downlisted onboard navigation parameters, including rendezvous navigation filter data

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and non-rendezvous navigation data. The Rndz ONAV Status display is shown below in Figure 3.10.5.1-1. Also included is a description of each parameter.

The G55 MED activates the RNMP, and defines the ephemerides used to compute range on Rndz ONAV Status. Normally FDO requests Dynamics to ship a G55\$ MED at the start of rendezvous phase in order to activate the "GRNG" computation (ground-computed range between target and chaser) assuming chaser in Eph 1 and target in Eph 3.

RNDZ_STAT:(RNDZ_STAT): ONAV ORBITAL STATUS											
110 /104					Rendezvous ONAV Status					B	
OGMT 018:22:53:56		OMET 001:15:43:43		OI 184		GN 22		SM 24		MNVF EXEC 202	
RGMT 018:22:53:57		SVT 018:22:53:58.108		TIME TAGS 0 T		ENG LAMB		ΔVTOT 0.17		TGO 00:01	
NGMT 018:22:53:52		STATE VECTOR		TUDS 018:21:35:44.7		TGT DEG 7		VGO X		-0.11	
GND-PFS 10		GND-TGT 11		ONDD REL		TVR ΔVX		8.5		Y 0.13	
U 125		-95		15564		0 ΔVY		-2.0		Z -0.03	
V -2243		146		48736		T_ST 018:22:50:07.8		TGT #		10	
W 556		142		-1865		T_C 000:00:00:00.0		TIG 018:22:17:14			
UD 2.3		-0.4		-76.5		T_FR 018:22:53:57.1					
YD 0.1		0.2		-6.4		T_E 18:22:53:41.79					
WD -0.2		0.1		0.3							
MM 201		KUI-SM		REL NAV		FLTR-PROP		IHC OMS		CUR PTG - TRK	
1 RNVA *		RR ACQ		POSITION		R 2067		AFT ADI		FUT PTG - STOP	
2 KUI ANI *		MODE PASV		U/D 14		A -289		SENSE -Z		8 TGT ID 1	
3 MEAS		RR OUT HGH		COV R 373		U -528		ATT LVL		14 BODY V 3	
4 SV-SEL FLIR		SIGNAL 2		COV V 0.62		V 1991		R 179.2 X X		15 PITCH 90.00	
5 AVG G *		RR RNG AUTO		16 COV INIT		W 8		P 17.2 Y Y		16 YAW 0.00	
		SCAN OK				UD -1.930		Y 1.7 Z Z		17 OM 0.00	
		DET				VD 0.439		DY DISP		LVLH ERROR	
		TRCK				WD 0.010		X -6.14		R 1.70 0.36	
NRNG 8.357		RNG 50616 G		13 RR_ANG <input type="checkbox"/>		VECTOR XFR		Y -10.84		P 287.36 0.26	
GRNG 8.792		R -28.70 G		RNG 50777		8 F->P		Z 18.38		Y 0.82 -0.03	
GRNG 53420		EL -0.26 G		RGRT -28.55		9 P->F		DY_COUNT 19		INRIL BURN	
GB 16.59		AZ -0.35		EL -0.26		10 O->T		CONT_ACC 91		R 253.13 158.78	
GB 18.02				AZ -0.35		11 T->O		DV_THRESH 3840		P 58.66 321.66	
12 ST ANG <input type="checkbox"/>		14 C_ANG <input type="checkbox"/>		C_OFFSET		S_TRK -Y -Z				Y 24.73 46.24	
Y -2.76		Y 0.00		X -0.9		SHUTTER / BO CL / CL /				DAP CONFIG 20	
H -3.11		X 0.00		Y 0.8		TGT TRK 5 * 6 *				A AUTO /VERN	
A D S		MARK HIST		BIAS		PRESENT / SUP				TRN PLS 0.10	
F G E		RESID RATIO		ACPT REJ↓		SCAN FF OF				ROT DSC 0.016	
RRNG 17 A * P		0.033 0.03		114 0		MODE B200 B200				PLS 0.010	
RGRT 20 A * P		0.39 0.06		113 0		STATUS OFOV				DB ATT 1.000	
R EL 23 A * P		-0.02 0.01		112 0		22 COAS SIGHT MODE				RATE 0.020	
R AZ A * P		0.07 0.00		112 0						JET P NOM N	
										OPT Y NOM T	
										PCT ARM	
M1 S66 AV BAY 2		FAN 3		018/22:33:23.62		RMS BRAKES OFF		IMJ		VAR PARAMS	
S2 S66 AV BAY 1		FAN 3		018/22:33:23.62				1 ATT		1 7000 6 2000	
G3 S66 SPLY H20		QTY 3		018/22:33:22.63				7 1 2 3		2 2000 7 0002	
K1 GNC 330		ITEM 23 EXEC				β -5.89 DAY		OPR * * *		3 8FA3 8 339B	
Y2 GNC 340		ITEM 28 EXEC				SUN HA/HP SR 01:25:01		SEL * * *		4 2000 9 453B	
B3 0						P 81 221 NN 00:20:49		BIT *		5 4000 0 E456	
D4 SM 2011						Y 4 202 SS 00:49:08		RML			
										Quit	

Figure 3.10.5.1-1: Rndz ONAV Status

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RNDZ_STAT:(RNDZ_STAT): ONAV ORBITAL STATUS									
110/104		Rendezvous ONAV Status					B		
OGMT 018:22:53:56 OMET 001:15:43:43		OI 184 GN 22 SM 24		MNVF EXEC 202		ENG LAMB AVTOT 0.17			
RGMT 018:22:53:57 SVT 018:22:53:58.108				TUDS 018:21:35:44.7		TGO 00:01			
MGMT 018:22:53:52		STATE VECTOR		TIME TAGS 0 T		TGT PEG 7 VGO X -0.11			
GND-PFS 10 GND-TGT 11 ONDD REL				TUDT 018:20:15:00.0		TVR AVX 8.5 AVY -2.0 AVZ -0.6		Z -0.03	
U 125 -2243 556		-95 146 142		15564 48736 -1865		T_ST 018:22:50:07.8		TGT #	
V 2.3 UD 0.1 VD -0.2		-0.4 -0.2 0.1		-76.5 -6.4 0.3		T_C 000:00:00:00.0		10 TIC 018:22:17:14	
W 0.1 WD -0.2						T_FR 018:22:53:57.1			
						T_E 18:22:53:41.79			
MM 201		KII-SM		REL NAV		FLTR-PROP		AFT ADJ	
1 RNAV *		RR ACQ		POSITION		R 2067		SENSE -2	
2 KII ANT *		MODE PASV		U/D 14		A -289		ATT LVL	
3 MEAS		RR OUT HGH		COV R 373		U -528		R 179.2 X X	
4 SV-SEL FLTR		SIGNAL 2		COV V 0.62		V 1991		P 17.2 Y Y	
5 AVG 6 *		RR RNG AUTO		16 COV INIT		W 8		Y 1.7 Z Z	
		SCAN OK DET				UD -1.930		DV DISP	
NRNG 8.357		TRCK		13 RR_ANG		VD 0.439		X -6.14	
GRNG 8.792		RNG 50616 G		RNG 50777		WD 0.010		Y -10.84	
GRNG 53420		R -28.70 G		RGRT -28.55		VECTOR XFR		Z 18.38	
GB 16.59		EL -0.26 G		EL -0.26		8 F->P		DV_COUNT 19	
OB 18.02		AZ -0.35		AZ -0.35		9 P->F		CONT_ACC 91	
						10 O->T		DV_THRESH 3840	
						11 T->O			
12 ST ANG		14 C_ANG		C_OFFSET		S_TRK -Y -Z		DAP CONFIG 20	
Y -2.76		Y 0.00		X -0.9		SHUTTER / BO CL / CL /		A AUTO /VERN	
H -3.11		X 0.00		Y 0.8		TGT TRK 5 * 6 *		TRN PLS 0.10	
						PRESENT / SUP		ROT DSC 0.016	
A D S		RESID RATIO		MARK_HIST		SCAN FF OF		PLS 0.010	
F G E				ACPT REJ↓		MODE B200 B200		DB ATT 1.000	
RRNG 17 A * P		0.033 0.03		114 0		STATUS OFOV		RATE 0.020	
RGRT 20 A * P		0.39 0.06		113 0		22 COAS SIGHT NODE		JET P NOM N	
R EL 23 A * P		-0.02 0.01		112 0				OPT Y NOM T	
R AZ A * P		0.07 0.00		112 0				ECT ARM	
								VAR PARAMS	
M1 S66 AV BAY 2 FAN 3 018/22:33:23.62				BIAS STATE		RMS BRAKES OFF		1 ATT	
S2 S66 AV BAY 1 FAN 3 018/22:33:23.62				0 -0.270 0.005 -0.053				7 1 2 3	
G3 S66 SPLY H20 QTY 3 018/22:33:23.63								OPR * * *	
								SEL * * *	
K1 GNC 330 ITEM 23 EXEC								RTI *	
Y2 GNC 340 ITEM 28 EXEC								RML	
B3 0									
D4 SM 2011									
								Quit	

Figure 3.10.5.1-2: Time Tags, Downlist, & State Vector Segment

## 1. TIME TAGS & DOWNLIST

- F/V Flight number and vehicle ID.
- OGMT/OMET (LDR, HDR) Onboard GMT and MET of receipt of Operations Instrumentation (OI) data. Values are frozen during Loss of Signal (LOS). MSID: M40H0107J, M40H0121J.
- RGMT (LDR, HDR) GMT time tag of the latest data from remote tracking sites (RTS). MSID: M40H010BJ
- SVT (HDR) GMT time tag of current onboard state vector. V95W0200C
- MGMT TrS GMT (updates every 12 seconds)
- OI (LDR, HDR) Indicates the OI downlist data format in use. An asterisk in the second field means static data. V75X4070D, M40H0134J (static), 40H0135J (suspect).
- GN Indicates the Guidance Navigation and Control (GNC) computer downlist

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(LDR, HDR)	format in use. An asterisk in the second field means static data. Data formats are 22 (OPS 2), 62 (LDR form of 22), 32 (on-orbit Flight Control System Checkout, OPS 8), and 72 (LDR) form of 32. MSID: V93Q0022CX, M40H0234J, M40H0235J.
SM (LDR, HDR)	Indicates the Systems Management (SM) computer downlist data format in use (24 or 26). An asterisk in the second field means static data. MSID: V93Q0022CY, M40H0334J, M40H0235J.
O, T	Orbiter and Target state vector failure flag. "F" will be displayed to the right of either field for failure of the onboard predictor following uplink. Failure to predict the Orbiter vector will occur when the uplinked vector is > 15 hrs in the future. MSID V90X4770X for OF, V90X4769X for TF.
TUDS	Time at which the onboard prediction to current time was completed using the last uplinked Orbiter state vector. V94W3727C.
TUDT	Time tag of the last uplinked target state vector. V90W4939C.
T-ST	Time of last star tracker measurement. V90W4853C.
T-C	Time of last COAS measurement. V90W4841C.
T-RR	Time of last rendezvous radar measurement. V90W4837C.
TE	Time tag of downlisted Orbiter vector. V95W0200C

### 2. STATE VECTORS

GND-PFS 10 (LDR, HDR)	The onboard FILT Orbiter state vector is subtracted from the ground Orbiter ephemeris vector of the same time tag. The result is displayed in UVW coordinates centered on the ground ephemeris vector. (U = radial upward, V = downtrack, W = out-of-plane toward orbital angular momentum vector (north)). V95H0185C-7C, V95L0190C-2C
GND-TGT 11	The onboard target state vector is subtracted from the ground target ephemeris vector of the same time tag. Result is displayed in UVW coordinates V95H0862C-4C, V95L0867C-9C.
ONBD_REL (LDR, HDR)	The onboard relative state is computed by subtracting the downlisted filtered Orbiter state vector from the downlisted target state vector. Result is displayed in Orbiter-centered UVW coordinates. SCOMP35.



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RNDZ_STAT:(RNDZ_STAT): ONAV ORBITAL STATUS									
110/104					Rendezvous ONAV Status				
GMT 018:22:53:56		OMET 001:15:43:43		OI 184		GN 22		SM 24	
RGMT 018:22:53:57		SVT 018:22:53:58.108		MNRV EXEC 202		ENG LAMB		ΔVTOT 0.17	
MGMT 018:22:53:52		STATE VECTOR		TIME TAGS 0 T		TUDS 018:21:35:44.7		TGO 00:01	
GND-PFS 10		GND-TGT 11		ONDD_REL		TUDI 018:20:15:00.0		TGT PEG 7	
U	125	-95	15564	T_ST 018:22:50:07.8		TVR ΔVX 8.5		X -0.11	
V	-2243	146	48736	T_C 000:00:00:00.0		0 ΔVY -2.0		Y 0.13	
W	556	142	-1865	T_RR 018:22:53:57.1		ΔVZ -0.6		Z -0.03	
UD	2.3	-0.4	-76.5	T_E 18:22:53:41.79		TGT #		10	
YD	0.1	0.2	-6.4			TIG		018:22:17:14	
WD	-0.2	0.1	0.3						
1 RNAV *		RR ACQ		REL NAV POSITION		FLTR-PROP		AFT_ADI	
2 KU ANT *		MODE PASV		U/D 14		R 2067		SENSE -Z	
3 MEAS		RR OUT HGH		COV R 373		A -289		ATT LVL	
4 SV-SEL FLTR		SIGNAL 2		COV V 0.62		U -528		R 179.2 X X	
5 AVG G *		RR RNG AUTO		16 COV INIT		V 1991		P 17.2 Y Y	
NRNG 8.357		SCAN OK		13 RR_ANG		W 8		Y 1.7 Z Z	
GRNG 8.792		TRCK		RNG 50777		UD -1.930		DV DISP	
GRNG 53420		RNG 50616 G		RNG -28.55		VD 0.439		X -6.14	
QB 16.59		R -28.70 G		EL -0.26		WD 0.010		Y -10.84	
QB 18.02		EL -0.26 G		AZ -0.35		VECTOR XFR		Z 18.38	
		AZ -0.35				8 F→P		DV_COUNT 19	
12 ST ANG		14 C_ANG		C_OFFSET		9 P→F		CONT_ACC 91	
Y -2.76		Y 0.00		X -0.9		10 O→T		DV_THRESH 3840	
H -3.11		X 0.00		Y 0.8		11 T→0			
A D S		MARK_HIST		BIAS		S_IRK -Y -Z		DAP CONFIG 20	
F G E		RESID RATIO		ACPT REJ↓		SHUTTER / BO CL / CL /		A AUTO /VERN	
RRNG 17 A * P		0.033 0.03		114 0		TGT TRK 5 * 6 *		TRN PLS 0.10	
RGRT 20 A * P		0.39 0.06		113 0		PRESENT / SUP		ROT DSC 0.016	
R EL 23 A * P		-0.02 0.01		112 0		SCAN FF OF		PLS 0.010	
R AZ A * P		0.07 0.00		112 0		MODE B200 B200		DB ATT 1.000	
						STATUS OFOV		RATE 0.020	
						22 COAS SIGHT MODE		JET P NOM N	
M1 S66 AV BAY 2		FAN 3		018/22:33:23.62		RMS BRAKES OFF		OPT Y NOM T	
S2 S66 AV BAY 1		FAN 3		018/22:33:23.62				PCT ARM	
G3 S66 SPLY H20		QTY 3		018/22:33:22.63				VAR PARAMS	
K1 GNC 330		ITEM 23 EXEC		β -5.89		DAY		1 7C00 6 2000	
Y2 GNC 340		ITEM 28 EXEC		SUN HA/HP SR 01:25:01		OPR * * *		2 2000 7 0002	
B3 0				P 81 221 NN 00:20:49		SEL * * *		3 8FA3 8 339B	
D4 SM 2011				Y 4 202 SS 00:49:08		BIT *		4 2000 9 453B	
						RML		5 4000 0 E456	
Quit									

Figure 3.10.5.1-3: REL NAV Segments

### 3. REL NAV (SPEC 33)

- MM Current major mode. V90Q8001C.
- 1 RNAV An asterisk appears if relative navigation enable (Item 1) is executed. V90X4765X.
- 2 KU ANT An asterisk appears if KU band antenna enable (Item 2) is executed. Orbiter and target state vectors are passed from the GN&C GPC to the SM GPC for KU antenna pointing. V93X6859X.
- 3 MEAS An asterisk appears if sensor measurement enable (Item 3) is executed. Sensor data can be used to update the Orbiter SV. V90X1417X.
- 4 SV-SEL Indicates the source of the navigated relative state. PROP = propagated vector, FILT = filtered state vector. V90X4986X.
- 5 AVG G An asterisk appears if average G, the powered flight propagation integrator, is on. If on, IMU sensed accelerations are incorporated into the Orbiter state vector. V90X1289X.
- NRNG RSS of position components of the UPP relative state (NM).

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M08G0502C.

GRNG	Computed range between Orbiter and target based on ground ephemerides (NM and FT). This comp requires G55\$ MED.
G $\theta$	Ground computed elevation angle to the target. It is driven by the same MED as GRNG.
O $\theta$	-Z sense LVLH pitch angle, which corresponds to the onboard theta if the Orbiter is in TGT TRK with an OMICRON of O. It represents target elevation angle only if the -Z axis is pointed at the target, with the +Y axis pointed south.
RR	Current rendezvous radar mode being used for searching and tracking (M01G3202R): DESIG – GPC designate. AUTO – Auto track. ACQ – GPC acquisition. MAN – Manual slew.
MODE	Indicates COMM for COMM mode, PASV for radar with a passive target, and COXXOP for radar with a target with a transponder.
RR OUT	Shows the radar output power switch setting – LO, MED or HI.
SIGNAL	RR received signal strength. INCO has a different calibration curve which must be utilized in order for this data to be valid when not in COMM mode.
RR AUTO	AUTO or MIN according to the crew selected Item 1 or 2 on SM 201 ANTENNA MANAGEMENT. Use of MIN forces the radar to always search at 2500', EL=0, AZ=0.
SCAN	OK if the crew tb is barberpole, WARN if the crew tb is gray. Below this tb is a field which will be SRCH when the radar is in search, and DET when an object is detected. The lowest field will show TRCK when the crew TRACK tb goes to gray.
RNG	Range to target measured by radar and output by SM at 0.96 sec rate, along with inhibit (I) or data good (G) flag (FT) V74U2623J, V74X2615J.
RGRT	Range-rate to target measured by radar and output by SM at 0.96 sec rate, along with inhibit (I) or data good (G) flag (FPS) V74U2621J, V74X2616J.
EL	Elevation angle to target measured by radar and output by SM at 0.96 sec rate, along with inhibit (I) or data good (G) flag V74U2619J, V74X2590J.
AZ	Azimuth angle to target measured by radar and output by SM at 0.96 sec rate V74U2618J.
U/D	Magnitude of the position update to the filtered state vector for the current

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	filter cycle (FT). V90H4999C.
COV R	RSS of the three diagonal elements of the covariance matrix corresponding to position (FT). V90H0438C.
COV V	RSS of the three diagonal elements of the covariance matrix corresponding to velocity (FPS). V90L0439C.
16 COV INIT	An asterisk appears during re-initialization of Orbiter/target covariance matrix. V90X1415X.
RR_ANG	An asterisk appears if rendezvous radar is selected as the source of angles data (ITEM 13). V90X4866X.
RNG	Actual radar measurement of range passed to nav (FT) V90X4895C.
RGRT	Actual radar measurement of range-rate passed to nav (FPS) V90U4896C.
EL, AZ	Actual radar measurement of target elevation and azimuth angles passed to nav V90U4894C, V90U4893C.
ST_ANG	An asterisk appears if star tracker is selected as the source of angles data. V90X4868X.
H, V	Target position given in star tracker horizontal (H) and vertical (V) Cartesian coordinates. V90U4833C, V90U4834C.
C_ANG	An asterisk appears if the COAS is selected as the source of angles data. V90X4880X.
X, Y	Target position given in COAS X, Y Cartesian coordinates. V90U4848C, V90U4847C
C_OFFSET X, Y	Displacement of the target being tracked by the -Z star tracker in the COAS field of view, in COAS X, Y coordinates. V95H4940C, V95H4941C.
X EL X AZ	The characters to the left of EL and AZ tell which sensor is selected as the source of angles data (M03G0502R, V90J1416C). S = star tracker R = rendezvous radar C = COAS
A F	Indicates the value of the AUTO, INHIBIT, FORCE flag for each measurement type (M14G0502R, M15G0502R, M13G0502R, M13G0502R): A = AUTO. I = INHIBIT. F = FORCE.
D G	Indicates whether the data good flag is on for each measurement type. An asterisk appears if data good flag is on, field is blank if flag is off.

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V90X4899X, V90X4900X, M04G0502E, M04G0502E.

S E	Indicates the value of the sensor edit flag for each measurement type. Tells when data are being incorporated into the nav filter (M09G0500R, M10G0500R, M08G0500R, M07G0500R).  Blank = Sensor edit flag off, data good flag off. X = Sensor edit flag on, measurement rejected. S = Sensor edit flag STAT (statistics), residual and ratio computed, but measurement not incorporated. P = Sensor edit flag PROCESSED, measurement accepted. F = Sensor edit flag FORCED, measurement accepted.
RESID	The residual computed by the rendezvous nav filter for each measurement type. Shows the difference between the raw measurement and the nav estimate of what the measurement should be. V90H0221C, V90H0711C, V90H0214C, M01G4501C.
RATIO	Ratio of the change in the filtered state to 6 times the maximum allowable change. Values should converge to approximately zero. V90U0222C, V90U0713C, V90U0217C, V90U0216C.
MARK HIST ACPT RJ	Indicates the number of each measurement type which have been accepted or rejected by the filter. Used to determine when nav is converged, and when to do FILT to PROP state vector transfers. MSID V90J1400C, V90J1401C, V90J1403C, V90J1402C for ACPT. MSID V90J1405C, V90J1406C, V90J1408C, V90J1407C for RJ.
BIAS STATE	Indicates the sensor bias computed by the rendezvous nav filter for each measurement type. V90U4297C, V90U4298C, V90U4296C, V90U4295C.

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RNDZ_STAT:(RNDZ_STAT): ONAV ORBITAL STATUS																				
110/104					Rendezvous ONAV Status					B										
OMGT 018:22:53:56		OMET 001:15:43:43		OI 184 GN 22 SM 24		MNRV EXEC 202		ENG LAMB		AVTOT 0.17										
RGMT 018:22:53:57		SVT 018:22:53:58.108		TIME TAGS 0 T		TUDS 018:21:35:44.7		TGO		00:01										
MGMT 018:22:53:52		STATE VECTOR		TUDI 018:20:15:00.0		TGT PEG 7		TVR AVX 8.5		X -0.11										
GND-PFS 10		GND-TGT 11		ONDD_REL		T_C 000:00:00:00.0		AVY -2.0		Y 0.13										
U	125	-95	15564	T_ST 018:22:50:07.8		T_RR 018:22:53:57.1		AVZ -0.6		Z -0.03										
V	-2243	146	48736	T_E 18:22:53:41.79		TGT #		TIG 018:22:17:14												
W	556	142	-1865																	
UD	2.3	-0.4	-76.5																	
VD	0.1	0.2	-6.4																	
WD	-0.2	0.1	0.3																	
MOM 201			KUI-SM			REL NAV			THC			OMS			CUR PTG -			TRK		
1 RNAV *			RR ACQ			POSITION			R			SENSE -Z			FUT PTG -			STOP		
2 KUI ANT *			MODE PASV			U/D 14			A			ATT LVL			8 TGT ID			1		
3 MEAS			RR OUT HGH			COV R 373			U			R 179.2			X			X		
4 SV-SEL FLTR			SIGNAL 2			COV V 0.62			V			P 17.2			Y			Y		
5 AVG G *			RR RNG AUTO			16 COV INIT			W			Y 1.7			Z			Z		
			SCAN OK			DET			UD			DV DISP			LVLH			ERROR		
NRNG 8.357						13 RR_ANG *			VD			X -6.14			R 1.70			0.36		
GRNG 8.792			RNG 50616 G			RNG 50777			WD			Y -10.84			P 287.36			0.26		
GRNG 53420			R -28.70 G			RGRT -28.55			VECTOR XFR			Z 18.38			Y 0.82			-0.83		
GB 16.59			EL -0.26 G			EL -0.26			8 F->P			DV_COUNT 19			INRIL			BURN		
GB 18.02			AZ -0.35			AZ -0.35			9 P->F			CONT_ACC 91			R 253.13			158.78		
12 ST ANG			14 C_ANG			C_OFFSET			10 O->T			DV_THRESH 3840			P 58.66			321.66		
Y -2.76			Y 0.00			X -0.9			11 T->0						Y 24.73			46.24		
H -3.11			X 0.00			Y 0.8			S_IRK -Y -Z						DAP CONFIG 20					
A D S			MARK_HIST			BIAS			SHUTTER / BO			CL / CL /			A AUTO /VERN					
F G E			RESID RATIO			ACPT REJ ↓			TGT TRK			5 * 6 *			TRN PLS 0.10					
RRNG 17 A * P			0.033 0.03			114 0			PRESENT / SUP						ROT DSC 0.016					
RGRT 20 A * P			0.39 0.06			113 0			SCAN			FF OF			PLS 0.010					
R EL 23 A * P			-0.02 0.01			112 0			MODE			B200 B200			DB ATT 1.000					
R AZ A * P			0.07 0.00			112 0			STATUS			OFOV			RATE 0.020					
									22 COAS SIGHT MODE						JET P NOM N					
M1 S66 AV BAY 2			FAN 3			018/22:33:23.62			RMS BRAKES OFF			DMU			OPT Y NOM T					
S2 S66 AV BAY 1			FAN 3			018/22:33:23.62						1 ATT			ECT ARM					
G3 S66 SPLY H20			QTY 3			018/22:33:22.63						7 1 2 3			VAR PARAMS					
K1 GNC 330			ITEM 23 EXEC									OPR * * *			1 7000 6 2000					
Y2 GNC 340			ITEM 28 EXEC									SEL * * *			2 2000 7 0002					
B3 0												BIT *			3 8FA3 8 339B					
D4 SM 2011												RML			4 2000 9 453B					
															5 4000 0 E456					
										Quit										

Figure 3.10.5.1-4: Fltr-Prop, THC, & DV\_Disp Segments

## 4. FLTR - PROP

- R The RSS of the position difference between the filtered and propagated state vectors (FT). V90H4997C.
- A The semi-major axis difference between the filtered and propagated state vectors (FT).
- U, V, W Difference between filtered and propagated position vector expressed in UVW coordinates (FT).
- UD, VD, WD Difference between filtered and propagated velocity vector expressed in UVW coordinates (FT).
- 8 F->P An asterisk appears and remains on for one nav cycle when a FILT to PROP transfer has been executed. V90X4984X.
- 9 P->F An asterisk appears and remains on for one nav cycle when a PROP to FILT transfer has been executed. "Filter restart." V90X4985X
- 10 O->T An asterisk appears and remains on for one nav cycle if an ORB to TGT transfer has been executed. V90X1413X.

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11 T->0 An asterisk appears and remains on for one nav cycle if a TGT to ORB transfer has been executed. V90X1414X.

### 5. THC & DV DISP

THC PWR Indicates power to FWD or AFT THC. V73X3003X, V73X3022X.  
Below PWR will be displayed an F or an A if the Forward Aft THC is powered.

CAUTION: because of display limitations, only power supply A is used to drive the FWD THC discrete. Certain failure scenarios can result in a powered FWD THC with no indication on this display.

AFT ADI SENSE Aft ADI sense switch (-X, -Z) V72K5180X.

AFT ADI ATT Aft ADI attitude reference (INR, LVL, REF) V72K2103X.

AFT ADI R, P, Y Aft ADI roll, pitch, yaw angles W07G0200C, W08G0200C, W09G0200C.

OMS L, R Indicates asterisk if OMS engine firing V43K4583X, V43K5583X.

X, Y, Z Next to X, Y & Z will appear a + or – to indicate THC deflection toward that body axis.

CAUTION: for reasons unknown, not all deflections are indicated, even with high data rate.

RCS X, Y, Z Next to X, Y & Z will appear a + or – to indicate the direction of thrust on Orbiter body coordinates due to an RCS jet firing.

CAUTION: for reasons unknown, not all firings are indicated. Also, due to display limitations, L4D, R4D, and vernier jets were deleted. Finally, attitude control jet firing may be confusing. Roll and Pitch may result in a Z+- being driven, while Yaw may result in a Y+- being driven.

DV\_DISP (X, Y, Z) Accumulated IMU-sensed inertial delta-velocities accepted by nav in M50 X, Y, and Z axes. V90L5181C-3C.

DV\_COUNT The number of cycles of IMU data accepted into nav during maneuvering. V90J5184C.

CONTACC Sensed acceleration over the last nav cycle. V90A4944C.

DV THRESH Acceleration threshold below which IMU-sensed accelerations are not used by nav (unless RCS firings are taking place). Crew can change by item entry on SPEC 21. V90A4747C.

### 6. STAR TRACKERS (SPEC 22)

SHUTTER / BO Indicates whether star tracker shutters are open (OPN) or closed (CLS). V71X5024B

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TGT TRACK (5, 6)	An asterisk appears under the appropriate ST if target track mode is selected. V90U4836C.
PRESENT / SUP	An asterisk appears under the appropriate ST if a star is present in the field of view. V71X5526B, V1X5026B.
SCAN	If the full field scan mode (10 X 10 deg) is selected, FF appears. If the offset mode (1 X 1 deg) is selected, OF appears. V95J4930C, V95J4929C.
MODE	<p>A 4-digit hexadecimal word providing the current status of the ST mode of operation (V71M5520P, V71M5020P):</p> <p>First digit:     A = Shutter open.                   B = Shutter closed.</p> <p>Second digit:   0, 1, 2, 3 = no star or target present. (Intensity)     4, 5, 6, 7 = star or target present.</p> <p>Third and fourth digit:   00 = no intensity                                   FF = saturated (too bright)</p>
STATUS	<p>A hexadecimal half-word that gives star tracker status information. Used during self test and ST passes to monitor lock-on status. Values (V95J4930C, V95J4929C):</p> <p>0000 – Blank, tracker locked on 0001 – Fail self-test. 0002 – Pass self-test. 0003 – False target. 0004 – Out of field-of-view. 0005 – High angular rate. 0006 – No target present.</p>
22 COAS SIGHT MODE	An asterisk appears if COAS sight mode is selected by executing item 22 on SPEC 22. V95X4963X.

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RNDZ_STAT:(RNDZ_STAT): ONAV ORBITAL STATUS											
110 /104					Rendezvous ONAV Status					B	
OMGT 018:22:53:56		OMET 001:15:43:43		OI 184		GN 22		SM 24		MNVR EXEC 202	
RGMT 018:22:53:57		SVT 018:22:53:58.108		TIME TAGS 0 T		TUDS 018:21:35:44.7		TUDT 018:20:15:00.0		ENG LAMB ΔVTOT 0.17	
MGMT 018:22:53:52		STATE VECTOR		GND-PFS 10		GND-TGT 11		ONDD_REL		TGO 00:01	
U	125	-95	15564	U/D	14	R	2067	AFT_ADI	SENSE -2	TVR ΔVX 8.5	X -0.11
V	-2243	146	48736	COV R	373	A	-289	ATT LVL		0 ΔVY -2.0	Y 0.13
W	556	142	-1865	COV V	0.62	U	-528	R 179.2	X X	ΔVZ -0.6	Z -0.03
UD	2.3	-0.4	-76.5	16 COV INIT		V	1991	P 17.2	Y Y	TGT #	
YD	0.1	0.2	-6.4	13 RR_ANG		W	8	Y 1.7	Z Z	10 TIC 018:22:17:14	
WD	-0.2	0.1	0.3	RNG 50616 G		UD	-1.930	DV_DISP		CUR PTG - TRK	
MOM 201		KI-SM		REL NAV		FLTR-PROP		IHC OMS		FUT PTG - STOP	
1 RNAV *		RR ACQ		POSITION		R 2067		PWR L R		8 TGT ID 1	
2 KI ANT *		MODE PASV		U/D 14		A -289		RCS		14 BODY V 3	
3 MEAS		RR OUT HGH		COV R 373		U -528		X X		15 PITCH 90.00	
4 SV-SEL FLTR		SIGNAL 2		COV V 0.62		V 1991		Y Y		16 YAW 0.00	
5 AVG G *		RR RNG AUTO		16 COV INIT		W 8		Z Z		17 ON 0.00	
NRNG 8.357		SCAN OK DET		13 RR_ANG		UD -1.930		DV_DISP		LVLH ERROR	
GRNG 8.792		RNG 50616 G		RNG 50777		VD 0.439		X -6.14		R 1.70 0.36	
GRNG 53420		R -28.70 G		RGRT -28.55		WD 0.010		Y -10.84		P 287.36 0.26	
QB 16.59		EL -0.26 G		EL -0.26		VECTOR XFR		Z 18.38		Y 0.82 -0.83	
QB 18.02		AZ -0.35		AZ -0.35		8 F→P		DV_COUNT 19		INRIL BURN	
12 ST ANG		14 C_ANG		C_OFFSET		9 P→F		CONT_ACC 91		R 253.13 158.78	
Y -2.76		Y 0.00		X -0.9		10 O→T		DV_THRESH 3840		P 58.66 321.66	
H -3.11		X 0.00		Y 0.8		11 T→0				Y 24.73 46.24	
A D S		MARK_HIST		BIAS		S_TRK -Y -Z		SHUTTER / BO CL / CL /		DAP CONFIG 20	
F G E		RESID RATIO		ACPT REJ↓		STATE		TGT TRK 5 * 6 *		A AUTO /VERN	
RRNG 17 A * P		0.033 0.03		114 0		0		PRESENT / SUP		TRN PLS 0.10	
RGRT 20 A * P		0.39 0.06		113 0		-0.270		SCAN FF OF		ROT DSC 0.016	
R EL 23 A * P		-0.02 0.01		112 0		0.005		MODE B200 B200		PLS 0.010	
R AZ A * P		0.07 0.00		112 0		-0.053		STATUS OFOV		DB ATT 1.000	
								22 COAS SIGHT MODE		RATE 0.020	
M1 S66 AV BAY 2		FAN 3		018/22:33:23.62		RMS BRAKES OFF		IMU		JET P NOM N	
S2 S66 AV BAY 1		FAN 3		018/22:33:23.62				1 ATT		OPT Y NOM T	
G3 S66 SPLY H20		QTY 3		018/22:33:22.63				7 1 2 3		PCT ARM	
K1 GNC 330		ITEM 23 EXEC		β -5.89		DAY		OPR * * *		VAR PARAMS	
Y2 GNC 340		ITEM 28 EXEC		SUN HA/HP SR 01:25:01				SEL * * *		1 7000 6 2000	
B3 0				P 81 221 NN 00:20:49				BIT *		2 2000 7 0002	
D4 SM 2011				Y 4 202 SS 00:49:08				RML		3 8FA3 8 339B	
										4 2000 9 453B	
										5 4000 0 E456	
Quit											

Figure 3.10.5.1-5: MNVR EXEC, UNIV PTG, & DAP Segments

## 7. MNVR EXEC

**ENG** Engine selection is indicated with a 1 (Both OMS), 2 (left OMS), 3 (Right OMS), or 4 (RCS); which corresponds to the item entries on the crew display V94J3791C.

Guidance mode is indicated by EXDV or LAMB. When a target is computed on SPEC 34, the solution will appear in the PEG 7 Δv slots V94X4029X.

**DVTOT** Total Δv to be burned (fps) V94L3795C

**TGO** Time to burn (mm:ss) V90W1941C

**TVR** Thrust vector roll angle (deg) V93H6936C

**TGT PEG 7** PEG 7 Δv components (fps) V93L6950C-2C

**VGO** Computed body VGOs (fps) V94U3800C-2C

**TGT#** Target set from SPEC 34 V95J7466C



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TIG	Displayed only in GMT V94W3790C
8. <u>UNIV PTG</u>	
CUR PTG	Indicates the current control option selected by the crew. Possible values and their Universal Pointing item numbers are (M0G2400R): TRK (Item 19) MNVR (Item 18) ROT (Item 20) STOP (Item 21)
FUT PTG	Indicates the future-loaded control option selected by the crew. Possible values and their Universal Pointing item numbers are (V95J7483C): TRK (Item 19) MNVR (Item 18) ROT (Item 20) STOP (Item 21)
8 TGT ID	Identifies target type used for the TRK option. V93U6810C.
14 BODY V	Identifies the Orbiter body vector to be directed at the target. See 3.10.6.2.1 for definitions. V93U6805C
15 PITCH	Pitch component of the specified Orbiter body vector. V93U6806C
16 YAW	Yaw component of the specified Orbiter body vector. V93U6807C.
17 OM	Omicron angle. Specifies attitude orientation about the selected body vector. V93H6825C.
LVLH (R, P, Y)	Current Orbiter roll, pitch, and yaw angles in the local vertical, local horizontal reference frame (DEG). TDR20-22.
ERR	Attitude differences in roll, pitch, and yaw between the current and required attitude selected using the MNVR or TRK options (DEG). V95H7490C, V95H7491C, V95H7492C.
INRTL (R, P, Y)	Current Orbiter roll, pitch, and yaw angles in the inertial ADI reference frame (DEG). TDR20-22.
BURN	Inertial burn attitude computed by MM202 maneuver exec guidance (DEG). V93U6910C.
9. <u>DAP</u>	
DAP CONFIG 20	Defines which Digital Autopilot (DAP A or B) is selected, the DAP control mode (AUTO or MAN), and the jets selected (NORM or VERN). V72X2808X, V72X2897X, V72X2896X.
TRN PLS	Current translational pulse size for a single manual translational pulse command (FPS) V90U2795C.

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- ROT DSC** Discrete attitude maneuver rate magnitude (deg/sec) of the DAP and thrusters V90U2787C. ROT RATE on SPEC 20.
- ROT PLS** Current rotational pulse size (DEG/SEC) for a single manual rotational pulse command V90U2794C
- DB ATT** Current deadband, or maximum attitude error (deg) allowed in each axis by the DAP, when DAP is in AUTO V90H2785C
- DB RATE** Current rate deadband (deg/sec) allowed in each axis by the DAP, when DAP is in AUTO V90U2786C
- JET P** Indicates attitude control mode Nom, or Low (inhibits upfiring jets) and option full, nose, or tail (F, N, T) V90X2793X, V90X2788X.
- JET Y** Indicates attitude control mode (Nom only)--ignore letter that follows V90X2817X, V90X2789X
- PCT ARM** Arm of PCT pulse to achieve docking (asterisk shown when armed) V90X0109X.

RNDZ_STAT:(RNDZ_STAT): ONAV ORBITAL STATUS											
110 /104 Rendezvous ONAV Status <span style="float:right">B</span>											
OGMT 018:22:53:56 OMET 001:15:43:43 RGMT 018:22:53:57 SVT 018:22:53:58.108 MGMT 018:22:53:52		OI 184 GN 22 SM 24		MNVR EXEC 202 ENB LAMB AVTOT 0.17 4 TGT PEG 7 TGO 00:01 TVR AVX 8.5 VGO X -0.11 0 AVY -2.0 Y 0.13 AVZ -0.6 Z -0.03 TGT # 10 TIG 018:22:17:14							
STATE VECTOR GND-PFS 10 GND-TGT 11 ONDD REL U 125 -95 15564 V -2243 146 48736 W 556 142 -1865 UD 2.3 -0.4 -76.5 YD 0.1 0.2 -6.4 WD -0.2 0.1 0.3		TIME TAGS 0 T TUDS 018:21:35:44.7 TUDT 018:20:15:00.0 T_ST 018:22:50:07.8 T_C 000:00:00:00.0 T_RR 018:22:53:57.1 T_E 18:22:53:41.79									
MM 201 1 RNAV * 2 KII ANT * 3 MEAS 4 SV-SEL FLIR 5 AVG G *		KU-SM RR ACQ MODE PASV RR OUT HGH SIGNAL 2 RR RNG AUTO SCAN OK DET TRCK		REL NAV POSITION U/D 14 COV R 373 COV Y 0.62 16 COV INIT		FLTR-PROP R 2067 A -289 U -528 V 1991 W 8 UD -1.930 VD 0.439 WD 0.010 VECTOR XFR 8 F->P 9 P->F 10 O->T 11 T->O		ITC PWR L R AFT ADJ SENSE -Z ATT LVL R 179.2 X X P 17.2 Y Y Y 1.7 Z Z DV DISP X -6.14 Y -10.04 Z 18.38 DV_COUNT 19 CONT_ACC 91 DV_THRESH 3840		CUR PTG - TRK FUT PTG - STOP 8 TGT ID 1 14 BODY V 3 15 PITCH 90.00 16 YAW 0.00 17 OM 0.00 LVLH ERROR R 1.70 0.36 P 287.36 0.26 Y 0.82 -0.83 INRTL DURN R 253.13 158.78 P 58.66 321.66 Y 24.73 46.24	
NRNG 8.357 GRNG 8.792 GRNG 53420 GB 16.59 OB 18.02		RNG 50616 G R -28.70 G EL -0.26 G AZ -0.35		13 RR_ANG <input type="checkbox"/> RNG 50777 RGRT -28.55 EL -0.26 AZ -0.35		C_OFFSET X -0.9 Y 0.8		S_TRK -Y -Z SHUTTER / BO CL / CL / TGT TRK 5 * 6 * PRESENT / SUP SCAN FF OF MODE B200 B200 STATUS OFOV 22 COAS SIGHT MODE		DAP CONFIG 20 A AUTO /VERN TRN PLS 0.10 ROI DSC 0.016 PLS 0.010 DB ATT 1.000 RATE 0.020 JET P NOM N OPT Y NOM T ECT ARM	
MARK_HIST BIAS STATE 0 0 -0.270 0.005 -0.053		RESID RATIO ACPT REJ↓ 0.033 0.03 114 0 0.39 0.06 113 0 -0.02 0.01 112 0 0.07 0.00 112 0		RMSG BRAKES OFF IMU 1 ATT 7 1 2 3 OPR * * * SEL * * * BIT * RMJ		VAR PARAMS 1 7000 6 2000 2 2000 7 0002 3 8FA3 8 339B 4 2000 9 453B 5 4000 0 E456		12 ST ANG <input type="checkbox"/> Y -2.76 H -3.11 14 C_ANG <input type="checkbox"/> Y 0.00 X 0.00		M1 S66 AV BAY 2 FAN 3 018/22:33:23.62 S2 S66 AV BAY 1 FAN 3 018/22:33:23.62 G3 S66 SPLY H20 QTY 3 018/22:33:22.63 K1 GNC 340 ITEM 23 EXEC Y2 GNC 330 ITEM 28 EXEC B3 0 D4 SM 2011	
β -5.89 DAY SUN HA/HP SR 01:25:01 P 81 221 NN 00:20:49 Y 4 202 SS 00:49:08											
Quit											

Figure 3.10.5.1-6: Miscellaneous Segments

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### 10. ONBOARD FAULT SUMMARY

Displays GPC fault messages from onboard telemetry. The most recent message is displayed at the top, along with each GPC that detected the error, followed by the GMT.

### 11. GPC SCRATCHPAD

Displays crew item entries to the GPCs along with GPC display page. Most recent is displayed at top.

### 12. RMS

BRAKES                      ON/OFF indication

### 13. ORBITAL PARAMETERS

$\beta$                       Central angle between the sun and the orbit plane for TrS Eph 1 (DEG) (+ if the sun is north of the plane).

Sun P, Y                      Pitch and yaw angles to the sun body center, measured from the Orbiter +X axis, in a pitch yaw sequence.

HA/HP                      Height of apogee and perigee based on TrS Eph 1 (NM)

SR, NN, SS                      Time to the next orbital sunrise, noon, and sunset based on TrS Eph 1. A text indicator is also driven showing DAY or NITE, as appropriate.

### 14. IMU

ATT                      Indicates which IMU is selected for attitude data. V90J2560C.

123                      An octal number which indicates which IMU's are available for use by nav. The most significant bit indicates the availability of IMU 1, and the least significant bit indicates the availability of IMU 3. Possible values (V90J2503C):

- 7 (111) – All 3 IMU's are available.
- 6 (110) – IMU's 1 and 2 are available.
- 5 (101) – IMU's 1 and 3 are available.
- 4 (100) – Only IMU 1 is available.
- 3 (011) – IMU's 2 and 3 are available.
- 2 (010) – Only IMU 2 is available.
- 1 (001) – Only IMU 3 is available.
- 0 (000) – No IMU's are available.

OPR                      An asterisk appears if the corresponding IMU is in operational mode. If blank, the IMU is powered off or is in standby. V71X2403X, V71X3403X, V71X4403X.

SEL                      An asterisk appears under IMU's which have not been deselected by the crew. A blank indicates the IMU has been deselected. V93X6711X, V93X6712X, V93X6713X.

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BIT Asterisk shown if IMU registering hardware, software, or temperature BITE.

RM Indicates the status of the redundancy management on each IMU. Nominally, these should be blank (M07G4100R, M08G4100R, M09G4100R):  
C = commfault  
F = failed IMU  
D = IMU dilemma

### 15. VAR PARAMS

1-10 These are open slots in the downlist which the GNC flight controller can change to downlist different variables. During rendezvous, slots 4 and 5 are used to indicate the -Z and -Y ST mode of operation respectively.

Possible values (hex) for these slots are:

0000 or 1000	Term Idle
2000	Target Track
4000	Star Track
	Self-Test

### 3.10.6 JURE Operations

This section documents FDO processes specific to Joint Underspeed Recovery (JURE), a contingency scenario in which ISS rendezvous capability is restored by lowering ISS orbit altitude. Such a scenario may develop following a MECO underspeed, but JURE can also arise from any loss in Orbiter propulsive capability, such as an OMS He leak. Because ISS burns are required to achieve a JURE rendezvous, complex coordination with the ISS flight control team, including Russian specialists based at MCC-M, is required. Nearly all of this coordination involving FDO is performed through the TOPO discipline.

The JURE ops concept seeks to achieve rendezvous in the highest possible orbit to minimize ISS propellant consumption. Beyond a mean usage rendezvous, the only Orbiter propellant budgeted is steep deorbit<sup>24</sup>, including launched cargo return, and attitude maintenance protecting the following timeline.

- 1) Dock on FD4 or FD5
- 2) Undock on FD7
- 3) EOM through EOM+2 ascending ConUS DOPS on FD8 through FD10

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<sup>24</sup> Although steep deorbit is optimized for ascending ConUS opportunities on FD8 through FD10, Orbiter propellant budgeting must cover similar opportunities starting on FD5 or FD6 in case JURE is aborted.

## FDO Console Handbook Section 3.10: Rendezvous Operations

The ISS JURE propellant budget includes orbit lowering to support rendezvous recovery, followed by orbit raising back to the altitude at Shuttle launch assuming complete cargo exchange with the Shuttle. This ISS propellant budget is subject to real time review by the ISS Mission Management Team (IMMT). If the ISS budget is found to be excessive, rendezvous recovery efforts will be suspended and the Shuttle will deorbit without conducting ISS mated ops.

NOTE: the Orbiter propellant budget assumes launched cargo return, while the ISS budget assumes complete cargo transfer. This conservative approach permits rendezvous recovery efforts to be aborted at any time without jettisoning cargo.

### 3.10.6.1 History

Following initial technical interchanges with Russian Ballistics and TOPO representatives in 1998, JURE procedures were available for operational use during STS-88/2A, STS-96/2A.2, and STS-101/2A.2a. Proficiency among FDO, TOPO, and Ballistics personnel was maintained throughout this period by conducting periodic paper simulations. To minimize procedural complexity and ISS burn constraints, JURE rendezvous was targeted to a circular orbit in association with these initial ISS missions.

Starting with STS-106/2A.2b, the Shuttle mission following Service Module (SM) launch in 2000, ISS mass began to increase dramatically. At this point, ISS Russian Segment (RS) control also transitioned from Khrunichev to Rocket Sciences Corporation Energiya (RSC-E). These changes had fundamental implications for JURE operations. Increased ISS mass greatly reduced the  $\Delta v$  contribution available to JURE from ISS. Although this reduction was partially offset by increased RS propellant storage capacity and 2000-sec Progress burn arcs, additional JURE constraints were imposed by RSC-E.

Limited ISS rendezvous recovery capability was coordinated for STS-106/2A.2b and STS-92/3A in 2000, but an operationally viable JURE was not possible in the post-SM Era until STS-110/8A in 2002. In addition to full accord with RSC-E trajectory planning constraints, post-2001 JURE procedures maximize recovery capability by targeting an elliptical rendezvous orbit. This orbit arises from ISS burn TIGs at a fixed argument of latitude designed to minimize subsequent Orbiter deorbit  $\Delta v$ .

### 3.10.6.2 Supporting Documentation

In addition to this FDO Console Handbook material, the following documentation is pertinent to JURE operations.

## FDO Console Handbook Section 3.10: Rendezvous Operations

- 1) Flight Rule C4-TBS, Off-Nominal Shuttle Orbit: circumstances, actions, and constraints relating to JURE operations (consult pertinent annex rule prior to Volume C publication)
- 2) OIP 2.2.5, Decision for Shuttle Ascent Joint Underspeed Recovery: procedures by which the IMMT decides whether or not to allocate ISS propellant required by a JURE rendezvous
- 3) OIP A7.16.6, Shuttle Ascent Joint Underspeed Recovery: detailed procedures by which FDO, TOPO, Ballistics, and VIPeR coordinate JURE trajectory data
- 4) JURE Spreadsheet Design Spec: detailed theory and test results for JURE Excel spreadsheet software supporting initial Orbiter/ISS propellant consumption estimates and preflight minimum rendezvous phasing capability estimates (reference path DM32\Apps\MCC PC Applications\JURE\ for this documentation and a spreadsheet baseline)

### 3.10.6.3 Spreadsheet Functional Overview

The JURE spreadsheet is used by FDO Support to produce a preliminary estimate of the highest achievable ISS rendezvous orbit based on PROP's post-OMS-1 consumables margin<sup>25</sup>. This margin, expressed in lbm and referred to as Raise The Orbit (RTO), withholds the following consumption from post-OMS-1 usable quantities.

- 1) Mean rendezvous and docking, commencing with NCC
- 2) Undocking and emergency separation
- 3) Launched cargo return with EOM+2 on FD10
- 4) Nominal entry

The spreadsheet compares an input Orbiter propellant margin to consumption estimates starting with OMS-2 and extending through final NC and steep deorbit. This comparison serves as an independent check that rendezvous near the "no higher than" ISS orbit will indeed consume available Orbiter propellant with a near-zero residual.

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<sup>25</sup> A secondary JURE spreadsheet function deals with developing an approximate rendezvous phasing strategy. The spreadsheet's phasing function had been used to assist OMP JURE plan convergence, but inclusion of an NSR burn in JURE plans has eliminated this need. Currently, JURE spreadsheet phasing functions are only applied to estimating JURE minimum phasing capability as detailed in Section 3.10.6.5.

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The spreadsheet also permits two distinct ISS burn strategies to be developed such that the desired rendezvous recovery orbit is achieved. The first strategy is preferred and confines one or two ISS burns to FD3 or FD4. Because rendezvous cannot occur any earlier than the day following ISS burns, postponing them to FD4 is only justified by extremely large phase angles. On a given day, the first ISS burn has TIG on DO-1, and the second burn, if required, has TIG on DO-2 if both burns are performed by Progress with a Matching Unit (MU) installed. If ISS uses a burn mode other than Progress thrusters with MU support, a second burn must be postponed until DO-3 due to RS commanding limitations. The second strategy requires more than two ISS burns, typically with two on FD3 and one or two on FD4.

**CAUTION:** RS propulsion operations are constrained by maximum burn duration limits as documented in SSP 50261-02, *ISS Generic Groundrules and Constraints, Part 2: Execution Planning*, Section 7.6.2. The operative maximum JURE burn duration is typically 2000 sec, and it pertains to Progress Rendezvous & Docking (R&D) thrusters. If two burns are required on a particular flight day, RS planners prefer any not constrained by maximum duration be associated with the second TIG of the day.

**NOTE:** an ISS burn nomenclature has been developed to rapidly communicate JURE strategy with TOPO and Ballistics personnel. The nomenclature uses 4-letter acronyms, each letter corresponding to an ISS burn in chronological order. An "N" signifies a null burn, a "P" signifies a posigrade burn, and an "R" signifies a retrograde burn. With current ISS propellant reserves, most viable JURE strategies are either RRNN or NNRR, depending on rendezvous phase angle (small/intermediate or large, respectively).

With an ISS burn sequence and OMS-2 phase angle specified, the spreadsheet then permits apsis heights associated with OMS-2/3, NC-1, NH, and the final NC burns to be entered manually. The object of associated manual apsis height iterations is to achieve -40 nm curvilinear LVLH X-position at the final NC burn, whose TIG is 4 hrs prior to the specified docking time.

**NOTE:** another spreadsheet function computes a "no lower than" docking orbit based on a specified ISS propellant budget. This "round trip" budget supports rendezvous recovery, together with prelaunch orbit height restoration after Shuttle mated operations. Margin with respect to this budget is also computed based on specified ISS burns in the spreadsheet's phasing plan. These ISS propellant budget functions are purely informative. They don't drive selection of the highest possible docking orbit because that's a function of Orbiter propellant reserves. Preliminary ISS propellant consumption estimates from the spreadsheet may be useful to informal initial JURE feasibility assessments. However, adequate time exists for TOPO and VIPeR to prepare refined consumption estimates supporting IMMT rendezvous recovery GO/No-GO deliberations.

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### 3.10.6.4 Confidence Run

Because JURE operations must be conducted in a compressed timeline, adequate preparations prior to an ascent sim or a launch attempt are essential. These preparations are collectively referred to as the JURE Confidence Run, and they result in three primary products.

- 1) A JURE spreadsheet configured assuming nominal post-MPS Orbiter apsis heights and an ISS burn sequence utilizing 4 maximum-duration burns or the lowest rendezvous perigee height at which Orbiter over-phasing is avoided
- 2) A TSA Global ephemeris modeling ISS JURE burns corresponding to the spreadsheet's phasing plan and burn mode engine characteristics specified by TOPO
- 3) An Orbiter-only rendezvous recovery OMP plan consistent with the JURE spreadsheet configuration

CAUTION: marginal phasing cases and launch windows with multiple panes may require Confidence Runs producing multiple product datasets.

CAUTION: because current MTT capabilities don't include a BFL guidance option, ISS burns in a dual-vehicle OMP plan cannot be accurately transferred to an ephemeris. Rendezvous recovery OMP targeting therefore utilizes an Orbiter-only OMP plan. This plan fetches a target state vector from an ISS ephemeris following the final JURE burn. Relative motion in this plan will therefore be incorrect prior to the last ISS deboost.

CAUTION: modeling a long ISS burn as a single impulse in the dual-vehicle OMP JURE plan will over-estimate ISS deboost perigee-lowering capability. In critical cases, only  $N + 1$  burns will achieve a desired rendezvous  $H_p$  in a dual-vehicle plan when, in fact,  $N + 1$  burns are necessary in an ISS ephemeris with precision BFL burn modeling. Other cases exist in which ISS orbit shape following deboost is critical to efficient Orbiter burn targeting. Such a case may appear to have an efficient dual-vehicle plan solution, but substantial Orbiter-only plan rework will be required based on more accurate BFL modeling in an ISS ephemeris.

CAUTION: if an Orbiter NSR burn is necessary to address critical ISS orbit shaping, it cannot be targeted before the final ISS burn in a dual-vehicle plan. For this reason, JURE targeting utilizes an Orbiter-only OMP plan whose target state vector is fetched from the ISS JURE ephemeris following all deboosts. If it's necessary to plot relative motion throughout rendezvous recovery, use RelMo in E-to-E mode after the Orbiter-only plan is iterated in an Orbiter ephemeris.

The following procedure performs a JURE Confidence Run.



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- 1) TUP a 10-day "STDN No" TSA ephemeris off the latest ISS state vector. Verify correct orbit counts and drag profile. This trajectory is referred to as the "ISS ephemeris" in this procedure.
- 2) Manually enter a "maximum effort" rendezvous recovery burn plan to the ISS ephemeris. This will be an RRNN sequence if over-phasing is a concern, but larger phase angles may permit an RRRR sequence.
  - a) Verify ISS JURE propellant available, engine characteristics, and MU status with TOPO.
  - b) Set TIGs at AN +34 min if using 4 Progress R&D jets; AN +31 min if using 8 pulsed jets. Round these TIGs to the nearest even-GMT-minute to duplicate Russian Ballistics SOP. Use DO-1/2 if MU is installed or DO-1/3 otherwise.
- 3) Develop an Orbiter-only OMP rendezvous recovery plan referencing the maximum effort JURE ISS ephemeris.
- 4) Load the JURE spreadsheet from DM32\Apps\MCC PC Applications\JURE\. Use Excel's File : Save As... menu item to save a write-enabled copy to the PC's Desktop using a name specific to this Confidence Run.
- 5) Select the spreadsheet's Config segment and fill out interactive cyan-colored cells in its Initial Conditions, Engine Characteristics, and ISS TIG Constraints sections. In Cell C16, specify a JUREHp value equal to that targeted by the final burn in the ISS ephemeris.

NOTE: reference TSA Checkout Monitor data in its center column to obtain all initial apsis heights for the spreadsheet. In the case of ISS apses, fetch Checkout from the ISS ephemeris at the first burn's TIG.

- 6) Archive TSA and spreadsheet configurations as required for later use. If a Max ITEM 9 update is required (see Section 3.10.6.8), an expendable copy of the archived spreadsheet(s) may now be used for this purpose.

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## 3.10.6.4.1 JURE Spreadsheet Illustrations

As an aid to JURE spreadsheet configuration and interpretation, reference the following illustrations and accompanying notes. The "Phasing" Sheet is no longer used in the JURE Confidence Run and is retained for reference in connection with minimum phasing procedures in Section 3.10.6.5.

**"Config" Sheet**

	A	B	C	D	E	F	G	H	I	J
1										
2		<b>Initial Conditions</b>				<b>Engine Characteristics</b>				
3		<b>Pre-JURE ISS</b>	<b>Post-OMS-1</b>			<b>Thruster</b>	<b>lbfThrust</b>	<b>lbm/secFlow</b>	<b>fpsExhaust</b>	<b>fpsΔY Avail</b>
4						<b>Orbiter</b>	OBP	12000	38.5	631.0
5		kgWeight	lbmWeight			<b>ISS</b>	8R&Ds	193.9	0.723	168.3
6		135965	255812							
7						<b>Est. ISS Capability</b>		<b>Est. Orbiter Capability</b>		
8		kgΔPropAvail	lbmΔPropAvail			nmHave=	185.2	nmHave=	186.0	
9		3000	15600			nmHa=	207.5	nmHa=	207.8	
10						nmHp=	162.8	nmHp=	164.2	
11		nmHaxHp	nmHaxHp			nmΔHd=	22.6	<b>ΔYc Coef: abc</b>	<b>ΔYd Coef: def</b>	
12		211.4	126.5			fpsΔVd=	81.6	-6.625000E-04	1.8219450E-03	
13		204.2	32.5					3.5871250E+00	1.1939463E+00	
14								5.2218750E-01	5.1194446E+01	
15		hrsAscNodeMET	nmJUREHp			<b>ISS TIG Constraints</b>		<b>Orbiter Capability Quadratic Coef</b>		
16		0.362775	163			1st TIG DO=	1	Q=2Hi - Ha - 23=		-71.8
17						2nd TIG DO=	2	A=a + 4d=		0.00662528
18		degAscNodeLong	ΔlbnToISS			minAscNode +	31	B=b + 2e + 4dQ=		5.4517549E+00
19		-110.7725	26778					C=c + dQ^2 + eQ + f		
20								- ΔY=		-6.5560456E+02
21		hrsNodalPeriod						ΔY × (C + ΔY) -		
22		1.53655235						B^2/(4A)=		-1146.14
23										
24		deg/orbΔλ								
25		-23.4341183								
26										
27		nmInitHave	nmInitHave			<b>BNS Format 3</b>		<b>PEG-7</b>		
28		207.8	79.5			mψΔY=	12.011	fpsΔYx=	-36.89	
29						degYaw=	200.56	fpsΔYy=	13.84	
30						degPitch=	1.22	fpsΔYz=	-0.84	
31										
32						<b>Ap</b>	<b>Kp</b>			
33						13.90	2.84			
						13.87	2.84			

- B6: from TOPO's prime ISS ephemeris
- B9: rough estimate from TOPO/VIPeR (finalized only in real time by IMMT)
- B12/13: at first ISS TIG
- B16/19: at first ISS ascending node following launch
- C9: from PROP (gas available for rendezvous through final NC plus steep deorbit)
- C16: initially from Cell I10
- C19: net Resupply/Return from Co-Lead FDO
- F10: "no lower than" ISS Hp capability (based in part on Cell B9 rough estimate)
- F17: DO-2 if Matching Unit is installed; DO-3 otherwise
- F18: +31 min for 8 pulsed Progress R&D jets; +34 min for 4 continuous jets
- G4: sum of LOMS + ROMS ECT thrusts
- G5: from TOPO
- H4: sum of LOMS + ROMS ECT flow rates
- H5: from TOPO
- I10: "no higher than" Orbiter Hp capability

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## "Phasing" Sheet

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												

<b>nmFinalNC R</b>		-62
--------------------	--	-----

<b>Total Propellant</b>		
	<b>lbmOrbiter</b>	<b>kgISS</b>
<b>Burned</b>	15368.7	3000.7
<b>Margin</b>	231.3	(0.7)

<b>minGMTLO Slip</b>	
2.0	

<b>degOMS-2 Phase</b>	
<b>Old</b>	<b>New</b>
50.0	57.8

- CD8: set no-earlier-than last ISS TIG +4 hrs
- CD10: set to first DOR noon after 14 hrs MET +4 hrs
- EF4: iterate to obtain Cell G15 near -40 nm
- EF5: most robust phasing plans are low-altitude or circular post-NC-1
- E6/7: approximate ISS Ha decreases during long burn arcs: do not modify
- F6/7: iterate so Cells L6/7 agree with ISS JURE ephemeris Δv values
- G4: initially from nominal OMP plan (use an "OMS-2 only" HA plan during ascent)
- G15: curvilinear LVLH-X chaser offset from target
- H6: -700° for FD3 ISS TIGs, -1060° for FD4, 20° - 360° (n - 1) for FDn
- J18: verify Orbiter margin > -25 lbm; otherwise, set Config sheet Cell C16 Hp lower
- K18: a negative ISS margin is not an immediate constraint to pressing with JURE ops
- L6/7: if 2 ISS burns required on one flight day, the first must be maximum duration

### 3.10.6.4.2 JURE Rendezvous OMP Plan MCT Template

A great deal of frustration with unstable JURE rendezvous OMP plans was experienced following their introduction in 1998. An OMP MCT baseline was often difficult to develop in a JURE Confidence Run, and it would also frequently fail to run under even slightly different post-launch simulation conditions. In 2005, it was discovered this instability is all but eliminated by introducing an NSR burn to the Confidence Run baseline MCT. This NSR is effective because it achieves a co-elliptic Orbiter trajectory on FD1/2 with respect to the ISS trajectory *after* its final burn on FD3/4. With a co-elliptic condition established *before* terminal Orbiter burns achieving the lowered rendezvous orbit, terminal shaping and phasing difficulties leading to retrograde burns



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ascending ConUS deorbit  $\Delta v$ . Consequently, if OMS-1/2 and NC-1a have not raised the orbit significantly, a nearly zero post-MECO argument of perigee will still prevail at NSR TIG, and  $ARG = 0$  will be a good initial guess for a posigrade burn TIG with nearly zero radial component. More radical apsidal rotations imparted by burns prior to NSR may require ARG values nowhere near zero to achieve a purely posigrade NSR. Regardless of its value, iterating on ARG involves less typing than would interactions with a primary constraint's multiple time fields. When iterating TIG to achieve a null radial  $\Delta v$  component on a posigrade NSR, the rule-of-thumb is to shift ARG in the direction of PEG-7  $\Delta Vz$ 's sign. This rule reverses when NSR is retrograde.

As a JURe rendezvous plan evolves toward operational maturity, remain mindful that NSR's primary role is to maintain stability in OMP solutions. If NSR can be postponed from its FD1 baseline TIG to FD2, crew and FCT personnel will probably appreciate it. Moreover, if NSR  $\Delta v$  becomes small, it can probably be deleted altogether. In such cases, NC-1a has likely achieved a sufficiently co-elliptic condition.

Regardless of its placement in a JURe plan, NPC may play a critical role in rendezvous recovery. It may be mandatory to combine planar corrections with other posigrade burns throughout the plan because these corrections aren't present in the JURe spreadsheet's estimate of Orbiter achievable rendezvous orbit height capability. To this end, attempts to combine NPC with NC-1a are probably warranted. It may also be possible to damp at least some residual planar motion in combination with other posigrade burns by manually iterating on their respective PEG-7  $\Delta Vy$  components such that NPC is progressively minimized. If planar corrections cannot be effectively hidden in other burns, it will be necessary to lower rendezvous perigee still further to cover this cost.

The NC-6 primary constraint, together with its LITO secondary, achieve the first sunset -36 min TIG (-38.5 min if  $ISS |\beta| < 15^\circ$ ) following 14 hrs MET on the day of rendezvous. Under most circumstances, FAOs are OK with day-of-rendezvous timelines placing the first TIG after 14 hrs MET. If necessary to obtain maximum phasing, FAOs are usually GO to perform the final NC by 20 hrs MET (assuming one rev from final NC to  $T_i$ ) when otherwise faced with the prospect of a one-day delay in docking. In the JURe baseline MCT, it's therefore only necessary to change primary constraints associated with NC-5 and NC-6 to alter docking by hours or days earlier or later. In this manner, it's easy to shift a plan between FD4 and FD5 rendezvous when working marginal cases.

