3.4 REFERENCE DOCUMENTS

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Systems Data Book 3.4-1
Data Processing System Dictionary 3.4-1
Payload Systems Data/Malfunction Book 3.4-1
Maps and Charts Book 3.4-1

Reference Data Book

The Reference Data (REF DATA) Book contains lists of critical inoperative equipment with the loss of a bus or subbus and an ac/dc power outlet chart. There are also lists of input/output (I/O) GPC parameters lost when selective MDMs are inoperative. Additionally, there is a list of all fault messages, C/W and fault detection and annunciation (FDA) tables, and a complete stowage list for crew equipment, clothing, and FDF.

Systems Data Book

The Systems Data Book (SYS DATA) is a large document containing selected schematics of most orbiter systems and structures taken directly from the Space Shuttle Systems Handbook. These schematics are augmented by photographs of major components and structures.

Data Processing System Dictionary

The Data Processing System Dictionary (DPS DICT) contains a compendium and explanation of all CRT displays onboard the orbiter. It also has program notes on software limitations and peculiarities with corrective instructions.

Payload Systems Data/Malfunction Book

The Payload Systems Data/Malfunction (PL SYS DATA/MAL) Book, detailed in the Off-Nominal section, can also be considered a Reference document because of some of the payload related data it contains.

Maps and Charts Book

The Maps and Charts Book contains landing charts, an orbit map (with a movable 3 revolution groundtrack), star charts, and a World Atlas. The World Atlas also contains a list of Earth sites for observation and photography. Although the Maps and Charts Book controls these media, they are stowed as separate items on the flight deck and middeck.

3.5 OPERATIONAL USE

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FDF Fabrication

Materials acquired for the fabrication of FDF articles or for inflight supplies fall under four categories:

- Printed material (print shop products, photos, maps)
- Commercial materials (paper boards, pens, markers, ring binders)
- JSC Components (edge labels, map frames, accessory bags)
- Certified and approved materials with Federal Stock Numbers purchased through the JSC Stores Stock Catalog.

These items used by FDF Operations must be in compliance with current safety, reliability, and quality assurance (QA) standards, or in receipt of a Material Usage Agreement (MUA) waiver. Appendix G of the CPMP identifies the documents containing these standards and describes the physical dimensions of all JSC fabricated FDF items used onboard the orbiter.

Considering the tremendous volume of critical information being presented in the Shuttle FDF, it is essential that special symbols be used to abbreviate procedures.

,	comma — read "... and ..."
/	slash — read "... and/or ..."
()	parentheses — read "... or ..."
➤	or » chevron — read "exit"
√	checkmark — read "verify ..." or "check ..." or "check with ..."
+	plus followed by space then value — read as "add"
+	plus followed by value without space — read as "positive"
–	minus followed by space then value — read as mathematical "subtract"
–	minus followed by value without space — read as "negative"
↑	up arrow — upper limit exceeded
↓	down arrow — lower limit exceeded
Δ	delta — read "change"
••	double dot — indicates that preceding data is to be highlighted in flight book
|	vertical line — read "... or ..." between alternate conditional statements
|	vertical bar — in page margin to indicate change in procedure since last publication
	dotted box — encloses alternate or optional steps
* * * *	vertical stars — brackets contingency steps
	box — CRT callout
n	box — read "block n" which refers to corresponding block of procedures

FDF Symbols

Preliminaries

The development of the FDF for a mission normally starts about a year prior to the launch date. The preliminary work for payloads and Spacelab may start as much as 2 years prior to launch. The earliest FDF official publications (typically the Flight Plan and payload related books) are designated as Preliminary documents. These books are published approximately eight months prior to the launch date, after the Cargo Integration Review (CIR). Preliminary documents are not under the formal change control of the CPCB. Accordingly, they are under continual development, and changes may be made informally by any cognizant individual by working through the Book Manager.

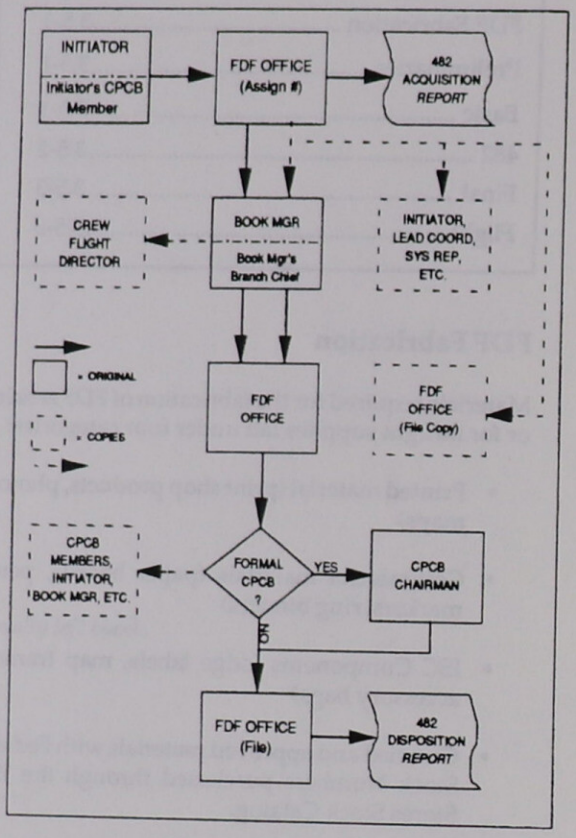
Basic

Approximately 4 months prior to the launch date, the Basic editions of all flight specific/supplement FDF are published. The documents are now under the configuration control of the CPCB and all changes must be requested through formal channels that include approval by cognizant personnel. Generic documents are also subject

to these formal change requirements, although their publication cycles are independent of mission cycles. Only those Generic books that incorporate temporary flight-specific pages will normally require changes during the FDF preparation for a specific mission. About 3 weeks after the publication of the Basic FDF document, a Flight Operations Review (FOR) is held at JSC. The FOR is a formal review of payload related documents that the flight crew and ground controllers will use for training and flight. It also provides a forum to verify that authorized customer requirements have been met and that safety and Shuttle operational requirements related to payload operations are correct. Representatives from the Flight Crew Operations and Mission Operations Directorates, Shuttle Integration and Operations Office, customer personnel, and other NASA personnel, as required, are invited to attend. These representatives may submit Discrepancy Notice (DN) forms regarding additions (for existing requirements), deletions, or modifications to any FDF document under review for that specific flight. The DNs are evaluated by the book manager who recommends approval, disapproval, or withdrawal to the FOR "preboard." DNs recommended for disapproval or withdrawal will be reviewed in "splinter" meetings as required. Final action on all of the DNs is taken by the formal FOR board, which is chaired by the Manager, Space Shuttle Integration and Operations, and made up of management personnel representing the mission payload(s) and NASA directorates. DNs receiving an approval will usually be incorporated into the next publication cycle of the appropriate document. If the data are critical to crew training, the material will be immediately incorporated into all pertinent training documents via simulation packages (Sim Pacs).

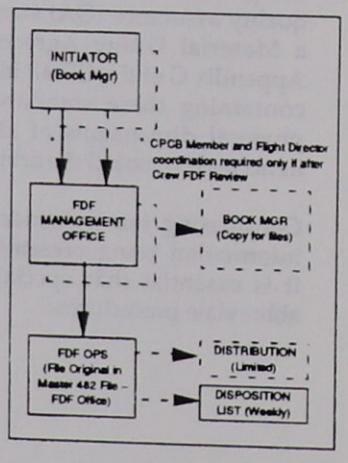
482

Subsequent to the FOR, changes to FDF must be made via a Crew Procedures Change Request, JSC Form 482-B. The 482 process is detailed in CPMP Appendix D. As before, anyone may submit a 482 requesting a change to a particular FDF document. The 482 will be reviewed by cognizant personnel and approved or disapproved. Disapproval by anyone in the review process causes the 482 to be dispositioned by the CPCB. There is an appellate process for 482's disapproved at the CPCB through the appropriate Level II board. An alternative method of changing minor FDF material is available via an EZ 482. This form requires much less review and fewer signatures, but its use is quite limited.



482 Flow

EZ 482 Flow



Approximately 4 months prior to flight, the crew determines the allowable additions and deletions to the quantities of FDF documents and supplies they wish to have onboard.

Final

Approximately 6 weeks prior to flight, the Final versions of flight specific/supplement FDF documents are published. Changes can still be made to the FDF after publication of the Final version via a 482. Changes that affect a small percentage of the pages in a book will normally be implemented with a Page Change Notice (PCN). When more than one half of the pages must be reprinted, or many affected pages are scattered throughout a book, a complete revision (REV) will be printed. Other authorized changes may be implemented via an Errata Pack. These changes may be pen and ink modifications or reprints of a particular page. Technical modifications of the flight documents by the crew during their review will be promulgated in an Errata Pack subsequent to the completion of a 482. A duplicate copy of the FDF is available to the crew while they are in quarantine at JSC. The prime and an identical backup set of the FDF are configured for flight and shipped to KSC separately.

Flight

The crew has access to the backup copy of the FDF while in the crew quarters at KSC. On launch day, FDF representatives turn over the carry-on FDF to the Astronaut Support Person (ASP), who installs the appropriate FDF documents for launch. The suit technicians lay out the other carry-on FDF for the crew to stow in their FDF bags. After the crew has ingressed, the ASP makes the final installations and adjustments of the cue cards, flip books, and checklists. Although the number can vary slightly for a particular mission or crew, at launch there are about seven copies of the three ascent related checklists, five flip books, and 34 cue cards out/mounted for the crew's use. The checklists are attached to lanyards, while the cue cards and flip books are affixed with Velcro. Additional cue cards and checklists are readily available to the crew in the CDR/PLT's FDF containers and the MS's FDF bags for certain low probability contingencies. The CDR and PLT post insertion checklists are also stowed in the FDF containers.

Approximately 1 hour after launch, when the crew transitions to the Post Insertion Checklist, MS 3 retrieves selected FDF from a middeck locker. Items not needed right away are usually placed in a stowage bag on the back of the CDR or PLT's seat. At this time, ascent related material is stowed in a helmet bag and placed into a "return to Houston" stowage bag. Subsequent to Mission Control's "go for orbit ops," the crew may unstow additional FDF as required. FDF control during the on-orbit phase of the mission is basically a crew decision. There are certain contingency FDF documents (CONT Deorbit, Entry, Entry PCL) that should be readily available. Others may be mounted in a convenient place in the orbiter, stowed in a temporary location, or stowed in the FDF locker. Prior to the last sleep cycle, the crew will begin the stowage of on-orbit oriented FDF. During the deorbit preparation phase, the crew stows the remainder of their on-orbit FDF and installs the Deorbit and Entry Cue Cards, Flip Books, and Checklists.

After landing, the ASP enters the orbiter and collects the Deorbit and Entry FDF and places them in "return to Houston" bags with the other FDF. They are returned to Houston with the crew. Kneeboard cards and other items of importance to the crew are collected by the suit technicians and returned to Houston as soon as possible. During postflight debriefings, the crew has access to the flown FDF, kneeboard cards, and microcassettes to help reconstruct events of the mission. The flown FDF is copied onto microfiche and after 6 months it is transferred to the National Archives in Washington, D. C. The backup copies are reused if feasible, or destroyed. The crew may request portions of the backup material as mementoes.

FLIGHT PHASE	EVENT	SOFTWARE			FLIGHT DATA FILE	
			MAJOR MODE **			
		MEMORY CONFIG	GNC	SYSTEMS MGMT	FLIGHT PROCEDURES	TROUBLESHOOTING PROCEDURES *
ASCENT	Precount	9	901	—	Ascent Checklist	
	Terminal Count	1	101	—		
	First Stage	1	102	—	Ascent Flip Book Cue Cards	CDR Flip Book Pilot Flip Book Pilot Overhead Flip Book Cue Cards
	second Stage	1	103	—		
	Orbital Insertion	1	104	—		
	Orbit Circularization	1	105	—	Ascent Checklist Cue Cards	Ascent Pocket Checklist
	Post-Insertion Coast	1	106	—	Post-Insertion Checklist	Orbit Pocket Checklist STS Malfunction Procedures
	RTLS 2nd Stage	1	601	—	Ascent Flip Book	CDR Flip Book Pilot Flip Book Pilot Overhead Flip Book Cue Cards
	Glide RTLS–1	1	602	—		
	Glide RTLS–2	1	603	—		
ORBIT	Orbit Coast	2	201	—	Post Insertion Checklist Flight Plan Orbit Operations Checklist Payload Checklists Deorbit Preparation Checklist	Orbit Pocket Checklist Cue Cards STS Malfunction Procedures
	Orbital Maneuver	2	202	—		
	On-Orbit Checkout	8	801	—		
	Orbit Operations	4, 5	—	201,401		
	Payload Bay Door Operations	4, 5	—	202, 402		
ENTRY	Predeorbit Coast	3	301	—	Deorbit Preparation Checklist Entry Checklist	Entry Pocket Checklist Cue cards
	Deorbit Maneuver	3	302	—	Entry Checklist Cue Cards	
	Preentry Monitor	3	303	—		
	Early Entry	3	304	—	Cue Cards	CDR Flip Book Pilot Flip Book
	TAEM/Landing	3	305	—		
	Post-Landing	9	901	—	Entry Checklist	Pilot Overhead Flip Book Cue Cards

* During ascent and entry, the Mission Specialist uses the Ascent/Entry Systems Procedures.

** Major modes separated by a dashed line have automatic transitions from one to the next. Major Mode discussion is in Section 2.6, Data Processing System.

Shuttle Mission Overview

4. OPERATING LIMITATIONS

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4.10 Center of Gravity Limitations 4.10-1
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This section delineates limitations for selected orbiter systems, equipment, and operations. It is not all inclusive. Limitations which the flight crew should be aware of have been emphasized. It must be noted that operations up to and including the given limits for one system may cause a violation of the limits for another. An example would be flying at the flight control system maximum allowable KEAS. This KEAS would overspeed the landing gear with a lower maximum allowable KEAS.

"Limitations are those measurable or detectable operational limits, which if exceeded, will affect crew safety or result in performance degradation."

4.1 INSTRUMENT MARKINGS

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Panel O3 Meters 4.1-16

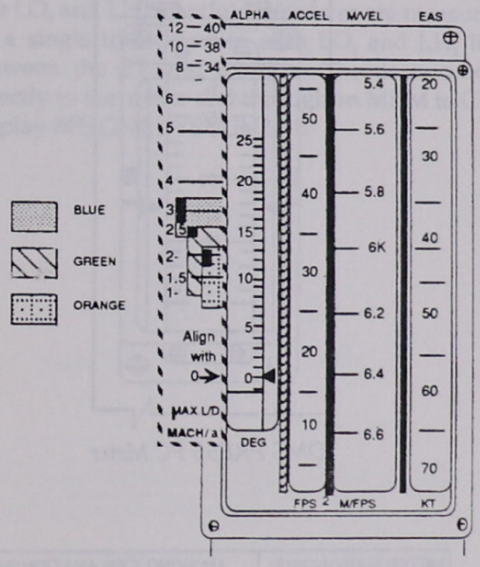
Description

Instrument markings reflect the normal range (green) and upper/lower limits (red). Caution and warning alarms/tones will normally sound at the points marked in red. In some cases an SM alert will sound prior to the limits on the meters being reached. The meter indications in this section are arbitrary and are not intended to reflect actual flight conditions.

Panel F6 Indicator

Alpha/Mach Indicator

The maximum lift to drag (L/D) Mach/angle of attack (alpha) limits for the Alpha/Mach indicator are printed on an Entry Checklist cue card and affixed by Velcro to the indicator. The maximum L/Ds for Mach 3, 2.5, and 2 are indicated by black rectangles. The regions surrounding the maximum L/D zones are colored to show proper alpha ranges for those speeds. The Mach 3 to 2.5 region is shaded pink. The Mach 2.5 to 1 region is shaded green. The Mach 2 to .5 region is shaded orange. The color selection is strictly arbitrary.



Alpha/Mach Indicator with Cue Card Attached

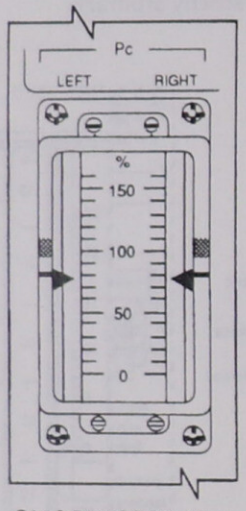
Panel F7 Meters

Normal operating ranges are indicated by: ▒ - GREEN

High/low limits are indicated by: ▬ - RED

OMS PRESS Pc Meter

The left and right Pc (thrust chamber pressure) is measured by a sensor that is routed through a dedicated signal conditioner (DSC) before being displayed on the Pc Meter and sent to the GPCs.

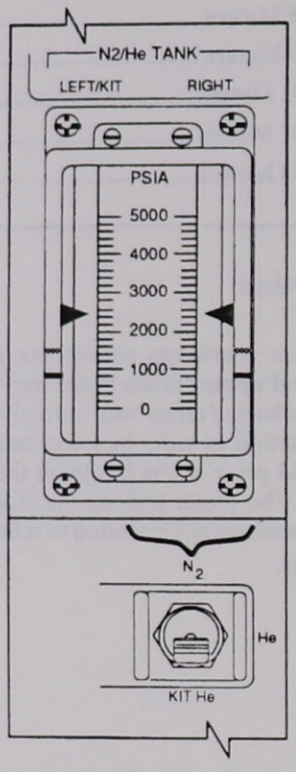


OMS PRESS PC Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
95 — 110% Pc (green)	Normal operating range
80% (red)	Low limit (Class 2 C/W); 72% allowed during ullage blowdown
105% Pc	= approximately 131 psia chamber pressure
80% Pc	= approximately 100 psia chamber pressure

OMS PRESS N2/He Tank Meter

Separate N2 and He pressure sensors (left and right) are wired through a DSC to the meter and GPCs. Redundant pressure sensors provide the pressure readings for N2 and He on the GNC SYS SUMM 2 display.

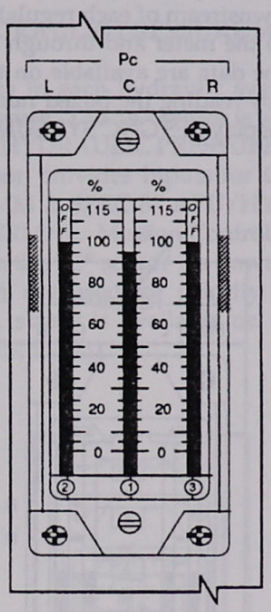


OMS PRESS N2/He TANK Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)	
1500 psia (green)	Low limit (Class 3 C/W)	
750 psia (red)	110 psia above tank fail limit (640 psia)	} He
1200 psia (unmarked)	Low limit (Class 3 C/W)	
720 psia (red)	280 psia above tank fail limit (470 psia)	} N_2

MPS PRESS Pc Meter

The left, center, and right Pc (thrust chamber pressure) are measured by a sensor that is wired via the GPCs through flight forward multiplexer demultiplexer (MDM) 2, 1, or 3 respectively, to the Pc meter. Power failure of an MDM or a data path failure will cause the affected Pc meter to drop to zero. GPC failure and some flight forward MDM failures can cause the affected Pc reading to freeze.



MPS PRESS Pc Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
65 — 104% Pc (green)	Normal operating range (104% is the nominal maximum with power available up to 109%)
104% Pc	= approximately 3,126 psi chamber pressure
109% Pc	= approximately 3,276 psi chamber pressure

WARNING

MDM power failure can cause MPS Pc indication to drop to zero. Confirm engine failure with acceleration cues, MPS He consumption, or MCC call.

WARNING

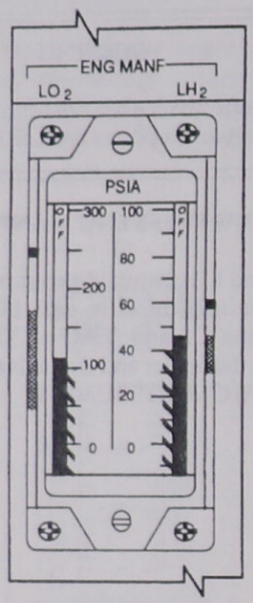
MPS performance has not been verified in flight beyond a power level of 104 percent.

MPS PRESS ENG MANF Meter

The LO_2 and LH_2 manifold pressures are measured by a single transducer in each LO_2 and LH_2 line between the ET and SSMEs. The data is sent directly to the meter and through an MDM to CRT display BFS GNC SYS SUMM 1.

MPS PRESS ENG MANF Meter

The LO_2 and LH_2 manifold pressures are measured by a single transducer in each LO_2 and LH_2 line between the ET and SSMEs. The data is sent directly to the meter and through an MDM to CRT display BFS GNC SYS SUMM 1.



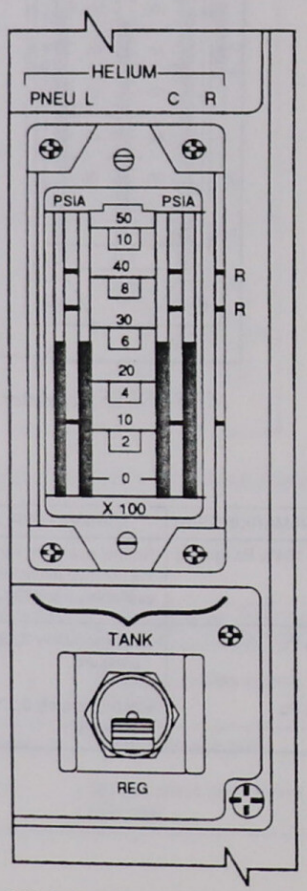
MPS PRESS ENG MANF Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
45 — 175 psia (green)	Normal operating range for LO_2
249 psia (red)	High limit (Class 2 C/W) for LO_2
30 — 45 psia (green)	Normal operating range for LH_2
60 psia (red)	High limit (Class 2 C/W) for LH_2

MPS PRESS HELIUM Meter

The pneumatic, left, center, and right He tank pressures are measured by a single sensor in each system manifold. Data is sent directly to the meter and through an MDM to the GPCs. The data are available on this meter (TANK selected) by reading the upper (non-boxed) numbers x 100 and on CRT display BFS GNC SYS SUMM 1.

The Pneumatic regulator, Left, Center, and Right He Regulator A pressures are measured by a single sensor downstream of each regulator. Data is sent directly to the meter and through an MDM to the GPCs. The data are available on this meter (REG selected) by reading the boxed numbers x 100 and on CRT display BFS GNC SYS SUMM 1.



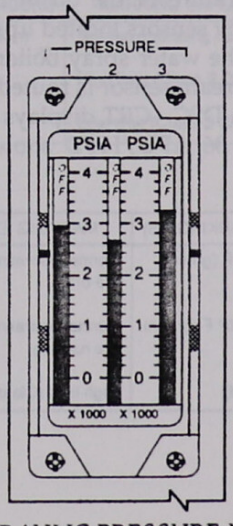
MPS PRESS HELIUM Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
(TANK)	(TANK)
1150 psia (red)	Low limit (Class 2 C/W)
(REGULATOR)	(REGULATOR)
810 psia (red)	High limit (Class 2 C/W)
680 psia (red)	Low limit (Class 2C/W)
R	Regulator

Panel F8 Meters

HYDRAULIC PRESSURE Meter

Three sensors in each hydraulic system measure the fluid pressure. The "A" sensor is wired through a DSC to the HYDRAULIC PRESSURE meter while the "B" sensor provides inputs for CRT displays SM SYS SUMM 2, SPEC 87 APU/HYD and SPEC 87 HYD THERMAL. Mission Control has access to the data from the "C" sensor via downlist data. All three sensors are used for priority rate limiting (PRL). PRL status is available on CRT display OVERRIDE (SPEC 51).

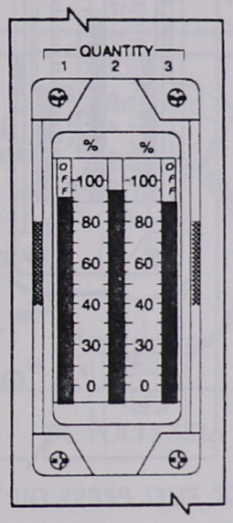


HYDRAULIC PRESSURE Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
2900 — 3200 psia (green)	Normal operating range
2400 psia (red)	Low limit (Class 2 C/W)
500 — 1000 psia (green)	Normal "low pressure" operating range

HYDRAULIC QUANTITY Meter

A sensor located in each of the three hydraulic reservoirs provides the information displayed on the HYDRAULIC QUANTITY Meter and on CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD. Data is sent to the meter and GPCs via a DSC. It is also sent to the GPCs via an orbiter instrumentation MDM.



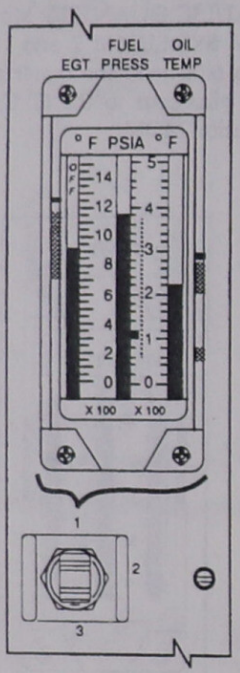
HYDRAULIC QUANTITY Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
40 — 80% (green)	Normal operating range

APU EGT, FUEL PRESS, OIL TEMP Meter

APU EGT

There are two EGT sensors in each of the three APU turbines. Data from one sensor is routed through a DSC and displayed on the EGT meter and CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD. The redundant sensor does not provide data to the meter.



APU EGT, FUEL PRESS, OIL TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
700° — 1160° F (green)	Normal operating range
1260° F (red)	High limit (see NOTE)

NOTE

Data from the EGT transducers has often been unreliable. Consequently, EGT "out of limits" data from the transducers require verification from other sources and will not activate the C/W system.

Fuel Pressure

There are two sensors: one on the N_2 side and one on the fuel side. Both go to the CRT display, SPEC 86 APU/HYD, but only the N_2 side sensor goes to the meter via a DSC.

METER MARKINGS(S)	MARKING EXPLANATION(S)
50 — 370 (green)	Normal operating range; however, it would require multiple failures before the pressure could reach 50. SM alert sounds at 100 and 350 psia
110 psia (red)	Low limit for hot restart

Oil Temperature

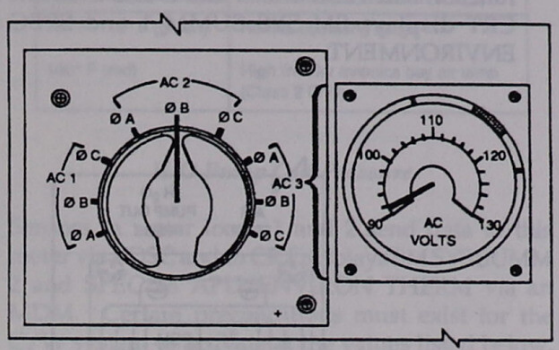
The temperature of the oil in the three APUs is measured by sensors located upstream and downstream of the water spray boilers. The data from the downstream sensor is routed to the OIL TEMP Meter via a DSC. CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD show data from both sensors.