### 3.10.6.5 Minimum Phasing Capability

NOTE: prior to STS-121/ULF1.1, OIP A7.16.2.5 required FDO to estimate minimum JURe phasing capability in deg as a function of recovered rendezvous  $H_p$  in km. The Lead FDO supplied these data to TOPO for relay to Russian Ballistics such that they were received no later than one week prior to the initial launch attempt. Per agreement

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with Russian Ballistics at the June 6, 2006 Flight Mechanics Telecon, the JURE minimum phasing capability product is no longer required.

Minimum phase capability is partly dependent on MCC-M constraints. Chief among these is ISS JURE TIGs limited to no earlier than DO-1 of Shuttle FD3, approximately 40 hrs after launch. To perform an ISS burn earlier than this point would require MCC-M planning prior to each Shuttle launch attempt. Due to JURE's remote probability, MCC-M management cannot justify this a-priori planning with the limited resources available. Consequently, a JURE rendezvous cannot occur before FD4. Moreover, it's possible for the Shuttle to launch into a nominally viable phasing case that becomes over-phased when a lower rendezvous altitude is targeted by ISS under the delayed TIGs constraint. The over-phased condition arises from the > 40-hr delay in lowering ISS altitude to that required by JURE. This delay's phasing impact is only magnified by Shuttle inability to target the higher ISS rendezvous altitude anticipated at launch.

NOTE: maximum JURE phase capability isn't generally a concern. Typically, JURE phase rates are higher than those anticipated at launch. In cases where phase rate is lower than nominal, rendezvous must be delayed. Although Orbiter mission duration may not support a delayed rendezvous, impact to maximum phasing capability from timeline limitations cannot be anticipated before a specific JURE scenario arises.

### 3.10.6.6 Flight Note

No later than the initial launch attempt's L -1 day time frame, FDO Support publishes a flight note describing JURE capability. In the event this attempt is scrubbed or postponed, the flight note need not be republished unless a pertinent ISS orbit or configuration change occurs. The following example can be used as a template with flight-specific overlays.

If a Joint Underspeed Recovery (JURE) scenario develops following Shuttle launch, an MMT GO/NoGO to lower ISS orbit height is required by Launch +27 hrs (reference OIP 2.2.5). A GO would support initial ISS translations as early as the DO1 on Shuttle FD3 at approximately Launch +40 hrs (reference Flight Rule UF-2\_C4-1, "Off-Nominal Shuttle Orbit"). Prelaunch ISS JURE propulsion capability estimated by VIPeR amounts to 500 kg, permitting ISS perigee to be lowered to a minimum height of approximately 180 nm (333 km).

Although minimal ISS orbit lowering is compatible with virtually any operational rendezvous phase angle at OMS-2, lowering with one maximum-duration ISS burn lasting 2000 sec requires launching into phase angles exceeding approximately 70 deg. If

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ISS perigee is lowered to 165 nm (306 km), OMS-2 phase must be greater than approximately 130 deg. Launch into a phase angle incompatible with JURE constraints may result in loss of rendezvous for the mission regardless of ISS propulsive capability.

### 3.10.6.7 Launch Day FDO Support Procedures

The following FDO Support actions will probably commence after final launch window targeting is complete several hours before launch. A JURE scenario due to MECO underspeed is assumed with FDO Support actions falling chiefly between OMS-1 and OMS-2. This is, in all likelihood, the most time-compressed JURE response. Other JURE scenarios arising well after a nominal MECO and OMS-2 are possible.

- 1) Prior to launch, perform the following preparations.
  - a) Restore all TSA Global data archived by the JURE Confidence Run. Check associated Jacchia values, ECT configuration, and OMP constraints tables.
  - b) Update TSA Global ISS JURE ephemerides with new anchors and the preferred launch time.

CAUTION: a change in GMTLO will alter TIG GMTs in a JURE ephemeris. Note TIG GMTs before the GMTLO update and preserve them with TSA Maneuver Edit (ME). For a later GMTLO, simply perform a fetch at the new TIG with ME and re-transfer to the ephemeris for each burn in chronological order. For an earlier GMTLO, all burns must be deleted before they're re-input with ME.
  - c) Load Confidence Run JURE spreadsheet(s) on PC and update as required.
  - d) Conduct JURE strategy tag-up with MARS and Profile.
  - e) Report JURE Confidence Run status to FDO.
- 2) After launch, take the following actions prior to MECO regardless of flight status.
  - a) Monitor mirrored TrS VAT via TVETS. When ISS anchor (V38) receives a confirmed GMTLO by ~40 sec MET, re-anchor the pertinent Global ISS JURE ephemeris to pick up the confirmed GMTLO.

CAUTION: a GMTLO slip will shift TIG GMTs later accordingly. Launch delays more than ~30 sec probably warrant maneuver edits in the JURE ephemeris.
  - b) Monitor Earth-relative speed  $V_E$  on the FDO Launch Digitals display. When  $V_E > \sim 11500$  fps, a crew ATO select will steer toward the IYs required for ISS rendezvous. Prior to this point, an ATO select or sensed SSME shutdown will steer into the current orbit plane, and the rendezvous is aborted.

NOTE: the ATO steering  $V_E$  threshold is an ILOAD called "V Mission Continue" (HAL mnemonic = V\_MSSN\_CNTN). Flight-specific values are published in ASCT-08.

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- 3) Perform the following actions immediately after a JURe is apparent.
  - a) Input Orbiter post-OMS-1 weight to spreadsheet Config segment Cell C6.
  - b) Obtain JURe propellant margin from PROP and input it to spreadsheet Config segment Cell C9.
  - c) Note the "no higher than" JURe rendezvous Hp in Config Cell I10.
  - d) Configure the TSA Global ISS JURe ephemeris with Maneuver Edit/Delete such that the final ISS burn matches Config Cell I10's Hp. Inform MARS of when to fetch an ISS state vector from this ephemeris into the OMP plan.  
NOTE: while awaiting ISS JURe ephemeris reconfiguration, MARS may be instructed to begin JURe rendezvous plan development by fetching after the burn closest to Config Cell I10's Hp.
  
- 4) While MARS develops the JURe rendezvous plan, perform the following actions.
  - a) Report preliminary rendezvous recovery status to FDO, then TOPO.
  - b) Use TSA Vector Edit to fetch a TSA Global ISS JURe ephemeris state vector following the final ISS burn and store it in the TrS VAT as the ISS JURe B/O.
  - c) Configure E4 with DM options and the ISS drag profile and then TUP it off the ISS JURe B/O.  
CAUTION: it's impractical to model ISS JURe burns in TrS ephemerides because no BFL guidance capability is available to track long burn arcs in LVLH hold, and a dedicated E4 VTL doesn't exist. Consequently, it's inadvisable to static start E4 much before anchor vector time.
  - d) Activate M4 mirroring and inform MARS a target vector supporting the OMP JURe plan can now be fetched from M4.  
CAUTION: verify TrS DMT target offsets for this MARS iteration reference E4.
  
- 5) When MARS is satisfied with OMS-2 targeting supporting rendezvous recovery phasing, report the desired apsis height to FDO.
  
- 6) Post-OMS-2, consult OIPA7.16.6 for further JURe coordination actions, then support Ascent transition to Orbit 2 as required.

CAUTION: ISS thruster entries present in Global's ECT at launch are generic to all Russian Segment propellant systems. Only when ISS JURe  $\Delta v$  requirements become known after launch will it be possible for MCC-M to identify specific propellant systems to be used for orbit-lowering burns. Any of these systems may have a blow-down status such that its specific impulse differs by up to 30% from that corresponding to Global ECT entries. It may therefore be necessary to model each system's efficiency with a dedicated ECT thruster post-OMS-2. This consideration may lead to significant JURe rendezvous plan refinement prior to the first ISS retrograde burn.

CAUTION: contrary to minimum JURe phasing capability computed by Section 3.10.6.5 procedures and reported in the Section 3.10.6.6 flight note, an OOP "wrap jump" burn may be performed by the Orbiter to increase phase angle  $\sim 360^\circ$  if circumstances such



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as Contingency Shuttle Crew Support (CSCS) warrant this action. A wrap jump entails burning north near argument of latitude ( $u$ ) =  $90^\circ$  or south near  $u = 270^\circ$  with  $\Delta v$  near 270 fps. This impulse shifts LAN eastward the required amount to increase phase by one "wrap" while leaving inclination very nearly unchanged. A wrap jump may be regarded as toggling the sign of TDR  $V_z$  when it's small in magnitude. Current deorbit  $\Delta v$  is unaffected by a wrap jump. This OOP burn can probably be performed to retain *either* a deorbit or a rendezvous capability if OMS tank fail is available ( $> 270$  fps  $\Delta v$  is available in both OMS pods). Proceeding uphill towards rendezvous after a wrap jump burn will generally result in loss of deorbit capability.

### 3.10.6.8 Max ITEM 9 Computation

The following procedure computes a "Max ITEM 9" OMS dump estimate following which rendezvous and steep deorbit are still barely achievable. It assumes nominal zero-underspeed MECO, together with a minimum rendezvous perigee following ISS retrograde burns during Joint Underspeed Recovery (JURe). This minimum  $H_p$  is that expected from the JURe Confidence Run. By default, it results from 4 maximum-duration ISS burns performed over 2 consecutive flight days. At OMS-2 phase angles less than  $\sim 200^\circ$ , however, this minimum rendezvous  $H_p$  is constrained to be higher due to over-phasing considerations, and Max ITEM 9 becomes correspondingly lower. Because JURe spreadsheet iterations are required to compute Max ITEM 9, an expendable copy of the pertinent JURe Confidence Run spreadsheet should be obtained. Case-specific numeric data in the following steps are from an August 27, 2004 FDO/PROP paper sim.

- 1) Select the JURe spreadsheet's Config tab.
- 2) Tie PROP's nominal OMS Assist Raise The Orbit (RTO) OMS equivalent propellant available in Cell C9 to Orbiter weight at OMS-2 TIG in Cell C6. In this case,  $C9 = C6 - 236532$  such that nominal  $C6 = 255277$  produces nominal  $C9 = 18745$ .
- 3) Enter progressively smaller values in Cell C6, reflecting OMS dump propellant consumption, until estimated maximum Orbiter rendezvous  $H_p$  in Cell I10 reaches the minimum  $H_p$  at which over-phasing becomes likely (or the  $H_p$  corresponding to 4 maximum duration ISS burns if phase angle is large enough). In this case,  $C6 = 250277$  produces  $I10 = 154.0$ , the  $H_p$  below which more than 2 maximum ISS retrograde burns will result in an over-phased condition.
- 4) Enter the Cell I10 value into the Cell C16 targeted rendezvous perigee height.
- 5) Select the appropriate JURe spreadsheet ISS burn plan tab. In this case, the ISSburns1day tab is selected. If necessary, interact with cyan apsis height cells in

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Columns E and F to insure the only retrograde (red) Orbiter  $\Delta v$  in Column L is Deorbit. This produces an accurate Orbiter consumption estimate in Cell J17 (ISSburns1day tab) or J20 (ISSburns2days tab).

- 6) Check Orbiter propellant margin in Cell J18 (ISSburns1day tab) or J21 (ISSburns2days tab). If the value has a magnitude greater than 50 lbm (red values are negative margins; black values are positive), adjust rendezvous perigee height in Config Cell C16 until this condition is obtained. In this case, rendezvous Hp = 154 nm produces an Orbiter margin of +18.7 lbm.

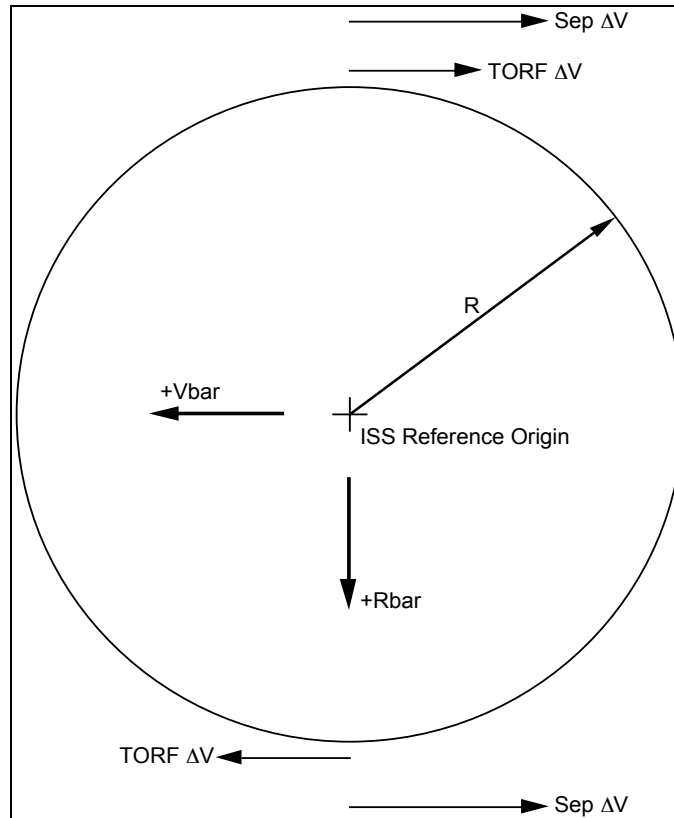
NOTE: the Cell J18/J21 margin estimate is more precise than that supporting analytic Config Cell I10 computations, and the 50 lbm accuracy equates to 0.2% ITEM 9 precision.

- 7) Round the Orbiter consumption estimate in Cell J17 (ISSburns1day tab) or J20 (ISSburns2days tab) up to the nearest whole lbm. In this case, J17 = 13726.3  $\Rightarrow$  13727.
- 8) Subtract estimated Orbiter consumption from the nominal RTO value. This is the maximum OMS propellant available to dump without compromising a minimum Hp JURE rendezvous and steep deorbit. In this case, Max Dump = 18745 - 13727 = 5018 lbm.
- 9) Add Max Dump to the nominal OMS Assist propellant consumption, divide the sum by 260 lbm/%, and round down to the next integer %. This is the Max ITEM 9 estimate. Report this value to Ascent FDO before launch (see Section 3.10.4.1.1.17). In this case, Max ITEM 9 =  $(5018 + 5907)/260 = 42.02\% \Rightarrow 42\%$ .

### 3.10.7 ISS Sep Modeling and RelMo

When the Orbiter performs a nominal final sep burn following joint operations with ISS, it has typically been executing a Twice-Orb-Rate Flyaround (TORF) of radius R. Unless deorbit must be performed later that day, the sep will be retrograde (reference FR C4-158, Shuttle Final Sep Burn Guidelines). In the absence of contingencies rendering final sep time-critical, it will be performed on the Rbar directly above or below ISS. To precisely model expected relative motion between the ISS and Orbiter following final sep requires both the initial position and velocity offsets between the two vehicles be accounted for by RelMo input. To this end, consider sep geometry in inertial space as illustrated by Figure 3.10.7-1.

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**Figure 3.10.7-1: TORF Sep Geometry**

### 3.10.7.1 Predicted ISS Sep RelMo Procedure

The following procedure is used to develop a post-sep Orbiter chaser state vector for use with a given ISS target state vector at sep. The state vector pair then serves to generate a static RelMo plot and associated digital data set. Because only *relative* motion is significant in this application, the Orbiter/ISS state vector pair input to RelMo may be developed well in advance of undocking.

- 1) Obtain TORF rotation rate (ROT RATE) in deg/sec from the Rendezvous Checklist, Section 6, Reference Data, ISS RNDZ OPS DAP CONFIGURATIONS. On STS-113/11A, the TORF DAP was A9 and its rotation rate was 0.1300 deg/sec. This rotation rate is equal to the TORF angular rate and is roughly twice the orb rate,  $\omega$ . Thus,  $2\omega = \frac{0.1300 \pi}{180} = 0.002269$  rad/sec.
- 2) Obtain TORF radius R in ft from the Rendezvous Checklist. On STS-113/11A, R = 450 ft.

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- 3) Obtain sep burn duration TGO in sec from the Rendezvous Checklist. Use this with expected PMP Orbiter weight at sep  $W$  in lbm and ECT propulsive thrust  $T$  in lbf to compute sep change-in-velocity magnitude  $\Delta V_{SEP}$  in fps.

$$\Delta V_{SEP} = \frac{32.174}{W} * T * TGO$$

On STS-113/11A, TGO = 12 sec,  $W = 212297$  lbm, and PX2  $T = 1753.5$  lbf, yielding  $\Delta V_{SEP} = 3.189$  fps.

- 4) Obtain a predicted ISS M50 state vector in ft and ft/sec at final sep and enter it as the Inertial Basis Vector (Cells B5-10) in the Excel State Vector Offset (ESVO) spreadsheet. An ESVO copy can be retrieved from `DM32\Apps\MCC PC Applications\ESVO\ESVO.XLS`. From STS-113/11A archives, the WST135 anchor is propagated to the 8/20:11:40 MET final sep time to produce the Figure 3.10.7.1-1 basis vector.

NOTE: the state vector entered to ESVO Cells B5-10 may be in any inertial reference frame, but that frame will be maintained in ESVO output state vector Cells E13-18. Likewise, any valid units may be used with the input state vector, but they must be consistent with subsequent LVS offset units and will be reflected in Cells E13-18 units as well.

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```

=====
                                Checkout Monitor V5.0.1
=====
Comments: STS-113 WST 135 Prop to Final Sep
=====
GMT: 336:21:01:26.985 |   HA:   216.6026 NM |   INV ORBITAL ELEMENTS
MET: 008:20:11:40.000 | METHA: 008:21:04:53 | IHave      214.42  NM
ORB:           138? |   HP:   211.4537 NM | IHA        216.99  NM
VID:           L  V11 | METHP: 008:20:18:38 | IHP        211.84  NM
=====
M50 STATE VECTOR      |   Vi  25173.8246 F/S | STOP OPTION      T
                       |   Vrel 24170.2672 F/S | GMTTH           336:16:15:00
   POSITION ( FT )      |   FPai -0.032644    | METTH           008:15:25:13
   X   14455664.5      |   AZr   71.0949     |-----
   Y   -2033644.0      |   AZi   71.8754     | REFDAY          24 Nov 2002
   Z   16742884.1      |   LATc  49:12:18N   | LO   2002:328:00:49:46.985
                       |   LATc  49.204872   | EPH STANDARD    TUP: 0
   VELOCITY ( F/S )    |   LATd  49:23:01N   | VEH WEIGHT:     398030.0
   VX  -2501.291969    |   LATd  49.383735   | KV  1.0000      KC   1.000
   VY  24520.637089    |   LONG  034:16:11W  | AREA            5935.90
   VZ   5118.919928    |   LONG -34.269647   | INT MED         D/E
                       |   Hs   211.88786 NM |-----
   POSITION ( M )        |   Ho   218.51784 NM |   KEPLERIAN ELEMENTS
   X   4406086.54      |   Ho  1327739.65    | A             3655.9598 NM
   Y   -619854.69     |   R    3655.82203 NM | E             0.000571
   Z   5103231.08     |-----
                       |   Tan  008:21:24:52 | Im50           51.33343
                       |   Lam  119:30:16W  | Iteg           51.61532
   VELOCITY ( M/S )    | BETA ANG  11.853    | WPm50          161.12044
   X   -762.393792     | PERIOD   01:32:26.721 | WPteg          161.22060
   Y   7473.890185     | RAm50    351.9921    | RAAm50         285.39058
   Z   1560.246794     | DEcM50   48.9150    | N              273.75130
                       |                      | M              273.81659
=====

```

**Figure 3.10.7.1-1: STS-113/11A WST135 Anchor Final Sep ISS Prediction**

- 5) Enter the Orbiter's Local Vertical Spherical (LVS, equivalent to LVC in this application) position offset  $r$  in ft to ESVO Cells B13-15. In the STS-113/11A example, sep was expected from the  $-R_{bar}$ , so  $B13 = 0$ ,  $B14 = 0$ , and  $B15 = -450$ .
- 6) Compute the Orbiter's post-sep LVS velocity  $\Delta V_{TOT}$  in ft/sec. This is the sum of three inertial velocity components.
  - a)  $\Delta V_{TORF} \equiv$  inertial TORF linear velocity at sep  $TIG^{26} = 2\omega \times r$
  - b)  $\Delta V_{SEP}$ , whose magnitude is computed in Step 3
  - c)  $\Delta V_{LVS} \equiv$  inertial linear velocity due to LVS rotation at the sep location<sup>27</sup>  $= \Omega \times r$

Thus,  $\Delta V_{TOT} = \Delta V_{TORF} + \Delta V_{SEP} - \Delta V_{LVS}$ . The STS-113/11A example provides the following result.

<sup>26</sup> In the subsequent expression, the vector  $\omega$  acts in the +Y LVS direction according to the right-hand rule.

<sup>27</sup> In the subsequent expression, the vector  $\Omega$  acts in the -Y LVS direction according to the right-hand rule. For all practical purposes in this procedure,  $\Omega = \omega$  in magnitude.

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$$\Delta \mathbf{V}_{TOT} = \begin{bmatrix} X & Y & Z \\ 0 & 2\omega & 0 \\ 0 & 0 & -450 \end{bmatrix} + \begin{bmatrix} -3.189 \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} X & Y & Z \\ 0 & -\omega & 0 \\ 0 & 0 & -450 \end{bmatrix} = \begin{bmatrix} -1.021 & -3.189 & -0.510 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta \mathbf{V}_{TOT} = \begin{bmatrix} -4.720 \\ 0 \\ 0 \end{bmatrix}$$

- 7) Enter  $\Delta \mathbf{V}_{TOT}$  components to ESVO Cells B16-18. In the STS-113/11A example, ESVO's display will resemble Figure 3.10.7.1-2.

1	A	B	C	D	E
		Optional Basis Vector Comment			
2		STS-113 WST 135 Predicted Orbiter Sep			Cartesian OOP Offset Per MOC
3					RelMo Digs
					0
4		Inertial Basis Vector			
5	X	14455664.5			
6	Y	-2033644.0			
7	Z	16742884.1			
8	YX	-2501.291969			
9	YY	24520.637089			
10	YZ	5118.919928			
11					
12		Output Inertial Vector's LVS Offset From Basis Inertial Vector			Output Inertial Vector
13	X	0.0		X	14455957.3
14	Y	0.0		Y	-2033685.2
15	Z	-450.0		Z	16743223.3
16	YX	-4.720000		YX	-2500.875219
17	YY	0.000000		YY	24516.536523
18	YZ	0.000000		YZ	5118.062041
19					
20		NOTE: All Input Units Must Be Consistent And Will = Output Units			

**Figure 3.10.7.1-2: Typical ESVO Final Sep Offset Processing**

- 8) Using TSA Vector Edit, enter the required post-sep Orbiter state vector in M50 ft and ft/sec as provided by ESVO Cells E13-18.
- 9) Generate a RelMo static curve using the Orbiter as chaser and ISS as target. Verify input to ESVO Cells B13-18 agrees with CLV RelMo digital position and velocity output at the final sep time.
- 10) Unless the predicted ISS basis vector used with ESVO changes dramatically, it and the corresponding Orbiter offset vector may be retained as a valid RelMo pair for use during real time post-sep monitoring.

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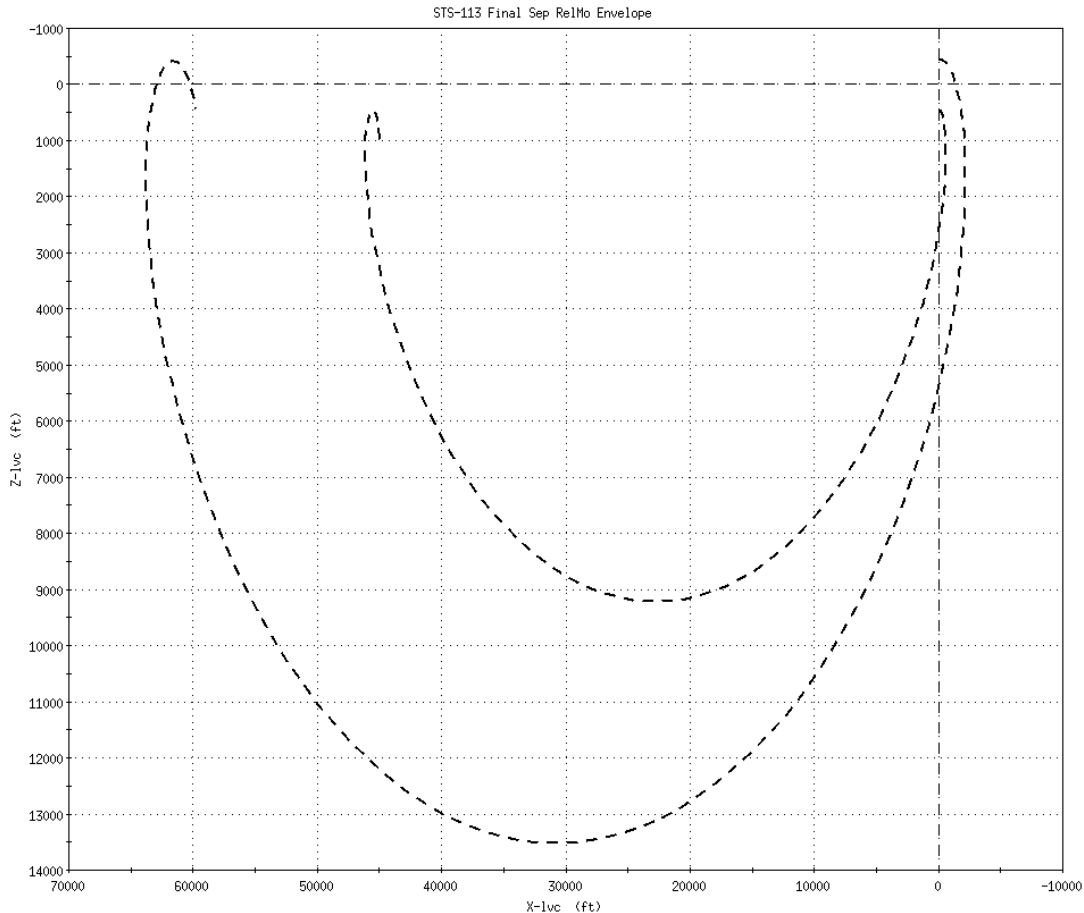
It may be desirable to pair two Orbiter vectors with the ISS prediction at sep such that RelMo plots departures from both ends of the Rbar. In the case of sep from the +Rbar, FRCS jets are used such that the value of T in Step 3 is slightly different. In the STS-113/11A example, the +Rbar T = 1786.1 lbf. The +Rbar  $\Delta V_{TOT}$  computation proceeds as follows.

$$\Delta V_{TOT} = \begin{bmatrix} X & Y & Z \\ 0 & 2\omega & 0 \\ 0 & 0 & +450 \end{bmatrix} + \begin{bmatrix} -3.248 \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} X & Y & Z \\ 0 & -\omega & 0 \\ 0 & 0 & +450 \end{bmatrix} = \begin{bmatrix} +1.021 & -3.248 & +0.510 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta V_{TOT} = \begin{bmatrix} -1.717 \\ 0 \\ 0 \end{bmatrix}$$

Both predicted RelMo static curves, each paired with the Figure 3.10.7.1-1 ISS target state vector sep prediction from STS-113/11A, appear in Figure 3.10.7.1-3.

**NOTE:** the Figure 3.10.7.1-3 RelMo curves were generated assuming zero drag for the Orbiter and ISS.



**Figure 3.10.7.1-3: STS-113/11A Post-Sep RelMo for -Rbar and +Rbar Departures**

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### 3.10.7.2 Theoretical ISS Sep RelMo Verification

To gain further insight into Figure 3.10.7.1-3's RelMo plot, consider the -Rbar sep trajectory and its phase rate of  $\Delta X = 62000 \text{ ft/rev} = 10.2 \text{ nm/rev}$ . If the post-sep ISS-relative inertial retrograde velocity =  $1.021 + 3.189 = 4.210 \text{ fps}$  is applied to the  $8/3 \text{ nm/rev-fps}$  conversion factor, an expected  $\Delta X = 11.2 \text{ nm/rev}$  results. The  $1 \text{ nm/rev}$  deviation is equivalent to an ISS-relative post-sep retrograde velocity  $0.375 \text{ fps}$  less than expected by the conversion factor.

Implicit in the conversion factor is an initially null position offset between the Orbiter and ISS. In the -Rbar sep case, the Orbiter's position  $450 \text{ ft}$  above ISS partially reduces effective retrograde relative velocity applicable to the conversion factor. Before taking the Orbiter's initial position offset from ISS into account, the conversion factor itself will be refined to conform with the precise ISS geocentric distance  $r = 22213196.8 \text{ ft}$  and speed  $v = 25173.824620$  from Figure 3.10.7.1-1. To this end, an earth reduced mass  $\mu = 1.407646853e16 \text{ ft}^3/\text{sec}^2$  is adopted and applied to the energy integral such that the Figure 3.10.7.1-1 osculating semi-major axis  $a_0$  is obtained.

$$a_0 = \left[ \frac{2}{r} - \frac{v^2}{\mu} \right]^{-1} = 22214002.7 \text{ ft}$$

Now compute a post-sep semi-major axis  $a_s = 22208709.3 \text{ ft}$  by subtracting  $3 \text{ fps}$  from  $v$  and applying the energy integral as before. Next, compute mean geocentric angular rates for each semi-major axis by adapting Kepler's Third Law relating orbit period to semi-major axis.

$$\omega_0 = \sqrt{\frac{\mu}{a_0^3}} = 0.00113320016 \text{ rad/sec}$$
$$\omega_s = 0.00113360533 \text{ rad/sec}$$

The post-sep phase rate is then obtained as follows.

$$\Delta X = a_0 (\omega_s - \omega_0) \frac{2\pi}{\omega_0} = 49904 \text{ ft}$$

Using this case-specific conversion factor, the expected phase rate for null initial Orbiter offset from ISS is  $49904 (4.210/3) = 70032 \text{ ft}$ . This rate equates to an effective excess post-sep retrograde velocity of  $3 (70032 - 62000)/49904 = 0.483 \text{ fps}$ .



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With this refined excess retrograde velocity in mind, return to consideration of the Orbiter's -Rbar position offset from ISS and its effect on phase rate. Even when moving at the same inertial velocity as ISS, the Orbiter will have an excess semi-major axis equal twice that of its -Rbar displacement. This LVC velocity component is sometimes referred to as a by-product of the "tether effect". Cutting a tether linking a zero-mass Orbiter to ISS at this point would contribute the same kinetic energy to the Orbiter's trajectory. To compute the tether effect's contribution, merely double the difference in circular orbit speed between ISS and Orbiter positions.

$$\Delta V_x = 2 \left( \sqrt{\frac{\mu}{r + 450}} - \sqrt{\frac{\mu}{r}} \right) = -0.510 \text{ fps}$$

Correction for the sep -Rbar position offset verifies the RelMo phase rate to a precision far greater than that actually flown, leaving an effective relative velocity residual of 0.027 fps. This residual is equivalent to a phase rate error of  $49904 (0.027/3) = 449$  ft, well within the precision to which the RelMo phase rate of 62000 ft/rev could be read from the Figure 3.10.7.1-3 plot.

### 3.10.7.3 Ephemeris-Based ISS Sep Modeling/Confirmation

Because of TORF motion and the nominal vertical position offset from ISS, the Orbiter's sep burn can't be accurately confirmed with conventional IMU data alone. Moreover, data entry associated with ESVO-based techniques would delay timely burn confirmation. Combining elements from ESVO modeling with insights from the previous section leads to a procedure yielding reasonable sep burn accuracy in an Orbiter ephemeris. This procedure can be used to direct input a sep burn, and then confirm it based on telemetry. The following nomenclature is used.

$\omega$  = geocentric orbit rate

$\Omega$  = DAP-commanded Orbiter body rotation rate =  $2\omega$  in TORF

$\theta$  = Orbiter LVLH pitch angle

**CAUTION:** the following procedure assumes a TORF is in progress at sep TIG. Some breakout scenarios may depart from this condition to a degree that sep modeling and confirmation techniques described in this section become invalid.

**NOTE:** before this procedure was devised, STS-113/11A sep from ISS was confirmed using only IMU-sensed  $\Delta v$ . Confirmation amounted to the  $[-3.1, 0.0, -0.4]^T$  fps PEG-7 targets. Using this procedure, the confirmed targets would have been  $[-3.6, 0.0, -0.4]^T$  fps.

## FDO Console Handbook Section 3.10: Rendezvous Operations

- 1) Obtain TORF radius  $R$  in ft and rotation rate  $\Omega$  in deg/sec from the Rendezvous Checklist ( $\Omega = 2\omega$  is the PROX OPS rotation rate, usually A9/B9, in the DAP Table).  
Compute TORF angular rate  $2\omega = \frac{\pi \Omega}{180}$  in rad/sec.
- 2) Obtain LVLH pitch angle  $\theta$  at sep TIG. For -Rbar TIG,  $\theta = 180^\circ$ . For +Rbar TIG,  $\theta = 0$ .
- 3) Obtain sep burn total propulsive velocity change magnitude  $\Delta V_{SEP}$  from computation (see Step 3 in the Section 3.10.7.1 Predicted Sep RelMo procedure) or from DVsensor.
- 4) Compute the posigrade component of ISS-relative TORF velocity at sep TIG.  
 $\Delta \mathbf{VX}_{TORF} = 2\omega R \cos \theta$
- 5) Compute the posigrade component of  $\Delta V_{SEP}$ .  
 $\Delta \mathbf{VX}_{SEP} = \Delta V_{SEP} \cos \theta$
- 6) Compute effective posigrade component of radial position offset from ISS at sep TIG<sup>28</sup>.  
 $\Delta \mathbf{VX}_{RPO} = -\frac{R \cos \theta}{880}$
- 7) To model all sep dynamics, direct input the sep burn with PEG-7 targets as follows.  
 $\Delta \mathbf{VX} = \Delta \mathbf{VX}_{TORF} + \Delta \mathbf{VX}_{SEP} + \Delta \mathbf{VX}_{RPO}$   
 $\Delta \mathbf{VY} = \Delta \mathbf{VZ} = 0$
- 8) To confirm the sep burn, first note PEG-7  $\Delta v$  corresponding to the sep burn in DVsensor. This may entail adding multiple DV counts. Next, recalculate  $\Delta \mathbf{VX}_{TORF}$  and  $\Delta \mathbf{VX}_{RPO}$  as required and add them to the PEG-7  $\Delta \mathbf{VX}$  obtained from DVsensor. Finally, have DYNAMICS confirm the sep burn using each PEG-7 component's total sum.

As a numeric example of this modeling technique, consider the following data obtained prior to STS-113/11A undock.

$$\Omega = 0.1300 \text{ deg/sec}$$

$$\theta = 180^\circ$$

$$\Delta V_{SEP} = 3.19 \text{ fps}$$

---

<sup>28</sup> The following formula merges the rule-of-thumb  $\pm 1760 \text{ ft } \Delta a = \pm 1 \text{ fps } \Delta \mathbf{VX}$  with the tether effect explained in the previous section. The tether effect contributes an effective  $\Delta \mathbf{VX} = -2 R \cos \theta$ , where  $R \cos \theta$  is the Rbar position component relative ISS at sep TIG.

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Computation results from the foregoing procedure appear below.

$$2\omega = \frac{\pi \Omega}{180} = 0.00227 \text{ rad/sec}$$

$$\Delta \mathbf{VX}_{\text{TORF}} = 2\omega R \cos \theta = -1.02 \text{ fps}$$

$$\Delta \mathbf{VX}_{\text{SEP}} = \Delta V_{\text{SEP}} \cos \theta = -3.19 \text{ fps}$$

$$\Delta \mathbf{VX}_{\text{RPO}} = -\frac{R \cos \theta}{880} = +0.51 \text{ fps}$$

$$\Delta \mathbf{VX} = \Delta \mathbf{VX}_{\text{TORF}} + \Delta \mathbf{VX}_{\text{SEP}} + \Delta \mathbf{VX}_{\text{RPO}} = -3.70 \text{ fps}$$

Using the phasing rule-of-thumb  $\pm 49904 \text{ ft } \Delta X/\text{rev} = \mp 3 \text{ fps } \Delta VX$  developed in Section 3.10.7.2,  $-3.70 \text{ fps } \Delta VX$  is equivalent to a phase rate of  $+61500 \text{ ft/rev}$ . The equivalent phase rate modeled using an ESVO state vector pair with RelMo is  $62000 \text{ ft/rev}$ . The primary difference between RelMo curves using an ESVO post-sep state and the sep burn input to the Orbiter ephemeris is the initial position offset in the ephemeris case is zero.

# **FDO Console Handbook Section 3.10: Rendezvous Operations**

**Section 3.10 Concludes On This Page**

## **FDO Console Handbook Section 3.11: USSTRATCOM**

### **3.11 United States Strategic Command (USSTRATCOM)**

The United States Strategic Command (USSTRATCOM) is one of nine U.S. unified commands under the Department of Defense (DOD). The current USSTRATCOM resulted from integration of two previous unified commands on October 1, 2002.

- 1) United States Space Command (USSPACECOM) formerly oversaw DOD space and information operations
- 2) USSTRATCOM formerly responsible for U.S. strategic forces command and control

USSTRATCOM is headquartered at Offutt Air Force Base, Nebraska (10 miles south of Omaha), with geographically separated units at the following locations.

- 1) Cheyenne Mountain Air Force Station, Colorado (Cheyenne Mountain Operations Center)
- 2) Lackland Air Force Base, Texas (Joint Information Operations Center)
- 3) Arlington, Virginia (Joint Task Force - Computer Network Operations)

USSTRATCOM's missions are to establish and provide full-spectrum global strike, coordinated space, and information operations capabilities to meet both deterrent and decisive national security objectives. It provides operational space support, integrated missile defense, specialized planning expertise, global command and control, communications, intelligence, surveillance and reconnaissance to the joint warfighter.

The Cheyenne Mountain Operations Center (CMOC) is the central collection and coordination center for a worldwide system of satellites, radars, and sensors that provide early warning of any missile, air, or space threat to North America. In support of the USSTRATCOM space mission, CMOC provides a day-to-day picture of what is in space and where it is located. Cheyenne Mountain operations are conducted by 7 centers manned 24 hours a day, 365 days a year (see Figure 3.11-1).

- 1) Command Center
- 2) Air Warning Center
- 3) Missile Warning Center
- 4) Space Control Center
- 5) Operational Intelligence Center
- 6) Systems Center
- 7) Weather Center

The primary FDO interface with Space Command is the Space Control Center (SCC). The SCC controls the Space Surveillance Network (SSN), which detects, tracks, identifies, and catalogs all man-made objects detectable by radar and optical sensors. The SCC performs orbit analysis and maintains current orbit elements on these objects. These tasks are similar to those Ground NAV performs. However, the SCC must maintain orbit elements for over 9000 objects. The SCC is also responsible for protecting US assets in

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space. It performs this role through conjunction analysis between other objects and the Space Shuttle and through threat and warning notifications. The backup FDO interface with SCC is the Alternate Space Control Center (ASCC) located in Dahlgren, Virginia. Formerly a Naval Space Surveillance (NAVSPASUR) facility, ASCC transitioned to the Air Force Space Command in 2004 and is known as "Alt Space".

FDO's primary points of contact in the SCC are the Space Battle Manager (SBM)<sup>1</sup> and the Orbital Safety Analyst (OSA). Responsible for all conjunction assessment (CA) support, the SBM directs all required analyses and coordinates extra sensor tasking, etc. The OSA runs the Astrodynamics Safety Workstation (ASW) and performs processing of all threat objects. FDO should also be familiar with the Orbital Analyst position. A complete list of SCC console positions appears below.

**SCC Commander**: position in command of SCC.

**SBM/Deputy Commander**: assists SCC Commander and is in charge of the space surveillance mission. He is the prime FDO point of contact in support of orbit safety and space defense missions.

**SCO – Space Control Officer**: responsible for space defense threat processing.

**SCO Tech – Space Control Technician**: prime interface with the SSN and US payload owners/operators.

**OA – Orbital Analysts**: maintain high interest element sets and process new launches, burns, etc.

**OSA – Orbital Safety Analyst**: contractor responsible for processing conjuncting objects on the ASW.

**SPA – Systems Programmer Analyst**: contractor responsible for computer system support.

Two high level documents govern the NASA/JSC interface with USSTRATCOM.

- 1) *Memorandum Of Agreement (MOA) Between The Department Of Defense (DOD) And The National Aeronautics And Space Administration (NASA) For Support Of NASA Spaceflight Operations*
- 2) *USSTRATCOM/JSC Operating Instruction For Human Space Flight Support (OI)*

### 3.11.1 JSC/USSTRATCOM Data Transfer

USSTRATCOM provides multiple services for the SSP, including threat and warning notification, collision avoidance screening, satellite break-up notification, space object identification, and radar restrictions coordination. SSP interfaces to all USSTRATCOM services, except threat and warning events, come from the Johnson Space Center (JSC) Flight Dynamics Officer (FDO). The Shuttle Flight Director (FD) is responsible for threat and warning FCT actions, but FDO should be prepared to coordinate classified and other communications for FD as requested.

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<sup>1</sup> The SBM position was formerly known as Space Control Analyst (SCA).

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The SSP provides a few services to USSTRATCOM such as Shuttle state vectors, Shuttle launch countdown status, MCC status and overall mission status. These services are FDO's responsibility. The Ascent FDO provides verbal countdown status.

### 3.11.2 Conjunction Screening

One of USSTRATCOM's primary services to the SSP is Conjunction Assessment (CA). The OSA performs a CA using Super COMBO software on the ASW platform. SuperCOMBO predicts conjunctions between a specified Shuttle "asset" and other space objects in the SCC database passing within a specified minimum range. A SuperCOMBO CA processes all cataloged objects including analyst objects, a subset with insufficient tracking to be permanently cataloged. Lower fidelity General Purpose (GP) object elements can be processed by SuperCOMBO, but OSA typically uses higher accuracy Special Perturbations (SP) data of comparable accuracy to MCC's Shuttle tracking.

NOTE: SBM performs CAs using Computation of Misses Between Orbits (COMBO) software on the SPADOC platform as a backup to OSA's Super COMBO screening. Although COMBO typically utilizes GP elements, SP tracking can be processed if circumstances warrant the additional SPADOC workload.

Both cataloged and analyst objects are generally orbital debris which may not even be correlated with a known object or launch. Unfortunately, USSTRATCOM can only perform a CA on objects "big" enough to be tracked by ground-based sensors. Many orbiting objects exist in a size range big enough to damage the Orbiter, but small enough to avoid detection.

An unclassified subset of objects cataloged by USSTRATCOM is maintained in the **Satellite Situation Report**. The report identifies launch dates, object names, types (rocket body, payload, etc.), and some orbit elements. These data may be accessed through USSTRATCOM's "Space-Track" web site, and a link is provided on the FDO Home page. Access to Space-Track data requires prior UserID/password registration.

#### 3.11.2.1 Vector Transfer and CA Schedules

USSTRATCOM provides FDO with CA results within 1 hr of receiving an Orbiter state vector from FDO. If no conjunction is found, the OSA (SBM as backup) reports "negative conjunctions". The FDO/USSTRATCOM Vector Transfer Schedule, developed by the Lead FDO, can be found in the mission-specific FDO Databook. The Vector Transfer Schedule can be modified in real time as needed and can be communicated verbally over the NORAD COORD loop.

Prelaunch screening is performed by USSTRATCOM based on predicted OMS-2 burnout vectors. This screening reduces probability of launching into a close conjunction which could occur between insertion and the first good ground tracking solution at approximately 4 hrs MET.

From 3 hrs MET to End Of Mission (EOM), the following rules apply.

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Coasting flight: a current-time state vector should be sent to USSTRATCOM every 8 hrs, generally at 0600, 1400, and 2200 GMT. Additionally, whenever there is a significant change to the ground ephemeris, FDO should send USSTRATCOM an updated state vector to reflect the change.

Planned burn: a predicted post-burn state vector should be sent to USSTRATCOM as soon as the burn is properly modeled. A post-burn state vector should also be sent to USSTRATCOM after confirmation. Any significant update to either the predicted or confirmed state vector should be transmitted as well.

Contingency burn: a confirmed post-burn state vector should be sent to USSTRATCOM as soon as possible after the burn.

Deploys: a predicted post-Perigee Kick Motor (PKM) or post-deploy payload state vector and a post-separation Orbiter state vector should be sent to USSTRATCOM as soon as burns are properly modeled. A post-separation Orbiter state vector should be sent to USSTRATCOM as soon as possible after confirmation. Any significant update to either the predicted or confirmed state vectors should be transmitted as well.

Contingency jettison or deploy: in a contingency jettison or deploy, such as a Remote Manipulator System (RMS) jettison, the ground ephemeris Orbiter state vector at the time of jettison is considered to be the jettisoned object's state vector. After a separation burn has been executed, the object's state vector and the Orbiter's confirmed post-separation state vector should be sent to USSTRATCOM.

Overboard items: particularly during EVA, tools or payload components may inadvertently be released from the Orbiter's vicinity at low relative speeds. Although it may not be possible for FDO to send USSTRATCOM an overboard item's state vector, OSA should be contacted promptly to convey release time and an object description. In some cases, notably STS-107 FD2, FDO may not be aware an item has departed the Orbiter. Every shift, the SBM and OSA routinely review all SSN tracking of the Orbiter, looking for unusual data such as an unreported co-orbital object. Should data of this nature be encountered, OSA immediately reports its detection to FDO and the SSN is tasked to determine the unexpected object's orbit and physical characteristics ASAP.

A CA is run at least once per SCC shift, when a new Orbiter vector is received, or when an object in the catalog is updated.

### 3.11.2.2 Vector Transfer and CA Procedures

FDO Sends USSTRATCOM Vector: via fax, FDO sends a Greenwich True Equator-of-Date Rotating (TDR) vector, in meters and meters/second, and time of the vector in GMT, according to the mission-specific FDO Databook schedule. A TSA Vector Manipulation function automates message preparation. If TSA is not functioning, a form is available for this purpose. The form for sending vectors to USSTRATCOM is illustrated in Figure 3.11.2.2-1. Regardless of whether TSA or the form is used, include the pertinent anchor vector ID (AVID) at some point in the vector description. Because the TSA software is not critically certified, its TDR state vector components must be verified using TrS or TSA Checkout Monitor.



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<b>TO:</b>	RUWOKDB/HQ USSPACECOM CMAFS CO//SSC//		
<b>INFO:</b>	RUWRCAH/HQ USSPACECOM CMAFS CO//SPADOC// RUEBJLA/NAVSPASUR ASPADOC DAHLGREN VA		
<b>FROM:</b>	RUWTBCA/NASA JOHNSON SPACE CENTER HOUSTON TX//FDO//		
	PHONE (713)483-5685		
USSPACECOM VECTOR			
Vector Description:	_____		
MET of Data Transfer Confirmation	_____		
<u>TDR COORDINATE SYSTEM</u>			
X=	_____		m
Y=	_____		m
Z=	_____		m
XD=	_____		m/s
YD=	_____		m/s
ZD=	_____		m/s
VECTOR TIME (GMT) =	_____		
ORBIT COUNTER =	_____		
<b>PRIORITY:</b>	IMMEDIATE		

**Figure 3.11.2.2-1: USSTRATCOM Vector Form**

USSTRATCOM Sends Orbital Conjunction Message (OCM) or Negative Conjunctions Message: on receipt of the Shuttle or payload state vector from FDO, OSA (SBM is backup) will screen this vector versus the catalog for all objects penetrating a  $\pm 10 \times 40 \times 40$  km UVW box centered on the asset for 72 hrs, starting at vector epoch. The OSA will request increased tasking from the space surveillance network for any object predicted to penetrate the  $\pm 10 \times 40 \times 40$  km UVW box. This increased tasking will allow better prediction of the object's position and covariance at TCA. If any object is predicted to penetrate a  $2 \times 25 \times 25$  km UVW box centered on the asset within 36 hours of vector epoch, OSA will notify FDO and send an Orbital Conjunction Message (OCM) for each conjuncting object if so requested. If no conjunctions are predicted, OSA will verbally notify FDO that a "negative conjunctions" condition exists. Box dimensions are given according to a  $\Delta U \times \Delta V \times \Delta W$  (radial miss, by downtrack miss, by crosstrack miss) convention.

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**CAUTION:** covariance data received from USSTRATCOM in an OCM are restricted because they may reveal USSTRATCOM sensor capabilities. These "For Operational Use Only" (FOUO) data are not classified, but they are not releasable to foreign nationals or other individuals not directly involved with the CA process. As such, USSTRATCOM covariance data should not be included in any Flight Note nor discussed directly over voice loops.

**NOTE:** the OSA (SBM is backup) will report conjunction status for a single vector within 1 hour of vector receipt from FDO. If multiple vectors are sent, OSA will process them serially and report the conjunction status of each vector in the order it is processed. The OSA may take up to an hour to process each vector and will process them in the priority order specified by FDO. Generally, FDO should direct the OSA to process predicted burnouts first. These state vectors usually result in the largest change to current conjunction status.

### 3.11.2.3 Reboost Screening Considerations

Posigrade or retrograde burns greater than 15 min duration require a change to the screening process during the burn arc. The vehicle will fly to the edge, or even outside the 2x25x25 km reporting box during the course of long burns. Both the screening box size and the burnout vector need to be supplemented to insure all possible conjunction threats are reported. Since USSTRATCOM screening begins at vector time, the burnout vector must also be coasted back to TIG with AM or DM integrator options to insure boxes from the no-burn trajectory overlap those circumscribing the backward-coasted post-burn trajectory. For longer reboosts at higher accelerations, this overlap may not be achieved using standard screening/reporting box dimensions. In these cases, the box will have to be expanded during the reboost's time span.

To determine the necessary expanded box dimensions, RelMo Mode 1 digitals are run for the no-burn case relative to burn modeling for the duration of the reboost. The radial component of the expanded box should be set to the larger of 2 km or half the maximum radial offset determined by the Mode 1 run. The downtrack dimension of the screening box should be set to half the maximum downtrack offset plus 25 km. The crosstrack dimension does not change. These increases in the USSTRATCOM screening/reporting boxes are only necessary for the duration of the burn and should be reset back to 2x25x25 post-reboost. The larger notification box will provide overlap between the actual reboost powered flight arc and the coasted vectors from its endpoints such that the intent of the standard  $\pm 2 \times 25 \times 25$  km notification box is honored. Usually these hybrid box sizes will be determined preflight by the Lead FDO, but they may need to be determined real-time for an unplanned reboost.

The following 3 vectors are sent for each reboost to be screened with an expanded box. Vector number 2 is all that is necessary for the standard box.

- 1) No-burn vector with a time tag at TIG  
Comment: "AVID Reboost n Predicted Initiation"
- 2) Predicted burnout vector propagated back to TIG with AM or DM integrator options  
Comment: "AVID Reboost n Burnout Coast to Initiation"
- 3) Predicted burnout vector at burnout  
Comment: "AVID Reboost n Predicted Burnout"

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The OSA (SBM is backup) will notify FDO of any conjunctions within the expanded box for the time period between reboost initiation and termination. This period is defined to begin at Vector 1/2's GMT and end at Vector 3's GMT. Any conjunction reported by OSA during the reboost period must be assessed by FDO using the actual reboost trajectory. Be aware that USSTRATCOM/OSA-computed miss distances will not be valid in this timeframe except near TIG and burnout.

### 3.11.2.4 Day Of Rendezvous (DOR) Screening Procedures

In association with DOR CA, special procedures are invoked to manage workload and maintain situational awareness during this dynamic phase of flight. The pre-DOR Planning Team provides USSTRATCOM the following *predicted* state vectors. Inputs to USSTRATCOM should be provided such that any conjunctions are reported in time to brief the oncoming Rendezvous Execute FD during handover.

- 1) Orbiter Post-NH (if required)
- 2) Orbiter Post-Final NC
- 3) Target at Ti TIG (nominal PET = 0)

To minimize CA response delays, USSTRATCOM only reports conjunctions based on coasting these state vectors 12 hrs into the future. In addition, USSTRATCOM covers potential relative motion dispersions and rendezvous breakouts by applying a special 5x55x25 km reporting box to the predicted target 12-hr coast. The Planning Team should verify these procedures to be applicable when confirming predicted DOR state vectors are received by USSTRATCOM.

**CAUTION:** the target state vector at Ti should be annotated with the comment PREDICTED <target name> AT TI: USE 5X55X25 KM REPORTING. Box terminology is omitted from this comment because OSA actually clears an ellipsoidal volume circumscribing the reporting box.

Due to these special DOR procedures, the Rendezvous Execute shift normally only needs to send an *actual* Orbiter state vector following target docking/grapple. When confirming receipt of this actual state vector, FDO should also verify USSTRATCOM will transition back to standard reporting procedures. Rationale behind DOR-specific procedures was presented by DM32 to OFTP #212 on April 2, 2004.

**NOTE:** as long as the rendezvous is proceeding toward nominal Ti and docking times, relative motion dispersions due to navigation and burn execution don't warrant a CA update during the Rendezvous Execute shift. In such cases, relative motion will be corrected before a CA response from USSTRATCOM can be received and processed by FDO. Consequently, the only conceivable scenarios requiring a pre-docking CA update during this shift are those leading to a rendezvous breakout not covered by the 5x55x25 km reporting box.

### 3.11.2.5 Prelaunch Conjunctions

Flight Rule A4-3 governs the case of a conjunction issued pre-launch. Two CA runs, covering the period up to 0/02:00 MET, are performed by USSTRATCOM based on

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predicted OMS-2 cutoff Orbiter state vectors issued at L -24 hrs and L -3 hrs. Unplanned countdown holds do not justify additional CA runs. If a run reveals a conjunction with any cataloged object penetrating a  $\pm 5 \times 15 \times 5$  km UVW box centered on the Orbiter, launch GMT will be slipped to the next even minute until a subsequent CA run fails to obtain a conjunction. Under no circumstances will launch GMT be adjusted due to CA results reported after 5 min prior to resuming the count at T -9 min.

### 3.11.2.6 On-Orbit Conjunctions

On-orbit conjunctions may require evasive action with a collision avoidance burn. Flight Rules A4-106 and C4-51 govern these cases. Upon receipt of conjunction data from USSTRATCOM, FDO should confirm the conjunction, notify the flight director, and plan an evasive maneuver, if necessary.

FDO should notify the FD of any Orbiter conjunction predicted by USSTRATCOM as soon as time permits, regardless of its TCA, spacing, or presumed accuracy. This prevents sources external to MCC from confronting the FD with inquiries before a FDO briefing, however preliminary, is delivered. Initial notification should be made verbally. After FDO independently confirms the conjunction, a Flight Note documenting results to the FD is recommended. The Flight Note should include at a minimum the predicted TCA, collision probability ( $P_c$ ), and UVW miss distances. Unless the FD chooses to do so, the conjunction should not be discussed on any loop. This procedure has been used by the SSP to minimize dissemination of sensitive events, but FDO may need to remind the FD of this. Before a conjunction becomes public knowledge, other controllers should understand its circumstances are FOUO and not for dissemination outside MCC.

There are 2 methods for evaluating a conjunction: the box method and the probability method.

#### 3.11.2.6.1 Box Method

The box method is the simpler method of evaluating a conjunction and is based on trend analysis of the miss distance at CPA. If a miss is inside the red or yellow thresholds, as defined by flight rules, the risk of a collision may warrant an avoidance maneuver. As miss distance decreases, the probability of a collision increases. Since relative approach direction information is not used in the box method, box shape in the flight rules is based on expected UVW uncertainties derived from statistic analysis.

Data required for the box method includes state vectors and drag parameters for the object and asset. The object state vector is sent from USSTRATCOM to the FDO in the form of an OCM, a Vector Covariance Message (VCM), or a TRAILX. Samples of each of these message formats are illustrated in Section 3.11.3. The vectors in the OCM and VCM messages can be extracted electronically on the FDO workstation using the USSTRATCOM Drop Box in TVETS. The TRAILX is received via fax and must be manually input. Object drag is modeled based on USSTRATCOM's computed ballistic coefficient. Ballistic coefficients are contained in the OCM and VCM but not the TRAILX. If a TRAILX is sent, the ballistic coefficient will need to be obtained from OSA verbally. In the rare event that the ballistic coefficient is unavailable, drag must be modeled base on the Radar Cross-Section (RCS). Dependent on radar frequency in addition to target size/shape, RCS is not directly analogous to aerodynamic cross-section except for

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spherical objects. In lieu of a ballistic coefficient, however, it is better than nothing. Ground NAV provides Shuttle or asset data.

The miss distance of the conjunction is computed using RELMO Mode 2. RELMO Mode 2 finds all CPAs that meet the range and time span criteria specified by FDO. In RELMO, the Chaser is defined as the object and the Target is defined as the Shuttle or asset. Even though most debris objects are very small, the weight of the object should never be set to less than 5000 lbm due to problems with extremely light weights and the powered flight numerical integrator (PFNI). Assuming an object weight of 5000 lbs, the area of the object equals 12200 times the ballistic coefficient. This assumes a  $C_D$  of 2.0 and converts the metric USSTRATCOM ballistic coefficient into  $\text{ft}^2$  units required for RELMO. If an RCS is used, the area in  $\text{ft}^2$  is  $10.8 * \text{RCS}$ . The object KCON is 1.0. Ephemeris 1 characteristics are used for the Shuttle. The miss distance is recomputed every time a new object vector is received from USSTRATCOM or a significant state vector update has been received from Ground NAV. All conjunction data should be logged on the conjunction spreadsheet in V:\fdo\STS-xxx\.

The key to the box method is evaluating the miss distance trend along with its magnitude. Over time, many conjunctions will move out of the avoidance box, making an avoidance maneuver unnecessary. Generally, this depends on the Orbiter attitude timeline from current time until TCA. A water dump or IMU align maneuver may be enough to move CPA outside an avoidance burn box. A vent uncertainty of 0.1 lbs can yield a downtrack displacement of 7 nm after 12 hrs. Even if the conjunction stays in the box, there are cases where an avoidance maneuver is unnecessary. If miss distance jumps are equivalent to box dimensions with each state vector update, or the miss distance is consistently at or trending toward a box edge (particularly in the radial direction), a maneuver may not be warranted. Also, the Shuttle configuration or mission operations may not easily support a maneuver without imposing other types of risk to the crew or mission. Examples of this kind of risk trade are documented in the flight rule rationale.

### 3.11.2.6.2 Probability Method Background and Supporting Data

Probability of collision ( $P_C$ ) is the more accurate conjunction risk measurement. The  $P_C$  is based not only on the miss distance at TCA, but also on conjunction geometry and the uncertainty, or covariance, associated with both the object and the asset state vectors. Adding the covariance of the object and the asset and applying this sum to the miss distance determines  $P_C$ . Relative approach direction determines which object covariance components are added more completely to which asset covariance components. As an approximate example, a front-quartering collision has the object downtrack covariance added to the asset crosstrack covariance and vice-versa. Figure 3.11.2.6.2-1 depicts the behavior of  $P_C$  with respect to uncertainty for any given miss distance. The maximum  $P_C$  occurs when the covariance components are the same size as the miss distance components. If the uncertainty is much smaller than the miss distance, a very small  $P_C$  can result. Although it's known a close miss will occur, there's also little chance this miss will become a hit. Conversely, if the state vector uncertainties are very large, a low  $P_C$  may result even if the miss distances are near zero. In this case, the miss distance implies a hit is imminent, but we really don't know where the object and/or asset is, so there's little faith in the prediction.

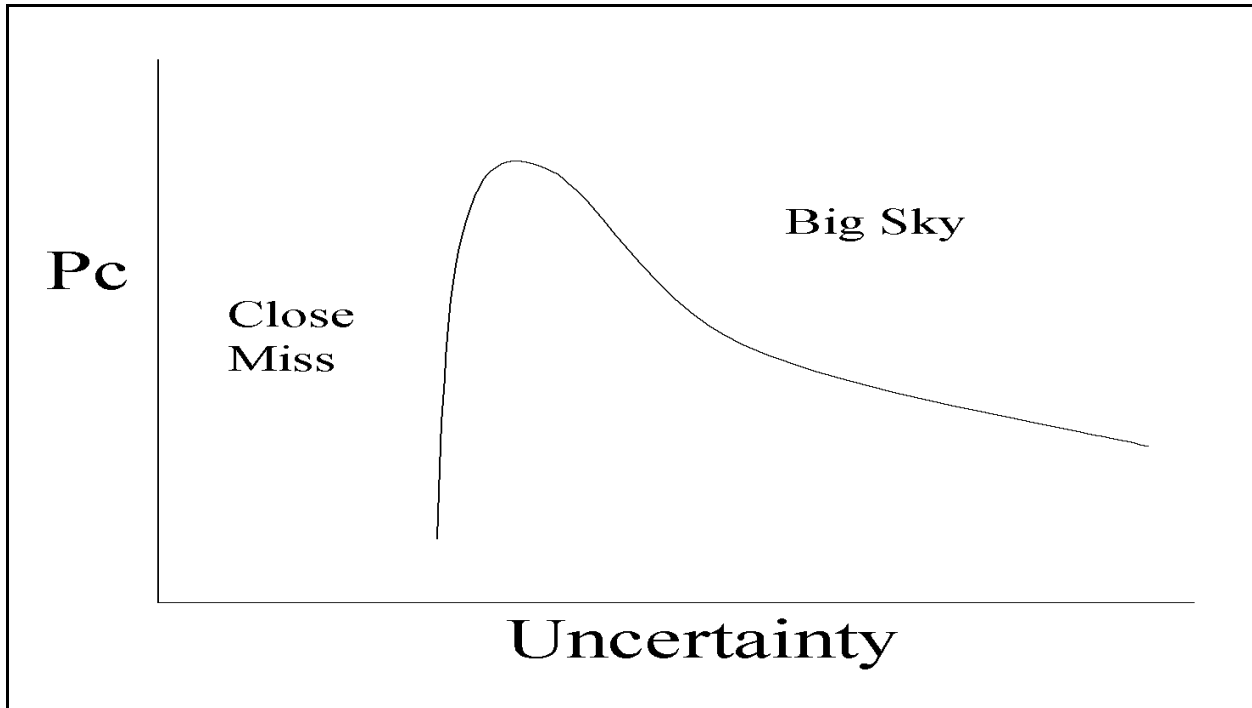


Figure 3.11.2.6.2-1:  $P_c$  Versus Uncertainty

In comparing the probability method to the box method, the most common difference is the  $P_c$  method will lead to fewer avoidance maneuver recommendations. When a maneuver recommendation is made based on  $P_c$ , a false alarm is less likely than under box-driven decisions. Box sizes are based on average covariances, and their shapes are based on the average collision angle. Small covariances will frequently show there is no cause for concern when a conjunction penetrates the red/yellow box. Conversely, the  $P_c$  method also detects rare high-risk conjunctions lying outside a box criterion. Depending on the covariance and conjunction geometry, these cases can occur if radial miss is near zero and crosstrack and/or downtrack miss is outside the box.

FDO should verify the conjunction using object data from the OCM and the latest Shuttle/asset data from Ground NAV. The OCM contains time of closest approach (TCA), relative miss distance at TCA, state vectors for the asset and object at TCA, covariances associated with the asset and object state vectors propagated to TCA, ballistic coefficients, and tracking and modeling information for each. FDO should determine that the OCM contains valid data per the guidelines in Figures 3.11.2.6.2-2a/b/c. If any anomalies are discovered, the OSA should be contacted.

**CAUTION:** TrS and TSA trajectory prediction requirements may not adequately address some types of conjuncting object motion for  $P_c$  purposes. Specifically, two trajectory types may give rise to significant  $P_c$  errors, and each is a permanent limitation with respect to ephemeris generation software.

- 1) An Earth gravity harmonics modeling singularity in TrS may introduce significant trajectory prediction errors if a near-polar pass occurs prior to TCA. Consequently, FDO should be concerned whenever conjuncting object inclination approaches  $90^\circ$ .
- 2) Both TrS and TSA may be incapable of accurately predicting near-rectilinear motion. Sounding rockets such as Black Brandt can exhibit near-rectilinear motion. A near-

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rectilinear trajectory will have perigee near the geocenter at a height approaching -3444 nm.

In either of these cases, use Checkout Monitor to verify the object ephemeris state vector doesn't significantly deviate from the OCM state vector at the OCM epoch. If it does, an object ephemeris static start time closer to TCA may be warranted. In extreme cases, a downmode to UVW boxes may be necessary (see Section 3.11.2.6.4).

Asset data should be ignored in the OCM because FDO will perform more accurate state vector and covariance propagations to TCA with Ground NAV assistance. USSTRATCOM orbit determination is done using multiple tracking arcs with only a few data points from each tracking arc and a fit span up to 36 hrs. USSTRATCOM assumes coasting flight even if FDO has provided knowledge of maneuvers, water dumps, or other trajectory perturbing events. Ground NAV has a much smaller fit span and is aware of past and predicted trajectory perturbing events such as water dumps and maneuvers. Therefore, the Shuttle covariance USSTRATCOM generates over a 36-hr time span is significantly less accurate than Ground NAV data.

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Item	Check	Response	Effect	Comments	
Delay Between Last Accepted Object Observation and Message Prep Time	Delta > 1 hour	Alert OSA, request future OCMs be generated immediately after obs download. Suspect any calculations using this OCM unless it's confirmed by other OCM evaluations.	Use of "old" observation data negatively affects the quality of all data in msg.	New tracking data for all potential Shuttle conjuncting objects is uploaded into the ASW every 30 min.	
DC Span	<b>EDR</b>	If LUPI/EDR not consistent with a row in the Check, request explanation from OSA.  Typically, DC Span should follow the guidelines shown in the previous column. However, if there are a low number of observations, the DC Span will need to be increased to obtain a good fit. See Weighed RMS.	An inconsistent DC Span can adversely affect USSTRATCOM's orbit determination process. Values outside this range may indicate object tracking issues causing excessive variations between OCMs.	Generally the DC Span is 4 - 5 days. During a solar maximum, it may drop to about 2 days.	
	<b>LUPI/DC Span (days)</b>				
	0 - 0.001				≥ 6
	0.001 – 0.003				3 - 6
	0.003 – 0.005				2 - 4
	0.005 – 0.01				2 - 3
	0.01 – 0.1	1 - 2			
	> 0.1	0.25 – 1.5			
Number of Tracks	a. < 10 per day	a. Minimal tracking data are indicated. This may warrant discussion with OSA. Is this level of tracking expected to continue?	a. Sparse tracking data may indicate considerable variations among OCMs, especially for high-e, low-perigee, or high-drag objects (EDR > 0.001).	The figure in this OCM field is the total number of contributing tracks during the DC Span. A track is a continuous set of observations from one sensor. The system normally eliminates about 10-15% of raw observations to get a good DC fit. OSA generally retains > 80% of observations.	
	b. > 35 per day	b. The object is extremely well tracked during the DC span.	b. OCMs should produce consistent results.		

**Figure 3.11.2.6.2-a: OCM Evaluation Criteria**



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Item	Check	Response	Effect	Comments
Weighted RMS	Expect value near 1.0  If > 1.2, fit may be starting to diverge.	If Weighted RMS value > 1.2, request explanation from OSA.  Value may be high due to a small number of observations and increased DC Span.	A high Weighted RMS indicates a poor fit to observations. The closer to 1.0, the better the fit.	A high Weighted RMS value shows poor knowledge of an object's location. Unfortunately, this is not necessarily reflected in the covariance matrix.
Ballistic Coefficient	a. Negative number for conjuncting object	a. Contact OSA to determine if the object is maneuverable. If not, alert them to the issue and request new data.	a. Unless the object maneuvers and adds energy to its orbit, the ballistic coefficient in the msg should always be positive. A negative number may invalidate all OCM data. It probably indicates an anomaly in tracking data used for the solution.	By the USSTRATCOM definition, ballistic coefficient = $C_D A/m$ (coefficient of drag X frontal area / mass) in units of meters squared per kilogram.
	b. Significant variation of this number between OCMs	b. See EDR section.		
Energy Dissipation Rate	a. Negative number for conjuncting object	a. See Ballistic Coefficient comments	b. This number has a direct effect on the size of the covariance used in computations and thus on the $P_c$ computed.	
	b. Significant variation between successive OCMs (order of magnitude change)	b. This number probably should not be varying significantly between messages. Contact OSA and discuss reasons.		
Scaled Object Covariance	Large changes in position sigma between successive OCMs. These terms should not be experiencing large swings after several OCMs have been received.	If the object has maneuvered during the new fit arc, sigmas should be larger compared with previous OCMs. If the object has not maneuvered, discuss covariance data with OSA.	Changes in the covariance will directly affect $P_c$ computations.	Position sigmas are the square root of the leftmost three diagonal elements of the matrix. Usually, these terms can be expected to decrease as time to TCA decreases.

**Figure 3.11.2.6.2-2b: OCM Evaluation Criteria (continued)**

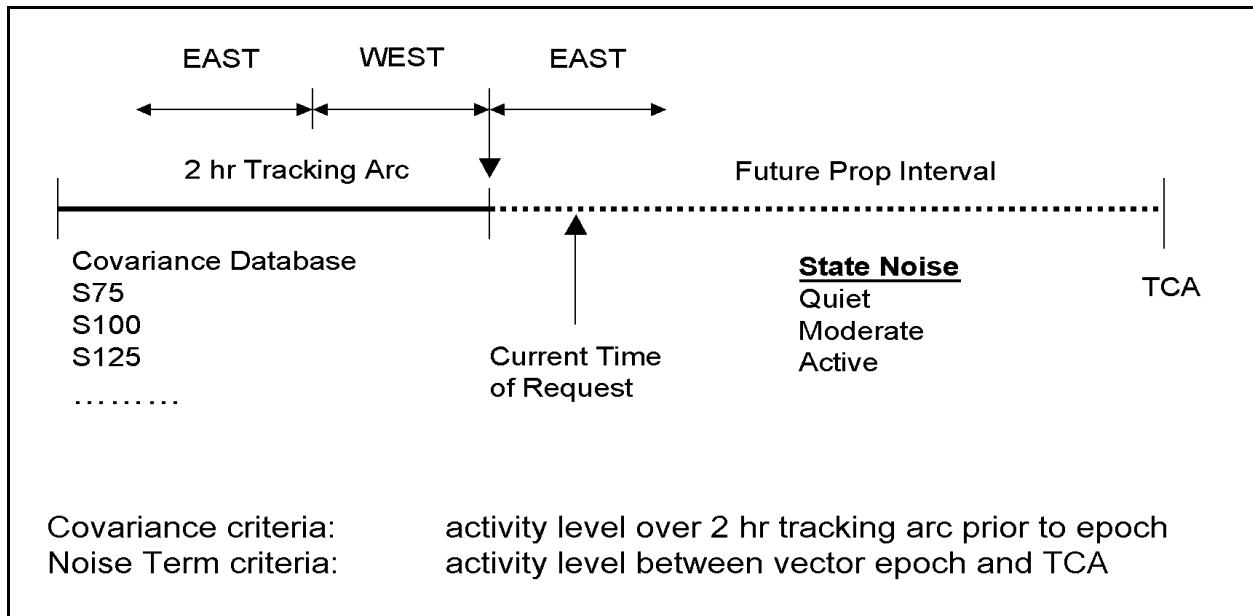
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Item	Check	Response	Effect	Comments
Miss Distance	Within 24 hrs of TCA, significant changes among OCMs (assuming no more than approx. 3 hours between messages).	If neither object has maneuvered, the relative miss distance should not change drastically between successive OCMs received within a few hours of each other.	Miss distance changes will directly affect $P_c$	Miss distances will change as the conjunction evolves, but significant jumps between successive OCMs may indicate a need to redevelop data.
High e or low perigee objects	$e \geq 0.001$ or $H_p \leq 300$ km	Data may vary more than other object classes. For low perigee cases, EDR may vary significantly between OCMs depending on the fit arc.	High e, low perigee objects are generally the most difficult to track, and covariance data reflect this. These objects are more likely to exhibit tracking gaps, and covariance data may thus fluctuate more than for other more well tracked objects. Additionally, EDR for these objects varies widely with true anomaly.	
Small miss distance coupled with small covariances, especially before TCA -12 hrs	Miss <2 km RSS and Covariance < 500 m downtrack	More $P_c$ sensitivity to miss distance changes than for larger uncertainties	Due to concentrated covariance density as miss increases even slightly, $P_c$ changes may be significant. With the variation seen in miss distances over the course of a conjunction, especially when time to TCA is over a few hrs, this type of conjunction may see the most variation in $P_c$ as OCMs accumulate.	
Early in any conjunction	Right after initial conjunction identification	Large variations in all data may be expected.	Right after conjunction identification, USSTRATCOM initiates maximum tracking on the object of concern. If an OCM is received before or soon after this increased tracking is initiated, there may be a significant change between those data and any transmitted after highly tasked tracking data are processed.	
Covariance Data very large	Same number in every matrix cell: 10 earth radii	Do not use this OCM,. Contact OSA for new data	N/A	This value is a computer default obtained when OSA cannot effectively fit the data through all required orbit elements.

**Figure 3.11.2.6.2-2c: OCM Evaluation Criteria (concluded)**

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Ground NAV will provide 3 pieces of asset data to FDO for a particular conjunction: a state vector from the latest valid batch solution, a generic Shuttle covariance, and a Shuttle covariance propagation scale factor known as a noise term. Ground NAV provides the asset state vector epoched to batch end time. The latest state vector from the batch should always be used because its time tag becomes that of the asset covariance and minimizes covariance propagation time. Figure 3.11.2.6.2-3 illustrates temporal relationships between the batch end time asset vector epoch, the time FDO requests data from Ground NAV, and TCA. It also indicates which time interval is pertinent to the covariance and which applies to the noise term.



Ground NAV also informs FDO which generic Shuttle local covariance to select from TSA's Covariance Administration Table (CAT) based on activity within the tracking arc or the 2 hrs prior to the asset vector epoch, whichever is longer. Generic Shuttle covariances are derived from SFOC Transmittal Form number NAV-00-48500-045, dated June 21, 2000 (see Figure 3.11.2.6.2-4). It is assumed any trajectory disturbances prior to the tracking arc have been tracked out and are reflected in the state vector itself. The local covariance represents trajectory disturbances remaining to be tracked.

Since the covariance Ground NAV provides is local to the asset vector epoch and only represents trajectory uncertainty at that time, it will need to be propagated to TCA during the  $P_C$  computation. Ground NAV will inform FDO which generic noise term (see Figure 3.11.2.6.2-5) to use in this propagation. The propagated covariance then reflects expected trajectory disturbances between the asset vector epoch and TCA. These noise terms were derived from average values of historic S75 covariance growth during 12-hour periods at 3 different disturbance activity levels. They are based on SFOC Transmittal Form number NAV-00-48500-049, dated June 27, 2000, together with several working group meetings throughout the Summer of 2000.

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Local Covariance	Global SSP CAT Slot	Criteria
S100	C44	a) Quiescent b) ISS docked ops, vent active or not req. c) FES active d) Cabin Depress (except 102) e) Water Dump – OOP or < 1 hr arc
S200	C45	a) Single attitude mnvr b) ISS docked ops w/unmodeled growth
S300	C46	a) Cabin Depress - 102 OOP b) Water Dump - radial > 1 hr arc c) Attitude mnvr – docked ops, Shuttle control
S400	C47	a) 2 attitude mnvrs b) Single burn
S500	C48	a) > 2 attitude mnvrs b) IMU alignment c) Reboost ISS – vent modeled
S750	C49	a) Cabin Depress - 102 inplane b) Water Dump - downtrack > 1 hr arc c) Water Dump – docked ops, Shuttle control d) 2 burns e) IMU/COAS calibration f) HUD calibration
S1000	C50	a) > 2 burns b) Prox Ops c) APU activation d) Reboost ISS - no vent modeled

**Figure 3.11.2.6.2-4: Generic Shuttle Covariances**

**CAUTION:** during the 2 hrs immediately preceding batch solution end time, or associated tracking arc if longer, select the worst-case covariance. Only consider those criteria associated with the covariance under assessment.

Noise Level	Noise Term	Average Attitude Mnvrs / Rev
Quiet	1.615E-07	≤ 0.374
Moderate	4.75E-06	0.374 to 1.125
Active	1.164E-05	≥ 1.125

**Figure 3.11.2.6.2-5: Covariance Propagation Noise Terms**

**CAUTION:** apply noise level/term from batch solution end time to TCA.

All object data provided by USSTRATCOM in the OCM are at TCA. However, ASW software has an atmosphere model generating excessively tight covariances following propagation to TCA. Therefore, the FDO SPADOC Drop Box automatically applies an appropriate scale factor to the object covariance while extracting it from the OCM. The default scale factor used by FDO for all OCM covariance data is currently 1.66, although true (analytic) scale factors are derived from the propagation time to TCA. A single

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representative scale factor was chosen primarily for operational ease, and its conservatism does not dramatically affect any probability of collision computations inside of 36 hours to the conjunction. The values shown in Figure 3.11.2.6.2-6 are actual computed covariance scale factors based on increased tasking for an object of concern and USSTRATCOM's recent upgrade to the High Accuracy Satellite Drag Model (HASDM) in the ASW. The table is provided for informative purposes only. The matrix multiplier row shows values appropriate for use with current FDO SPADOC Drop Box software.

Prop Time, hours	0	6	12	18	24	30	36	48	72
Component Scale Factor	1.10	1.16	1.20	1.23	1.26	1.29	1.31	1.34	1.40
Matrix Multiplier	1.21	1.34	1.44	1.52	1.59	1.66	1.71	1.81	1.96

**Figure 3.11.2.6.2-6 Covariance Scale Factors**

After extracting object data from the OCM using the SPADOC dropbox, the TCA,  $P_C$ , and miss distances should be computed using the vector to ephemeris (V2E) option in RELMO Mode 2. Reference Section 3.11.2.6.3 for procedures. Mode 2 inputs are identical to those used in the box method. Ephemeris 1 should be updated on Ground NAV's latest solution epoched to batch end time to obtain a VAM Target ephemeris for the asset. This is especially important if there is a vent prior to TCA. In order to calculate the  $P_C$ , covariance data and the asset's physical size (radius) must also be defined. In the Mode 2 menu, covariance time tags will default to vector time tags, becoming the anchor epoch for an ephemeris. These times will be correct for standard operations (object/Chaser covariance and state vector are at TCA, asset/Target state vector and covariance are at batch end time). The noise term and the radius will have to be defined for the asset. Ground NAV supplies the noise term. The radius defines a sphere centered on the CG that fully contains the asset. This value is 69 ft for the free flight Shuttle and should be determined preflight by the Lead FDO for docked operations or deployable assets. Unless the object is as large as the asset, the object is assumed to be a point mass and the object radius is set to zero. The point mass assumption for most objects is valid because the asset radius value defines an area much greater than the actual asset cross-section. The exception to this is extremely large objects (i.e. Shuttle size) or small deployable assets. In those cases, a best estimate radius should be used for both the object/Chaser and asset/Target. All conjunction data should be logged at `V:\fdo\STS-xxx\` for trend evaluation.

### 3.11.2.6.2.1 Predicted Burnout Conjunctions

Conjunctions with predicted burnout state vectors are processed the same as coasting flight conjunctions. A burn placed between current time and TCA does not affect the state vector or covariance supplied by Ground NAV. Rather, the burn's influence is captured in the noise term because it's a future event.

### 3.11.2.6.2.2 Post-Deploy Asset Conjunctions

Post-deploy asset conjunctions require vector-to-vector (V2V) RELMO Mode 2 processing and a modified procedure to handle the asset state vector. Ephemeris 1 should still be updated on Ground NAV's latest solution, but a vector must then be grabbed from Ephemeris 1 at deploy time. If there is a spring ejection  $\Delta V$  at deploy or the asset performs maneuvers, these asset translations should be modeled, typically in Ephemeris

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4. The Ephemeris 4 anchor will be fetched from Ephemeris 1 at the deploy/undock time. If the deployable is released without an impulse and the Shuttle performs all separation maneuvers, building Ephemeris 4 is unnecessary.

Next, run RELMO Mode 2 V2V, fetching the asset/Target vector from Ephemeris 4 pre-TCA or from Ephemeris 1 at deploy time, whichever is appropriate. The asset/Target covariance time tag will again default to vector time, the undock/deploy epoch in this case. This is wrong. The asset covariance time tag must always be set to the Ground NAV solution's batch end time, which is the anchor vector of Ephemeris 1. Since RELMO Mode 2's V2E option does not allow a covariance time tag for the asset/Target prior to the start of the target ephemeris, the V2V option is required.

This case will almost certainly require corrections to RELMO default drag characteristics and radius values for the asset/Target. Drag characteristics will have to be corrected to asset data if the Target/asset vector was fetched from Ephemeris 1. Asset/Target radius must be set to the larger object or asset value. If object radius cannot be determined, setting asset/Target radius to the Shuttle value of 69 ft will yield a very conservative answer. Verify Ground NAV is using Shuttle events up to deploy/undock time, followed by asset events thereafter, to determine the correct noise term.

### 3.11.2.6.2.3 No OCM (Loss of ASW) Considerations

If the ASW machine goes down for any reason, USSTRATCOM is unable to generate OCMs. In this case, the conjunction will be processed using the SPADOC machine. Consequently, only a COMBO and TRAILX will be sent to FDO. It may still be possible to use the probability method, however, depending on the threat object's catalog number. TOPO maintains estimated covariance data for objects with perigees below ISS altitudes. These data are contained in 2 lookup tables at V:\FDO\USSPACECOM\Probability Method\. The first lookup table, called Object LOOKUP\_yymmdd, is a covariance selection table based on object number and time from last observation to TCA. The second table, called Object sigmas\_yymmdd, contains the generic position covariance sigmas. Ballistic coefficient needs to be obtained from OSA verbally. If the object number does not appear in the Object LOOKUP\_yymmdd file, the box method must be used.

### 3.11.2.6.2.4 No Dropbox Interface

In the event the dropbox fails, USSTRATCOM must fax OCMs to FDO. FDO then manually inputs the object vector and object covariance position components. Input covariance data occupy the 3 upper-leftmost diagonal elements. The covariance is then scaled with Covariance Edit using a value of 1.66 as the multiplication factor.

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### 3.11.2.6.3 Probability Method Procedure

- 1) Retrieve OCM from SPADOC Drop Box into TSA VAT/CAT.
  - A) If an electronic OCM is unavailable, USSPACECOM fails over to faxing the OCM to the FDO console (or may fax a COMBO or TRAILX message). Annotate each printed OCM as "OCM 01", "OCM 02", etc. to create a chronological series pertaining to each object. In this case, the object state vector from the OCM will need to be manually entered using Vector Edit and the position covariance data from the OCM will be manually entered using Covariance Edit (see Step 4).

CAUTION: the OCM is in units of meters in a TDR frame of reference. Ensure these units are correctly selected when manually entering the object state vector and covariance. Also confirm you are entering the Object (not the Asset) information.
  - B) If OCM is available, verify a valid Object number, TCA, and MSG Prep time exist, ensure MET format is selected (for mission operations, sim coordination with USSTRATCOM may require GMT), and then highlight the desired OCM in the SPADOC Drop Box. Select "File/Receive..." and verify that the following default options are configured correctly.

NOTE: double-click an OCM in the Drop Box to view its contents prior to processing.

    - i) **Vehicle = SSP** (receive vectors/covariances to shuttle VAT/CAT)
    - ii) **System = Global** (receive vectors/covariances to global area)
    - iii) **Asset = NONE** (do not receive asset vector or asset covariance for standard operations, all asset related fields should gray out)
    - iv) **Object = BOTH** (receive both object vector and object covariance)
    - v) **OV Slot, OC Slot = 0** (receive object vector and object covariance to next available slots in the VAT and CAT, respectively, or specify desired slot number)
    - vi) **OMass = 5000 Lbs**
    - vii) **OSF = 1.7** (rounded from 1.66 value in covariance scaling table)
    - viii) **OVComment = OBJECT NNNNN MSG DDD:HH:MM** (where NNNNN is the object number, and DDD:HH:MM is the days, hours, and minutes of the message preparation time)

NOTE: MSG Prep time should be used to chronologically track OCMs (and the associated vectors/covariances) in the dropbox, FDO Log, and the VAT/CAT. This is in lieu of the OCM number.
    - ix) **Reference time (GMT/CAL) = YYYY:DDD:HH:MM:SS.SSS** (should match the lift-off time)
  - C) Modify the Import Menu field **OCComent = OBJECT NNNNN MSG DDD:HH:MM SF 1.7** (remove "TCA DDD:HH:MM" in order to view the MSG time in the CAT, until CAT comment field can support the full comment length).

NOTE: MSG Prep time should be used to chronologically track OCMs (and the associated vectors/covariances) in the dropbox, FDO Log, and the VAT/CAT. This is in lieu of the OCM number.
  - D) Select OK to import selected vectors and covariances.
  - E) Scan Advisory Services for any error messages related to Drop Box processing and to verify the expected messages.
  - F) Verify desired vectors and covariances are transferred to the VAT and CAT, respectively.
- 2) Verify USSTRATCOM TCA with Mode 2 RELMO.

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- A) Get latest valid Shuttle vector from Ground NAV epoched at batch end time.
- B) Verify pre-TCA E1 configuration and anchor E1 on Ground NAV vector.
- C) For conjunctions with Shuttle, run RELMO V2E
- D) For conjunctions with a deployed asset, run RELMO V2V:
  - i) If asset deployed without eject or asset sep burns pre-TCA, fetch E1 vector at undock/deploy time.
  - ii) If asset has eject or sep burns, model asset in E4 and fetch final pre-TCA E4 burnout vector
- E) Verify the following Mode 2 drag profiles prior to execution.

Trajectory	Weight (lbm)	Area (ft <sup>2</sup> )
Chaser = Object	5000	12200 * Ballistic Coef.
Target = Shuttle Asset	E1 or Asset	E1 or Asset

**CAUTION:** the box method must be used in 2 cases.

- i) Relative velocity magnitude < 200 mps (RSS).
- ii) Radial miss is the largest miss component.

- 3) Get asset covariance data from Ground NAV.
  - A) FDO provides TCA to NAV.
  - B) Ground NAV provides:
    - i) Local covariance selection to be made from Global CAT
    - ii) Noise term selection (quiet, moderate, or active).
  
- 4) If an electronic OCM is not available, either an estimated object covariance or a manually entered covariance must be used. From the TSA DNAV, select Covariance: Covariance Edit.
  - A) If using a faxed OCM, perform the following actions.
    - i) Verify appropriate units (MT) are selected.
    - ii) Enter the covariance time (vector time, usually TCA, from OCM).
    - iii) Ensure the "COV" button is selected.
 

**NOTE:** the OCM message provides variances and covariances, but Covariance Edit defaults to expecting correlation coefficients. The middle of the display should have "Diagonal is variances" and "Lower triangular is covariances" annotations.
    - iv) Enter the lower left triangle of the UVW position variances and covariances per boxed elements in the following example.
 

**NOTE:** covariance velocity components do not need to be entered unless the covariance is to be propagated.

	U	V	W	UD	VD	WD
U	0.17419E+05	0.00000E+00	0.00000E+00	0.00000E+00	-0.23701E+00	0.00000E+00
V	0.00000E+00	0.12143E+05	0.00000E+00	-0.75008E+00	0.00000E+00	0.00000E+00
W	0.00000E+00	0.00000E+00	0.13622E+05	0.00000E+00	0.00000E+00	0.00000E+00
UD	0.00000E+00	-0.29300E+02	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
VD	-0.47480E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
WD	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

NOTE: UPPER TRIANGULAR IS CORRELATION COEFFICIENTS  
 DIAGONAL IS VARIANCES  
 LOWER TRIANGULAR IS COVARIANCES

- v) Input Multiplication Factor = 1.7 (must click "Accept" to get this input field).



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- vi) Add a comment using the format specified in Step 1B.
- B) If OCM is unavailable, use the "Object LOOKUP" file in the `V:FDO\USSPACECOM\Probability Method` directory to select the correct BIN, based on the object number and time from TCA. Then perform the following actions.
  - NOTE: if the object number is not in the table, no estimated covariance data is available,  $P_c$  cannot be computed, and the box method must be used.
  - i) Verify appropriate units are selected.
  - ii) Press the "INPUT SIGMAS" button.
    - NOTE: middle of display MUST have "Diagonal is sigmas" annotation.
  - iii) Set multiplication factor to 1 (default value).
  - iv) Input Destination Comment with format "OBJECT NNNNN LSET XX BIN ZZ", where NNNN is the object number, XX is the chronological elset, and ZZ is the bin number associated with the elset.
- 5) Calculate  $P_c$ :
  - A) Use RELMO Mode 2 V2E (V2V for post-deploy asset conjunction).
  - B) Input appropriate vectors and drag characteristics.
    - i) Object: Drag & Weight per OCM Ballistic Coefficient
    - ii) Shuttle: Ephemeris 1 or asset data
  - C) Input covariance data.
    - i) Object: use scaled covariance or estimated data if OCM unavailable.
    - ii) Asset: use Global CAT slot per Ground NAV input.
    - iii) Cov Time = vector times (asset = anchor vector time for ephemeris 1)
    - iv) State Noise: Object = 0, Shuttle is per Ground NAV selection
      - Quiet = 1.615e-07
      - Moderate = 4.750e-06
      - Active = 1.164e-05
  - D) Input radius: Object = 0, Shuttle Alone = 69.0 ft  
mated Shuttle = flight-specific  
asset = larger of asset and object
  - E) Click "Compute Probability".

NOTE: when verifying  $P_c < 10^{-7}$  during collision avoidance burn planning, do not incorporate this burn into noise term selection criteria. See Flight Rule for rationale.

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### 3.11.2.6.4 Special "Box Downmode" Cases

There are 2 special cases in which the probability method should not be used even if all data are available.

#### 3.11.2.6.4.1 Low Relative Velocity Case

The low relative velocity case results in a highly variable and erroneous  $P_c$  calculation. Two related factors are responsible for this degraded accuracy. First, TSA does not find the correct TCA nor miss distance or conjunction geometry for low relative velocity. Second, nearly identical object/asset geocentric velocities violate a  $P_c$  computation assumption that relative motion in the immediate vicinity of CPA is linear. Most conjunctions occur between objects that have very diverse planes and/or apsis heights, which result in very high relative velocity conjunctions. Relative motion in the immediate vicinity of CPA for high relative velocity conjunctions is for all practical purposes linear. Analysis has shown the linear motion assumption provides reasonable  $P_c$  data for conjunctions with relative speeds greater than 200 mps, but it breaks down at some point below that speed. Therefore the box method should be used for all conjunctions with relative velocity magnitudes lower than 200 mps. The box method is still valid even though the TCA and miss distance are wrong. Due to low relative velocity, the miss distance doesn't change greatly if TCA error is small.

#### 3.11.2.6.4.2 Radial Miss Case

The radial miss case is defined as a conjunction where radial miss is the largest miss component. It results in an accurate  $P_c$  calculation, but values among successive OCMs and asset covariance propagation times can be highly variable and therefore unusable. The uncertainty of the radial component of a state vector varies significantly as a function of where you are in the orbit. Peak to trough radial uncertainty changes occur approximately every quarter period with minimal differences in peak-to-peak maximums or trough-to-trough minimums over the course of several orbits. This leads to great variations in the  $P_c$  if the magnitude of the radial miss of a conjunction is between the trough and peak radial uncertainty AND the overall uncertainty is in the "sweet spot" of the  $P_c$  vs. uncertainty curve where a small change in uncertainty can yield a large change in  $P_c$ . All of these  $P_c$ s are correct but unusable since they vary greatly even when the propagation time is changed by as little as 15 minutes and everything else remains the same. It is important to note that it is entirely possible that the FDO will be completely unaware that he is in this situation unless he performs a very time-consuming manual iteration on covariance propagation time. Therefore, FDO should use the box method for all cases that the radial miss is the largest miss component.

Downtrack uncertainty also varies based on where you are in the orbit, but it grows significantly with propagation time, so the localized variations in uncertainty are not significant when compared with the overall growth of the downtrack uncertainty over time.

#### 3.11.2.6.5 Collision Avoidance Maneuvers

If the final conjunction  $P_c$  (or miss distance if box method) is inside the yellow or red threshold, a maneuver may be necessary. The Yellow criterion states a burn will be

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executed only if there is no impact to primary mission or payload objectives. The Red threshold requires an avoidance burn be performed unless it would result in Shuttle reflight, vehicle hardware damage, additional EVA, or additional risk for the current or future crew or vehicle. Flight Rules A4-106 and C4-51 document these  $P_C$  thresholds.

FDO should discuss any avoidance burn option with FD over the AFD Conference loop or verbally at the FD Console. If a decision is made to perform an avoidance burn, FD may elect to advise the crew via A/G about an hour prior to TIG. At this point, the whole world is aware of the situation, and it is acceptable to discuss conjunction matters on the FD loop.

For the  $P_C$  method, an avoidance burn must, at a minimum, reduce the  $P_C$  to  $10^{-7}$  for that conjunction. This condition is verified by recomputing the  $P_C$  using the change in the Shuttle vector realized by doing the avoidance burn, but not using the change in noise term introduced by a maneuver between current time and TCA. In other words, Ground NAV's noise term selection should be based on all activity except the dedicated avoidance burn. If the avoidance burn is simply a modification of an already existing burn, Ground NAV's noise term selection is unaffected. This is conservative and guarantees the avoidance maneuver increases miss distance sufficiently. If the noise term was increased to reflect the avoidance maneuver, resulting covariance inflation could, in some cases, actually reduce  $P_C$ . A reduced  $P_C$  can even arise from a maneuver in the wrong direction actually reducing miss distance. If using the box method, the avoidance maneuver must drive closest approach outside the yellow avoidance box.

The burn ultimately performed will depend on when it can be executed. Dedicated avoidance burns usually are not planned more than 1 to 2 orbits before TCA to ensure the maneuver is necessary. Typically, an object will move outside the yellow or red threshold based on state vector updates alone. An avoidance burn performed 12 hours prior to a conjunction probably destined to become a non-event is not an efficient use of the crew's time or Orbiter propellant. Exceptions to this caveat can be made based on mission timeline and/or configuration. For example, if an existing burn can be modified with minimal impact to prevent the conjunction, it may be performed even if TIG is several hours prior to TCA. Two types of small avoidance maneuvers ( $\Delta VTOT = 2$  or 3 fps) will almost always work.

Type 1: a posigrade or retrograde burn one-half orbit from the conjunction, causing the object to be missed in the radial direction. This type of maneuver is time-critical.

Type 2: a posigrade or retrograde burn several orbits prior to conjunction. This causes the object to be missed in the downtrack direction due to phasing. Because it's not time-critical, this maneuver can be performed anywhere in the orbit.

Other avoidance burn strategies may be considered. For example, if a conjunction is expected to occur after a planned separation burn, simply change the size of the sep burn. Exactly what needs to be done will be case-dependent. Sometimes the avoidance burn can be used to advantage in other ways, such as adjusting end-of-mission crossrange or lighting (see Section 3.7) or reducing deorbit  $\Delta V$  with a retrograde avoidance burn at the optimum perigee adjust TIG.

After an avoidance burn is planned, FDO sends the predicted burnout vector to USSTRATCOM. The OSA runs a CA on this vector to evaluate future conjunctions. As time allows, FDO will iterate on TIG and/or  $\Delta V$  of the avoidance burn until the resultant orbit is cleared of conjunctions within the yellow threshold for the next 36 hrs. FDO also works with FAO to ensure TIG is acceptable from a timeline standpoint.

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Once an acceptable maneuver solution has been found, notify FD and PROP of the  $\Delta V$  and TIG. At this point, prepare a PAD and PEG-7 command load for the crew. The PAD will be read up to the crew on A/G. FDO monitors and confirms the burn using standard on-orbit burn procedures. If an avoidance burn is to be performed in a mated configuration with ISS or another loads-sensitive payload such as HST, flight-specific reboost procedures will be applicable in place of a PEG-7 PAD and command load.

### **3.11.3 USSTRATCOM Vector and Conjunction Messages**

This section documents format and content associated with messages received from USSTRATCOM. Message types received most frequently are associated with conjunctions and the ASW facility. These are followed by less routine types used during facility outages or as ancillary data.

#### **3.11.3.1 OCM**

OCMs are generated on the ASW machine at USSTRATCOM and contain the object and asset state vector and covariances as well as modeling information such as the ballistic coefficient. All data in the OCM are associated with the USSTRATCOM computed TCA. This is the standard message sent by USSTRATCOM for conjunctions. See Figures 3.11.3.1-1a/b.

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```
<> ORBITAL CONJUNCTION MESSAGE FOR: INTRNTL SPACE STATION
<> REAL
<> MESSAGE CREATION TIME: 1999 334 (30 NOV) 18:49:36.000 CENTER: CMOC
<> MESSAGE VERSION: V2.0
<> *****
<> RELATIVE DATA:
<> TIME OF CLOSEST APPROACH (UTC): 1999 335 (01 DEC) 13:16:10.768
<> MISS DISTANCE (M): 7097
<> RELATIVE SPEED (M/S): 12002
<> CLOSEST APP. REL. POSITION (M):      -4909.2      -3398.6      3837.0
<> CLOSEST APP. REL. VELOCITY (M/S):    223.6      -9118.9     -7801.7
<> *****
<> ASSET: 25544                                INT. DES.: 1998-067A
<> COMMON NAME: ISS (ZARYA)
<> TIME OF LAST ACCEPTED OB (UTC): 1999 334 (30 NOV) 10:19:21.471
<> LUPI/DC SPAN USED (DAYS): 1.99/ 1.99 RESIDUAL ACCPT: 98.0 %
<> NUM OBS AVAIL/USED: 281/ 278 NUM TRACKS AVAIL/USED: 70/ 68
<> APOGEE (KM): 375 PERIGEE (KM): 364 INCLINATION (DEG): 51.6
<> RADAR CROSS SECTION (M2): 178.5751 WEIGHTED RMS: 1.161
<> BALLISTIC COEFFICIENT (M2/KG): 0.006810
<> SOLAR RADIATION PRESSURE COEFFICIENT (M2/KG): 0.000500
<> ENERGY DISSIPATION RATE (W/KG): 1.28860E-02
<> GEOPOTENTIAL: EGM-96 30Z,30T DRAG: JACCHIA 70 LUNAR/SOLAR: ON
<> SOLAR RAD PRESS: OFF SOLID EARTH TIDES: OFF IN-TRACK THRUST: OFF
<> -----
<> ASSET TDR POSITION (M): -5621898.827 3245938.228 -1827107.120
<> ASSET TDR VELOCITY (M/S): -3625.484343 -3089.340250 5655.143070
<> -----
<> *****
<> CONJUNCTING SATELLITE: 25887                                INT. DES.: 1999-043E
<> COMMON NAME: DELTA R/B(1)
<> TIME OF LAST ACCEPTED OB (UTC): 1999 334 (30 NOV) 17:59:07.072
<> LUPI/DC SPAN USED (DAYS): 1.97/ 1.68 RESIDUAL ACCPT: 90.2 %
<> NUM OBS AVAIL/USED: 117/ 100 NUM TRACKS AVAIL/USED: 43/ 37
<> APOGEE (KM): 1330 PERIGEE (KM): 318 INCLINATION (DEG): 52.3
<> RADAR CROSS SECTION (M2): 17.7327 WEIGHTED RMS: 1.288
<> BALLISTIC COEFFICIENT (M2/KG): 0.020550
<> SOLAR RADIATION PRESSURE COEFFICIENT (M2/KG): 0.000000
<> ENERGY DISSIPATION RATE (W/KG): 1.07450E-02
<> GEOPOTENTIAL: EGM-96 30Z,30T DRAG: JACCHIA 70 LUNAR/SOLAR: ON
<> SOLAR RAD PRESS: OFF SOLID EARTH TIDES: OFF IN-TRACK THRUST: OFF
```