METER MARKINGS(S)	MARKING EXPLANATION(S)
50° — 70° F (green)	Normal operating range when APUs are off
200° — 270° F (green)	Normal operating range when APUs are running
290° F (red)	High limit (Class 2 C/W)

Panel F9 Meters

AC VOLTS Meter

AC phase voltage (A, B, and C) is read directly at each of the three buses. There is no AC AMPS meter for the AC system that monitors AC current. The data is sent to this meter and to CRT displays SM SYS SUMM 1 and SM SPEC 67 ELECTRIC.

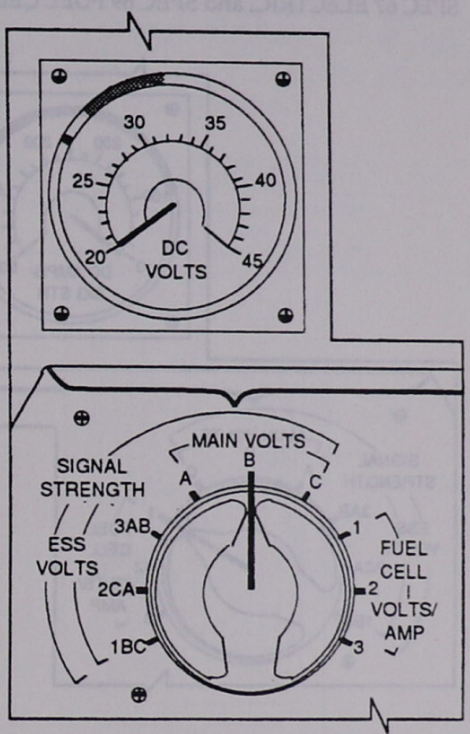


AC VOLTS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
115 — 119 (green)	Normal operating range
123 (red)	High limit (Class 2 C/W)
108 (red)	Low limit (Class 2 C/W)

DC VOLTS Meter

DC voltage is read directly at each fuel cell, main bus, and essential bus. The data is routed to the meter and to CRT displays SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS.

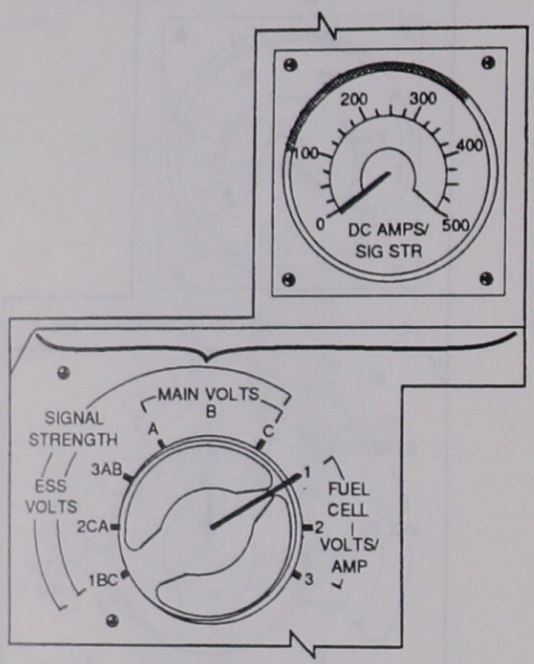


DC VOLTS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
28 — 32 (green)	Normal operating range (SM alert at 32.5)
26.4 (red)	Low limit (Class 2 C/W)

DC AMPS/SIG STR Meter

A current sensor for each of the three fuel cells provides an input to the DC AMPS/SIG STR Meter. ("SIG STR" refers to S-band signal strength which is also monitored on this meter.) Essential and main bus current are not monitored. The data also appears on CRT displays SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS.



DC AMPS/SIG STR Meter

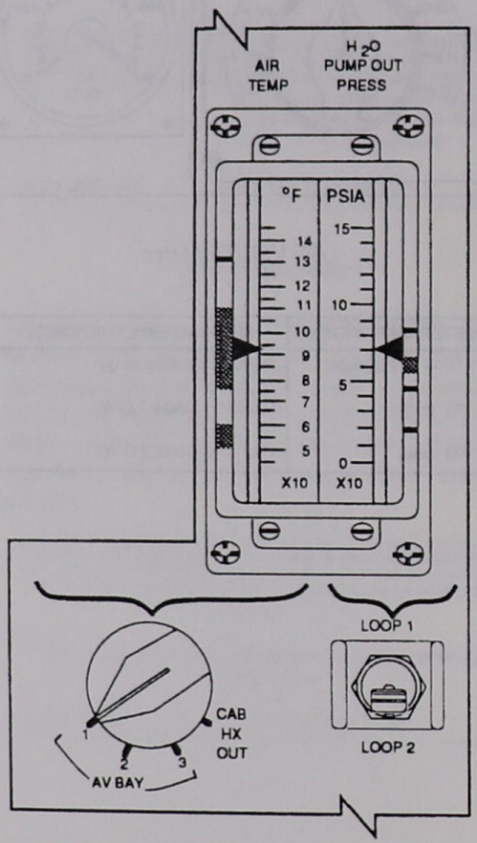
METER MARKINGS(S)	MARKING EXPLANATION(S)
90 — 350 A (green)	Normal operating range

Panel O1 Meters

AIR TEMP, H_2O PUMP OUT PRESS Meter

Cabin Heat Exchanger Air Temperature

Temperature data from a sensor downstream from the cabin heat exchanger is sent directly to the dual function AIR TEMP Meter and is also available on CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.



AIR TEMP, H_2O PUMP OUT PRESS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
50° — 60° F (green)	Normal operating range

Avionics Bay Air Temperature

Temperature data from a sensor located downstream of the avionics bay fans is sent directly to the AIR TEMP Meter. This data is also available on CRT displays SM SYS SUMM2 and SPEC 66 ENVIRONMENT.

METER MARKINGS(S)	MARKING EXPLANATION(S)
75° — 110° F (green)	Normal operating range
130° F (red)	High limit for avionics bay air temp (Class 2 C/W)

H_2O Pump Out Pressure

Sensors in water loops 1 and 2 send data to this meter via a DSC and to CRT displays SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM via an MDM. Certain preconditions must exist for the C/W system to activate at the values listed below. Those preconditions may be found in the FDF Reference Data book.

METER MARKINGS(S)	MARKING EXPLANATION(S)
Loop 1	
55 — 65 psia (green)	Normal operating range
79.5 (unmarked)	High limit (Class 2 C/W)
19.5 psia (red)	Low limit (Class 2 C/W)
Loop 2	
55 — 65 psia (green)	Normal operating range
81 psia (red)	High limit (Class 2 C/W)
45 psia (red)	Low limit (Class 2 C/W)

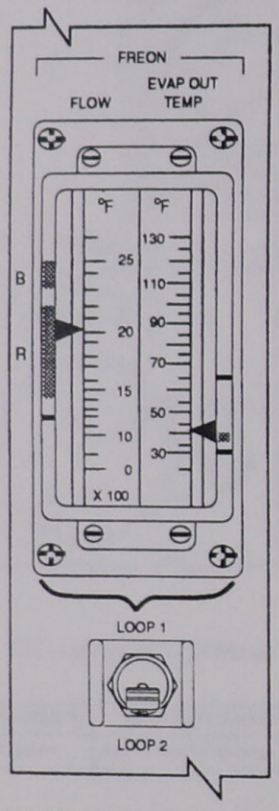
NOTE

SM Alerts will occur at 75 psia (high) and 50 or 20 psia (low), depending on preconditions, for both loops.

FREON FLOW, EVAP OUT TEMP Meter

Flow

A sensor located upstream from the H2O/Freon Interchanger in Freon Loops 1 and 2 provides a readout of Freon interchanger flow directly to the meter and to CRT displays SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM.



FREON FLOW, EVAP OUT TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
2300 — 2500 psia (green)	Normal operating range (Flow Proportioning Valve in Payload (PL), SM alert at 1300 psia)
1400 — 2200 psia (green)	Normal operating range (Flow Proportioning Valve in Interchanger (ICH), SM alert at 1950 psia) [Change pending to meter markings to reflect C/W limits]
1200 psia (red)	Low limit (Class 2 C/W)
B	Bypass
R	Radiator

Evaporator Out Temperature

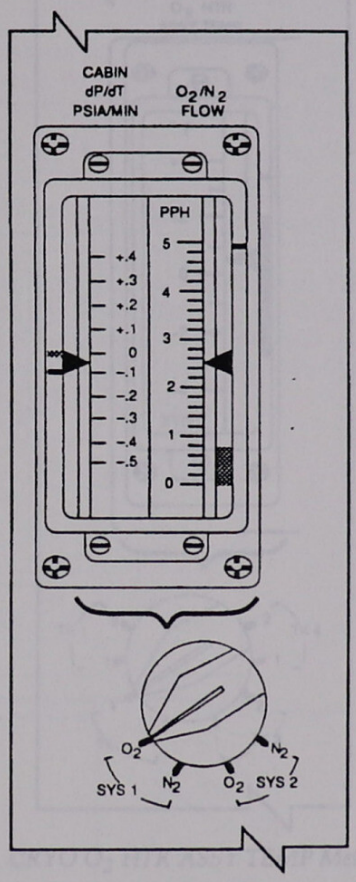
A sensor located downstream from the flash evaporator in each Freon Loop 1 and 2 provides data directly to the meter and to CRT displays SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM.

METER MARKINGS(S)	MARKING EXPLANATION(S)
38° — 40° F (green)	Normal operating range
65° F (red)	High limit (Class 2 C/W)
32° F (red)	Low limit (Class 2 C/W)

CABIN dP/dT PSIA/MIN, O2/N2 FLOW Meter

Cabin dP/dT

The indication on this meter is a direct readout of the dP/dT sensor. The data is also transmitted to CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT. The CRT displays also contain an additional backup dP/dT supplied by computations.



CABIN dP/dT PSIA/MIN, O2/N2 FLOW Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
0.0 psia (green)	Normal operating range
-0.08 psia (red)	Low limit (Class 2 C/W)

O2/N2 Flow

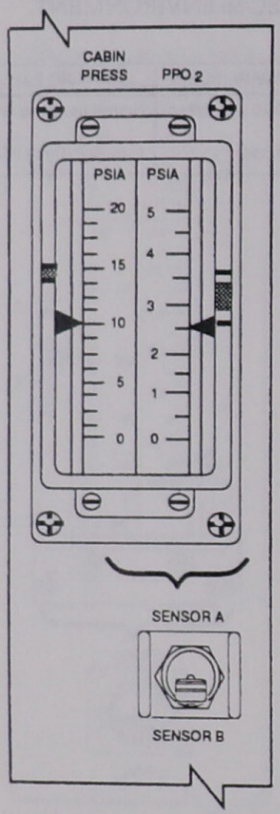
An O2 and N2 flow sensor in each of the two Pressure Control Systems (4 total) send data directly to the O2/N2 FLOW Meter. The readings are also available on CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.

METER MARKINGS(S)	MARKING EXPLANATION(S)
0.0 — 0.75 pph (green)	Normal operating range
4.9 pph (red)	High limit (Class 2 C/W)

CABIN PRESS, PPO_2 Meter

Cabin Pressure

A cabin pressure sensor provides a direct indication for this meter and for CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT. (The airlock pressure on the CRT ENVIRONMENT display can be used as a backup.)



CABIN PRESS, PPO 2Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
14.3 — 14.7 psia (green)	Normal operating range
15.2 psia (red)	High limit (Class 2 C/W)
13.8 psia (red)	Low limit (Class 2 C/W)

PPO_2

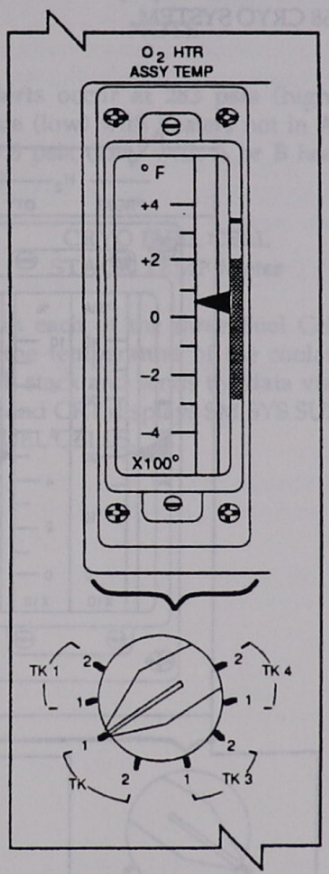
Dual selectable sensors (A or B) send data directly to this meter and for CRT displays SM SYS SUMM 1 and SPEC 66 ENVIRONMENT.

METER MARKINGS(S)	MARKING EXPLANATION(S)
2.95 — 3.45 psia (green)	Normal operating range
3.6 psia (red)	High limit (Class 2 C/W)
2.7 psia (red)	Low limit (Class 2 C/W)

Panel O2 Meters

CRYO O_2 HTR ASSY TEMP Meter

A temperature sensor in each of the eight O2 tank heater assemblies monitors the temperature of warmed O2 and sends the data via a DSC to this meter and CRT displays SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM.



CRYO O_2 HTR ASSY TEMP Meter

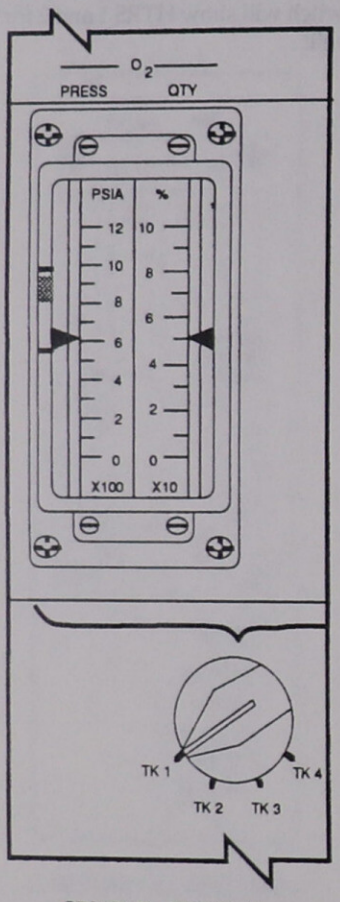
METER MARKINGS(S)	MARKING EXPLANATION(S)
-300° — +200° F (green)	Normal operating range
+ 349° F (red)	High limit (Class 2 C/W)

NOTE

For OV-105, the *METER TANK SELECT* switch will show HTRS 1 and 2 for tank 5 as well.

CRYO O_2 PRESS Meter

One sensor for each of the O_2 tanks provides pressure data via a DSC to the meter and SM program while another sensor (heater controller) sends data to CRT displays SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM.



CRYO O_2 PRESS Meter

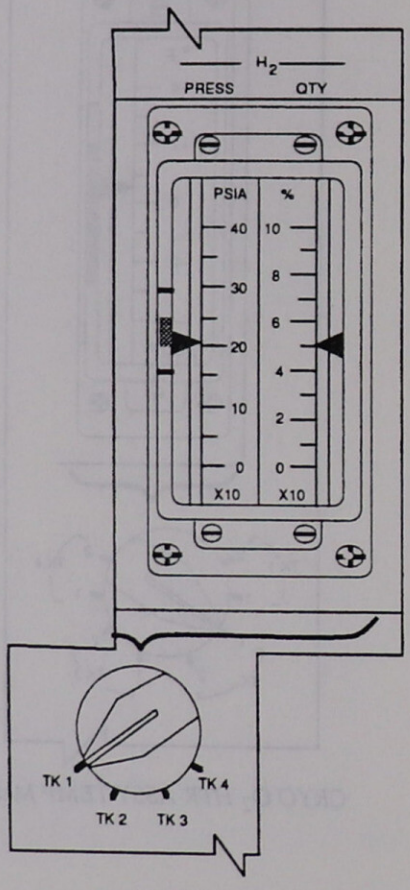
METER MARKINGS(S)	MARKING EXPLANATION(S)
802 — 930 psia (green)	Normal operating range
985 psia (red)	High limit (Class 2 C/W)
540 psia (red)	Low limit (Class 2 C/W)

NOTE

SM alerts occur at 960 psia (high) and 575 psia (low), with heaters not in AUTO or 740 psia (low) with A or B heater in AUTO.

CRYO H_2 PRESS Meter

One sensor for each of the H_2 tanks provides pressure data to the meter via a DSC and SM software while another sensor (heater controller) sends data to CRT displays SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM.



CRYO H_2 PRESS Meter

NOTE

Tank 5 *SELECT* position is included on OV-105.

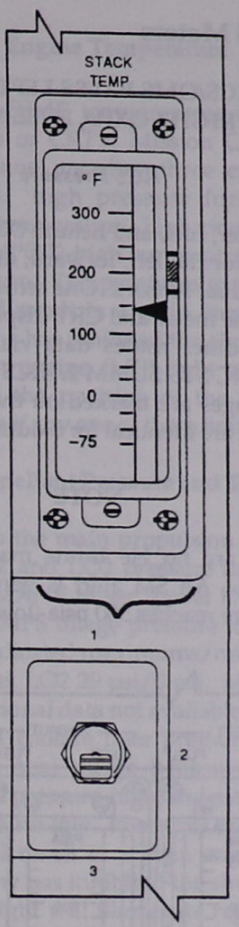
METER MARKINGS(S)	MARKING EXPLANATION(S)
200 — 250 psia (green)	Normal operating range
293.8 psia (red)	High limit (Class 2 C/W)
153 psia (red)	Low limit (Class 2 C/W)

NOTE

SM alerts occur at 283 psia (high) and 165 psia (low) with heaters not in AUTO, or 189.8 psia (low) with A or B heater in AUTO.

CRYO FUEL CELL STACK TEMP Meter

A sensor in each of the three Fuel Cell systems measures the temperature of the coolant leaving the fuel cell stack and sends the data via a DSC to this meter and CRT displays SM SYS SUMM 1 and SPEC 69 FUEL CELLS.



CRYO FUEL CELL STACK TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
190° — 225° F (green)	Normal operating range
243.7° F (red)	High limit (Class 2 C/W)
172.5° F (red)	Low limit (Class 2 C/W)

NOTE

SM alerts occur at:

High	Low	If FC Output is:
(1) 212°F	180°F	Less than 3.5 kW
(2) 222°F	190°F	3.5 — 7.5 kW
(3) 238°F	198°F	More than 7.5 kW

Panel O3 Meters

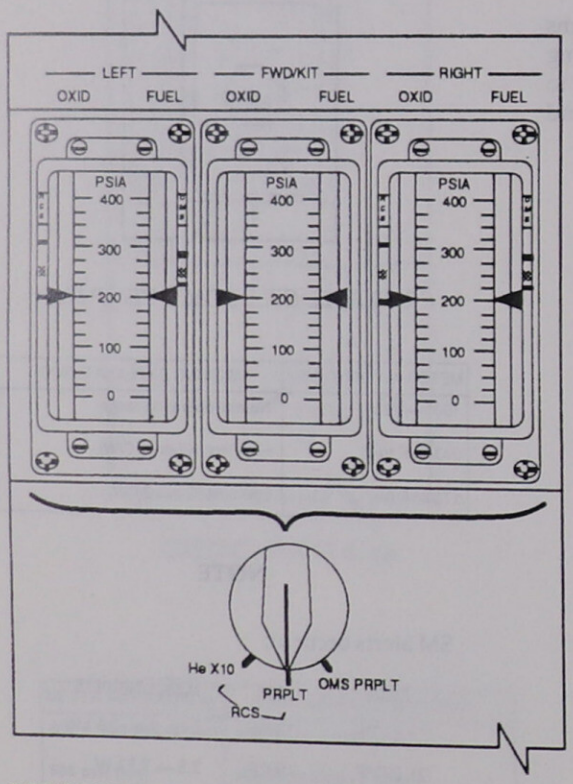
RCS/OMS PRESS LEFT/FWD/ RIGHT OXID, FUEL Meter

RCS Pressure

RCS oxidizer, fuel, and helium (X10) pressures are displayed for the left, forward, and right systems by way of dual sensors. One sensor sends data via a DSC to the meter and CRT display SPEC 23 RCS while the other routes data via a DSC to CRT display GNC SYS SUMM 2. RCS pressure limits/ normal ranges are marked on the left side of the meters and are identical for oxidizer and fuel.

NOTE

There are no He limits marked on the meters. An SM alert is generated if He pressure reaches 500 psia (low).



RCS/OMS PRESS LEFT/FWD/RIGHT OXID, FUEL Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
235 — 255 psia (green)	Normal operating range
312 psia (red)	High limit (Class 2 C/W)
200 psia (red)	Low limit (Class 2 C/W)

OMS Pressure

OMS oxidizer and fuel pressures are displayed for the left and right systems by way of a single sensor in each tank. The sensors send data via a DSC to the meters and CRT display GNC SYS SUMM 2. OMS limits/normal ranges are marked on the right side of the meters and are identical for oxidizer and fuel.

METER MARKINGS(S)	MARKING EXPLANATION(S)
245 —255 psia (green)	Normal operating range
284 psia (red)	High limit (Class 3 C/W; Class 2 and BFS C/W at 288 psia)
232 psia (red)	Low limit (Class 2 hardware C/W; software 234 psia)

4.2 ENGINE LIMITATIONS

CONTENTS

Space Shuttle Main Engines 4.2-1
Orbital Maneuvering System 4.2-2
Reaction Control System 4.2-3

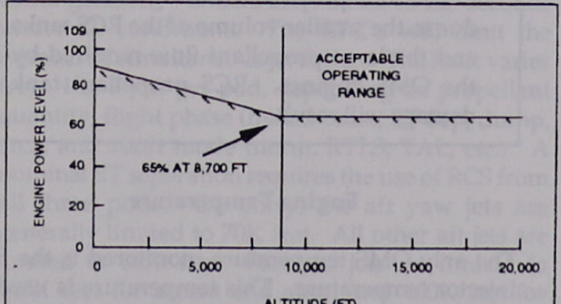
Space Shuttle Main Engines (SSME)

Power

The SSME are designed to operate from 65 percent Pc to 109 percent Pc above 8,700 MSL. The GPC's can command the engines only within this Pc range. The following chart shows minimum Pc's for altitudes below 20,000 ft. MSL. The engines are limited to 736 seconds of operation in the range of 65 percent to 104 percent Pc.

WARNING

Shuttle MPS in flight performance has not been verified beyond a power level of 104 percent Pc.



MINIMUM THROTTLE VS. ALTITUDE CONSTRAINT

MINIMUM MAIN ENGINE POWER LEVEL (%RPL)	ALTITUDE ABOVE SEA LEVEL (FT)
90.0	0
82.0	2,500
76.0	5,000
68.0	7,500
65.0	≥ 8,700

Pc Chart

Engine Temperature

There are no SSME temperatures monitored on orbiter meters or CRT's. Mission Control Center (MCC) personnel monitor three critical engine temperatures: high pressure fuel turbopump (HPFT)-high temperature, high pressure oxidizer turbopump (HPOT)-high temperature, and HPOT low temperature. Temperatures exceeding any of the limits will result in a main engine shutdown unless the crew has inhibited the shutdown limits. The red main engine (ME) light will illuminate regardless of the position of the LIMIT SHUT DOWN switch if any one of these limits is exceeded.

Engine Propellant Pressure and Temperature

In addition to the main propulsion system (MPS) manifold LH2 and LO2 pressure limits indicated on the ENG MANF Meter (panel F7), an SM alert will sound if MPS ullage pressure for LH2 or LO2 reaches the indicated maximums/minimums: LH2 46 psi/31.6 psi, LO2 29 psi/0 psi. MCC personnel monitor additional data not available on crew CRTs such as HPFT coolant liner pressure-high, HPOT intermediate seal purge pressure-low, HPOT secondary seal pressure-high, and main combustion chamber pressure-low. Pressures exceeding any of the limits will result in a main engine shutdown unless the crew has inhibited the shutdown limits. The red ME light will illuminate regardless of the position of the LIMIT SHUT DOWN switch.

Engine Nozzle Position

The MPS nozzles have sufficient dynamic envelope such that they can collide with one another, OMS engine nozzles or pods (upper SSME), or the body flap (lower SSMEs). The crew cannot monitor this envelope. Post MECO, the GPC's will position the nozzles to prevent interference and control entry heating on the lower engine nozzles. SODB Vol 1, section 3, and The Shuttle Performance Analysis Databook (SPAD), Chapter 6, graphically depict the nozzle envelopes.

Engine He Pressure

In addition to the MPS He Regulator pressure limits indicated on the MPS HE REG A Meter (panel F7), an SM alert will sound if the Regulator A pressure reaches 806 (high) or drops to 679 (low). He

Regulator B data is only available on CRT display BFS GNC SYS SUMM 1 and has no C/W limits. Pneumatic He accumulator pressure is also available on this CRT display.

SM Alert for Engine He Pressure		
Accum low	—	700 psi
Reg low	—	700 psi
Reg high	—	806 psi
TK low	—	3800 psi

An SM alert will also sound if the He dP/dT exceeds 20 psi per 3 second sample.

Engine AC Power

Main engine controller operation requires that all three AC phases and voltages must not fall below 100 volts (root mean square) for longer than 500 msec. Should this happen, channel switchover (A to B) or engine shutdown will occur. An electronic lockup can occur if the main engine controller loses both channels of Pc or fuel flow data. This will cause the controller to maintain the last commanded throttle position. The crew will see the corresponding amber MAIN ENGINE STATUS light illuminate and an MPS ELEC (L,R,C) message.

Engine Hydraulics

If the hydraulic pressure drops to approximately 1200 psig a shuttle valve will shut off the inlet and outlet hydraulic lines to all five affected SSME control valves freezing the engine at the last commanded throttle position. This is reversible if system pressure recovers above approximately 1200 psig prior to the main controller issuing a throttle command. Engine throttle commands during this "soft lockup" will cause the engine to enter a "hard lockup" that is not reversible. The throttle will retain the last commanded position (prior to entry into "soft" lockup). The crew will see the correspondinging amber MAIN ENGINE STATUS light illuminate and an MPS HYD (L,R,C) message. Affected engine shutdown will be either automatic or manual based on a vehicle performance assessment by the Flight Dynamics Officer.

Orbital Maneuvering System (OMS) Engines

Engine Chamber Pressure

There is no maximum Pc for the OMS engines due to the stoichiometry of the fuel/oxidizer mixture. Except during ullage blowdown, the OMS Pc should never fall below 80 percent. Operation with low Pc may cause engine damage or combustion instability.

Engine Operations

The engines are not rated for use below 70K feet due to exhaust flow separation and damage to the nozzles. With normal engine shutdown purge the following limitations apply: (1) Engine firings of less than 2 seconds are prohibited due to possible propellant freezing or hard starts. (2) The minimum engine off-time between firings is 240 seconds for normal operations and 30 seconds for launch abort operations (15 second minimum burn) due to possible propellant freezing or hard starts. Without normal engine shutdown purge, the off-time increases to 10 minutes (for burns more than 10 seconds).