**Figure 3.11.3.1-1a: Orbital Conjunction Message (OCM)**

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```

<> -----
<> SAT. TDR POSITION (M):      -5615215.744   3247996.666  -1825893.715
<> SAT. TDR VELOCITY (M/S): -1034.809382  -4675.084864  -5957.235787
<> *****
<> ASSET COVARIANCE: (1,1) TO (6,6)  (M^2, M^2/S, M^2/S^2)
<>      U          V          W          UD          VD          WD
<>
<>                COVARIANCE DATA DELETED
<>
<> SAT. COVARIANCE: (1,1) TO (6,6)  (M^2, M^2/S, M^2/S^2)
<>      U          V          W          UD          VD          WD
<>
<>                COVARIANCE DATA DELETED
<>
<> *****
<> ASSET COVARIANCE (7,1) TO (8,8)  (M^3/KG, M^3/KG-S, M^4/KG^2)
<>
<>      (7,1)      (7,2)      (7,3)      (7,4)      (7,5)      (7,6)
<>      (7,7)      (7,8)
<>
<>      (8,1)      (8,2)      (8,3)      (8,4)      (8,5)      (8,6)
<>      (8,7)      (8,8)
<>
<> SAT. COVARIANCE (7,1) TO (8,8)  (M^3/KG, M^3/KG-S, M^4/KG^2)
<>
<>      (7,1)      (7,2)      (7,3)      (7,4)      (7,5)      (7,6)
<>      (7,7)      (7,8)
<>
<>      (8,1)      (8,2)      (8,3)      (8,4)      (8,5)      (8,6)
<>      (8,7)      (8,8)
<>
<> *****
<> *****
<> NOTES:
<>
<> -- TIME OF CLOSEST APPROACH IS THE VECTOR AND COVARIANCE TIME TAG
<> -- DC SPAN IS THE TIME SPAN FOR THE LISTED NUMBER OF TRACKS
<> -- NUMBER OF TRACKS IS THE NUMBER OF 1 OR MORE OBSERVATION SENSOR
<>    TRACKS ACQUIRED FROM A QUALITY SENSOR DURING THE DC TIME SPAN
<> -- TDR (EFG) STATE VECTORS ARE EARTH-FIXED ROTATING VECTORS
<>    REFERENCED TO THE TRUE EQUATOR OF DATE.
<> -- RELATIVE VECTORS AND COVARIANCE MATRICES ARE IN ASSET-CENTERED
<>    INERTIAL UVW (RADIAL, IN-TRACK, CROSS-TRACK) COORDINATES
<> -- THE (7,X), (X,7) COMPONENTS OF THE COVARIANCE MATRICES ARE FOR
<>    ATMOSPHERIC DRAG EFFECTS
<> -- THE (8,X), (X,8) COMPONENTS OF THE COVARIANCE MATRICES ARE FOR
<>    SOLAR RADIATION PRESSURE EFFECTS

```

**Figure 3.11.3.1-1b: Orbital Conjunction Message (OCM)**

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### 3.11.3.2 VCM

VCMs are generated on the ASW machine at USSTRATCOM and contain the state vector for the requested object at the requested time. The covariance in this message should be ignored because it is in units that are incompatible with TSA. This message can be sent when only a state vector is needed, such as a preflight target vector. Only EFG coordinates of the vector, which are equivalent to TDR, should be used. See Figure 3.11.3.2-1.

```
<> SP VECTOR/COVARIANCE MESSAGE - V2.0
<> REAL
<> MESSAGE TIME (UTC): 1999 236 24 AUG 12:39:03.000 CENTER: CMOC
<> SATELLITE NUMBER: 25544 INT. DES.: 1998-067A
<> COMMON NAME: ISS (ZARYA)
<> EPOCH TIME (UTC): 1999 236 (24 AUG) 02:39:12.012 EPOCH REV: 4323
<> J2K POS (KM): 2689.02594794 -3235.39055444 5290.29769992
<> J2K VEL (KM/S): 6.101137927910 4.653042995330 -0.258697481663
<> ECI POS (KM): 2689.07058105 -3235.45465144 5290.23581240
<> ECI VEL (KM/S): 6.101494525175 4.652548569641 -0.259179252984
<> EFG POS (KM): 1974.51309898 -3714.91122550 5290.23581240
<> EFG VEL (KM/S): 6.649605629447 3.169791466391 -0.259179252984
<> GEOPOTENTIAL: EGM-96 30Z,30T DRAG: JAC70/MSIS90 LUNAR/SOLAR: ON
<> SOLAR RAD PRESS: OFF SOLID EARTH TIDES: OFF IN-TRACK THRUST: OFF
PAGE 2 RUCEAAC0276 UNCLAS
<> BALLISTIC COEF (M2/KG): 0.647300E-02 BDOT (M2/KG-S): 0.000000E+00
<> SOLAR RAD PRESS COEFF (M2/KG): 0.000000E+00 EDR(W/KG):
<> THRUST ACCEL (M/S2): 0.000000E+00 C.M. OFFSET (M): 0.000000E+00
<> SOLAR FLUX: F10: 188 AVERAGE F10: 164 AVERAGE AP: 19.0
<> TAI-UTC (S): 31 UT1-UTC (S): UT1 RATE (MS/DAY):
<> POLAR MOT X,Y (ARCSEC): IAU 1980 NUTAT:
<> TIME CONST LEAP SECOND TIME (UTC): 1997 182 (01 JUL) 00:00:00.000
<> INTEGRATOR MODE: ASW COORD SYS: J2000 PARTIALS: FAST NUM
<> STEP MODE: AUTO FIXED STEP: OFF STEP SIZE SELECTION: MANUAL
<> INITIAL STEP SIZE (S): 20.000 ERROR CONTROL:
<> VECTOR U,V,W SIGMAS (KM):
<> VECTOR UD,VD,WD SIGMAS (KM/S):
<> COVARIANCE MATRIX (EQUINOCTIAL ELS): ( 7X 7) WTD RMS:
```

**Figure 3.11.3.2-1: Vector Covariance Message (VCM)**

**NOTE:** even if a state vector is requested from OSA totally outside a conjunction context, data typically sent from the ASW will nevertheless be an OCM instead of a VCM. This OCM will have TCA at the requested state vector time, null miss distance, and identical object/asset data. After the OCM is imported to a TSA VAT, either the object or asset state vector may be processed.

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### 3.11.3.3 COMBO

A COMBO contains the miss distance and TCA for a conjunction. This message will only be transmitted if an OCM cannot be sent. See Figure 3.11.3.3-1.

SATELLITE RELATIVE MOTION PROGRAM (UNITS: KM, KM/SEC)										
FROM 912582300 0.			TO 912601100 0.			MAX SEP		100.00		
RELATIVE MINIMA										
DATE		SATELLITES		AZ2	EL2	AZSUN	ELSUN	SPACING		
PHI1	LAMBDA1	H1	PHI2	LAMBDA2	H2					
DU	DV	DW	DUDOT	DVDOT	DWDOT					
X1	Y1	Z1	X2	Y2	Z2					
XDOT1	YDOT1	ZDOT1	XDOT2	YDOT2	ZDOT2					
DIHEDRAL		EL. SET NOS.								
91	259	4	6	50.641	21700V10363	41.2	15.5	227.6	-19.5	1.130
56.740468	250.056842	578.7153	56.735614	250.070550	579.0157					
0.3020	0.8193	-0.7173	0.01246	-6.56559	-7.49411					
2268.734	-3079.610	5793.041	2269.861	-3079.597	5792.968					
5.48590	5.18833	0.61265	5.28812	-3.64545	-3.99105					
82.32451	1	554								

**Figure 3.11.3.3-1: COMBO Message**

All COMBO parameters are defined in the remainder of this section. The first 3 parameters are followed immediately by their respective values on the COMBO message.

**FROM:** start GMT of COMBO processing in YYDDDDHHMMSS.SSS format.

**TO:** stop GMT of COMBO processing in YYDDDDHHMMSS.SSS format.

**MAX SEP:** maximum separation in km at CPA, the threshold below which conjunction output is triggered during COMBO processing.

Values for the following COMBO parameters appear in corresponding positions at the end of the message.

**DATE:** GMT of conjunction CPA in YY DDD HH MM SS.SSS format.

**SATELLITES:** primary satellite (Orbiter) catalog number, illumination indicator, and secondary satellite catalog number in PPPPPISSSSS format. The illumination indicator is blank if the secondary satellite is not in sunlight and "V" if it is.

**AZ2:** psuedo-azimuth of the secondary satellite, as viewed from the primary satellite, in deg at CPA. This angle is measured "south" of "downtrack" in the primary's local horizontal plane (see Figure 67 in NORAD document TP SCC 008).

**EL2:** psuedo-elevation of the secondary satellite, as viewed from the primary satellite, in deg at CPA. This angle is measured positive "above" the primary's local horizontal plane (see Figure 67 in NORAD document TP SCC 008).

**AZSUN:** psuedo-azimuth of the sun, as viewed from the primary satellite, in deg at TCA.



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ELSUN: psuedo-elevation of the sun, as viewed from the primary satellite, in deg at TCA.

SPACING: separation of satellites at CPA in km.

PHI1(2): latitude of primary (secondary) satellite at CPA in deg.

LAMBDA1(2): longitude of primary (secondary) satellite at CPA in deg.

H1(2): height of primary (secondary) satellite at CPA in km.

DUVW: vertical/downtrack/crosstrack distance of secondary relative primary in km at CPA.

DUVWDOT: vertical/downtrack/crosstrack velocity of secondary relative primary in km/s at CPA.

XYZ1(2): XYZ-components of primary (secondary) satellite TEME position in km at CPA.

XYZDOT1(2): XYZ-components of primary (secondary) satellite TEME velocity in km/s at CPA.

DIHEDRAL: dihedral angle, or the wedge angle between primary and secondary satellite orbit planes in deg.

EL. SET NOS.: sequence number for the primary and secondary element sets.

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### 3.11.3.4 TRAILX

A TRAILX contains the state vector for a requested object at the requested time. This message is normally sent along with a COMBO if the ASW machine is down, in which case the vector is at TCA. See Figure 3.11.3.4-1.

```
GP EPHEMERIS FOR SATELLITE 10363 ELEM. SET 554 SECTION 1
  TIME (YY MM DD HH MM SS.SSS) REV NO.
X ( KM. ) Y ( KM. ) Z ( KM. ) XDOT(KMSC) YDOT(KMSC) ZDOT(KMSC)
PHI (DEG) LAM (DEG) H ( KM. ) VEL (KMSC) AZ (DEG) GAM (DEG)
COORDINATE SYSTEM GEOCENTRIC ROTATING CARTESIAN EQ OF DATE
  91 9 16 4 6 0. 76065
-1284.869 -3270.849 5986.137 -0.393485 -6.535392 -3.635857
 59.75267 248.55389 579.199 7.48903 164.32593 0.11585
END OF MESSAGE
```

**Figure 3.11.3.4-1: TRAILX Message**

The remainder of this section lists all TRAILX parameters and their definitions.

ELEM. SET: sequence number for the element sets.

SATELLITE: primary satellite (Orbiter) catalog number.

TIME: GMT of state vector.

XYZ: XYZ-components of satellite TEME position in km.

XYZDOT: XYZ-components of satellite TEME velocity in km/s.

PHI: latitude of satellite in deg.

LAMBDA: longitude of satellite in deg.

H: height of satellite in km.

VEL: velocity of the satellite in km/s

AZ: azimuth of the satellite.

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### 3.11.3.5 2 Line Elements

An alternate mechanism USSTRATCOM uses to provide FDO with a state vector is the USSTRATCOM 2 line element set. These elements are USSTRATCOM mean elements in the earth True Equator Mean Equinox (TEME) coordinate system. Figure 3.11.3.5-1 is an example of standard 2 line elements format. The TSA Vector Edit application can handle these elements as input. Output of this application is an M50 state vector stored in the TSA VAT.

Typically, 2 line element sets are used pre-mission by FDO for rendezvous planning, satellite sighting opportunities, etc. Elements were used on STS-32 to monitor LDEF's orbit decay and on STS-35 to investigate Mir communication opportunities for the Shuttle Amateur Radio Experiment (SAREX). They were also used pre-flight on STS-44 to assess opportunities for the Ultraviolet Plume Instrument (UVPI) to view the Orbiter.