CAUTION

OMS engines must never be interconnected to use RCS propellant during OMS burns due to the smaller volume of the RCS tanks and the large propellant flow required by the OMS engines. RCS propellant tank damage will result.

Engine Temperature

The only OMS temperature monitored is the fuel injector temperature. This temperature is used to assess engine burn stability.

A fault message will be generated if the fuel injector temperature in either OMS pod exceeds 260° F (indicative of low or high fuel inlet pressure).

Engine Propellant

If the OMS propellant quantity is less than 11 percent, an RCS settling burn should be accomplished prior to OMS ignition. OMS propellant quantity should be less than 22 percent to remain within the structural limit for landing.

Engine Nozzle Position

If a nozzle moves more than .7 degrees from its stowed position, a fault message will be generated to the ground and crew. If MCC is satisfied that it has moved more than 1.5 degrees inboard or up during the maximum q-bar regime of ascent, then the OMS engine will not be fired.

Engine N2 Pressure

The minimum nitrogen pressure for starting an OMS engine is 299 psi (254 psi for contingencies though abnormal start could occur). The maximum number of starts that can be supported with the N2 system is 17.

Reaction Control System (RCS) Jets

Jet Operations

The maximum nominal firing duration for forward and aft primary jets is 150 seconds, or 300 (-X forward RCS) and 800 (+X aft RCS) seconds for contingencies. Verniers are limited to 125 seconds under all conditions. The GPC's will limit the number of simultaneous jet firings. The limit varies from 4 to 7 jets per pod, depending on propellant quantity, flight phase (mated coast, ET Sep, dump, etc.), and abort mode (norm, RTLS, TAL, etc.). A nominal ET separation requires the use of RCS from all three pods. On entry, the aft yaw jets are generally limited to 70K feet. All other aft jets are limited to 165k feet. Forward jets are limited to 165K feet for ascent and abort and 400K feet for entry except for program test inputs (PTIs).

ET SEPARATION RCS REQUIREMENTS		
Jet Group	Minimum Requirements	
	Nominal	RTLS
FWD down	1	3
AFT left	1	3
AFT right	1	3
AFT up	1/side	2/side
AFT down	1/side	2/side
FWD yaw	—	1/side

ET Separation Chart

Jet Propellant

The propellant tanks are not usable if pressure is less than 185 psi. During ascent and orbit (also entry when g load is low) the maximum allowable pressure differential between tanks prior to initiating a crossfeed is 80 psi. When acceleration is between 0 and 1.5 g's, the maximum differential is 55 psi. The maximum acceleration for initiating a crossfeed is 1.5 g. A minimum of 1405 lb of aft propellant is required for entry from orbital inclinations of 28.45 degrees through 30 degrees. An additional 200 lb is redlined for entry from inclinations greater than 30 degrees.

RCS He Tank Pressure

The He tanks are considered lost if pressure is less than 456 psi.

4.3 AIRSPEED LIMITATIONS

CONTENTS

Ascent 4.3-1
Entry 4.3-1
Approach and Landing 4.3-1

Ascent

The maximum airspeed (based on the q-bar limit of 819 psf) for OV 103, 104, and 105 is 492 KEAS where KEAS = $\sqrt{q\text{-}bar} \times 17.18$). The OV 102 limit is 483 KEAS. These limits are based on thermal protection system (TPS) constraints. Flight design planning for each mission keeps the vehicle's airspeed (via q-bar) below about 465 KEAS.

There is no official minimum airspeed for ascent. There is, however, a minimum orbit (dictated by flight rule) that designates 80 nm as the minimum acceptable altitude. This altitude (given a minimum apogee of 155 nm) assures at least 48 hours before orbital decay to 400,000 ft. (A 105 nm X 85 nm orbit can be tolerated for a few hours before the orbiter must deorbit or raise the perigee.) The minimum circular orbit allowed by flight rule is 105 nm.

Entry

The maximum speed during entry is also a function of q-bar which varies during the descent profile. It reaches a maximum value at 342 psf or 318 KEAS.

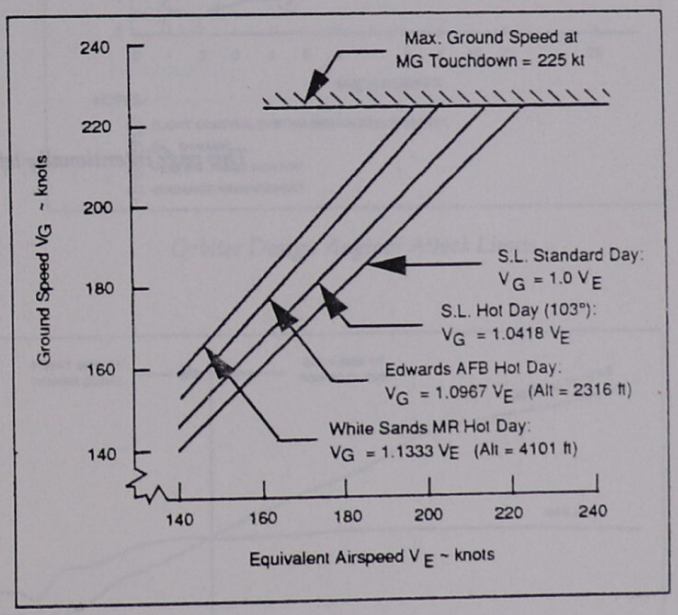
The minimum speed during entry (subsonic) is approximately 151 KEAS for a 207,000 lb vehicle. This speed is based on the maximum usable angle of attack (alpha) which prevents the orbiter from flying on the back side of the lift-to-drag (L/D) curve.

Approach and Landing

The maximum speed in the landing configuration is 297 KEAS due to the restriction of q-bar on the landing gear doors (300 psf).

The minimum speed for a 207,000 lb vehicle at touchdown in the nominal landing configuration is approximately is 151 KEAS due to potential body flap or elevon scrape.

The maximum main gear touchdown groundspeed of 225 kts must be converted for temperature and density variations to arrive at the maximum KEAS airspeed. The maximum nose gear tire speed is 217 kts, but aerodynamic loads (due to negative alpha), occurring just prior to nose gear touchdown dictate touchdown with nose gear at much lower speeds (maximum to date 182 KGS).



GS vs EAS

4.4 ANGLE OF ATTACK LIMITATIONS

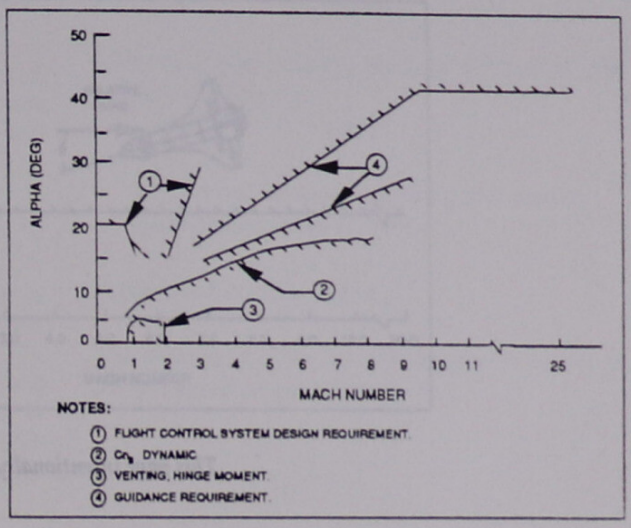
CONTENTS

Entry 4.4-1
Approach and Landing 4.4-1

Entry

The maximum alpha for the orbiter during entry is designed to protect the TPS, maintain control in the three axes, meet structural requirements during venting, assure aerosurface hinge moments remain within limits, and keep the orbiter within guidance limits. Consequently, the alpha limits may be well below the maximum usable alphas.

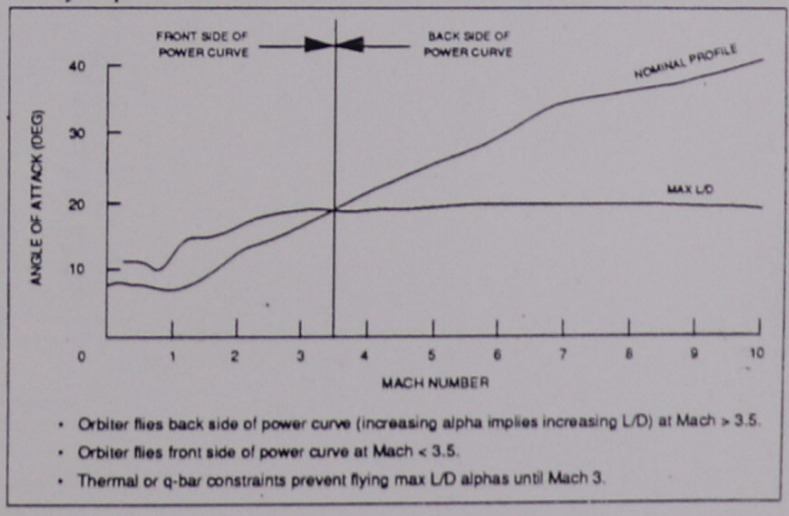
The minimum alpha used in the aero database is -10 degrees.



Orbiter Design Angle of Attack Limits

Approach and Landing

The maximum usable alpha during approach and landing is 20 degrees until final flare, when the alpha must be limited to about 14.7 degrees to prevent body flap or elevon scrape.

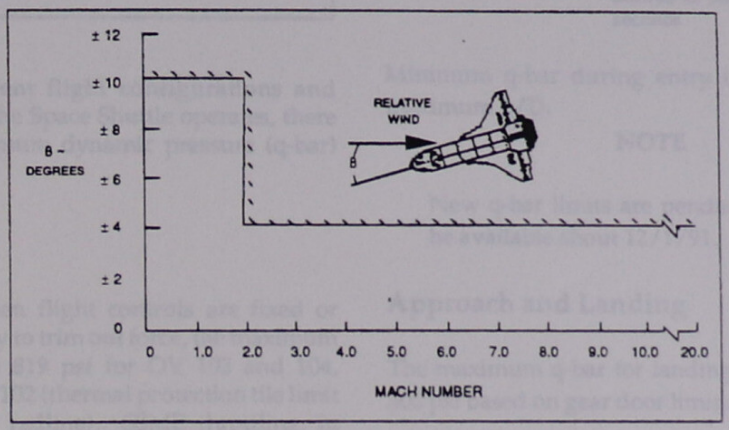


Orbiter Nominal Angle of Attack Profile

4.5 SIDESLIP LIMITATIONS

Numerous sideslip limitations for the various ascent flight phases (SRB separation, ET separation, aborts, etc.) are available in the Shuttle Performance Assessment Databook (SPAD). During entry (2< Mach <12), the crew will manually trim to reduce RCS jet firings if steady state sideslip exceeds 2 degrees, one or more yaw jets fire continuously, or if scaled Ay (sensed lateral acceleration) exceeds the 2 jet capability.

In the landing configuration the maximum sideslip angle is ±5 degrees.



4.6 DYNAMIC PRESSURE LIMITATIONS

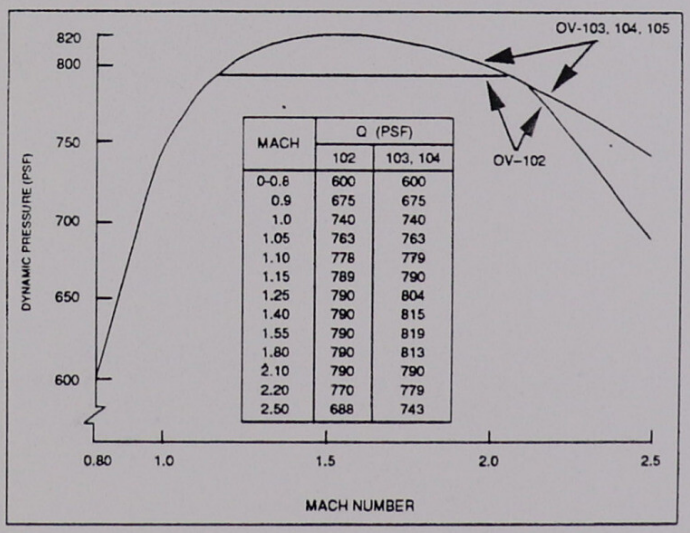
CONTENTS

Ascent 4.6-1
Entry 4.6-1
Approach and Landing 4.6-1

Due to the different flight configurations and regimes in which the Space Shuttle operates, there are multiple maximum dynamic pressure (q-bar) values.

Ascent

During ascent when flight controls are fixed or moved only slightly to trim out force, the maximum allowable q-bar is 819 psf for OV 103 and 104, and 790 psf for OV 102 (thermal protection tile limit and flutter/buffet redline). SSME throttling, in conjunction with SRB propellant loading, typically keeps the pressure below 700 psf.



MACH	Q (PSF)	
	102	103, 104
0-0.8	600	600
0.9	675	675
1.0	740	740
1.05	763	763
1.10	778	779
1.15	789	790
1.25	790	804
1.40	790	815
1.55	790	819
1.80	790	813
2.10	790	790
2.20	770	779
2.50	688	743

Entry

Current flight design limits for q-bar are as follows:

MACH		Q-BAR
≥ 5	—	≤ 300 psf
> 3 but < 5	—	≤ 342 psf
< 3	—	≤ 300 psf
< 1	—	Exursions 300 to 340 psf allowed for periods ≈ 15 seconds

Minimum q-bar during entry is defined by the maximum L/D.

NOTE

New q-bar limits are pending and should be available about 12/1/91.

Approach and Landing

The maximum q-bar for landing gear extension is 300 psf based on gear door limits.

4.7 CROSSWIND LIMITATIONS

Although the orbiter design landing crosswind limit is 20 kts, Flight Rule 4-64 limits it to 15 kts based on flight experience and Ames Vertical Motion Simulator simulations for lateral control and tire wear. Long duration missions or landings with one failed APU lower the crosswind limit to 12 and 10 kts respectively.

4.8 LANDING WEIGHT LIMITATIONS

Maximum Landing Weight

The maximum landing weight, based on the weight used to certify the main gear and tires is 239,903 lbs (which is officially accepted to be 240,000). Flight Rule (4-72) limitations for nominal end of mission (EOM) landing weight is 230,000 lbs. Planned EOM weights above that value must have a flight-specific waiver. The abort landing weight for AOA, RTLS, and TAL was recently set at 240,000 lbs.

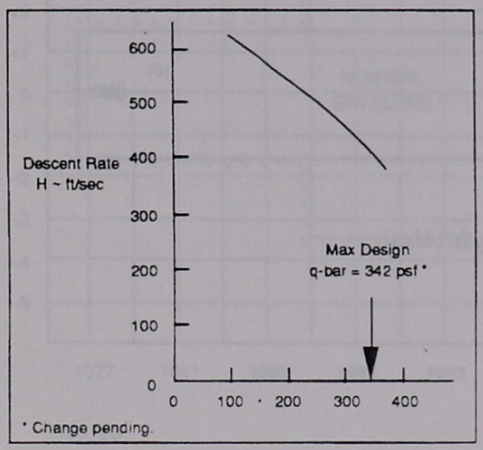
4.9 DESCENT RATE LIMITATIONS

CONTENTS

Entry 4.9-1
Main Gear Touchdown 4.9-1
Nose Gear Touchdown 4.9-1

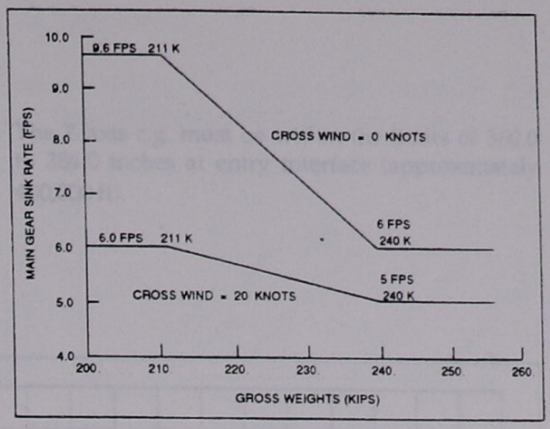
Entry

Below 100,000 ft the maximum rates of decent (H-dot) must not exceed 486 fps. The following graph shows maximum H-dots for different dynamic pressures.



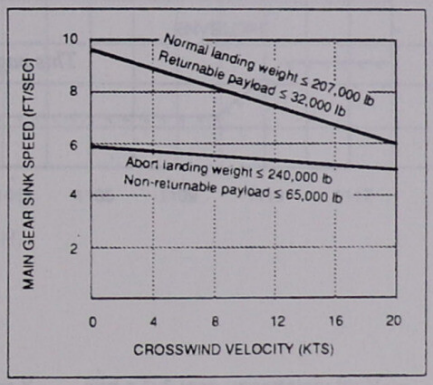
Main Gear Touchdown

The maximum rate of descent at main gear touchdown is 9.6 fps for landing weights less than 211,000 lb and no crosswind. The following graph shows the rate of descent limits for various orbiter weights.



Main Gear Sink Rate

The type of payload returned in the payload bay also establishes the maximum allowable sink rate at main gear touchdown. The following graph shows the limit for crosswind and sink speed for the main gear for returnable and non-returnable payloads.



Landing Sink Rate vs. Crosswind Velocity

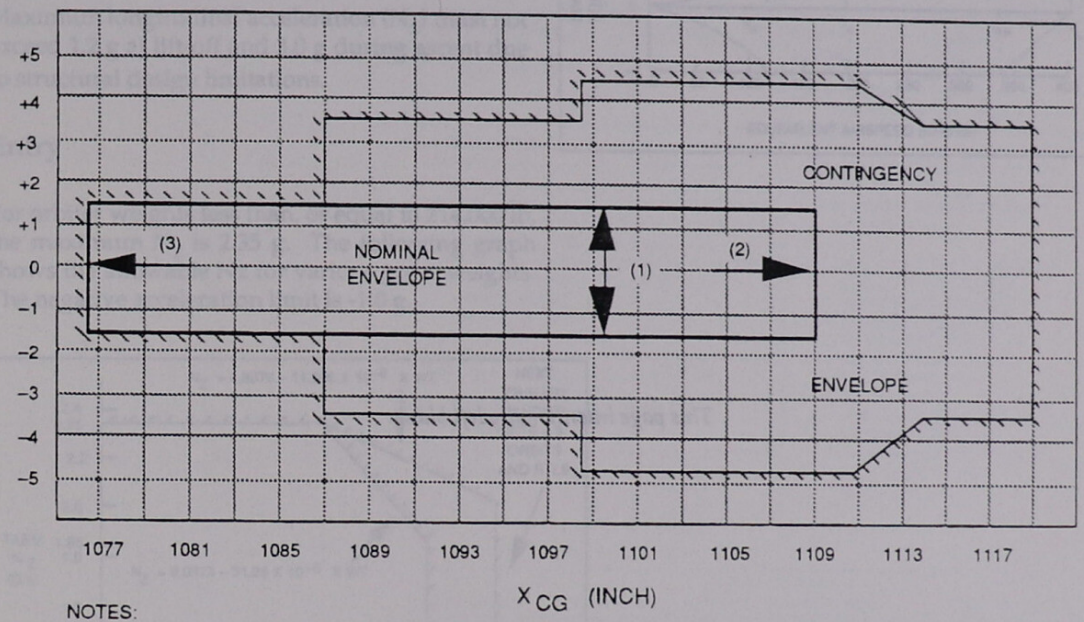
Nose Gear Touchdown

The maximum rate of descent at nose gear touchdown must not exceed 11.5 fps (9.9 degrees per second) or the rate needed to prevent nose gear vertical loads in excess of 90,000 lbs. (Operational rates of descent average 5 fps.)

4.10 CENTER OF GRAVITY LIMITATIONS

Although ground personnel will normally monitor and direct changes to the orbiter's c.g. for entry, the crew may in "lost comm" situations be required to perform this task. The X and Y axis c.g. envelopes for entry are shown on the following graph:

The Z axis c.g. must be within the limits of 360.0 to 384.0 inches at entry interface (approximately 400,000 ft).



NOTES:

(1) Verified aero boundary.
(2) Design envelope aft limit.
(3) Flight manifest forward limit (X = 1076.7 inches).
(4) Nominal CG envelope reflects a 1 inch uncertainty for X_{CG} and a 0.5 inch uncertainty for Y_{CG}.

4.11 ACCELERATION LIMITATIONS

CONTENTS

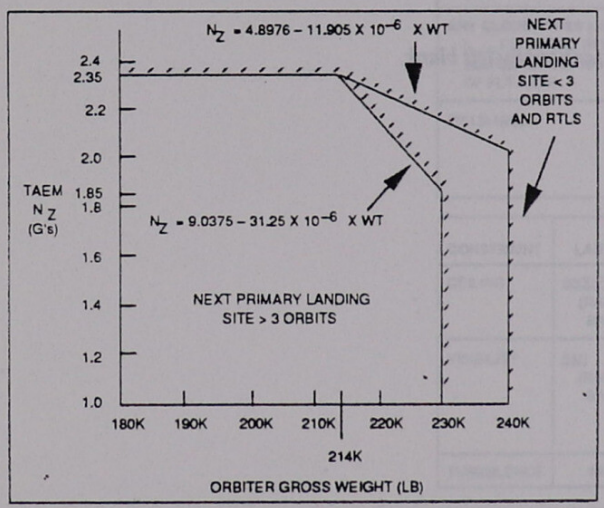
Ascent 4.11-1
Entry 4.11-1

Ascent

Maximum longitudinal acceleration (N_z) must not exceed 1.2 g at lift-off and 3.0 g during ascent due to structural design limitations.

Entry

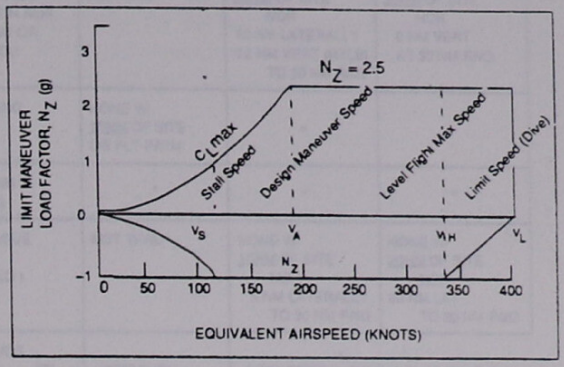
For orbiter weights less than, or equal to 214,000 lb, the maximum N_z is 2.35 g. The following graph shows the allowable Nz for various gross weights. The negative acceleration limit is -1.0 g.



Orbiter Operational Maneuver Limits

Vn Diagrams

The following Vn diagram demonstrates the acceleration limits in the TAEM region of entry.



4.12 WEATHER LIMITATIONS

Weather limitations for launch, abort landing, and end of mission landing are presented in the table on the right.

CONSTRAINT	LAUNCH	RTLS / TAL	EOM / AOA
PRECIPATION – VISIBLE RAIN/VIRGA – PRECIP ECHO ON RDR – CUMULONIMBUS OR TOWERING CU	NONE IN FLT PATH	NONE W/ 20NM OF SITE NOR 10 NM LATERALLY &2 NM VERT (RTLS) TO 30 NM RNG	NONE W/ 30NM OF SITE NOR 2 NM VERT AT 30 NM RNG
VISIBLE LIGHTNING	NONE W/ 10NM OF SITE OR FLT PATH	"	"
THUNDERSTORMS (INCL ANVIL)	"	"	"
DETACHED OPAQUE ANVILS (< 3 HRS OLD)	NOT THRU	NONE W/ 10NM OF SITE NOR 5 NM LATERALLY TO 30 NM RNG	NONE W/ 20NM OF SITE NOR 20 NM LAT TO 30 NM RNG
CUMULUS CLOUDS – TOPS > +5 C (____FT) – TOPS > –10 C (____FT) – TOPS > –20 C (____FT)	– NOT THRU – AVOID BY 5 NM – AVOID BY 10 NM		
CB DEBRIS CLOUDS	NOT THRU		
VERT CONT LAYER ≥ 4500 FT WHEN ANY 0 C TO –20 C (____FT TO ____FT)	NOT THRU		
ANY CLOUD TYPES ≥ 0 C (____FT) **ASSOC WITH DISTURBED WX W/5 NM OF FLT PATH**	NOT THRU		
FIELD MILL	1 MIN AVE > 1 KV/M W 15 MIN 5 NM		

* **EXCEPTION:** RTLS MAY BE GO IF WX FRCST & JUDGEMENT – SUPPORTED BY CONTIN RADAR & AIRCRAFT INDICATE ALL:

1. ISOL OR WIDELY SCATTERED LT RAIN (TOPS < 20 KFT)
2. HORIZ MOVEM IS STABLE & NO SIGNIF CONVECTIVE DEVELOP EXPECTED
3. BOTH APPROACHES TO OTHER RNWY MEET ALL LNDG CRIT
4. VERT CLEARANCE OF 2 NM W/ 10 NM LATERALLY OF APPROACH PATH EXISTS & IS EXPECT TO EXIST THRU LANDING

CONSTRAINT	LAUNCH	RTLS / TAL / AOA / NEXT PLS / EOM (NON–KSC)	KSC EOM
CEILING	8000 FT (RANGE SAFETY)	• NO MLS : 10000 FT • MLS : 8000 FT (WITH WX RECON)	10000 FT (CLOUDS < 10000 MUST BE ≤ 0.2 OBSERVED AT GO/ NO GO)
VISIBILITY	5 MI (RANGE SAFETY)	• NO MLS : 7 SM • MLS : 5 SM (IF PAPI VISIBLE FROM 8000 FT TO PREFLARE, & BALL BAR VISIBLE FROM PREFLARE TO FINAL FLARE)	
TURBULENCE	N/A	≤ MODERATE	≤ MODER

CONSTRAINT	LAUNCH	DAY	NIGHT	EDO (> 10 FD)	1 APU DOWN	KSC EOM
SURFACE WINDS	RTLS: 15 XW LCC: SEE COMPASS ROSE (NOTE 3)	HW: ≤ 25 KT XW: ≤ 15 KT INCL GUST GUST ≤ 10 KT TW: ≤ 15 KT ≤ 10 AVE (225 KT TIRE SPEED)	HW: ≤ 25 XW: ≤ 12 INCL GUST GUST ≤ 10 KT TW: ≤ 15 KT ≤ 10 AVE (225 KT TIRE SP)	12 XW	10 XW (LIGHT TURB)	12 XW (≤ 205000) 10 XW (> 205000) PEAK WIND: ≤ 20 KT

5. NORMAL PROCEDURES SUMMARY

CONTENTS

5.1 Pre-Launch 5.1-1
5.2 Ascent 5.2-1
5.3 Orbit 5.3-1
5.4 Entry 5.4-1
5.5 Post Landing 5.5-1

This section summarizes nominal procedures for a generic Space Shuttle mission. More detailed procedures may be found in the Astronaut Support Personnel Book, the various Flight Procedures Handbooks (FPH), and Flight Data File (FDF) documents. The FPH documents also contain rationales for the various procedures listed herein. For flight specific training, refer to the applicable FDF checklists/cue cards.

5.1 PRE-LAUNCH

Pre-Launch Procedures

Hr:Min (approx)

L-33:00	Astronaut closeout crew (C^2 or "cape crusaders") conduct communications checks with the launch team. Caution and warning (C/W) volumes are adjusted so the air-to-ground communication can be heard over the C/W tone. UHF Guard is checked, and headset interface units (HIUs) are checked for proper operation, along with intercom (ICOM) loops A and B. If the ICOM recorder has been manifested, it is installed and tested. Text and graphics system (TAGS) paper is installed.
L-18:30	C^2 insures crew module has been vacuumed and performs ascent switch list configuration.
L-16:30	The backup astronaut support person (ASP) conducts a check of the middeck and flight deck and installs certain cue cards, flipbooks, and checklists.
L-12:45	The backup ASP adjusts CDR and PLT seats to the full down and aft position and then configures all seats for launch. Rotational hand controllers (RHCs) are adjusted, and speed brake thrust controllers are set full forward.
L- 8:15	Pad is cleared for tanking.
L-5:35	ASP reports panel *ABORT* light status when initiated by the Flight Director.
L-5:30	ASP Checklist is initiated. Checklist includes a communications check, potable/supply water quantity adjustment, LiOH canister installation, air sample, pre-ingress switch reconfiguration, ECLSS fuel cell payload "flow" position verification, navigation aids activation, and C/W memory clearing.
L-4:55	Crew wake up.
L-4:25	Crew breakfast and photo opportunity.
L-3:55	CDR, PLT, MS2 get weather briefing. MS1/3 (PSs) don flight clothing and equipment.
L-3:45	CDR, PLT, MS2 don flight clothing and equipment.
L-3:15	Crew departs for the Pad.
L-2:45	Crew arrives at the White Room; ASP verifies the CDR and PLT Launch/Entry Suit (LES)/flight equipment is properly configured prior to seat ingress, assists with their ingress and the installation of ascent FDF, monitors CDR/PLT communication air-to-ground checks, assists with the post ingress switch reconfiguration, and coordinates the C/W and inter-com volume adjustment; as the MSs ingress, the ASP verifies their LES/flight equipment configuration and assists ingress and communication hook up and checks.
L-1:45	ASP verifies all non-flight equipment is removed from the crew compartment, terminates communication with the Launch Control Center (LCC), and egresses.
L- 1:30	After the hatch is closed, a cabin leak check is performed.
L-1:20	CRTs will already have the following displays: (1) GNC GPC MEMORY

(2) GNC 104 GND IMU CNTL/ MON

(3) GNC GPC MEMORY; IMU preflight alignment begins at this time

L- 1:05 CDR initiates the cabin vent redundancy checks at LCC direction.

Min:Sec (approx)

L-52:00 CDR prepares for the primary avionics software system (PASS)/backup flight system (BFS) transfer. GNC BFS MEMORY display is assigned to CRT display 3.

L-50:00 CDR places the *OMS ENG* switches to *ARM/PRESS* for GN2 pressurization and opens the cabin vent isolation valve.

L-45:00 All crewmembers conduct an A/G voice check with MCC and receive updates to ascent/ abort data.

L-42:00 CDR initiates PASS/BFS transfer and closes the cabin vent isolation valve (if not already directed to do so by LCC).

L-30:00 Planned 10 min hold; OPS 1 Load is initiated and GNC FAULT is displayed on CRT 1 while C/W is cleared. A ground-controlled fuel cell purge takes place about this time.

L-29:00 CDR initiates BFS to OPS 1 with BFS, puts GNC FAULTS display on CRT 3, and clears C/W.

L-27:00 PLT conducts horizontal situation configuration for TAL sites and RTLS to KSC with CRTs 2/3 displaying GNC 50 HORIZ SIT/ BFS GNC 50 HORIZ SIT. When this activity is complete, the PLT configures for OMS interconnect with PASS and BFS. Displays for CRTs 1-3 are GNC LAUNCH TRAJ, GNC SYS SUMM 1, BFS, GNC SYS SUMM 2.

L-26:00 PLT performs the MPS He reconfiguration by opening He and pneumatic isolation valves.

L-25:00 The OMS/RCS crossfeed valves are configured for launch by the Launch Processing System.

L-19:00 Planned 10 min hold which synchronizes L and T time.

T-9:00 Go for launch given, and event timers started.

T-8:00 PLT connects essential buses to the fuel cells.

T-7:30 Access arm retracts, and the crew makes final checks on seat positions, suit closures, and restraints.

T-6:00 PLT performs APU prestart and verifies three gray *"READY TO START"* talkbacks. CRT 1-3 displays are GNC LAUNCH TRAJ, GNC SYS SUMM 1, AND BFS, SM SYS SUMM 2.

T-5:00 Pilot starts APUs and verifies normal pressure. CDR turns off flash evaporator feedline heaters.

T-3:25 Main engine nozzles are gimballed during the next 30 sec. The crew may feel the motion/vibration.

T-2:30 PLT clears the C/W with GNC 99 FAULT and BFS GNC 99 FAULT display on CRTs 2 and 3. Displays are then changed to GNC SYS SUMM 1 and BFS GNC LAUNCH TRAJ.

T-2:00 All crewmembers start O2 flow and close their visors.

T-0:07	Ignition sequence for main engines begins. Crew monitors Pc's increase.
T-0:03	Crew monitors main engines, which should have Pc's above 90 percent.

5.2 ASCENT

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Powered Flight 5.2-1
OMS Burns 5.2-2
Post Insertion 5.2-4

Powered Flight

Min:Sec (approx)

T-0:00 — SRB ignition, software transitions to MM 102, main engines at ~100 percent Pc, and event timer counts up from zero. Throughout ascent phase the crew monitors vehicle performance using CRT and dedicated displays intervening as required/directed by MCC. The crew also uses the Flight Instruments, ADI cue card, No-Comm Ascent Abort Mode Boundaries, and Contingency Abort cue cards, to monitor the ascent trajectory and maintain awareness of abort options. Cue cards are used for malfunctions procedures.

Typical CRT displays for Ascent are CRT 1 ASCENT TRAJ, CRT 2 GNC SYS SUMM 1, and CRT 3 BFS ASCENT TRAJ. CRT 3 is also used for both BFS GNC and SM SYS SUMM 1/2 as required.

Mission Elapsed Time (MET)

Min:Sec (approx)

0:04 — If 104 percent is programmed for launch, at a velocity of 60 fps, the main engines are commanded to that level.

0:07 — At a velocity ≥ 127 fps the vehicle rolls, yaws, and pitches to the heads-down ascent attitude. Crew monitors and engages the BFS if maneuver not begun when required or not properly completed.

0:20 or 0:30 (flight specific) — Crew monitors main engines throttling down to limit maximum flight dynamic pressure and to adjust for off-nominal performance. Throttle level can vary depending on flight design and SRB performance.

1:00 — Crew monitors main engines throttling back up to ~104 percent. Manual throttle may be selected if required.

1:30 — Maximum q-bar phase is passed. Control Stick Steering (CSS) may now be selected in lieu of BFS Engage if PASS guidance is not nominal.

2:00 — ASCENT TRAJ display will indicate PC < 50 when both SRB Pc's drop below 50 psi. SRB separation should occur shortly thereafter (no later than MET 2:20). If SRB separation is inhibited, crew should be prepared to correct out of limit condition (for automatic SRB jettison) or manually separate SRBs. When the SRBs are separated GNC changes to MM 103. BFS commands flash evaporator system (FES) on via payload buses.

Post SRB separation the crew checks PASS and BFS TMECOs converge to expected values to verify performance of Ascent Guidance.

MET Min:Sec (approx)	
3:00	Crew verifies the flash evaporator is working properly (T < 60° F and decreasing on EVAP OUT T overhead meter).
8:30	Main engine cutoff (MECO) occurs on direct insertion (DI) missions. Red *MAIN ENGINE STATUS* lights illuminate. Time may vary slightly depending on flight profile. MECO time should closely match time seen in simulations. PLT should be prepared for manual shutdown if automatic sequence fails (if in manual throttle, manual shutdown required, unless low level cutoff occurs, prior to target velocity).
Post MECO	Crew verifies external tank (ET) separation (*MAIN ENGINE STATUS* lights extinguish). If ET separation is inhibited, the crew must null rate(s) (if > .7 degree/sec) or react to feedline disconnect failure; MS2 verifies *ORBITAL DAP* lights illuminated indicating MECO confirmed for ET separation. MECO velocity should be approximately 25, 650 fps (standard insertion (SI) due East) or 25,850 fps (DI due east). -Z translation occurs and GNC transitions to MM 104 at completion of -Z translation (if THC not out of detent prior to completion of translation).

OMS Burns

SI	OMS 1 targets will appear on GNC OMS 1 MNVR EXEC displays (CRTs 1 and 2). The burn is executed for SI OMS 1 and available for DI OMS 1 if required due to a large underspeed. The OMS 1 Burn cue card and the OMS 1 Burn Monitor cue card are referenced for normal OMS 1 Burn procedures and malfunctions that occur during the burn. Crew selects *INRTL* on *ADI ATTITUDE* switch and begins the automatic maneuver to burn attitude if OMS 1 burn is required. When in the proper attitude, the error needles should be centered and ADI attitude should match burn attitude on the MNVR display. VGOs should be cross-checked for proper burn attitude and guidance.
MECO Min:Sec (approx	
+1:45	EXEC key must be pressed on CDR/PLT keyboard within 15 seconds of OMS TIG to enable burn. CRT 1 in GNC OMS 1 MNVR EXEC, CRT 2 in SYS SUMM 1, and CRT 3 BFS, GNC SYS SUMM 2.
+2:00	OMS 1 ignition. Crew monitors burn (OMS Pc ~100 percent, engine control valves ~100 percent, He pressure decreasing slowly, engine inlet pressure drops to ~200 psi, OMS quantity decreases ~15 sec after ignition, delta VTOT decrementing nominally) and prepares to respond in case of an off-nominal burn; burn duration ~2:30. Two seconds after the end of the burn, the CDR places the *OMS ENG* switches to *OFF* and trims out. any delta V residuals in the X and Z directions. If DI (or if OMS 1 is MECO +6 min or more), the MPS propellant dump is initiated at MECO +2 min.

DI or SI
Post OMS 1

The crew performs the tasks listed in the Post OMS 1 procedures section of the Ascent Checklist. CDR and PLT turn *FLT CNTLR POWER* switches (2) *OFF* to prevent inadvertent inputs to the RHCs (which can initiate manual DAP).

NOTE

Taking *FLT CNTLR POWER* switches to *ON* on *OFF* may cause the DAP to downmode from Auto to Manual. Power surges in the system can be confused with an RHC input causing the DAP to downmode.

MET

Min:Sec (approx)

12:55

PLT verifies the *BODY FLAP* push button light is out (light will extinguish at the end of a timer. During that time, the MPS dump should have completed (~2:21 duration). APU shutdown is then performed.

CDR manually activates the FES and its heater prior to the OPS 2 transition and securing BFS. PLT activates the B heaters for the cryo O2 and H2 tanks.

PLT sets the *AC BUS SNSR* switches to the *AUTO TRIP* position (*OFF* during ascent to prevent SSME loss due to bus trip).

CDR/PLT modes GPCs to MM 105 for the OMS 2 burn. Once in OPS 105, the crew refers to the Ascent Pocket Checklist for malfunction procedures.

CRT displays are as follows:

(1) GNC OMS 2 MNVR EXEC
(2) GNC SYS SUMM 1
(3) BFS, GNC OMS 2 MNVR EXEC

CDR/PLT load OMS 2 targets as required and OMS gimbal trim data (OMS 1 trim remains until changed. Gimbals do not move until 15 sec prior to burn); OMS targets are verified (PASS and BFS).

PLT secures MPS engine power and vacuum inerts the O2 and H2 lines for ~30 min, terminating ~5 min prior to OMS 2 burn.

PLT closes the ET umbilical doors.

WARNING

ET centerline latches must be stowed prior to door closure to prevent door drive mechanism damage.

PLT prepares OMS for the burn by verifying proper valve configurations.

CDR, PLT set *ADI ATTITUDE* to *INRTL* position and maneuver to the burn attitude.

OMS 2 Burn
TIG

Min:Sec (approx)

-5:00

PLT terminates MPS vacuum inerting. Crew transitions to OMS 2 Burn and Burn Monitor cue cards for procedural reference.

CDR, PLT make final verification of burn attitude, DAP selection, OMS gimbal trim, He PRESS/EVAP ISOL valve positions, and activate their *FLT CNTLR POWER*. CRT 3 display is changed to BFS, GNC SYS SUMM 2.

-2:00

CDR/PLT set *OMS ENG* switches to *ARM/PRESS* and verify the engine press valves are open.

TIG Min:Sec (approx)	
-0:15	CDR/PLT initiates EXEC command to perform burn. There is no need for the crew to correct attitude errors prior to OMS 2 ignition since OMS engine thrust vector control (TVC) will fly the vehicle to the proper attitude. OMS TVC can be used to take out attitude errors up to 90 degrees, the maximum error limit for OMS ignition to occur.
TIG MET Hr:Min (approx)	
00:30-00:60 (00:42 nominal for DI)	CDR, PLT monitor OMS 2 burn, Pc's (~100 percent), delta VTOT and time to go (TGO) decreasing, bipropellant valves (100 percent), and perigee increasing. Crew prepares to complete burn with single engine or RCS if failures occur. Burn duration is ~2 min for 160 nm circular orbit (based on nominal ascent).
OMS 2 Cutoff	
+2 sec	CDR/PLT secure OMS engines (2 sec delay for purge) and trim all axes residuals < 2 fps (< 0.2 fps for orbit critical burns).
Post OMS 2	The crew returns to the Ascent Post OMS 2 section of the Ascent Checklist for nominal procedures and the Ascent Pocket Checklist for malfunctions. CDR/PLT secure *FLT CNTLR POWER* and verify the *DAP* is in *AUTO*.
	CDR performs an OMS TVC gimbal check (secondary then primary checks are conducted to verify operations prior to on-orbit use).
	PLT reconfigures OMS and RCS valves for on-orbit operations.
	CDR/PLT change to MM 106. CRT displays for 1 and 3 are PASS and BFS GNC OMS 2 MNVR COAST, CRT 2 is GNC SYS SUMM 1. Crew stows ascent related FDF and unstows the Post Insertion Checklist, Orbit Operations Checklist and Pocket Checklist, cue cards, and the orbiter Malfunction Book.

Post Insertion

The Post Insertion Checklist is used for nominal procedures. The Orbit Pocket Checklist and Malfunction Book are references for malfunctions. During post insertion the following six activities must be accomplished to prepare for on-orbit operations:

(1) Reconfigure to on-orbit software and GPC configuration.

(2) Activate radiators.

(3) Open payload bay doors.

(4) Purge the fuel cells.

(5) Align IMU via star trackers (usually not completed until a night pass after post insertion phase is complete).

(6) Doff and stow LES, reconfigure cockpit for orbit operations.

MET

Day/Hr:Min (approx)

0/0:53 CDR/PLT reconfigure the GPCs. On-orbit software (OPS 2) is loaded into GPCs 1 and 2. Systems management (SM) software is loaded into GPC 4. GNC OPS 3 data is loaded into GPC 3 and "freeze dried" (taken off line to preserve an independent source of data) while GPC 5 retains BFS software but is placed in *HALT*. With SM software loaded, uplink for S-band and TDRSS is enabled with a DPS utility. Since only 3 CRTs can be assigned to the PASS, CRT 3 is deassigned, and CRT 4 (powered up during MS aft flight deck configuration) is assigned to GPCs 2 and 4 (GNC and SM OPS). pulse-code modulation master unit (PCMMU) formats are loaded for on-orbit high and low data rate telemetry. Displays are called up as required, but the crew must be careful to avoid assigning all three CRTs to the same GPC; e.g., don't use all three CRTs for SM.

Mission/Payload Specialists egress seats during this period. MSs perform the following functions on the middeck:

- Install UV filter on hatch window (except OV 102).
- Repressurize water supply tank A.
- Unstow and configure head-sets and microphones.
- Configure middeck audio distribution unit (ADU) and speaker box.
- Stow ascent FDF in "return to Houston" bags and unstow on-orbit FDF.
- Close appropriate circuit breakers.
- Activate galley (or water dispenser).
- Stow the escape pole.
- Activate the waste collection system (WCS).

These activities may be accomplished piecemeal during the next hour.

0/0:59 An MS begins flight deck configuration to include: open cabin vent and cabin vent isolation cb's (to preclude accidental venting), activate the OMS and RCS heaters, which will keep them at 55° to 90° F (A-heater in AUTOMATIC, B-heater OFF), activate APU lube oil heaters and tank/fuel line H2O heaters. Although the generator bed temperatures will remain warm until about MET 6:00, a caution is included at this point to monitor the APU fuel pump outlet and bypass line temperatures and activate the heaters if required. Aft flight deck communication configuration is accomplished (OV 102 aft ATU is set up), S-Band communication is configured for TDRSS at the high rate, R15 cb's are closed as required, CRT 4 is powered up, ascent thrust vector control, engine interface units, and master event controllers for the main engines are secured, and the display driver units (DDUs) cb's for the aft flight controllers and displays are closed.

MET Day/Hr:Min (approx)	
0/1:00	MSs unstow and activate the Payload General Support Computers (PGSCs).
0/1:08	PLT verifies the payload electrical bus configuration (payload dependent).
0/1:10	CDR, PLT don their headsets and configure their personal communications equipment, normally selecting push-to-talk (PTT) for air-to-ground and voice activation (VOX) for intercom.
0/1:12	PLT executes an automatic maneuver to the PLBD opening attitude -ZLV with a flight specific bias. This is a time critical action; *DAP A/AUTO/PRI* are selected.
0/1:18	CDR activates the radiators by placing both the *RADIATOR BYPASS VALVE MODE* and *CONTROLLER LOOP (A)* switches (2 each) in *AUTOMATIC*.
0/1:20	An MS sets up the aft panel *PAYLOAD BAY FLOOD* switches as required (given possible payload limitations) for PLBD opening. Lights require ~3 min for full bright). If the CCTV is to be used for PLBD opening, it will be activated at this time.
0/1:28	PLT or MS2 initiates automatic PLBD opening with CRT 4 display SM PL BAY DOORS and switch throws on panel R13L. Centerline latches take ~20 sec, forward and aft bulkhead latches take ~30 sec, and each door (starboard then port) opens in ~63 sec. After the doors are open and power removed from them, display SM ANTENNA is usually selected for CRT 4 when other displays are not required.
	The MCC will uplink table maintenance block updates (TMBU) as required.
0/1:35	CDR activates star trackers.
0/1:36	If there are no indications of problems with the major orbiter systems at this point, the MCC will issue a GO for orbit operations.
0/1:37	CDR, PLT egress seats, and all crew doff and stow launch/entry suits. During this time, the MCC will uplink the orbiter state vector and RCS quantity compensations.
0/1:50	PLT initiates the fuel cell automatic purge and verifies H2 and O2 flow increase on CRT display SM 69 FUEL CELLS.
0/1:52	CDR selects CRT display SM 88 APU/ENVIRON THERM on CRT 1, and if Freon loops are operating nominally (Freon loop radiator out temp < 60° F), secures the flash evaporator and turns the high load evaporator off. Radiators are deployed at this point if required. CRT 1 is returned to GNC UNIV PTG display.
0/1:56	CDR selects GNC 22 S TRK/COAS CNTL display on CRT 1 and activates the star tracker self test (~20 sec). Both star tracker doors are opened (8 to 12 sec), and star trackers are activated. CRT 1 is returned to GNC UNIV PTG display.
0/1:57	PLT verifies the Main B Supply H2O Dump Isolation cb is closed then opens the supply H2O dump isolation valve to ensure redundant dump capability.
0/2:00	PLT activates the APU steam vent heaters to remove any possible ice formation on the water spray boiler (WSB) vent openings.

MET

Day/Hr:Min (approx)

0/0:2:05 MS/PS seats are removed and stowed.

0/2:10 After go for vernier operations from MCC, CDR verifies use of vernier jets is safe (radiators operating and FES hi-load off) and activates verniers on MCC call. DAP selection is typically *A/AUTO/VERN*.

0/2:12 Crew configure controls for on-orbit operations by using panel diagrams in the Post Insertion Checklist that depict switch positions.

0/2:20 If the remote manipulator system (RMS) is flown, initial activation procedures begin at about this time. RMS AC cb's are closed, power is applied to the manipulator controller interface unit, RMS shoulder brace is released, heaters are activated, and if required by payload operations or constraints, the arm is deployed.

0/2:21 PLT performs the hydraulic thermal conditioning steps in the Orbit Operations Checklist which allows the GPCs to operate hydraulic circulation pumps when pressures or temperatures are below set limits. Payload electrical constraints may alter this activity.

0/2:24 MS resets C/W system from ascent to on-orbit operations. Limits for some systems are changed while others are inhibited.

0/2:25 CDR performs automatic maneuver to the IMU alignment attitude. This is a time critical action. (The time depends on the flight profile).

0/2:27 PLT switches the APU fuel pump and gas generator cooling from system A (activates during APU shutdown procedure) to system B for system verification.

0/2:29 Fuel cell performance is plotted using with FUEL CELL PURGE cue card.

5.3 ORBIT

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Orbit Operations

This section summarizes typical orbit operations for METs 0/2:30 through 0/22:00. Activities occurring after 0/6:30 are representative of subsequent flight days until the last full on-orbit day. Actual activities and times will vary from mission to mission.

D/H:M (approx)

0/2:30 Crew completes post insertion activity. Post Insertion Checklist is stowed, and crew refers to the Flight Plan for nominal activities. The Photo/TV Checklist is unstowed, and camera assembly is begun. Other equipment required for flight day (FD) 1 activities is unstowed and set up.

0/2:45 IMU alignment (S TRK) is accomplished during orbiter night pass. CRT display GNC 21 IMU ALIGN and GNC 22 S TRK/COAS CNTL are used for this activity. A COAS calibration may also be scheduled near the IMU alignment time.

0/3:10 Aft controller checkout initiated in each axis with the output verified on CRT 4 display GNC 25 RM ORBIT.

0/3:20 Ku-band antenna is deployed (~23 sec). Antenna data is monitored on display SM ANTENNA.

0/3:30 Ku-band antenna activation (comm mode only normally). Signal strength is available on panel F9 DC AMPS/SIG STR meter (Ku selected) as well as SM ANTENNA display.

0/3:45 APU steam vent heaters are secured (initiated at MET 2 hr).

0/3:50 CRYO O2 tank heater sensor check is accomplished to verify short circuit protection for the O2 tank heaters (CRT display SM 68 CRYO SYSTEM).

0/4:00 APU fuel pump/valve cooling (B) is secured on a call from the MCC. Unless there is a FD 1 deploy or other mission specific requirement, the first on-orbit meal is prepared and eaten at this time.

0/6:30 APU gas generator and fuel pump heaters (B) are activated at panel A12 to keep the generator bed 360° to 425° F and the fuel pump 80° to 95° F (the B heaters are used to exercise the redundant system).

(various times) Crew begins payload activities. This may include payload deploy, Spacelab activation, or secondary experiment activation depending on the type of mission.

0/8:00 Pre-sleep activities begin 3 hr (2:15 for dual shift operations) prior to the sleep period (this can be shortened to 2 hours for single shift and 1:30 for dual shift operations if required). With the exception of the IMU alignment, the sequence of pre-sleep activities is at the crew's discretion. Pre-sleep activities on the flight deck include:

- IMU alignment maneuver may not be required if attitude allows star trackers to collect data on stars of opportunity.

- Manually purge fuel cells (FD 1 only to save ground turnaround time). Use CRT display SM 69 FUEL CELLS to monitor purge. All other purges will be uplinked from MCC.

- Conduct supply/waste water dump, monitored using CRT display SM 66 ENVIRONMENT (purges and dumps are not accomplished during star tracker use due to possible contamination)

- Configure cryo heaters and manifold valves as directed by MCC.

- Update SM checkpoints.

- Set CRT timer for crew wake up and C/W alert tone duration.

- Adjust the cabin temperature control as required.

- Power down unnecessary electrical equipment (CRTs, TV power, TV cameras, VTR, cabin and PLB lights, DDUs).

- Reposition the Ku-band antenna cable to prevent chafing.

- Install window shades/filters.

- Remove power from primary reaction jet drivers (8) to preclude primary jet ON failures.

- Maneuver to sleep attitude.

Minor payload or experiment related activity can also be scheduled during the pre-sleep if required.

Pre-sleep activities on the middeck include:

- IMU Alignment.

- Food preparation and cleanup for the evening meal.

- CO2 absorber (LiOH) replacement (one of two canisters is replaced).

- General housekeeping and WCS cleaning.

- Setup of next day's equipment (if practical).

- Write/record mission notes.

- Configure communications panels and lighting.

- Empty TAGS paper tray to minimize paper jams.

0/9:50 APU gas generator and fuel pump heaters (A) are activated at panel A12 along with the APU tank/fuel line/H2O system (A) heaters (3) (B heaters off).

0/11:00 Sleep period is scheduled to begin no later than 16 hr after the crew's launch day wake up (4:55 prior to launch) but can be extended up to 2 hr if unexpected launch holds occur. The sleep period will be scheduled for 8 hr but can be shortened to 6 hr if required.

0/19:00 The post-sleep period begins about 8 hr after the start of the sleep period and extends for 3 hr for single shift operations (1:30 for dual shift) but may be shortened to 2 hr (1:15 dual shift) if required. IMU alignment/COAS maneuvers and activities are scheduled for specific times. The sequence of other activities is up to the crew.

Middeck post-sleep activities include:

- Reconfigure lighting and communications panels.
- Replace CO2 absorber (one of two canisters is replaced).
- Review teleprinter/TAGS messages.
- Install O2 bleed orifice (first post-sleep) to increase O2 to the middeck.
- Meal preparation and cleanup.
- General housekeeping.

Post-sleep flight deck activities include:

- IMU Alignment. Maneuver may not be required if attitude allows star trackers to collect data on stars of opportunity.
- Reconfigure lighting, window shades, communications panels and instruments.
- Reposition Ku-band antenna cable.
- Power on CRTs (3).
- Deselect BFC CRT display.
- Adjust cabin temperature.
- Configure OMS/RCS interconnect as required to preserve aft RCS propellant.
- Power primary RJD drivers (8) ON.
- Initiate supply/waste water dump (pre or post IMU alignment).
- Configure cryo heater/manifold valves per MCC instructions.
- Conduct another cryo O2 tank heater sensor check (see MET 0/3:50).