```
1 16609U 86 17 A 91352.98490832 .00041243 00000-0 48679-3 0 9460
2 16609 51.6026 79.3814 0002717 222.0560 138.0208 15.60908275333981
```

**Figure 3.11.3.5-1: Example of 2 Line Elements**

Following is a list of parameters contained in the 2 line element set. Figure 3.11.3.5-1 illustrates the format of each line. Items with an asterisk are required inputs to TSA Vector Edit.

**NOTE:** assuming transmission over AutoDin or other telecommunications link, both element set lines will end with a checksum digit supplied as a means to detect transmission errors. If elements are transmitted via FAX, as is often the case for history data requests, the checksum digit is not appended.

There are seven parameters in line 1, starting with the leftmost item and moving to the right.

- 1) USSTRATCOM Object Number: "16609" is the catalog number USSTRATCOM has designated for this object. A "U" indicates an unclassified object.
- 2) International Designator: "86 17 A" for this element set. The "86" indicates launch year was 1986, while "17" tallies the 17th launch of the year, and "A" shows it was the first object resulting from this launch.
- 3) \*Epoch Time: "91352.98490832" is the GMT (UT1 is given, to be precise) associated with these elements. Year is 1991 and the decimal day-of-year is 352.98490832. Conversion software would turn the decimal day into 352/23:38:16.079 GMT in this case.
- 4) N-Dot Over 2: ".00041243" is the daily rate of change in the number of revs the object completes each day, divided by 2. Units are revs/day<sup>2</sup>. This is a "catch all" drag term used in the Simplified General Perturbations (SGP4) USSTRATCOM predictor.
- 5) N-Double-Dot: ".00000-0" is a second-order drag term in the SGP4 predictor used to model terminal orbit decay. It measures the second time derivative in daily mean

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motion, divided by 6. Units are revs/day<sup>3</sup>. The last two characters define an applicable power of 10 (".12345-5" = 0.0000012345).

- 6) BSTAR: ".48679-3" is another drag term in the SGP4 predictor. Units are earth radii<sup>-1</sup>. The last two characters define an applicable power of 10. Do not confuse this parameter with B-Term, the USSTRATCOM special perturbations factor of drag coefficient, multiplied by reference area, divided by weight.
- 7) EISet Number: "946" is a running count of all 2 line element sets generated by USSTRATCOM for this object. Since multiple agencies perform this function, numbers are skipped on occasion to avoid ambiguities. The counter should always increase with time until it exceeds 999, when it reverts to 1.

There are eight parameters in line 2, starting with the leftmost item and moving to the right.

- 8) USSTRATCOM Object Number: "16609" is the catalog number USSTRATCOM has designated for this object. A "U" indicates an unclassified object.
- 9) \*Inclination: "51.6026" is the TEME mean inclination in deg.
- 10) \*Right Ascension of the Ascending Node: "79.3814" is the TEME mean right ascension of the ascending node in deg.
- 11) \*Eccentricity: "0002717" is the mean eccentricity. A leading decimal must be applied to this element's value before input to TSA.
- 12) \*Argument of Perigee: "222.0560" is the TEME mean argument of perigee in deg.
- 13) \*Mean Anomaly: "138.0208" is the mean anomaly in deg.
- 14) \*Mean Motion: "15.60908275" is the mean number of orbits per day the object completes. There are a total of 8 digits after the decimal, leaving no trailing space(s) when the following element exceeds 9999.
- 15) \*Epoch Rev: "33398" is the orbit number at Epoch Time. This epoch is chosen very near the time of true ascending node passage as a matter of routine. After converting 2 line elements to M50, check the resulting TDR position Z-component. If it's negative, decrement the Epoch Rev by one before input to an ephemeris orb counter.

### 3.11.4 Radar Restrictions

Many powerful radar sites in operation around the world have the potential to interfere with Orbiter avionics, Orbiter Docking System (ODS) Pyrotechnic devices or EMU communications. Although most of these are located in foreign countries and not under USSTRATCOM control, there are several very powerful USSTRATCOM radar sites responsive to restrictions posed by the Orbiter's trajectory. For these radars, the Planning Team FDO computes periods during which the Shuttle will be susceptible to interference. Periods for the following flight day (crew wakeup to crew wakeup) are documented in a Radar Restrictions Message to USSTRATCOM.

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Affected radar sites will either reduce power to safe levels or avoid tracking the vehicle during the times specified in this message. Slant range limits for these sites are derived from plots of electric field strength versus frequency. Electric field strength limits are quantified in *NSTS 07700, Volume X, Book 2, Appendix 10.11, Section 4.0*, which defines maximum electric field intensity as a function of radar frequency to minimize Space Shuttle Orbiter avionics, ODS pyros, or EMU communications interference. The Engineering branch responsible for keeping these limits current is EV7, the Systems Analysis and Verification Branch. Prior to each flight, the Lead FDO should verify there have not been any changes to the limits by contacting EV7.

**NOTE:** site-specific data for all facilities subject to radar restrictions appear in this handbook's FOUO Annex (located at DM32\DOCS\FDOCHB\pdfBL\Vo13a.pdf), Section 3a.3. Prior to each flight, the Lead FDO should verify these parameters are current by consulting with the Inter-agency Working Group (IWG) chair. Updates to range limits in the Radar Site Table can be calculated as discussed in Section 3.11.4.1.

If a payload has problems operating in the overall electromagnetic environment including ground-based radars, payload representatives must seek a resolution with MS2/Integration Engineering Office. One solution might be to impose radar restrictions on USSTRATCOM radars similar to those used for the Orbiter. In addition, MS2 will perform any analysis to determine whether or not a radar can safely track the Orbiter without avionics interference.

Radar restrictions must be run each planning shift starting with the prelaunch shift. Shuttle restrictions must be run for a 24 hr period starting with crew wakeup (or launch). A "CANCELLATIONS WILL BE COORDINATED THROUGH THE SPACE CONTROL CENTER" disclaimer is manually appended to facilitate verbal restriction cancellation if required (see Figure 3.11.4-1). The Planning Team FDO or TRAJ determines radar restrictions using the following "O" procedures.

- O1) Retrieve the appropriate state vectors or ephemeris, store in TSA Local, and run the TSA RADAR processor. This program utilizes a database of radar sensors, each with its specific electromagnetic interference (EMI) range threshold. A list of these sensors, together with their EMI thresholds and other data, appears in Section 3a.3. The time period associated with any close approach to or violation of a sensors' EMI threshold range is tabulated in RADAR output. Use the "H" sites when running Shuttle restrictions during standalone operations and the "L" sites when running Shuttle restrictions during mated operations with the ISS.
- O2) Prepare a Radar Restrictions Message by clicking the SPACECOM MESSAGE key on TSA's RADAR Summary display (see Figure 3.11.4-1 for an example). The message must include the period of validity and list all restrictions during that time. A restriction consists of the sensor name for which a violation is predicted, together with times of rise/set on the site horizon to the nearest second. In addition, times for penetrating and departing the slant range EMI violation sphere must be provided. These are rounded conservatively by specifying 10 sec to the SPACECOM MESSAGE's interactive POWERDOWN BIAS field. The TCA is also shown to the nearest second, along with the slant range at CPA to the nearest tenth of a nm. If there are no violations, a "no restrictions" message must be sent so sensors have positive confirmation of unconstrained operation.
- O3) Fax a copy of the Radar Restrictions Message to the COMSEC Equipment Facility (CEF) and place a copy in the USSTRATCOM section of the Clipboard Binder. CEF copies the message into a message template containing all the header routing information and sends it to the SCC and ASCC. The SCC (or

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ASCC) is required to coordinate all restrictions with the affected radar sites. The FDO POC in the SCC for radar issues is the OSA.

In the case of entry radar restrictions, any site with EMI potential must be checked by the Planning Team with the following "E" procedures.

- E1) Run RADAR out of an M1 copy in TSA Local from the period start time to the TIG of the first DO burn opportunity of the day. Any restrictions should be entered in the "STANDARD RESTRICTION (APPLIES REGARDLESS OF DEORBIT CASE)" section of the Entry RADAR restrictions message.
- E2) Run RADAR out of an M1 copy in TSA Local containing no DO burns from the TIG of the first DO burn opportunity of the day to the end of the applicable period. Any restrictions should be entered in the "WAVEOFF RESTRICTION (APPLIES IF ORBITER DOES NOT DEORBIT DURING THE PERIOD COVERED BY THIS MESSAGE)" section of the Entry RADAR restrictions message.
- E3) For each DO opportunity make the corresponding entry ephemeris PRIME and transfer the corresponding DO burn to an E1 copy. Copy ephemeris R and the deorbit burn ephemeris mirror to TSA Local. Then run RADAR with the mirror copy as the source from the DO TIG to EI (check the Entry Elapsed Time display for the EI time). Enter any RADAR restriction in the "opportunity-specific" section of the RADAR restriction message. Finally, run RADAR out of the entry ephemeris copy by entering ephemeris R as the source. Enter any RADAR restriction in the "opportunity-specific" section of the RADAR restriction message. If a phased array sensor violates an EMI range threshold, bias time and az-el data 10 sec early at restriction start and 10 sec late at restriction end. For mechanical tracker sensor violations, restrict operation during the entire period the Orbiter is above the sensor's horizon.
- E4) Manually prepare a RADAR Restrictions Message using a PC baseline form at S:\divisions\dm\private\dm32\docs\messages\radar.doc (see Figure 3.11.4-2). Restrictions associated with all viable deorbit opportunities during the period of validity must be provided by this message. The oncoming Entry Team will cancel restrictions in near real-time as required by wave-offs or a landing.
- E5) Save the message on the "v:" drive in the appropriate "eom" or "eom\_1" directory, using the name "radar.doc". Message copies go to the CEF and the USSTRATCOM section of the clipboard binder. USSTRATCOM is required to verbally confirm receipt of the message.

As part of shift handover, the oncoming FDO should review radar restrictions computed by the Planning Team. If a significant change in trajectory occurs due to an unplanned orbit adjust burn or a major change in mission timeline (for example, a deploy and sep burn have been delayed a day), radar restrictions may need to be recomputed. The same procedures described above should be used to recompute restrictions as required.

If there has been a launch delay, radar restrictions may need to be recomputed. The Orbit 2 FDO must recompute radar restrictions and send USSTRATCOM a new message if different results are obtained. The only launch slip not requiring radar restrictions to be recomputed is if the ascent was nominal (no underspeed or ATO) and the MECO target was Earth-relative. In this case, the Orbit 2 FDO should send USSTRATCOM a new message which slips restrictions equal to the amount of launch slip.

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CLASSIFICATION: UNCLASS

TO: (To be supplied by the CEF)  
INFO: (To be supplied by the CEF)  
FROM: NASA JOHNSON SPACE CENTER HOUSTON TX//FDO//  
SUBJECT: RADAR TRACKING RESTRICTIONS (U)

1. (U) PERIOD COVERED BY THIS MESSAGE:  
GMT START: 2002:334:14:00:00.000  
GMT STOP: 2002:335:14:00:00.000

2. (U) PLEASE OBSERVE THE FOLLOWING RADAR TRACKING RESTRICTIONS FOR THE PERIOD OF THIS MESSAGE.

3. (U) SENSORS NOT IDENTIFIED IN THIS MESSAGE HAVE NO RESTRICTIONS. TRACKING RESTRICTIONS WILL BE UPDATED ONCE PER DAY OR AS REAL-TIME CHANGES OCCUR.

SITE ID:  
RESTRICTION

RESTRICTION	GMT TCA:	RESTRICTION	SLANT RANGE
GMT START:		GMT STOP:	AT TCA (NMI)
CAVP (PARCS CONCRETE, ND EVA)			
335:01:51:55	335:01:53:38	335:01:55:20	217.6
335:03:28:35	335:03:30:04	335:03:31:33	287.9
EGLP (EGLIN, FL EVA)			
334:22:37:24	334:22:40:17	334:22:43:11	215.7
MILM (MILLSTONE HILLS, MA EVA)			
334:22:39:21	334:22:44:46	334:22:50:13	226.4

PHASED ARRAY RADARS SHOULD USE POWER REDUCTION PROCEDURES FOR THE PERIOD(S) LISTED.  
CANCELLATIONS WILL BE COORDINATED THROUGH THE SPACE CONTROL CENTER.

**Figure 3.11.4-1: Radar Restrictions Message**

NOTE: If there are no radar restrictions, Figure 3.11.4-1 Item 2 should read as follows:

2. (U) PLEASE OBSERVE THE FOLLOWING RADAR TRACKING RESTRICTIONS FOR THE PERIOD OF THIS MESSAGE:  
  
THERE ARE NO RESTRICTIONS

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CLASSIFICATION: UNCLASS

TO: (To be supplied by the CEF)  
 INFO: (To be supplied by the CEF)

FROM: NASA JOHNSON SPACE CENTER HOUSTON TX//FDO//

SUBJECT: RADAR TRACKING RESTRICTIONS

1. (U) PERIOD COVERED BY THIS MESSAGE:  
 165/12:00:00 TO 166/12:00:00

2. (U) PLEASE OBSERVE THE FOLLOWING RADAR TRACKING RESTRICTIONS FOR THE PERIOD OF THIS MESSAGE:

SITE ID	RESTRICTION START (GMT)	TCA (GMT)	RESTRICTION STOP (GMT)	SLANT RNG AT TCA(NM)
<u>STANDARD RESTRICTION (APPLIES REGARDLESS OF DEORBIT CASE):</u>				
ALTAIR (KMAC-KWAJALEIN ISLAND)				
	110/13:12:14	110/13:16:02	110/13:19:50	134.6
<u>ENTRY RESTRICTIONS (APPLY FOR KSC DEORBIT ON ORBIT 181):</u>				
PARCS (CAVALIER AFB, ND)				
	110/15:09:25	110/15:10:16	110/15:11:07	35.5
	AZ = 310 DEG	AZ = 193 DEG	AZ = 133 DEG	
EGLIN AFB FLORIDA (EGAC)				
	110/15:09:25	110/15:10:16	110/15:11:07	177.3
	AZ = 310 DEG	AZ = 193 DEG	AZ = 133 DEG	
<u>ENTRY RESTRICTIONS (APPLY FOR EDW DEORBIT ON ORBIT 182):</u>				
COBRA DANE (CDAC-SHEMYA AFS, AK)				
	110/16:27:33	110/16:28:16	110/16:29:00	52.4
	AZ = 254 DEG	AZ = 332 DEG	AZ = 155 DEG	
<u>ENTRY RESTRICTIONS (APPLY FOR KSC DEORBIT ON ORBIT 182):</u>				
COBRA DANE (CDAC-SHEMYA AFS, AK)				
	110/16:27:43	110/16:28:24	110/16:29:06	72.7
	AZ = 255 DEG	AZ = 335 DEG	AZ = 54 DEG	
EGLIN AFB FLORIDA (EGAC)				
	110/16:48:00	110/16:49:52	110/16:52:01	129.7
	AZ = 255 DEG	AZ = 335 DEG	AZ = 54 DEG	
<u>WAVEOFF RESTRICTION (APPLIES IF ORBITER DOES NOT DEORBIT DURING THE PERIOD COVERED BY THIS MESSAGE):</u>				
COBRA DANE (CDAC-SHEMYA AFS, AK)				
	111/00:27:43	111/00:28:24	111/00:29:06	147.67
PHASED ARRAY RADARS SHOULD USE POWER REDUCTION PROCEDURES FOR THE PERIOD(S) LISTED.				

3. (U) SENSORS NOT IDENTIFIED IN THIS MESSAGE HAVE NO RESTRICTIONS. TRACKING RESTRICTIONS WILL BE UPDATED ONCE PER DAY OR AS REAL-TIME CHANGES OCCUR.

**Figure 3.11.4-2: Entry Radar Restrictions Message**



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### 3.11.4.1 Updating Ranges in the Radar Site Table

The Space Shuttle Program has chosen to limit intentional exposure of the Space Shuttle and Extra-Vehicular Activity (EVA) equipment to External Radio Frequencies (RF)<sup>2</sup>. This attempts to protect the Shuttle and EVA equipment against potentially harmful levels of RF energy. The limits are defined in terms of electric field intensity and are given in dbmicroV/m versus Frequency (MHz) for graphing purposes. The value of electric field intensity in decibel-microVolts per meter (db- $\mu$ V/m) units ( $E_{db}$ ) can be calculated from the standard units, V/m (E), using Equation 1.

$$E_{db} = 20 \log_{10} \left( \frac{E}{10^{-6}} \right) \quad (1)$$

Alternatively, E can be calculated from  $E_{db}$  using Equation 2.

$$E = 10^{\frac{E_{db}}{20} - 6} \quad (2)$$

Electric field intensity limits are defined in NSTS 07700, Figures 10.11-2 (Maximum On-Orbit External RF Environment Level) and 10.11-3 (Maximum On-Orbit External RF Environment Level For EVA Equipment). These limits are enforced ensuring the Orbiter will pass not pass within a specified slant range from each RADAR site controlled by USSTRATCOM. This slant range will be referred to as  $R_{min}$ .

This section documents the process for calculating  $R_{min}$ . The first step in the calculation is determining which Electric Field Intensity value corresponds to each RADAR site. Consult Figures 10.11-2 and 10.11-3 in Volume X, Book 2 of NSTS 07700. The figure is a function of frequency, so determine the primary operating frequency of the RADAR and read the curve to determine the required Electric Field Intensity limit. If the RADAR operates over a range of frequencies, choose the most restrictive limit (smallest value). Using Equations 1 and 2, ensure the limit is obtained in units of V/m for each RADAR site. Since there are two RADAR processor groups per site (H and L), a limit for use during standalone operations should be calculated for the H group, and a limit for use during mated operations should be calculated for the L group. Use the most restrictive limit for each group.

The corresponding range limit,  $R_{min}$  is derived from the RADAR equation. The RADAR equation defines peak power density ( $P_D$ ) in Watts/m<sup>2</sup> at any point in free space in the direction that the antenna is pointing as follows<sup>3</sup>.

$$P_D = \frac{P_t G}{4 \pi R^2}, \text{ where: } (3)$$

$P_t$  is Peak Transmitted Power in Watts

G is the unitless Antenna Gain

R is the range at which to calculate  $P_D$  ( $R_{min}$  in this case)

<sup>2</sup> NSTS 07700, Volume X - Book 2, *Space Shuttle, Flight and Ground System Specification, Environment Design, Weight and Performance, and Avionics Events*, (Revision M, June 9, 1999), pg. 10.11-12A.

<sup>3</sup> Bassem R. Mahafza, Ph.D., *Radar Systems Analysis and Design Using MATLAB*, New York: Chapman & Hall/CRC, (2000), pg. 22.

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Equation 3 can be slightly modified to include Antenna Loss by incorporating a unitless Loss parameter (L) as shown in Equation 4.

$$P_D = \frac{P_t G}{4 \pi R^2 L} \quad (4)$$

Since limits are given in Electric Field Intensity, convert  $P_D$  in Watts/m<sup>2</sup> to Volts/m. Power (in Watts) is defined in Equation 5.

$$P = \frac{V^2}{Z}, \text{ where:} \quad (5)$$

V is electric potential in Volts  
Z is impedance in Ohms,  $\Omega$

To obtain  $P_D$  in Watts/m<sup>2</sup>, divide both sides of Equation 5 by unit area and obtain Equation 6.

$$P_D = \frac{E^2}{Z} \quad (6)$$

Therefore, the Electric Field Intensity in V<sup>2</sup>/m<sup>2</sup> is defined with Equation 7.

$$E^2 = Z P_D \quad (7)$$

Finally, since RADAR energy is propagating through free space, the impedance (Z) being sought is the characteristic impedance of free space given as  $Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 376.73 \Omega$ ,

where  $\mu_0$  is the permeability of free space and  $\epsilon_0$  is the permittivity of free space.

Substituting Equation 4 into Equation 7 produces Equation 8.

$$E^2 = Z_0 \left[ \frac{P_t G}{4 \pi R^2 L} \right] \quad (8)$$

Solving for R in Equation 8 yields Equation 9.

$$R_{\min} = \frac{R}{1852} = \sqrt{Z_0 \left[ \frac{P_t G}{4 \pi E^2 L} \right]} \quad (9)$$

In Equation 9, E is the electric field intensity limit obtained from the NSTS 07700 table. The units for R will be meters. Because the TSA RADAR Site Table requires nm units, R is divided by 1852 m/nm to obtain  $R_{\min}$ .

In Equation 9, there are 4 unknowns ( $P_t$ , G, L and E). There is also one constant previously given as  $Z_0 = 376.73 \Omega$ . The value of E is provided by NSTS 07700 and may be different for each RADAR site depending on its primary operating frequency. Finally, there are 3 unknowns remaining and these are peculiar to each RADAR site and must be provided by the appropriate site or USSTRATCOM. The required values are

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- 1)  $P_t$  is peak transmitted power. This is often given in Megawatts but must be supplied in Watts to Equation 9. To obtain Watts from Megawatts, multiply Megawatts by  $10^6$ .
- 2)  $G$  is the antenna gain (unitless).
- 3)  $L$  is the antenna loss (unitless).

Often, values of gain and loss are provided in db units.

$$G \text{ (in db)} = 10 \log_{10} G \quad (10)$$

$$L \text{ (in db)} = 10 \log_{10} L \quad (11)$$

If this is the case, Equation 9 can be rewritten as follows with  $R_{min}$  again in nm units.

$$R_{min} = \frac{10^{\frac{1}{20} \left( 10 \log_{10} P_t + G - L - 10 \log_{10}(4\pi) - 10 \log_{10} \left( \frac{E^2}{Z_0} \right) \right)}}{1852} \quad (12)$$

Previous values of the 4 unknowns for each RADAR site are listed in this handbook's FOUO Annex (located at DM32\DOCS\FDOCHB\pdfBL\Vo13a.pdf), Section 3a.3. These need to be verified before each flight to determine if they are current. If there are changes,  $R_{min}$  will have to be recalculated.

FDOs can use Equations 10 or 12 as required to calculate the required value for  $R_{min}$ . These equations have been entered into a spreadsheet located in the path S:\Divisions\DM\Private\DM32\Apps\Discipline CM\xlRADAR. The values of  $R_{min}$  for each site will then be entered into the RADAR Site Table (RST).

### 3.11.5 Threat and Warning Messages

As part of its mission to protect US space assets, the SCC provides advisory, warning, and verification notifications of potential hostile events that may affect the SSP. Threat categories include orbit insertion anti-satellite (ASAT) weapons, direct ascent ASAT weapons, radio frequency interference (RFI) / energy weapons, directed energy weapons, nuclear weapons, and sabotage. The FD is responsible for all threat and warning responses, and all such message traffic coming into the CEF should be addressed accordingly. However, the CEF occasionally routes this traffic to FDO. If this happens, FDO should immediately carry the message to the FD. Receivable messages are listed in Figure 3.11.5-1.

USSTRATCOM may request a current state vector from FDO at any time without giving rationale for the request. Such requests may or may not be related to threat and warning issues. FDO should comply immediately to any USSTRATCOM state vector request.

As a requirement for certification, every FDO must attend a briefing and read documents describing JSC response to threat and warning events. The FDO/USSTRATCOM point of contact arranges briefings. Since messages and FDO procedures are classified SECRET, very little can be explained here. If it becomes necessary to discuss classified information, the STU-III on the FDO console can be used for receive-only, classified

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communications. Two-way classified discussions should be performed in a secure location like the CEF.

**WARNING:** associating a threat/warning cause to an effect and/or resulting action is classified SECRET.

SCC <-----TTY (CEF)----->FLT

Message From SCC to FD			Response from FD to SCC			
Message Code	Description	Comments	Message Code	Description	Content	Action
SU02	Verified Space Systems Attack	An attack has occurred and has been verified	SA04	Verified Space Systems Attack	Acknowledgement of an SU02 message or initiated by FD after attack	See Classified Flight Rules ASAP Send SA04 message to SCC
SU03	Space Advisory	Initiates a "Space Event". Based on pre-event indicators, abnormal events, information/warning	No message reply required	N/A	N/A	N/A
SU04	Probable Space Systems Attack	An attack may have occurred but has not yet been verified	No message reply required by SA05 Status message advisable	Space Status	Real-time overall assessment of Shuttle, ISS, and MCC status (Green, Yellow, or Red with explanation)	See Classified Flight Rules ASAP  Send SA05 message to SCC
SU05	Space Cancellation	Cancels a space event and states why	SA06	Space Cancellation	Acknowledges receipt of Space Cancellation notice	Send SA06 message to SCC
SU06	Space Information	Free form data exchange	SA07	Space Information	Provides SCC with requested information or used to request information from SCC	Send SA07 message to SCC as required
SU39	Status Request	Request for an SA05 Status Message	SA05	Space Status	Real-time overall assessment of Shuttle, ISS, and MCC status. (Green, Yellow, or Red with explanation)	Send SA05 message to SCC

**Figure 3.11.5-1: Warning Messages**

### 3.11.6 Satellite Breakups

Occasionally, USSTRATCOM sensors track multiple objects where only one was expected, indicating a possible satellite breakup. When this occurs, USSTRATCOM will send a potential breakup message to FDO/TOPO indicating approximately when the breakup occurred, the catalog number of the fragmented satellite, and an OCM (see figure 3.11.3-1).

It can be days or weeks before orbits of major breakup fragments have been accurately determined. This task is complicated because a breakup may involve thousands of pieces, or just a few. Consequently, it is unlikely a confirmed breakup message will be sent to FDO/TOPO within 24 hours of the event.

If there has been a confirmed breakup, USSTRATCOM will notify FDO via a call on the NORAD COORD loop and via a standard message routed through the CEF. As soon as

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possible, a TRAILX or OCM for the parent object will be sent to FDO. At the same time, OSA and SBM both run a CA against the parent satellite. Additional information, such as the number of objects associated with the breakup, location of the breakup, and orbital elements for high and low objects will be provided as soon as they become available. Concern should be elevated if a conjunction is predicted with the parent object's trajectory at the breakup argument of latitude or  $180^\circ$  from it. Objects in the debris cloud will all tend to pass through these "pinch points" repeatedly, even if an explosion was associated with the breakup. CA runs will include any cataloged objects or analyst satellites associated with the breakup.

### 3.11.6.1 Satellite Breakup Procedures

Historically, actual satellite breakup events occur about six to seven times a year. Breakups are nearly impossible to predict and difficult to assess. Consequently, procedures to deal with them are flexible and under continual review and modification. If FDO is faced with working a breakup, a few general procedures should be followed.

- 1) Upon receipt of a potential breakup message, inform the FD. Remember to do this in person or over the AFD loop and not over the FD loop.
- 2) After receiving a confirmed breakup message, together with a CA predicting conjunction with the parent satellite to within 100 km, notify the FD. Consideration should then be given to performing an avoidance burn if the conjunction occurs less than 24 hours after breakup.

CAUTION: the foregoing rule-of-thumb assumes a non-violent breakup  $\Delta v$  of 1 fps. A breakup known to have resulted from an explosive event will disperse debris much more rapidly.

NOTE: because of uncertainties surrounding a breakup, there is no way to completely assess the probability of being hit by individual debris or to determine how long the debris cloud will take to disperse. Assume flying anywhere near a recent breakup is extremely risky, since there may be thousands of debris particles in a cloud surrounding the original object's trajectory. Until 1999, a burn decision in the breakup scenario had been based entirely on best engineering judgment. In 1999, the Orbital Debris program Office (SN3) introduced the Satellite Breakup Risk Assessment Model (SBRAM), which helps evaluate increased risk due to a breakup. More information on SBRAM can be found in Section 3.11.6.2.

NOTE: there is nothing magic about the 24 hours and 100 km criteria, but common sense dictates older breakups pose a smaller risk. If the Orbiter has a conjunction of 95 km, it may not be worth taking evasive action if mission success would be compromised. However, if the spacing is 10 km, FDO should probably be arguing for an avoidance burn.

NOTE: there is also no way to know exactly what burn will achieve a "safe" distance from the debris. If possible, obtain a spacing of at least 100 km at the time of conjunction. Remember: the sooner the burn is executed, the greater the miss distance for a given  $\Delta V$ . No flight rules have been written to govern response to satellite breakups.

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In the past, USSTRATCOM has failed to notify FDO of a confirmed breakup during pre-launch and launch countdown timeframes. Because it is a risk to fly anywhere near recent breakups, a pre-launch FDO/USSTRATCOM tagup has been established at L -12 hrs. At this time, the Planning Team FDO will initiate a breakup conference with the OSA/SBM on the NORAD COORD loop. This conference comes at a convenient point for FDO to also provide USSTRATCOM with launch countdown status and inquire about foreign launches or "space events" which could interfere with Shuttle launch. During the conference, FDO will ask OSA/SBM if there have been any recent breakups or satellite separations. If OSA/SBM reports a recent breakup has occurred, FDO should gather as much information about the breakup as possible to determine launch impacts.

### 3.11.6.2 Satellite Breakup Risk Assessment Model (SBRAM)

SBRAM is a PC-based tool providing the following support.

- 1) Quantified short-term hazard posed to manned missions from recent breakups
- 2) Characteristics of the threat: magnitude, velocity, direction, etc.
- 3) Efficacy of mitigation measures, such as EVA timing

SBRAM requires the time, type, and location of a breakup event, as well as a vector for the "target" object (Shuttle, ISS, etc.). This information is received from USSTRATCOM. The resulting debris particle orbits are propagated with drag and other perturbations. The program then determines close approaches to the target object. For each close approach, a probability of collision ( $P_c$ ) is computed. To accomplish this, the debris and target objects are represented as 3-dimensional spatial distributions. Overlap between these areas is then examined for each conjunction's geometry. Next, multiple Monte Carlo runs are made to compute the total hazard.

SBRAM presents several plots for evaluation:

- 1) Total  $P_c$  per day per  $m^2$  vs. days after breakup
- 2)  $P_c$  per  $m^2$  vs. yaw angle
- 3) Average number of cases vs. probability of individual encounter per  $m^2$
- 4) Yaw angle vs. days after breakup

Evaluation of breakup events is currently a shared responsibility. When notification of a breakup event is received, FDO should, in addition to the steps outlined in Section 3.11.6.1, notify the designated KX representative ASAP.

Upon notification, the KX rep will take the data FDO has collected on the event, run SBRAM, and report results back to FDO.

### 3.11.7 Clearing Spacecraft Translations

Under agreements with NASA or USSTRATCOM, many spacecraft operations organizations are required to obtain advance clearance before performing a translation

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maneuver. When clearance is sought during a Shuttle mission, FDO is usually tasked with confirming safe motion of the translating spacecraft relative to the Orbiter.

In some cases, it may be possible for FDO to model the translation of concern as a finite ephemeris burn with PFNI. This approach is rarely taken because it requires knowledge of the spacecraft's guidance mode, its engine characteristics (thrust and flow rate), and its burn targets in addition to a pre-TIG state vector. A much simpler approach, which virtually guarantees FDO will accurately assess relative motion, has the spacecraft operator supply predicted state vectors immediately before and after the contemplated translation.

The two-state approach may impose its own difficulties on FDO. Two relative motion runs, one for each vector, could be used to assess clearance. However, if the translation is substantial in duration (a low-acceleration deorbit burn, for example), neither run provides much accuracy near the burn's centroid. The following procedure utilizes OMP to target an SOI/SOR burn pair approximating the translation. When transferred as near-impulsive events, the SOI/SOR burns permit the post-burnout state to be implicitly incorporated into a spacecraft ephemeris anchored off the pre-TIG state. One relative motion run may then be made between spacecraft and Orbiter ephemerides.

- 1) Input the pre-TIG and post-burnout spacecraft state vectors to VAT slots Va and Vb, respectively.
- 2) Anchor the spacecraft ephemeris off Va with an appropriate drag profile and static start time.
- 3) Define a simple SOI/SOR MCT in OMP with SOI at the translation's TIG and SOR at its burnout. Set all SOR CXYZ position offsets to zero.

NOTE: an SOI/SOR pair is preferable to a TPI/TPF pair in this application. Recall SOR is targeted to maintain the specified position offset 0.75 orbits later, while TPF merely stops relative motion at the TPF epoch.

- 4) Execute the SOI/SOR MCT in OMP, fetching Va as the chaser state and Vb as the target state. In OMP, both states should adopt the spacecraft ephemeris drag profile.
- 5) Transfer the OMP SOI/SOR plan to the spacecraft ephemeris using engine characteristics imposing minimum burn durations (typically several seconds) which can still be modeled by PFNI. Depending on spacecraft weight, a 2-OMS thruster may be ideal in this application, or a Miscellaneous thruster can be configured appropriately.

The spacecraft ephemeris is then ready for relative motion assessment with an Orbiter ephemeris.

### 3.11.8 Space Object Identification (SOI)

After STS-107 and the loss of OV-102 *Columbia*, NASA worked with the DOD to make SOI data collections a standard requirement for Shuttle and ISS. SOI requirements are specified in Appendix A of the *Memorandum of Agreement (MOA) Between the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA) For Support to NASA Spaceflight Operations*. The USSTRATCOM/Office of

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*Space Operations Interagency Operating Instruction for Human Space Flight Support (OI)* contains operational details covering SOI operations between USSTRATCOM and JSC.

The Lead FDO and the FDO USSTRATCOM POC will coordinate Shuttle mission SOI requirements with USSTRATCOM during the USSTRATCOM pre-mission tagup at approximately Launch -7 days. The *Lead FDO Handbook* presents more details concerning analysis and products required to support the pre-mission tagup.

Unplanned SOI requests should be made only after concurrence from FLIGHT. Emergency or unplanned requests should be made through the SBM (formerly SCA) with OSA cognizance. The SBMs are familiar with the process for requesting special support from the SSN and are the appropriate points of contact for emergency SOI support.

### 3.11.8.1 Procedures

The following subsections detail FDO activities relating to SOI activity.

#### 3.11.8.1.1 Pre-Mission Data Promotion

Pre-mission trajectory data must be provided to various users for mission support planning. These data are provided to users via FDOWeb at URL <https://mod2.jsc.nasa.gov/dm/FDO/FLIGHTS/index.htm>. The *Lead FDO Handbook* specifies the timeline and procedures for promoting data to FDOWeb for pre-mission planning. The DM32 USSTRATCOM POC coordinates external user access to FDOWeb. Note that, in accord with DA9 policies and procedures for administering user accounts, it is possible that external user accounts may become delinquent between missions. A pre-mission DM32 USSTRATCOM POC responsibility is to ensure USSTRATCOM and other external users have access to FDOWeb before each flight.

#### 3.11.8.1.2 In-Flight Data Promotion Requirements

Orbiter trajectory data will need to be promoted to the FDO Trajectory Web (FTW) server multiple times throughout a mission. Pre-mission, the Lead FDO will have received data posting requirements from the DM32 USSTRATCOM POC, the mission's Lead Flight Director, or MOD. The Lead FDO will have folded these requirements into the USSTRATCOM vector transfer schedule. Two types of FTW updates will be required

- 1) Updates required by NASA SUPPORT users
- 2) Updates required for pre-planned SOI activities (OSA users)

An additional type of update may be required, and it will be directed by FLIGHT or MOD. Detailed data promotion steps targeting the FTW server and utilizing Trajectory Web Applications (TWA) software, together with associated notification requirements, are presented in the following subsections.



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### 3.11.8.1.2.1 NASA SUPPORT Updates

#### L-1 Day

Based on a current Ground NAV or USSTRATCOM target vector, Lead FDO updates the G1 rendezvous plan ephemeris and promotes it.

#### Post-OMS-2 Through Docking

As required by the vector transfer schedule, FDO Support promotes M1 to FTW beginning as early as OMS-2 confirmation. The promoted ephemeris may only be a few hours long if the schedule requires promotion before a rendezvous plan can be transferred to E1/M1.

As soon as the M1 rendezvous plan reflects a post-OMS-2 tracking update, FDO Support copies the `Events.txt` file in G1 to the M1 directory. FDO Support then promotes M1. These actions will be coordinated with the Orbit 2 FDO. Note that M1 should end after planned docking prior to this promotion.

As required by the vector transfer schedule (NASA SUPPORT users), FDO updates and promotes M1. In each case, M1 should end after planned docking.

#### Docked Operations Through Deorbit

For these mission phases, DM32 USSTRATCOM POC or the Lead FD will inform FDO when trajectory data need to be promoted. FDO will need to update the vector transfer schedule accordingly. Prior to each promotion, update M1 to at least 96 hrs length with the latest tracking and burn plan, including mated reboots.

Entry ephemerides provided by the Entry FDO are promoted beginning two days prior to predicted entry day. Thus, NEOM entry ephemerides would be promoted beginning on NEOM -2 days, followed by updates as directed by the Entry FDO. On NEOM -1 day these NEOM updates would be in addition to initial promotions of NEOM +1 day entry ephemerides.

**CAUTION:** NASA SUPPORT requirements are independent of SOI requirements (documented in Section 3.11.8.1.2.2) and must be accomplished rigorously in accord with the vector transfer schedule. The FDO requirement is to transfer the best ephemeris possible at each update time. A NASA SUPPORT update may also serve as a SOI update if the two promotions happen to occur at the same time.

### 3.11.8.1.2.2 SOI Updates

#### SOI Activities -1.5 Hrs

- 1) Approximately 1.5 hrs before each scheduled SOI AOS, update M1 based on NAV's best source and promote M1. File AcqMon hard copy SOI AOS times in the Clipboard Binder's USSTRATCOM section for future reference.
- 2) No later than 1 hr before a scheduled SOI AOS, call OSA, ALT SPACE, and NASA SUPPORT to communicate FTW status (presumably, data are good for

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SOI operations). Also communicate rendezvous plan status if applicable. The intent is to provide all information necessary for successful SOI data collection.

NOTE: if a burn will be executed between the SOI -1.5 hr point and SOI AOS, communicate to OSA, ALT SPACE, and NASA SUPPORT that a post-burn evaluation will be made and an FTW update will be provided as required.

NOTE: refer to Section 3.11.8.1.3 for required update notification steps. The SCC will use promoted data to update the network prior to SOI data collection. SCC is required to call FDO if SCC accesses promoted data at times other than when FDO has called with an update notification. This requirement ensures SCC is using the proper data. Steps in Section 3.11.8.1.3 spell out required notification specifics.

### **3.11.8.1.2.3 Updates Directed By FLIGHT Or MOD**

FLIGHT or MOD may request FDO update FTW at specific times independent of the vector transfer schedule. In such cases, perform the following steps.

- 1) Update and promote M1 based on NAV's best source.
- 2) Notify NASA SUPPORT, OSA, and ALT SPACE per Section 3.11.8.1.3.

### **3.11.8.1.3 TWA Data Promotion, QA, and Notification**

The following procedures are required to transfer ephemeris data to the FDO Trajectory Web (FTW) server. A checklist used to document summarize and document this process appears in Appendix 3.N. Software collectively referred to as Trajectory Web Applications (TWA), supports FTW data posting. TWA is composed of 2 DEC ALPHA applications and 4 PC applications as follows.

#### **DEC ALPHA Applications**

Ephemeris to Web Transfer (EPHWEBXR) is used to select and transfer ephemeris, `Events.txt`, and ATL files from the DEC ALPHA to the OpsFTP server (`jsc-mas-pf1`).

Mission Plan Table Generation (MPTGEN) is used to create/edit events for the selected ephemeris. This application provides meaningful maneuver and event labels for external customers viewing ephemeris data on FTW. Two event types are displayed in the MPTGEN events table.

- 1) Maneuvers contained in the selected ephemeris MPT
  - 2) User Events manually entered in MPTGEN (such as docking and reboost)
- Clicking "Process" in MPTGEN updates the `Events.txt` file in the selected ephemeris directory.

#### **PC Applications (located on the FTW server)**

Site Manager Automation Component is used to transfer ephemeris, `Events.txt`, and ATL files from the OpsFTP server to the FTW server (`jsc-mas-is1`). This

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application also executes SSPPX3. There is no user interface to SSPPX3. It is executed automatically when files are transferred to the OpsFTP server.

SSPPX3 is used to create the `TrajectorySummary.txt` file viewed on FTW. In addition, it creates a J2K ASCII ephemeris file for each ephemeris transferred. Nominally, the Site Manager Automation Component executes this process automatically. A backup SSPPX3 execution method is presented in Section 3.11.8.2.2.

External customers use Java Checkout Monitor to retrieve vectors at desired epochs and Java Next Station Contact to access acquisition data for specified ground sites. FDO will generally use these applications only to QA data transfer.

User's guides for EPHWEBXR, Java Checkout Monitor, and Java Next Station Contact user's guides can be found on the DM32 Discipline Software web site at the following path.

```
S:\Divisions\DM\Private\DM32\Apps\Discipline CM\Web  
Pages\disc_cm.htm
```

The MPTGEN User's Guide is located in the TOCSS configuration management document area at the following path.

```
S:\Divisions\DM\Private\TOCSS\DOC_CM\MPTGEN
```

Overall system architecture is detailed in the TWA ICD found at the DM32 Discipline Software web site.

### 3.11.8.1.3.1 Orbit Ephemeris TWA Data Promotion

- 1) Select "XFER Ephemeris to Web" from the FDO DNAV. The EPHWEBXR GUI will appear. Note the GUI defaults to "Orbit Ephemeris" mode (button at the top).
- 2) Select the desired Source ephemeris (System and Location).

System: **M, G, or L**

M = Mirror

G = Global

L = Local

Location: Eph**X** or Eph**MX**

For a Local and Global Source, selections include Eph1 through Eph8.

For a TrS Mirror Source, selections include EphM1 through EphM10.

**NOTE:** the Comment text field will be populated based on the `eph_names.cfg` file if a standard comment exists for that ephemeris. Otherwise, the comment will be retrieved from the ephemeris-specific `EPH.DATA` file. If desired, the user can modify or replace any comment.

- 3) Click the "MPTGEN" button. The MPTGEN GUI will appear. The events table will be populated with two types of events.
  - 1) Maneuvers contained in the selected ephemeris MPT
  - 2) User Events manually entered in MPTGEN (such as docking and reboost)

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MPTGEN will interface with the Source ephemeris `Events.txt` file if it exists. This file is used to associate names with maneuvers in the ephemeris and to manage user input events. The Lead FDO will configure a baseline `Events.txt` file pre-flight. However, changes will need to be made as the flight progresses (see Step 5 in this procedure). If required, the `Events.txt` file configured pre-mission can be copied from the `Global/Ephem/Eph1/` directory to the Source ephemeris directory.

- 4) Verify MPTGEN displays maneuvers from the Source ephemeris and any user input events (docking, reboost, etc).
- 5) Add/Edit/Delete events as appropriate using MPTGEN's editing capabilities. Examples include updated docking and reboost times. Refer to Section 3.2 of the MPTGEN User's Guide for more details.

**CAUTION:** change MPTGEN's default L/O Time or Comment fields only after all other changes in the MPTGEN events table are completed. Otherwise, L/O Time or Comments changes will revert to the defaults.

- 6) Once MPTGEN's Event Table is updated, click the Process button. This will write the data displayed in the Events table to the `Events.txt` file in the Source ephemeris directory. Close MPTGEN from the File menu. EPHWEBXR will come back to the foreground.
- 7) In EPHWEBXR, toggle the Transfer ATL checkbox to "Yes" if a new ATL file is available. The default setting is "No".
- 8) Select the desired FTW server Destination (Slot and Activity).

Slot:     X  
          The Slot destination has ten available slots (1-10, with 1 as default).

Activity: **Ops1**, **Sim**, or **Dev**.

Ops1= <https://ops1.jsc.nasa.gov/apps/fdoweb>  
Sim=   <https://sim1.jsc.nasa.gov/apps/fdoweb>  
Dev=   <https://dev3.jsc.nasa.gov/apps/fdoweb>

The Destination Activity indicates the FTW path where ephemeris data will be transferred, and its default is based on the environment variable `SIM_TYPE`. If `SIM_TYPE = MISSION`, the activity equals Ops1. Otherwise, activity equals Sim. When a destination activity is selected that is not the default, a "Yes" or "No" confirmation is required before proceeding.

If the current domain is listed in the `restricted_domains.cfg` file, Dev will be the only option. This safeguard was placed in the system to prevent promotions to the Ops1 or Sim paths from the CDE. However, if EPHWEBXR is used in the CDE and the safeguard does not work (i.e. Ops1 or Sim are options), take care not to promote to Ops1 or Sim.

- 9) Input your JSC-MAS username and password and click Transfer. Expect a few messages along the way, but eventually a Transfer Complete message will appear listing the files transferred. The transfer should be completed in less than a minute. Should red error messages appear in place of the green Transfer Complete, refer to the EPHWEBXR User's Guide, Section 5, for error message descriptions. If necessary, refer to the troubleshooting and backup procedures in Section 3.11.8.2.

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### 3.11.8.1.3.2 TWA Data Promotion For Entry Ephemerides

- 1) Select "XFER Ephemeris to Web" from the FDO DNAV. The EPHWEBXR GUI will appear. Note the GUI defaults to "Orbit Ephemeris" mode (button at the top).
- 2) Toggle the Ephemeris mode button to Entry Ephemeris.
- 3) Select the desired Source Location ephemeris. Location selections include the EphR entry ephemeris and all entry ephemerides with a 12-character filename. After selection, the Source Comment field will display the name of the selected ephemeris directory, except for EphR. For EphR, the ephemeris comment is obtained from the corresponding EPH.DATA file.
- 4) Select the desired FTW server Destination (Slot and Activity).

Slot: X

The Slot destination has ten available slots (1-10, with 1 as default).

The NEOM ephemerides are delivered by Entry FDO at NEOM -2 days and promoted to the first available slot based on landing site preference and the order of the opportunity. The NEOM +1 opportunities are delivered on NEOM -1 day and promoted to remaining slots, again in order of landing site preference and opportunity, until available slots are filled.

If subsequent deliveries are necessary due to deorbit wave-off, the next day's opportunities are re-promoted over the opportunities that were waved-off and the subsequent day's opportunities are delivered to the remaining slots. Any extraneous slots are deleted using maintenance procedures from Section 3.11.8.1.3.3.

Activity: **Ops1**, **Sim**, or **Dev**.

Ops1= <https://ops1.jsc.nasa.gov/apps/fdoweb>

Sim= <https://sim1.jsc.nasa.gov/apps/fdoweb>

Dev= <https://dev3.jsc.nasa.gov/apps/fdoweb>

Destination Activity indicates the FTW path to which ephemeris data will be transferred, and its default is based on the environment variable `SIM_TYPE`. If `SIM_TYPE = MISSION`, Activity is Ops1. Otherwise, Activity is Sim. When a destination activity is selected that is not the default, a confirmation is required before proceeding.

If the current domain is listed in the `restricted_domains.cfg` file, Dev will be the only option. This safeguard was placed in the system to prevent promotions to the Ops1 or Sim paths from the CDE.

**CAUTION:** if EPHWEBXR is used in the CDE and the safeguard does not work (i.e. Ops1 or Sim are options), take care not to promote to Ops1 or Sim.

- 5) Input your JSC-MAS username/password and click Transfer. Expect a few messages along the way, but eventually a Transfer Complete message will appear listing the files transferred. The transfer should be completed in less than a minute. Should red error messages appear in place of the green Transfer Complete, refer to

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the EPHWEBXR User's Guide, Section 5, for error message descriptions. If necessary, refer to the troubleshooting and backup procedures in Section 3.11.8.2.

### 3.11.8.1.3.3 QA and Data Archive Maintenance

About a minute after receiving the Transfer Complete message from EPHWEBXR, perform the following steps.

- 1) Go to the appropriate FTW URL in Internet Explorer.  
Ops: <https://ops1.jsc.nasa.gov/apps/fdoweb>  
Sim: <https://sim1.jsc.nasa.gov/apps/fdoweb>  
Dev: <https://dev3.jsc.nasa.gov/apps/fdoweb>
- 2) Click on the appropriate Traj Summary tab (O for Orbit or E for Entry) and select the appropriate Slot from the Vehicle pulldown menu.
  - a) Verify File Last Updated time is correct.
  - b) Verify Ephemeris Comment and TUP number (third line on Trajectory Summary page) versus ephemeris source and TUP number.
  - c) Verify Trajectory Event Summary labels, METs,  $\Delta v$ , etc. for user input events.
  - d) Verify state vectors exist for initial/final trajectory points and for each event.
- 3) Click on the appropriate Checkout tab (O for Orbit or E for Entry). Answer any username/password prompts with JSC-MAS account (`jsc-mas\<username>`) responses. Select the appropriate Slot (Slot 1 will be selected by default). Verify the newly promoted data are displayed. Verify ephemeris comment at the top of the Checkout Monitor matches that of the source ephemeris.

CAUTION: in general, Checkout data will not update when toggling between two spacecraft selections if the start time of the selected ephemeris is the same as that of the previously selected state vector. However, the ephemeris comment will update. To force a complete update, select a different time or toggle between two spacecraft selections with different times. If the start time is identical between promoted ephemerides, inform the FTW customer of this issue with the delivery notification.

- 4) Click on the appropriate Ephemeris tab (O for Orbit or E for Entry) and verify the date/time associated with the transferred dataset, ephemeris comment, and files promoted.

NOTE: the transfer time may differ slightly (by 1 or 2 sec) from the time indicated on the Traj Summary page.

- 5) Save the Trajectory Summary file. On the Ephemeris Data page, right-click on the `TrajectorySummary.txt` icon, select `Save Target As...` and save to `V:\Fdo\<$flight_id>\TrajectorySummary\TrajectorySummary_<nn>_<doy>_<hhmm>.txt`. In this filename, `<nn>` indicates the data slot, while `<doy>` and `<hhmm>` denote the GMT at which the save is performed.

NOTE: if the filename is selected instead of the icon, an error message will appear when the save is attempted, indicating that Internet Explorer cannot download the file.

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- 6) Delete data from slots that are no longer applicable. Reference Section 3.11.8.3 (FTW Site Maintenance).

NOTE: the nominal Orbit data delivery is one trajectory dataset based on M1. No other Orbit slots will normally exist. However, EPHWEBXR and FTW support delivery of up to 10 Orbit data slots. If an additional slot is required, it should be purged of data once they are no longer applicable. Entry datasets are deleted after all opportunities for that day are waved-off. Subsequent entry days are then (re)promoted beginning with Slot 1 as appropriate.

### 3.11.8.1.3.4 FTW Customer Notification

Clear communication is essential to SOI operations success. The following notification steps must be followed after each FTW update.

CAUTION: a scheduled FTW update may be cancelled, usually because the previous update remains acceptable or "best source" at the scheduled update time. A "negative update" status and rationale must nevertheless be reported to FTW users via NORAD COORD and e-mail per the following procedure. This action is necessary to ensure users don't assume an FTW failure after a scheduled update fails to be posted.

- 1) Notify OSA, NASA SUPPORT, and ALT SPACE of the FTW update. Use the NORAD COORD loop and wait until all operators acknowledge they're present.

CAUTION: if NASA SUPPORT is not present on the NORAD COORD loop during a NASA SUPPORT update notification, ask the OSA/SBM to relay notification to NASA SUPPORT. If NASA SUPPORT doesn't confirm notification within 10 min, continue to attempt NASA SUPPORT notification on NORAD COORD at 10-min intervals until receipt is confirmed.

- 2) Indicate what events motivated the trajectory data update (i.e. new tracking, burn confirmation, updated rendezvous plan).
- 3) Have the OSA (required for SOI updates) or NASA SUPPORT (required for NASA SUPPORT updates) read back the File Last Updated time displayed on FTW's Traj Summary page for each slot updated. Verify others on the loop copy the time(s). This will ensure all are using the correct data.
- 4) For SOI activities, indicate which COASTING ARC # is relevant for the upcoming SOI activity. Refer to the vector by its label on the Trajectory Summary. The OSA must read back the COASTING ARC #, vector label, and the associated vector time (GMT).
- 5) Send notification e-mail to FTW users. The template is available at `V:\Fdo\USSPACECOM\SOI\FTWUpdate.ofc`. It contains a table with the 10 Orbit slots and a second table with the 10 Entry slots. A description and the update GMT are listed for each slot. To modify the e-mail notice, perform the following actions before sending it.
  - a) For each trajectory slot posted (either new or existing slots that are still applicable), enter a descriptive title and change the template's FTW update GMT.
  - b) Blank out the FTW update GMT for remaining slots.
  - c) Indicate if an ATL file is being delivered along with the FTW update GMT.

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- d) Update the FTW point-of-contact phone number.

NOTE: separate tables for Orbit and Entry are contained in the template. Ensure both tables are changed (updated or blanked) as appropriate prior to sending the e-mailed notification.

CAUTION: the notification template requests responses be directed to the FDO Console phone number or the FDO group e-mail account, JSC-FlightDO@ndc.nasa.gov. Consequently, it's good practice for FDO or TRAJ to check the FDO account at least once during a shift. In addition, nothing prevents a notification recipient from replying directly to the sender. In this case, only the sender will receive the notification recipient's response, potentially incurring a substantial communication delay.

OSA and NASA SUPPORT will be extracting data from FTW *only* when FDO notifies them of updates. However, to ensure stale data are not inadvertently used, OSA and NASA SUPPORT are required to call FDO if they intend to extract data at any other time.

### 3.11.8.1.4 Unplanned SOI Requests

If FLIGHT requests SOI operations at times other than those planned pre-mission, take the following steps to request SOI.

- 1) Update E1/M1 based on NAV's best source.
- 2) Determine what SOI passes will be available in the near future by filtering SOI sites in AcqMon. Transfer ephemeris data to the PC and use SOOT to get an idea of lighting conditions during Maui passes. Download SOOT software from the following path.  
V:\FDO\APPS\Discipline CM\Web Pages\disc\_cm.htm
- 3) Notify FLIGHT of potential SOI opportunities. Do not perform subsequent steps in this procedure without FLIGHT's authorization to schedule unplanned SOI.
- 4) Call the SBM on the NORAD COORD loop. Describe the situation and request SOI for upcoming passes. Coordinate with the SBM to determine which passes will be used. This may require multiple calls as the SBM and OAs coordinate with USSTRATCOM/J22 and the sensor sites.
- 5) For each SOI opportunity, follow the steps in Section 3.11.8.1.2.2 (SOI Updates).
- 6) When USSTRATCOM indicates SOI data are available, notify FLIGHT and KX per Section 3.11.8.1.5 SOI Product Notification steps.

### 3.11.8.1.5 SOI Product Notification

It is FDO's responsibility to ensure SOI data are collected per the plan agreed to pre-mission. After the data are collected and analyzed by USSTRATCOM SOI personnel, SOI products will be made available to JSC by USSTRATCOM/J225 via Secret Internet Protocol Router Network (SIPRNet). J225 personal will notify FDO of product availability via commercial telephone.



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FDO's remaining responsibility is to inform JSC imagery analysts the data are available. Notify KX/Image Science and Analysis via telephone and e-mail using the contact information in the addendum to the Beeper List in the mission data book. KX personnel will then obtain SOI data from the CEF.

In very rare circumstances, FLIGHT or MOD may request FDO/TRAJ to retrieve SOI or other data from the CEF SIPRNet terminal. If so directed, perform the following actions.

- 1) Inform CEF that access to data on the SIPRNet is needed. Allow at least 20 min of lead time for CEF preparation. All CEF personnel have access to the SIPRNet terminal and have been instructed to help DM personnel retrieve data as required.
- 2) Retrieve the SOI data from the CEF SIPRNet terminal. Instruct CEF personnel to download, store, and print SOI products (or other data) per instructions in the CEF. Remember that SOI products are classified SECRET or FOUO. Follow the proper procedures for handling classified material (see JSC Security Management Directive, SMD 500-24 for guidelines). CEF personnel are trained in handling classified material and can lend assistance.
- 3) Deliver the data to FLIGHT/MOD, or the designated recipient. FLIGHT/MOD may request SOI products be stored in the MPSR safe until the data can be retrieved.

### **3.11.8.2 TWA Downmodes and Troubleshooting Procedures**

In the event TWA does not properly promote ephemeris data to FTW, the following downmodes and troubleshooting steps should be followed to insure OSAs and NASA SUPPORT have the required data in a timely manner. If an FTW update is due immediately, implement the FAX downmode. Use the troubleshooting procedure only as time permits.

#### **3.11.8.2.1 TWA Downmode to FAX**

##### **NASA SUPPORT FTW Updates**

- 1) Call NASA SUPPORT on NORAD COORD and inform them of the FTW problem. Declare a Backup FAX downmode until further notice. Obtain acknowledgements from NASA SUPPORT, OSA, and ALT SPACE.
- 2) Print out USSPACECOM messages at the vector times listed in the NASA SUPPORT Backup Delivery Table as attached to the USSTRATCOM Vector Transfer Schedule.
- 3) FAX the vectors to the backup NASA SUPPORT FAX number listed in the addendum to the FDO Data Book's Beeper List.
- 4) Call NASA SUPPORT on NORAD COORD and verify receipt of all vectors.

##### **SOI FTW Updates**

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- 1) Call OSA on NORAD COORD and inform them of the FTW problem. Declare a Backup FAX downmode until further notice. Obtain acknowledgements from OSA, NASA SUPPORT, and ALT SPACE.
- 2) If AOS for the SOI pass has changed by more than  $\pm 30$  seconds compared to the previous posted ephemeris, print out a USSPACECOM message from M1 with an epoch approximately an hour before the SOI AOS. FAX the message to OSA. Take care to provide a vector with an epoch after any pre-SOI burns. If the  $\pm 30$  seconds threshold has not been broken, an updated vector is not required.
- 3) Call OSA and verify vector receipt or direct OSA to use data posted previously.

**CAUTION:** when TWA-based FTW updates are unavailable, NASA SUPPORT and OSA vector deliveries must be performed independently. In this case, NASA SUPPORT vectors will be unsuitable for use as a SOI vector. This is in contrast to TWA updates documented in Section 3.11.8.1.2.1, which may well serve both purposes.

### 3.11.8.2.2 Troubleshooting Steps

The following troubleshooting actions are listed from least to most intensive for a given problem. As time constraints dictate, downmoding to the Backup Fax procedure may be necessary.

Problem	Recommended Action(s)
Red Transfer Failed dialog received from EPHWEBXR	Try again. If the transfer is not successful after a few tries, invoke the FAX downmode (see Section 3.11.8.2.1).
Green "Transfer Complete" dialog received from EPHWEBXR, but files do not appear on FTW	Make sure the process has had enough time (at least a minute) to execute.  Check the correct Destination (Vehicle and Activity) ephemeris has been selected. If not, select the correct Destination and try again. Otherwise, perform Manual Posting procedure following this table.
FTW problems beyond those listed above	Call MAS Support at 281-792-6100 (8-5 Central, M-F) or 281-467-0661 (after hours pager) and report the problem. MAS Support will attempt to fix the problem by next business day.

The following Manual Posting procedure has been useful in addressing SiteManager and SSPPX3 outages resulting in FTW data voids.

- 1) Use EPHWEBXR to transfer files to be posted. After this transfer, files will be located in the OpsFTP\TrajTrans\- 2) Delete the AutomationInstructions.xml file from the OpsFTP\TrajTrans\- 3) Copy remaining files to \\jsc-mas-isl\fdodata\$\<Activity>\OrbitEphem\Inbox\- 4) Manually execute the SSPPX3 by going to the following web page:  
<https://<Activity>.jsc.nasa.gov/apps/fdoweb/admin/NotifyOrbi>

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tEphem.aspx. To re-execute the page after it has been brought up once, use the "Refresh" button. This web page is also used when transferring entry data.

- 5) Delete files from the OpsFTP location if they still exist there.

### 3.11.8.3 FTW Site Maintenance

After a mission or simulation is completed, FTW should be cleared of data. Files can be deleted from the site via the following web page:

OPS: <https://ops1.jsc.nasa.gov/apps/fdoweb/admin/deletedata.asp>

SIM: <https://sim1.jsc.nasa.gov/apps/fdoweb/admin/deletedata.asp>

All files can be deleted from FTW, data for specific slots (1-10) can be deleted, or just the ATL can be deleted.

### 3.11.9 Space Radiation

Occasionally during an STS mission, USSTRATCOM will provide data on solar flares, geomagnetic storms, or other solar events in a Space Information Message. The CEF will route the message to FDO, although typically the message will be addressed to the FD. FDO should make two copies of this message. The original is passed to the FD, a copy is given to SURGEON, and another copy goes in the USSTRATCOM section of the clipboard binder.

FDO is not responsible for analyzing or interpreting these data. The Space Radiation Analysis Group (SRAG), a SURGEON back room position, performs this function. SRAG receives data on solar events from a multitude of sources, including the National Oceanic and Atmospheric Administration Space Environment Services Center. Call SRAG at x33618 or on the STS Radiation loop.

### 3.11.10 Points of Contact

FDO is responsible for all operational interfaces between SSP and USSTRATCOM except threat and warning message traffic, which is a FD responsibility. Voice interface with USSTRATCOM from the Mission Control Center (MCC) is performed on the NORAD COORD loop. Talk capability on this loop is restricted to FDO, TOPO, and FD. The OSA normally answers the NORAD COORD loop if "SPACE, Houston FDO" is called.

A special procedure is available for FDO to contact OSA on the NORAD COORD loop. This process, known as "ring-down", sounds a buzzer at the OSA Console to signal that FDO is trying to call. FDO can ring-down USSTRATCOM by putting NORAD COORD in talk mode, then pressing "RING" on the DVIS panel. At the OSA Console, a light will illuminate and a click will be heard over the NORAD COORD loop. Pressing RING again will reactivate these cues. The SBM will respond when OSA is unavailable.

If this procedure fails, several alternatives are available. FDO can call Houston Voice on the Voice Control loop and request a ring-down on NORAD COORD. Houston Voice rings OSA and monitors the loop until an answer is received. The OSA is then asked to call

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FDO on the NORAD COORD loop. FDO can also call the OSA/SBM on a BLACK (non-secure) phone at 719-474-4460. If for some reason this fails, the Department of Defense (DOD) Landing Support Officer (LSO) can call the command center at Cheyenne Mountain Air Station with an alternate phone number, or the JSC CEF can try to raise them via a dedicated circuit to USSTRATCOM.

For real time classified conversations with USSTRATCOM, use the FDO console's Secure Telephone Unit (STU-III). The STU-III can be used as either a BLACK or RED (secure) phone, so it is extremely important all users be completely familiar with STU-III procedures to avoid security violations. Copies of **STU-III Security Procedures** (JSC 22913), the **STU-III User's Guide**, ops notes, and a list of phone numbers are maintained at the FDO Console. USSTRATCOM may call on the STU-III at any time for classified communications, so proficiency in STU-III procedures is essential.

### 3.11.11 Collision Avoidance Sim Coordination

A means to coordinate FDO conjunction simulations with the Orbit Safety Analyst (OSA)<sup>4</sup> has been developed. This technique preserves the simulated TDR trajectory, reproducing it in real GMT for OSA processing against the current debris catalog. It then preserves the threat object's TDR trajectory when it's reproduced in SGMT for FDO collision probability ( $P_c$ ) analysis. Computation and application of an SGMT-to-GMT "SIM BIAS" delta-time is facilitated by a simple Excel spreadsheet called SimBias. The technique provides FDO training in interactions with all personnel and procedures required to obtain an Orbit Conjunction Message (OCM) and compute a  $P_c$  from it. Before applying the coordination technique, several caveats must be considered.

- 1) Because OSA may have higher priority activities to work, significant delays may be incurred in obtaining any OCM for analysis.
- 2) There is no guarantee OSA's conjunction analysis will yield any Time of Closest Approach (TCA) or  $P_c$  suitable for specific FDO or Flight Control team (FCT) training objectives.
- 3) Current OCM routing capabilities to FDO's SPADOC drop box automatically separate simulated message traffic from real traffic only when the simulated conjunction is performed under a SIM activity in OPS. This separation is accomplished by utilizing an EXERCISE drop box distinct from the REAL drop box in use by TOPO for continuous ISS operations. If the simulation is to be performed in a MIS activity, default routing to the REAL drop box can be redirected to the EXERCISE drop box, preserving separation from ISS operations. To accomplish this, use a text editor and change the "REAL" string to "EXERCISE" in TSA Local's System/monitor\_config.txt file. An example of this file prior to modification in a MIS activity follows.

```
DROP BOX CONFIG 0.7Alpha 5000 xedit
"RSA", "ip-bastion1", "/private-in/rsa/mission/ballistics", y, rsav, rsae, misc
"SPADOC", "cmc-mrs-gw", "/C/FDO/REAL", y, cmcv, cmcc, misc
"GSFC", "localhost", "/users/trjcom/ASA01/SSP109_MIS/Global/DropBox/gsfv/in", n, gsfv,
misc
"FDPA", "localhost", "/users/trjcom/ASA01/SSP109_MIS/Global/DropBox/fdpa", n, fdpav,
fdpae, misc
```

---

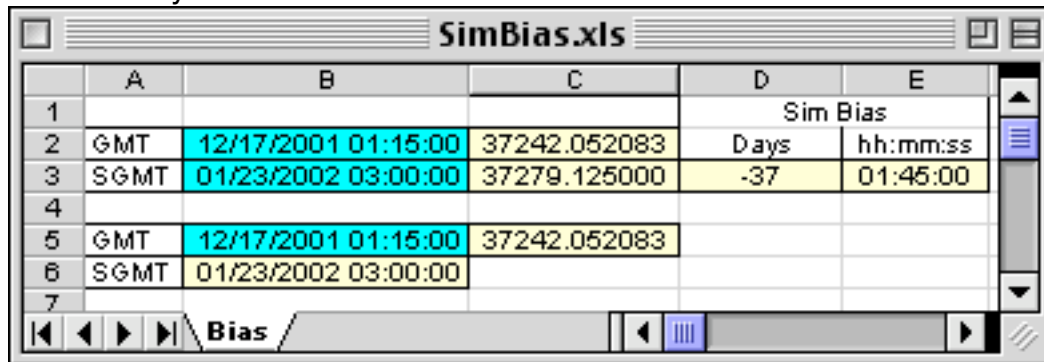
<sup>4</sup> Although OSA is cited as USSTRATCOM point-of-contact throughout this procedure, Alt Space may be prime or desire participation during any particular simulation. If Alt Space is prime, note covariance transmission capability from ASCC will not be available.

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### 3.11.11.1 Coordination Procedure

To coordinate collision avoidance simulation, perform the following steps.

- 1) Declare FDO intent to simulate collision avoidance with affected personnel.
  - a) If a TOPO is on duty, determine if any conjunctions with the real ISS are being worked. Should FDO's simulation objectives pose a conflict to any such activity, those objectives should be postponed to avoid the conflict. It may then be necessary to halt further collision avoidance simulation coordination at this point.
  - b) Contact the OSA and determine if FDO's simulation objectives pose an excessive burden or if unacceptable delays will be experienced due to higher priority tasks. If so, it may be necessary to halt further collision avoidance simulation coordination at this point.
  - c) Contact COMSEC Equipment Facility (CEF) and advise personnel to expect collision avoidance simulation message traffic in FDO's Exercise Drop Box.
- 2) After the simulator is moded to RUN, compute the SIM BIAS delta-time using a copy of the SimBias spreadsheet (reference Figure 1) from DM32\USSPACECOM\Probability Method\SimBias.xls. Enter any time-homogeneous snapshot of current GMT and SGMT to Cells B2 and B3, respectively. The desired SIM BIAS is then displayed in Cells D3 and E3. Note this action must be repeated after any hold or reset in the SGMT clock.



	A	B	C	D	E
1				Sim Bias	
2	GMT	12/17/2001 01:15:00	37242.052083	Days	hh:mm:ss
3	SGMT	01/23/2002 03:00:00	37279.125000	-37	01:45:00
4					
5	GMT	12/17/2001 01:15:00	37242.052083		
6	SGMT	01/23/2002 03:00:00			
7					

**Figure 1: Example SimBias Spreadsheet Configuration**

**CAUTION:** although cells in Column B are displayed in 24-hour time format, they must be entered in 12-hour AM/PM format. This is an Excel limitation.

- 3) Fetch the desired asset state vector into the USSTRATCOM Message menu, then enter the SIM BIAS delta-time computed in Step 2. Verify the message's GMT tag is reasonable, then print the message. Before FAXing to OSA, mark the message "EXERCISE" at top and bottom.
- 4) If OSA reports "negative conjunctions" on the FAXed state vector, and any conjunction is desired for training objectives, the notification box can be expanded to identify the closest threat object. Request an OCM(s) as appropriate.

**CAUTION:** an OCM will only be routed to FDO's Exercise Drop Box if OSA enters "EXERCISE" two lines after the "QQQQ" record. This action should be verified prior to any OCM request. Otherwise, simulation message traffic may be inadvertently routed to the real Drop Box.

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- 5) When an OCM arrives in the Exercise Drop Box, receive pertinent data in appropriate VAT/CAT slots. If TSA Global system launch time is configured correctly, OCM processing will pick up the simulation launch time. Launch time can be verified in the vector and covariance menu prior to receiving the vector.
- 6) Manipulate the threat object's state vector for simulation processing. These actions first apply SIM BIAS in reverse to convert the state vector's TCA time tag from GMT to equivalent SGMT while preserving TDR elements. Next, the state vector's GMTLO is converted from TCA SGMT to the simulated launch time while preserving state vector SGMT.
  - a) Enter the state vector's TCA GMT into SimBias Cell B5. Truncate any decimal seconds digits. The equivalent TCA SGMT will be displayed in Cell B6.
  - b) Use Vector Rotation to change the state vector's TCA GMT launch time to the equivalent Cell B6 TCA SGMT launch time while preserving TDR elements. Restore any truncated decimal digits to the Cell B6 value entered to Vector Rotation.

NOTE: this step cannot easily be performed with Vector Edit because this menu cannot display TDR elements while time tags are edited. The TDR elements would have to be manually input first.
  - c) If the simulated lift-off time was not already picked up in Step 5, copy the rotated state vector into TrS or modify the rotated state vector's GMTLO with Vector Edit.

CAUTION: before modifying GMTLO in Vector Edit, be sure to select GMT for the displayed vector time. Otherwise, the rotated state vector's SGMT will be inadvertently shifted from TCA SGMT to the simulated GMTLO.
- 7) Process the OCM's threat object covariance and manipulated state vector per standard procedures to obtain a  $P_c$  value.
- 8) Report the conjunction TCA and  $P_c$  to Trench Monitor for Sim Team assessment. If the conjunction doesn't conflict with other simulation objectives, the Sim Team may elect to integrate it with their script and potentially involve the entire FCT. Otherwise, FDO will be advised to play the conjunction as a discipline-specific exercise. In that case, any Flight Notes used to document results or trends should be prioritized as "N/A - Info Only".
- 9) At simulation termination, notify OSA further USSTRATCOM support to FDO can be suspended.

### 3.11.11.2 SPADOC Drop Box Configuration

For simulations in which a FDO trainer plays the OSA role, the `monitor_config.txt` file should be modified in order to point the SPADOC Drop Box software to the `SimulatedSTRATCOMDropBox` directory. In order to alter the file, it must first be copied to a working directory (such as `/tmp/`) so the FDO trainer has permission to change the file. Perform the following steps to configure the simulation for local drop box operations.

- 1) Copy the `monitor_config.txt` file from either the `/users/trj/Database/Global/TSA#.#/System/` directory or the `/users/trjcom/ASA01/SSP###_SIM/Global/System/` directory to `/tmp/` or

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another working directory (where #.# and ### are the TSA version number and flight number, respectively).

- 2) Use a text editor to modify the SPADOC line of the `monitor_config.txt` file. The baseline file used for mission operations before modification appears in Figure 3.11.11.2-1. After modification, the file will appear as in Figure 3.11.11.2-2.

```
DROP BOX CONFIG 0.7Alpha 10000 xedit 30
"RSA" , "ip-bastion2", "$TVETS_RSA_PATH" , y, rsav, rsan, rsaa, rsa14, misc
"SPADOC", "cnc-mrs-gw", "$TVETS_SPADOC_PATH" , y, cmcc, cmcv, misc
"GSFC" , "localhost" , "$TVETS_GSFC_PATH" , n, gsfc1, gsfc2, misc
"FDPA" , "localhost" , "$TVETS_FDPA_PATH" , n, fdpav, misc
Object Mass (lbs): 5000.0
```

**Figure 3.11.11.2-1: monitor\_config.txt Baseline File**

```
DROP BOX CONFIG 0.7Alpha 10000 xedit 30
"RSA" , "ip-bastion2", "$TVETS_RSA_PATH" , y, rsav, rsan, rsaa, rsa14, misc
"SPADOC", "localhost" , "/users/fdo/SimulatedSTRATCOMDropBox" , y, cmcc, cmcv, misc
"GSFC" , "localhost" , "$TVETS_GSFC_PATH" , n, gsfc1, gsfc2, misc
"FDPA" , "localhost" , "$TVETS_FDPA_PATH" , n, fdpav, misc
Object Mass (lbs): 5000.0
```

**Figure 3.11.11.2-2: monitor\_config.txt Modified For Simulation Use**

- 3) Copy the new `monitor_config.txt` file into the appropriate Global area using XDir or an xterm window. The destination directory should be `/users/trjcom/ASA01/SSP###_SIM/Global/System/`. Perform this step only after the initial checkpoint has been taken to avoid capturing an incorrect default configuration.
- 4) Start the SPADOC Drop Box. A username and password will not be required. Follow the procedures called out in section 3.11.2.6.3 to process OCM or VCM messages.
- 5) The FDO trainer should copy all OCM or VCM files to the `/users/fdo/SimulatedSTRATCOMDropBox/` directory to simulate OSA electronic file transfer to the SPADOC Drop Box.
- 6) After the simulation, copy the original file from `/users/trj/Database/Global/TSA#.#/System/` back into the Global area (where #.# is the TSA version number).

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### 3.11.12 Space Flight Assessment Reporting

At FD or USSTRATCOM request, FDO is responsible for reporting MCC and Shuttle status over the NORAD COORD loop in accord with OI Section 5.5.2. In the case of a USSTRATCOM request, FDO must first obtain FD concurrence regarding the status to be reported. Status is "Green", "Yellow", or "Red" per Figure 3.11.12-1 conditions.

Status	MCC Condition	Shuttle Condition
Green	Nominal ops for all in-flight vehicles	Nominal flight duration using nominal trajectory
Yellow	All in-flight vehicles cannot be supported simultaneously	Nominal flight duration or trajectory cannot be maintained, but not Red
Red	No in-flight vehicle can be supported in the next 6 hrs	Early deorbit in less than 24 hrs or incapacitated

**Figure 3.11.12-1: Space Flight Assessment Status Definitions**

**WARNING:** associating a threat/warning cause to an effect and/or resulting action is classified SECRET. See Section 3.11.5. It may be necessary to report status using secure communications.

**NOTE:** by default, USSTRATCOM will assume MCC and Shuttle status are Green until notified otherwise.

**Section 3.11 Concludes On This Page**



## **FDO Console Handbook Section 3.12: Orbit Team Tasks**

### **3.12 Orbit Team Tasks**

This section summarizes flight-phase-dependent tasks which any Orbit FDO/TRAJ team can expect to perform during a mission. Notable exceptions are emergency deorbit duties performed by TRAJ in lieu of an LSO. References to more detailed information are given in parenthesis following each item.

#### **3.12.1 Summary of Prelaunch Planning Shift Tasks**

- 1) Prelaunch Winds/Loads Updates (FDOCH 3.12.10)
- 2) Abort Advisory Check (FDOCH 3.12.4)
- 3) FCO Collision Avoidance (COLA) Clearances (FDOCH 5.9.3.2)
- 4) Prelaunch COMBO Message (FDOCH 3.11.2.1)
- 5) Prelaunch RADAR Restrictions Message (FDOCH 3.11.4)
- 6) Block 1 Trajectory Message Inputs (FDOCH 3.12.5)
- 7) Ground-Up Rendezvous State Vector Transfers (FDOCH 3.12.14)
- 8) ConUS DOPS Spreadsheet XR Limits Verification (FDOCH 3.12.19)

#### **3.12.2 Summary of Orbit Shift Tasks**

- 1) Shift Handover Guidelines (FDOCH 3.12.6)
- 2) Console Log (FCOH 1.1, historic examples on file)
- 3) Voice Loops (FCOH 1.5, FCOH 6.2.5, FDOCH 2.1.3.1)
- 4) Console Configuration (FDOCH 2.1.2, FDOCH 3.2.3)
- 5) Ephemeris Maintenance (FDOCH 3.3)
- 6) TRAJ Duties In Lieu Of LSO (FDOCH 3.12.11)
- 7) Weather Briefing Coordination (FDOCH 3.12.12)
- 8) PLS Selection (FR A4-107)
- 9) OMS Leak OOP TIG Window Computation (FDOCH 3.9)
- 10) Mission Summary Message Inputs (FDOCH 3.12.7)
- 11) On-Orbit And Entry Mass Properties (FDOCH 3.6)
- 12) COMBO Message (FDOCH 3.11.3.3)
- 13) State Vector Updates (FDOCH 3.3, FDOCH 3.5.6)
- 14) Next PLS and EOM Deorbit Targeting (FDOCH 4.2.2)
- 15) Hard Copy Book and Clipboard Maintenance (FDOCH 3.12.8)
- 16) Radar Restriction Updates (FDOCH 3.11.4)
- 17) Vehicle-to-Vehicle Sightings (FDOCH 3.12.9)
- 18) TDRSS Scheduling (FDOCH 3.12.13)
- 19) SpOC Team Data Transfer (FDOCH 3.12.20)

## FDO Console Handbook Section 3.12: Orbit Team Tasks

### 3.12.3 Orbit Phase Planning Team Checklist

- 1) COMPUTE DEORBIT COSTS
  - a) Check weather to determine PLS site selection.
  - b) If supporting the first Orbit Phase Planning Shift, compute steep and shallow deorbit costs using current mass properties for next two PLSs. Otherwise, compute deorbit costs for next next PLS only.
  - c) Provide TIG and deorbit costs to PROP. PROP uses deorbit costs for trend purposes only until required. Be sure to specify any increase in deorbit DV to cover worst case increase due to expedited separation. Request PROP predicts at TIGs corresponding to the deorbit costs supplied in 1b.
- 2) PREDICT PLS MASS PROPERTIES
  - a) Request predicted quantities from EGIL, EECOM, and MMACS at TIGs corresponding to the deorbit costs supplied in 1b.  
NOTE: MMACS values don't nominally change between ascent and FCS Checkout.
  - b) With predicted quantities in PMP, run OMS depletion (doors closed) and ballast.
  - c) Save PMP predicted data as "plsNNN.xs4", where NNN = PLS TIG orbit number. Next PLS data should also be saved as "predicted.xs4".
  - d) Provide predicted PLS total Orbiter weight(s) and ballast to PROP. Request Tank Fail and Prop-to-FDO.
- 3) CHECK DATA BOOK USSTRATCOM DELIVERY SCHEDULE
  - a) USSTRATCOM state vectors at 06z, 14z, 22z, burnout, post-deploy, etc.
  - b) Earth Observations state vectors
- 4) EVALUATE PADJ OPTIMUM TIG AND OOP WINDOW  
NOTE: multiple curves may be required if large OMS burn or large deploy/retrieve WGL is planned.
- 5) PREPARE EXECUTE PACKAGE INPUTS
  - a) Mission Summary Message (see Section 3.12.7)  
NOTE: gather next 2 PLS TIGs, PADJ, Prop-to-FDO, Tank Fail, and NOTAMS.
  - b) Review next flight day's timeline.
- 6) REVIEW/PROCESS PREVIOUS FLIGHT DAY'S CARGO TRANSFERS
- 7) GENERATE RADAR RESTRICTIONS (USE EVA LIMITS IF APPLICABLE)
- 8) SUPPORT STANDARD SHIFT ACTIVITY
  - a) Process current mass properties
    - i) Compile real time mass properties with PLBD open OMS Depletion.
    - ii) WGL appropriate ephemerides and sync ECT trims.
    - iii) Pass total Orbiter weight to PROP.
  - b) Prepare Shift Handover Sheet (see Section 3.12.6).
- 9) REFERENCE SECTION 3.10.4.2.11.2 PRIOR TO DAY-OF-RENDEZVOUS

## FDO Console Handbook Section 3.12: Orbit Team Tasks

- 10) PERFORM EPHEMERIS MAINTENANCE STEPS
  - a) Check all mirrored ephemerides for accuracy
  - b) Check M3/M1 WGLs vs. cargo transfer spreadsheet, deploys/installs, etc.
  - c) Update M2 mirror and turn off
  - d) Post M2 to IPS (see Section 3.12.18)
  - e) Update G1 and G3 and post to PAO (see Section 3.12.16)
  
- 11) PERFORM THE FOLLOWING ACTIONS PRIOR TO DEORBIT SHIFT
  - a) Compute end-of-mission mass properties (see Section 3.6).
  - b) Conduct deorbit planning as required (see Section 4.3.6).
  - c) Generate DOL sheets as required (see Section 4.5.1).
  - d) Update entry ephemerides and acquisitions as required (see Section 3.4.1.5).
  - e) Perform entry winds table input as required (see Section 4.4.1).
  - f) Generate entry RADAR restrictions message (see Section 3.11.4).
  - g) Draft Entry Summary Message inputs (see Section 4.5.2).
  - h) Draft DEL PAD (see Section 4.5.4).
  - i) Assess relative motion with respect to ISS and other deployed/overboard objects through each viable deorbit burn opportunity, considering underburns in cases violating the Rule of Halves

### 3.12.4 Abort Advisory Checks

To declare a Shuttle abort during ascent, MCC (FD or FDO) or ROCC (Flight Control Officer {FCO}, formerly Range Safety Officer {RSO}) activates an "abort light" in the forward crew station. Two redundant channels, A and B, are dedicated to the associated abort command. A single channel commanding an abort is sufficient to activate the light. If both channels command an abort, the light becomes over-bright. The FD Console is capable of issuing abort commands over either or both channels. It can also reset all abort commands, extinguishing the light. From the FDO Console, it's only possible to activate the light over channels A and B. No single channel command or abort reset can be made.

Abort commands are issued from the FDO Wfcr29 workstation using a graphic user interface (GUI) or a hardware button. The hardware button is operational only when the GUI is enabled by the COMMAND position in the Ops Support Team (OST) back room, and the GUI can be enabled only after it's activated by selecting the appropriate FDO DNAV menu item.

During the prelaunch Planning shift, usually at about L -8 hrs 45 min, NTD will call for the Abort Advisory Check to be performed. Before and during this period, FDO should monitor the NTD loop. Procedures are found in S0007, Operational Maintenance Instruction (OMI), Volume IV and are summarized below.

**NOTE:** activation actions called for in Step 1 may be taken at any time following Wfcr29 workstation initialization and after logging into the Command Server.

**NOTE:** this first Abort Advisory Check does not involve the FCO, therefore Wfcr10 does not normally need to be activated at this time. At FD request, however, Wfcr10's abort interface can be activated in FCO's absence, and a ROCC technician can be requested to verify flashing abort PBIs at the FCO Console. A final check at L -5 hrs is performed specifically to test/verify FCO's abort switches. For this check, FDO should also monitor the FCO Prime loop as well as the NTD loop. A second GUI can be activated and enabled on the TRAJ Wfcr10 workstation, but an abort command window doesn't appear as it does

## FDO Console Handbook Section 3.12: Orbit Team Tasks

on Wfcr29. The only indicator of a successful FCO hardware connection is provided by the Advisory Services message **Abort\_HW\_Interface: abort hardware process has been started**. When the Wfcr10 GUI is enabled, abort commands can be issued from one of two hardware PBIs at the FCO Console. The FD Wfcr28 backup workstation is interfaced with FCO's other PBI.

**NOTE:** FDO's only duty in the event of an **Abort\_HW\_Interface** failure is to report the problem to GC and FD. Should troubleshooting be necessary, it may be helpful to know Wfcr10 interfaces with FCO PBI FC2 and Wfcr28 interfaces with FCO PBI FC1.

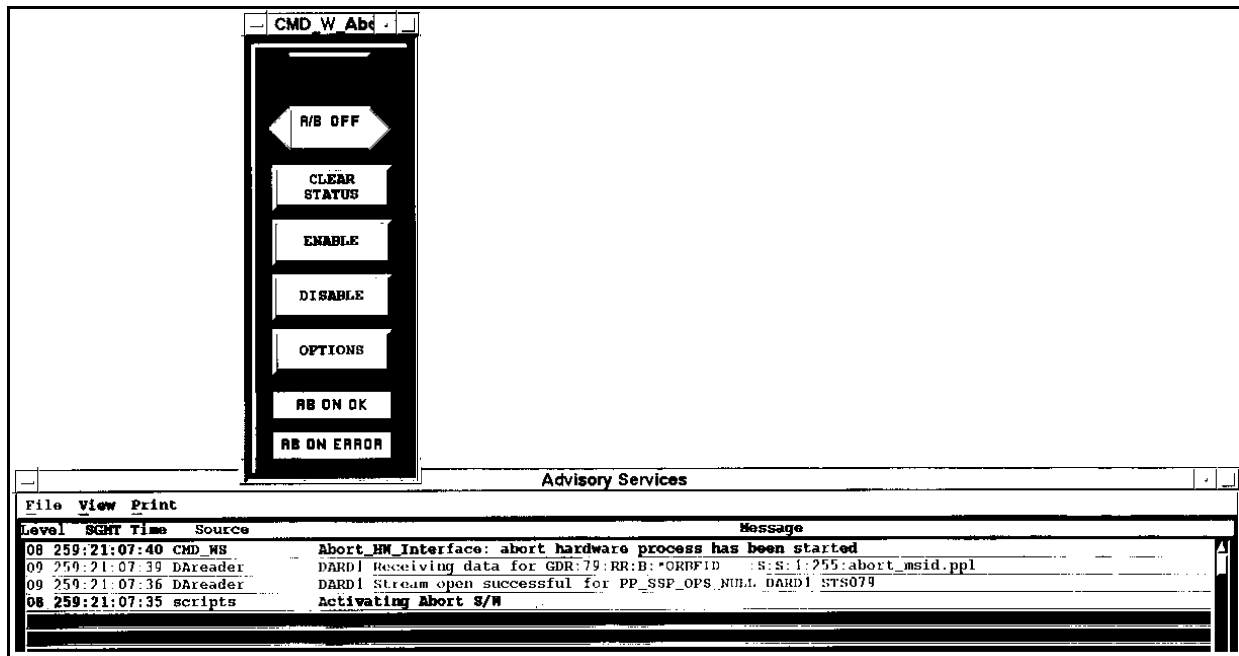


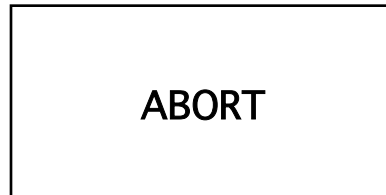
Figure 3.12.4-1: Abort Graphic User Interface (GUI) Registration

**CAUTION:** the hardware abort "button" is really a hinged switch pivoting about its top edge. Reliable command generation therefore requires contacting the button as far below center as practical. Failure to do so may result in failure to generate any commands and, in extreme cases, button hardware damage rendering it non-functional.

- 1) Before registering any abort GUI with the Command Server, verify with GC that associated loopback circuits are disabled. If loopback circuits are enabled at registration time, the GUI process will be inhibited from functioning. In this case, the only recovery path requires dropping the GUI and logging off the Command Server.
- 2) NTD requests FD perform the Abort Advisory Check. Immediately register Wfcr29's abort GUI using FDO DNAV path **Applications : Abort Switch : FDO : Activate GCS Abort**. The activation process can be monitored on the workstation's Advisory Services window (see Figure 3.12.4-1). Iconify the abort GUI after it appears.
- 3) FD has GC enable the FD Console for A/G voice, permitting FD to make abort command call-outs to the crew station.

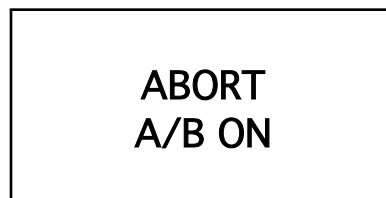
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- 4) FD has GC enable the FD and FDO Consoles for commanding. This action can be verified on the **Command Summary** display. Access this display from FDO DNAV path **Gen Traj : Command Loads Sub-Menu : Command Server : TELCOM SSP Displays : Command Summary**. Above the Command Tracking section, FD and FDO fields should have green background coloration (see Figure 3.12.4-4). At this point, the FDO H/W button should appear as in Figure 3.12.4-2.



**Figure 3.12.4-2: FDO H/W Button After Console Enabled**

- 5) The COMMAND console enables the abort command and GC arms the Command Server. The FDO Console's H/W button should illuminate and read **ABORT AB ON** as in Figure 3.12.4-3.



**Figure 3.12.4-3: FDO H/W Button Following Abort Command Enabled**

- 6) FD issues single and dual-channel abort commands with intervening abort resets as appropriate. During this process, FD makes call-outs of each action and the Astronaut Support Person (ASP) responds with off/on abort light observations.
- 7) After resetting the abort light, FD calls for the FDO Console to issue abort commands. Immediately depress the illuminated abort H/W button. The button can be released once its detent's "click" is felt, and its illumination should flash 3 times, once for each command transmission. Verify transmission by scanning the **Command Summary** display's Command Tracking segment for **ABORT AB ON** commands from the FDO console (see Figure 3.12.4-4).
- 8) Immediately notify FD the abort commands have been issued. The ASP should respond with an "on" abort light observation.
- 9) When FDO commanding is complete, FD has GC disable FD and FDO commanding. Then deactivate the abort GUI using FDO DNAV path **Applications : Abort Switch : FDO : Deactivate GCS Abort : Yes**.

**NOTE:** failure of the FDO abort hardware button is NOT a constraint to launch. Failure of both FCO abort hardware buttons IS a constraint to launch per FR A3-151C.

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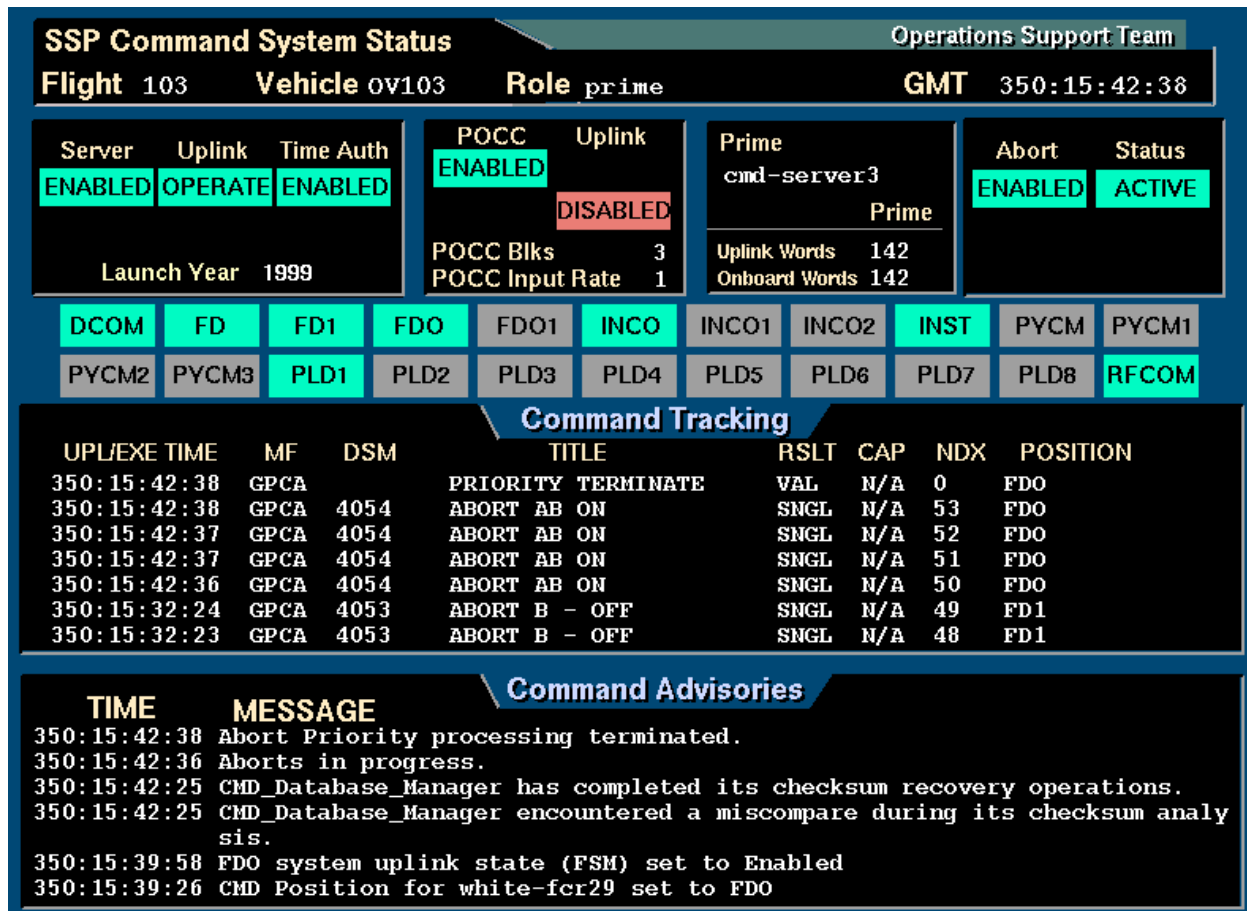


Figure 3.12.4-4: Command Summary Abort Check Status

### 3.12.5 Block 1 Trajectory Message Inputs

The Block 1 Trajectory Message is a four-page weather report to the crew that also contains pertinent trajectory information including expected deorbit TIGs, out-of-plane (OOP) TIG window information, NOTAMs, maximum attitude rates during load relief, and any other relevant information for the first flight day should all communication with the Orbiter be lost. FDO inputs to the Block 1 Trajectory Message are illustrated in Figure 3.12.5-1. These inputs are recorded by the crew in Section 8 of the Ascent Checklist.

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BLOCK 1 TRAJECTORY MESSAGE				
DEORB ORB	APPROX TIG	SITE/RWY	OOP TIG WINDOW	
			OPEN	CLOSE
2	ø:ø2:19	EDW 22	ALWAYS BURN	OUT-OF-PLANE
3	ø:ø3:57	EDW 22		
4	ø:ø5:11	GUA ø6L		
5	ø:ø7:ø5	HNL ø8R		
6	ø:ø8:43	HNL ø8R		
7-15	-	-		
<b>MAX RATES (1st STAGE)</b>		<b>MISCELLANEOUS</b>		
NOTE: IGNORE ATTITUDE ERRORS DURING LOAD RELIEF		NOTAMS:		
ROLL _____	%sec at _____	_____		
PITCH _____	%sec at _____	_____		
YAW _____	%sec _____	_____		
<b>TRAJECTORY LOFTING (2nd STAGE)</b>		_____		
LOFTED/DEPRESSED _____		nm at VI _____ K fps		
LSO/13 MAY 92		8-4	ASC/ /FIN	

**Figure 3.12.5-1: Typical Block 1 Trajectory Message Appearance**

Pre-mission, the Lead LSO provides all information on the message except the OOP TIG window data and maximum rates. The Lead FDO verifies deorbit TIGs on the message with the latest version of deorbit opportunities. The OOP TIG window data are provided by the pre-launch FDO to the message as window open and window close METs for orbits 2 through 6. The last line of window data uses the standard on-orbit notation of the window referenced to ascending node times and covers orbits 7 through 15. For some high inclination missions, it may be necessary to extend window open/close METs through Orbit 7. Since the pre-launch OMS loading process will always be nearly balanced, only one window is required to cover both left and right OMS tanks. An MET reference is used for early orbits since the crew does not have node-relative insight to orbit position until SPoC software is running. This normally occurs during the post-insertion time frame, although SPoC activation ultimately depends on crew preference and workload. Block 1 data only cover the first flight day and will be updated when the crew receives its Mission Summary Message the following day.

**NOTE:** if possible, the Lead FDO should supply OOP TIG window data to the Lead LSO to support a flight's final ascent sim or the L -1 Day Crew Briefing. This permits the crew to pose any questions before launch.

To compute OOP TIG window METs for orbits 2 through 6, first compute open and close times with respect to the ascending node per Section 3.7.1.5 assuming a nominal post-OMS-2 trajectory. Then compute window METs by adding  $\Delta s$  relative the ascending node to each nodal crossing MET. Use pre-launch predictions of  $\Delta V$  available provided by PROP to support the OMS tank fail computations. These  $\Delta V$ s should assume nominal usage through OMS-2. Format of the OOP TIG window data is similar to that of the standard Mission Summary Message. If a window exists for orbits 2 through 6, the window open and close times will be given in MET. If steep tank fail capability exists, the message

## FDO Console Handbook Section 3.12: Orbit Team Tasks

"ALWAYS BURN OOP" appears on that line. If shallow tank fail capability does not exist, the message "ALWAYS BURN RETROGRADE" appears. The last line uses standard ascending node reference times for orbits 7 through 15. This line may also be used to give OOP window information if a deploy or other activity that would change the previous data is planned for Flight Day 1.

### 3.12.6 Shift Handover Guidelines

To obtain current shift scheduling information, call the MCC Scheduling Recorder at 483-1076 (regarding sims) or 483-1077/8 (regarding missions or long sims). Updates are made by the Data Systems Supervisor (DSS) on notification by GC.

Handover takes place during the 1-hour overlap between oncoming and offgoing shifts. The goal of handover is for the oncoming team to come up to speed on the status of the mission in preparation for taking over trajectory responsibilities from the offgoing team. Any nonessential, on-the-job training (OJT), or SPAN personnel generally leave during handover to avoid congestion in the trench. Those remaining should take care not to interfere with handover at any console.

During this period, the offgoing FDO and TRAJ continue real time operations until dismissed by the offgoing FD. The oncoming team will begin its shift by monitoring loops and reviewing data from the departing shift. The shift handover is accomplished when the oncoming FD has been briefed by the offgoing FD and by each oncoming flight control team member over the AFD CONF loop. Once handover is complete, the offgoing team will be released by their FD.

As a minimum, the oncoming FDO and TRAJ team conducts the following activities.

- 1) Monitor FD and AFD CONF loops
- 2) Review log entries, clipboard postings, and distributed Flight Notes since last on console
- 3) Read latest weather forecast
- 4) Brief the oncoming FD on the current trajectory status

The offgoing team summarizes mission trajectory status for the oncoming team and continues normal duties until handover is complete. A handover checklist has been developed to facilitate a concise, consistent data transfer between teams. The checklist can be found in `V:\STS-XXX\Handover.doc`. It contains a trajectory status, a short written summary of significant past and upcoming events, some landing site status items, the current Trajectory Server (TrS)/TSA ephemeris configuration, and a place to note current FDO action items. This handover checklist is divided into two parts: the top half supports the Flight Director briefing and the remainder provides status to the oncoming FDO. Usually this sheet is used as a reference during the rest of the oncoming shift until the next handover checklist is completed. By handover completion, the sheet received by the offgoing team should be filed in the log book. See Figure 3.12.6-1 for an example of a handover sheet. Below is a description of its contents.

#### FD Briefing Data

- 1) Current Orbit: current heights of apogee and perigee from Checkout Monitor
- 2) Relative Motion Data: current target range and phasing rate



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- 3) Previous/Upcoming Traj Events: significant trajectory events such as deploys, expected deploy times, burns, etc.
- 4) Conjunctions: upcoming or past conjunctions with MET, associated range, FDO's maneuver recommendation, and planned maneuver strategy or executed maneuvers if applicable
- 5) PLS, ORB, TIG & WX/WINDS: data for the next 2 PLS opportunities (ORB is the TIG orbit)

### FDO/Traj Shift Handover

- 1) Site/RWY Status: runway or instrumentation status, such as runway down due to water, TACANs down, etc.
- 2) NOTAMs: lakebed or NAVAID status and expected recovery times obtained from LSO flight note to FDO (see Figure 3.12.11.1-1)
- 3) Other/WX Sheet: known conditions at sites other than those for upcoming PLSs and number of current weather sheet
- 4) EPH Config: status and time/size of last update for each ephemeris
- 5) Mass Prop: TrS ECT trims and DMP/EDS mass properties configurations;  $\Delta$ OMS used in DMP/EDS (from PROP)
- 6) Tank Fail Data: tank fail capability for each tank ("Always burn OOP" for steep capability; "Always burn RETRO" for no shallow capability; specify window open and close if shallow-only capability)
- 7) The offgoing FDO initials the checklist block adjacent to the statement attesting the secure telephone key has been received by the oncoming TRAJ (this is nominally the last entry made in the offgoing team's checklist as it's filed in the FDO Log)
- 8) Tasks/Status/Anomalies: new FDO action items and status and non-standard data repository locations, along with mission problems or anomalies
- 9) Events: last checkpoint, upcoming USSTRATCOM message, upcoming radar restrictions, and other data due.

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### FDO HANDOVER CHECKLIST    O1-> O2    FLIGHT DAY X    MET X/XX:XX FD Briefing Data - STS-XXX

CURRENT ORBIT HA x HP (nm)	Object	RELATIVE MOTION DATA		MET
		CLV X (nm)	CLV VX (nm/rev)	

PREVIOUS/UPCOMING TRAJ EVENTS:			CONJUNCTIONS:	
PLS	ORB	TIG	WX/WINDS	

#### FDO/TRAJ Shift Handover

SITE/RWY STATUS	NOTAMS	OTHER / WX SHEET

#### Ephemeris Config

<b>1</b>	Orbiter – short term	<b>2</b>	Orbiter – long term
<b>3</b>	ISS	<b>4</b>	

#### Mass Properties

DMP/EDS:	ECT TRIMS
ΔOMS =	Last Currents @ x/xx:xx MET

Tank Fail Data		OOP WINDOW		OPT PADJ
TANK	TANK FAIL (LEAK DIRECTION)	OPEN	CLOSE	
RIGHT				
LEFT				

Offgoing FDO initials do hereby bear witness that secure telephone key custody has been transferred to the oncoming TRAJ or to the MPSR safe.	<b>EVENTS</b>
Tasks/Status:	Last Checkpoint @ x/xx:xx MET
Anomalies:	Next SV Transfer @ x/xx:xx MET
	RADAR Restrictions: x/xx:xx MET

**Figure 3.12.6-1: FDO Handover Sheet**

To obtain current shift scheduling information, call the MCC Scheduling Recorder at 483-1076 (regarding sims) or 483-1077/8 (regarding missions or long sims). Updates are made by the Data Systems Supervisor (DSS) on notification by GC.

## FDO Console Handbook Section 3.12: Orbit Team Tasks

### 3.12.7 The Mission Summary Message (MSM)

The MSM is a compilation of "big picture" items, Orbiter systems data, payload data, and trajectory information transmitted to the Orbiter crew via the Thermal Impulse Printer System (TIPS). Because of the MSM's broad scope and crew readership, the Flight Activities Officer (FAO) coordinates its content, review, and transmission. An MSM is available to the crew following each sleep period for single shift missions. During dual shift missions, two MSMs are uplinked during each 24-hour period. Only one of these MSMs, typically that intended for the crew on duty during daily PLS deorbit opportunities, will normally require FDO inputs. Data provided by FDO informs the crew of current orbit Ha/Hp, target range and phasing rate during rendezvous, upcoming PLS TIGs, anomalous landing site or navaid conditions, responses to an OMS tank failure or leak, current or predicted OMS quantities, and deorbit propellant capabilities.

Inputs to the MSM are usually supplied by the Planning Team FDO to the Message and Timeline Support Officer (MATS), an FAO MPSR position. An uplink deadline driven by crew wake-up constrains scheduling of MSM activities. Preparation of FDO inputs is time consuming, begins early in the Planning shift, and ends with MSM review late in the shift. Because FDO must typically collect data from EECOM, EGIL, MMACS, and PROP to generate MSM inputs, schedule bottlenecks often arise. Coordination with other FCR operators, including FD, is required if these delays conflict with an MSM deadline. A well-defined template is used to enter FDO MSM inputs in the console personal computer. The file is then submitted as an attachment in an internal flight note, and MATS is notified of its availability.

#### 3.12.7.1 FDO Inputs to the Mission Summary Message (MSM)

FDO provides the following MSM inputs.

- 1) Orbit apogee and perigee in nautical miles at crew wake up MET
- 2) Notices to Airmen (NOTAMs) for any viable landing site
- 3) Next PLS opportunity orbit numbers, TIGs, and forecast weather
- 4) OMS tank fail capability status
- 5) Leaking OMS actions
- 6) Current OMS quantities
- 7) OMS quantities following planned burns
- 8)  $\Delta V$  available from OMS, Aft RCS, and Forward RCS

Figure 3.12.7-1 illustrates the format used to transmit MSM inputs.

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```
TO: MATS                                FDO: R. BALETTIE
FROM: FDO                                MET: 4/16:00
SUBJECT: FD6 MISSION SUMMARY INPUTS

YOUR CURRENT ORBIT IS: 177 X 175

NOTAMS:
-----
    EDW LAKEBED RED
    NOR LAKEBED GREEN
    ROBERTS FIELD - NOT RECOMMENDED
    EDW 111 TACAN DOWN
    TTS 59Y TACAN SINGLE STRING ONLY

NEXT 2 PLS OPPORTUNITIES:
-----
    EDW ORB 83 - 05/05:55      230/07P14 FEW060 SCT250
    EDW ORB 99 - 06/06:11      210/10P15 SKC

OMS TANK FAIL CAPABILITY:
-----
    R OMS FAILS: YES (SHALLOW TARGETS)
    L OMS FAILS: YES (SHALLOW TARGETS)

LEAKING OMS PRPLT BURNS:
-----
    R OMS LEAK:      BURN OUT-OF-PLANE AN+10 < TIG < AN+50
                     OTHERWISE BURN RETROGRADE

    L OMS LEAK:      BURN OUT-OF-PLANE AN+10 < TIG < AN+50
                     OTHERWISE BURN RETROGRADE

CURRENT OMS QUANTITIES (%):
-----
    L OMS OX = 40.26          R OMS OX = 43.27
    FU = 44.60                FU = 47.14

DELTA V AVAILABLE:
-----
    OMS                    418 FPS
    ARCS (TOTAL ABOVE QTY1)  42 FPS
    -----
    TOTAL IN THE AFT        460 FPS

    ARCS (TOTAL ABOVE QTY2)  96 FPS
    FRCS (ABOVE QTY 1)      61 FPS

    AFT QTY 1                117 %
    AFT QTY 2                49 %
```

Figure 3.12.7-1: Typical FDO Inputs to the Mission Summary Message

## FDO Console Handbook Section 3.12: Orbit Team Tasks

### 3.12.7.2 Mission Summary Message (MSM) Input Procedures

Because MSM inputs are often collected and processed over a period of several hours, the deadline for submission to MATS must be known in advance. Deadlines should be coordinated preflight by the Lead FDO and Lead FAO to ascertain which FCR team(s) will be involved in MSM preparation. Updates to MSM deadlines are usually solicited or provided during FCR team handovers. It may be necessary for the Orbit 2 Team to initiate MSM data requests if inputs must be submitted to MATS early in the Planning shift. At other times, the Orbit 1 Team may be called on to complete review of the MSM. Typically, however, all MSM activity falls within the Planning Team's shift.

The following steps cover MSM generation procedures at the FDO Console.

- 1) Approximately 5 hours prior to the MATS submission deadline, TRAJ issues requests for predicted consumable quantities at the "next next PLS" deorbit TIG (see Section 3.6.7.3). If the Planning Team's shift falls at the end of FD<sub>n</sub>, the PLS TIG of interest is during FD<sub>n + 2</sub>. At the end of FD<sub>1</sub>, the Planning Team TRAJ also requests predictions for FD<sub>2</sub>'s PLS TIG because PROP has yet to obtain an Orbiter weight at this time which reflects measured ascent dispersions. During the Planning shift prior to an end-of-mission deorbit attempt, TRAJ also requests predictions for that attempt's TIG. In this way, PROP will receive an Orbiter weight update less than 24 hours prior to a planned deorbit TIG. The Orbiter weight at PLS TIG permits PROP to issue an **OMS TANK FAIL ANALYSIS** and a **PROP to FDO FORM** which drive FDO's MSM inputs.

NOTE: an unwritten understanding with EECOM, EGIL, MMACS, and PROP dictates that consumables predictions can be expected within 2 hours of when they're requested. See Section 3.6.7.3 should workarounds be required in the event of unacceptably tardy data.

- 2) It may be necessary for TRAJ to run the Perigee Adjust processor (PADJ). At a minimum, an optimal PADJ "node plus" TIG covering the next flight day should be manually derived from DMP output. See Section 3.9.4.5 for PADJ procedures.
- 3) A pair of DMP runs is made to obtain STEEP and SHALLOW deorbit  $\Delta V$ s at the next next PLS of interest. These  $\Delta V$ s are voiced to PROP for input to OMS tank failure computations. They are also retained for use with PADJ output.
- 4) While awaiting predicted quantities and PADJ output, TRAJ can begin filling out the MSM template. The **YOUR CURRENT ORBIT IS** Ha x Hp values are obtained using a Checkout Monitor (MSK 2300) from the nominal ephemeris at crew wake-up. The FDO Log is consulted to find the most recent LSO Flight Note, whose items are transcribed into the MSM's **NOTAMS** section. Finally, current weather forecast sheets are used with DOPS to select sites and corresponding data for the **NEXT 2 PLS OPPORTUNITIES** section.

CAUTION: particularly during periods of uncertain weather forecasting, daily PLS selection may become dynamic. Since PLS call-outs on the MSM cover "no-comm" scenarios for the crew, EDW is usually selected unless weather or lighting concerns override this consideration. If weather violations are forecast for all 3 ConUS sites, the location associated with the most benign violations becomes

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PLS. If the Planning Team selects a new PLS different from the currently published DOPS, the change must be coordinated with LSO, FAO, and FD.

- 5) After receiving predicted quantities, TRAJ performs a predicted mass properties update (see Section 3.6.7.3) as soon as possible. The resulting Orbiter weight at PLS TIG is voiced to PROP, who can then generate an **OMS TANK FAIL ANALYSIS** and a **PROP to FDO FORM**.
- 6) Using the **OMS TANK FAIL ANALYSIS** with PADJ output and  $\Delta V$ s computed in Step 3, TRAJ computes **OMS TANK FAIL CAPABILITY** and **LEAKING OMS PRPLT BURNS** inputs to the MSM template per Section 3.9.4.5 procedures. Figure 3.12.7-1 cites customary **OMS TANK FAIL CAPABILITY** and **LEAKING OMS PRPLT BURNS** inputs.
- 7) The **PROP to FDO FORM** is used by TRAJ to fill out **OMS QUANTITIES** and **DELTA V AVAILABLE** sections in the MSM template. To locate pertinent **PROP to FDO FORM** data and understand how they are manipulated for MSM input, consider the Figure 3.12.7-2 example.

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PROP to FDO FORM Fri Feb 4 20:33:50 1994

---

STS-60 PLANNING  
 Deorbit MET: 1/14:30 Deorbit TIG: 3/08:35  
 Deorbit Weight: 231524 lbs

Predicted at Deorbit	RCS						OMS			
	L		R		F		L		R	
	OX	FU	OX	FU	OX	FU	OX	FU	OX	FU
Gaged % lb	87.4 1180	88.4 751	85.1 1149	86.4 734	74.6 1007	75.9 645	40.26 3243	44.60 2184	43.27 3485	47.14 2308
Ballast lb	0		0		0		374		374	
Deorbit Redlines	44.1 970		44.1 970		N/A		N/A		N/A	
Usable lbs OMS Deorbit	N/A		N/A		N/A		4533		4901	
Delta V Av OMS Deorbit	N/A		N/A		N/A		201.8		216.2	
Usable lbs RCS Deorbit	1923		1872		1575 --a-----b-- 1536 1485		4533		4901	
Delta V Av RCS Deorbit	N/A		N/A		63.5 --a-----b-- 61.9 59.8		167.2		181.0	
Usable lbs Above Entry R/L	953 --a--c--b-- 605 1347		902 --a--c--b-- 555 1297		N/A		N/A		N/A	
Delta V Av Above Entry R/L	34.9 --a--c--b-- 22.1 49.4		33.0 --a--c--b-- 20.3 47.5		N/A		N/A		N/A	

	Protect lbs	Quantity lbs	pct	Total Delta-V Straight	fps Incnt
a) Aft Quantity 1:	1630	2565	117	522.3	452.5
b) Aft Quantity 2:	146	1081	49	574.7	504.9
c) Aft Hp:		775	35	28.4	

Flight VRCS Usages FRCS->2-X (T/O)

**Figure 3.12.7-2: PROP to FDO FORM Example**

**NOTE:** PROP to FDO FORM data referenced in Steps 7a through 7g are accompanied by numeric examples obtained directly from Figure 3.12.7-2. Numeric results from these steps have been transcribed to corresponding locations in Figure 3.12.7-1.

- a) From the **Gaged %** line, enter all OMS quantities to the corresponding locations in the MSM template.

**CAUTION:** if OMS burns are planned for the upcoming flight day, it may be desirable to supply pre-burn, post-burn, or both data sets to the crew. Either FDO or TRAJ should coordinate these inputs with PROP. In addition, OMS/RCS interconnect planning may render OMS gauging inaccurate. For

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these cases, PROP will want to input the quantities the crew has onboard instead of the actual quantities from the **PROP to FDO FORM**.

- b) From the **Delta V Av OMS Deorbit** line, truncate the sum of **L** and **R OMS**  $\Delta$ Vs at the single fps digit ( $201.8 + 216.2 = 418$ ). Enter this value to the **OMS** line of the MSM template's **DELTA V AVAILABLE** section.
  - c) From the **Delta V Av Above Entry R/L** line's **a** columns, truncate the sum of **L** and **R RCS**  $\Delta$ Vs at the single fps digit ( $22.1 + 20.3 = 42$ ). Enter this value to the **ARCS (TOTAL ABOVE QTY1)** line of the MSM template's **DELTA V AVAILABLE** section.
  - d) Sum the MSM template values entered in Steps 7b and 7c ( $418 + 42 = 460$ ), then enter this value to the **TOTAL IN THE AFT** line of the MSM template's **DELTA V AVAILABLE** section.
  - e) From the **Delta V Av Above Entry R/L** line's **b** columns, truncate the sum of **L** and **R RCS**  $\Delta$ Vs at the single fps digit ( $49.4 + 47.5 = 96$ ). Enter this value to the **ARCS (TOTAL ABOVE QTY2)** line of the MSM template's **DELTA V AVAILABLE** section.
  - f) From the **Delta V Av RCS Deorbit** line's **a** column, truncate the **F RCS** value at the single fps digit (61). Enter this value to the **FRCS (ABOVE QTY 1)** line of the MSM template's **DELTA V AVAILABLE** section.
  - g) Transcribe **Aft Quantity 1** and **Aft Quantity 2** values in the **pct** column (117 and 49, respectively) to corresponding lines of the MSM template's **DELTA V AVAILABLE** section.
- 8) Copies of the completed MSM template are passed by TRAJ to FDO and PROP for review.
  - 9) Upon receiving concurrence from both FDO and PROP, TRAJ transmits completed and approved MSM inputs to MATS.
  - 10) The entire MSM is reviewed by FDO and pertinent disciplines prior to uplink.

### 3.12.8 Hard Copy Book and Clipboard Binder Maintenance

A separate binder for hard copies is maintained at the FDO Console. This binder contains data other than those specifically assigned to a section in the clipboard binder. A complete paper trail of all important computations performed and all data distributed to other operators is made possible with the supplementary information filed in the hard copy book. Hard copies are also used for post-flight analysis, Flight Design products, and reconstruction of FDO Console activities. Checkout Monitor, Vector Compare, FDO Deploy Comp, PADJ curves, Deorbit Summary Table, Execute Package, Rendezvous Constraints Table, weather forecasts, entry analysis/winds, and PSAT hard copies are typical items filed.



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The Clipboard binder is maintained to permit quick and easy storage and access of the following information. Each is a separate section in the clipboard binder.

- 1) **USSTRATCOM** (see Section 3.11): copies of message traffic to and from USSTRATCOM go in this section. These include vectors sent to USSTRATCOM, OCMs and space weather messages received from USSTRATCOM, and RADAR Restriction Messages with RADAR program output.
- 2) **Trajectory Messages**: an uplinked copy of FDO inputs to each Mission Summary Message is in this section. Other special messages to the crew originated by FDO, such as uplinked ReIMo plots, are posted here.
- 3) **Planned/Executed Maneuvers**: DMT hard copies for all planned or executed maneuvers appear in this section. Each DMT should be annotated with its PADed name and its planned/confirmed status.
- 4) **Command Loads**: hard copies of all command loads uplinked by FDO are maintained here.

### 3.12.9 Vehicle-to-Vehicle (V2V) Sightings

On a non-interference basis, predictions supporting crew sightings of other orbiting vehicles can be accomplished with support and coordination from USSTRATCOM, FAO, and POINTING. The first such sightings were made of space station *Mir* during STS-35 in connection with the Shuttle Amateur Radio Experiment (SAREX) operations. The Flight Director Office and USSTRATCOM have informally agreed to support further sighting attempts if USSTRATCOM, MCC, and crew workloads permit.

Sightings from one spacecraft to another spacecraft are very similar to sightings of a spacecraft from a ground observer. Most of the same constraints still apply.

- 1) The target spacecraft must be above the horizon with respect to the observer spacecraft (elevation > 0.0).
- 2) The target spacecraft must be lit by the Sun (solar elevation > 0.0).
- 3) The lit side of the target spacecraft must be roughly facing the direction of the observer spacecraft (solar elongation between ~75° and 180°).

A ground observer has the additional constraint to be in “darkness” since the Sun will wash out the sky. In general, “darkness” is defined as solar elevation less than -6°. This constraint is not completely valid while in orbit since stars and other objects can still be observed even in daylight. However, the best observation is still made while the “observer” spacecraft is in darkness.

Vehicle-to-vehicle sightings exhibit greater variety than ground sightings because acquisition time can vary from a few minutes (like ground sightings) to several hours. These variations depend on the wedge angle and phase rates between the two orbits. Additionally, very long acquisitions can have several periods of sighting potential instead of the usual one for ground sightings.

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A viable sighting target must first be selected. The following selection criteria should be evaluated.

- 1) Target altitude greater than the Orbiter's is highly desirable. This avoids viewing the target against Earth background clutter at closest approach. Lower altitude target sightings near the Earth's terminator are possible (*Mir* was viewed in this geometry during STS-37). Because of this additional restriction on where conjunctions can occur, however, observations are less likely.
- 2) On the order of 10 square meters of bright, diffusely reflecting surface material (solar arrays can help but don't count, as they are specular reflectors) must be distributed more or less evenly over the target. This gives a reasonable chance the target's intrinsic brightness will be adequate, regardless of its attitude with respect to the Sun.

A target state vector is always required before any processing can be accomplished. Many times, there is a specific target of interest that is desired for sighting opportunities. During the early Shuttle Program, the target was usually *Mir*. Later, it was the International Space Station or the Hubble Space Telescope. Contact USSTRATCOM for any target of interest not otherwise available.

There are two sighting prediction methods. The first uses PSAT with an ephemeris anchored on the target vector as a secondary ephemeris to the Orbiter ephemeris. This generates acquisitions akin to TDRS V2V data for the Orbiter. The second method uses Java applet called JavaV2V available on the FDO home page.

### 3.12.9.1 V2V Sightings Using PSAT/AcqMon

PSAT is the only certified V2V acquisitions tool available to the FDO Console. However, PSAT acquisitions only indicate whether or not a line-of-sight unobstructed by Earth exists between two spacecraft. This is a significant shortcoming when predicting sightings because two of the three constraints described above go unchecked. The best that PSAT can provide is AOS, LOS, and pass duration. Once this information has been obtained, assistance from FAO and/or POINTING will be required to determine the geometry between the two vehicles and to the Sun. To obtain PSAT V2V acquisition data, perform the following actions.

- 1) Create an ephemeris for both the target and observer spacecraft.  
NOTE: the target ephemeris must be in TSA Global.  
CAUTION: non-standard TDRSS acquisitions will be associated with the observer spacecraft ephemeris under this procedure. This ephemeris should probably be created in or copied to TSA Local.
- 2) Using the PSAT user interface, select the observer ephemeris for processing. Ensure the T Net = Yes, and the associated EPH button is selected. Click the adjacent EPHEM button to invoke the Secondary Ephemeris Selection (SES) dialog. Highlight the target ephemeris and un-highlight any unnecessary TDRSS ephemerides in the SES. Save and exit the SES.
- 3) Click the Execute button on the PSAT user interface and monitor successful acquisition data generation.

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- 4) Using Acqmon to reference the observer ephemeris, select TDRS acquisitions. The resulting display will contain intervals when unobstructed line-of-sight exists between observer and target.
- 5) Contact FAO or POINTING with AcqMon acquisition times to determine if geometry will provide a sighting opportunity. In addition, FAO will assess crew availability for target viewing and which window(s) will be used during the observation period(s).

Processing ISS as the observer spacecraft and HST as the target spacecraft produce the following AcqMon example.

```
=====
Acquisition Monitor 6.0 (GMT)  AOS
                                TDRS TABLE
                                ISS
                                Local      SSP115      Eph 1
                                GMTR      2006:305:12:00:00.000
=====
```

Mis'n/Daily Orbit	TDRSS	AOS (GMT)	LOS (GMT)	Delta
4/ 5	GE2	305/17:26:58	305/17:50:11	00:23:13
21/ 7	GE2	306/18:30:25	306/18:46:11	00:15:46
21/ 7	GE2	306/19:08:16	307/01:04:03	05:55:47
25/11	GE2	307/01:26:47	307/01:43:16	00:16:29
42/12	GE2	308/02:22:58	308/02:47:24	00:24:26
42/12	GE2	308/03:00:46	308/08:20:12	05:19:26
46/16	GE2	308/08:29:13	308/08:57:32	00:28:19
46/16	GE2	308/09:30:37	308/09:32:16	00:01:39

**Figure 3.12.9.1-1 PSAT Results of ISS viewing HST**

To reiterate, AcqMon only displays line-of-sight acquisition data. There is no indication of lighting conditions or V2V geometry.

### 3.12.9.2 V2V Sightings Using JavaV2V

JavaV2V is an uncertified NASA SkyWatch spin-off application. It uses two Earth orbiting satellites, one as the target vehicle and the other as the observer vehicle, to predict when the observer can make a visual sighting of the target. JavaV2V can assist in the chore of gathering target vectors and provides complete pass geometry information, including line-of-sight projection onto the celestial sphere (SkyTrack display).

JavaV2V was developed after STS-107 when *Columbia's* crew reported seeing what they thought might be ISS and requested MCC confirmation. Checking PSAT, as described in the previous section, revealed ISS was indeed above Earth's limb at the time in question. The FDO Console relayed to the crew that ISS was indeed what they saw. Extensive post-flight analysis indicated ISS was not in fact sighted. Favorable lighting geometry did not support ISS sightings from *Columbia*, and a different satellite was correlated with the crew's report.

The Java V2V applet can be accessed from the FDO home page or at the following URL.

<http://spaceflight.nasa.gov/realdata/sightings/SSApplications/Post/JavaSSOP/JavaV2V.html>

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As shown in Figure 3.12.9.2-1, the JavaV2V user interface is nearly identical to that of NASA SkyWatch v.1.4.

**CAUTION:** JavaV2V is not certified, and its output should be thoroughly checked with PSAT or POINTING before relay to the crew.

If JavaV2V output is consistent with PSAT results, Java V2V can provide good tabular results as well as the SkyTrack image to assist the shuttle or ISS crew in making the sighting. Preliminary testing indicates the applet is very good at making precise V2V sighting predictions.

The screenshot shows the Java V2V User Interface with the following data:

Field	Value
Target Vehicle	HST (TLE)
Observing Vehicle	ISS
Epoch Time (TLE)	06304.22065410
Vector Time (GMT)	2006/305:12:00:00.000
Inclination (deg)	28.469
RA of node (deg)	243.0609
Eccentricity	3.985E-4
Arg of perigee (deg)	186.4751
Mean anomaly (deg)	173.5787
Mean motion (rev/day)	15.0011954
Weight (lbs)	23935.0
Area (sq. ft)	39.7
X (ft)	1846034.188756
Y (ft)	-13734684.144044
Z (ft)	17092581.991641
VX (ft/sec)	24372.570243
VY (ft/sec)	6336.716677
VZ (ft/sec)	2414.349992
Weight (lbs)	470356.2
Area (sq. ft)	5704.87
Start Time (GMT)	2006/305:12:00:00.000
Comment	JavaV2V

Buttons: Next Pass, Next Sighting, SkyWeek, Super SkyWeek

**Figure 3.12.9.2-1: Java V2V User Interface (Vectors From Figure 3.12.9.1-1)**

Like NASA SkyWatch, JavaV2V allows FDO to select a wide variety of target and observing vehicles without having to contact USSTRATCOM. Fortunately, JavaV2V supports Cartesian state vector and ephemeris data input as well as two-line element (TLE) data. For all vehicles except for ISS, the source of TLE data is the Celestrack web site, which generally updates TLEs once each day. For ISS, TOPO who updates ephemeris data three times each week. The following procedures relate to JavaV2V operation.

- 1) Select a target and an observing spacecraft. If the spacecraft is listed in the pull down menu, feel free to use that. If not, enter the vector in the space provided. M50, J2K, TDR, and TLE formats are supported.

**NOTE:** JavaV2V begins processing acquisitions at the ephemeris start or vector epoch, regardless of current time. Processing can be minimized by selecting an ephemeris start or vector epoch shortly before a sighting time interval of interest.

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- 2) Click the Next Pass button to obtain the first time the target spacecraft breaks the observer's horizon, regardless of whether a sighting is possible or not. Using the "Next Pass" button is recommended if a comprehensive table is desired covering the interval from rise to set with observing periods highlighted. Multiple "Next Pass" clicks may be required in order to find a sighting opportunity. Click the "Next Sighting" button to display the next sighting the observer spacecraft has with the target. In this case, the data table will only show those times when the spacecraft is predicted to be visible.  
NOTE: for very large tables, it's advisable to make the table step size larger than the default 20 sec. Use the field provided in the "Variables" tab to adjust time between table records.  
NOTE: the SkyWeek function will produce sightings with the target spacecraft for the next seven days (or whatever interval has been specified in the "Variables" tab). Similarly, the SuperSkyWeek button will produce sightings for all spacecraft in the target selection list for the entire week (or specified interval).
  
- 3) Check the Table tab for most recently computed digital acquisition results (these are displayed automatically after Next Pass/Sighting processing). The following example table was obtained from the foregoing input vectors and illustrates the beginning of a sighting shortly after HST rises above the ISS horizon.

The screenshot shows the Java V2V software interface with the 'Table' tab selected. The interface includes several input fields for acquisition and loss of signal times, time of closest approach, max elevation, vehicles, and a comment. A message states 'A sighting is possible on this pass.' Below this is a table with the following data:

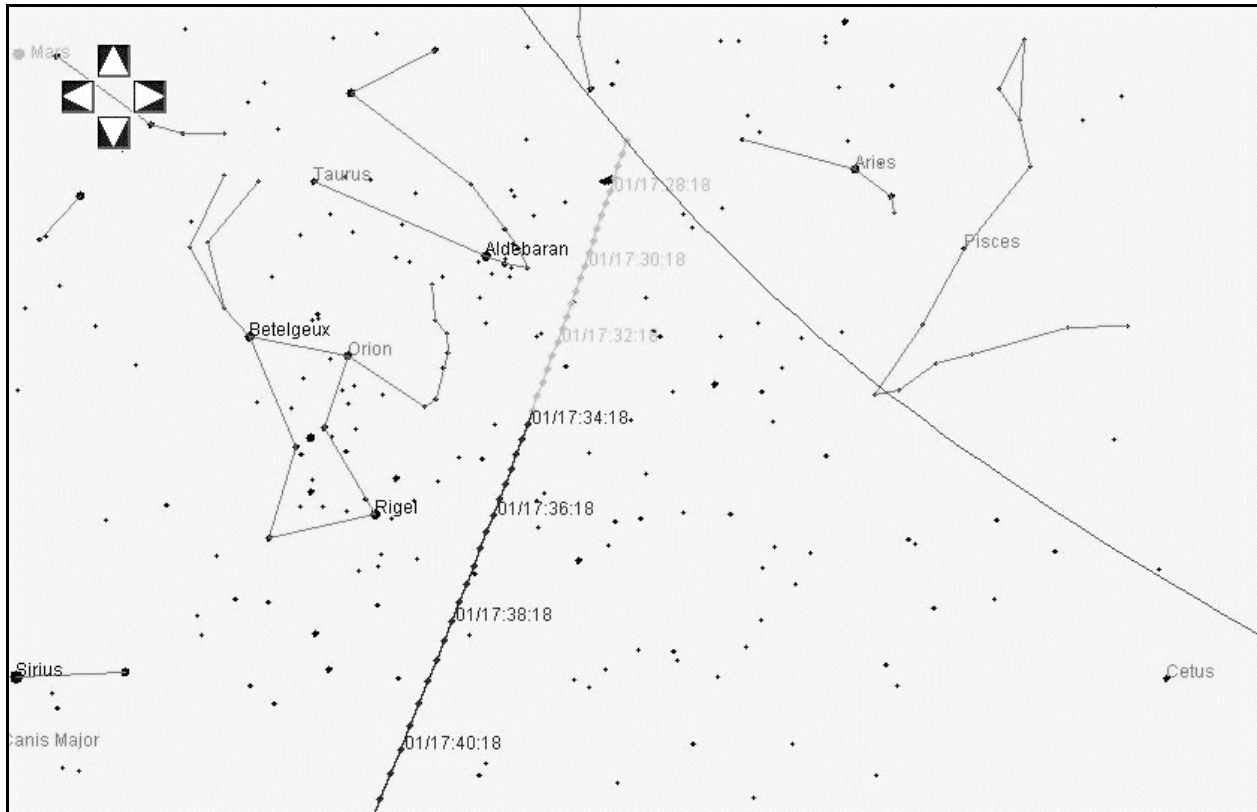
Time (GMT)	Azimuth	Elevation	Range	TGT Solar	Solar Elong	OBS Solar
DOW/MM/DD/HH:MM:SS	Deg E of N	Deg	NM	Alt (Deg)	Deg	Alt (Deg)
Thr Nov 01/17:33:18	265.0	004.5	02719	030.2	151.6	062.6
Thr Nov 01/17:33:38	263.7	004.7	02705	031.4	150.6	063.7
Thr Nov 01/17:33:58	262.4	004.9	02691	032.7	149.5	064.8
Thr Nov 01/17:34:18*	261.0	005.0	02678	033.9	148.4	065.9
Thr Nov 01/17:34:38*	259.7	005.2	02666	035.2	147.2	067.0
Thr Nov 01/17:34:58*	258.4	005.4	02654	036.4	146.0	068.0
Thr Nov 01/17:35:18*	257.1	005.6	02642	037.7	144.8	069.1

At the bottom of the interface are buttons for 'Next Pass', 'Next Sighting', 'SkyTrack', 'STOP!', and 'Print...'.

Figure 3.12.9.2-2 Java V2V Tabular Output

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- Click the SkyTrack button to display lines of sight from the observer to the target spacecraft projected onto the celestial sphere. The following example is consistent with the preceding digital table.  
NOTE: the observer's Earth's horizon projection is only applicable at the moment of AOS by default. Horizon mappings at TCA and LOS times may be specified using the Variables tab.



**Figure 3.12.9.2-3 Java V2V SkyTrack Output**

- Run PSAT with the same trajectories and verify acquisition times are consistent.  
NOTE: AOS and LOS times can vary by as much as 2 min if horizon crossing is not well defined.
- Contact FAO or POINTING with the times of the sighting to determine if crew availability will permit a viewing and which window(s) will be used during the observation period(s). Provide bright stars or constellations the target spacecraft will be passing through at what times.

### 3.12.10 Prelaunch Winds/Loads Updates

During the period L -13 hrs to L -1 hr, the WINDS coordinator gathers and analyzes launch and abort winds data, including balloon files and forecasts for the TAL and ConUS landing sites. Prior to Ascent FDO's arrival, products from this analysis begin arriving at the FDO Console. The Planning Team FDO posts copies of the TAL and ConUS winds on the weather (WX) clipboard and logs any off-nominal items (balloon bursts, etc) from the

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WINDS coordinator. These items are part of the handover between the Planning and Ascent FDO. The WINDS Coordinator will promote electronic forecast winds files into the Global/Winds/ directory whenever they become available.

### **3.12.11 TRAJ Duties In Lieu Of LSO**

The Landing Support Officer (LSO) is the focal point for much of the coordination for worldwide Orbiter landing support. During a nominal entry, LSO performs the following functions.

- 1) Act as liaison between MCC and external interfaces such as the State Department, FAA, Search and Rescue operations, DOD facilities, and augmented landing sites
- 2) Provide information to the site on Orbiter status (deorbit burn time, landing time, etc.)
- 3) Update MCC on landing site status (runways and nav aids)
- 4) Run the Approach and Landing Processor (ALP) using forecast and balloon weather data as a backup to Entry Dynamics Simulator (EDS) analysis

During a mission, LSOs support ascent, entry, and a daily telecon to tagup with PLSs. There will be an LSO on-call during the remainder of the flight. During the on orbit phase when an LSO is not on console, TRAJ is responsible for fielding LSO questions and performing LSO duties as needed.

#### **3.12.11.1 Nominal Duties**

LSO duties for which TRAJ is responsible include the following items.

- 1) Answer questions regarding
  - a) Site release schedules
  - b) Runway or navaid status
  - c) Weather at a site
- 2) Receive runway or navaid status updates from sites
- 3) Monitor the daily telecon at 9:30 AM Central time on Landing Field Prime 1 (LFP 1) or via phone, as time and work load permit
- 4) Perform LSO duties as needed during an emergency deorbit situation

After the daily telecon, LSO writes a Flight Note to FDO summarizing current NOTAMs as well as ConUS and ELS site status (see Figure 3.12.11.1-1). Weather information may be included if it impacts site operations. After launch, LSO updates the site release schedule as needed and distributes it to the sites and to FDO. The FDO site release schedule copy resides in the data book. Sites may call on the phone or on LFP 1 to update their status. Note they may ask for LSO even though TRAJ will take the call.

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FLIGHT NOTES	
To: FDO	10/31/92
FROM: LSO	
NOTAMS: (No change)ROBERTS NOT RECOMMENDED	
GUAM PRIMARY TACAN DOWN	
EDW LAKEBEDS RED	
LANDING SITES:	
KSC - GREEN, CONVOY READY TO SUPPORT REV 159 LANDING	
NOR -	
EDW - LAKEBEDS RED, CONVOY WILL NOT BE AVAILABLE ON EOM DAY	
GUA - TYPHOON MAY HIT TOMORROW; WILL CALL FDO CONSOLE TODAY	
AT APPROX 1457; THEY'LL BE REQUESTING EARLY RELEASE TO SECURE EQUIPMENT; J. BANTLE HAS APPROVED THEIR EARLY RELEASE -- THEIR CALL TO DO WHAT'S NECESSARY	
JSC Form 1033 (Mar 79)	

**Figure 3.12.11.1-1: Sample Flight Note from LSO**

### 3.12.11.2 Emergency Deorbit Duties

**CAUTION:** this material is provided for introductory and personal study purposes only. During an emergency deorbit, refer to the Emergency Deorbit Checklist in Section 4.9.20.

During an Emergency Deorbit, the first priority is deorbit targeting and PADs generation. If time permits, the Entry FDO, TRAJ, GPO, and LSO should be called in ASAP. TRAJ will provide LSO support until an LSO can arrive. In this capacity, if deorbit is imminent, TRAJ must notify the targeted landing site to clear airspace for the Orbiter. The US State Department must be contacted prior to notifying an overseas non-DOD site. This helps insure the Orbiter's arrival isn't considered a hostile violation of foreign airspace. Also, if site personnel don't speak English, an American Embassy can be contacted by the State Department to help notify the site of the Orbiter's pending arrival. In summary, the following tasks are performed during an emergency deorbit.

- 1) Generate deorbit targets and PADs.
- 2) Call in the Entry FDO, TRAJ, GPO, and LSO.
- 3) If the Section 4.9.20 Emergency Deorbit Checklist calls out an LSO duty before an LSO arrives, TRAJ should be prepared to perform the following actions.
  - A) Establish communication with the targeted landing site.

**CAUTION:** up-to-date site phone numbers can be found under the glass at the FDO or LSO consoles.



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- a) If this is a ConUS site, contact "LRD" for KSC, "WGM" for NOR, or "GOM" for EDW on LANDING FIELD PRIME 1 or via phone.
  - b) If this is a DOD site, contact the SOC (call sign "DOD CAPE") on DDMS COORD, and have them notify the site. The SOC may also be contacted via phone. DOD sites include Andersen, Bermuda, Diego Garcia, Honolulu, Moron, and some East Coast Abort Landing Sites (ECALs).
  - c) If this is a non-DOD site in the US, call FAA HQ Flow Control Duty Officer (FCDO).
    - i) Advise FCDO of targeted landing site and touchdown time.
    - ii) Call Houston Voice on VOICE CTRL loop and establish FAA loop communications to FAA Ops Center. Request an FAA loop patch with landing site's tower or contact tower directly via phone.
  - d) If this is a non-DOD site outside the US, contact the State Department Watch Officer (SDWO). Have SDWO notify NASA Liaison from Advanced Technology. When the NASA Liaison arrives, call Houston Voice on VOICE CTRL and request STATE DEPT loop activation.
    - i) Advise NASA Liaison of landing site and Orbiter touchdown time.
    - ii) Have NASA Liaison request airspace and runway clearance.
    - iii) Attempt comm with site as listed on LSO phone list and hope personnel speak English.
- B) When communication is established with the site, provide the following landing information.
- a) Request Orbiter airspace and runway clearance.
    - i) Provide time and coordinates for Orbiter @ 60 Kft. Obtain these from ENTRY ELAPSED TIME (EET, MSK 505) at M = 1.5.
    - ii) Provide touchdown time and runway.
  - b) Advise that the Orbiter has no go-around or taxi capability.
  - c) Advise that hypergolics are on board. Recommend a 1250 ft corridor around the Orbiter be maintained post-rollout.
  - d) Recommend no approach to the Orbiter unless requested by crew.
- C) Try to establish the status of runways and nav aids.
- a) Are MSBLS (augmented sites) and TACAN nav aids operable?
  - b) Are visual landing aids (PAPIs and BallBar) operable at augmented sites?

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- c) What are surface conditions on the runway or lakebed (wet, dry, ice, debris)?
- d) What is the weather status (surface winds, ceiling, visibility, and altimeter setting)?
- e) In the case of a night landing, are Xenon lights (at augmented sites) or approach/edge lights active?
- f) What is the status of fire, crash, and rescue forces?

**CAUTION:** the Daily PLS Convoy needs at least 4 hours' notice and is only on call until 4 hrs before the PLS landing time. Convoys at other times or sites are available strictly on a best effort basis. High-speed tracking ( $\geq 2$  sites required for filter) is available only to EDW, NOR, and KSC. In addition, HNL has 1 high-speed site, but the probability of Orbiter acquisition on an HNL approach is very low. It is also unlikely the HNL high speed radar could be manned in time to support an emergency deorbit.

### 3.12.12 Weather Briefing Coordination

During nominal orbit operations, Spaceflight Meteorology Group (SMG) personnel supply weather forecasts on a daily basis. These forecasts are issued just prior to the daily Mission Management Team (MMT) meeting and cover ConUS landing opportunities during the current and following 2 flight days. The day before a planned deorbit, SMG forecasts are issued on a shift-by-shift basis until landing.

On orbit, the SMG's FCR point-of-contact is the FDO Console. Forecast sheets for FD, CAPCOM, and FDO are transmitted to the FDO Console, where circled weather violations of Flight Rule A2-6 criteria are checked. Any mistakes should first be verified with SMG via the Weather voice loop, then corrected on the sheets. Following FDO concurrence, the sheets are distributed to FD and CAPCOM. At this point, FD may call for a formal briefing by SMG on the Flight loop. It's FDO's task to coordinate this briefing with SMG over the Weather loop. Because of limited support during nominal orbit operations, SMG personnel will not be available to provide formal briefings to all FCR shifts. If FD requires a contingency briefing at a time when all personnel are off-duty, SMG can be contacted via phone or beeper using information in the FDO Data Book. Since jargon in SMG forecast sheets is unfamiliar to many operators, some of the more commonly encountered METAR terms and acronyms are defined in Figure 3.12.12-1 below.

Category	Abbreviation	Definition
CLOUDS	-	Thin (preceding SCT, BKN, or OVC implies $\leq 0.5$ cloud cover is opaque)
	BKN	Broken ( $\frac{4}{8} < \text{cloud cover} < \frac{8}{8}$ )
	CAVOK	Ceiling and visibility OK (visibility $> 6$ miles; clear below 5000 feet)
	CLR	Automated station report of clear conditions below 12000 feet
	CB	Cumulonimbus
	CU	Cumulus
	FEW	Few ( $\frac{0}{8} < \text{cloud cover} < \frac{2}{8}$ )
	OVC	Overcast ( $\frac{8}{8}$ cloud cover)
	SCT	Scattered ( $\frac{2}{8} < \text{cloud cover} < \frac{4}{8}$ )

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Category	Abbreviation	Definition
	SKC	Clear ( $\frac{0}{8}$ cloud cover)
	TCU	Towering Cumulus
	V	Variable cloud cover
WIND (DDSSGXX)	DD	True heading from which wind is blowing in 10s of degrees
	SS	Steady-state wind speed in knots
	G	Gust wind speed prefix
	XX	Gust wind speed in knots
	VRB/YY	Variable wind direction at speeds $\leq$ YY knots
PRECIPITATION	DZ	Drizzle
	GR	Hail
	GS	Small hail or snow pellets
	IC	Diamond dust
	PE	Ice pellets
	RA	Rain
	SG	Snow grains
	SN	Snow
	UP	Unknown precipitation
OBSCURATION	BR	Mist
	DU	Widespread dust
	FG or F	Fog
	FU	Smoke
	HZ	Haze
	PY	Spray
	SA	Sand
	VA	Volcanic ash
	X	Sky totally obscured
	-X	Sky partially (0.1 to 0.9) obscured
OTHER WX	DS	Dust storm
	FC	Funnel cloud
	NSW	No significant weather
	PO	Well developed dust or sand whirls
	SH	Showers
	SQ	Squall
	SS	Sandstorm
	TS	Thunderstorm
	WS	Wind shear
DESCRIPTORS	-	Light
	"no sign"	Moderate
	+	Heavy
	AO	Automated observations
	AOA	Augmented automated observation
	BC	Patches
	BECMG	Becoming
	BL	Blowing
	DR	Drifting
	FM	From
	FZ	Supercooled or freezing
	LDG	Landing

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Category	Abbreviation	Definition
	M	Minus
	MI	Shallow
	PROB	Probability
	RE	Recent
	RMK	Remark
	RWY	Runway
	TEMPO	Temporary
	TKOF	Takeoff
	VC	Vicinity
UNITS	A	Inches Hg * 100 (air pressure)
	KMH	Kilometers per hour
	KT	Knots
	MPS	Meters per second
	Q	HectoPascals (air pressure)
	SM	Statute miles

**Figure 3.12.12-1: SMG Forecast Sheet Nomenclature**

Example: Aviation Routine Weather Report (METAR = hourly; SPECI = special)

**KPIT 1955Z 22015G25KT 3/4SM R22L/2700FT TSRA OVC010CB 18/16 A2992**

<b>KPIT</b>	ICAO location indicator
<b>1955Z</b>	Issuance GMT hrs (hh) and min (mm) in hhmm format
<b>220</b>	True azimuth wind direction in °
<b>15G25KT</b>	Steady state and gust wind speeds in kts
<b>3/4SM</b>	Prevailing visibility in statute mi
<b>R22L/2700FT</b>	Runway designator and associated visual range in ft
<b>TSRA</b>	Significant present, forecast, and recent weather
<b>OVC010CB</b>	Cloud coverage, height (in kilofeet * 10), and type
<b>18/16</b>	Current air temperature and dew-point temperature in °C
<b>A2992</b>	Altimeter setting in inches Hg * 100

Observations transmitted via METARs and SPECIs are supplemented by International Aerodrome Forecasts (TAF = routine; TAF AMD = amended).

Should a contingency deorbit be under consideration during a period when SMG is off-duty, TRAJ is responsible for obtaining the latest ConUS and ELS observations. A table of these coded observations is available from SMG's web page, and a link is provided on the FDO home page. On the workstation, an SMG web page can be accessed via the FDO DNAV path Applications/Tools/Weather. For updated weather observation data, click on the "ELS OBS" tab in the left margin. See Figure 3.12.12-2 for an abbreviated example of SMG web page output.

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LATEST WEATHER OBSERVATIONS SPACEFLIGHT METEOROLOGY GROUP															
TIME 1514Z DATE 9/11/1997															
UNITED STATES															
ID	HMS	CLOUDS			VIS	WX	TF	DPF	TC	DPC	WIND	GUS	ALT	DENSAL	
KSC	1455	SCT025	BKN210		10		84	73	29	23	20003		29.99	1884	
EDW	1456	SCT040			30		70	52	21	11	21007		29.84	3809	
NOR	1455	SCT060	SCT100		40		70	57	21	14	VRB05		30.06	5802	
DOV	1455	BKN020	BKN070	OVC120	7		77	72	25	22	20011		29.96	1493	
DYS	1455	BKN070	BKN250		7		75	50	24	10	16010		30.04	3254	
EDF	1455	SCT034	SCT050		15		45	45	7	7	06001		30.01	-643	
FMH	1455	SCT007	BKN011	OVC025	7		66	61	19	16	08008		30.17	569	
HNL	1450	SCT028	SCT060		10		76	70	24	21	08006		29.92	1437	
LNK	1454	SCT095			10		66	52	19	11	15008		30.04	1958	
MUO	1455	SCT055	BKN120	BKN220	30		61	55	16	13	30007		29.80	4157	
MUO	1503	SCT055	BKN120	BKN220	30	TS	61	55	16	13	27005		29.80	4157	
MWH	1452	SCT049	SCT110		10		67	56	19	13	VRB03		29.71	2418	
MYR	1450	SCT060	SCT150		10		75	68	24	20	09005		29.94	1342	
NKT	1455	SCT005	BKN020	OVC050	5	FG	71	68	22	20	00000		30.02	1000	
NTU	1456	SCT020	BKN035	OVC090	7	-SHRA	71	68	22	20	14008		29.95	1072	
ORL	1450	CLR			10		88	68	31	20	VRB03		29.98	2212	
PSM	1455	OVC008			7		63	61	17	16	07007		30.21	293	
RCA	1455	SCT050	SCT090	BKN220	30		61	48	16	9	31003		29.82	4436	
CANADA															
ID	HMS	CLOUDS			VIS	WX	TF	DPF	TC	DPC	WIND	GUS	ALT	DENSAL	
YAW	1500	BKN020			15		63	55	17	13	36006		30.22	317	
YJT	1500	BKN016			15		57	48	14	9	02005		30.22	-221	
YQX	1500	OVC002			3	DZ	52	52	11	11	01015		30.16	48	
YYT	1500	OVC002			1	DZ	54	52	12	11	01012		30.05	261	
CARRIBEAN															
ID	HMS	CLOUDS			VIS	WX	TF	DPF	TC	DPC	WIND	GUS	ALT	DENSAL	
BDA	1455	SCT024			7		81	72	27	22	03009		30.11	1550	
ZQA	1500	SCT015			7		86	77	30	25	15011		29.94	2127	
SOUTH AMERICA															
ID	HMS	CLOUDS			VIS	WX	TF	DPF	TC	DPC	WIND	GUS	ALT	DENSAL	
						AWG	NOT AVAILABLE								
						BGR	NOT AVAILABLE								
						BRF	NOT AVAILABLE								
						CIP	NOT AVAILABLE								
EQU	1500	SCT040	BKN300		7		66	43	19	6	17005		30.27	11517	
OCA	1500	SCT030			7		88	70	31	21	07008		29.94	2174	
						VMI	NOT AVAILABLE								

**Figure 3.12.12-2: SMG WWW Page "ELS WX" Example**

Columns in the SMG WWW page are defined as follows.

- 1) **ID** is the landing site's ICAO ID.
- 2) **HMS** is the observation's GMT in 24-hour hhmm format.

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- 3) **CLOUDS** contains cloud cover and height (in kilofeet \* 10) for each observed deck.
- 4) **VIS** is the visibility in statute mi.
- 5) **WX** contains any precipitation or fog notation.
- 6) **TF** is surface air temperature in °F.
- 7) **DPF** is surface dew-point temperature in °F.
- 8) **TC** is surface air temperature in °C.
- 9) **DPC** is surface dew-point temperature in °C.
- 10) **WIND** is wind direction dd (°/10) and speed ss (kts) in ddss format.
- 11) **GUS** is wind gust speed in kts.
- 12) **ALT** is altimeter setting in inches Hg.
- 13) **DENSAL** is density altitude in ft.

### 3.12.13 TDRSS Scheduling

Finite TDRSS resources must be scheduled among an ever-increasing number of user spacecraft, including the Shuttle. Each user has a planned TDRSS priority timeline subject to sudden changes if any user declares an emergency. Particularly when the Shuttle's priority is low, conflicts with other users may result in planned communications outages outside the typical ZOE. Any planned outage should involve coordination with and situational awareness from all Flight Control Team members.

At any point during a mission, GC is responsible for communicating current TDRSS scheduling to the Flight Control Team. The current schedule is accessed using the Master DNAV menu path **Shuttle/GC/Print SHO**. This will invoke a TDRS show selection menu. On this menu, select the flight number and then press the "View SHO" button. This will invoke the current TDRS Scheduling Display, as illustrated by Figure 3.12.13-1. The display is exited by pressing the return key when focus is directed at its window. In contrast to TDRS acquisitions displayed by PSAT, (see Section 3.4.2), which account only for Earth blockage, TDRSS acquisition times in GC's display also reflect communication outages due to handovers and resolved conflicts with other users. Although, GC's display only provides AOS (EVENT START) and LOS (EVENT STOP) in GMT, FDO consults it regularly to verify planned communications will support critical trajectory events.