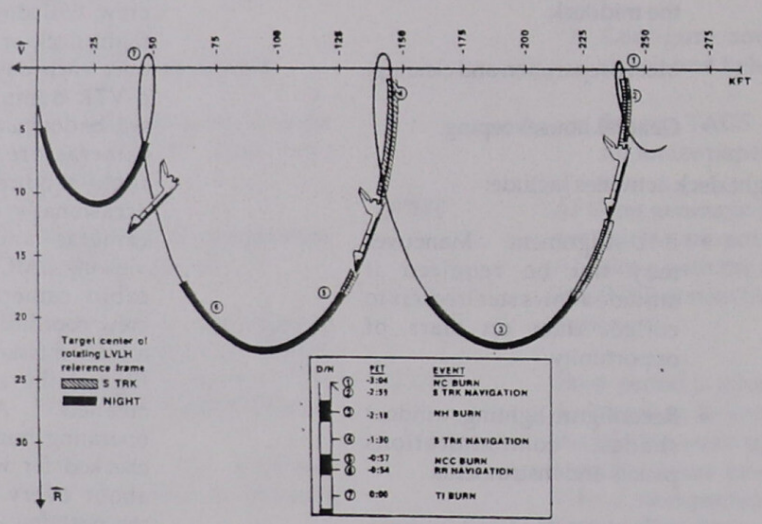
0/22:00 The crew begins a full workday on orbit with their flight specific activities. Each day, Photo/TV scenes will be activated per the P/TV Checklist. Normally, the crew will downlink live TV of flight deck or middeck activities once each day. At a minimum, a VTR dump of crew activities will be downlinked. When the PLB cameras are not required for flight requirements, MCC will occasionally ask to control the cameras and conduct Earth viewing. MCC will not activate cabin cameras without prior crew coordination. Once during a 4 day mission (twice for longer flights) the avionics filters are cleaned. Additionally, the operating humidity separator is checked for water accumulation about every 12 hours during the first few on-orbit days and cycled between the A and B separator. Once each flight day (the morning of likely/scheduled EVAs and entry day), each crewmember has an opportunity to communicate privately with a flight surgeon during a private medical conference (PMC).

OMS (RCS) Burns

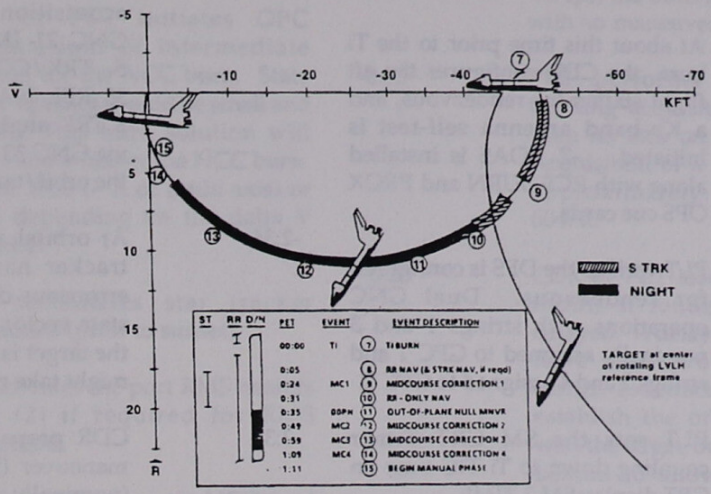
OMS/RCS burns are used on orbit to raise or lower the orbital altitude, for rendezvous phasing, and deorbit. The burn may be done with one or both OMS engines or the RCS depending on the delta V required. Propellant for the burn can come from either OMS pod or the RCS system. OMS BURN cue cards (OMS-2/ORBIT OMS BURNS (2) and OMS BURN MONITOR (2)) are installed on the forward panels for the burn. On-orbit burns require OPS 202 (302 for entry) with CRT displays GNC ORBIT MNVR EXEC and GNC SYS SUMM 2. Procedures for on orbit OMS/RCS burns are similar to those discussed in the OMS 2 section. Burn target data is normally uplinked by MCC and loaded automatically. If delta V total > 6 fps an OMS burn will be required. If delta V total is ≥ 4 and ≤ 6 fps, a +X RCS burn is used (thereby limiting the amount of forward RCS burned). If the delta V total < 4 fps, the burn is multi-axis (RCS) with no maneuver to burn attitude.

Rendezvous

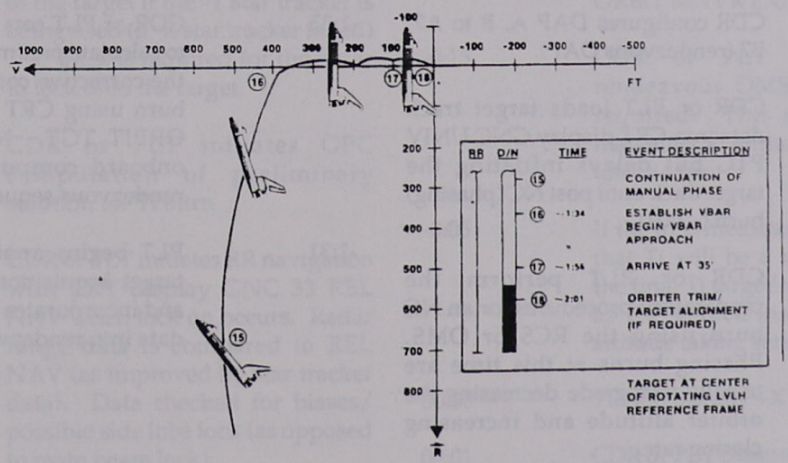
Scheduled rendezvous pro-cedures actually begin at launch since the launch window will have been designed to properly phase the orbiter with the target, saving time, fuel, and optimizing the lighting on the target. This section summarizes the major events that occur during the final phases of a rendezvous. Flight specific rendezvous procedures are located in the Rendezvous Checklist. Flights without a planned rendezvous utilize the Contingency Rendezvous Checklist for generic procedures. The Phase Elapsed Time (PET) below is referenced to Target Intercept (Ti) TIG. PET is used to track rendezvous events and is normally displayed on the CRT. Actual times will vary depending on flight profile.



Rendezvous Profile — NC Burn Through Ti Burn



Rendezvous Profile — Post Ti Burn



Rendezvous Profile — Manual Phase to Prox Ops

PET Hr:Min (approx)	
-3:44	At about this time prior to the Ti burn, the CDR configures the aft flight station for rendezvous, and a Ku-band antenna self-test is initiated. -Z COAS is installed along with RCS BURN and PROX OPS cue cards.
-3:42	PLT verifies the DPS is configured for rendezvous. Dual GNC operations with strings 1 and 3 nominally assigned to GPC 1 and strings 2 and 4 assigned to GPC 2.
-3:39	PLT sets the SM CRT Timer counting down to Ti TIG time on CRT display SM 2 TIME.
-3:37	CDR or PLT enables rendezvous navigation through CRT displays GNC 33 REL NAV and loads Base Time (TI TIG) on GNC 34 ORBIT TGT. CDR, PLT, and MS2 work together on targeting and burn set up and NAV state management.
-3:34	CDR configures DAP A, B to A7, B7 (rendezvous DAP).
-3:29	CDR or PLT loads target track data into CRT display GNC UNIV PTG but delays initiating the target track until post NC (phasing) burn (~3:03).
-3:24	CDR or PLT perform the preparatory procedures for an NC burn using the RCS or OMS. Phasing burns at this time are usually retrograde decreasing the orbiter altitude and increasing closing rate.
-3:04	NC burn TIG.
-3:03	Target track initiated.
-2:59	PLT initiates star tracker target acquisition with CRT displays GNC 21 IMU ALIGN, GNC 22 S TRK/COAS CNTL, and GNC 33 REL NAV. After evaluation, S TRK angle data is incorporated via GNC 33 REL NAV to improve the orbit/target relative state.
-2:36	At orbital sunset PLT ends star tracker navigation to prevent erroneous data from being fed to state vector computations. When the target is not lit the star tracker might take marks on a star.
-2:32	CDR prepares for height adjust maneuver (NH) burn if required (nominally not required).
-2:18	NH burn TIG.
-1:57	PLT configures for rendezvous radar (RR) acquisition when the range to the target is <150 k ft via switches on panel A1U (Ku) and CRT display GNC 33 REL NAV.
-1:33	CDR or PLT sets up the computer to calculate preliminary solution for the corrective combination (NCC) burn using CRT display GNC 34 ORBIT TGT. NCC is the first onboard computed burn of the rendezvous sequence.
-1:31	PLT begins another star tracker target acquisition at orbital noon and incorporates star tracker angle data into rendezvous navigation.

PET Hr:Min (approx)	
-1:14	CDR or PLT initiates GPC computations of intermediate solution for the NCC burn. State vector updates should be small and stable. This burn solution will determine whether the NCC burn will be RCS (+ X or multi axis) or OMS depending on the delta V required.
-1:05	PLT terminates star tracker operations (prior to sunset).
-1:04	MS activates the port RMS heaters A/B (2) if required for RMS operations.
-1:01	CDR or PLT computes NCC final solution and prepares for burn. Normally NCC delta V is less than 6 fps allowing the RCS to be used for the burn.
-0:57	NCC TIG.
-0:55	CDR or PLT initiates -Z axis track of the target if the -Y star tracker is being used (if -Z star tracker failed) . -Z track is required for the radar to lock onto the target.
-0:54	CDR or PLT initiates GPC computation of preliminary solution for Ti burn.
-0:52	CDR or PLT initiates RR navigation with CRT display GNC 33 REL NAV when lock on occurs. Radar range data is compared to REL NAV (as improved by star tracker data). Data checked for biases/ possible side lobe lock (as opposed to main beam lock).
-0:38	CDR initiates intermediate Ti burn solution when the state vector updates are small and stable. If delta V total is > 6 fps, an OMS burn will be required. If delta V total is ≥ 4 and ≤ 6 fps, a +X RCS burn is used. If the delta V total is < 4 fps, the burn is multi-axis RCS with no maneuver to burn attitude.
-0:23	PLT performs RR automatic tracking acquisition if there has been no lock on prior to 60 k ft. Acquisition of a .5 sq m target is approximately 100 percent at 60 k ft.
-0:20	CDR or PLT loads Ti delay burn inputs if rendezvous must be delayed. Ti delay burn PAD would have been provided by MCC earlier. Execution of this burn will establish the orbiter co-altitude with the target, but following along behind to allow extra time for rendezvous completion.
-0:17	CDR initiates computation of the final Ti burn solution if the intermediate solution shows OMS or +X RCS burn will be required (reference delta V total). Final solution on GNC 34 Orbit TGT will be preceded by burn setup on GNC ORBIT MNVR EXEC.
-0:15	CDR or PLT prepares for rendezvous OMS/RCS burn as required. This may involve a maneuver to attitude if the delta V total >4 fps.
-0:05	If the intermediate solution shows that Ti will be a multi-axis burn, the final Ti targeting is performed, as the vehicle has remained in attitude taking sensor data.
00:00	Ti TIG (usually +X RCS).
00:01	CDR or PLT computes preliminary MC 1 target solution with CRT display GNC 34 ORBIT TGT.

PET Hr:Min (approx)	
00:03	CDR or PLT conducts post Ti navigation procedures when the maneuver to attitude is complete (usually -Z). CRT display GNC 33 REL NAV is used to incorporate RR data (star tracker data is not preferred post Ti since its accuracy is based on point light sources).
00:04	MS powers up the RMS if required, and no rendezvous delay is planned.
00:05	MS maneuvers RMS to preliminary position for proximity operations.
00:12	CDR or PLT initiates GPC computation of MC 1 intermediate solution when the state vector updates are small and stable.
00:18	CDR initiates GPC computation of final MC 1 burn solution (-4 min to TIG).
00:20	CDR prepares for RCS burn.
00:22	MC 1 TIG.
00:24	CDR initiates GPC computation of preliminary MC 2 burn solution with CRT display GNC 34 ORBIT TGT. Star tracker (if utilized) is terminated just prior to sunset. If no sensor data is available at any time during rendezvous, then the BREAKOUT procedures must be initiated.
00:33	CDR initiates MC 2 intermediate solution when state vector updates are small and stable.
00:36	CDR manually nulls out of plane component (YDOT) with THC, referencing CRT display GNC 33 REL NAV for target/orbiter relative state information. This maneuver is performed at the node where the orbiter and target orbits cross (the actual time may vary).
00:44	CDR conducts MC 2 final solution (TIG -5 min).
00:45	CDR prepares for RCS burn.
00:49	MC 2 TIG. MC 2 TIG will slip to satisfy an onboard targeting elevation angle constraint. After any slip, the MC 2 elapsed time is used to reference crew actions. The following PET times are valid only if MC 2 planned TIG = actual TIG.
00:50	CDR begins MC 3 preliminary solution if RR data available (if -Y star tracker was being used, a maneuver to -Z track is done).
00:54	CDR initiates MC 3 final solution (-4 min TIG).
00:58:30	MC 3 TIG.
1:00	CDR initiates preliminary MC 4 solution.
1:03	MS configures CCTV.
1:05	CDR initiates final MC 4 solution (-4 min TIG).
1:07	CDR prepares for RCS burn.
1:09	MC 4 TIG.
1:10	Manual trajectory control begins at about 22 minutes after MC 2. CDR establishes inertial line-of-sight rates by selecting inertial attitude hold and using the aft THC to keep the target stable in -Z COAS. The CDR will fire jets as required to get the orbiter/ target range rates within these braking gates: -4 fps at 2 k ft, -2 fps at 1.5k ft, and -1 fps at 1 k ft.
1:19	CDR configures DAP A, B to A8, B8 for proximity operations.

Proximity Operations

Proximity operations begin when the range to the target is <1,000 ft and the relative velocity is < 1 fps. Proximity operations may involve V-Bar (standard), R-Bar, or inertial approach.

1:20	CDR configures for V-Bar on CRT display GNC UNIV PTG (orbiter tail to earth and target on the -Z axis) but does not command track until V-Bar has been achieved. Braking gates are -0.5 fps for 500 ft, -0.4 fps for 400 ft, and -0.3 fps for 300 ft.
1:25-1:34	CDR commands -Z LV track when the orbiter reaches the target's V-Bar using GNC UNIV PTG (ITEM 19). For an inertial approach, DAP will remain in INRTL. Normally at 200 ft DAP is transitioned to LOW Z (flight specific). MS begins to provide ranging and relative position information using the PLB CCTV camera angles.
01:50	CDR puts RR (Ku) in standby when the range to target is 80 ft (nominal break track distance). When range is 60 ft, CDR selects NORM Z and continues the approach to the target. MS utilizes the CCTV camera angles to provide ranging, R-dot and position cues to the CDR. Visual cues and MS calls are the CDR's only source of rendezvous data.
01:52	CDR nulls rates when target is in end effector camera field-of-view (if RMS required).
01:55	CDR maneuvers to proper RMS grapple or station keeping position as required.
01:58	PLT disables rendezvous navigation, and CDR configures Ku-band for communications. MS powers RMS down as required.

Last Full On-Orbit Day

The last full on-orbit day includes the nominal flight day activities plus general cabin stowage, FCS checkout, RCS hot fire, and those unique procedures that must be accomplished prior to transition to the Deorbit Prep Checklist (-04:00 TIG). Prior to the pre-sleep activities the crew conducts entry planning, secures CRT 4 (if not required), and stows the KU-Band antenna. (If TAGS messages are required, antenna stowage will slide into the deorbit preparation.)

Pre-sleep and post-sleep activities are nominal with the exception of the continuation of general cabin stowage. Additionally, fluid loading preparation (four 8 oz containers per person) and cabin air samples may be accomplished in the post-sleep period or deorbit preparation. The O2 bleed air orifice is removed and stowed. The flight control system is checked for proper entry operation (also saves ground test time). The test (conducted in two parts) will be accomplished with an APU (MCC designated) but may be done with a circulation pump if required.

FCS Checkout, Part 1

FCS checkout Part 1 consists of the following activities:

- Power on FCS sensors and controls prior to the transition to OPS 8. Aerosurface amplifiers (ASAs) must be ON prior to OPS 8 if an APU is used and OFF if a circulation pump is used.
- CRT 1 display is GNC FCS/DED DIS C/O, and CRT 2 display is SM 86 APU/HYD.
- Event timer is set to count up (to track APU ON time).
- Hydraulic thermal conditioning is terminated, and APU is prepared for operation.
- ON MCC GO selected APU is brought on line in low pressure and event timer is started.
- If APU operation is nominal, normal pressure is selected for actuator checkout (CRT display SM 87 HYD THERMAL).

- Proper elevon switching valve operation should be noted.
- Surface drive is initiated (some surfaces may not drive properly right away due to cold hydraulic fluid). Test should be complete in about 30 sec.
- A secondary actuator check is initiated to test the bypass feature of the actuators. When test is complete, the APU is shutdown and hydraulic thermal conditioning re-enabled (if required). Expect a marked structural vibration when ports pop during the secondary actuator check.

FCS Checkout, Part 2

Part 2 of the FCS checkout begins with a sensor test (CRT 2 display GNC 40 SENSOR TEST). The TACAN is turned ON (other sensors ON from Part 1) and the orbiter is placed in free drift (CRT display GNC UNIV PTG). The crew then initiates the sensor tests (accelerometer assemblies (AAs), microwave landing system (MLS), TACAN, radar altimeter, rate gyro assemblies (RGA), and air data transducer assemblies (ADTA)). Sensors failing the test will be deselected for entry.

Following the sensor test, the FCS mode/channel switch test is conducted. These procedures verify FCS switch contacts and all entry-critical switches (flight controller power required). The next series of procedures verify proper operation of controllers and their associated switches (left and right). Finally the DDUs and head-up displays (HUDs) are tested and adjusted for entry. When the FCS checkout is complete, the DPS is returned to OPS 2 GNC (G8 to G2 transition), and all entry equipment is secured.

RCS Hot Fire

This test is conducted to verify the operation of seldom used RCS jets (thereby decreasing ground turnaround time). Manual DAP is selected and the orbiter is verified/placed in free drift. Each RCS jet is tested (CRT display GNC 23 RCS) and the results noted (3 sec delay between pulses to allow time for a fault message and 30 sec delay if a failure is annunciated). When the Hot Fire test is complete the vehicle is placed in inertial hold to allow damping of rates before returning to the required attitude. RJDs, DDUs, and MDMs are then secured as required.

5.4 ENTRY

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Deorbit Preparation

TIG

Hr:Min (approx)

-4:00 The crew transitions to the Deorbit Prep Checklist for nominal procedures. PLT sets CRT timer for deorbit TIG using the GNC 2 TIME display and SM timer.

-3:58 DAP is verified/placed in A1/AUTO/VERN.

-3:56 CDR initiates radiator coldsoak by placing RAD *CNTLR OUT TEMP* switch to the *HI* position and activating topping FES to minimize propulsive venting. Vehicle is maneuvered to "tail sun" attitude (-X SI) for the coldsoak.

-3:50 MSs continue entry stowage along with deactivation of the galley/water dispenser.

-3:45 Radiators are stowed (if deployed).

-3:35 Specialists install seats and FDF containers.

-3:30 to -2:30 MS performs payload deactivation/entry preparation in this time frame as required.

-3:27 DPS is configured for deorbit preparation. Inactive GPCs are taken to STBY then RUN.

-3:05 Ku-band antenna is stowed (if not already accomplished in last pre-sleep period).

-2:58 Automatic maneuver to IMU alignment attitude is accomplished.

-2:49 CDR initiates radiator bypass to retain Freon coldsoak. Alternate FES is checked out to save ground test time. PLBDs will not be closed until this check out and until Freon temperatures are down to 39° F. DAP is put in B/AUTO/PRI to hold the IMU alignment attitude. H20 crossover valve is opened to allow all water tanks to feed the FES equally.

-2:46 MS prepares for PLBD closing (PLB lights activated (as required), cameras/VTR readied, RMS TV camera positioned and RMS heaters secured (if RMS flown)).

-2:44 CDR, PLT perform IMU alignment and verification, which ensures misalignments of less than .5 degree at Entry Interface (EI) using display GNC 22 S TRK/COAS CNTL and GNC 21 IMU ALIGN.

-2:40 PLT, MS close PLBDs using SM PL BAY DOORS display on CRT 4 (OPS 2) or BFS SM 63 PL BAY DOORS on CRT 3. When door closure is complete, CRT 4 is powered OFF.

-2:35 MS performs post PLBD closing procedures, which include securing PLB lights, deactivating/stowing cameras, powering CRT 3 ON, and taping down foot restraints (to prevent tripping during egress).

TIG

Hr:Min (approx)

-2:30 CDR receives MCC uplink of PAD. OMS propellant data, deorbit, entry, and landing data, current state vector, and deorbit targets are also uplinked. Prop PAD, DEL PAD, and MNVR PAD are read up to the crew by CAPCOM. Crew can use PGSC (SPOC) to determine targets and c.g. if required.

-2:27 PLT terminates hydraulic thermal conditioning.

-2:24 PLT activates APU water boiler steam vent heaters (2 hr prior to APU start).

-2:20 CDR, PLT power up FCS and DDUs for entry (RGAs and ASAs must be on prior to OPS 3 transition).

-2:17 CDR secures water loop 1 prior to OPS 3 transition (powered ON only for contingency in OPS 3).

-2:15 CDR monitors auto maneuver to attitude suitable for S-Band communications if required. Crew may maintain IMU alignment attitude or go to deorbit attitude depending on flight profile and TDRS position.

-2:10 PLT prepares for hydraulic repressurization of the main engine thrust vector controls (engine bells must be properly stowed to prevent thermal damage).

-2:07 PLT computes N2 quantity prior to OPS 3 transition to determine deorbit time available in case of a cabin leak.

-2:03 CDR, PLT configure DPS (three phases) to place GPCs 1, 2, 3, and 4 in PASS OPS 3 and GPC 5 in BFS, OPS 3. Prior to OPS 3 transition, entry TFLs are loaded and SM Checkpoint Initiate is performed to update the FDA in case a wave-off is required. Once in OPS 3, the crew refers to the Entry Pocket Checklist for malfunction procedures. CRT displays are normally: CRT 1 GNC DEORB MNVR COAST, CRT 2 GNC SYS SUMM 1, and CRT 3 BFS, GNC DEORB MNVR COAST.

-1:56 MS deactivates star tracker and closes doors.

-1:55 CDR, PLT, MSs perform entry switch list configuration and verification at this time. The following items will be performed or verified:

Forward Flight Deck

- Electrical power to brakes, brake heaters, anti-skid, and nose wheel steering (NWS) is applied.
- Verniers are secured.
- FES control is given to GPCs.
- One O2/N2 valve is opened in case of a cabin leak.
- Communications panels are configured to provide maximum redundancy.

Aft Flight Deck

- Activate entry monitoring equipment unique to particular vehicles (Aero-dynamic Instrumentation Package and Shuttle Infrared Leeside equip-ment-OV102, Modular Auxiliary Data System-OVs 103 - 105.

TIG	
Hr:Min (approx)	
	• Secure hydraulic heaters.
	• Secure the teleprinter (via dc utility Power MN C) and remove the power cable.
	• Connect an LES communications cable (DC Utility Power MNC).
	• Open Ku-band circuit breakers.
	Middeck
	• Configure communications panel for entry.
	• Pressure Control System (PCS) is configured for N2 water tank ullage pressure.
	• Close 14.7 cabin regulators (protects N2 if leak occurs)
	• Close O2 regulators (so O2 flow goes only to LES).
-1:40	MS enables MPS helium system pressure C/W (assists crew in isolating failed open regulator). Hydraulic system C/W parameters for low pressure are activated (alarm will sound immediately since APU's are OFF).
-1:39	Crew conducts entry review as required (15 min alloted).
-1:24	CDR, PLT don LESs.
-1:10	Specialists don LESs.
-1:04	Crew begins fluid loading (containers filled in post-sleep).
-0:59	CDR, PLT ingress seats.
-0:57	CDR, PLT remove HUD covers.
-0:53	Crew performs LES pressure integrity check.
-0:50	Crew doffs and stows on-orbit communications headsets.
-0:49	MS deactivates WCS.

Deorbit Burn

-0:47	CDR, PLT stow all unnecessary FDF items and transition to the Entry Checklist for the nominal procedures.
-0:46	CDR, PLT receive final deorbit update/uplink. Deorbit flight rules are verified with MCC. Exact time may vary.
0:40	CDR performs OMS TVC gimbal check (during AOS), using OMS MNVR EXEC display.
	PLT initiates APU pre-start procedures (during AOS). BFS, SM SYS SUMM 2 is used to check APU status.
	CDR, PLT conduct horizontal situation configuration using CRT 2 GNC 50 HORIZ SIT and CRT 3 BFS, GNC 50 HORIZ SIT then return CRT 2 to GNC SYS SUMM 1 and CRT 3 to BFS, GNC DEORB MNVR COAST.
	PLT initiates OMS burn preparation which includes checking engine trims and pressures.
	MS2 stows remaining headsets and activates MS2 communications; MS3 removes and stows side hatch UV filter (not OV 102), locking device, and Pyro Box Safing pin.
TIG	

TIG Hr:Min (approx)	
-0:25	PLT performs MPS reconfiguration and vent door closure with CRT 2 in GNC 51 OVERRIDE. CDR, PLT receive final deorbit update/uplink if required. MS1 and MS2 ingress their seats. CDR proceeds to OPS 302 and GO/NO GO is given for deorbit burn.
-0:15	CDR initiates maneuver to deorbit burn attitude on OMS MNVR EXEC display. CDR, PLT verify *OMS/RCS* switches in proper positions.
-0:05	PLT performs single APU start, one APU must be operating in low pressure prior to the burn. First APU start procedures vary depending on lake bed availability. CDR verifies the orbiter is in the deorbit burn attitude ± 5 degrees. The crew transitions to the Deorbit Burn cue card for nominal procedures. The Deorbit Burn Flight Rules cue card should be consulted prior to executing or continuing the deorbit burn past safe Hp if system failures occur.
Deorbit Burn	
0:00	Deorbit burn TIG. CDR, PLT monitor the burn using delta VTOT, VGO, TGO, and Hp from GNC OMS MNVR EXEC. BFS GNC SYS SUMM 2 display is used for OMS systems data. Deorbit burn monitoring and downmoding is discussed in Section 7 of this manual. As burn termination nears (TGO going to 0), crew monitors current perigee (HP) approaching targeted HP and delta VTOT approaching 0. Deorbit OMS burn time varies with orbital altitude. Typical burn times are 2-3 minutes. During the burn, the Deorbit Burn Monitor cue card is used for malfunction procedures.
OMS Cutoff	
+2 sec	If nominal burn, CDR secures OMS engines following the automatic purge and trims residual (<2 fps for steep targets and .5 fps for shallow ones). The crew returns to the Entry Checklist Post Deorbit Burn section for nominal procedures and to the Entry Pocket Checklist for malfunction procedures. PLT performs OMS/RCS reconfiguration by verifying the proper position of RCS switches and closing OMS HE and crossfeed valves; MS stows PGSC (SPOC). CDR proceeds to OPS 303. CDR loads or verifies the proper attitude data, and initiates maneuver to the entry interface -5 min attitude. CDR also conducts OMS gimbal powerdown verifying gimbals have driven to the proper entry position.
EI	
Min:Sec (approx)	
-20:00	CDR initiates a secondary actuator check, if not previously performed during FCS checkout and time allows, using GNC 53 CONTROLS on CRT 1, BFS, SM SYS SUMM 2 on CRT 3, and GNC DEORB MNVR COAST on CRT 2.