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STS086 TDRSS SCHEDULE						
STS086 TDRSS SCHEDULE						
GMT: 262:23:46:21						
ORB	STA	EVENT START	DURATION	EVENT STOP	H/O	COMMENTS
---	---	-----	-----	-----	---	-----
29	W-TDW	262:23:59:43	00:57:01	263:00:56:44	NORMAL	
29	E-TDE	263:00:57:04	00:38:59	263:01:36:03	NORMAL	
29	Z-TDZ	263:01:35:00		263:01:38:26		TDRS-Z H/O
-----						
30	W-TDW	263:01:37:26	01:00:32	263:02:37:58	NORMAL	
30	E-TDE	263:02:38:18	00:34:51	263:03:13:09	NORMAL	
30	Z-TDZ	263:03:12:09		263:03:19:25		TDRS-Z H/O
-----						
31	W-TDW	263:03:18:25	01:02:24	263:04:20:49	NORMAL	
31	E-TDE	263:04:21:09	00:31:28	263:04:52:37	NORMAL	
-----						
32	W-TDW	263:05:01:19	00:59:08	263:06:00:27	NORMAL	
32	E-TDE	263:06:00:47	00:34:34	263:06:35:21	NORMAL	
-----						
current TDRSS schedule: END						

**Figure 3.12.13-1: Current TDRSS Scheduling Display**

FDO also regularly seeks status regarding any identified TDRSS conflicts between the Shuttle and other users.

A conflict resulting in communications loss during a critical trajectory event should be a rare occurrence because most critical periods to SSP operations can be identified and coordinated prelaunch. However, unexpected launch slips and emergencies may arise which render previous coordination invalid. In such cases, FDO must work with GC and DFE to communicate SSP's requirements to network managers, or the critical trajectory event must be rescheduled around the conflict. Note that most burns aren't communications-critical. If a burn must be performed during a communications outage, it can be confirmed using RES targeting with help from the crew (see Section 3.7).

### 3.12.14 Ground-Up Rendezvous State Vector Transfers

Network elements, payload customers, and international partners frequently require prelaunch trajectory data for planning purposes. On missions with fixed ground tracks, Flight Design products satisfy these requirements. Unfortunately, ground-up rendezvous trajectory plans are unreliable even as late as FRR Cycle because the target's phase angle at launch is uncertain. The phasing plan will also undergo fundamental changes if the launch date slips. Final ground-up rendezvous trajectory data are therefore required from the Planning Team prior to any launch attempt. Many trajectory data requirements are documented in flight-specific publications such as a Flight Rules Annex or a JOIP.

A Memorandum of Agreement (MOA) between JSC and Sunnyvale (reference NASA-JSC letter DM3/01-04) documents trajectory coordination requirements associated with Remote Tracking Site (RTS) support to the Shuttle Program. At the time this MOA was written, the RTS network was controlled from Onizuka AFS in Sunnyvale, CA. In 2004, this

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function was transitioned to Schriever AFB near Colorado Springs, CO. In addition, dedicated NASCOM IIRV state vector transfers supporting trajectory coordination with Onizuka during flight have been replaced by TWA postings (see Section 3.11.8). Most TWA users require greater posted trajectory precision than RTS acquisitions planning by Center for Research and Support (CERES) personnel at Schriever. Consequently, TWA posting requests from CERES will be relatively rare. However, when such requests are received via DFE, they should be handled on a best-effort basis. Without RTS support, Ops Recorder dumps containing Orbiter telemetry accumulated during LOS periods must be conducted through TDRSS, potentially conflicting with other mission activities.

**NOTE:** most Ops Recorder dumps to RTS are performed in a downlink-only (1-way) communications mode. This permits 2-way TDRSS communications to be conducted simultaneously with the dump, providing maximum bandwidth. However, it is possible to perform 2-way communications with an RTS during TDRSS outages. During such periods, range, range-rate, azimuth, and elevation tracking data are sent to MCC from the site along with telemetry. Although it may be possible to view and edit these data in TrS with the LSIP, RTS tracking data are currently uncertified for orbit determination purposes.

### 3.12.15 Electronic Deorbit/Landing Data Transmission

This section provides a procedure to transmit Deorbit and Landing Data (DOL) and Entry Ground tracks in a form that may be posted to World-Wide Web (WWW) sites for viewing with any WWW browser. Typically, the procedure is invoked to deliver a DOL HTML file and ground track graphics files to PAO for subsequent posting.

**NOTE:** this procedure will generally not relieve FDO of the obligation to publish DOL and entry ground track data to Distribution D via printed media. Procedures to generate DOL data are beyond the scope of this volume and are maintained in Section 4.5.1.

- 1) Generate your DOL in the workstation using standard Section 4.5.1 procedures.
- 2) In an x-term window, change the current directory to `~fdo/Data/SSPxxx`, where `xxx` is the appropriate flight number. Next, create a new directory within the current directory named `sityyy`, where `sit` is the targeted landing site and `yyy` is the deorbit TIG rev. The following example UNIX commands are for an STS-85 deorbit to EDW with TIG on rev 120.

```
cd ~fdo/Data/SSP085
mkdir EDW120
```

- 3) With the completed DOL subscribe view visible on the workstation, open the XVIEW tool (FDO DNAV path Applications : Tools : XV) to grab, crop, reformat, and save the image. For detailed XV instructions, refer to Appendix 3.H.
  - a) Using XV, crop the DOL to remove unwanted data.
  - b) Using XV, modify the color and pixel dimension. Select 'Color Editor' from the 'Windows' pulldown button. In the column titled 'Colormap Editing' (leftmost column), select the 'Grey' button. Select the 'DIM' button and then the '1' button to specify one-bit pixel depth.



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- c) Save the file in the directory created in Step 2. Select 'Save' from the XV menu. Set 'Format' to GIF and 'Colors' to Greyscale. Save the DOL as EDW120\_pad.gif, for example (name must end with "\_pad.gif").
- 4) Using XV, crop and save the long, mid, and close range groundtracks as GIF files.
  - a) Insure the Entry Ephemeris and K51 MED are consistent with your DOL, then start the Entry Ground Track application by selecting "Entry/Groundtrack" from the FDO DNAV.
  - b) From the Entry Ground Track menu, select "Sequence/Scale Range 120 x 120 deg".
  - c) Using XV, grab the ground track image.
  - d) Crop the image to remove unwanted data.
  - e) Save the groundtrack in the directory created in Step 2 as EDW120\_long.gif, for example. Save the file in color.
  - f) From the Entry Ground Track menu, select "Sequence/Scale Range 14 x 14 deg". Repeat steps 4c through 4e using a save file name of EDW120\_mid.gif, for example.
  - g) From the Entry Ground Track menu, select "Sequence/Scale Range 1 x 1 deg". Repeat steps 4c through 4e using a save file name of EDW120\_close.gif, for example.

**NOTE:** the ~fdo/Data/SSPxxx/sityyy directory should now contain four separate files: one gif file containing the DOL data and three GIF files containing long, mid, and close range entry groundtrack plots. This configuration may be verified for the example scenario using the UNIX command `ls -l ~fdo/Data/SSP085/EDW120`.

- 5) Execute the DOL Convert UNIX shell script, creating a DOL file containing the DOL and the three groundtracks. This file will be formatted for WWW posting. The only argument the script requires is the sityyy substring associated with the .gif filenames. In the example scenario, the following UNIX command would be transmitted from an xterm window.

```
$USSCRIPTS/dol.convert EDW120
```

**NOTE:** the script will place updated DOL HTML data in the current directory using the filename DOL.html.

- 6) Use standard IPS file transfer procedures (see Appendix 3.I) to transfer the .html file, and .gif files to a PC.
- 7) Once all five files have been received via PC e-mail, save the attachments to an appropriate directory such as v:\fdo\STSxxx\entry\EOM\KSC###, where ### is the D/O TIG rev.
- 8) Verify the DOL data are complete and that the three Entry Ground Track plots are displayed below the DOL table.

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- 9) Deliver the five files to PAO via e-mail or by copying them to PAO's drop box at path `\\jsc-fs01\ap\PAO_Drop_Box\`.

### 3.12.16 NASA SkyWatch Posting Procedures

NASA SkyWatch is a web-based Java application. It predicts acquisition data for Earth orbiting satellites and will determine if any pass will be visible to a ground observer. Originally, NASA SkyWatch was designed as a replacement to the Shuttle Sighting Opportunities Program (SSOP) and was named JavaSSOP.

NASA SkyWatch resides on the Public Affairs Human Spaceflight web page (URL = `www.spaceflight.nasa.gov`) using a network of 4 "production" servers. PSINet maintains these servers under contract to NASA. To support high-volume public access, a single "staging" server is mirrored to the other 3. Generally, the mirrors are updated every half-hour.

NOTE: staging server access is only permitted from a pre-defined set of PCs for security purposes. In MCC OPS, the only PCs with staging server access privileges are at the FDO and TRAJ consoles. Obtain the staging server's NASA group ID and password from DM32/Bill Tracy (FDO SkyWatch point-of-contact) or DM33/Erin Hammond (TOPO SkyWatch point-of-contact) before attempting access. This information is also available from Kim Dismukes (JSC/PAO/Curator) at 281-483-4251 (voice) or 713-708-0528 (pager). The staging server IP address is 38.201.67.72.

NASA SkyWatch is supported by an Ephemeris Post-Processor Java application running once every hour on the staging server. Its job is to poll an inbox directory for ephemeris or TLE information, parse that data into a format easily read by NASA SkyWatch, and place the resulting files in a pre-determined location NASA SkyWatch can access. Finally, the Ephemeris Post-Processor will clean out the inbox and await the next input.

In addition to routing SkyWatch files, the Ephemeris Post-Processor scans each ephemeris file and creates an SVPOST text file for viewing by web browsers. An SVPOST file contains state vectors and TLEs at daily intervals and after each maneuver in the ephemeris. These data are generated until the ephemeris ends or its first 48 hours are polled, whichever occurs first. Maneuvers are summarized in a mission plan table that contains impulsive TIGs, M50 and LVLH  $\Delta V$  components, the  $\Delta V$  magnitude, and post-maneuver apogee and perigee heights. The SVPOST file is output to vehicle-specific sub-directories in the server path `realdata/sightings/SSapplications/Post/JavaSSOP/orbit/`. The server directory tree is illustrated in Figure 3.12.16-1, and an SVPOST example appears in Figure 3.12.16-2.

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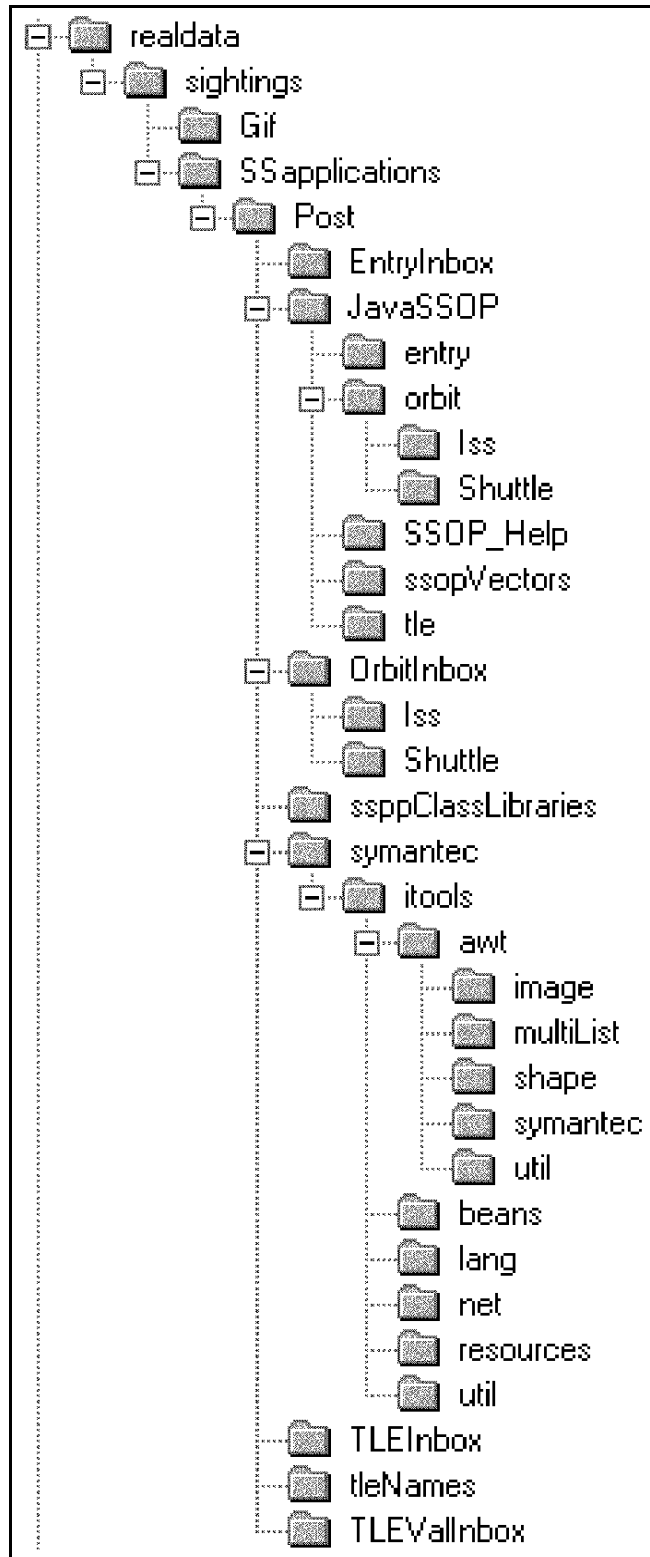


Figure 3.12.16-1: Server Directory Tree

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```
Lift off time (UTC) : N/A
Area (sq ft) : 1400.0
Drag Coefficient (Cd) : 2.0
90 day mean solar flux (jansky) : 172.0
12 month mean earth geomagnetic index : 2.39
```

Maneuvers contained within the current ephemeris are as follows:

IMPULSIVE TIG (GMT)	M50 DVx(FPS)	LVLH DVx(FPS)	DVmag(FPS)
IMPULSIVE TIG (MET)	M50 DVx(FPS)	LVLH DVx(FPS)	Invar Sph HA
DT	M50 DVx(FPS)	LVLH DVx(FPS)	Invar Sph HP

-----  
There are no maneuvers.

Coasting Arc #1 (begining on orbit 3809)  
-----

```
Vector Time (GMT): 2000/093/20:20:00.000
Vector Time (MET): N/A
Weight (LBS) : 72507.0
```

M50 Cartesian	M50 Keplerian
X = -6238406.49	A = 6737802.99 meter
Y = 2378162.45 meter	E = .0018466
Z = -829086.00	I = 51.67662
XDOT = -2399.541293	Wp = 26.02614
YDOT = -4236.540899 meter/sec	RA = 164.76550 deg
ZDOT = 5969.254966	TA = 324.93616
	MA = 324.99872
	Ha = 195.454 n.mi
	Hp = 185.700

M50 Cartesian	J2K Cartesian
X = -20467212.89	X = -6260499.82
Y = 7802370.24 feet	Y = 2308297.61 meter
Z = -2720098.43	Z = -859453.24
XDOT = -7872.510803	XDOT = -2381.007630
YDOT = -13899.412398 feet/sec	YDOT = -4263.262636 meter/sec
ZDOT = 19584.169836	ZDOT = 5957.640172

The mean element set is posted at the UTC for which position is just north of the next ascending node relative to the above vector time

TWO LINE MEAN ELEMENT SET

```
ISS
1 25544U 98067A 00093.84887981 .00046000 00000-0 42000-3 0 9006
2 25544 51.5874 165.6222 0008830 10.3175 349.8166 15.71913071 38106
```

**Figure 3.12.16-2: SVPOST Text File Example**

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### 3.12.16.1 Starting The Ephemeris Post-Processor

Following a staging server crash, it will be necessary to manually restart the Ephemeris Post-Processor. Invoke a Telnet client from PC Start menu path Programs : Communications: QvtTerm : Terminal, then connect to the staging server at IP address 38.201.67.72. Once connected, navigate to the Post directory as follows.

```
cd /var/webfiles/html/www/realdata/sightings/SSapplications/Post
```

To start the ephemeris post processor, type the following case-sensitive command.

```
nohup java ssppX2 > /dev/null/ &
```

Verify the Ephemeris Post-Processor has started by obtaining its process ID with the following command.

```
ps -ef | grep java
```

**NOTE:** the Ephemeris Post-Processor can be triggered into immediate execution by first terminating it with a `kill <process ID>` command, then restarting it with the foregoing `nohup` command.

### 3.12.16.2 Routing TSA Input Data To The Ephemeris Post-Processor

To get orbit trajectory input data to the Ephemeris Post Processor, three files must be copied from a TSA Ephem directory to a vehicle-specific sub-directory in the staging server path `/var/webfiles/html/www/realdata/sightings/SSapplications/Post/OrbitInbox/`. The three TSA source files are `eph.data`, `eph.asc`, and `eph.orb`. Data transfer is accomplished by invoking an FTP client from the PC Start menu path MCC Menu : Mail & Communications : WS\_FTP95 LE.

**NOTE:** small format differences exist between TUPable TSA ephemerides (`Eph<1-8>` in the Ephem directory tree) and mirrored Trajectory Server ephemerides (`EphM<1-10>` in the Ephem directory tree). Because the Ephemeris Post-Processor uses space-delimited logic to scan ephemeris files, these differences are not significant.

If it's necessary to establish or delete a new vehicle-specific subdirectory in `Post/OrbitInbox/`, use `mkdir` and `rmdir` commands with the Telnet client invoked from PC Start menu path Programs : Communications: QvtTerm : Terminal.

**CAUTION:** vehicle-specific sub-directories residing in `OrbitInbox` must have names with upper-case alpha characters.

To support TLE-unique data not contained in ephemeris files, vehicle-specific files in the `Post/TLEValInbox/` directory must be maintained for every sub-directory in `Post/OrbitInbox/`. Each file is named `<VehicleName>.ASC`, where `VehicleName` is a case-sensitive copy of the corresponding `Post/OrbitInbox/` sub-directory name. Because the Ephemeris Post-Processor only scans data trailing the first "=" (equal-space) in each TLEVal file record, these records can be labelled to simplify maintenance. A TLEVal file example appears below.

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```
Common Name = ISS
Catalog Number = 25544
International Designator = 98067A
Decay rate = .00075300
B* = 61380-3
Ndot/2 = .00053674
Nddot/6 = 00000-0
F10 = 217.0
Kp = 2.35
Cd = 2.36
```

**CAUTION:** all characters following the "=" in each record are significant, including blanks. If these cause a TLE substring to become invalid or to overflow, user applications will bomb or reject posted TLE data as invalid.

**NOTE:** in the unlikely event it becomes necessary to modify files in `Post/TLEValInbox/`, reasonable values can be obtained by requesting a current TLE pertaining to the catalog number of interest from the SCA.

**NOTE:** prior to a Shuttle launch, its Catalog Number and International Designator values are unknown. In these cases, use `99<FlightID>` (99109 was used for *Columbia* prior to STS-109 launch) for the former and six spaces (= ^^^^^) for the latter.

Input data for a Shuttle entry ephemeris are routed to staging server path `/var/webfiles/html/www/realdata/sightings/SSapplications/Post/EntryInbox/`. For each entry ephemeris, only the corresponding `TSA_eph.asc` file is copied via FTP. To support posting multiple entry ephemerides, each can assume any valid Unix file name in the `EntryInbox` directory, including one abbreviated from TSA's case-specific directory naming convention, (`KSC169.ASC`, for example).

Following a Shuttle mission, the following actions should be performed.

- 1) Delete the Shuttle sub-directory in `Post/OrbitInbox/`.
- 2) Delete all entry ephemeris files in the `Post/JavaSSOP/entry/` directory.

### 3.12.16.3 Routing TLE Input Data To The Ephemeris Post-Processor

A TLE-based SkySearch function is provided by SkyWatch to facilitate tracking objects not under JSC control. The Ephemeris Post-Processor supports this function by periodically polling TLEs at URL `http://www.celestrak.com/NORAD/elements`. The subset of TLEs polled actually available to SkySearch is governed by a `Names.dir` text file in the directory

`/var/webfiles/html/www/realdata/sightings/SSapplications/Post/tleNames/`. Each record in the `Names.dir` file contains an object common name, followed by a delimiting comma and the corresponding weight in `lbm`. The weight permits a drag profile area to be estimated from the pertinent TLE  $B^*$  value. An example `Names.dir` file appears below.

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COBE, 5000.0  
ERBS, 4949.0  
HST, 23935.0  
IRAS, 5000.0  
JERS-1, 5000.0  
ROSAT, 5000.0  
SEASAT 1, 5000.0  
STARSHINE 2, 5000.0  
STARSHINE 3, 5000.0  
UARS, 14388.0

**NOTE:** raw TLE data are stored in the `Post/TLEInbox/` directory when polling by the Ephemeris Post-Processor is complete. After TLEs are reformatted for SkyWatch use and stored in the `Post/JavaSSOP/tle/` directory, the raw data are deleted.

### 3.12.17 DOPS Update Procedures

The following actions perform an update to Deorbit Opportunities (DOPS) data and publish results to users. The DOPS processor is executed with a menu invoked from FDO DNAV path Applications : TSA : Deorbit/Entry Processors : DOPS : Local DOPS : Deorbit Ops Proc (DOPS).

**NOTE:** two separate DOPS runs must be made. A "ConUS only" run with "C" sites must be performed in TSA Global, then a run with "H" sites must be performed in TSA Local and archived. The first run insures all viable ConUS opportunities are represented in Global DOPS output.

**NOTE:** the DOPS menu requires an Outer Glideslope (OGS) input of 18° for heavyweight ILOADs or 20° for lightweight ILOADs to support sun angle violation computations. If predicted post-deorbit mass is > the weight switchpoint as displayed in PMP's CG Sum table, use 18°. Otherwise, use 20° for the OGS input.

**CAUTION:** setting System to "G" (save output to Global) in the DOPS menu will overwrite shared DOPS data in TSA Global. If a DOPS-based study or partial DOPS run is being performed, always set System to "L" (save output to Local).

**CAUTION:** for the ConUS DOPS run (Step 1 below), set DOPS menu dispersed and undispersed crossrange limits to values appearing in the latest flight-specific DSCT-05 product. Use a thermal limit only if it's more conservative. Post-deorbit apogee height should be within 10 nm of the value assumed by DSCT-05, or the pertinent crossrange limit may be invalid. In a marginal approach, acceptable crossrange can be confirmed by verifying VE > 6250 fps at the first roll-reversal. For 28.5° and 39° inclination missions, use the following crossranges for the right turn approaches (ref. STF AFDDFD-02-060, 5-29-2002).

Inclination	Approach/Direction	Undispersed XR	Dispersed XR
28.5°	A/R	896	829
	D/R	888	830
39°	A/R	883	818
	D/R	882	816

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**CAUTION:** for the ELS DOPS run (Step 14 below), set DOPS menu dispersed and undispersed crossrange limits to 1000 nm. This will ensure all viable ELS opportunities are listed. In a marginal approach, i.e.  $XR > \sim 850$  nm, acceptable crossrange can be confirmed by verifying  $VE > 2500$  fps at the first roll-reversal (ref. Flt. Rule A2-205B.1 and the following paragraph).

**NOTE:** dispersed and undispersed crossrange limits used in the DOPS Input Menu come from the DSCT-05 product. This product gives flight-specific maximum crossrange capability with respect to the approach and direction of the entry trajectory. The factor that influences this capability the most is altitude. Other lesser contributors to crossrange capability are weight, XCG, and atmosphere. Typically, heavier weight, forward XCG, and summer atmospheres give larger crossrange capability. The dispersed crossrange limit is based on having  $3\sigma$  entry protection for a roll reversal occurring prior to TAEM interface. That is defined as the first roll reversal occurring prior to  $VE = 6250$  fps. The undispersed crossrange limit is defined by the first roll reversal occurring prior to TAEM interface (2500 fps). In this case, zero- $\sigma$  protection is provided.

**CAUTION:** curve fits to DMP runs are used by DOPS to compute time of flight from deorbit TIG to landing. Per AR 006048, a permanent DOPS limitation, this computation and DOPS output in general are not valid at apogee heights above 350 nm.

**NOTE:** in the following procedure,  $FD\langle X \rangle$  is a storage directory corresponding to Flight Day X (FDX). Create this directory with  $X = 1, 2, 3, \dots$  as required to denote the current flight day.

**NOTE:** the CONUS DOPS spreadsheet application (Step 12 below) and the ChronDOPS spreadsheet application (Step 18 below) contain a Visual Basic for Applications (VBA) script that executes when the spreadsheet is opened. The VBA script uses the Macro feature in Microsoft Excel. Therefore, Excel Macro Security must be set correctly for Macros to run properly. The security level of Excel Macros must be set to Medium or Low for these spreadsheets to run. If the Security setting is set to High, the Macro features will automatically be disabled. To check the setting, use the Tools menu pulldown and select Macro  $\rightarrow$  Security. This will bring up a Security dialog box. The level should be set to Medium or Low. Medium is recommended. If Security is set to Medium, a dialog box will be displayed each time CONUS DOPS or ChronDOPS is executed to notify the user that the spreadsheet contains Macros.

- 1) Execute the DOPS menu with System = Local and Sites = C.
- 2) QA DOT and Ascending Node output.
- 3) Compare PLS/EOM TIGs and XRs in Local DOT to previous DOPS data in FDO databook.
- 4) Compare times in Local Ascending Node display to previous nodal data in FDO databook.
- 5) If D/O TIGs and node times change  $< 4$  min, exit this procedure. No DOPS update is required.
- 6) Insure PLS and EOM orbit selections are correct, then rerun DOPS with System = Global and Sites = C.



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- 7) Check the Global DOT and the Ascending Node data for consistency with Local DOPS run.
- 8) Print 2 Global DOT hard copies and 1 Global Ascending Node hard copy. Replace FDO Data Book hard copies with these updates. Hand carry the second DOT to MCC Repro for Distribution D publication.
- 9) Print Global DOT to the file  
/users/fdo/Data/<flight\_id>/DOPS/FD<X>/dops.txt,  
where a <flight\_id> example = SSP110, and FD<X> is the current flight day.
- 10) Export the dops.txt file to the pcdrop directory's DOPS drop box (reference Appendix 3.I).
- 11) Export the dops.txt file to the directory v:\Fdo\<flight\_id>\CONUS DOPS Data (Reference the JSC-MAS FTP section in Appendix 3.I for MCC file export procedures). Rename this file to DOPS.fd<X>.txt for use in the CONUS DOPS PC application.
- 12) Run the CONUS DOPS application on the PC (located at v:\Fdo\APPS\CONUS DOPS\Latest\Bin\CONUS.xls). For detailed CONUS DOPS instructions, refer to the corresponding CONUS DOPS User's Guide at  
S:\Divisions\DM\Private\DM32\Apps\Discipline CM\CONUS DOPS\Latest\Docs\UG-CONUS DOPS\*, where \* is the latest certified version of CONUS DOPS.
- 13) Save the output in the v:\Fdo\<flight\_id>\CONUS DOPS Data folder as DOPS.fd<X>.xls.
- 14) Rerun DOPS with System = Local and Sites = H. Set XR limits to 1000 nm (reference CAUTION statement above).
- 15) Print the ELS DOPS and Sun Glare/Sun Angle data to the following respective files.  
/users/fdo/Data/<flight\_id>/DOPS/FD<X>/chron.txt  
/users/fdo/Data/<flight\_id>/DOPS/FD<X>/sun\_angle.txt
- 16) Link the DOPS data to support Master DNAV access (all spaces in the following command lines are significant).  
cd /users/fdo/Data/<flight\_id>/DOPS/Latest  
ln -sf ../FD<X>/\* .
- 17) Export the ASCII file created in Step 15, chron.txt, to the PC and rename as ChronDOPS.fd<X>.txt, where <X> is the current flight day and is used to distinguish between multiple DOPS data files. Store the file in the v:\Fdo\<flight\_id>\ChronDOPS Data folder. Reference the JSC-MAS FTP section in Appendix 3.I for MCC file export procedures.
- 18) Run the ChronDOPS application on the PC (located at  
v:\Fdo\APPS\ChronDops\Latest\Bin\DOPS.xls). For detailed ChronDOPS instructions, refer to the ChronDOPS User's Guide at  
S:\Divisions\DM\Private\DM32\Apps\Discipline

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CM\ChronDOPS\Latest\Docs\UG-ChronDOPS\* PC.doc, where \* is the latest certified version of ChronDOPS.

- 19) Save output in the V:\Fdo\\ChronDOPS Data folder as ChronDOPS.fd<X>.xls.
- 20) Record DOPS updates in the FDO Console Log.

### 3.12.18 FAO Timeline Trajectory Coordination

Perform this procedure to coordinate FDO trajectory planning with FAO timeline updates performed on IPS. Coordination requests usually come from TIMELINE over MOCR DYN once every few days. The FDO source ephemeris data will generally originate in Global/Ephem/EphM2/, but any valid TSA ephemeris or Trajectory Server mirror can be used.

- 1) From the appropriate Global/Ephem/ subdirectory, export EPH.ASC and EPH.ORB files to IPS. The targeted IPS data repository will be a subdirectory in the /ips/msn/gds/gen\_common/fao/FdoData/ tree. Create the subdirectory with a name according to the convention FdoData/STS-<NNN>/<AVID>/, where NNN is the appropriate mission number and AVID is the source ephemeris anchor ID.

NOTE: if unfamiliar with data export procedures, only consult Appendix 3.1 for general background information. The export in this step targets an IPS directory, not an e-mail address, and the topo/pcdrop/ IPS directory tree is not pertinent.

- 2) Select Admin : Admin Stuff : msnxapp01 Shell from the FDO DNAV. Using the resulting Xterm, perform an rlogin to IPS.

NOTE: most FDOs have differing userIDs in MCC OPS and IPS. The Xterm will prompt for an IPS password after defaulting to the inappropriate MCC OPS userID. Respond to the password prompt with a <cr>. The Xterm will then prompt for an IPS userID.

- 3) In the Xterm, type  
cd /ips/msn/gds/gen\_common/fao/FdoData/STS-<NNN><cr>.
- 4) Default permissions conferred on the target IPS directory will not support FAO access. In the Xterm, type chmod 775 <AVID><cr> to support read-only access by any MCC OPS user.

NOTE: also type chmod 775 .. STS-<NNN>; cd STS-<NNN><cr> in the Xterm if the STS-<NNN> directory was created in Step 1.

- 5) Similar FAO-incompatible permissions have been conferred on the EPH.ASC and EPH.ORB files in the target directory. To correct these, type  
chmod 664 <AVID>/EPH.\*<cr>.

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### 3.12.19 ConUS DOPS Spreadsheet Crossrange Limits Verification

The ConUS DOPS spreadsheet application references a file named `DSCT05.xls` to obtain flight-specific deorbit crossrange limits for processing. This file is stored in MAS PC path `V:\Fdo\\CONUS DOPS Data\`. Prior to a mission's first launch attempt, the Planning Team verifies `DSCT05.xls` crossrange limits match those from the DSCT-05 product filed in the FDO Data Book. If a change to `DSCT05.xls` is necessary, first remove the Read-Only protection by right clicking on `DSCT05.xls` in Windows Explorer and selecting Properties. On the General tab in the Properties window, ensure the "Read-only" checkbox is unchecked before selecting the OK button. The `DSCT05.xls` file may then be modified and saved using Excel. After modifications have been completed and the file closed, reselect the Read-only checkbox in the file's properties window to re-enable Read-Only protection.

**CAUTION:** it's sometimes necessary to update the DSCT-05 product *during* a mission, typically due to an off-nominal trajectory. In such cases, a corresponding `DSCT05.xls` update is also necessary.

### 3.12.20 Space Operations Computing (SpOC) Data

The value of a laptop computer aboard the Orbiter was first demonstrated on STS-9, when a World Map application with ground track graphics and digital displays enhanced crew situational awareness. The laptop's role has grown dramatically, and it is now considered mandatory equipment for every Shuttle flight. Applications currently run on the Payload and General Support Computer (PGSC) to provide a single crew interface for mission-related software and payload control.

One of the PGSC applications is Deorbit Manager. This software computes landing site opportunities and CG envelopes for the Orbiter in the event a contingency deorbit is necessary. Pre-mission, Deorbit Manager is configured with Flight Design products. Landing site data are obtained from NAVO-16B, D23C and NCYCLE are based on DSCT-30, runway crossrange information is obtained from DSCT-05, and some deorbit conditions are initialized using DSCT-13. Along with pre-mission input data, Deorbit Manager uses real-time information provided by FDO. Real-time data includes atmospheric parameters (F10 and Kp), Paperless Mass Properties (PMP) buildups, and Orbiter/ISS state vectors. The following procedures describe pre-mission coordination and in-flight electronic data transfer of atmospheric parameters, PMP, and state vector data to the SpOC Team.

**NOTE:** SpOC personnel are customers of Flight Design products NAVO-16B, DSCT-05, DSCT-13, and DSCT-30. These products are received via email from the Schedule and Data Management Group.

#### 3.12.20.1 Pre-Mission Coordination

The SpOC Team will require several sets of PMP and state vector data from FDO delivered on a daily basis throughout the course of a mission. Prior to each flight, the SpOC Lead for the mission will provide the Lead or Co-lead FDO a schedule of these delivery times for each data set. If this schedule is not delivered by L-1 week, a request for the schedule should be submitted to the SpOC Team. Figure 3.12.20.1-1 is an example of a SpOC data delivery schedule.

## FDO Console Handbook Section 3.12: Orbit Team Tasks

Date	Delivery of Data From FDO	Request SpOC State Vector Time (MET) (dd/hh:mm) *	SpOC OCA Update Delivery to OCA Officer (Latest)	Approx. Uplink Time (MET) (dd/hh:mm)	SpOC Team Member
Wed 3/2/05	3/2/05, 2:00 PM	0/14:00	3.12.20.1.1.1.1.1 hu, 3/3/05, 5:00 AM	0/14:00	
Thu 3/3/05	3/3/05, 2:00 PM	1/12:30	3.12.20.1.1.1.1.2 ri, 3/4/05, 3:30 AM	1/12:30	
<p>Delivery times for the SpOC OCA Update Schedule are based on a xx/xx/05 launch time of x:xx AM (CST). If there are any required changes to the SpOC OCA update delivery times, please contact MS4/Alex Peña (W: (281) 244-1193, H: (281) 992-0156, Pgr: (713) 990-6338).</p> <p>* The state vector times are based on 1) at least one hour prior to crew wake and 2) no later than the approximate (earliest) uplink time.</p>					

**Figure 3.12.20.1-1: Example SpOC Data Delivery Schedule**

### 3.12.20.2 In-Flight Electronic Data Transfer

The following data will be part of the electronic SpOC package.

- 1) GNAV Traj Init display (needed first day only)
- 2) Shuttle Checkout Monitor display
- 3) ISS Checkout Monitor display (if not docked)
- 4) PMP displays
  - a) Orbiter Build-Up
  - b) Cargo Build-Up
  - c) Non-Prop
  - d) Cryogenics
  - e) CG Sum-Mass Prop

The GNAV Traj Init display is only delivered once after launch because F10 and Kp values will remain unchanged through the mission. Using delivery times provided pre-mission in the SpOC data delivery schedule, Orbiter and ISS state vectors must be delivered using TSA Checkout's text file print capability. The PMP data must be delivered electronically using PMP's file export capability, which generates a file in comma-separated values (CSV) format. Start the data export process at least 15 min before scheduled delivery time to ensure the data are available to the SpOC Team at the requested time. Specific SpOC data generation procedures appear in the ensuing subsections. Associated data export procedures appear in Appendix 3.I.

## FDO Console Handbook Section 3.12: Orbit Team Tasks

NOTE: in the event of issues with the electronic file transfer process, provide SpOC with hardcopies of the GNAV Traj Init display (first day only), PMP displays, and Orbiter/ISS state vectors at the requested time.

### 3.12.20.2.1 GNAV Traj Init Display File Generation

Call up the GNAV Traj Init display and obtain an X-Windows dump of its contents. See Appendix 3.H.1 for "xwd" procedures. The PCDrop export process (see Appendix 3.I.1) will convert the dump's .xwd file to a .gif file for SpOC Team use.

### 3.12.20.2.2 PMP CSV File Generation

- 1) Open the most current PMP data file available.
- 2) From PMP's File menu, select Export. The Export Data dialog window will appear.
- 3) In the File Format pulldown, select Comma Separated Values.
- 4) In the Selection text box at the bottom of the Export Data GUI, enter the file name as `/users/fdo/Data/SSPXXX/SPOC/PMP_DD_HHMM.csv`, where XXX is the flight identifier and DD, HH, and MM are the MET day, hour, and minute of the requested SpOC state vector MET.  
NOTE: if the SPOC directory does not exist for Flight xxx, it will have to be generated using XDir or the `mkdir` Unix command.
- 5) Select OK.

### 3.12.20.2.3 Orbiter/ISS State Vector File Generation

- 1) Use TSA Checkout Monitor to display the M50 Orbiter state vector using the appropriate ephemeris at the requested SpOC state vector MET.
- 2) Print the TSA Checkout to a file. Enter File pathname as `/users/fdo/Data/SSPXXX/SPOC/ORB_DD_HHMM.txt`, where XXX, DD, and HHMM are as defined in Step 4 of the previous section.
- 3) Select OK.
- 4) Repeat the foregoing steps, if required, for the M50 ISS state vector, saving to pathname `/users/fdo/Data/SSPXXX/SPOC/ISS_DD_HHMM.txt`.

# **FDO Console Handbook Section 3.12: Orbit Team Tasks**

**Section 3.12 Concludes On This Page**

## FDO Console Handbook Appendix 3.A: Acronyms

The following alphabetized acronym list translates, but does not necessarily define, each entry. Every acronym character is preserved in its translation, while other translated characters are lower case.

NOTE: see Section 3.12.12 for a dedicated explanation of frequently encountered weather-related acronyms and nomenclature.

1 CACS.....	usaf 1st Command And Control Squadron
$\Delta t$ .....	change in time
$\Delta V$ .....	change in UVW down track position
$\Delta v$ .....	change in velocity
A.....	ADI
	Axis
A/G.....	Air-to-Ground
AAS.....	Any Attitude Separation
ACQ.....	ACQuisition
AcqMon.....	Acquisitions Monitor
ACTS.....	Advanced Communications Technology Satellite
ADCOM.....	Aerospace Defense COMmand
ADI.....	Attitude Direction Indicator
AEG.....	Analytic Ephemeris Generator
AFB.....	Air Force Base
AFD.....	Alternate Flight Director
AFS.....	Air Force Station
AIF.....	Auto-Inhibit-Force
AIM.....	Attitude Improvement Maneuver
AK.....	AlasKa
ALP.....	Approach and Landing Processor
AM.....	Avant Midi
AME.....	Abort Maneuver Evaluator
AMU.....	Attitude Matching Update
ANG.....	ANGLe
AOA.....	Abort Once Around
AOS.....	Acquisition Of Signal
APSO.....	APSidal Offset burn
APU.....	Auxilliary Power Unit
ARCS.....	Aft Reaction Control System
ARD.....	Abort Region Determinator
AR.....	Anomaly Report
AS.....	Advisory Services
ASAP.....	As Soon As Practical
ASAT.....	Anti-SATellite
ASC.....	ASCending
	ASCent
	ASCension island
ASCC.....	Alternate Space Control Center
ASCII.....	American Standard Code for Information Interchange
ASW.....	Astroynamics Safety Workstation
ATL.....	Attitude Time Line
ATO.....	Abort To Orbit
ATT.....	ATTitude
AVID.....	Anchor Vector IDentification

## FDO Console Handbook Appendix 3.A: Acronyms

AZ.....	AZimuth
B/U.....	Build-Up
BAC.....	Boeing Aerospace Company
BBCT.....	Batch-to-Batch Control Table
BFI.....	Body Fixed Inertial
BFS.....	Backup Flight System
BIM.....	Burn Initialization Maneuver
BOS.....	Bright Object Sensor
BRTS.....	Bilateration Ranging Transponder System
C/L.....	CenterLine
C/O.....	CheckOut
CA.....	Conjunction Assessment
CAF.....	Contractor Accountable Function
CAP.....	Celestial Acquisition Processor
CAPCOM.....	CAPsule COMmunicator
CAT.....	Covariance Administration Table
CBDST.....	Cargo Bay Door Status Table
CC.....	Capsule Communicator
CCC.....	Combined Control Center
CCTV.....	Closed-Circuit TeleVision
CD.....	Coefficient of Drag
CDR.....	CommanDeR
CDT.....	Central Daylight Time
CDUT.....	Create count-Down/count-Up Timers
CEF.....	Comsec Equipment Facility
CERES.....	CENter for REsearch and Support
CET.....	Create Event Timer
CG.....	Center of Gravity
CIL.....	Critical Items List
CIRC.....	CIRCularization burn
CIU.....	Cargo Interface Unit
CL.....	CLOsed
CLV.....	Curvilinear Local Vertical local horizontal
CMC.....	Cheyenne Mountain Complex
CMD.....	CoMmanD
CMG.....	Control Moment Gyro
CMOC.....	Cheyenne Mountain Operations Center
CNCL.....	CaNCeL
CO.....	COlorado
COAS.....	Crew Optical Alignment Sight
COLA.....	COLLision Avoidance
COMBO.....	Computation Of Misses Between Orbits
COMSEC.....	COMMunications SECUrity
CONFIG.....	CONFIGuration
ConUS.....	Continental United States
COTM.....	Command Off-The-Moc
COTS.....	Commercial Off-The-Shelf
COVAR.....	COVARiance matrix
CPA.....	Closest Point of Approach
CR.....	Change Request
CRP.....	Configuration Requirements Processor
CRTSCT.....	CReaTe Station Characteristics Table



## FDO Console Handbook Appendix 3.A: Acronyms

CSCS.....	Contingency Shuttle Crew Support
CSM.....	Command Systems Monitor
	Countdown Status Message
CSR.....	Customer Support Room
CST.....	Central Standard Time
CSTC.....	Consolidated Satellite Test Center
CTL.....	Close To Launch
CTRL.....	ConTRoL
CUR.....	CURrent
CY.....	Calendar Year
D.....	Down
D/L.....	DownLink
D/O.....	Deorbit
DAO.....	Defense Analysis Officer
DAP.....	Digital Auto Pilot
DC.....	Differential Correction
DCMDR.....	Deputy crew CoMmanDeR
DCT.....	Deorbit Constraints Table
DDD.....	Digital Display Driver
DDMS.....	Department of Defense Mercury Support
DE.....	Development Ephemeris
DEC.....	DEClination
DEL.....	DELta
DEMOS.....	Distributed Earth Modeling System
DEPT.....	DEPartmenT
DEU.....	Display Electronics Unit
DFE.....	Data Flow Engineer
DFL.....	Data Format Load
DIGS.....	DIGitalS
DKI.....	DockIng Initiation
DMP.....	Deorbit Maneuver Processor
DMT.....	Detailed Maneuver Table
DNAV.....	Display NAVigation
DOD.....	Department Of Defense
DOL.....	DeOrbit and Landing data
DOPS.....	Deorbit OPportunities
DOR.....	Day-Of-Rendezvous
DOS.....	Disk Operating System
DOT.....	Deorbit Opportunities Table
DPLY.....	DePLoY
DPS.....	Data Processing Systems
DSB.....	DiSaBled
DSC.....	DeSCending
	Dynamic Standby Computer
DSM.....	Data Summary Message
DSS.....	Data Systems Supervisor
DST.....	Deorbit Summary Table
DT.....	Delta Time
DTE.....	Digital Television Equipment
DTO.....	Detailed Test Objective
DTP.....	$\Delta$ T Processor
DV.....	Delta Velocity
DVIS.....	Digital Voice Instrumentation System

## FDO Console Handbook Appendix 3.A: Acronyms

DVM.....	Delta Velocity Magnitude
DVPY.....	Delta Velocity with Pitch and Yaw burn
DVYP.....	Delta Velocity with Yaw and Pitch burn
DYN.....	DYNamics
ECAL.....	East Coast Abort Landing
ECT.....	Engine Characteristics Table
EDR.....	Energy Dissipation Rate
EDS.....	Entry Dynamics Simulator
EDT.....	Eastern Daylight Time
EDW.....	EDWards air force base
EECOM.....	Emergency, Environmental, and CONsumables Management systems
EET.....	Entry Elapsed Time
EGIL.....	Electrical, Generation, and Integrated Loading systems
EI.....	Entry Interface
EL.....	ELEVation
ELE.....	ELEVation
ELEV.....	ELEVation
ELS.....	Emergency Landing Site
ELV.....	Expendable Launch Vehicle
EMCC.....	Emergency Mission Control Center
EMI.....	ElectroMagnetic Interference
EMU.....	Extravehicular Mobility Unit
ENA.....	ENABled
ENB.....	ENABled
ENT.....	ENTry
EOM.....	End Of Mission
	Equations Of Motion
EPH.....	EPHemeris
EPHB.....	EPHemeris Begin GMT
EPHE.....	EPHemeris End GMT
EPP.....	Entry Precise Predictor
EPSAP.....	Entry Predicted Site Acquisition Processor
EPSAT.....	Entry Predicted Site Acquisition Table
ERR.....	ERRor
ESA.....	European Space Agency
ESD.....	Enhanced SAMMI Display
EST.....	Eastern Standard Time
ET.....	External Tank
ETET.....	End To End Test
EVA.....	Extra-Vehicular Activity
EXDV.....	EXternal Delta-V burn
EXEC.....	EXECute
F.....	Forward
F10.7.....	solar radiation Flux
FAA.....	Federal Aviation Administration
FADS.....	Flight Analysis and Design System
FAO.....	Flight Activities Officer
FAX.....	FAsimile
FCDO.....	Flow Control Duty Officer
FCO.....	Flight Control Officer
FCOH.....	Flight Control Operations Handbook
FCR.....	Flight Control Room

## FDO Console Handbook Appendix 3.A: Acronyms

FCT	Flight Control Team
FD	Flight Day Flight Director
FDf	Flight Data File
FDO	Flight Dynamics Officer
FDOCH	Flight Dynamics Officer Console Handbook
FEP	Front-End Processor
FES	Flash Evaporator System
FFNI	Free Flight Numeric Integrator
FID	Flight Dynamics officer
FILT	FILTered state vector
FL	FLorida
FOIG	Flight Operations Integration Group
FOUO	For Operational Use Only
FPH	Flight Procedures Handbook
FPS	Feet Per Second
FR	Flight Rule
FRCS	Forward Reaction Control System
FRISDV	FRISbee Delta-V
FRR	Flight Readiness Review
FSM	Facility Systems Manager
FTP	File Transfer Protocol
FTW	Fdo Trajectory Web
FY	Fiscal Year
G/G	Ground-to-Ground
GA	Group Administrator
GAF	Government Accountable Function
GAS	Get-Away Special
GC	Ground Control
GCI	Ground-Commanded Intercept
GDR	Generalized Data Retrieval
GEM	Goddard Earth Model
GIF	Graphics Interchange Format
GMT	Greenwich Mean Time
GMTLO	Greenwich Mean Time at LiftOff
GMTR	Greenwich Mean Time Reference
GN&C	Guidance Navigation & Control
GNC	Guidance Navigation and Control
GND-PFS	GrouND minus Primary Flight Software
GOM	(Edwards AFB) Ground Operations Manager
GP	General Perturbations
GPC	General Purpose Computer
GPM	General Purpose Maneuver
GPO	Guidance Procedures Officer
GPS	Global Positioning System
GRO	Gamma Ray Observatory
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking and Data Network
GTCP	Ground Target Contacts Processor
GUI	Graphic User Interface
GUR	Ground-Up Rendezvous
H	angular momentum vector

## FDO Console Handbook Appendix 3.A: Acronyms

HA.....	Height Adjust burn High Availability server
HAL.....	High-order Assembly Language
HASDM.....	High Accuracy Satellite Drag Model
HASH.....	Height Adjust with apsidal SHift burn
HD.....	Height Desired
HDR.....	High Data Rate
HHL.....	Hand-Held Lidar
HNL.....	Honolulu
HQ.....	HeadQuarters
HST.....	Hubble Space Telescope
HTBP.....	Hydroxyl Terminated PolyButadiene
HTML.....	HyperText Markup Language
HTS.....	Hawaii Tracking Site
IA.....	Instrument Axis
ICAO.....	International Civil Aviation Organization
ICD.....	Interface Control Document
ICV.....	Inter-Center Vector
ID.....	IDentification
IGN.....	IGNition
IGS.....	Inner Glide Slope
IH.....	Inertial Hold
IIRV.....	Improved Inter-Range Vector
ILOAD.....	Initial LOAD
IMU.....	Inertial Measurement Unit
INCO.....	INstrumentation and Communications Officer
INIT.....	INITial
IP.....	Impact Point Internet Protocol
IPS.....	Integrated Planning System
IRIS.....	Italian Research Interim Stage
ISS.....	International Space Station
IUS.....	Inertial Upper Stage
J2K.....	earth mean equator and equinox of Julian epoch 2000.0
JEUS.....	Joint Expedited Undocking and Separation
JIN.....	Jsc Internal Network
JIS.....	Joint Integrated Simulation
JOIP.....	Joint Operations Integration Plan
JPL.....	Jet Propulsion Laboratory
JSC.....	Johnson Space Center
JURe.....	Joint Underspeed Recovery
K.....	Keyhole
KCON.....	K-factor for CONStant area drag ( $C_D/2$ )
KP.....	geomagnetic index
KSC.....	Kennedy Space Center
KVAR.....	K-factor for VARiable area drag (attitude-dependent)
L.....	Launch Left LVLH
LAGEOS.....	LAser GEOdynamics Satellite

## FDO Console Handbook Appendix 3.A: Acronyms

LAN	Local Area Network
	Longitude of the Ascending Node
LDEF	Long Duration Exposure Facility
LDR	Low Data Rate
LEO	Low Earth Orbit
LFP	Landing Field Prime
LiDAR	Light Detection And Ranging
LINS	Laser Inertial Navigation System
LOMS	Left Orbit Maneuvering System
LOS	Loss Of Signal
LRD	Landing Recovery Director
LSDV	Line-of-Sight Delta Velocity burn
LSIP	Low-Speed Interface Processor
LSO	Landing Support Officer
LST	Landing Site Table
LUPI	Length of UPdate Interval
LV	Local Vertical
LVC	Local Vertical Curvilinear
LVLH	Local Vertical Local Horizontal
LW/LT	Launch Window/Launch Targeting
M	Mach
M50	earth Mean equator and equinox of Besselian epoch 1950.0
MARS	Maneuver And Rendezvous Specialist
MATS	Message And Timeline Support officer
MAXEL	MAXimum ELevation
MC	Midcourse Correction
MCC	Mission Control Center
MCC-H	Mission Control Center-Houston
MCC-M	Mission Control Center-Moscow
MCT	Maneuver Constraints Table
MDL	Mission Data Load
MDM	Multiplexer/DeMultiplexer
MEAS	MEASurement
MECO	Main Engine Cut-Off
MED	Manual Entry Device
MER	Mission Evaluation Room
MET	Maneuver Evaluation Table
	Mission Elapsed Time
METAR	Aviation Routine weather report
MIDDS	Meteorological Interactive Data Display System
MM	Major Mode
MMACS	Mechanical Maintenance And Crew Systems officer
MMT	Mission Management Team
MNVR	MaNeuVeR
MOA	Memorandum Of Agreement
MOC	Mission Operations Computer
MOCR	Mission Operations Control Room
MOD	Mission Operations Directorate
MOU	Memorandum of Understanding
MPM	Manipulator Positioning Mechanism
MPS	Maneuver Plan Status display
MPSR	Multi-Purpose Support Room
MPT	Mission Planning Table

## FDO Console Handbook Appendix 3.A: Acronyms

MR/MS	.....	MoonRise/MoonSet
MRL	.....	Manipulator Retention Latch
MRMS	.....	MoonRise MoonSet
MSBLS	.....	Microwave Scanning Beam Landing System
MSC	.....	Mission Systems Contract
MSFC	.....	Marshall Space Flight Center
MSID	.....	Measurement Stimulus IDentifier
MSK	.....	Manual Select Keyboard
MSM	.....	Mission Summary Message
MTM	.....	Moc Telemetry Message
MTT	.....	Maneuver Transfer Table
MU	.....	Matching Unit
MXL	.....	Minus X Low thrusters
NASA	.....	National Aeronautics and Space Administration
NASCOM	.....	NASa COMmunications
NAV	.....	NAVigation
NAVAID	.....	NAVigation AID
NC	.....	Nth Central phasing burn
NCC	.....	Nth Corrective Combination burn
ND	.....	North Dakota
NEOM	.....	Nominal End-Of-Mission
NH	.....	Nth Height correction burn
NHRD	.....	Nth Height adjust with RaDial component burn
NM	.....	Nautical Miles
NOR	.....	NORthrup strip
NORAD	.....	NORth american Aerospace Defense command
NOSH	.....	NOde SHift burn
NOTAM	.....	NOtice To AirMen
NPC	.....	Nth Plane Change burn
NS	.....	Node Shift burn
NSC	.....	Next Station Contacts
NSR	.....	Nth Slow Rate coelliptic burn
NSS	.....	Network Simulation System
NSTS	.....	National Space Transportation System
NTD	.....	Nasa Test Director
O/B	.....	OnBoard
OA	.....	Orbital analysis Officer
OAL	.....	Orbital Analyst Leader
OA0	.....	Orbital Analyst Officer
OCF	.....	One Cycle to Flight
OCM	.....	Orbital Conjunction Message
ODDL	.....	Operational Digital Data Load
OGS	.....	Outer Glide Slope
OI	.....	Orbiter Increment
		Operational Interface
OID	.....	Operational Interface Document
OJT	.....	On-the-Job Training
OM	.....	OMicron angle
OMI	.....	Operational Maintenance Instruction
OMP	.....	Orbital Maneuver Processor
OMPBP	.....	Orbital Maneuver Processor Bench Program
OMS	.....	Orbital Maneuvering System

## FDO Console Handbook Appendix 3.A: Acronyms

ONAV	Orbiter NAVigation
OOP	Out Of Plane
OP	OPen
OPCL	Orbit Pocket CheckList
OPS	OPerational Sequence OPerationS
OPT	OPTimum
ORB	ORBit ORBiter
ORBT	Optimized RBar Targeting
OSA	Orbital Safety Analyst
OSC	On-Scene Commander
OST	Operations Support Timeline
OSW	Orbital Safety Workstation
OTREL	Orbiter/Target RELative state vector
OV	Orbiter Vehicle
P	Pitch angle
PABX	Public Access phone
PAD	Pre-Advisory Data
PADJ	Perigee ADJust
PAM	Payload Assist Module
PAO	Public Affairs Officer
PAPI	Precision Approach Position Indicator
PASS	Primary Avionics System Software
PBI	Push Button Indicator
PC	Personal Computer Plane Change burn
PCA	Point of Closest Approach
PCN	Page Change Notice
PDP	Plasma Diagnostics Package
PDRS	Payload Deploy and Retrieval System
PDT	Pacific Daylight Time
PEG	Powered Explicit Guidance
PERM	PERManent
PET	Phase Elapsed Time
PFNI	Powered Flight Numeric Integrator
PI	Payload Interrogator
PIP	Payload Integration Plan
PKM	Perigee Kick Motor
PLBD	PayLoad Bay Doors
PLO	PayLoads Officer
PLOS	Pitch Line Of Sight
PLS	Primary Landing Site
PM	Post-Meridian
PMF	Perigee Motor Firing
PMP	Paperless Mass Properties
POC	Point-Of-Contact
POCC	Payload Operations Control Center
POSI	POSIGrade
PPD	Projection Plotboard Display
PRCS	Primary Reaction Control System
PRD	Program Requirements Document
PRI	PRImary

## FDO Console Handbook Appendix 3.A: Acronyms

PROP	PROPERTIES PROPulsion officer PROPagated state vector
PROT	PROTECT
PSAP	Predicted Site Acquisition Processor
PSAT	Predicted Site Acquisition Table
PST	Pacific Standard Time
PTM	Processed Telemetry Message
PX	Plus X
PYR	Pitch-Yaw-Roll
QTY	QUANTITy
QuAC	Quick Analysis of Crosswinds
R	Right Roll angle
RAAN	Right Ascension of the Ascending Node
RADEC	Right Ascension DEClination
RCS	Radar Cross Section Reaction Control System
RCT	Rendezvous Constraints Table
REF	REFerence
REINIT	REINITialization
REL	RELative
RELMAT	RELative MATrix
RELMO	RELative MOTion
RES	RESiduals
RETRO	RETROgrade
RFDO	Rendezvous Flight Dynamics Officer
RFI	Radio Frequency Interference
RGPO	Rendezvous Guidance Procedures Officer
RHC	Rotational Hand Controller
RLW	Rendezvous Launch Window
RM	Redundancy Management
RMD	Relative Motion Digitals
RMS	Remote Manipulator System Root Mean Square
ROCC	Range Operations Control Center
ROMS	Right Orbit Maneuvering System
ROSS	Realtime Operations Support Software
ROTR	ROTation
RPM	Rbar Pitch Maneuver
RR	Rendezvous Radar
RAA	Relative Right Ascension
RSED	Remote Site Entry Display
RSOC	Rockwell Space Operations Company
RSS	Root Sum of Squares
RTL	Return To Launch Site
RTO	Raise-The-Orbit
RTP	Rendezvous Targeting Processor
RTS	Remote Tracking Site
RVTL	Reentry Vent Time Line
RWY	Runway
RY	Runway



## FDO Console Handbook Appendix 3.A: Acronyms

SA	Save Area
	Space Analyst
SAMMI	Standards Automated Man-Machine Interface
SAP	Satellite Acquisition Processor
SAREX	Shuttle Amateur Radio EXperiment
SAT	SATellite
SATACQ	SATellite ACQuisition
SBM	Space Battle Manager
SBRAM	Satellite Breakup Risk Assessment Model
SCA	Satellite Control Analyst
SCC	Space Control Center
SCD	Space Control Director
SCG	Security Classification Guide
SCO	Space Control Officer
SCOM	Shuttle Crew Operations Manual
SCT	Station Characteristics Table
	Space Control Technician
SDD	Space Defense Director
SDWO	State Department Watch Officer
SEC	SECondary
SEL	SElect
SEP	SEParation
SES	Secondary Ephemeris Selection
	Shuttle Emergency Separation
SFOC	Space Flight Operations Contract
SGMT	Simulated Greenwich Mean Time
SH	Shallow
	SpaceHab
SHO	ScHeduling Order
SIM SUP	SIMulation SUPervisor
SIPRNet	Secret Internet Protocol Router Network
SM	Systems Maintenance
	Servicing Mission
SMATL	Synch Moc Attitude TimeLine
SMG	Spaceflight Meteorology Group
SMS	Shuttle Mission Simulator
SNIP	Shuttle Nose InPlane
SOC	Support Operations Center
SODB	Shuttle Operational Data Book
SODS	Shuttle Operational Data Submittal
SOI	Space Object Identification
	Stable Orbit Initiation burn
SOM	Stable Orbit Midcourse burn
SOMP	Shuttle Operational Mass Properties
SOP	Standard Operating Procedure
SOR	Stable Orbit Rendezvous burn
SOSC	Shuttle Operations Support Center
SP	Special Perturbations
SPA	Systems Programmer Analyst
SPADOC	SPAce Defense Operation Center
SPAN	SPacecraft ANalysis
SPARTAN	Shuttle-Pointed Autonomous Research Tool for AstroNomy
SPEC	SPECialist function

## FDO Console Handbook Appendix 3.A: Acronyms

SPoC	Shuttle Portable Computer
SpOC	Space Operations Computing
SR/SS	SunRise/SunSet
SRAG	Space Radiation Analysis Group
SRB	Solid Rocket Booster
SRSS	SunRise SunSet
SRTM	Space Radar Topography Mission
SSC	Space Surveillance Center
SSP	Space Shuttle Program
SSN	Space Surveillance Network
SSOP	Shuttle Sighting Opportunities Program
SSUS	Spin-Stabilized Upper Stage
SSV	Space Shuttle Vehicle
SRAG	Space Radiation Analysis Group
SRM	Solid Rocket Motor
ST	STeep Star Tracker
STAMPS	Spacecraft Trajectory Analysis and Mission Planning Simulation
STDN	Spaceflight Tracking and Data Network
STF	Sfoc Transmittal Form
STS	Space Transportation System
STU	Secure Telephone Unit
SUI	Software User Interface
SVS	Space Vision System
TACAN	TACTical Air Navigation
TAEM	Terminal Area Energy Management
TAF	international Aerodrome Forecast
TAL	Transoceanic Abort Landing
TAO	Trajectory Applications Officer
TBD	To Be Determined
TBS	To Be Supplied
TCA	Time of Closest Approach
TCS	Trajectory Control Sensor
TDDP	Trajectory Design Data Pack
TDR	True equator of Date Rotating Trajectory Data Retrieval
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TEE	True Equator and Equinox of epoch
TEG	True Equator and Greenwich meridian of epoch
TEI	True of Epoch Inertial
TEME	True Equator Mean Equinox of epoch
TEMP	TEMPorary
TGO	Time to GO
TGT	TarGeT
THC	Translational Hand Controller
THET	THETa phase angle
Ti	Terminal phase initiation burn
TIG	Time of IGnition
TIPS	Thermal Impulse Printer System
TLM	TeLeMetry
TM	TeleMetry
TMBU	Table Maintenance Block Update

## FDO Console Handbook Appendix 3.A: Acronyms

TMCC.....	Temporary Mission Control Center
TOAST.....	Trajectory Operational Application Software Task
TOCSS.....	Trajectory Operations Computer Systems Support
TOD.....	True equator and equinox Of Date
TOPO.....	Trajectory OPerations Officer
TORF.....	Twice Orbit Rate Flyaround
TORVA.....	Twice Orbit Rate Vbar Approach
TOS.....	Transfer Orbit Stage
TPF.....	Terminal Phase Final burn
TPI.....	Terminal Phase Initiation burn
TPM.....	Terminal Phase Midcourse burn
TRAJ.....	TRAJectory officer
TRK.....	TRAck
TrS.....	Trajectory Server
TSA.....	Trajectory Software Application
TSU.....	Trajectory Software Upgrade
TTIT.....	Telemetry to Trajectory Interface Table
TUP.....	Trajectory UPdate
	ram-like
TV.....	Thrust Vector
TVC.....	Thrust Vector Control
TVETS.....	Trajectory/Vector/Ephemeris Transfer System
TVR.....	Thrust Vector Roll
TWA.....	Trajectory Web Applications
U.....	Up
	local geocentric radial Up
U/L.....	UpLink
UNIV PTG.....	UNIVersal PoinTinG
UPP.....	User Parameter Processor
URL.....	Uniform Resource Locator
US.....	United States
USA.....	United Space Alliance
USSPACECOM.....	United States SPACE COMmand
USSTRATCOM.....	United States STRATegic COMmand
UTC.....	Coordinated Universal Time
UVPI.....	UltraViolet Plume Instrument
UVW.....	mutually-orthogonal axes U, V, and W
V.....	local horizontal Velocity
V2E.....	Vector-to-Ephemeris
V2V.....	Vector-to-Vector
VASI.....	Visual Approach Slope Indicator
VAT.....	Vector Administration Table
VC.....	Vector Compare
VCM.....	Vector Covariance Message
VCT.....	Vehicle Constants Table
VEC.....	Vector Elements Calculator
VECTOT.....	VECTor TOTal
VGET.....	Vector GET
VGO.....	Velocity to GO
VID.....	Vector IDentification
VIT.....	Vent Initialization Table
VRCS.....	Vernier Reaction Control System

## FDO Console Handbook Appendix 3.A: Acronyms

VTL.....	Vent Time Line
VTS .....	Vandenberg Tracking Site
VV.....	Velocity Vector
VX.....	Velocity X component
VY.....	Velocity Y component
VZ.....	Velocity Z component
W .....	angular momentum vector
WFCR.....	White Flight Control Room
WGL.....	Weight Gain or Loss
WGM .....	White sands Ground operations Manager
WIN .....	WINdow
WPA.....	Window Protect Attitude
WSF.....	Wake Shield Facility
WSGT.....	White Sands Ground Terminal
WSS .....	Workstation Software Support
WT.....	WeighT
WWW.....	World-Wide Web
WX.....	Weather
XFTP.....	X-window File Transfer Protocol
Y.....	Yaw angle
ZOE.....	Zone Of Exclusion

**Appendix 3.A Concludes On This Page**

## FDO Console Handbook Appendix 3.B: EMCC Activation Procedures

The following actions (shaded blocks denote primary responsibility) are performed in response to Emergency Mission Control Complex (EMCC) activation.

Action	LSO	MCC FDO	EMCC FDO
Notify EMCC trajectory team (FDO, GPO, TRAJ, ESE) of activation and contact LSO. Obtain Social Security Numbers for each person and forward to FD. Discuss w/EMCC FDO who will collect hardware for deployment.			
Update ConUS DOPS as required.			
Contact DDMS SOC (DDMS Coord or black phone). Provide estimated landing times and sites. Request current status of all DOD landing sites and support forces.			
Notify SPADOC of EMCC activation.			
Notify FAA of planned landing site and time if required.			
Notify KSC LRD of EMCC activation (Landing Field Prime 1 or their console phone).			
Notify State Department of EMCC activation so they are aware of current mission status.			
Notify DM management.			
Request DFE transmit a valid 48-hr IIRV (Improved Inter-Range Vector) planning set to GSFC and the ER CCC. DFE notify DoD TRK of EMCC activation.			
Update the onboard state vector prior to EMCC Team deployment or take GPS to NAV – AUTO.			
In conjunction with FAO and NAV, advise the crew to maintain an attitude providing thermal conditioning and minimal trajectory perturbations if GPS is not available.			
Execute the EMCC FDO Deployment Checklist (FDOCH Volume 4) in order to prepare equipment and documentation for transport to EFD.			
Supervise off-loading and transfer of equipment to KSC LCC.			

NOTE: the MCC FDO/TRAJ assumes LSO actions if LSO is unavailable, and the EMCC FDO assumes LSO and/or MCC FDO actions if either is unavailable.

Reference the 450-EMCC-CAP document (available via FDO home page) for further information.

# **FDO Console Handbook Appendix 3.B: EMCC Activation Procedures**

**Appendix 3.B Concludes On This Page**

## FDO Console Handbook Appendix 3.C: Orbit FDO Flight Rule Index

### Orbit Maintenance and Navigation

Rule	Title
A2-102	MISSION DURATION REQUIREMENTS
A2-103	EXTENSION DAY REQUIREMENTS
A2-109	PREFERRED ATTITUDES FOR WATER DUMPS
A2-131	ATTITUDE RESTRICTIONS FOR ORBITAL DEBRIS
A4-3	ORBIT CONJUNCTIONS/CONFLICTS
A4-101	ONBOARD NAVIGATION MAINTENANCE
A4-102	MINIMUM ORBITAL LIFETIME
A4-103	OFF-NOMINAL ORBITAL ALTITUDE RECOVERY PRIORITIES
A4-106	DEBRIS AVOIDANCE CRITERIA FOR PREDICTED CONJUNCT'NS
A4-158	MANEUVER EXECUTION MATRIX
A4-206	NAVIGATION FILTER MANAGEMENT AUTO/INHIBIT/FORCE (AIF)
A10-21	LOSS OF APU/HYDRAULIC SYSTEM(S) ACTIONS
A10-141	NOSE WHEEL STEERING (NWS)
A10-142	TIRE PRESSURE (CIL)
A10-303	[Ku-Band] ANTENNA CONTINGENCY PROCEDURES
A10-1001	MMACS GO/NO-GO CRITERIA
A11-20	UPLINK COMMANDING DURING OPS TRANSITIONS
A11-21	CRITICAL UPLINK COMMAND POLICY
A11-51	LOSS OF TWO-WAY VOICE
A11-52	LOSS OF BOTH VOICE AND COMMAND [Sleep Vector]
A11-53	LOSS OF COMMAND
A11-54	LOSS OF TELEMETRY
A11-1001	COMMUNICATIONS GO/NO-GO CRITERIA
A12-5	[RMS] ORBITER AVOIDANCE MANEUVERS CONSTRAINT (CIL)
A12-6	[RMS] OMS/RCS CONSTRAINTS
A12-182	RMS/PAYLOAD JETTISON
A14-2	CONFIRMED ARTIFICIAL EVENT DEFINITION
A14-8	PROJECTED OPERATIONAL DOSE LIMIT VIOLATION DEFINITION
A14-1001	SPACE ENVIRONMENT GO/NO-GO CRITERIA

### OMS/RCS Leak and Perigee Adjust

Rule	Title
A4-104	OMS LEAK/PERIGEE ADJUST
A6-106	OMS ENGINE BURN TO DEPLETION
A6-201	OMS/RCS LEAKING HE TANK BURN
A6-202	OMS LEAKING HE SYSTEM BURN
A6-203	OMS LEAKING INLET LINE PERIGEE ADJUST BURN
A6-205	RCS LEAKING PROPELLANT TANK BURN

**FDO Console Handbook Appendix 3.C:  
Orbit FDO Flight Rule Index**

**OMS/RCS**

<b>Rule</b>	<b>Title</b>
A2-113	OMS/RCS DOWNMODING CRITERIA
A2-114	OMS/RCS MANEUVER CRITICALITY
A2-115	ENGINE SELECTION CRITERIA
A6-357	FORWARD RCS CONTINGENCY PROPELLANT AVAILABLE
A6-51	OMS FAILURE MANAGEMENT [CIL]
A6-52	RCS FAILURE MANAGEMENT
A6-107	OMS ENGINE FAILURE MANAGEMENT
A6-103	OMS BURN DOWNLIST REQUIREMENT
A6-153	RCS JET MAXIMUM BURN TIME
A6-301	OMS USABLE PROPELLANT
A6-302	RCS USABLE PROPELLANT
A6-303	OMS REDLINES [CIL]
A6-304	FORWARD RCS REDLINES
A6-305	AFT RCS REDLINES
A6-351	OMS PROPELLANT MANAGEMENT MATRIX
A6-353	CG MANAGEMENT
A6-354	RCS ENTRY REDLINE PROTECTION
A8-53	OMS TVC LOSS
A8-113	OMS TVC SYSTEM MANAGEMENT



## FDO Console Handbook Appendix 3.C: Orbit FDO Flight Rule Index

### Deorbit

Rule	Title
A2-6	LANDING SITE WEATHER CRITERIA [HC]
A2-128	EMCC/TMCC ACTIVATION
A2-201	DEORBIT GUIDELINES
A2-202	EXTENSION DAY GUIDELINES
A2-203	DEORBIT DELAY GUIDELINES
A2-204	MDF DEORBIT GUIDELINES
A2-205	EMERGENCY DEORBIT
A2-207	LANDING SITE SELECTION
A2-257	DEORBIT BURN TERMINATION
A2-301	CONTINGENCY ACTION SUMMARY
A2-1001	ORBITER SYSTEMS GO/NO-GO
A4-105	MINIMUM TIME OF FREE FALL
A4-107	PLS/EOM LANDING OPPORTUNITY REQUIREMENTS
A4-108	TIRE SPEED, BRAKING, AND ROLLOUT REQUIREMENTS
A4-109	DEORBIT PRIORITY FOR EOM WEATHER
A4-151	[Entry Planning] IMU ALIGNMENT
A4-152	DEORBIT BURN TARGETING PRIORITIES
A4-153	CG PLANNING
A4-154	DOWNTRACK ERROR
A4-155	SUN ANGLE LIMITS AND GLARE CITERIA FOR IGS AND OGS
A4-159	ORBITER LANDING WEIGHT
A4-202	DEORBIT BURN COMPLETION
A6-355	OMS PROPELLANT DEFICIENCY FOR DEORBIT
A6-356	DEORBIT PLANNING CRITERIA
A8-7	ENTRY SYSTEMS SINGLE-FAULT TOLERANCE VERIFICATION
A8-104	FCS CHECKOUT
A8-110	IMU SYSTEM MANAGEMENT
A8-1001	GNC GO/NO-GO CRITERIA
A17-201	CABIN PRESSURE INTEGRITY
A17-202	8 PSIA CABIN CONTINGENCY 165-MINUTE RETURN CAPABILITY

## FDO Console Handbook Appendix 3.C: Orbit FDO Flight Rule Index

### Entry

Rule	Title
A2-207	LANDING SITE SELECTION
A2-209	LANDING SITE SELECTION FOR AN INFLIGHT EMERGENCY
A2-251	BAILOUT
A2-252	GCA CRITERIA
A2-255	CREW TAKEOVER
A2-258	BFS ENGAGE
A2-260	ENTRY LOAD MINIMIZATION
A2-261	ENTRY DTO/AUTO MODE/CROSSWIND DTO GO/NO-GO
A2-262	LANDING DTO'S
A2-263	STA/WEATHER AIRCRAFT RUNWAY APPROACH OPERATIONS FOR SITES WITH ONLY ONE RUNWAY
A2-264	EMERGENCY LANDING FACILITY CRITERIA
A3-51	TRAJECTORY PROCESSING REQUIREMENTS
A3-201	TACAN REDUNDANCY REQUIREMENTS AND ALTERNATE TACAN SELECTION PHILOSOPHY
A3-202	MLS
A3-203	LANDING AID REQUIREMENTS
A4-110	AIMPOINT, EVALUATION VELOCITY, AND SHORT FIELD SELECTION
A4-156	HAC SELECTION CRITERIA
A4-157	ENERGY DOWNMODING
A4-201	DELTA-T UPDATE CRITERIA
A4-203	ENTRY NAVIGATION UPDATE PHILOSOPHY
A4-204	DELTA STATE POSITION UPDATES
A4-205	DELTA STATE VELOCITY UPDATES
A4-208	ENTRY TAKEOVER RULES
A4-209	AERO TEST MANEUVERS
A8-17	EQUIPMENT REQUIRED FOR EMERGENCY AUTOLAND
A8-18	LANDING SYSTEMS REQUIREMENTS
A8-20	ENTRY ELEVON SCHEDULE SELECTION CRITERIA
A8-114	ENTRY BODY BENDING FILTER SELECTION
A10-21	LOSS OF APU/HYDRAULIC SYSTEM(S) ACTIONS
A10-146	BRAKING

### Rendezvous

Rule	Title
A2-116	RNDZ/PROX OPS DEFINITIONS
A2-119	RNDZ/PROX OPS SENSOR REQUIREMENTS
A2-121	RNDZ/PROX OPS PROPULSION SYSTEMS MANAGEMENT
A2-122	RENDEZVOUS MANEUVERS
A2-123	RENDEZVOUS MANEUVER SOLUTION SELECTION CRITERIA
A2-124	RENDEZVOUS MANEUVER EXECUTION
A2-125	RNDZ OPS DELAY
A2-126	RNDZ/PROX OPS BREAKOUT
A2-127	RENDEZVOUS GUIDANCE
A7-11	GNC GPC REDUNDANCY REQUIREMENTS
A8-109	STAR TRACKER SYSTEM MANAGEMENT [CIL]

**FDO Console Handbook Appendix 3.C:  
Orbit FDO Flight Rule Index**

**Pre-Launch**

<b>Rule</b>	<b>Title</b>
A3-151C	MCC/KSC/45 SPW INTERFACE

# **FDO Console Handbook Appendix 3.C: Orbit FDO Flight Rule Index**

**Appendix 3.C Concludes On This Page**

## FDO Console Handbook Appendix 3.D: Orbit Trajectory Downlist Index

This index is by no means exhaustive. It is provided as a means to easily locate commonly referenced downlist quantities used by trajectory disciplines. The S/D column indicates the precision (single or double) of the corresponding HAL mnemonic. A "." appearing in the LDR column indicates corresponding MSIDs are available in the low data rate GNC DFL 62 downlist. This column contains ?s for quantities whose LDR support has yet to be determined. The current GNC DFL is displayed next to the "GN" field at the upper right of ONAV ORBITAL STATUS, MSK 549.

Quantity	HAL Mnemonic(s)	MSID(s)	S/D	LDR
Orbiter M50 sensed acceleration in ft/sec**2	A_SENSED	V95A0902C - 4C	D	
Orbiter M50 state vector in GMT hrs, ft, and ft/sec	T_LAST_FILT_TLM	V90W4285C	D	.
	R_FILT_TLM	V90H4277C - 9C	D	.
	V_FILT_TLM	V90L4281C - 3C	D	.
Last Orbiter state vector uplink time tag in GMT hrs	T_ORB_STATE_UPDATE	V94W3727C	D	
Target M50 state vector in GMT hrs, ft, and ft/sec	T_TV	V90W0315C	D	
	R_TV_TLM	V90H4287C - 9C	D	.
	V_TV_TLM	V90L4291C - 3C	D	.
Last target state vector uplink time tag in GMT hrs	T_TV_STATE_UPDATE	V90W4939C	D	
Left-handed M50-to-Orbiter-body quaternion in sec	T_CURRENT_FILT_Q_M50BODY_IMU	V90W4749C V95U0873C - 6C	D S	
Orbiter M50 vent acceleration in ft/sec**2	VENT_SS	V90U4964C - 6C	S	
Orbiter vent on and off times in GMT hrs	TFON	V90W4959C	D	
	TFOFF	V90W4960C	D	
Orbiter geodetic altitude in ft	ALT_SS	V90H4945C	S	?
Orbiter M50 aerodynamic drag in ft/sec**2	D_SS	V90U4842C - 4C	S	?

# **FDO Console Handbook Appendix 3.D: Orbit Trajectory Downlist Index**

**Appendix 3.D Concludes On This Page**

## FDO Console Handbook Appendix 3.E: Emergency Deorbit

Immediately perform the following actions.

- 1) \_\_\_\_\_ TRAJ pages or calls ENTRY FDO and LSO. Provide landing GMT and landing site/runway.
- 2) \_\_\_\_\_ Delete all future maneuvers in E1.
- 3) \_\_\_\_\_ Enter checklist segment based on scenario in the following table.

<b>Checklist Usage</b>	
<b>SCENARIO</b>	<b>ACTION</b>
A. Deorbit burn has occurred	Go to Block A (then D, E, F as directed)
B. Deorbit immediately	Go to Block B (then D, E, F as directed)
C. Deorbit ASAP (TIG > 20 min from now)	Go to Block C (then D, E, F as directed)

## FDO Console Handbook Appendix 3.E: Emergency Deorbit

### BLOCK A CREW HAS BURNED ALREADY

- A1) \_\_\_\_\_ Direct crew to ENT FS p 3-34 (starred block) for MM303 Attitude (also located in Cont. D/O Prep p 10-16).  
NOTE: if a PEG-7 deorbit burn is in progress after a protracted comm outage, supply FD and crew with equivalent PEG-7 targets from DMP. In lieu of applicable DMP targets, refer to Figure 3.9.7-1.
- A2) \_\_\_\_\_ Have NAV run DAE using post-burn vector (B70, START, NONE, V53\$) and then proceed with remaining steps in NAV CHB SOP 6.7, ANY TIME DEORBIT procedure.
- A3) \_\_\_\_\_ Access 'OUTPLANE Plot' and 'CUR DAE Output' from the FDO DNAV's ASCENT menu.
- A4) \_\_\_\_\_ Check for a Landing Site within the DAE footprint on 'OUTPLANE PLOT'.  
NOTE: to zoom plot, draw box around region using left mouse button. To unzoom plot, click right mouse button. To extend plot to show high/low latitudes, hold CNTRL key and draw small box in center of screen using left mouse button. Then draw box around entire region using left mouse button without holding CNTRL key.

#### If a landing site exists in the DAE footprint, perform Steps A5 and A6.

- A5) \_\_\_\_\_ Choose best site based on WX, if available, and LSO Priority list.
- A6) \_\_\_\_\_ Check ENT FS p. 3-2 through 3-4 to determine if site is in the O/B LST.  
a) \_\_\_\_\_ If YES, no LST synch required. **Go to SYNC LANDING SITE TABLES (Step D5).**  
b) \_\_\_\_\_ If NO, an LST synch is required. **Go to SYNC LANDING SITE TABLES (Step D1).**

#### If no landing site exists in the DAE footprint, perform Step A7.

- A7) \_\_\_\_\_ Note Impact Point LATD and LONG on CRNT DAE OUTPUT display.

**Go to SYNC LANDING SITE TABLES (Step D3).**



## FDO Console Handbook Appendix 3.E: Emergency Deorbit

### BLOCK B DEORBIT BURN REQUIRED ASAP (TIG WITHIN 20 MINUTES)

NOTE: while doing Steps B2, B4, and B5, NAV can start working Step B6. If Step B3 is executed, NAV has to wait for targets before starting Step B6.

NOTE: depending on the failure scenario requiring this immediate deorbit, the crew will be working in the Contingency Deorbit Prep book, most likely Section 10 (Emergency Deorbit). The procedure in Section 10 is designed for 20 min < TIG < 2 hrs 40 min. With < 20 minutes available, some steps such as PLBD closure must be delayed while others are eliminated.

- B1) \_\_\_\_\_ Have the crew manually maneuver to LVLH  $Y=0$ ,  $P=180^\circ$ ,  $R=0$ .
- B2) \_\_\_\_\_ If in a near-circular orbit ( $H_a - H_p \leq 50$  nm), read up pseudo-Deorbit PAD to crew (thruster, TVR, current weight and trims, C1, C2,  $\theta_T$ , HT, and TIG). Use either B2a (DMP targets) or B2b (generic targets) as the source for C1/C2/ $\theta_T$  (DMP is preferred).
- a) \_\_\_\_\_ Obtain C1/C2/ $\theta_T$  from an existing DMP solution in same orbit (get C1, C2, and  $\theta_T$  from DOD display in lieu of DMT).
  - b) \_\_\_\_\_ Obtain C1/C2/ $\theta_T$  from altitude/inclination-dependent tables (see Figures 3.9.7-4a/b in Section 3.9.7.3.7).
  - c) \_\_\_\_\_ HT = 65.832 nm (400000 ft).
  - d) \_\_\_\_\_ TIG = current time + estimated time to maneuver to burn attitude.
- B3) \_\_\_\_\_ If in an elliptical orbit ( $H_a - H_p > 50$  nm) or generic targets are otherwise unacceptable, perform the following steps.
- CAUTION: step B3 is currently a placeholder until DMP's validity in elliptical orbits is determined. Until this validity is known, generic deorbit targets from Step B2 are preferred, and Step B3 should not be performed.
- a) \_\_\_\_\_ Run DMP from current orbit to first available site (check ELS DOPS).
  - b) \_\_\_\_\_ Read up pseudo-Deorbit PAD, providing thruster, TVR, current weight and trims, C1/C2/ $\theta_T$  from DOD, HT = 65.832 nm, and TIG = current time + estimated time to maneuver to burn attitude.
- B4) \_\_\_\_\_ Have the crew load targets in OPS 3. Verify targets on MNVR Monitor, if possible.
- B5) \_\_\_\_\_ Give 'GO' for maneuver to deorbit burn attitude.
- B6) \_\_\_\_\_ Have NAV run NAV CHB SOP 6.7, ANY TIME DEORBIT.
- a) \_\_\_\_\_ Specify deorbit targets (use Figure 3.9.7-4a/b or DOD).
  - b) \_\_\_\_\_ Provide TIG and ephemeris to NAV.
- NOTE: an example call would be "NAV, run Emergency Deorbit, use H7 targets, E1, and TIG at 1/03:27 MET".
- B7) \_\_\_\_\_ Access 'OUTPLANE Plot' and 'CUR DAE Output' from the FDO DNAV's ASCENT menu.
- B8) \_\_\_\_\_ Check for a Landing Site within the DAE footprint on 'OUTPLANE PLOT'
- NOTE: to zoom plot, draw box around region using left mouse button. To unzoom plot, click right mouse button. To extend plot to show high/low latitudes, hold CNTRL key and draw small box in center of screen using left mouse button. Then draw box around entire region using left mouse button without holding CNTRL key.

## FDO Console Handbook Appendix 3.E: Emergency Deorbit

**If a landing site exists in the DAE footprint, perform Steps B9 and B10.**

B9) \_\_\_\_\_ Choose best site based on WX, if available, and LSO Priority list.

B10) \_\_\_\_\_ Check ENT FS p. 3-2 through 3-4 to determine if site is in the O/B LST.  
a) \_\_\_\_\_ If YES, no LST synch required. **Go to SYNC LANDING SITE TABLES (Step D5).**  
b) \_\_\_\_\_ If NO, an LST synch is required. **Go to SYNC LANDING SITE TABLES (Step D1).**

**If no landing site exists in the DAE footprint, perform Step B11.**

B11) \_\_\_\_\_ Note Impact Point LATD and LONG on CRNT DAE OUTPUT display.

**Go to SYNC LANDING SITE TABLES (Step D3).**

## FDO Console Handbook Appendix 3.E: Emergency Deorbit

### BLOCK C DEORBIT ASAP (TIG > 20 MINUTES AWAY)

NOTE: the crew will be working in the Contingency Deorbit Prep book, most likely Section 10 (Emergency Deorbit). The procedure in Section 10 is designed for 20 min < TIG < 2 hrs 40 min. Depending on time available, some steps may be delayed or eliminated.

- C1) \_\_\_\_\_ Have the crew manually maneuver to LVLH Y=0, P=180°, R=0.
- C2) \_\_\_\_\_ Check ELS DOPS for available sites or check Chron DOPS spreadsheet, if available, for sites, priorities, and common names.

**If no site is available within allotted time to deorbit (probable system failure scenario), perform Steps C3 through C12.**

- C3) \_\_\_\_\_ Run DMP from current orbit to first available site (regardless of TIG).
- C4) \_\_\_\_\_ Transfer the DMP solution into E1 and override/change TIG to the latest acceptable TIG per the system failure scenario.
- C5) \_\_\_\_\_ Have NAV run DAE off E1 deorbit burnout (B70, START, NONE, MVE1XX\$), per NAV CHB SOP 6.7.
- C6) \_\_\_\_\_ Have NAV update NOW24 per NAV CHB SOP 6.7.
- C7) \_\_\_\_\_ Access 'OUTPLANE Plot' and 'CUR DAE Output' from the FDO DNAV's ASCENT menu.
- C8) \_\_\_\_\_ Note Impact Point LATD and LONG on CRNT DAE OUTPUT display.

**Execute Steps C9/C10/C11 only if time allows.**

- C9) \_\_\_\_\_ Update TSA LST manually with NOW24 (Impact Point coordinates).
- C10) \_\_\_\_\_ Run DMP to NOW24 (fetch/search just prior E1 TIG).
- C11) \_\_\_\_\_ Transfer DMP solution to E1, replacing previous deorbit maneuver.
- C12) \_\_\_\_\_ **Go to Step C16.**

**If one or more sites are available within allotted time to deorbit, perform Steps C13 through C23.**

- C13) \_\_\_\_\_ Verify acceptable weather prior to selecting site. Obtain ELS Wx from Chron DOPS output or SMG ELS Wx website (PC or DNAV).

CAUTION: surface wind direction on the SMG ELS Wx web site is TRUE; not MAGNETIC. When inputting winds into QuAC for assessing runways, select 'T' under the REF column.

- C14) \_\_\_\_\_ If SMG on console, request upper wind forecast for landing site. When winds data arrive, have NAV run their CHB SOP 6.12 Part A as time permits.
- C15) \_\_\_\_\_ Run DMP to site with appropriate thrusters and transfer solution to ephemeris. Advise FD of landing site selection.

## FDO Console Handbook Appendix 3.E: Emergency Deorbit

- C16) \_\_\_\_\_ Run Orb Normal to landing site or NOW24. Check Drag vs. VE and Groundtrack for acceptable entry profile.
- C17) \_\_\_\_\_ Build PEG-4D command load (411XX) and uplink (see DM-CH-05, Flight Dynamics Command Procedures).

### Perform Steps C18 - C20 as time permits.

- C18) \_\_\_\_\_ Have TRAJ build and display deorbit TIG wall clock or ensure OIGN is queued.
- C19) \_\_\_\_\_ Time permitting, build MNVR PAD. Otherwise, voice up TIG, TGO, and Notes.
- C20) \_\_\_\_\_ Fill out top part of DEL PAD (set L, R OMS fail HPs = 80). Include TIG slip, if possible.
- C21) \_\_\_\_\_ Have the crew load targets in OPS 3 and verify them on MNVR Monitor, if possible.
- C22) \_\_\_\_\_ Give 'GO' for maneuver to attitude.
- C23) \_\_\_\_\_ **Go to BLOCK D, SYNC LANDING SITE TABLES, as follows.**  
a) \_\_\_\_\_ Step D1 if landing site is not in onboard LST.  
b) \_\_\_\_\_ Step D3 if landing site is the Impact Point (NOW24).  
c) \_\_\_\_\_ Step D4 if landing site is in the onboard LST.

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### BLOCK D SYNCH LANDING SITE TABLES (Onboard, TrS, EDS, TSA)

NOTE: the following steps require landing site and TACAN command loads to be built and uplinked. Reference DM-CH-05, Flight Dynamics Command Procedures, and Section 3.9.7.3.4, Emergency Landing Site Uplink Notes.

CAUTION: Steps D1 and D3 use the standard LS/TACAN command manager application found on FDO DNAV path Gen Traj : Command Loads Sub-menu : Landing Site TACAN.

CAUTION: Step D2 uses the Emergency LS/TACAN command manager application, found on FDO DNAV path Gen Traj : Command Loads Sub-menu : Landing Site TACAN w/GLOBE (Emergency Tool).

- D1) \_\_\_\_\_ If the landing site is not onboard, but is resident in EDS and TSA LSTs, perform the following actions.
- a) \_\_\_\_\_ Build LS/TACAN command load (41203/41303) for landing site using LS/TACAN command manager (replace slot 3) and uplink to Onboard (must be in OPS 3).
  - b) \_\_\_\_\_ Update TrS LST using LS/TACAN command manager "Update TRS" button.
  - c) \_\_\_\_\_ **Go to Step D5.**
- D2) \_\_\_\_\_ If the landing site is not resident in EDS and TSA LSTs, access the GLOBE database for uplink with the following actions.
- a) \_\_\_\_\_ Request NAV load site into EDS using NOW24 script with manual override of site coordinates to specified ELS location.
  - b) \_\_\_\_\_ Build LS/TACAN command load (41203/41303) for landing site using LS/TACAN w/GLOBE (Emergency Tool) command manager (replace slot 3) and uplink to Onboard (must be in OPS 3)
  - c) \_\_\_\_\_ Update TrS LST using LS/TACAN command manager "Update TRS" button.
  - d) \_\_\_\_\_ **Go to Step D5.**
- D3) \_\_\_\_\_ If the landing site remains NOW24 (no site in DAE footprint), perform the following actions.
- CAUTION: if neither Step A2 nor Step B6 has been performed, first have NAV update TrS and EDS LSTs with NOW24.
- a) \_\_\_\_\_ Build LS command load (41203) for NOW24 in Slot 3 using LS/TACAN command manager (use manual option in command manager and input NOW24 data from CUR DAE Output display) and uplink in OPS 3.
  - b) \_\_\_\_\_ **Go to Step D6.**
- D4) \_\_\_\_\_ If landing site is onboard, no LST synch is required. **Go to Step D5.**
- D5) \_\_\_\_\_ Re-run Orb Normal only if Block A or B steps have been executed.
- a) \_\_\_\_\_ Run Orb Normal to landing site in DAE footprint using burnout vector in E1 or V53, as applicable.
  - b) \_\_\_\_\_ **Go to Step D6.**

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- D6 \_\_\_\_\_ Post-deorbit, direct crew to select landing site for entry per one of the following actions.
- a) \_\_\_\_\_ If NOW24 or ELS is loaded into slot 3, expect ITEM 41 + 2 on SPEC 50.
  - b) \_\_\_\_\_ If landing site already existed onboard, expect ITEM 41 + X on SPEC 50, then ITEM 4 EXEC if necessary to select secondary runway. Get AREA number X from ENT FS, pp. 3-2 through 3-4.
  - c) \_\_\_\_\_ **Go to Block E.**

## FDO Console Handbook Appendix 3.E: Emergency Deorbit

### BLOCK E OTHER COORDINATION (TRAJ duties if LSO not present)

NOTE: LSO will perform these actions after being contacted, even if still en route to MCC. When paging LSO, supply landing site/impact coordinates and landing GMT.

References: 1) FDO Console Handbook Sections 3.12.11.2 and 4.9.22  
2) Example dialogue in Section 3.9.7.3.5

CAUTION: Block E actions rely heavily on the foregoing references. These documents should be used to achieve clear and concise communication.

- E1) \_\_\_\_\_ Communicate with SAR forces through DOD Cape on DOD COORD (see Section 3.9.7.3.5 example) and supply the following information.
- a) \_\_\_ Projected Impact Point or Landing Site (runway #, if available)
  - b) \_\_\_ Projected landing GMT
- E2) \_\_\_\_\_ Contact the landing site airfield per the following interfaces.
- a) \_\_\_ If CONUS landing site, phone “LRD” for KSC, “GOM” for EDW, and “WGM” for NOR. Transition to LANDING FIELD PRIME 1.
  - b) \_\_\_ If DOD landing site, contact “DOD Cape” on DOD COORD.
  - c) \_\_\_ If non-DOD landing site in US, contact FAA HQ ATC System Comm Center Duty Officer and request the site be alerted. Also attempt direct site contact.
  - d) \_\_\_ If non-DOD landing site outside US, contact State Department Watch Officer at Ops Center via NASA liaison - State Department loop. See Section 3.9.7.3.3, Emergency Landing Comm Checklist.
- E3) \_\_\_\_\_ Exchange the following information with airfield personnel (see Section 3.9.7.3.5 example).
- a) \_\_\_ Provide projected landing GMT and runway.
  - b) \_\_\_ Declare spacecraft emergency.
  - c) \_\_\_ Request immediate airspace and runway clearance.
  - d) \_\_\_ Obtain current Wx observations.
- E4) \_\_\_\_\_ **Go to Block F.**

## FDO Console Handbook Appendix 3.E: Emergency Deorbit

### BLOCK F ENTRY PLANNING

- F1) \_\_\_\_\_ Monitor and confirm deorbit burn.
- F2) \_\_\_\_\_ Build EI clock (TRAJ)
- F3) \_\_\_\_\_ Direct crew to ENT FS p. 3-34 (starred block) for MM303 ATTITUDE (also located in Cont. D/O Prep p. 10-16).
- F4) \_\_\_\_\_ Have NAV run Orb Normal off burnout vector (V53 or confirmed burn) to landing site or NOW24. If upper level winds data available (see Step C14), turn Approach/Land ON to access file.
- F5) \_\_\_\_\_ Evaluate Drag vs. VE, Groundtrack, etc.
- F6) \_\_\_\_\_ Fill out Entry portion of DEL PAD. Annotate with "N/A" for upper winds if data are not available.
- F7) \_\_\_\_\_ At EI -5 min, project Entry plots on front screens and workstation with the following actions. Monitor entry (or bailout).
- a) \_\_\_\_\_ For display on front screens, invoke Applications : Auto Display  
Configs : Large Screen Entry Displays : Entry Displays from FDO DNAV.
  - b) \_\_\_\_\_ For display on workstation, invoke Applications : Auto Display  
Configs : HiSpeed Entry (FDO) from FDO DNAV.
  - c) \_\_\_\_\_ Invoke Ascent : Bailout display from FDO DNAV to monitor bailout events.

**Appendix 3.E Concludes On This Page**



## FDO Console Handbook Appendix 3.F: CCC Timer Creation

Three types of timers are supported in the CCC. The following table summarizes their behaviors assuming creation at time T. Target Time  $T_z$  is the instant at which the timer reads zero, Activation Time  $T_a$  is the instant at which the timer becomes dynamic, and Expiration Time  $T_x$  is the instant at which the timer becomes static.

Timer Type	Target Time ( $T_z$ )	Activation Time ( $T_a$ )	Expiration Time ( $T_x$ )
DOWN	T before $T_z$	T before $T_a^1$ before $T_z$	$T_x$ at $T_z$
UP	any time	$T_a$ at $T_z$	T and $T_a$ before $T_x$
DOWN/UP <sup>2</sup>	T before $T_z$	T before $T_a^1$ before $T_z$	T and $T_a$ before $T_x$

The following procedures create CCC timers for display only at the FDO Console (Local) or throughout the CCC (Global).

- 1) Select **Global Apps : Timers/Clocks : Control Panel** from the Master DNAV menu bar. The **Timing Services Control Panel - Client (TSC)** window will appear (see Figure 3.F-1).

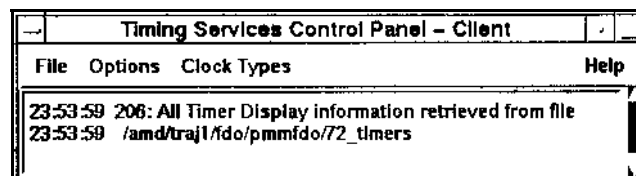


Figure 3.F-1: TSC Window

- 2) To create a DOWN timer or an UP timer, select **Clock Types : Create... : Event Timer...** from the TSC window's menu bar. The **Create Event Timer (CET)** window will appear (see Figure 3.F-2).

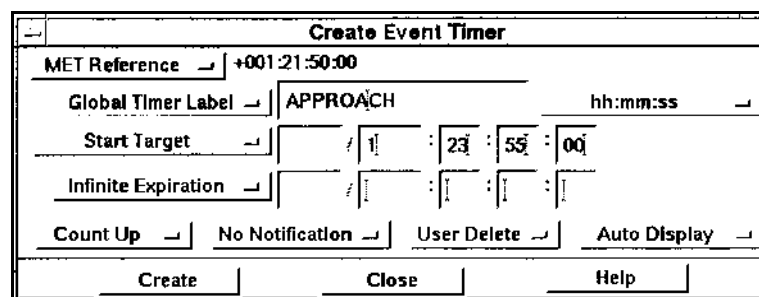


Figure 3.F-2: CET Window with Standard UP Timer Inputs

Configure pull-down fields and enter values in the CET window per the following table.

<sup>1</sup>Theoretically, it should be possible to immediately activate a DOWN timer by specifying  $T_a$  at or before T. Unfortunately, immediate activation results in a DOWN timer which can't be modified. Until this DRed condition is cleared, near-immediate DOWN timer activation should be achieved by specifying  $T_a$  one second in the future.

<sup>2</sup>A DOWN/UP timer is actually a linked pair of DOWN and UP timers. When the DOWN timer deactivates, the UP timer activates. Modification of the DOWN timer prior to  $T_z$  results in corresponding modifications to the paired UP timer.

## FDO Console Handbook Appendix 3.F: CCC Timer Creation

DOWN Timer		UP Timer	
Field	Value	Field	Value
MET Reference		MET Reference	
Global <sup>3</sup> Timer Label	ASCII string < 16 char <sup>4</sup>	Global <sup>3</sup> Timer Label	ASCII string < 16 char <sup>4</sup>
hh:mm:ss		hh:mm:ss	
Future Start Duration	000:00:00:01 <sup>1</sup>	Start Target	Tz in d:hh:mm:ss MET
Target Expiration	Tz in d:hh:mm:ss MET	Infinite Expiration	
Count Down		Count Up	
No Notification <sup>5</sup>		No Notification <sup>5</sup>	
User Delete		User Delete	
Auto Display		Auto Display	

Click the CET window's **Create** button.

- 3) Perform this step to create a DOWN/UP timer. Select **Clock Types : Create... : Count Down Count Up Timer...** from the TSC window's menu bar. The **Create Count-down/Count-up Timers (CDUT)** window will appear (see Figure 3.F-3).

Figure 3.F-3: CDUT Window with Standard DOWN/UP Timer Inputs

Configure pull-down fields and enter values in the CDUT window per the following table.

<sup>3</sup>Select **Local Timer Label** from pulldown if timer display is to be restricted to the FDO Console.

<sup>4</sup>If a Global timer is to be displayed by GC "on the wall", hardware limitations require the label string be less than 9 characters in length.

<sup>5</sup>This option suppresses DVIS tone activation at Tz. If a tone is desired, select the **DVIS 2 Sec** pulldown option. Selection of the **Continuous** pulldown option is not recommended because subsequent manual action is required to deactivate the DVIS tone following Tz.

## FDO Console Handbook Appendix 3.F: CCC Timer Creation

MET Reference		
Field	DOWN Timer Column	UP Timer Column
		Count Up Timer
Timer Label	ASCII String < 16 char <sup>4,6</sup>	ASCII String <sup>4,6</sup>
Start Time	000:00:00:01 <sup>1</sup>	
Start Type	Future Start Duration	
Target Time	Tz in d:hh:mm:ss MET	
Timer Type	Target Expiration	Infinite Expiration
Location	Global Timer <sup>3</sup>	
Display	Auto Display	
Notification	No Notification <sup>5</sup>	No Notification <sup>5</sup>
Time Format	hh:mm:ss	hh:mm:ss
Deletion		User Delete

Click the CDUT window's **Create** button.

<sup>6</sup>Since a DOWN/UP timer is really a DOWN timer linked to an UP timer, different names must be applied to each member of the pair. By convention, both timers are assigned the same prefix, the DOWN timer receives a "-" suffix, and the UP timer receives a "+" suffix.

# **FDO Console Handbook Appendix 3.F: CCC Timer Creation**

**Appendix 3.F Concludes On This Page**

## FDO Console Handbook Appendix 3.G: Orbit Rules of Thumb

This appendix groups conversion factors and other useful "rules of thumb" into categories for quick reference. All relationships are at least roughly linear in nature. An "@" symbol designates any applicable assumptions. Depending on the accuracy required, these assumptions may yield acceptable results throughout the Orbiter's flight envelope.

**CAUTION:** any rule called a "shift" only documents a change in magnitude. No sign convention is supplied.

### G.1 Orbit Element Shifts @ H = 160 nm

- a) Inclination Shift = 442 fps/° (fps = PEG-7 ΔVY near node)
- b) Node Shift = 211 fps/° @ i = 28.5° (fps = PEG-7 ΔVY near anti-node)
- c) Apsis Height Shift = 1.76 fps/nm (fps = PEG-7 ΔVX near other apsis)
- d) Period Shift = 2.26 sec/nm (nm = mean ΔH) = 0.642 sec/fps (fps = PEG-7 ΔVX)

### G.2 CLV ReIMo @ H = 160 nm

PEG-7 ΔVx = +1 fps		PEG-7 ΔVy = +1 fps		PEG-7 ΔVz = +1 fps	
ΔX @ 1 Rev	ΔZ @ 0.5 Rev	ΔY @ 0.25 Rev		ΔX @ 0.5 Rev	ΔZ @ 0.25 Rev
-2.68 nm	-0.568 nm	+0.142 nm		+0.568 nm	+0.142 nm

- a)  $\dot{\Delta X} = +9.42 * [\text{mean } \Delta Z \text{ du}] \text{ du/rev}$  (du = any distance unit)<sup>1</sup>
- b)  $\dot{\Delta X} = +0.00174 * [\text{mean } \Delta Z \text{ du}] \text{ du/sec}$  (du = any distance unit)
- c)  $\dot{\Delta X} = -2.68 \text{ nm/rev/fps} = -0.0426^\circ/\text{rev/fps}$  (fps = PEG-7 ΔVX)

### G.3 Geocentric Phase θ @ H = 160 nm

- a)  $\dot{\theta} = -0.0994^\circ/\text{hr/nm}$  (nm = mean ΔH)
- b)  $\dot{\theta} = -0.150^\circ/\text{rev/nm}$  (nm = mean ΔH)
- c)  $\dot{\theta} = -0.0159^\circ/\text{nm}$  (nm = CLV ΔX)

### G.4 Propellant Systems

System	Max Load (lbf)	Inches Per 100 Pounds		Pounds Per Foot Per Second <sup>2</sup>	
		X-CG	Y-CG	Translation <sup>3</sup>	Attitude Control
FRCS	2164	-0.36	0.0	24 - 26	6 - 7 (ARCS)
ARCS	4592	+0.11	0.04	25 - 28	0.5 (FRCS)
OMS	24266	+0.13	0.04	22 - 24	0.0

### G.5 Time Zones

- a) EST = GMT - 5 hrs      CST = GMT - 6 hrs      PST = GMT - 8 hrs
- b) EDT = GMT - 4 hrs      CDT = GMT - 5 hrs      PDT = GMT - 7 hrs
- c) Daylight time extends from 2 AM the first Sunday in April until 2 AM the last Sunday in October<sup>4</sup>

<sup>1</sup>This rule is a restatement of NAV's Vector-Compare-based downtrack position (ΔV) extrapolation from semi-major axis deviation (Δa):  $\Delta V(\text{extrapolated}) = \Delta V(\text{current}) - 10 * \Delta a(\text{current})$ .

<sup>2</sup>Supplied values are for Orbiter weights over the range 220000 - 240000 lbf.

<sup>3</sup>RCS efficiencies are for NORM-Z translations. Under LOW-Z, +Z translations consume approximately 325 pounds per foot per second.

<sup>4</sup>This is true for KSC, JSC, NOR, EDW, and most ConUS sites. Different local conventions may apply to other US and foreign locations.

# **FDO Console Handbook Appendix 3.G: Orbit Rules of Thumb**

**Appendix 3.G Concludes On This Page**

## FDO Console Handbook Appendix 3.H: MCC Graphics Export

There are multiple methods of generating graphics files from workstation displays and screen dumps. In the past, the X-window dump (xwd) command was used to perform this function in FDO procedures. The addition of direct FTP capability from the MCC workstations to the MAS PCs creates an environment in which it is desirable to create PC image files, such as jpg or gif formats, on the workstation. Due to this new capability, use of the X-View tool will become more common.

### H.1 X-Windows Dump (xwd)

The unix xwd command can be used to generate window or screen dump image files. The images generated with this command are in a format not recognized by standard PC graphics viewers. In order for such files to be useful in PC documentation, the file must be converted to a gif file using the TOPO PCDrop file transfer method. See Appendix 3.I for instructions transferring files via this method.

To create a graphics file with the contents of an individual window on the screen, type the following command into an xterm on the screen that contains the window of interest.

```
xwd > <filepath><filename>.xwd
```

When this command is executed, the mouse cursor will change to a plus sign. The next window that is clicked will be dumped to a file with the file name specified in the command line.

To create a graphics file with the contents of the entire screen, type the following command into an xterm on the screen of interest.

```
xwd -root > <filepath><filename>.xwd
```

When this command is executed, the whole screen will be immediately dumped to a file with the file name specified in the command line.

If the user wishes to capture a window with pop-up menus visible, the following command can be used to achieve this result.

```
sleep <seconds>; xwd -root > <filepath><filename>.xwd
```

In this command, <seconds> should be an integer number representing the number of seconds the system will wait before performing the screen dump. During this time, the pop-up menus can be configured. At the end of the sleep time, the entire screen will be dumped to an image. This image can later be cropped to the dimensions of interest.

**NOTE:** to capture a window's frame along with its contents, type

```
xwd > -frame <filepath><filename>.xwd
```

 in an xterm on the same screen.

### H.2 X-View (XV)

The X-View application contains graphics generation and basic graphics editing capabilities. It can be used in place of an xwd command to create a window image. X-View is capable of saving captured images in multiple file formats, which makes it a better tool to use if the images are to be transferred to the PC via the FTP method (see Appendix 3.I). For more information on X-View, the user's guide is available on the s: drive (S:\Divisions\DM\Private\DM32\USERS\Barrett\xvdocs.ps).

**NOTE:** since pulldown menus are in themselves X-windows, they may be captured into an image. However, they cannot be captured along with their parent window in a single image

## FDO Console Handbook Appendix 3.H: MCC Graphics Export

unless they are “tear-away” menus. Once the menus are torn away from their parent window, they can be captured using the middle mouse button selection described in Section H.2.2.2.

### H.2.1 GIF File Creation Procedures

Following this procedure will produce a .gif image of a single window. Many other options are available in this application. Some are described in Section H.2.2.

- 1) Launch X-View from the FDO DNAV under Applications : Tools : XV
- 2) When the **xv** window with the “flying fishies” graphic loads, right click on it to bring up the main **xv controls** application window.

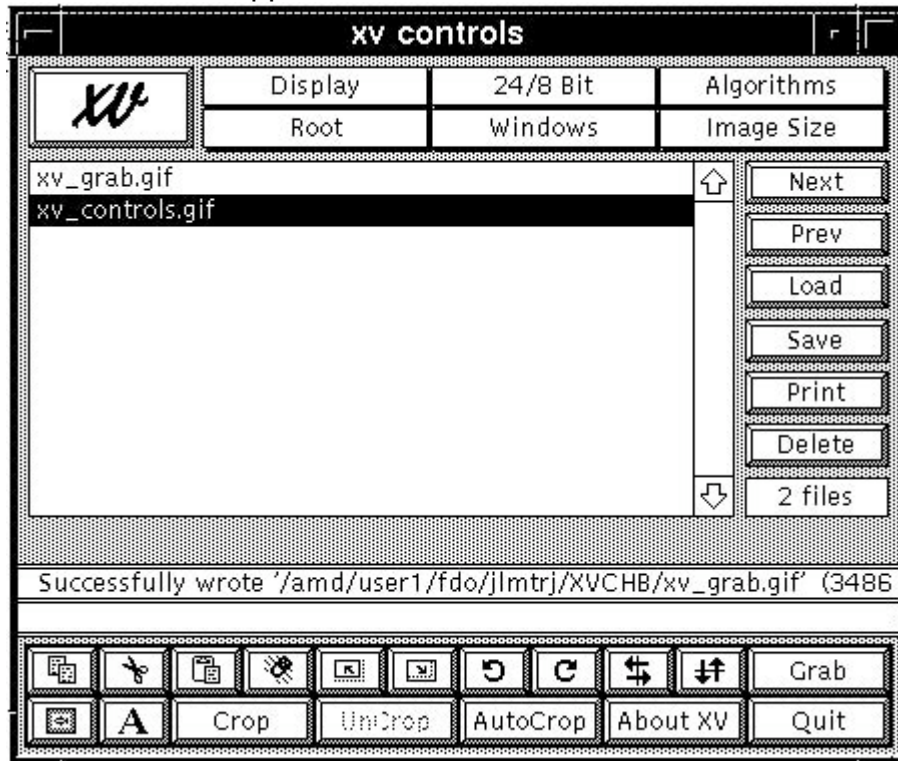


Figure 3.H-1: XV Controls Window

- 3) In the lower right corner, click Grab.
- 4) In the **xv grab** window's “Delay: 0 seconds” input, change 0 to 2, check the Hide XV windows checkbox, and select the AutoGrab button.



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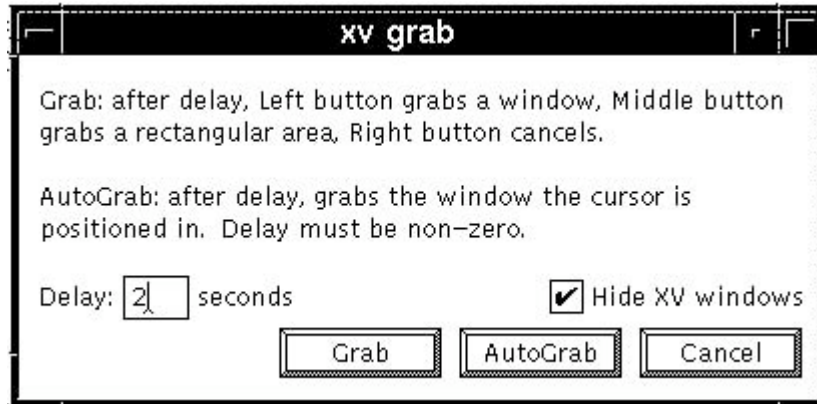


Figure 3.H-2: XV Grab Window

- 5) In the next two seconds, place the cursor on the window for which you wish to create a graphic. It is not necessary to click on the window. When the two seconds are up, the window will automatically be captured and the resulting image will be displayed in the "flying fishies" **xv** window.
- 6) If you desire to make the image into a black and white image or reverse the colors of the image, do the following:
  - a) Click and hold the Windows button in the **xv controls** window.
  - b) Select Color Editor from the pulldown menu.
  - c) If reverse video is desired, click the RevVid button.
  - d) If black and white is desired,
    - i. Click the Gray button to convert the image to greyscale
    - ii. Click the Dim button
    - iii. Click the 1 button next to the Dim button

NOTE: These actions must be taken in this order or the final product may vary.
- 7) To save the graphic to a file, click the Save button located in the **xv controls** window on the right side.

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- 8) When the **xv save** window loads, select the desired file format (GIF) from the Format pulldown in the upper right corner. Navigate to the desired location of the file and enter a file name ending in the extension gif.

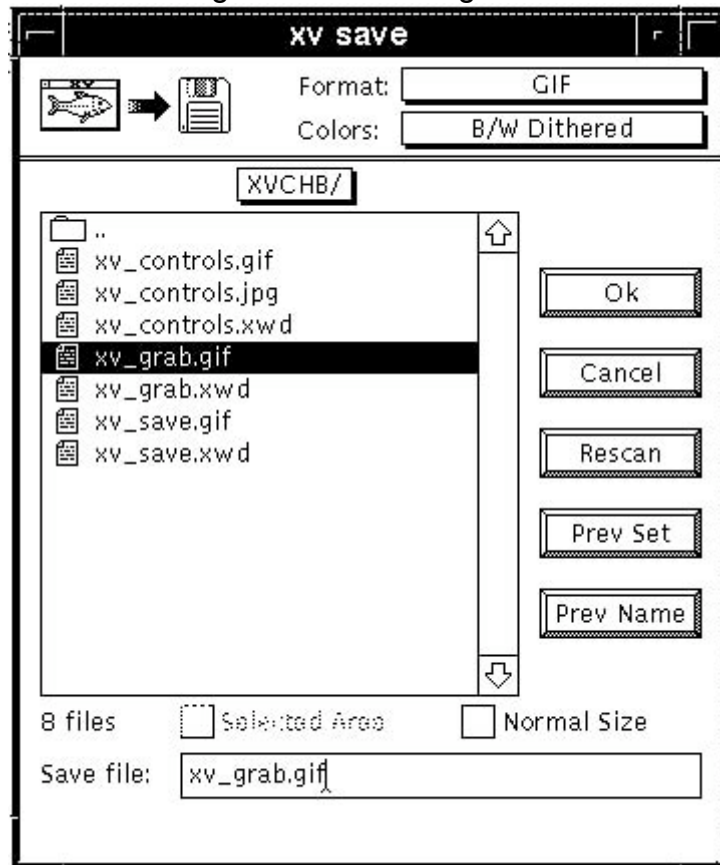


Figure 3.H-3: XV Save Window

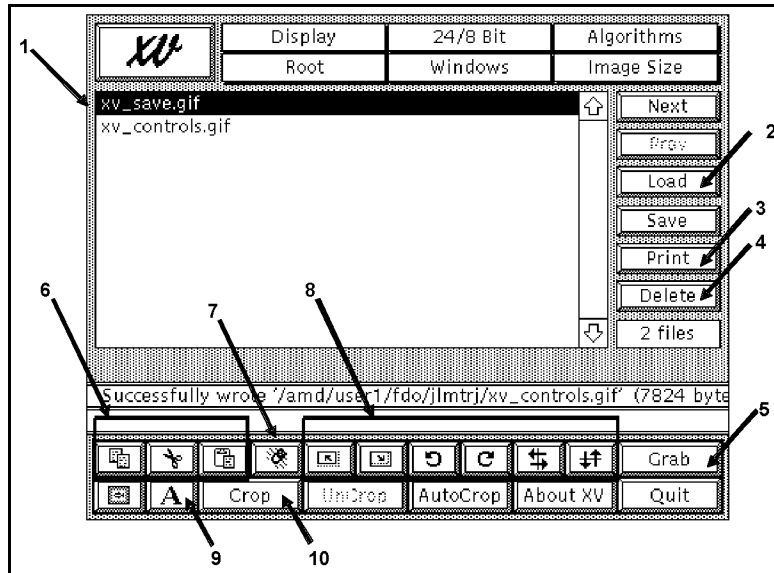
### H.2.2 Other XV Functionality

The X-View application provides a good deal more functionality than was contained in the procedure in Section H.2.1. Some of this functionality is described in this section, although the following sections are not exhaustive.

#### H.2.2.1 XV Controls Menu

The following paragraphs describe functionality of different widgets on the **xv controls** menu. Some functionality is described in detail; other functionality is merely mentioned.

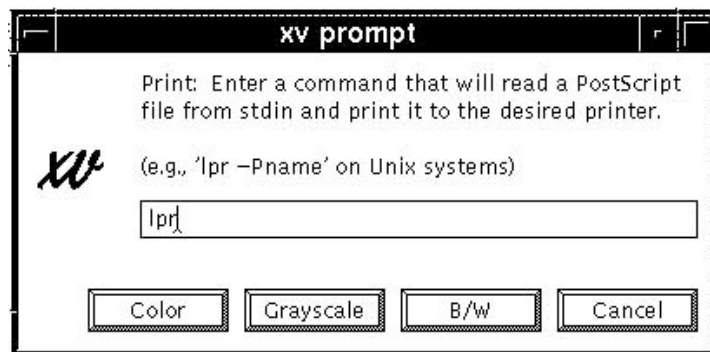
## FDO Console Handbook Appendix 3.H: MCC Graphics Export



**Figure 3.H-4: XV Controls Window Buttons**

The following numbers correspond to the numbered labels in Figure 3.H-4.

- 1) This area shows the files that are available for modification. Double-clicking on one of these file names will cause the picture to be displayed in the “flying fishies” window. This picture can then be edited using the other control buttons.
- 2) To load a file into the application, click the load button and select the file from the list in the **xv save** menu that pops up. When loaded, the file name will appear in the area described in Label 1. Note that gif, jpeg, tiff, bmp, and xwd (at the least) will successfully load into the application.
- 3) The print button invokes the **xv prompt** window (see Figure 3.H-5). Entering a unix print command into the text line on this window will send the picture to a printer. The picture can be sent in color, grayscale, or black and white.



**Figure 3.H-5: XV Prompt Window**

- 4) The delete button will delete the selected file. The file can be deleted either from only the **xv controls** list (Label 1), or off the hard disk and the **xv controls** list.
- 5) The grab button pulls up the **xv grab** window (see Section H.2.2.2).

## FDO Console Handbook Appendix 3.H: MCC Graphics Export

- 6) The three buttons in this area are standard copy, cut, and paste buttons.
- 7) This is the eraser button. It will erase anything selected in the “flying fishies” window, replacing the selected area with background color pixels. To select an area, click and drag a rectangle in the “flying fishies” window.
- 8) The buttons in this area stretch, rotate, and flip the image or selected portions of the image.
- 9) This button can be used to add text annotations to an image. An area on the image for the text must be selected before clicking the text button, or no text will appear on the image.
- 10) This button will crop the image to the dimensions selected by clicking and dragging on the image.

### H.2.2.2 XV Grab Dialog

The following paragraphs describe different ways to capture images using the **xv grab** dialog.

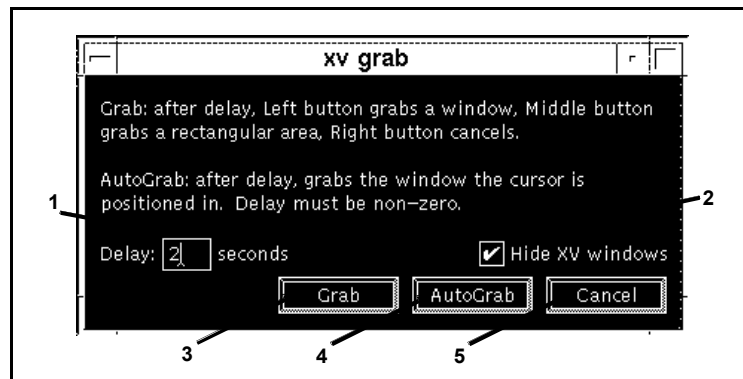


Figure 3.H-6: XV Grab Dialog

The following numbers correspond to the numbered labels in Figure 3.H-6.

- 1) Entering an integer value into the Delay field will trigger a corresponding delay in sec after the Grab or AutoGrab buttons are pushed before the image is to be captured. It is always advisable to change this field to a non-zero integer. The delay time can be used to configure the window to be imaged into the desired appearance. For instance, if the user desires to capture an image of a pulldown menu, the pulldown can be configured as desired during this delay time. After the delay is over, the window is available for capture with the menu's items visible.
- 2) When the Hide XV windows box is checked, all X-View windows will be hidden after the Grab or AutoGrab buttons are pushed. This is advisable so that XV windows do not mask windows the user wishes to image.
- 3) Pushing the Grab button will arm the application to grab the first window clicked after the delay specified in 1). The delay time is up when the workstation beeps and a momentary cursor change is noted. At this point, X-

## FDO Console Handbook Appendix 3.H: MCC Graphics Export

View will dump the first window left-clicked on into an image and display it in the “flying fishies” window. Alternatively, the user may capture part of or the entire screen by using the middle mouse button to click and drag a rectangle on the screen.

- 4) Pushing the AutoGrab button will cause whichever window the mouse cursor is in after the delay specified in Label 1 to be dumped into an image with no mouse click required.
- 5) The Cancel button returns the user to the **xv controls** menu without grabbing an image.

### H.2.2.3 XV Save Dialog

The following paragraphs describe different ways to save images using the **xv save** dialog.

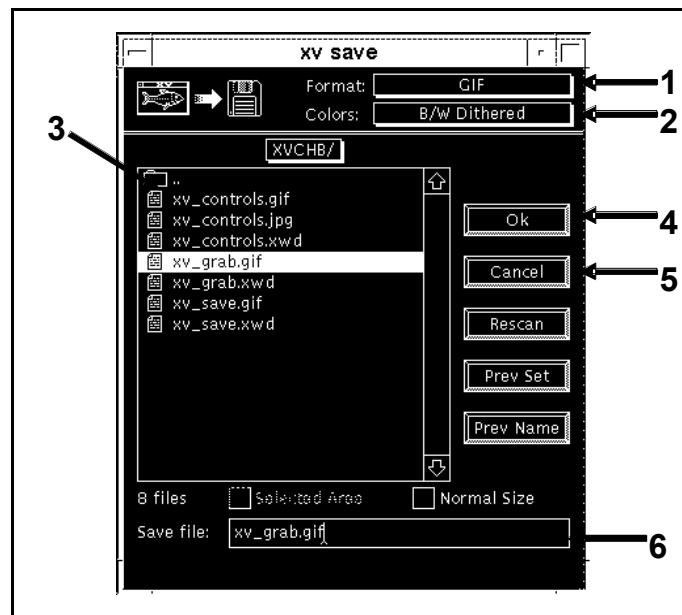


Figure 3.H-7: XV Save Dialog

The following numbers correspond to the numbered labels in Figure 3.H-7.

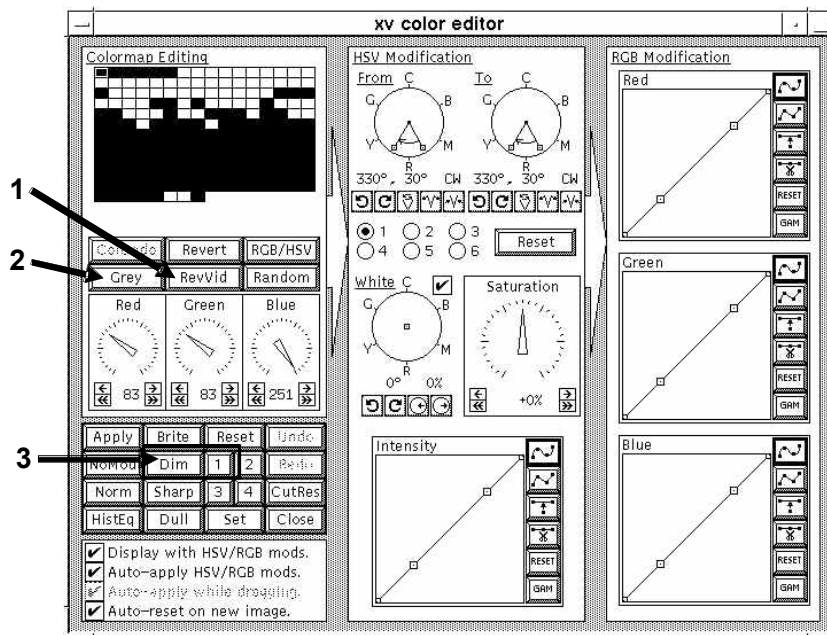
- 1) The Format pulldown allows the user to select the file format with which to save a captured image. GIF, JPEG, TIFF, and BMP are included, along with other formats.
- 2) The Colors pulldown allows the user to select full color, grayscale, b/w dithered, or reduced color. The image will be saved in color or not based on this input.
- 3) This area is a standard file/directory browser.
- 4) The OK button saves the file in the selected location.

## FDO Console Handbook Appendix 3.H: MCC Graphics Export

- 5) The Cancel button takes the user back to the **xv controls** menu without saving the image.
- 6) The file name in which the image will be saved is entered here.

### H.2.2.4 The Color Editor

The **xv color editor** contains many controls for manipulating the image colors, which will not all be covered here. The **xv color editor** is launched by clicking the Windows button on the **xv controls** window, and then selecting Color Editor. The following paragraphs describe the basics of the **xv color editor**.



**Figure 3.H-8: XV Color Editor**

The following numbers correspond to the numbered labels in Figure 3.H-8.

- 1) The RevVid button changes the color scheme of the image to reverse video.
- 2) The Grey button converts the image to greyscale.
- 3) The Dim button converts the image to an image of the dimension selected. For instance, pressing Dim then 1 would convert a greyscale image to a black/white image.

**Appendix 3.H Concludes On This Page**

## FDO Console Handbook Appendix 3.I: MCC File Export

There are two methods of transferring data from an MCC workstation to a PC. One method sends files through a TOPO-managed dropbox on the IPS system to the user's PC-based e-mail. The other method utilizes Xdir to FTP files directly to a directory on the JSC-MAS PC's v: \ drive. The most convenient method to use for a particular transfer will depend on the purpose of the transfer and user preference.

### I.1 TOPO PCDrop Method

To send files via the IPS TOPO dropbox, the user must have a valid IPS account, password, and dropbox directory. To set up your dropbox directory, talk to the TOPO managing these directories. At the time of this writing, the responsible TOPO is Jim Cooney. File export relies on a "cron job" script and directory tree associated with mission-critical IPS equipment under continual support. E-mail is automatically generated by the cron job with the exported file attached as uuencoded character data. Distribution for this e-mail depends on the IPS directory in which the exported file is stored.

The IPS TOPO dropbox transfer method has some limitations. Any text file whose MCC path is accessible may be exported. Graphic files obtained from the X-windows dump (xwd) utility may also be exported, but they must have a filename ending with an ".xwd" extension to be correctly processed. See Appendix 3.H for more information on X-window dump and other methods of creating graphics on the DEC workstation.

**CAUTION:** this procedure uses the workstation-based client "XDir" to transfer files into IPS directories on which the cron job operates. Other applications, such as the IPS-resident FrameMaker word processor, can also be used to supply files to the cron job's directories. If an exported file is created on IPS by an application other than XDir, care must be taken to insure the cron job has write permission for the file. Should this not be the case, the cron job cannot delete the file after it's mailed. Consequently, the file will be e-mailed to the same recipient(s) every few minutes until the cron job's server fails or manual action is taken to delete or move the file. All files transferred via XDir have write permission enabled for the cron job by default.

**CAUTION:** exported file size is limited to less than 7 MB by the cron job's e-mail support.

**NOTE:** many e-mail clients are programmed to interpret attached file association with an application based on the file's extension. Although .xwd files are an exception, it's customer-friendly to append exported text files with a .txt, .doc, or other appropriate extension.

**NOTE:** in addition to simple file transfers to single JIN recipients documented here, it's also possible to use cron job features supporting file export to e-mail distribution lists and individual recipients anywhere on the Internet. Consult the **PCDrop Users Guide** on the TOPO home page for details regarding these extended data export functions.

#### I.1.1 TOPO PCDrop Procedures

The following steps should be taken to export files to the user's e-mail via the TOPO PCDrop method.

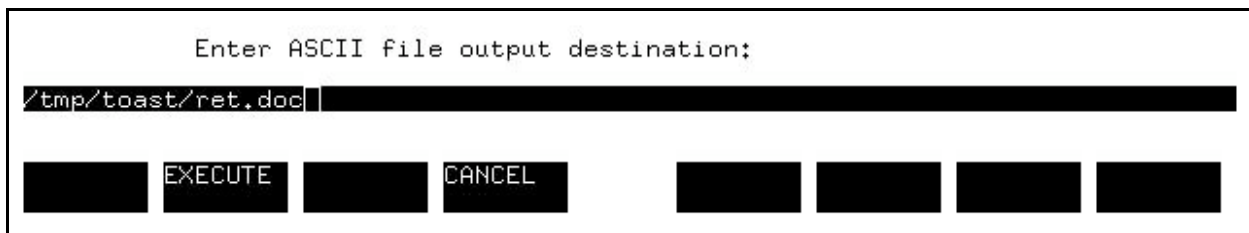
## FDO Console Handbook Appendix 3.I: MCC File Export

- 1) A text file corresponding to printable TSA output data is stored on the workstation's local hard disk or on the OPS LAN. Printing to a file is accomplished using application-specific File menu items in TSA processors with X-window user interfaces. For processors with TOAST Menu Handler user interfaces, file printing must first be enabled using the TSA DNAV's **Miscellaneous Functions** submenu. Menu Handler hardcopy function keys will then generate the desired files to a specified path. With either user interface, careful note of the output file's pathname must be made.

**CAUTION:** it's inadvisable to leave TOAST Executive printer output enabled when ASCII file output is also enabled. Although file output will proceed normally under these settings, printed output may be missing entire pages.

- 2) When a TOAST Executive hardcopy function is invoked, the **ASCII Printout** window (see Figure 3.I-1) will appear with a default file pathname. Modify the pathname's string as required, make note of the pathname, then click the **ASCII Printout** window's **EXECUTE** button. The specified file is created or replaced with characters equivalent to the printable TSA data.

**CAUTION:** avoid using any keyboard shortcuts to edit the **ASCII Printout** window's default file pathname. In particular, using F10 to delete the default yields unpredictable results. Click at the end of the string with the middle mouse button and use the hot backspace key as required instead of F10.



**Figure 3.I-1: TOAST Executive Text Output File Creation**

**CAUTION:** the `/tmp/` directory used in Figure 3.I-1 always exists and is visible only to your workstation. Two other directory paths are available in which to store a TOAST Executive ASCII file, and these are readable by any OPS LAN user. The first path is TOAST Executive's default and takes the form `/users/fdo/Data/<activityID>/<userID>/<sessionID>/<processID>/`. This default path may be altered only subsequent to the `<activityID>` directory, which is typically of the format `STSxxx`. The second OPS LAN path option is `/users/fdo/<userID>/`. Since this is your personal OPS LAN directory, it may be organized in any way you wish. Within these restrictions, the specified path may be used to create new directories.