EI

Min:Sec (approx)

-18:00 PLT performs forward RCS dump, as required for X axis c.g. control with CRT 1 in GNC 23 RCS, CRT 2 in GNC DEORB MNVR COAST and CRT 3 in BFS, GNC SYS SUMM 2. Dump times for various forward RCS quantities are listed in the Entry Checklist. It takes 90 seconds to dump 50 percent forward RCS with 4 jets (twice as long using a 2 jet dump).

CDR, PLT perform entry switch checks (using GNC 51 OVERRIDE on CRT 3 for some checks) and exercise brake pedals.

-13:00 PLT starts remaining (2) APUs, verifies nominal performance, then switches all 3 APUs to normal pressure and checks for uncommanded brake pressure on CRT 3 display BFS, SM THERMAL.

PLT performs main engine hydraulic system repressurization to ensure the nozzles are properly stowed.

-11:00 PLT initiates hydraulic fluid conditioning on MCC's call and monitors surface position indicators for aerosurface cycling.

Crew makes burn report to MCC and updates new state vector if required. All crew members inflate anti-g suits if desired.

All three CRTs are moded to GNC DEORB MNVR COAST (CRT 3 BFS). PLT transitions AC BUS sensors to MONITOR.

-6:00 The crew transitions to the Entry Maneuver cue card for nominal entry procedures.

-5:00 CDR transitions GPCs to OPS 304 when verified at EI-5 attitude. Crew switches to cue cards for malfunction procedures. CRT displays are: CRT 1 GNC ENTRY TRAJ, CRT 2 GNC SYS SUMM 1, CRT 3 BFS, GNC ENTRY TRAJ.

-3:00 PLT verifies *FWD RCS MANIFOLD ISOLATION* valve switches (4) are closed (unless forward RCS program test inputs (PTIs) are scheduled).

Entry Interface

\+ = Time from EI
– = Time to touchdown
Min:Sec (approx)

+0:00
-32:14 Orbiter reaches EI (~400,000 ft) at a velocity (V) of ~24,600 fps and descent rate (H-dot) of ~500 fps. The crew compares ADI, AMI, AVVI, data and RCS activity lights to Entry cue card data. ENTRY TRAJ (1 - 5), HORIZ SIT and GNC SYS SUMM 1 are monitored on CRTs 1 and 2. The BFS ENTRY TRAJ display is available on CRT 3 to compare PASS and BFS guidance. The PLT can call up BFS SYS SUMM displays as desired to check system operation.

+2:39
-29:35 Automatic elevon trim begins at a q-bar = .5 psf.

+3:32
-28:42 Aerosurface control begins at q-bar = 2.0 psf. CDR, PLT monitor elevon and aileron deflection angles on surface position indicator.

+ = Time from EI
- = Time to touchdown
Min:Sec (approx)

+4:45 -27:29	Closed loop guidance initiated at q-bar = ~8 psf or drag = ~3 fps^2. First roll maneuver takes place shortly after guidance box appears on ENTRY TRAJ to indicate closed loop guidance.
+5:00 27:14	Roll RCS jets deactivated at q-bar = 10 psf.
+5:18 -26:56	First bank command issued by guidance.
+6:10 -26:04	Maximum surface temperature region begins (Mach 24 to 19). Actual drag should be within .5 fps^2 of profile.
+8:04 -24:10	Pitch RCS jets deactivated at q-bar = 40 and lateral acceleration (N_Y) trim becomes active.
+11:49 -20:25	At drag = 11 fps, drag H updates begin in NAV filter. Crew monitors data on GNC 50 HORIZ SIT display.
+13:40 -18:34	MPS feedlines are pressurized prior to 200,000 ft.
	First roll reversal is issued by guidance when azimuth error (delta AZ) = ±10.5 degrees occurs at a flight specific velocity between 20,000 to 13,000 fps.
+13:45 -18:29	Equilibrium glide phase begins (flight path angle remains constant as a transition from temperature control to constant drag control).
+14:42 -17:32 V_{REL} = 19 k fps	Pitch and roll RCS activity lights are reconfigured when q-bar = 50 psf to indicate RCS saturation. PLT enters Item 6, twice on GNC 50 HORIZ SIT, to Left/Right OVHD and ensures guidance is computing for an overhead approach (if required).
+15:51 -16:23 V_{REL}=17 k fps	PASS and BFS TRAJ displays mode to ENTRY TRAJ 2.
+17:00 -15:14 V_{REL} = 15 k fps	NAVAID power on is verified and RESET performed. This insures NAVAIDs will warm up before they are required (in case they were off due to a powerdown).
+17:47 -14:27 V_{REL}=14,445 fps	Constant drag phase begins and continues until about 10,445 fps, maintaining drag at about 33 fps^2. Alpha begins to ramp down from ~40 to ~13 degrees at Terminal Area Energy Management (TAEM).
+17:57 -14:17 V_{REL}=14 k fps	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 3.
+18:57 -13:17 V_{REL}=12 k fps	Radiator bypass valves (2) are placed in automatic and radiator controller loops (2) are put in AUTO B(A).
+19:20 -12:54 V_{REL}=10.5 k fps	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 4.

+ = Time from EI
– = Time to touchdown
Min:Sec (approx)

+19:49
-12:25
V_{REL}=10:4 k fps — Orbiter enters transition phase where a linear drag profile is flown. Ranging is controlled by changes to the slope of drag profile.

+20:03
-12:11
V_{REL}=10 k fps — Speedbrake opens to 81 percent.

+21:15
-10:59
V_{REL} = 7.8 k fps — GPC opens landing gear hydraulic isolation valve 2.

+21:34
-10:40
V_{REL}=7.5 k fps — MCC has sufficient tracking for state vector update. This time can vary depending on ground track and tracking station performance.

+21:41
-10:33
V_{REL}=7.3 k fps — First TACAN acquisition.

+22:00
-10:14
V_{REL}=7 k fps — MCC and the crew compare TACAN data to NAV. If acceptable, MCC tells the crew to take TACAN. GNC 50 HORIZ SIT display is used to check TACAN errors and accept TACAN data for use by the NAV filter.

+22:41
-09:33
V_{REL}=6 k fps — PASS and BFS ENTRY TRAJ displays mode to GNC ENTRY TRAJ 5.

+23:30
-08:44
V_{REL} = M5 — At approximately 115,000 ft the air data probes are deployed. CDR, PLT begin aileron and rudder trim monitoring. The crew can check for good probe deploy discretes by noting the absence of OFF flags on the AMI and AVVI tapes when the *AIR DATA* select switch is taken from NAV to LEFT then RIGHT. Air data information will not be valid until Mach is <3.4.

+24:24
-07:50
V_{REL} = M4 — CDR, PLT begin H-dot monitoring at Mach 4, verifying descent rate < -500 fps.

+25:00
-07:14
V_{REL} = M3.4 — Using GNC 51 OVRD, GNC 50 HORIZ SIT, and instrument tapes the crew checks air data is close to NAV. MCC will give a GO to take air data to NAV and/or GNC using Items 25 and 28 on GNC 50 HORIZ SIT.

+25:30
-06:44
V_{REL} = M2.6 — PLT verifies APUs operating nominally. CDR, PLT activate HUDs.

Terminal Area Energy Management (TAEM)

+25:40
-06:34
V_{REL} = M2.5 — PLT verifies air data incorporated into guidance. If not, the CDR must take CSS control to avoid a transient when air data is incorporated. Software transitions automatically to OPS 305. Guidance enters TAEM phase. PASS and BFS ENTRY TRAJ displays are replaced with VERT SIT 1 displays.

+25:55
-06:19
V_{REL} = M2.4 — Fuselage vents open.

+ = Time from EI
- = Time to touchdown
Min:Sec (approx)

+26:50
-05:24
V_{REL} = M2.0 — Air data must be incorporated to Guidance and Control or the crew must stay within theta limits as shown on the VERT SIT display.

+27:53
-04:21
V_{REL} = M1.0 — RCS yaw jets are deactivated.

+28:17
-03:57
V_{REL} =M0.9 — CDR selects pitch, roll, and yaw (R/Y) CSS. Speed brake "commanded" versus "actual" position is verified (manual as required). PLT flight controller is verified ON. Nose wheel steering (NWS) is verified in GPC. PLT may take control for brief flying qualities evaluation prior to the HAC at the CDR's discretion.

+29:00
-03:14
V_{REL} = M0.7
Alt = 32 k ft — PLT verifies landing gear hydraulic isolation valves (2) are open. PASS and BFS VERT SIT displays transition to VERT SIT 2. PLT and CDR monitor PASS and BFS GNC 50 HORIZ SIT for Heading Alignment Cone (HAC) acquisition.

+30:00
-02:14
V_{REL} = 280 KEAS
Alt = 15 k ft — PLT monitors MLS acquisition. Residuals and ratios disappear from PASS GNC 50 HORIZ SIT upon MLS acquisition.

Approach and Landing

+31:00
-1:14
V_{REL} = 285 KEAS
Alt = 12 k ft — CDR, PLT monitor outer glide slope (OGS). At 10,000 ft crew verify Approach and Landing guidance (flashing A/L on CRT 1), body flap to TRAIL, and LES visors down (KSC).

+31:20
-0:54
V_{REL} = 285 KEAS
Alt = 5 k ft — Radar altimeter operation verified. PLT begins landing voice calls.

+31:30
-0:44
V_{REL} = 285 KEAS
Alt = 3 k ft — Speed brake command is verified.

+31:47
-0:27
V_{REL} = 285 KEAS
Alt = 2 k ft — CDR initiates preflare and PLT arms landing gear.

+32:00
-0:14
V_{REL} = 270 KEAS
Alt = 300 ft — PLT deploys the landing gear on call from CDR.

+32:06
-0:08
V_{REL} = 250 KEAS
Alt = 100 ft — Final flare begins.

+32:14
-0:00
V_{REL} = 185 to 205 KEAS — Main gear touchdown; PLT verifies speed brake to 100 percent.

+32:22
V_{REL} = 185 KEAS — CDR begins derotation at ~ 2 degrees/sec.

+ = Time from EI – = Time to touchdown Min:Sec (approx)	
+32:28 V_{REL} = 160 KEAS	Nose gear touchdown; PLT or MS2 selects SRB SEP to MAN/AUTO and depresses push button to backup automatic discretes for elevon load relief, NWS, and anti skid circuitry.
+32:40	CDR applies brakes at 140 KEAS or one half available runway remaining, whichever occurs first. Deceleration profile is typically 8 to 10 ft/sec^2.
+33:00 V_{REL} = 40 KEAS	CDR reduces braking to 4 ft/sec^2 until wheels stop.
+33:10	Orbiter stops; CDR reports "wheels stop" to MCC. Crew transitions to Post Landing Procedures in the Entry Checklist.

5.5 POST LANDING

- CDR and PLT safe RCS/ OMS, and deactivate air data probe heaters.
- MS safes the landing gear.
- PLT, after notifying MCC, opens the ET umbilical doors and performs RCS/OMS valves checkout and safing.
- CDR activate the NH3 boiler as required (MCC call or C/W).
- PLT initiates hydraulic load test on MCC call.
- CDR performs DPS transition to OPS 901 on MCC call; CRT 3 is moded to BFS, GNC BFS MEMORY.
- PLT sets body flap to trail and performs main engine reposition with PASS OPS 9 display GNC 105 TCS CONTROL. PLT also performs APU/HYD shutdown after main engine repositioning is complete.
- CDR performs PCS deactivation. With a GO for extended powerup from MCC, CDR/PLT begin system deactivation. CDR secures GPCs 2-4 reassigning strings to GPC 1 and informs MS to proceed with MS System Deactivation Procedures (LRU and APU heater deactivation, RCS/OMS heaters turned OFF).
- Convoy personnel open hatch.
- Flight Surgeon enters cabin for health check. ASP, suit tech, and Shuttle Processing Contract Spacecraft Operator (SPC SCO) enter the cabin to assist with egress and removal of experiments and early return items.
- CDR, MS, (PS) egress seats. MS, PS retrieve "return to Houston bags."
- CDR, PLT, MS, (PS) egress orbiter to begin post landing activities. After medical evaluations, showers, visits with family and post landing medical data collection, the crew returns to Houston. Normal return to Houston occurs 6 to 9 hours after landing.
- ASP removes special FDF but retains some entry related FDF until handover to LCC.
- ASP hands vehicle over to SPC SCO when MCC (Houston flight) hands off to Orbiter Test Conductor (OTC).

6. EMERGENCY PROCEDURES

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This section covers critical failures to which the crew must react expeditiously. Both performance-related and system failures are presented. Critical system failures are those requiring a response within 5 minutes to safe the system or restore its function. Performance-related failures may result in an abort, depending upon the severity. Launch and ascent aborts are discussed in detail.

The emergency procedures in this section are designed to be general in nature and not flight specific. Detailed procedures are available in Flight Data File (FDF) checklists. It is very important that crewmembers learn to recognize failures and react properly. Failure identification is the key. Only through study, training, and practice will a crewmember achieve the desired degree of proficiency prior to flight.

In some areas, actual crew operations are described, along with monitoring and control devices. This is particularly important for aborts, where dynamic flight cues, instruments, and cue cards must be rapidly interpreted. Some abort rationale is also included to ensure the crewmember understands various abort modes.

The key to most emergencies is to utilize all information available, including inputs from the Launch Control Center (LCC) while on the pad and post-landing, and from the Mission Control Center (MCC) during all flight phases. Both the LCC and MCC have an enormous amount of data at their disposal. With the highly trained Launch Team and Flight Team working together with the crew, most emergencies can be quickly identified and proper actions started.

Three levels of protection exist to prevent loss of a Shuttle due to failures: component failure prevention, vehicle design, and training.

Component failure prevention is accomplished through a stringent process of equipment design, qualification tests, maintenance, checkout, quality control, and proper operation.

The Shuttle is designed to a "fail-ops/fail-safe" philosophy. This means that loss of any one component can be tolerated without compromising the mission, and loss of a second component will not result in loss of vehicle or crew. Obviously, this requires redundant systems and system components. Managing this redundancy adds to Shuttle complexity.

The third level of protection is the human element: crew, MCC, and LCC training. In order to quickly and correctly respond to performance or systems problems, as well as complex multiple failures, the flight crew and ground crews must be experts on Shuttle systems and how to control them. Prior to flight, both the ground teams and the crew participate in many hours of intense simulations to improve their teamwork and knowledge of Shuttle systems. A stringent certification process is also in place to ensure qualified and current personnel in all disciplines.

Failures tend to fall into two general categories: single component and multiple.

For single component failures, patience is important. Shuttle design should allow time to properly analyze what has happened and what steps are necessary to regain the lost component or to optimize remaining systems to protect against additional failures. A common error

among inexperienced personnel is to act too quickly, do the wrong thing, and make the situation worse.

Multiple failures are more difficult to deal with, since reaction time must be short, and procedures may not be explicit. Most FDF procedures are written considering a maximum of two failures. To avoid burdensome complexity and maintain credibility, this is the only way to realistically tailor procedures to a vehicle as complex as the Shuttle. The result is that a specific procedure may not be available to guide the crew, or several procedures must be combined or executed in rapid succession. For these cases, the crew and ground teams must rely on their knowledge and training. Once again, reacting too quickly can jeopardize vehicle integrity.

In order to cope with potential failures in a dynamic environment, such as ascent or entry, the flight crew must constantly keep in mind their current status and mentally prepare for potential additional failures before they occur. This "staying ahead of the airplane" philosophy, along with system reconfiguration for optimization and built-in graceful degradation of systems, will enhance the chances of a successful outcome when multiple failures are encountered.

6.1 LAUNCH ABORT MODES AND RATIONALE

CONTENTS

Mode 1 – Unaided Egress/Escape 6.1-1
Mode 2 – Aided Escape 6.1-1
Mode 3 – Aided Escape 6.1-2
Mode 4 – Aided Escape 6.1-2

A Shuttle launch may be scrubbed or aborted up to solid rocket booster (SRB) ignition. Normally, launch scrubs prior to Space Shuttle main engine (SSME) start are followed by an orderly safing procedure and crew egress, assisted by the closeout crew. A fully fueled Shuttle on the launch pad may present an extremely hazardous situation if toxic vapors, fire, or structural damage are present. A launch abort after SSME start is automatically controlled by the Ground Launch Sequencer (GLS). The most serious hazard here is the presence of excess hydrogen, resulting in a hydrogen fire, which is invisible to the eye and very dangerous. This situation occurred during a launch attempt for STS-41D.

In the event of an emergency at the launch pad, the NASA Test Director (NTD), who mans a console in the Launch Control Center (LCC) firing room, is in command. Priority is flight and ground crew egress and escape, followed by preventing destruction of the Shuttle, facilities, complex, and support equipment.

Should an abnormal event occur that terminates a flight or prelaunch operation and results in substantial damage to the Shuttle and/or injury to personnel, the NTD will declare a contingency situation. This alerts fire and rescue personnel and puts in motion pre-planned procedures to minimize further damage and injuries.

The NTD may also initiate action if an emergency condition exists that requires immediate action to prevent loss of life or destruction of equipment. In preparation for a potential emergency condition, a hazardous condition may be declared if a threat to personnel health or safety exists. A hazardous condition may develop into an emergency condition.

Depending upon the severity of the situation on the launch pad, an emergency egress/escape may be required to evacuate personnel. The Shuttle program has classified four launch pad escape modes which are preplanned and rehearsed by the flight crew, closeout crew, and all launch pad personnel. Defining these modes prior to the development of an emergency condition or contingency situation ensures standard procedures can be followed and minimizes risk of additional injury and damage.

Mode 1 – Unaided Egress/Escape

This escape mode may be initiated by the NTD or flight crew. The NTD will direct that the orbiter access arm (OAA) be returned to its position at the crew module hatch. The fire/rescue crew will be dispatched if the NTD decides it is safe to do so. Escape from the Shuttle vehicle and the pad is performed by the crew. This procedure is practiced in trainers and mockups in Houston and rehearsed during terminal countdown demonstration test (TCDT) at KSC. Since crew complement varies from flight to flight, each crew must develop their own particular procedures. Use of a buddy system is strongly recommended. Egressing the Shuttle along the OAA and across the pad 195 ft level to the slidewire baskets through the water deluge fire suppression system is a hazardous operation. Given the very real potential of fire, toxic vapors, and explosion, flight crews must be well-trained and prepared.

Mode 2 – Aided Escape

Aided escape is initiated by the NTD, flight crew, or closeout crew. This mode is used when the six-person closeout crew is still on the pad. The closeout crew leader is responsible for assuring that all personnel egress from the Shuttle and proceed along the prescribed escape route to a safe area. The NTD will also alert the fire/rescue crew. Injured personnel will be assisted/carried along

the escape route, and basic first aid will be rendered if required. The closeout crew leader keeps the NTD informed of medical conditions and egress/escape progress.

Mode 3 – Aided Escape

Initiated by the NTD or flight crew, this mode is used after the closeout crew has departed, and a contingency occurs that requires assistance. The OAA is repositioned, and the fire/rescue crew proceeds to the pad to assist the flight crew. The actual egress/escape is similar to the Mode 2 operation, except the fire/rescue crew substitutes for the closeout crew.

Mode 4 – Aided Escape

This mode is initiated by the NTD, closeout crew, or flight crew. It involves a contingency where one or more members of the closeout crew or flight crew are trapped or injured. Rescue and escape are performed by the fire/rescue crew, assisted by the closeout crew and flight crew. Use of all seven slidewire baskets may be required. Personnel accountability is critical.

In summary, launch aborts may range from a scrub/turnaround to a complex rescue scenario. Crews must be very familiar with all hardware and procedures. This requires training and practice. Prior to any launch pad evolution, a careful review of emergency procedures is warranted.

6.2 ASCENT ABORTS

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Performance Aborts 6.2-1
Systems Aborts 6.2-3
Range Safety 6.2-4

Events that require an ascent abort can be generally grouped into performance and systems failures. Flight Rules that govern these two types of scenarios are incorporated into various real time MCC calls, along with the NO COMM MODE BOUNDARIES and the SYS FLIGHT RULES cue cards.

Performance Aborts

The amount of performance lost when a Shuttle engine loses thrust or fails is directly related to the time of the problem. Early engine degradation or failure while the Shuttle is heavy with fuel, may preclude achieving a safe orbit. Late engine problems may result in no underspeed at all. Fortunately, it is not necessary to fly all the way to main engine cut off (MECO) to find out how large the underspeed will be. By using a computer program called the abort region determinator (ARD), MCC can predict the underspeed that will result from any performance problem. Thus, the MCC can immediately determine whether the desired or even a safe orbit can be achieved. If a safe orbit cannot be achieved, some type of abort will be required.

There are two basic types of ascent abort modes: intact aborts and contingency aborts. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed to permit crew survival following more severe failures when an intact abort is not possible. A contingency abort will usually result in a crew bailout.

For cases where the orbiter comes close to achieving normal orbit, the abort might simply consist of going to a lower yet perfectly safe orbit. This is called an abort to orbit (ATO).

If even a low orbit cannot be achieved, an abort once around (AOA) may be used. The orbiter is placed into a sub-orbital trajectory leading to a landing after a single revolution of the Earth.

The next available abort mode, if performance does not permit an AOA, is a transoceanic abort landing (TAL), which results in landing on a runway in Europe or Africa.

Finally, for intact aborts, if an engine fails after lift-off and before TAL is possible, a return to launch site (RTLS) abort would be performed.

During powered flight, the crew tracks vehicle present abort capability by MCC voice calls. If communications are lost, the NO COMM MODE BOUNDARIES card provides a summary of ascent abort mode capability.

NEG RETURN (104)	8300
PRESS TO ATO (104)	10300
LAST MRN (104)	11000
PRESS TO MECO (104)	12200
DROOP BYD (109)	12600
SE BYD (104)	13800
LAST BEN (104)	15100
SE PRESS (104)	17200
LAST PRE MECO TAL	23000
LAST TAL	
AML	23800
BYD	24300
ROB	24700
KIN	25200
HDS	25400

2 ENG BYD (104)	5900
ABORT TAL BYD (5)	
EO VI	
DROOP BYD (109) (5)	
SE BYD (104) (5)	
2 ENG BEN (104)	6500
ABORT TAL BEN (2)	
EO VI	
DROOP BYD (109) (5)	
SE BYD (104) (5)	
SE BEN (109) (2)	
2 ENG MRN (104)	7600
ABORT TAL MRN (3)	
EO VI	
DROOP BEN (109) (2)	
SE BYD (104) (5)	
SE BEN (104) (2)	
SE MRN (109) (3)	

NO COMM MODE BOUNDARIES Cue Card

This card does not reflect off-nominal performance such as a stuck throttle. Only the ARD can calculate abort mode boundaries based on actual performance. The ARD takes real time performance into account when predicting real time mode boundaries.

The abort mode boundaries are flight-specific. Times change significantly due to differences in mass properties, environmental modeling, and performance characteristics. Boundary names may also change. For example, some missions will not have a Press to ATO boundary. Also, TAL sites are mission-specific. Higher inclination flights will require a different philosophy of calls and checklist mode boundaries than lower inclination flights.

A generic discussion of mode boundaries for a low-inclination flight is presented here. Flight-specific data is available from the Flight Dynamics Officers (FDO).

Two-Engine TAL

Two-engine TAL is usually the first mode boundary reached that allows a downrange abort. It is the earliest inertial velocity (V_I), or time in the trajectory at which AUTO guidance with 104% throttles may be used to successfully complete a TAL abort to the designated primary TAL landing site with two functioning engines. There is usually an overlap of RTLS and TAL capability. TAL is the preferred abort mode for engine and systems failures in this overlap region, since single engine completion capability is attained much earlier for TAL than RTLS. The MCC voice call for this boundary usually has the TAL site name included in it (e.g., Two Engine Ben Guerir).

Negative Return

The latest V_I or time in the trajectory at which AUTO guidance may be used to successfully complete an RTLS abort is NEGATIVE RETURN. Past this V_I, the orbiter will have too much downrange energy to successfully return to KSC. If there is an abort gap between NEGATIVE RETURN and TWO ENGINE TAL, the calls will be based on throttling the good engine(s) to maximum throttle - 109%.

Press to ATO

This boundary represents the earliest engine out V_I time in the trajectory at which the orbiter can achieve the design underspeed at MECO. The constraints on design underspeed are ET impact, minimum performance, minimum altitude, contingency c.g. envelope protection, and minimum net positive suction pressure (NPSP) for the main engines. This boundary occurs only on missions requiring a pre-MECO OMS dump to achieve the design underspeed.

Press to MECO

This is earliest engine out V_I on time in the trajectory where the orbiter can reach the design underspeed at MECO without a pre-MECO abort selection.

DROOP (109)

The DROOP boundary represents the lowest point in the trajectory where the Shuttle can successfully reach MECO and ET SEP with the failure of two engines without a trajectory droop below 265,000 ft. Going below this altitude violates ET heating constraints, and loss of the vehicle is expected. The resulting safe ET SEP state does not guarantee enough energy to reach a TAL site, but will provide bailout capability.

The DROOP boundary for staggered engines out is a function of first engine out V_I. The MCC voice call for the boundary will include the name of the TAL site that would be used should the DROOP procedure be required.

SINGLE ENGINE (SE) TAL (104)

The SE TAL 104% boundary represents the lowest V_I or time where AUTO guidance with 104% throttles can achieve the desired TAL site range-velocity target line with the failure of two main engines.

Both in-plane and out-of-plane TAL sites may be used. This complicates abort mode determination, and the TAL REDESIGNATION cue card, along with MCC calls, will be required. This card is used for sequential engine failures and indicates to the crew which TAL site is attainable.