- 3) From the TSA DNAV menu, select **XDir**. An XDir window will appear.
- 4) Navigate to the previously noted pathname, under which TSA created the text file, with the XDir window's **Goto** menu.

**NOTE:** XDir's **Goto** menu maintains a set of standard paths, as well as a history of those recently accessed. If the desired path doesn't appear in the menu, it can be specified after selecting the **Directory...** item.



## FDO Console Handbook Appendix 3.I: MCC File Export

- 5) From the XDir window's **Connect** menu, select the **Connect to Remote...** item, and the **Connect to Remote** window will appear as in Figure 3.I-2. If the correct HostID (UserID) string for your IPS login appears in the **Recently Referenced Hosts:** list, it may be double-clicked without further **Connect to Remote** interaction. Otherwise, enter **fdxcn01** to the **Host Name:** text widget and your IPS user ID to the **User Name:** text widget, then click the **Connect** button.

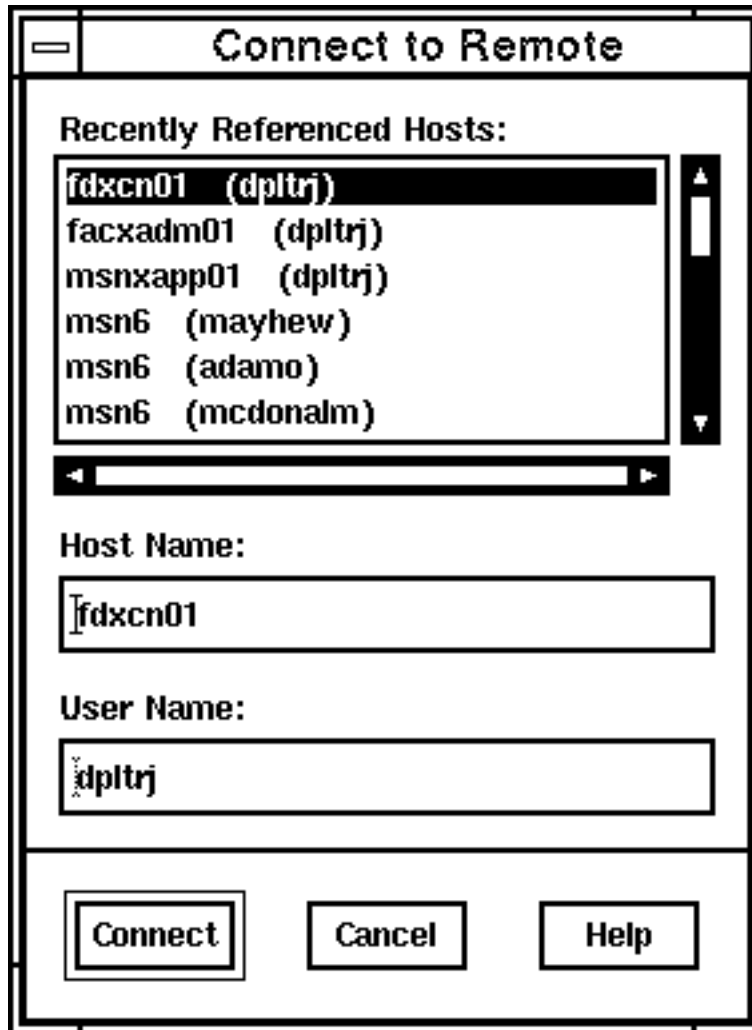


Figure 3.I-2: XDir's Connect To Remote Window

**CAUTION:** certain OPS configurations such as LSOS do not support remote host aliases like "fdxcn01". In such cases, the equivalent IP address must be substituted for a **Host Name** alias. A relevant list of IP addresses can be obtained per the Figure 3.I-3 Xterm transaction. From this example, **130.196.177.42** would be substituted for **fdxcn01**.

## FDO Console Handbook Appendix 3.I: MCC File Export

```
white-fcr10:/users/fdo > ypcat hosts | grep -e fdxcn
130.196.177.51 fdxcn05.ips.jsc.nasa.gov fdxcn05 # FADS_CR SERVER LINUX
130.196.177.42 fdxcn01.ips.jsc.nasa.gov fdxcn01 # FADS_CR SERVER LINUX
130.196.177.43 fdxcn02.ips.jsc.nasa.gov fdxcn02 # FADS_CR SERVER LINUX
130.196.177.55 fdxcn09.ips.jsc.nasa.gov fdxcn09 # FADS_CR SERVER LINUX
130.196.177.45 fdxcn04.ips.jsc.nasa.gov fdxcn04 # FADS_CR SERVER LINUX
130.196.177.44 fdxcn03.ips.jsc.nasa.gov fdxcn03 # FADS_CR SERVER LINUX
130.196.177.54 fdxcn08.ips.jsc.nasa.gov fdxcn08 # FADS_CR SERVER LINUX
130.196.177.52 fdxcn06.ips.jsc.nasa.gov fdxcn06 # FADS_CR SERVER LINUX
130.196.177.53 fdxcn07.ips.jsc.nasa.gov fdxcn07 # FADS_CR SERVER LINUX
white-fcr10:/users/fdo > □
```

**Figure 3.I-3: Remote Host IP Addresses With "fdxcn" Aliases**

- 6) Following interaction with the **Connect to Remote** window, an IPS password prompt appears. Enter your IPS password, then click **OK**. After a successful IPS login, XDir will spawn a child window pointed at your IPS home directory.
- 7) Use the child window's **Goto** menu to navigate to the desired subdirectory in `/ips/msn/gds/gen_common/topo/pcdrop/`. The parent (lower) and child (upper) XDir windows should appear as in the Figure 3.I-4 screen dump.

## FDO Console Handbook Appendix 3.I: MCC File Export

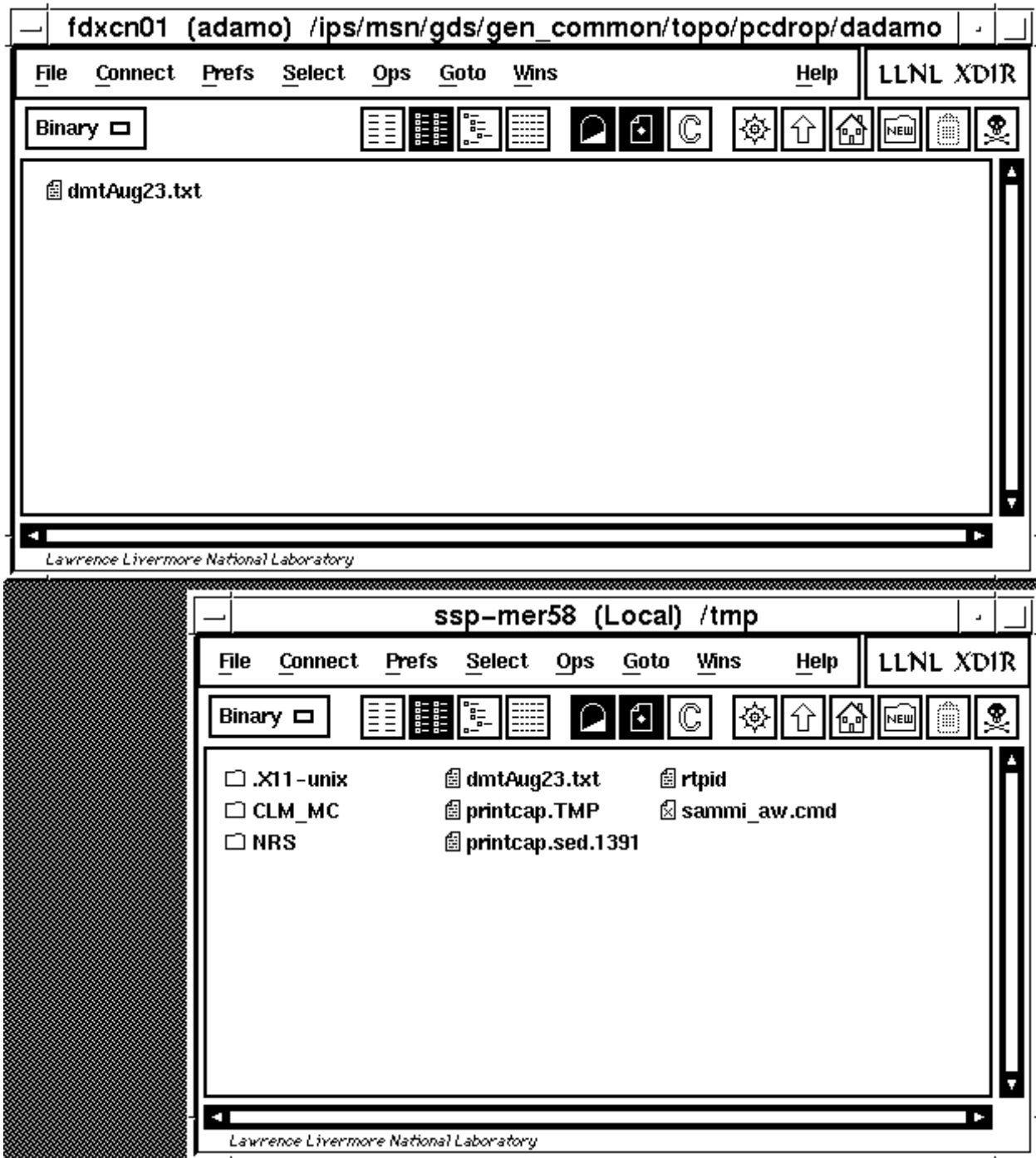


Figure 3.I-4: XDir Windows Configured For File Export

**NOTE:** the parentic substring in each XDir window title bar indicates the pertinent **Connect** menu userID; not a TSA database area. Thus, Figure 3.I-4's parent window shows the **/tmp** directory resides on the **pocc5** host being accessed by a **Local** user. The child window in this example indicates the pcdrop path resides on the **fdxcn01** host being accessed via remote login under the **adamo** userID.

- 8) Click on the parent window files to be exported, highlighting them. Click on one of the highlit files and drag it to the child window. Copies of all highlit parent window files will

## FDO Console Handbook Appendix 3.I: MCC File Export

appear in the child window, indicating OPS file exports to IPS. The cron job will e-mail these files to the associated IPS directory's distribution in less than 5 minutes. The IPS directory's contents will then be deleted.

### I.2 JSC-MAS FTP Method

To send files via FTP to the `V:\` drive, the user must have a valid JSC-MAS account, password, and access to the `\\Jsc-mas-pf1\OpsFTP\Fdo\` directory. The files will be posted to the folder `V:\Fdo\Fdo OpsFTP` (this is a shortcut to the `\\Jsc-mas-pf1\OpsFTP\Fdo\` directory). From there, the files can be moved wherever the user wishes.

**NOTE:** a convention has evolved whereby each user creates a subfolder to the `\\Jsc-mas-pf1\OpsFTP\Fdo\` directory in his/her name. You may create this directory yourself. Any FDO user can place files in or delete files from any of these directories.

**NOTE:** the `V:\` drive can be accessed from your office PC by mapping the `\\Jsc-mas-pf1\OpsFTP\Fdo\` directory. When doing this, be sure to select the "Connect using a different user name" option and enter `jsc-mas\<username>` and your MAS password.

**CAUTION:** this procedure should not be used to transfer `.xwd` files to the PC. Files of this type must undergo export via the TOPO PCDrop method to be converted into GIF images. See Appendix 3.H for instructions on using X-View to generate GIF files on the workstation. The unix command `xwdtopnm [file] | ppmtogif > [file]` can also be used to convert `.xwd` format to `.gif` format.

**CAUTION:** space is limited in the `\\Jsc-mas-pf1\OpsFTP\Fdo\` directory tree. Be sure to delete files from this folder as soon as possible when you have saved them elsewhere. If the space allocated fills up, neither you nor other users will be able to transfer files to the `V:\` drive until files are deleted. One large file may be enough to exceed storage space in this folder. Any FDO user can delete files to bring the storage back under allocation, but every effort should be made to clear the deletion with the owner of the data before deleting other users' files.

**CAUTION:** in extreme cases, total storage allocated the `\\Jsc-mas-pf1\OpsFTP\` directory tree may be exceeded. This may be due to usage in other disciplines whose files FDOs cannot delete. If this problem is encountered, the JSC-MAS Help Desk may be able to aid you.

#### I.2.1 JSC-MAS FTP Procedures

The following steps should be taken to export files to the PC via the JSC-MAS FTP method.

- 1) A text file corresponding to printable TSA output data is stored on the workstation's local hard disk or on the OPS LAN. Printing to a file is accomplished using application-specific File menu items in TSA processors with X-window user interfaces. For

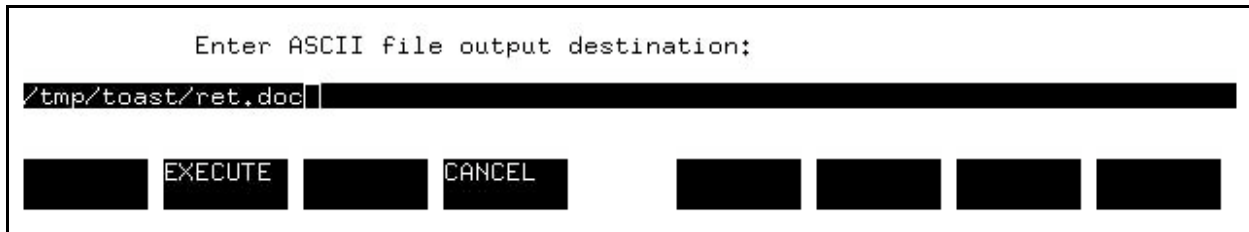
## FDO Console Handbook Appendix 3.I: MCC File Export

processors with TOAST Menu Handler user interfaces, file printing must first be enabled using the TSA DNAV's **Miscellaneous Functions** submenu. Menu Handler hardcopy function keys will then generate the desired files to a specified path. With either user interface, careful note of the output file's pathname must be made.

**CAUTION:** it's inadvisable to leave TOAST Executive printer output enabled when ASCII file output is also enabled. Although file output will proceed normally under these settings, printed output may be missing entire pages.

- 2) When a TOAST Executive hardcopy function is invoked, the **ASCII Printout** window (see Figure 3.I-5) will appear with a default file pathname. Modify the pathname's string as required, make note of the pathname, then click the **ASCII Printout** window's **EXECUTE** button. The specified file is created or replaced with characters equivalent to the printable TSA data.

**CAUTION:** avoid using any keyboard shortcuts to edit the **ASCII Printout** window's default file pathname. In particular, using F10 to delete the default yields unpredictable results. Click at the end of the string with the middle mouse button and use the hot backspace key as required instead of F10.



**Figure 3.I-5: TOAST Executive Text Output File Creation**

**CAUTION:** the `/tmp/` directory used in Figure 3.I-5 always exists and is visible only to your workstation. Two other directory paths are available in which to store a TOAST Executive ASCII file, and these are readable by any OPS LAN user. The first path is TOAST Executive's default and takes the form `/users/fdo/Data/<activityID>/<userID>/<sessionID>/<processID>/`. This default path may be altered only subsequent to the `<activityID>` directory, which is typically of the format `STSxxx`. The second OPS LAN path option is `/users/fdo/<userID>/`. Since this is your personal OPS LAN directory, it may be organized in any way you wish. Within these restrictions, the specified path may be used to create new directories.

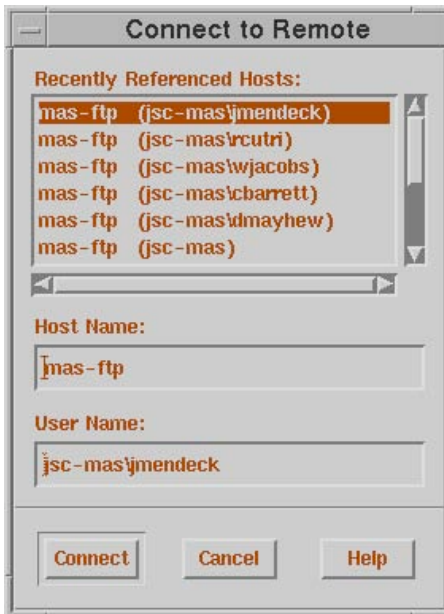
- 3) From the TSA DNAV menu, select **XDir**. An XDir window will appear.
- 4) Navigate to the previously noted pathname, under which TSA created the text file, with the XDir window's **Goto** menu.

**NOTE:** XDir's **Goto** menu maintains a set of standard paths, as well as a history of those recently accessed. If the desired path doesn't appear in the menu, it can be specified after selecting the **Directory...** item.

- 5) From the XDir window's **Connect** menu, select the **Connect to Remote...** item, and the **Connect to Remote** window will appear as in Figure 3.I-6. If the correct HostID (UserID) string for your MAS login appears in the **Recently Referenced**

## FDO Console Handbook Appendix 3.I: MCC File Export

**Hosts:** list, it may be double-clicked without further **Connect to Remote** interaction. Otherwise, enter **mas-ftp** to the **Host Name:** text widget and `jsc-mas\<username>` to the **User Name:** text widget, then click the **Connect** button.



**Figure 3.I-6: XDir's Connect To Remote Window**

- 6) When you are prompted for a password, enter your MAS PC password.
- 7) Make sure your transfer mode is Binary (on XDIR ASCII/BINARY switch is on the left side of the display).
- 8) Navigate to `\\Jsc-mas-pf1\OpsFTP\Fdo\<user folder>\`.
- 9) Click on the parent window files to be exported, highlighting them. Click on one of the highlighted files and drag it to the child window. Copies of all highlighted parent window files will appear in the child window, indicating OPS file exports to IPS. The cron job will e-mail these files to the associated IPS directory's distribution in less than 5 minutes. The IPS directory's contents will then be deleted.
- 10) On the PC, use Windows Explorer to navigate to `\\Jsc-mas-pf1\OpsFTP\Fdo\<user folder>`.
- 11) Copy your files to a permanent storage location.
- 12) Delete your files from `\\Jsc-mas-pf1\OpsFTP\Fdo\<user folder>\`.

**Appendix 3.I Concludes On This Page**

## FDO Console Handbook Appendix 3.J: Change Processing

- 1) The change initiator fills out a change request (CR) form. The CR form is available on the DM Server via pathname  
S:\Divisions\DM\Private\DM32\DOCS\FDOCHB\CRform.doc. See Figure 3.J-1 for an example of this form as it would be submitted by the initiator. At a minimum, the initiator supplies the submit date, a short change subject or title, a detailed description of the change, rationale for the change, and the initiator's organization/name. Supplementary material may be attached to the form by the initiator as required.
- 2) The initiator transmits the CR form to the pertinent documentation editor. Electronic or printed media may be used at the initiator's discretion.
- 3) The editor reviews the CR and formulates recommendations for implementation. The editor will also assess whether or not this CR affects the Command Procedures Handbook (CPH) at this time and indicate accordingly on the CR form.
- 4) For routine or purely editorial changes, the editor will perform all authoring tasks required by the CR. However, if the editor requires a dedicated author's expertise to implement the CR, associated technical content and schedule are reviewed with the pertinent group lead. When an author is identified on the CR, the editor approves it for implementation.
- 5) If the CR is disapproved for implementation, the initiator is informed of its disposition. The editor may elect to retain the CR on file for future reference or dispose of the CR completely.
- 6) If the CR is approved for implementation, the editor assigns it a tracking number and notifies the author to proceed. The editor initiates a CPH CR at this time, obtaining group lead approval, if the approved CR affects command procedures in any way. Affectivity includes pagination and any editorial updates, regardless of how minor. A CPH CR form may be obtained from the System Division's work instructions Master List.
- 7) The author optionally submits draft documentation to technical experts for peer review. The author incorporates any feedback from this process into a final draft.
- 8) The author submits the final draft to the editor.
- 9) The editor reviews and modifies the final draft for technical correctness and consistency with related documentation. The editor may request additional contributions from the author during this process.
- 10) The editor incorporates the final draft into a page change notice (PCN) original. The PCN may also contain final drafts related to other CRs and appropriate changes to the affected document's table of contents or revision history.
- 11) The editor reviews PCN content with the group lead, mapping changes into CRs authorized for implementation. Any CR affecting command procedures requires the editor present evidence of corresponding CPH CR approval by the FOIG or Flight Director Office to the group lead. If the PCN addresses the CR such that it has been completely implemented, the editor annotates the CR as closed by the pertinent PCN number. Some CRs may be left open because they must be implemented with multiple PCNs. When satisfied with PCN content, the group lead approves the PCN for publication by signing its cover memo.

## FDO Console Handbook Appendix 3.J: Change Processing

- 12) The editor supervises PCN reproduction and distribution. This includes posting the PCN to "general use" console and office copies. If necessary, the editor also distributes a copy of PCN segments affecting command procedures to the Flight Director Office. In conjunction with PCN distribution, the editor insures the appropriate Master List is updated accordingly.

### FDO Console Handbook Volume 3 Change Request (CR)

<b>Submit Date:</b> April 28, 1997	<b>CR #</b> <small>For Administrative Use Only</small>
<b>Subject:</b> Change Process Documentation	
<b>Description of Change or Addition:</b> Add an appendix describing the process under which FDO Console Handbook change traffic is managed.	
<b>Reason for Change or Addition:</b> This documentation is required to close an ISO-9000 internal audit action.	
<b>Initiated By:</b> DM32/Dan Adamo	<b>Assigned To:</b>
<small>For Administrative Use Only</small>	
<b>Command Procedures Handbook Affected?</b>	YES      NO
<b>Book Manager Authorization Signatures</b>	
<b>IMPLEMENT</b>	<b>CLOSE</b> (PCN =      )

Revised October 1999

**Figure 3.J-1: Initiated FDO Console Handbook CR Form**

**Appendix 3.J Concludes On This Page**



## FDO Console Handbook Appendix 3.K: OPS Data Management

This appendix first documents a procedure with which FDOs can archive MCC OPS data in a non-critical mass storage partition. By storing large or seldom-used datasets in this partition, saturation of the limited FDO data allocation in the critical OPS partition is less likely over time. A procedure for restoring data from an archive is also provided. Following these archive procedures is a table listing paths to OPS and related data repositories of interest to FDOs. The table includes a summary of each directory's contents. This appendix concludes with notes relating how reconfiguration data are organized and where they are stored in OPS.

**NOTE:** data restoration to the critical partition in MCC OPS is required to be complete less than one minute after it's lost. Data restoration to the non-critical partition is required in less than 24 hours.

To archive files in the current directory with names `<file1 file2 ...>`, perform the following steps.

- 1) Bundle the files into an archive named `<arch.tar>`.  
`tar cvf <arch.tar> <file1 file2 ...>`
- 2) Compress the archive, creating a file named `<arch.tar.gz>`.  
`gzip <arch.tar>`
- 3) Move the compressed archive to directory `<MyNonCritData>` in the non-critical partition's FDO directory tree.  
`mv <arch.tar.gz> /noncritical/DM/fdo/<MyNonCritData>`
- 4) Delete the original files.  
`rm <file1 file2 ...>`

To retrieve archived data in the current directory named `<arch.tar.gz>`, perform the following steps.

- 5) Uncompress the archive, creating a file named `<arch.tar>`.  
`gunzip <arch.tar.gz>`
- 6) Check the archive's contents (optional).  
`tar tv <arch.tar>`
- 7) Unbundle files from the archive.  
`tar xvf <arch.tar>`

## FDO Console Handbook Appendix 3.K: OPS Data Management

In the following table describing FDO data repositories, OPS pathnames use forward slashes (/), while those on PCs use backward slashes (\).

Path	Contents
/users/trj/Database/Global/TSA<x.y>/	Generic reconfiguration data baseline for TSA version <x.y>
/users/trj/Database/SSP<zzz>/cycle<a>/TSA<x.y>/	Reconfiguration data baseline for TSA version <x.y> specific to Flight <zzz> and MCC recon cycle <a>
/users/trj/Database/SSP<zzz>/cycle<a>/PMP/	PMP baseline specific to Flight <zzz> and MCC recon cycle <a>
/users/fdo/<userID>/	Data storage specific to user <userID>
/users/fdo/Data/SSP<xxx>/<sitYYY>/	DOL storage for flight <xxx>, landing site <sit>, and deorbit orbit number <YYY>
V:\fdo\STS<xxx>\entry\EOM\<sitYYY>\	DOL storage for flight <xxx>, landing site <sit>, and deorbit orbit number <YYY>
/users/fdo/Data/SSP<zzz>/DOPS/FD<n>/	DOPS output (DOT data in dops.txt, together with chron.txt and sun_angle.txt files) specific to flight <zzz> generated on Flight Day <n>
/users/fdo/Data/SSP<zzz>/DOPS/Latest/	Symbolic link used by Master DNAV DOPS viewer to access latest data
V:\Fdo\STS<zzz>\CONUS DOPS Data\DOPS.fd<n>.txt	DOPS DOT output specific to flight <zzz> generated on Flight Day <n> and serving as input to CONUS DOPS Excel application

## FDO Console Handbook Appendix 3.K: OPS Data Management

Path	Contents
V:\Fdo\STS<zzz>\ChronDOPS Data\ChronDOPS.fd<n>.txt	DOPS chron.txt output specific to flight <zzz> generated on Flight Day <n> and serving as input to ChronDOPS Excel application

For simulations, OPS Data (MCC Recon) and simulator data (SMS Load) must be consistent. To this end, a system has been established whereby the SMS Load is referenced to a particular MCC Recon cycle. This Recon cycle is imbedded as `cycle<a>` in pathnames to OPS Data referenced in the foregoing table.

The MCC Load Matrix is used to relate an SMS Load to the corresponding Recon database. This Matrix is actually a spreadsheet listing each flight's Recon cycle and corresponding SMS Load, along with many other attributes including TrS version and Flight Design cycle. This spreadsheet can be accessed from the FDO Home page by selecting IVT Web page, then Integration, then SSP Recon. It is also located at JSC-MOD-FS3 (S: Drive) path `DM32\USERS\Barrett\TSI\SSP MCC Load Matrix.xls`. The next-to-last Matrix column (labeled SMS LD) identifies the SMS Load, which also appears on the sim schedule. Look under the fourth column, labeled MCC W/S RCN CYC, to determine which Recon cycle should be used for the simulation.

To determine which Recon cycle has been established in the current activity, enter the following Unix command in an xterm window.

```
echo $TRJ_DB
```

This command will result in a displayed pathname akin to `/users/trj/Database/SSP116/cycle<a>`, where `<a>` is the MCC recon cycle.

In general, simulations are conducted using a one-cycle-to-flight (OCF) Flight Design cycle (last column on the MCC Load Matrix) until about one week prior to launch. At this time, the close-to-launch (CTL) cycle products are delivered, and MCC reconfiguration updates are made with these "latest and greatest" products included in trajectory data to be used for flight. A new MCC Recon cycle is not established for these updates unless highly unlikely major changes are to be delivered just before launch. Ultimately, CTL updates are made to the current MCC Recon cycle. Prior to making these updates, GA will store the pre-flight Recon cycle load in an archive directory. The MCC Recon cycle used for the flight will still have the same name ("cycled", for example) but will include the CTL product data. After the mission, the pre-flight Recon data are restored to the MCC Recon cycle for use during subsequent generic simulations.

**FDO Console Handbook Appendix 3.K: OPS Data Management**

**Appendix 3.K Concludes On This Page**

## FDO Console Handbook Appendix 3.L: ESDs

Many FDO MCC displays use the Standards Automated Man-Machine Interface (SAMMI) runtime environment. This is a commercial off-the-shelf (COTS) software tool developed by the Kinesix Corporation for displaying dynamic data under X Windows. SAMMI is utilized primarily for TrS trajectory and telemetry data. Many SAMMI displays have graphic user interfaces that allow users to send commands to TrS. These Enhanced SAMMI Displays (ESDs) provide the FDO Console with a more user-friendly means to control data being displayed by avoiding use of archaic MED strings. This appendix provides an overview of SAMMI displays with MED capability as well as detailed procedures and considerations associated with their use.

The following guidelines apply to all FDO-accessed ESDs.

- 1) Only FDO, TRAJ, and DYNAMICS flight controllers have MED capability with ESDs. Note that NAV has exclusive MED capability on several of their own displays.
- 2) Prior to changing a FDO-owned display via SAMMI MED, first verify that FDO is not currently using the display. For TRAJ, this means leaning over to see if FDO has the display called up. If so, get FDO's permission to reconfigure the display. Failing to coordinate could result in FDO's unintentional use of changed display contents. DYNAMICS should make a query on the appropriate DVIS loop to request a FDO-owned display, since they have no way of knowing if it is currently in use.
- 3) Prior to changing any display not owned by FDO, first check with the owner via DVIS. Also notify the owner when you're done with the display. Each display's ownership appears with its title in this appendix.
- 4) Controls are provided through simple push-buttons, pull-down menus, and text input fields. When a change is made to any of these items, a pink background will appear as a talkback indication. Once all inputs have been made and a push-button is clicked to send the command to TrS, pink backgrounds will disappear.
- 5) Time inputs are made in a **ddd:hh:mm:ss.sss** format. Time fields generally require a leading **P** entry to indicate Phase Elapsed Time (PET) or Mission Elapsed Time (MET). Time fields in Greenwich Mean Time (GMT) do not require a **P**. FDO-owned ESDs requiring time inputs have a **P** toggle button to clear the time field and provide a leading **P**. The exception to this rule is any acquisition display with PET in its title (PSAT PET, for example). A leading **P** should not be input to these displays. This can easily be remembered since these displays are not equipped with **P** push-buttons. Only the time field itself is present. Time fields can be cleared by pressing the F11 key or by clicking the **P** push-button, which alternately places a **P** in the time field and erases it.

CAUTION: prior to shipping an ESD-driven command to TrS, it's necessary to press the return (enter) key for SAMMI to accept your inputs. Positive confirmation is provided when the time field background changes from blue to pink.

- 6) The Advisory Services (AS) window should be used to troubleshoot any ESD command problems. AS provides an echo of the exact MED string, together with a message indicating whether TrS accepted or rejected the command.
- 7) Commands should not be sent to TrS during checkpoints.

# FDO Console Handbook Appendix 3.L: ESDs

## Trajectory Digitals (FDO-Owned)

You can generate an Orbiter or target requested state at a specified time or orbit on this display. Required inputs are a time/orbit toggle, a state time value or orbit number in the text field, and an ephemeris. Clicking **EXECUTE** will fill in the specified lower display quadrant with requested state information.

**NOTE:** the Orbit Monitor display uses the left **ORBITER** column of MSK 470 for current lighting conditions. Therefore, do not use the **ORBITER** column to generate requested states for ephemerides other than 1. For ephemerides other than 1, use the right **TARGET** column.

180		TRAJECTORY DIGITALS				0470T	
TDR COMP		UNABLE TO RETRIEVE THE ORBIT NUMBER AT				THE	
REQUESTED TIME.							
ORBITER		GMT <sub>r</sub> 312:19:46:00.00		TARGET			
EPH	1 ▾ /S	O/T	TIME	PET	EPH	3 ▾ /S	O/T ORB <input type="checkbox"/> PET <input type="checkbox"/>
INPUT	314:21:45:31	<input type="button" value="EXECUTE"/> <input type="button" value="CANCEL"/>		INPUT		<input type="button" value="EXECUTE"/> <input type="button" value="CANCEL"/>	
VID	OBT 031	GMT <sub>v</sub> 314:18:16:00.00		VID	OBT 031	GMT <sub>v</sub> 315:01:51:00.00	
CURRENT STATE				CURRENT STATE			
ORB	33	GMT 314:21:18:39		ORB	0*	GMT 314:21:18:39	
Wt	247326.0	MET 002:01:32:39		Wt	7876.0	MET 002:01:32:39	
Ha	191.9	SR 002:01:44:53		Ha	0.0E	SR 002:06:19:42	
H <sub>p</sub>	189.0	N 002:02:14:22		H <sub>p</sub>	0.0E	N 002:06:49:13	
H <sub>o</sub>	193.9	SS 002:02:43:50		H <sub>o</sub>	0.0E	SS 002:07:18:44	
V <sub>i</sub>	25249.7	MID 002:03:00:11		V <sub>i</sub>	0.0E	MID 002:07:35:02	
i <sub>m50</sub>	28.45	T <sub>p</sub> 01:31:41.51		i <sub>m50</sub>	0.00E	T <sub>p</sub> E	
a	3636.97	φ <sub>D</sub> -27.4411		a	0.00E	φ <sub>D</sub> 0.0000E	
η <sub>M50</sub>	326.7626	λ 42.5592		η <sub>M50</sub>	0.0000E	λ 0.0000E	
W <sub>P<sub>M50</sub></sub>	287.9953	β -42.4344		W <sub>P<sub>M50</sub></sub>	0.0000E	β 0.0000E	
RAAN <sub>M50</sub>	158.2817	γ <sub>i</sub> -0.0167		RAAN <sub>M50</sub>	0.0000E	γ <sub>i</sub> 0.0000E	
REQUESTED STATE				REQUESTED STATE			
ORB	34	GMT 314:21:45:31		ORB		GMT	
Wt	247326.0	MET 002:01:59:31		Wt		MET	
Ha	192.3	SR 002:03:16:29		Ha		SR	
H <sub>p</sub>	189.4	N 002:02:14:22		H <sub>p</sub>		N	
H <sub>o</sub>	189.6	SS 002:02:43:50		H <sub>o</sub>		SS	
V <sub>i</sub>	25270.1	MID 002:03:00:11		V <sub>i</sub>		MID	
i <sub>m50</sub>	28.48	T <sub>p</sub> 01:31:46.72		i <sub>m50</sub>		T <sub>p</sub>	
a	3639.27	φ <sub>D</sub> -0.0001		a		φ <sub>D</sub>	
η <sub>M50</sub>	351.9789	λ 143.4616		η <sub>M50</sub>		λ	
W <sub>P<sub>M50</sub></sub>	8.5316	β -42.5103		W <sub>P<sub>M50</sub></sub>		β	
RAAN <sub>M50</sub>	158.1296	γ <sub>i</sub> -0.0126		RAAN <sub>M50</sub>		γ <sub>i</sub>	

# FDO Console Handbook Appendix 3.L: ESDs

## Flight Independent VAT (FDO-Owned)

A VAT vector can be automatically displayed in Checkout Monitor by selecting the VAT slot number with the pull-down menu and clicking **EXECUTE**.

086		FLIGHT INDPNDT VAT		0472F	
SLOT	V11	<input type="button" value="EXECUTE"/> <input type="button" value="CANCEL"/>		GMT 261:16:41:27	
SLOT	NAME	GMT	COMMENT		
V01					
V02					
V03					
V04					
V05					
V06					
V07	ORB 00	3:49:33.000			
V08	MIR 00	3:49:33.000			
V09	TDRE 041	261:13:40:00.000			
V10	TDRW 174	261:13:40:00.000			
V11	TDRS 085	261:13:40:00.000			
V12	TDRS 049	261:13:40:00.000			
V13					
V14					
V15	ORB 000	261:23:38:59.760	ORBITER FOR BUILDING 5		
V16	TRG 000	261:23:38:59.760	TARGET FOR BUILDING 5		
V17					
V18					
V19					
V20					
				<input type="checkbox"/> Print	<input type="checkbox"/> Quit

# FDO Console Handbook Appendix 3.L: ESDs

## Mission Plan Table (FDO-Owned)

You can select which ephemeris MPT data are displayed in GMT or MET with this ESDs. Two independent pull-down menus are provided, permitting maneuver data for as many as two ephemerides to be displayed at once.

086		MISSION PLAN TAB PET			0475E	
ORB VID ORB 006 PET 000:11:12:27 MGMT 261:16:52:00 TGT VID MIR 006						
PETAV 000:08:10:00 EPH 1 /S <input type="checkbox"/> EPH 3 /S <input type="checkbox"/> PETAV 000:08:10:00						
CODE	PETIGN	$\Delta T$	$\Delta V$	$\Delta VREM$	h a	h P
10RE01RD	000:15:36:08.6	09:45:09	8.1	883	159.5	117.7
10RE02NH	001:01:21:17.6	14:18:54	92.8	790	211.9	117.8
10RE03NC	001:15:40:12.0	01:33:48	152.3	638	212.2	204.2
10RE04SI	001:17:14:00.5	01:16:54	8.9	629	212.2	209.4
12XE05SR	001:18:30:54.5		2.6	168	212.7	209.0



# FDO Console Handbook Appendix 3.L: ESDs

## Detailed Maneuver Table 1 & 2 (FDO-Owned)

Command capability is provided to select vehicle ephemeris and maneuver number for display. A target ephemeris governing Lambert offsets can optionally be specified.

180				DMT NO.1				0476C			
VEH EPH 4		TGT EPH		MNVN 1		EXECUTE		CANCEL			
GMTI 315:19:46:00.0				CODE 4BPE01FC				GMTR 312:19:46:00.0			
PETI 003:00:00:00.0				TV ROLL 0				TIGT 000:00:00:00.0			
$\Delta V_M$ 0.0		$\Delta t_B$ 00:00.0		SYSP TRIMS P 0.6		LY -5.7		OUTPUT MAT CURI 01			
VX <sub>I</sub> 7.09				RY 5.7				OSTAID OBT 031			
VY <sub>I</sub> 5.46		$\Delta t_{ULL}$ 00.0		WEIGHT 7876				GMTV 315:01:51:00			
VZ <sub>I</sub> -4.46		$\Delta t_{RCS}$ 00:00.0		TIG 003:00:00:00.0				PETV 002:06:05:00			
$\Delta V_{TO}$ 0.00		$\Delta t_{TO}$ 00.00		PEG 4 C1 0				OEPH 4/S			
INR AX LVLH LX				C2 0.0000				TSTAID			
P 24.1 P 15.2 YH 0.0				HT 0.000				GMTV			
Y 19.7 Y 360.0 PH 15.2				$\theta_T$ 0.000				PETV			
R 243.5 R 0.0 RH 0.0				PRPLT 0				TEPH .			
TGT VEH DATA				PEG 7 $\Delta V_X$ 10.0				FSTAID			
ELTIG $\theta_{BO}$				$\Delta V_Y$ 0.0				GMTV 000:00:00:00			
$\Delta H_{BO}$ $\theta_{BO}$				$\Delta V_Z$ 0.0				PETV 312:19:46:00			
OFFSET MVR 1 EPH				BURN ATT R 243				WOMS 19110			
MET				P 24				WRCS 4592			
$\Delta T$				Y 20				WFNL 7876			
$\Delta X$				$\Delta V_{TOT}$ 0.0				$\Delta W$ 0			
$\Delta Y$				TGO 00:00				$\Delta V$ REMAIN			
$\Delta Z$				VGO X 9.65				PRI 0.0SEC			
HA 192.5 HP 188.8				Y 0.00							
$\lambda_{AN}$ 152:39E HBI 191.5				Z 2.62							
$\omega_p$ 132.7 $\phi_{BI}$ 10:13N				TGT HA 193 HP 189				ORB			
i 28.48 $\lambda_{BI}$ 33:32W				0:52:41 0:06:50				PET			
e 0.00104 $\eta_{BI}$ 26.1				INTO UNTIL				$\phi_P$			
a 3638.8				DAY NIGHT				$\lambda_P$			

# FDO Console Handbook Appendix 3.L: ESDs

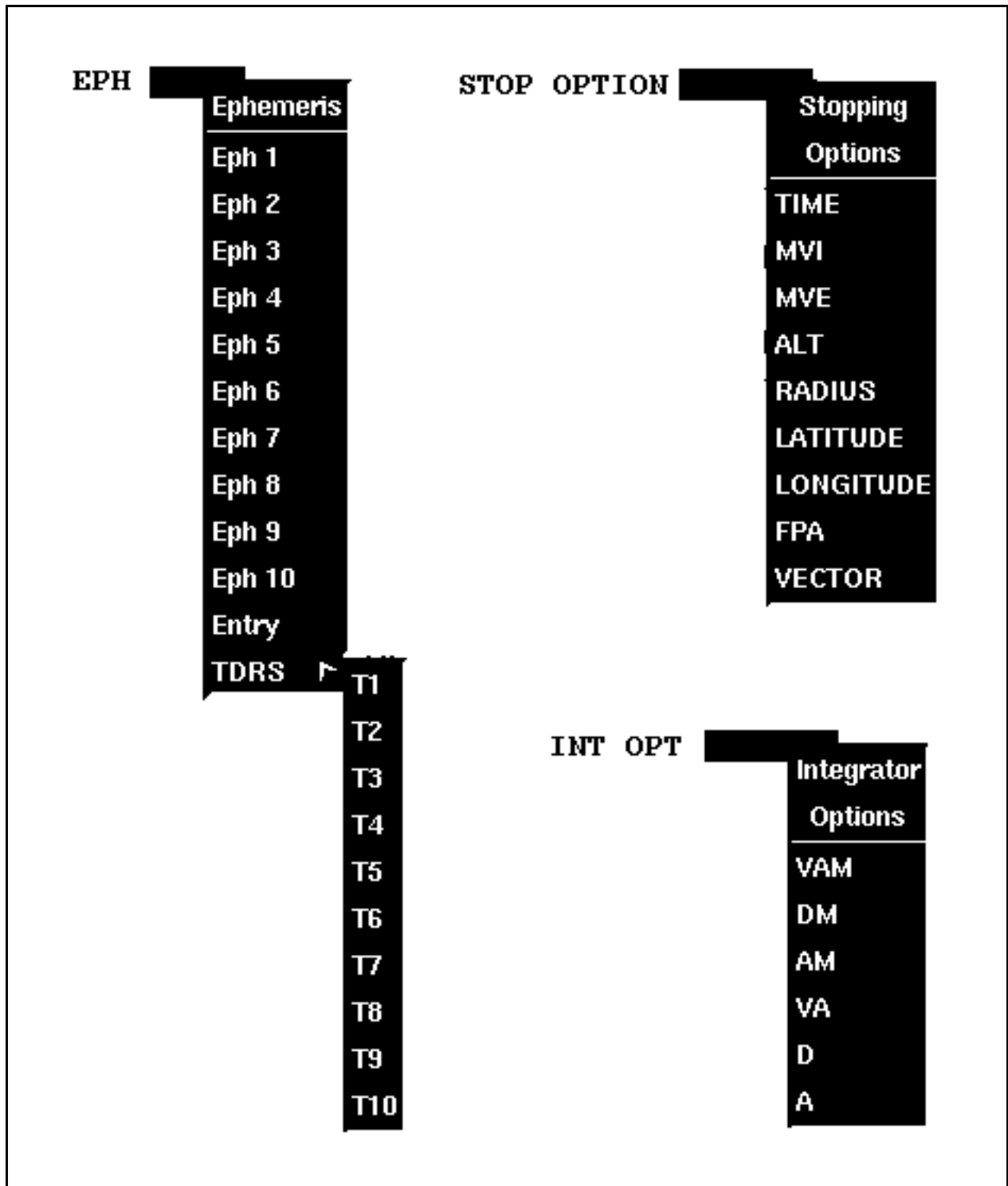
## Checkout Monitor 1-10 (FDO-Owned)

To fetch a vector into a Checkout Monitor, fill out pertinent interactive fields at the top of the display, then click the **XMIT** button. A simple VAT fetch is illustrated below.

Checkout Monitor 10		B
GMT 001:00:35:06.662		MET-016:06:35:06.338
Qualifier Q1 in error		
EPH <input type="checkbox"/>	STOP OPTION <input type="checkbox"/>	STOP VALUE <input type="checkbox"/>
VECTOR <input type="checkbox"/> v10	THRESHOLD <input type="checkbox"/>	
INT OPT <input type="checkbox"/>	LINK <input type="checkbox"/>	<input type="checkbox"/> UNDO
		<input type="checkbox"/> XMIT
GMT017:07:01:00.00	HA 19327.894	STOP OPTION VEC
MET000:00:09:13.00	METHA000:01:37:18	ALT, RAD
ORB	HP 19317.773	FPA
VID V10	METHP000:13:35:17	MVI, MVE
		LONG
M50 State Vector	VI 10085.6689	LAT
	V <sub>REL</sub> 389.8158	THRESH GMT
	γ 0.005720	MET
POSITION (FT)	ψ <sub>REL</sub> 180.6004	REFDAY 1/ 1/2002
X -138286312.7	ψ <sub>TEI</sub> 92.2149	LO 017:07:10:13.000
Y -215758.0	φ <sub>c</sub> 2:10:04S	EPH TUP
Z -4538734.8	φ <sub>c</sub> -2.167803	VEH WEIGHT
	φ <sub>h</sub> 2:10:12S	KV KC
VELOCITY (FPS)	φ <sub>d</sub> -2.169998	AREA
VX 27.515690	λ 41:01:41W	INT MED EPH
VY -10078.089588	λ -41.028179	SRP
VZ -389.962226	h <sub>s</sub> 19327.35474	KEPLERIAN ELEMENTS
	h <sub>o</sub> 19327.36524	A 22767.6045
POSITION (M)	h <sub>o</sub> *****	E 0.000190
X -42149668.10	R 22771.28286	I <sub>M50</sub> 2.90632
Y -65763.04	T <sub>an</sub> 000:08:51:47	I <sub>TEI</sub> 3.09886
Z -1383406.36	λ <sub>an</sub> 41:01:07W	W <sub>P<sub>M50</sub></sub> 72.02219
VELOCITY (MPS)	BETA ANG -19.807	W <sub>P<sub>TEI</sub></sub> 76.11307
VX 8.386782	PERIOD 023:56:08	RAAN <sub>M50</sub> 319.81192
VY -3071.801706	RA <sub>M50</sub> 180.0894	N 148.29166
VZ -118.860486	DEC <sub>M50</sub> -1.8798	M 148.28022

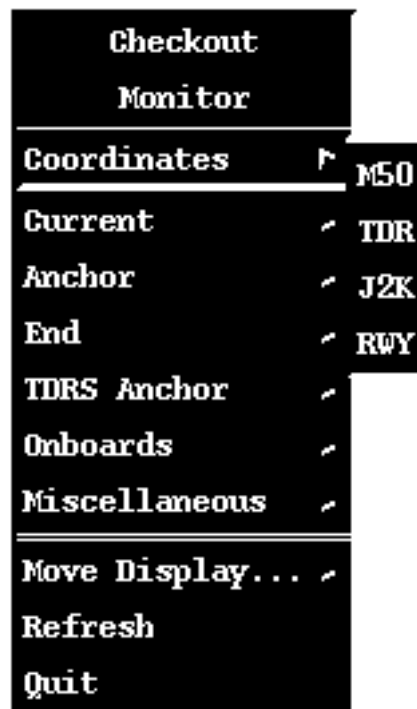
## FDO Console Handbook Appendix 3.L: ESDs

Users are encouraged to use fill out Checkout Monitor interactive fields using pop-up menus whenever possible. Pop-ups are invoked by clicking the rightmost mouse button as illustrated in the following examples.



## FDO Console Handbook Appendix 3.L: ESDs

Checkout Monitor display content can also be modified with a rightmost mouse button click below the window's interactive fields. The resulting pop-up menu is illustrated below.



# FDO Console Handbook Appendix 3.L: ESDs

## Attitude Timeline (POINTING-Owned)

POINTING flight controllers update the TrS Attitude Timeline (ATL) from their workstations. This action causes the first line in the ATL display to be set equal to the first line in the updated file, often scrolling the first displayed entry to some intermediate time during the mission. A push-button is available on the display to reset its first line to zero MET, permitting the entire ATL to be viewed. The display must be dropped and recalled in order for this change to take effect.

180		ATTITUDE TIMELINE					2330I		
		START TIME 312:00:00:00					NOTE: DISPLAY MUST BE DROPPED AND RECALLED TO RESET		
NO.	COMMENT	TIME	MODE	MATRIX	EIGEN AXIS	RATE	ATTITUDE		
		GMT/MET					ROLL	PITCH	YAW
1	UPLD ATL: TASIM	312:00:00:00	LVLH		P		0.00	0.00	0.00
2	-ZLV -XVV	000:19:46:00 312:22:16:00	LVLH		Y		0.00	180.00	0.00
3	-ZLV +YVV	000:02:30:00 314:16:23:30	LVLH				0.00	180.00	90.00
4	-ZLV -XVV	001:20:37:30 314:18:38:30	LVLH				0.00	180.00	0.00
5	-ZLV -YVV	001:22:52:30 314:22:18:30	LVLH				0.00	180.00	270.00
6	GYRO COMP INERT	002:02:32:30 314:23:52:46	IH	MIR603			123.89	185.28	53.62
7	GYRO MNVR	002:04:06:46 315:00:28:55	IH	MIR603			149.77	15.43	20.14
8	SETUP FOR SPAS	002:04:42:55 315:00:47:49	LVLH				0.00	305.00	0.00
9	SPAS DEPLOY	002:05:01:49 315:01:48:30	IH	MIR603			116.14	190.34	3.46
10	-XLV SEP 2	002:06:02:30 315:02:26:12	LVLH				0.00	90.00	0.00
11	BIAS -XLV	002:06:40:12 315:02:40:10	LVLH				0.00	140.00	0.00
		002:06:54:10							

Print     Quit

# FDO Console Handbook Appendix 3.L: ESDs

## Remote Site Entry (NAV-Owned)

Remote Site acquisition data are created by first selecting display units with the **UNITS** pull-down menu, then clicking **U50**. This action is mandatory the first time Remote Site Entry is run, and it will fill in units for the **RANGE** heading. Once range units have been specified, a **U50** click is only necessary if units are changed. Next, enter the desired site ID in the **SITE** text field (use Station Characteristics Table nomenclature), then click the **U51** MED push-button. As with the units input, a **U51** is only required for an initial Remote Site Entry run or when the site is changed. Finally, specify the ephemeris, TIME, and DT in decimal minutes, then click **U20**.

180		REMOTE SITE ENTRY			2682L	
GMT 314:21:37:07		PET REF 312:19:46:00		PET 002:01:51:07		
SITE ID KPTC		START TIME 315:04:20:00		A TIME 120 EPH 1		
L/L TO 46		CHAR FORMAT TRANSLATOR - OFF		VCT SLOT 2		
SAMPLE	SITE GMT TIME	AZIMUTH	ELEVATION	RANGE(NM)		
1	315:04:20:00	285.352	-15.605	2416.91023490		
2	315:04:22:00	281.629	-11.067	2002.51454509		
3	315:04:24:00	276.030	-6.148	1592.40914233		
4	315:04:26:00	266.703	-0.577	1201.24093644		
5	315:04:28:00	249.203	5.855	865.81727614		
6	315:04:30:00	216.462	10.891	683.30230201		
7	315:04:32:00	178.976	8.143	773.92351468		
8	315:04:34:00	156.558	1.625	1069.09538507		
9	315:04:36:00	144.895	-4.262	1445.37423862		
10	315:04:38:00	138.106	-9.370	1849.53143934		
11	315:04:40:00	133.648	-14.008	2261.59762357		
12	315:04:42:00	130.424	-18.368	2672.46327011		
13	315:04:44:00	127.910	-22.554	3076.95778320		
14	315:04:46:00	125.821	-26.623	3471.57950379		
15	315:04:48:00	123.993	-30.612	3853.64315085		
16	315:04:50:00	122.316	-34.540	4220.91931492		
17	315:04:52:00	120.713	-38.422	4571.46739000		
18	315:04:54:00	119.124	-42.265	4903.55275825		
19	315:04:56:00	117.493	-46.074	5215.60382954		
20	315:04:58:00	115.764	-49.853	5506.18948495		
21	315:05:00:00	113.872	-53.600	5774.00740848		
22	315:05:02:00	111.735	-57.314	6017.87833892		
UPCOMING ACQUISITION		EPSAT AOS LOS				
<input type="checkbox"/> U50	NM	<input type="checkbox"/> U20	1	<input type="checkbox"/> EPH	<input type="checkbox"/> Undo <input type="checkbox"/> Print <input type="checkbox"/> Quit	
<input type="checkbox"/> U51	KPTC	SITE	TIME 315:04:20:0	DT 2	mins	

Appendix 3.L Concludes On This Page

## FDO Console Handbook Appendix 3.M: ROSS DDDs

Realtime Operations Support Software (ROSS) discrete display driver (DDD) fields can be used to send commands to TrS. ROSS was developed by GPOs and is a real time data retrieval and monitoring system. Among other functions, ROSS is used to generate DDDs, displayed rectangular arrays in which fields are colored based on multiple event states. ROSS DDDs are located on the FDO DNAV under **Applications : ROSS x.y DDDs**, where "x.y" is a version number. Some examples are TrS Processors, Launch DDDs, and State Vector PBIs. In addition to displaying discrete information, ROSS DDDs can also send commands to TrS and display numeric data. For more information on ROSS, refer to the ROSS Users Guide residing on the GPO web pages. Descriptions of some ROSS DDD displays are included in this appendix.

## FDO Console Handbook Appendix 3.M: ROSS DDDs

**Rndz\_VAT\_Eph\_PBI**: this six-button DDD array provides you with capability to grab onboard FILT and TARGET vectors from the telemetry stream and store them in specified VAT slots when Rendezvous NAV is enabled. Three push-buttons are located along the array's top row. The left push-button stores FILT and TARGET vectors in VAT Slots 1 and 2, respectively, the middle push-button stores them in Slots 3 and 4, and the right push-button stores them in Slots 5 and 6. Vectors stored in the VAT by these push-buttons have a comment denoting the current onboard sensor selected for angles on SPEC 33 (ST, RR, or COAS). The associated number of angle marks is also included with the comment. These push-buttons will be green if telemetry is available and red if not. The second row of this array has three additional buttons for miscellaneous functions. The left button allows the user to TUP E1 with TrS V39 as its anchor. The middle button TUPs E3 with TrS V38. The right button grabs onboard FILT and TARGET vectors, stores them in V56 and V54, respectively, then TUPs E2 with V56 and E4 with V54. These push-buttons will turn yellow when a TUP is in progress and red when an ephemeris has **BAD** status.

NOTE: this PBI has spawned a variant used by ONAV to snapshot chaser/target state vectors during RELNAV operations. The ONAV variant has no TUP capability.

CAUTION: inform DYNAMICS whenever a MOC ephemeris is TUPed.

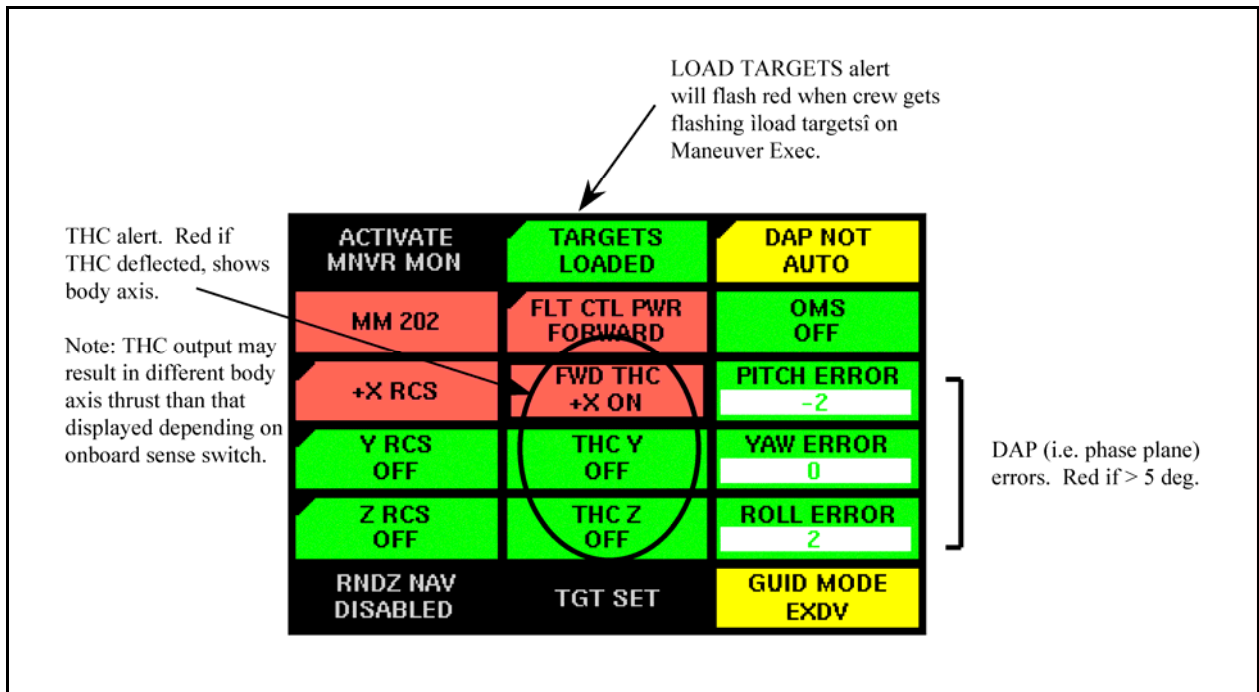
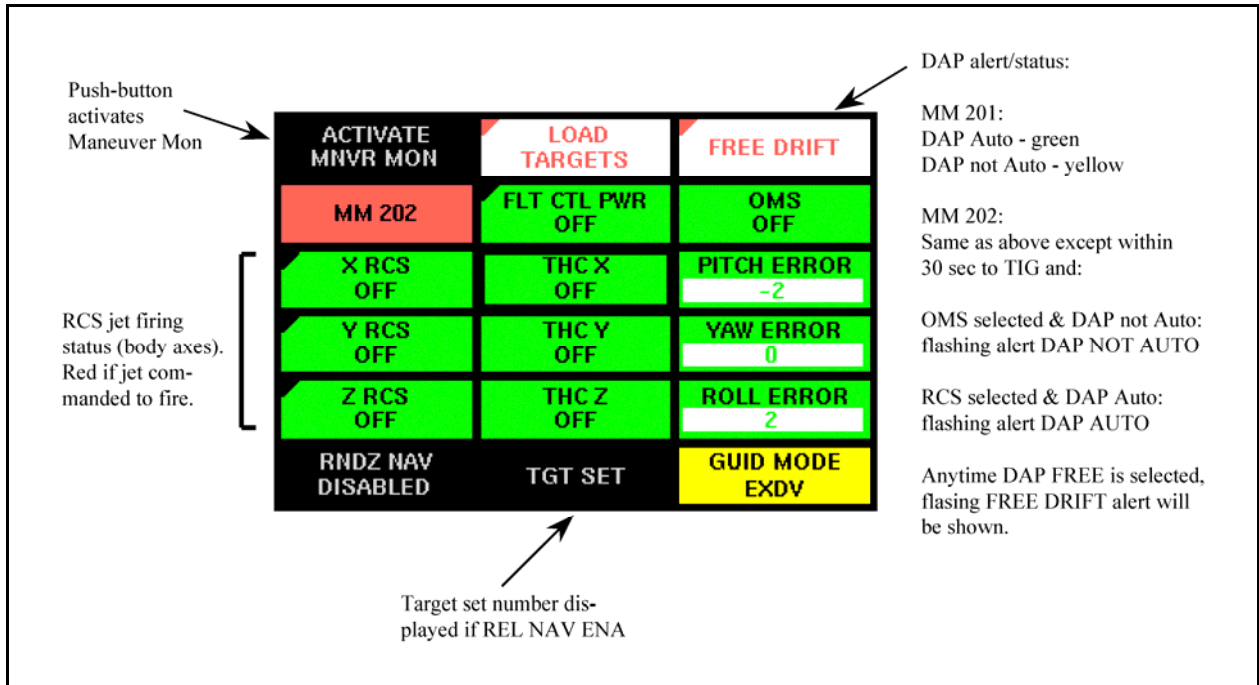
CAUTION: care should be exercised to avoid inadvertent ephemeris TUPs with **Rndz\_VAT\_Eph\_PBI**. Drop or iconify this DDD array when it's not in use.

Grab Onbds to V1/V2	Grab Onbds to V3/V4	Grab Onbds to V5/V6
TUP EPH1 On V39	TUP EPH3 On V38	Grab Onbds TUP 5 & 6



# FDO Console Handbook Appendix 3.M: ROSS DDDs

**Orbit FDO DDDs:** this set of DDDs facilitates FDO onboard systems monitoring during OPS 2. Access to Maneuver Monitor DDDs is also provided.



## FDO Console Handbook Appendix 3.M: ROSS DDDs

**Maneuver Monitor DDDs:** this set of DDDs consolidates multiple FDO burn uplink, load, and execution monitoring tasks in one compact display. It's invoked through the Orbit FDO DDDs. Ground-based data are linked to DMT-1. Ground/Onboard compares are only performed during OPS 202, and "red" thresholds are provided at the left of the following illustration.

	THRUSTER	DMT 1 NOT AVAIL	ONBOARD RCS	
No thruster compare performed	<b>TVR</b>	0	180	DMT1 thruster not available
TVR 0 deg	<b>P TRIM</b>	***** 4.7	***** 4.7	Note: Rows of asterisks divide up sections of data.
Trims 0.4 deg	<b>LY TRIM</b>	-6.5	7.9	
	<b>RY TRIM</b>	6.5	6.3	
No weight compare performed	<b>WEIGHT</b>	***** 246542	***** *WT NOT AVAIL** 2/06:27:20	No onboard weight displayed. Current ROSS MET shown here for ease of compare w/TIG.
TIG 1 sec	<b>TIG</b>	2/06:50:29	1/09:20:09	Note: ROSS MET rounding may result in up to 1 sec time error for MET and TIG.
ΔVs 0.1 fps	<b>PEG 7 DVX</b>	***** -0.4	***** 48.6	
	<b>DVY</b>	-0.0	0.0	
	<b>DVZ</b>	0.4	0.1	
Burn attitude 2 deg	<b>BURN ATT ROLL</b>	***** 348	***** 140	
	<b>PITCH</b>	116	9	
	<b>YAW</b>	63	347	
ΔVtot 0.21 fps	<b>DV TOT</b>	***** 0.5	***** 0.6	Pre-TIG compare performed ground vs. onboard. Post-TIG left hand colors set to RED until burn is trimmed out as follows:  ΔVtot < 0.21 fps Tgo < 1.1 sec VGOs < 0.2 fps Current Ha/Hp - Target Ha/Hp within 0.5 nm
TGO 1.1 sec	<b>TGO</b>	00:02	00:02	
VGOs 0.2 fps	<b>VGO X</b>	***** 0.49	***** 0.20	
	<b>VGO Y</b>	0.00	0.10	
	<b>VGO Z</b>	0.10	0.04	
No Ha/Hp compare performed pre-burn	<b>TGT CUR HA</b>	***** 192	***** 193	
	<b>TGT CUR HP</b>	192	192	

Note: DMT1 Tgt Hp incorrect in ROSS datastream (it is set to Ha). Fix in work.

**Appendix 3.M Concludes On This Page**

## FDO Console Handbook Appendix 3.N: FDO Trajectory Web (FTW) Update Checklist

FTW # \_\_\_\_\_ TUP# \_\_\_\_\_ AVID \_\_\_\_\_

Slot 1	Update GMT ____/____:____:____	Slot 2	Update GMT ____/____:____:____
Slot 3	Update GMT ____/____:____:____	Slot 4	Update GMT ____/____:____:____
Slot 5	Update GMT ____/____:____:____	Slot 6	Update GMT ____/____:____:____
Slot 7	Update GMT ____/____:____:____	Slot 8	Update GMT ____/____:____:____
Slot 9	Update GMT ____/____:____:____	Slot 10	Update GMT ____/____:____:____

### Ephemeris Update

- Using normal ephemeris evaluation techniques, update ephemeris if required.

### Posting (omit if no change to ephemeris since last update)

- In EPHWEBXR, select ephemeris.
- Change ephemeris comment, if desired.
- Launch MPTGEN from EPHWEBXR (Orbit only).  
 Edit event names appropriately.  
 Add user events, if desired.  
 Change comment if desired.  
 Process and close MPTGEN.
- Select ATL transfer, if desired (Orbit only).  
 ATL data path = /users/ptg/share/FDO\_ATL/MISSION/"filename".TRAJ
- Select slot and activity for web destination.
- Input user name/password and select Transfer.

### QA

- Pull up appropriate web location.
- Select Traj Summary and verify for each slot: last update time, ephemeris comment and TUP #, and event data.
- Select Checkout and verify for each slot: data displayed and comment.
- Select Ephemeris and verify for each trajectory slot: last update GMT, ephemeris comment, and files listed.
- Save Trajectory Summary file for each delivered slot to V:\Fdo\<<flight ID>\TrajectorySummary\TrajectorySummary<X>\_<nn>\_<doy>\_<hhmm>.txt  
 X = O(orbit) or E(entry), nn = slot #, doy and hhmm = Update GMT
- Verify last update date/time on Shuttle ATL (Orbit only).
- Delete slots that are no longer applicable via the following URL.  
<https://ops1.jsc.nasa.gov/apps/fdoweb/admin/deletedata.asp>

### Notification

- Notify OSA, ALT SPACE, and NASA SUPPORT of the update (or lack of update) on NORAD COORD loop.  
 Indicate trajectory events that motivated update: \_\_\_\_\_  
 Request readback of last update time by appropriate user
- Send e-mail notification template V:/Fdo/USSPACECOM/SOI/FTWupdate.ofc

### Documentation

- Place hardcopy of Trajectory Summary in Clipboard Binder's FTW section.
- Log Update GMT, parties contacted in Notification step, and any other handover data in FDO Log Book as appropriate.

# **FDO Console Handbook Appendix 3.N: FDO Trajectory Web (FTW) Update Checklist**

**Appendix 3.N Concludes On This Page**