NOTE: DROOP IS 109% THROTTLE:
FOR 104% THROTTLE, ADD 300 FPS

1ST E.O. VI		7700	7800	7900	8000	8100	8200	8300
DROOP BEN (109)	(2)	11200	11200	11200	11300	11300	11300	11300
SE BYD (104)	(5)	-	-	-	-	-	-	-
SE BEN (104)	(2)	15900	15900	15800	15700	15600	15600	15500
SE MRN (104)	(3)	17600	17500	17400	17300	17200	17000	16900

1ST E.O. VI		8400	8500	8600	8700	8800	8900	9000
DROOP BEN (109)	(2)	11400	11400	11400	11400	11400	11500	11500
SE BYD (104)	(5)	-	-	-	-	-	-	-
SE BEN (104)	(2)	15400	15400	15300	15200	15200	15100	15100
SE MRN (104)	(3)	16800	16700	16600	16500	16500	16400	16400

1ST E.O. VI		9100	9200	9300	9400	9500	9600	9700
DROOP BEN (109)	(2)	11500	11500	11500	11500	11600	11600	11600
SE BYD (104)	(5)	15800	15700	15600	15500	15300	15200	15100
SE BEN (104)	(2)	15100	15000	15000	15000	14900	14900	14900
SE MRN (104)	(3)	16400	16400	16400	16400	16500	16500	16500

1ST E.O. VI		9800	9900	10000	10100	10200	10300
DROOP BEN (109)	(2)	11600	11600	11600	11700	11700	11720
SE BYD (104)	(5)	15000	14900	14700	14600	14500	14400
SE BEN (104)	(2)	14900	14900	14900	14800	14800	14800
SE MRN (104)	(3)	16600	16600	16700	16700	16700	16800

MRN TAL REDESIGNATION Cue Card

As an example, if a TAL to MORON (MRN) has been initiated due to an engine failure at V_I = 7830 fps, the DROOP and single engine TAL boundaries would be:

- 11,200 DROOP to Ben Guerir (BEN)
- 15,900 SE to Ben Guerir (BEN)
- 17,500 SE to MORON (MRN).

These velocities assume 109% or 104% throttle, as specified in parentheses, is selected on the remaining engine. For DROOP BEN (104), add 300 fps to the DROOP BEN (109) velocity, or 11,500 fps in the example. These numbers are entered on the NO COMM MODE BOUNDARIES card and used to determine new abort mode boundaries.

NOTE

If a TAL site redesignation is required, it must be quickly accomplished on SPEC 50 to begin heading to the selected site, thus reducing crossrange during the entry phase.

Single Engine Press

Single engine press is the lowest V_I or time in the trajectory after which the critical underspeed can be attained with two engines out. Critical underspeed is the same as design underspeed minus the ET impact constraint. Other criteria may be found in the Flight Rules.

Last Pre-MECO TAL

This boundary is the latest V_I or time in the trajectory, with a single engine failure, that AUTO guidance can be used to achieve the designated TAL landing site Range/ Velocity (R-V) line. The engines are throttled down at TAL initiation to provide for a longer pre-MECO OMS dump. LAST pre-MECO TAL is normally not called out by the MCC.

Last TAL

Last TAL is the highest MECO velocity acceptable for successful completion of a TAL entry to a TAL site or an emergency landing site (ELS). This abort option is applicable to the early MECOs where V_I is below the AOA range. LAST TAL is not an MCC callout.

Systems Aborts

The SYS FLIGHT RULES cue card summarizes the Flight Rules requiring RTLS and TAL selection in response to critical systems failures.

	RTLS	TAL
OMS – 2 He TKs		
– 1 OX & FU TKS (diff pods)		X
– 2 OX or 2 FU TKS		X
APU/HYD — 2 ↓ & 1 failing	X	X
CABIN LEAK — (– EO dP/dT > .15)	X	X
CRYO — ALL O_2 (H_2)	X	X
2 FREON LOOPS ↓	X	X
2 MAIN BUSES ↓	X	
THERMAL WINDOW PANE	X	

SYS FLIGHT RULES Card

In most cases, additional insight provided by MCC is necessary to accurately and fully diagnose a failure and select the best response. In the event of sudden multiple failures, help by MCC is critical. For COMM loss, however, only the SYS FLIGHT RULES cue card is available.

OMS Capability

A severe loss of OMS capability can make it impossible to continue uphill and deorbit. For example, loss of two propellant tanks results in insufficient propellant to get to orbit. In this case, TAL will be required.

APU/HYD

With two APU/HYDs down and the third failing, a trajectory option with minimum time to the ground is desired. This enhances the potential to land prior to a complete loss of hydraulics.

Cabin Leak

Loss of cabin pressure integrity impacts both breathing oxygen and equipment cooling. A minimum time to the ground option is required.

Cryo

Loss of cryo O2 or H2 will result in a loss of fuel cells and all electrical power. An RTLS or TAL is required.

Freon Loops

Losing both Freon loops will eventually result in loss of all three fuel cells due to lack of cooling. Since this is time critical, RTLS is preferable over TAL.

Main Buses

Two main bus failures preclude ET door closure. Since TAL entry trajectories are thermally severe, RTLS is preferred. If RTLS is no longer possible (past NEGATIVE RETURN), pressing uphill is preferable to TAL.

Thermal Window Pane

Heating during nominal TAL entries is severe. With a thermal window pane failure, RTLS is preferable due to its more benign heating characteristics.

Range Safety

Launch vehicles convert vast amounts of chemical potential energy into equally vast amounts of kinetic energy to put their payloads into orbit. Despite all planning, design, and tests, the possibility that a malfunction could cause a vehicle to fly out of control toward a populated area must be considered. Range Safety's function is to terminate flights that are far enough out of normal bounds to endanger populated areas. This is accomplished by remotely detonating explosive charges aboard the vehicle.

For the Space Shuttle, there are explosive charges on each SRB and two on the ET. A single charge on each SRB runs the length of the motor casing. Detonation splits the casing, releasing chamber pressure and neutralizing thrust. In the ET, one charge each is placed on the LO2 and LH2 tanks. Detonation shatters the tanks, dispersing the oxidizer and fuel. Commands to detonate the charges would be sent from Cape Canaveral Air Force Station.

In order to protect populated areas, impact limit lines are drawn around them. No lethal piece of a vehicle can land behind an impact limit line. Since termination would have to occur well before an impact limit line is reached, destruct lines are drawn inside the boundaries of the impact limit lines. A vehicle passing outside the boundaries of the destruct line would be subject to termination.

Controllability

During first stage, trajectory deviations may lead to a violation of a destruct line by a Shuttle that is still under control. It may be possible to return the vehicle toward its nominal trajectory or to

safely execute an abort. Therefore, the Flight Director (FD) and Flight Dynamics Officer (FDO) are in voice communication with the Range Safety Officer (RSO) during ascent. If the RSO detects a violation, the FDO and FD are immediately informed. The FD must determine whether the Shuttle is controllable or uncontrollable, and inform the RSO. As long as the FD declares the Shuttle controllable, the RSO takes no action to terminate the flight for trajectory deviations alone.

Range Safety Limit Avoidance

A deviation from nominal trajectory that is large enough to warrant RSO action must be corrected. First stage options are:

- State vector update
- Engage CSS (after 90 seconds MET)
- Engage BFS.

In second stage, the options are:

- State vector update
- ATO selection
- Engage CSS
- TAL or RTLS selection
- Engage BFS
- SSME manual cutoff.

Options are listed in order of priority. The priorities are established such that higher priority options preserve lower priority options and involve fewer new dangers to the crew and Shuttle when possible.

6.3 RETURN TO LAUNCH SITE

CONTENTS

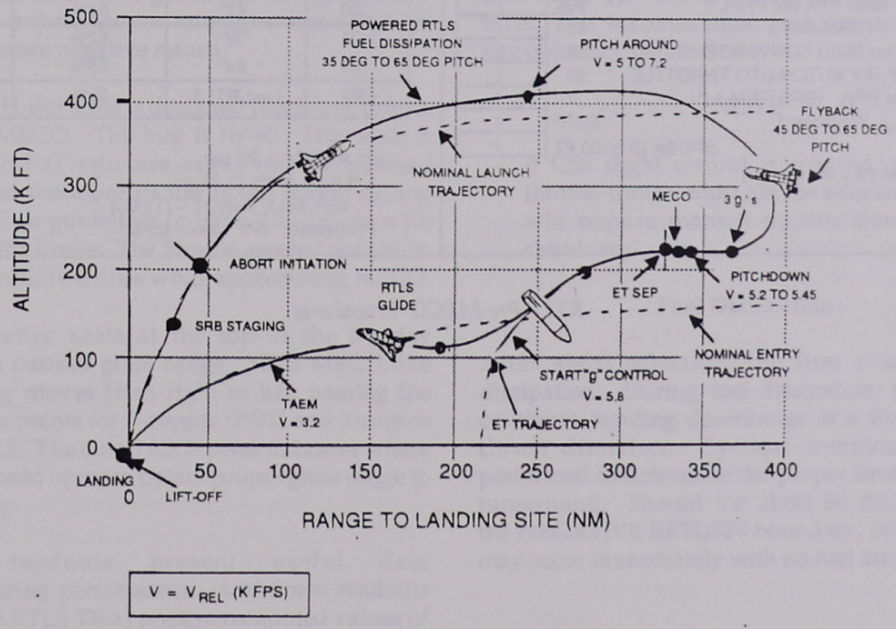
Powered Aborts 6.3-2
Gliding RTLS 6.3-6

RTLS abort is designed to provide intact abort capability for a suborbital return of the Shuttle to the KSC Shuttle Landing Field (SLF). An RTLS abort may be declared for an engine failure after liftoff and prior to NEGATIVE RETURN.

In order to reach the SLF, the Shuttle must reverse course and fly back the way it came. The turn to reverse course is called powered pitch around (PPA). Timing of this maneuver is critical. Engines must be shut down when the Shuttle has exactly enough speed and altitude to glide to the SLF runway. Also, for safe separation, the ET must have no more than 2% propellant remaining. Excessive propellant will slosh and could cause the ET and Shuttle to collide.

Selection of an RTLS abort is driven by several factors. Heat loading on the ET restricts RTLS selection to no earlier than 2 minutes and 30 seconds (2+30) after lift-off. For RTLS systems aborts, selection occurs at 3 minutes and 40 seconds. Abort overlap allows either an RTLS or a TAL to be selected. When RTLS/TAL overlap exists, TAL may be the preferred mode, since a second engine failure can be accepted and still make the runway. Also, the powered flight phase of RTLS is several minutes longer, causing more exposure to some types of MPS/SSME failures.

Once the decision is made to initiate an RTLS abort, MCC will direct the crew to "Abort RTLS." The FD will also turn on the *ABORT* light on panel F6, using a switch on his console, as a backup to the voice call. On-board, moving the *ABORT MODE* rotary switch to *RTLS* and depressing the Abort push button reconfigures GNC software to RTLS. As a backup, the crew can enter OPS 601 PRO on any PASS keyboard.



Typical RTLS Profile

Powered RTLS

Powered RTLS (PRTLS) begins when the abort is initiated and terminates at MECO. PRTLS guidance is designed to deliver the Shuttle to a MECO location at the proper altitude (I-load), flight path angle, and speed (function of range).

Guidance during PRTLS is closed loop. Computed MECO conditions are compared to desired MECO targets to determine a miss vector. This vector is then used to compute corrections in steering and throttle commands.

The crew monitors guidance using cue cards and CRT displays.

Should guidance not converge, the crew will see "GUID INHB" on the RTLS TRAJ display. MCC, in conjunction with the crew, will request CSS takeover if guidance does not converge within a reasonable time.

RTLS CDR

Abort initiated:
after 2:30 (2 eng)
at 3:40 (3 eng)

ABORT RTLS
* No Joy *
* OPS 601 PRO *

√GUIDANCE STATUS on RTLS TRAJ
Expect PPA when GUID % to go = 0
* If GUID 'INHIB': *
* √UNCONVERGED GUID TABLE *
* MAN PPA per PRPLT *
* REMAINING *
* After GUID CONVERGE: *
* P,R/Y AUTO/AUTO THROTTLE *
After PPA: √BFS ITEM 1 (*)
√Bugs, V_{rel}, Waypoint 1
Pitchdown (ß = 0°, α = –4°)

	WINDS
50K	/
40	/
30	/
20	/
7	/
SURF	/
SPDBK @ 3000 FT	/

RTLS PLT

If CSS: Man Throttle
Man MECO
√Pc = 104% (2 eng) / 69% (3 eng)
√DUMP

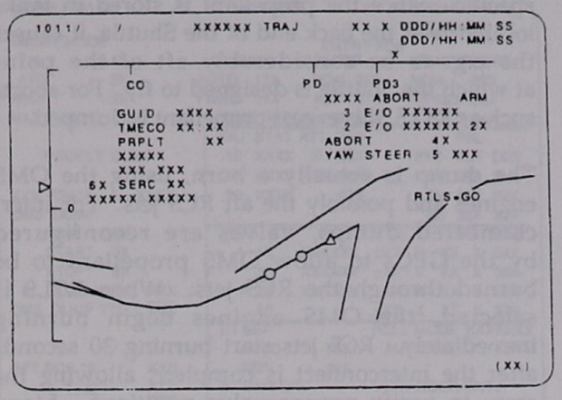
UNCONVERGED GUIDANCE TABLE

ENG OUT	OUTBOUND INITIAL φ	PITCHAROUND at % (10°/sec)	FLYBACK INITIAL φ
Liftoff	60°	44%	64°
:30	56°	47%	63°
1:00	57°	47%	63°
:30	56°	48%	62°
2:00	49°	51%	61°
:30	42°	51%	52°
3:00	38°	52%	50°
:30	34°	53%	48°
4:00	Last RTLS	52%	46°

√Pc AT PPA + 20 sec
* If Pc = 104% (2 eng): *
* G51 MAX THROT – ITEM 4 *
Pitchdown: √Pc → 65%

RTLS Pre-MECO Procedures

The primary display for PRTLS is RTLS TRAJ. Some of the information on this display comes directly from NAV and is independent of guidance.



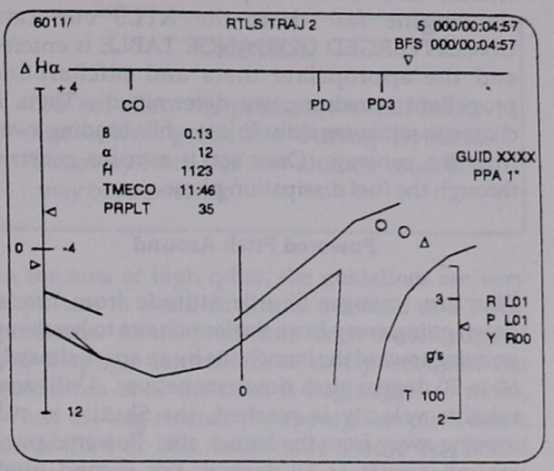
RTLS TRAJ Display

The central portion of the display is a plot of altitude versus horizontal component of V_{REL}, with the zero-velocity point at the end of the top trajectory line to the left of the screen midpoint. Shuttle position is plotted with a triangle. Predictors are generated to show 30 and 60 second positions. Trajectory lines are approximations of a generic set of high and low dispersed trajectories for an engine out at lift-off and just before negative return.

The Delta H-dot scale is designed to achieve proper H-dot at MECO. The bug is fly-to. This scale is only useful if you are right on the canned profile, and therefore its use is not taught during training. Two guidelines (q-bar = 2 and q-bar = 10) prescribe the limits. The Shuttle symbol should be between these two lines while approaching MECO.

A delta range scale at the top of the display represents current glide range. Near MECO, the cut-off bug moves from right to left, passing the pitchdown points for 3-engine (PD3) and 2-engine (PD) PRTLS. The cutoff (CO) point indicates where MECO should occur to obtain proper glide range to the runway.

Digital readouts present useful data for monitoring performance. Additional readouts on the BFS RTLS TRAJ present computed values of sideslip (beta), angle of attack (alpha), total vehicle acceleration, attitude errors, and computed throttle command.



BFS RTLS TRAJ 2 Display

In order to function properly, guidance needs to know the Shuttle's speed and time when an engine fails. Normally, the GPCs will capture this data, but the crew should also note the time. This becomes important later to determine key trajectory parameters.

NOTE

If CSS flight control is selected, manual throttle control must also be selected. This will require manual throttle down and shutdown.

Fuel Dissipation

After abort selection, the first phase is fuel dissipation. During fuel dissipation, the Shuttle continues heading downrange at a fixed inertial thrust direction. Cyclical computations are performed to determine the proper time to initiate turnaround. Should the abort be declared near the NEGATIVE RETURN boundary, pitch-around may occur immediately with no fuel dissipation.

For the crew to fly fuel dissipation phase in CSS, they must know the proper pitch angle (theta) and when to pitch around. Using the engine fail time, the RTLS cue card UNCONVERGED GUIDANCE TABLE is entered and the appropriate theta and pitcharound propellant remaining are determined. Theta is chosen to minimize altitude loss while heading away from the runway. Once set, it remains constant through the fuel dissipation phase.

Powered Pitch Around

This turn changes Shuttle attitude from heads-down going away from the launch site to heads-up pointing toward the launch site by an approximately 60 to 70 degree pitch down maneuver. Until zero relative velocity is reached, the Shuttle is still moving away from the launch site. Powered pitch around occurs at 10 degrees per second pitch rate in AUTO. This is a dramatic maneuver and is designed to prevent lofting while passing through vertical orientation.

Timing of powered pitch around is critical and must occur within a certain interval to ensure the Shuttle arrives at MECO with the proper amount of fuel remaining and the proper energy. The crew monitors guidance using the GUID % to go on the RTLS TRAJ 2 CRT display. The percentage displayed is the percent deviation of the predicted final mass from the RTLS mass target. When the percentage equals zero, PPA should occur.

Should guidance be unconverged, the crew should select CSS and manual throttle control and pitch around manually at the appropriate propellant remaining cue.

NOTE

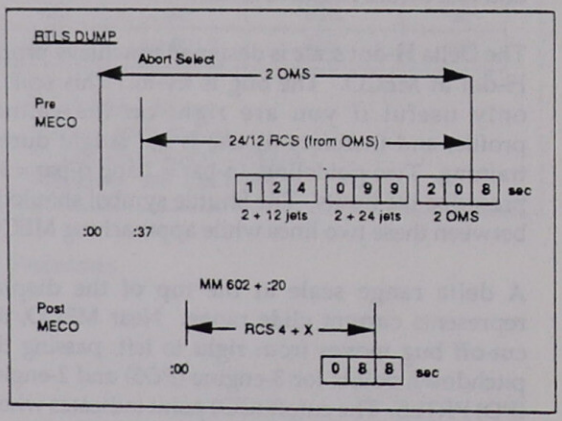
It is much better to pitch around slightly early than slightly late as late pitch arounds may result in not reaching a nominal RTLS MECO state.

OMS Dump

OMS propellant onboard at launch is mission specific. Since the propellant is stored in tanks located near the back end of the Shuttle, it causes the c.g. to be considerably aft of the point at which the Shuttle is designed to fly. For aborts such as RTLS, this excess propellant is dumped.

The dump is actually a burn, using the OMS engines and possibly the aft RCS jets. For interconnected dumps, valves are reconfigured by the GPCs to allow OMS propellant to be burned through the RCS jets. When RTLS is selected, the OMS engines begin burning immediately. RCS jets start burning 30 seconds after the interconnect is complete, allowing the crew to verify proper valve positions. Many missions have interconnected-inhibited dumps where the dump is through the OMS engines only.

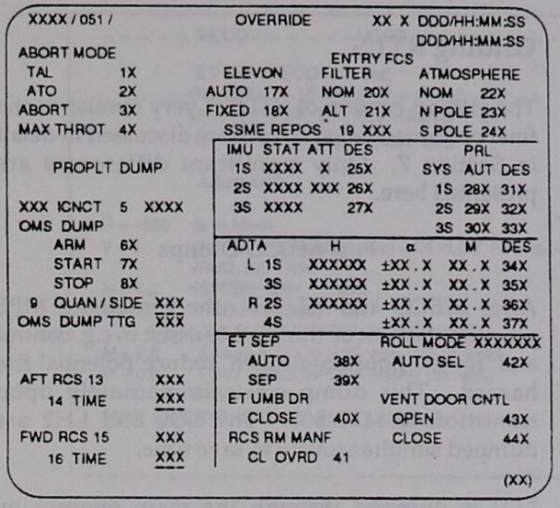
Normally, RTLS dumps are a combination of two OMS engines and 24 aft RCS jets. The jets used are four +X jets and 20 null jets. The +X jets fire directly aft and produce no significant rotational movement. Null jets fire in opposite directions so that they cancel each other out. Dump times are mission specific and are depicted on the RTLS/TAL DUMPS cue card.



RTLS/TAL Dumps

When the dump is complete, OMS/RCS valves are automatically reconfigured by the GPCs in preparation for MECO. If required procedurally, the crew can secure one or both OMS engines by

placing the *ARM/PRESS* switch in *OFF*. The entire dump can be terminated by executing a DUMP STOP on the OVERRIDE display (SPEC 51).



Dump time-to-go (TTG) counts down to zero during RTLS dumps. Interconnect can be inhibited or enabled by toggling ITEM 5.

Onboard failures, such as electrical or DPS problems, can cause serious OMS/RCS valve reconfiguration problems. "Smart Interconnect" Software should reconfigure the valves or inhibit some or all of the jets to prevent any serious problems.

Shuttle abort dumps are complex procedures and must be executed correctly in a time-critical situation. Consult the Ascent/Aborts Flight Procedures Handbook for additional information.

Flyback

This phase is part of PRTLS where the Shuttle points back toward the runway. Guidance computes steering and throttle commands that direct the Shuttle along the proper trajectory.

Should CSS control be required, the crew should stop the PPA maneuver at the initial flyback theta, as determined from the RTLS PLT UNCONVERGED GUIDANCE TABLE. The Shuttle pitch attitude must then be adjusted to fly back along or parallel to the guidelines on the RTLS TRAJ display.

> **CAUTION**
>
> Do not allow the predictors to fall below the lower guideline during flyback. Recovery from this low altitude condition may be impossible.

In the area of high q-bar, the guidelines are very important to avoid structural overload or ET SEP problems. As the predictors reach the left edge of the display, control theta to fly between the guidelines until the delta-R bug begins to move. When the bug reaches the appropriate pitch down mark (PD3 or PD), the Shuttle should be pitched down at 5 to 8 degrees per second to alpha = -4 degrees. At this point the crew should null beta. Simultaneously, the engines are manually throttled to 65 percent. These procedures are summarized on the RTLS CDR & PLT cue cards.

Powered Pitchdown

To satisfy altitude and flight path angle constraints at MECO, a positive angle of attack of about 30 degrees is required. However, to safely separate the ET, an alpha of -4 degrees is necessary. The transition between these attitudes is called powered pitchdown.

The maneuver must be completed rapidly (5 to 8 degrees per second) to avoid large sink rates, which could cause over-heating or over-stressing. Engines are throttled back to reduce trajectory impact.

MECO and ET SEP

Since the MECO time has been fixed by the GPCs, an attitude of alpha = -4 must be held until the delta-R bug reaches the CO mark, and the engines are shut down by the GPCs or manually. After shutdown, a mated coast phase occurs for approximately 13 seconds. During this phase, valves are closed, umbilicals retracted, and electrical connections deadfaced. Attitude is controlled by the RCS jets.

The Shuttle is then ready for ET SEP, which will occur automatically, provided certain constraints are within limits.

PARAMETER	TARGET	TOLERANCES	LIMITS, DEG/SEC
Roll rate, P	0°/sec	±5°/sec	.5 > P > –5
Pitch rate, Q	–.25°/sec	+.5°/sec, –4.75°/sec	+ .25 > Q > –5
Yaw Rate, R	0°/sec	±5°/sec	+ .5 > R > –.5
Angle of attack, α	–4°	+2, –85	-2° >α > -89° *
Side Slip angle, ß	0	±2°	2° > ß > -2° *

* Limits, deg.

RTLS ET Auto Separation Limits

These limits prevent separation in an unsafe attitude which might cause Shuttle/ET collision. If the parameters are not within limits, an ET SEP inhibit suspends the separation sequence until the out-of-limits is corrected or 6 seconds expire, whichever occurs first. The timer is necessary due to rapid q-bar buildup which makes a safe separation impossible regardless of attitude. Separation can be commanded manually using the ET *SEPARATION* switch and *ET SEP* push button on panel C3.

Immediately after ET SEP, the DAP performs a translation and pitch maneuver to fly the Shuttle away from the ET. This is accomplished by firing all of the Shuttle's downfiring jets. The combination of four forward and six aft downfiring jets results in a simultaneous translation and rotation, which moves the Shuttle up and away from the ET. Once the Shuttle achieves an alpha ≥ +10 degrees, the GPCs mode to MM 602 and the glide portion of RTLS (GRTLS) begins.

In CSS and manual throttle, a manual MECO must be performed using the *MAIN ENGINE SHUT DOWN* push buttons on panel C3. The alpha = -4 degree attitude must be maintained until ET SEP. This will require a small negative pitch rate due to H-dot increase, which causes alpha to become more positive. The -Z translation maneuver will occur automatically unless the CDR intervenes by moving the THC out of detent. If this is done, a manual -Z maneuver should be performed to ensure safe separation, and the pitch up manuever to alpha ≥ +10 degrees must also be manually performed. Generally, it is preferable to allow the DAP to perform these maneuvers automatically.

Gliding RTLS

The gliding portion of RTLS is very similar to the final portions of entry, which are discussed in detail in Section 7. Only significant differences are presented here.

Post-MECO Dumps

After MECO and ET SEP, the remaining MPS propellants must be dumped to assist in c.g. control and, for the liquid hydrogen, reduce potential fire hazard. This dump starts immediately upon transition to MM 602. The LO2 and LH2 are dumped simultaneously to save time.

LO2 is dumped through the main engines by opening the oxygen valves. Liquid hydrogen is dumped through an RTLS dump line on the orbiter port side aft. To assure a rapid LH2 dump, the hydrogen manifold is pressurized with helium.

The onboard software also allows a post-MECO dump of RCS propellant through the RCS jets to satisfy maximum tank landing weight constraints.

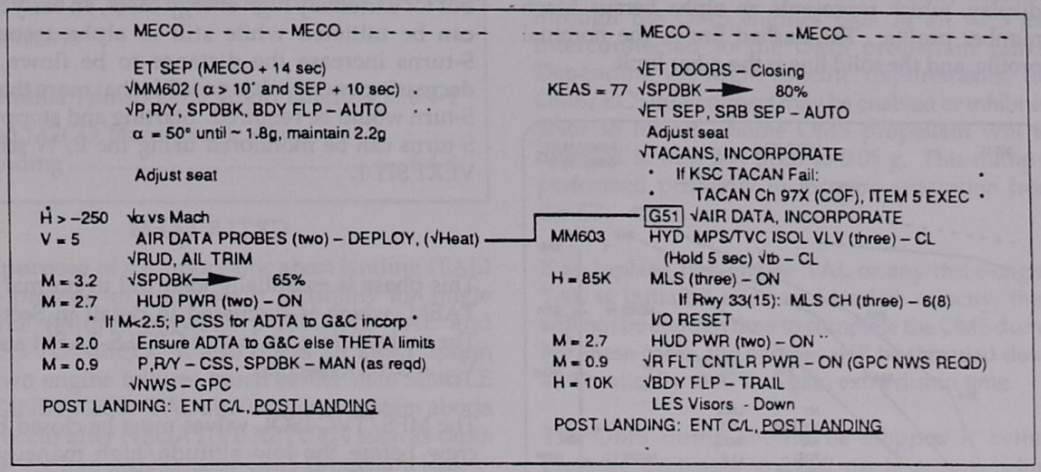
Guidance

During GRTLS, guidance manages the Shuttle's energy state to arrive at the runway with sufficient energy to complete a safe landing. GRTLS guidance is divided into five phases:

- Alpha Recovery
- N_z Hold
- Alpha Transition
- S-Turn
- GRTLS TAEM.

These phases provide for transition from a ballistic trajectory, through hypersonic gliding flight, to an energy management scheme designed to make the runway.

The crew monitors guidance or manually controls the Shuttle using cue cards and CRT displays.



CDR and PLT RTLS Flip Book Procedures

Alpha Recovery

Pullout from the ET SEP attitude must be accomplished quickly before aerodynamic forces build up to uncontrollable levels. To accomplish this, the Shuttle maneuvers to a high (alpha = 50 degrees) angle of attack using both RCS jets and aerodynamic controls.

Increasing dynamic pressure caused by the Shuttle falling into the atmosphere causes more lift to be generated by the wings. The resultant lift produces a Z–axis acceleration (N_z). At about 1.65 g, the DAP starts to reduce alpha to hold an N_z of 2.2 g's. The Shuttle design limit is 2.5 g.

Roll jets are secured at q-bar = 10. Pitch jets are secured at q-bar = 40. Yaw jets are required until Mach = 1.0. When q-bar = 20, the speed brake is ramped open to about 80 percent to enhance lateral stability by allowing the elevons to be trimmed down. Below Mach = 1.0, the speed brake position is modulated by TAEM guidance.

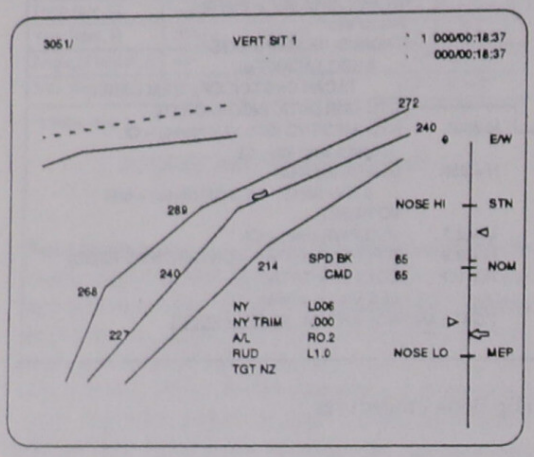
N_z Hold

Alpha is smoothly decreased to maintain the 2.2 g limit until H-dot is greater than -250 ft/sec. Excessive g-loading could cause structural damage and also dissipate excessive energy. The ADI pitch error needle displays N_z error during this phase.

Alpha Transition

Upon termination of N_z hold, alpha is changed to conform to a profile that is a function of Mach number. This profile provides the best vehicle control until active ranging begins in TAEM. Also, a bank maneuver is performed, either to null any heading errors to the heading alignment cone (HAC) tangency point, or to dissipate excess energy by turning (S-turn) away from the HAC. The maximum bank angle is 50 degrees. The ADI pitch error needle displays alpha error during alpha transition phase.

To fly the alpha transition in CSS, the display in the upper left corner of VERT SIT 1 is used. The Shuttle symbol initially appears in this portion of the display, which represents an alpha versus Mach number profile. The dashed line is the nominal profile, and the solid line is the q-bar limit.



Vertical Situation 1 Display

The ENTRY ALPHA cue card can also be used for alpha transition. Since there are no procedures to initiate S-turns manually, ranging is accomplished by exercising the OTT options described in Section 7. The MCC can also request a GCA and accomplish S-turns by asking the crew to fly appropriate headings.

S-Turn

Normally, an S-turn is not executed until TAEM, but for extremely high energy cases, an early S-turn can be initiated while still in alpha transition. S-turns increase the distance to be flown, thus decreasing energy. It is possible that more than one S-turn would be required. Starting and stopping of S-turns can be monitored using the E/W scale on VERT SIT 1.

GRTLS TAEM

This phase is essentially identical to normal entry TAEM, which is discussed in detail in Section 7. The main difference is that GRTLS TAEM starts at V_{REL} = 3200 ft/second.

The MPS/TVC ISOL valves must be closed by the crew before the low altitude/high maneuvering regions of TAEM to prevent PRL. These valves must remain open until MPS dump completion at approximately Mach = 4.5.

To conserve power during ascent, the MLS LRUs are powered off. They must be turned on and communication established (I/O RESET) at about 85 k ft during GRTLS.

Post landing procedures are the same as nominal end of mission, except that the hydraulic load test is not performed.

6.4 TRANSOCEANIC ABORT LANDING

CONTENTS

Nominal Transoceanic Abort Landing 6.4-1
Post MECO Transoceanic Abort Landing 6.4-4

The purpose of a transoceanic abort landing (TAL) is to provide an intact abort capability for single engine failures between 2 ENGINE TAL and PRESS TO MECO. It also offers an intact option for two engine failures much earlier than SINGLE ENGINE PRESS. TAL also supports system aborts that occur after NEGATIVE RETURN such as cabin leaks, cooling problems, or OMS propellant loss.

During a TAL abort, the Shuttle flies an entry trajectory across the ocean to land on a mission-specific runway. Landing occurs approximately 35 minutes after launch. Powered flight guidance has the capability to target seven different landing sites, which are selected based on runway length, weather, and orbital inclination. Landing sites near the nominal ascent ground-track are more efficient since crossranging requirements are reduced.

Nominal Transoceanic Abort Landing

TAL is selected prior to MECO by placing the *ABORT MODE* rotary switch on panel F6 in *TAL* and pressing the *ABORT* push button. Item entries on the OVERRIDE display (SPEC 51) may also be used to select TAL should the *ABORT MODE* switch fail. The crew should note the title of the ASCENT TRAJ display changes to TAL TRAJ. The Shuttle indicator (triangle) and predictors should follow the lower trajectory line on BFS TAL TRAJ 2.

Abort Dump

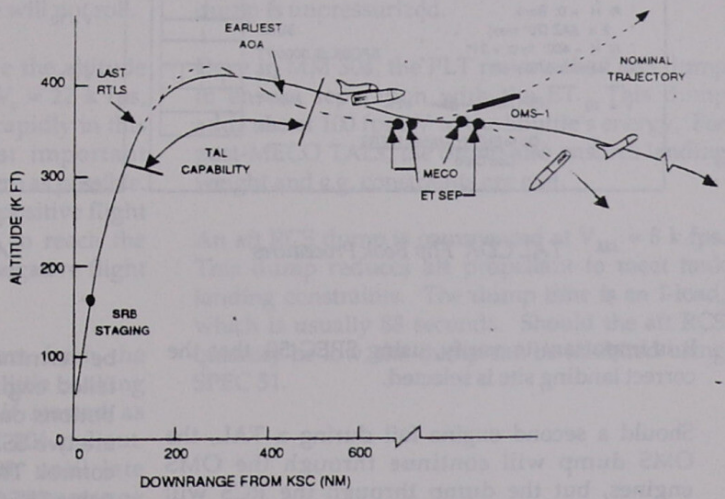
When TAL is selected, an abort dump begins immediately. OMS propellant is usually dumped through the OMS engines plus 24 aft RCS jets interconnected to the OMS propellant tanks. Depending on flight-specific requirements, the OMS/RCS interconnect may be enabled or inhibited prior to lift-off. Some OMS propellant will be dumped in MM 304 prior to 0.05 g. This dump is performed primarily to increase separation from the ET.

If an inplane two-engine TAL or any three-engine TAL is initiated after an I-loaded velocity, there will not be enough time to complete the OMS dump. For these cases, the engines will be throttled down automatically to 67% to gain extra dump time.

The OMS dump should be stopped if helium pressure decreases to 2,000 psi to ensure helium will not be ingested into the RCS lines.

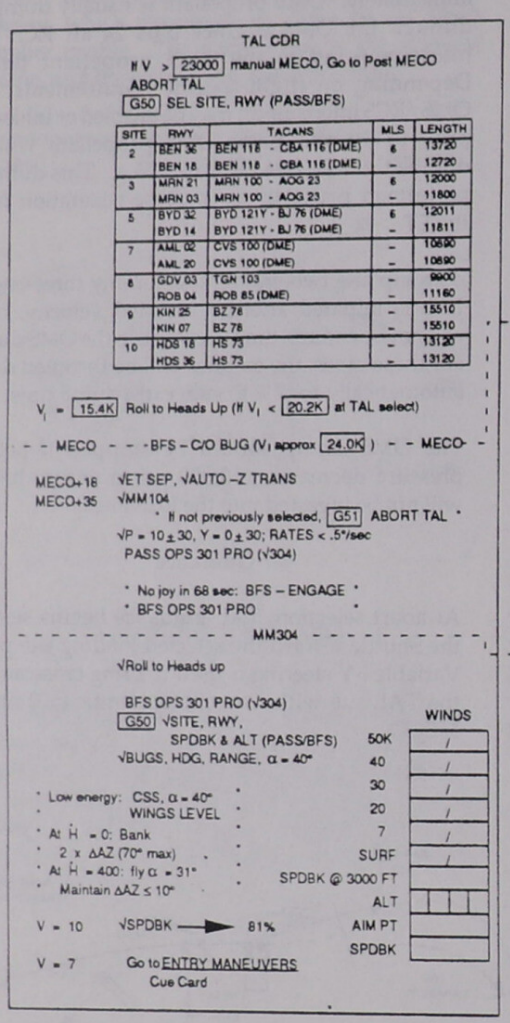
Guidance

At abort selection, TAL guidance begins steering the Shuttle toward the selected landing site plane. Variable I-Y steering is used to bring crossrange to the TAL site within acceptable limits (500 nm) at MECO.

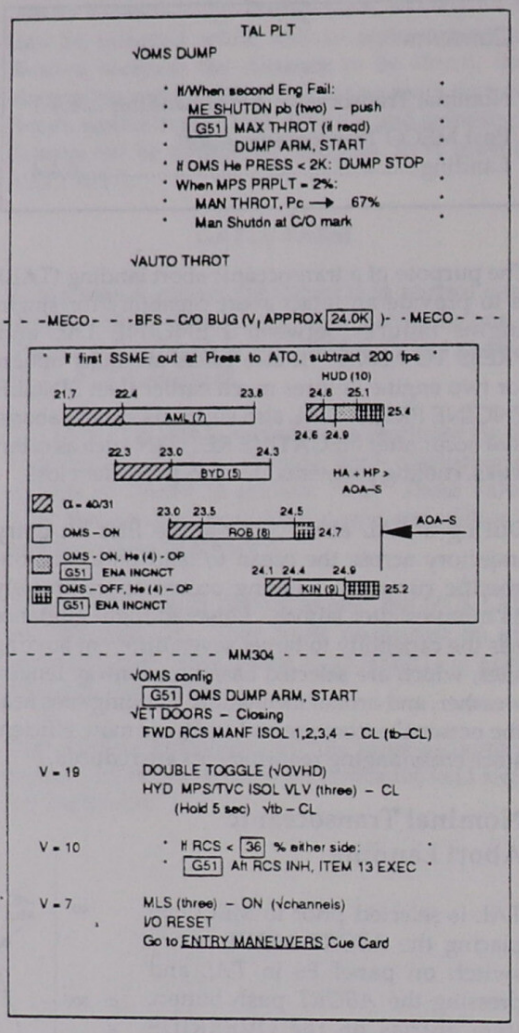


TAL versus Nominal Ascent

The crew monitors guidance during TAL aborts using the TAL CDR and TAL PLT cue cards.



TAL CDR Flip Book Procedures



TAL PLT Flip Book Procedures

It is important to verify, using SPEC 50, that the correct landing site is selected.

Should a second engine fail during a TAL, the OMS dump will continue through the OMS engines, but the dump through the RCS will be terminated. The crew must push the two failed engine *MAIN ENGINE SHUT DOWN* push buttons on panel C3 to notify guidance that there are two SSMEs out and establish single engine roll control. The contingency dump must also be started using SPEC 51.

CAUTION

Ensuring guidance recognizes two engines have failed is time-critical to enable single-engine roll control. Loss of control is likely in powered flight on one SSME without single-engine roll control.

Trajectory droop, along with guidance convergence and main engine performance, are the deciding factors in defining the earliest single engine TAL capability. Drooping below the 265 k ft limit will result in either an explosion due to ET heating or a loss of control. If two engines fail near the DROOP 109 boundary, the crew should throttle up to 109 percent. It will be necessary to pitch up to 60 degrees on the ADI if guidance is unconverged until the thrust-to-weight ratio improves. This will minimize sink rate and enable the Shuttle to remain above 265 k ft. When thrust-to-weight is greater than 1, the Shuttle will begin to climb and accelerate downrange.

To lessen ET heating effects and to put the Shuttle in the correct entry attitude at ET SEP, a roll to heads up is performed at an I-loaded reference velocity greater than 15,400 fps. If TAL is selected after this velocity, but before a velocity of approximately 20,200 fps, guidance will roll the Shuttle immediately. The roll is performed at about 5 degrees per second. After 20,200 fps until last pre-MECO TAL, the Shuttle will not roll.

After the roll, it is important to have the altitude and altitude rate under control by V_I = 22 k fps, because the Shuttle accelerates very rapidly in this region. Altitude rate is the most important parameter, and should be as close to zero as possible. It is far better to have a zero or small positive flight path angle and a low altitude than to reach the target altitude exactly with a large negative flight path angle:

TAL MECO occurs about 2,700 nm from the landing site. For inplane sites, very little banking for azimuth control is necessary if started as soon as possible after the first MM 304 pullout. Waiting to null out delta azimuth until late in the entry can severely reduce crossrange capability.

The MCC will recommend the best approach to the field. An overhead approach is preferred.

OPS Transition

TAL is a unique abort in that it requires transition to OPS 3 after MECO and ET SEP, which is time-critical. The PASS computers obtain this software from upper memory.

CAUTION

To prevent loss of control, engage BFS and key in OPS 301 PRO if the PASS does not mode into OPS 3 within 68 seconds.

About 3 minutes are available to complete the OPS transition between ET SEP and the start of dynamic pressure buildup depending on the altitude, flight path angle, and velocity at MECO. This period is critical. The Shuttle is entering the atmosphere, and the TRANS DAP is not designed for atmospheric flight. All procedures must be completed quickly and accurately. Ignore all systems problems unless they are extremely critical until correct entry flight control is available.

Post-MECO Dumps

An MPS dump similar to the RTLS dump begins automatically at MM 304. The TAL LH2 MPS dump is unpressurized.

Once in MM 304, the PLT restarts the OMS dump to ensure separation with the ET. This dump adds about 100 fps ΔV to the Shuttle's energy. For post-MECO TALs, the dump also ensures landing weight and c.g. constraints are met.

An aft RCS dump is commenced at V_{REL} = 8 k fps. This dump reduces aft propellant to meet tank landing constraints. The dump time is an I-load, which is usually 88 seconds. Should the aft RCS quantity be low, the dump can be inhibited using SPEC 51.

Entry

MM 304 is very similar to a normal end-of-mission entry which is discussed in detail in Section 7.

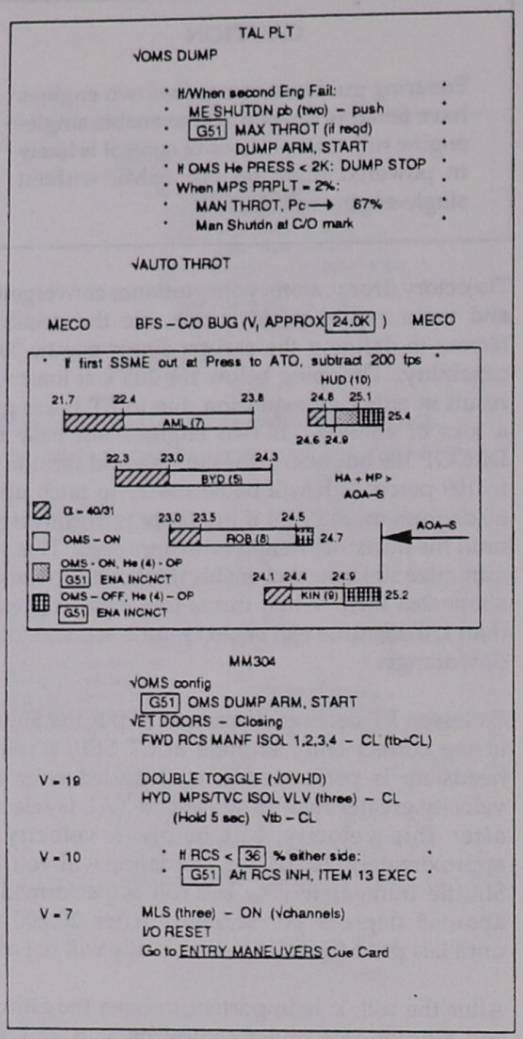
The shortfield speed brake option is automatically selected for TAL. Should nominal speed brake be desired, an ITEM 39 (S/B) on SPEC 50 will be required.

Post MECO Transoceanic Abort Landing

An intact abort capability is available between V_I ~ 21.5 to 23 k fps (mission specific) and AOA capability by using the TAL entry software. The abort is declared after MECO. For late systems problems after last pre-MECO TAL, the crew performs a manual MECO at the specified velocity using the *MAIN ENGINE SHUT DOWN* push buttons.

NOTE

For high inclination missions, a crew-initiated (MAN MECO) post-MECO TAL is not an option. This is because, for high inclination missions, the post-MECO TAL landing sites are ELSs, and the program has decided to try for an AOA rather than land at an ELS.



TAL PLT Flip Book Procedures

MECO velocity takes into account the ΔV due to SSME tailoff. This number is flight specific and depends upon inclination.

The boundaries chart shows approximate TAL site coverage for a range of early MECO conditions. Using the real time downrange abort evaluator (DAE), the MCC will determine the appropriate site and communicate data to the crew. Cue card boundaries are used for loss of communications.

Post MECO Dump

The late TAL post-MECO OMS dump is similar to the TAL OMS dump. For some cases when MECO velocity is near the upper limit, the OMS propellant must be dumped only through the RCS jets to minimize additional ΔV. This type of OMS dump is referred to as a non-propulsive OMS dump. Procedures remind the crew to place the *OMS ENG* switches on panel C3 to *OFF* in these areas. This dump must be stopped manually since the AUTO cutoff at the appropriate OMS propellant quantity is not operable with the OMS engines off. Interconnected dumps are performed only in indicated regions.

Guidance

Upon entry into MM 304, guidance will roll the Shuttle to heads up.

The crew should verify that the proper runway is selected. For low energy cases, CSS flight control is required until the Shuttle is within the trajectory lines on the ENTRY TRAJ display.

After runway selection is verified, and guidance is converged, AUTO flight control may be reselected. The remaining late TAL procedures are identical to the nominal TAL.

6.5 ABORT ONCE AROUND

CONTENTS

Powered Flight 6.5-1
OMS-1 ..... 6.5-1
OMS-2 ..... 6.5-3
Entry 6.5-4

The abort once around (AOA) abort mode is used in cases where Shuttle performance has been lost to such an extent that it is impossible to achieve a viable orbit, or not enough OMS propellant is available to accomplish the OMS-1, OMS-2, and deorbit burns. AOA may also be used when a major systems failure makes it necessary to land quickly.

In an AOA for a standard insertion, or a low performance direct insertion, one OMS burn is made to adjust the post MECO orbit such that a second burn will result in the orbiter deorbiting and landing at an AOA landing site. In an AOA for a systems failure during a nominal performance direct insertion, only the deorbit burn is required. Landing occurs about 1 hour and 45 minutes after lift-off.

There are two AOA trajectories with several different options for each one, depending upon the reason for performing an AOA: steep AOA and shallow AOA.

Entry trajectory for the steep AOA is very similar to a nominal entry and is the preferred trajectory due to thermal considerations. However, steep targets require more ΔV and therefore more propellant. Shallow AOA results in a flatter trajectory which places the Shuttle closer to the skipout boundary and thermal limits. This is less desirable, but requires less OMS propellant, which is important for severe underspeed cases or if both OMS helium tanks have failed with propellant quantities above max blowdown.

Execution of an AOA is determined by an MCC call and by checking the OMS-1 target solution against the OMS TARGETING cue card. If required, OMS-1 targets are loaded and burned. After OMS-1, the desired OMS-2 targets are selected on the MNVR EXEC display. Then the software is moded to OPS 3 and the appropriate OMS-2 (deorbit) targets are loaded and burned. After the deorbit burn, an entry is flown that is very similar to the nominal end of mission.

Powered Flight

A pre-MECO AOA can be selected only indirectly by first selecting ATO. This provides the earliest AOA capability by performing a pre-MECO OMS dump, switching to abort MECO targets, and possibly enabling variable I-Y steering.

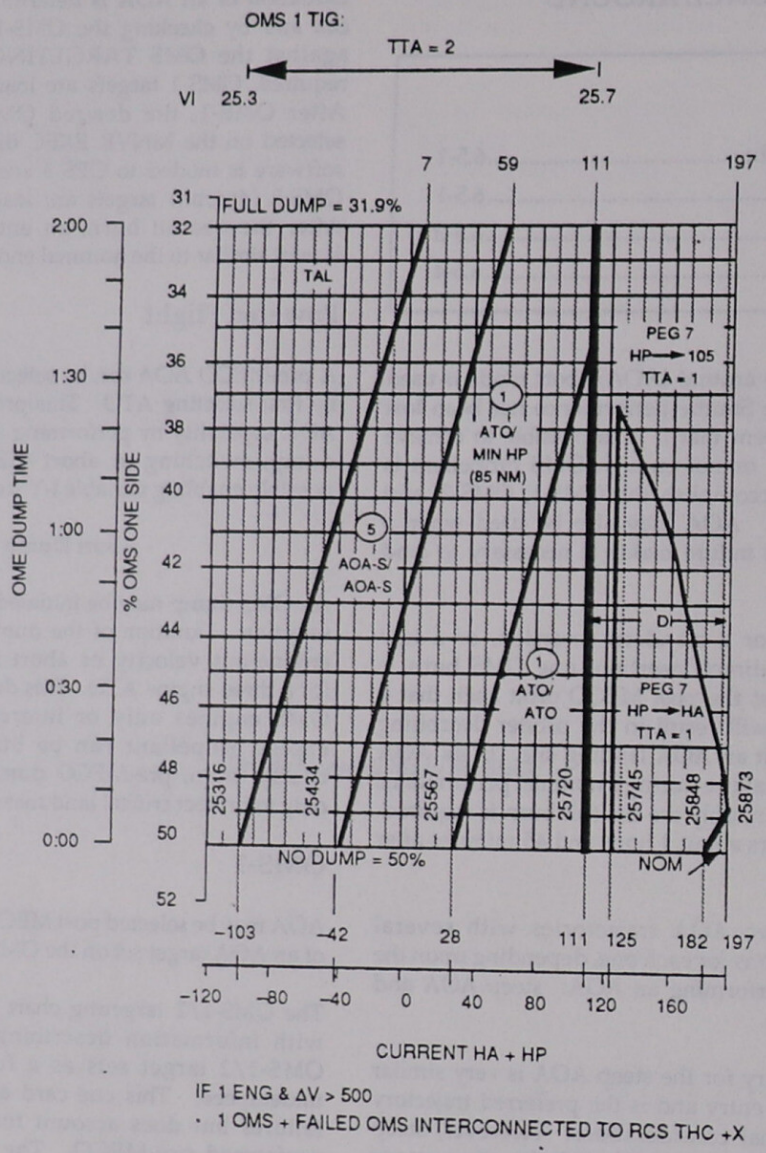
Abort Dump

An OMS dump may be initiated upon ATO abort selection. Duration of the dump is a function of engine-out velocity or abort selection velocity for a three engine ATO. This dump may be either OMS engines only or interconnected. Since excess propellant can be burned during the deorbit burn, pre-MECO dumps are performed only to protect critical land masses from ET debris.

OMS-1

AOA may be selected post MECO by crew selection of an AOA target set on the OMS MNVR display.

The OMS-1/2 targeting chart provides the crew with information describing the appropriate OMS-1/2 target sets as a function of MECO underspeed. This cue card assumes no system failures but does account for any ATO dump performed pre-MECO. The crew obtains the correct target set by calculating orbital energy (HA + HP) and noting the amount of OMS propellant remaining. Current HA + HP is obtained from the OMS-1 MNVR EXEC display after MM 104 transition.



OMS 1/2 TGTING Cue Card

The OMS 1/2 TGTING cue card should be used in conjunction with the SYSTEMS FAILURE card, and worst case requirements will prevail. For combinations of failures, MCC help will be required. In any case, MCC is prime for all target selections as long as COMM exists.

For all flights there exists an ATO OMS-1 target set that will allow either an ATO, AOA steep, AOA shallow, or minimum perigee (MIN Hp) OMS-2. This target set is referred to as the common targets. The common targets can be burned, and the decision to abort AOA may be delayed until after OMS-1 for most cases. If AOA is selected after OMS-1, the crew depresses the hydraulic systems instead of shutting down the APUs. This procedure avoids an APU shutdown and restart and conserves APU fuel.

OMS 2 TARGETING
(STD INSERTION)

FAILURE	OMS 2 TARGET
OMS – 1 PRPLT TK	PEG 7; TTA–1 CUTOFF Hp = 100
OMS – 2 N2 TKS (l'cnect to RCS) 2 OMS ENG 1 He TK EPS – MNA & B MNA & C	PEG 7: TTA–1 CUTOFF Hp = 80
OMS – 2 OX or 2 FU or 2 HE TKS 1 OX & 1 FU TK diff PODS	AOA/AOA-S
2 FREON LOOPS 2 H2O LOOPS 3 AV BAY FANS (BAYS 1,2) CABIN LEAK (BKUP dP/dT > .12)	AOA

ATO

NOTE

These tables only apply after ATO OMS 1 burn (ITGT = ①, AOA to EDW). Assumes OMS and ARCS deorbit

DUAL POD – OMS REQUIRED Includes 7.8% unusable (3.9% per pod)				
POST OMS 1 HP	ATO OMS 2 & STEEP D/O BURN (%)	MIN HP OMS 2 & SHALLOW D/O BURN (%)	AOA STEEP D/O BURN (%)	AOA SHALLOW D/O BURN (%)
95	35	15	33	20
90	36	13	31	19
85	37	11	30	17
80	39	12	28	16
75	40	14	26	14
70	42	16	24	12
65	43	17	22	10

SINGLE POD – OMS REQUIRED Includes 3.9% unusable				
POST OMS 1 HP	ATO OMS 2 & STEEP D/O BURN (%)	MIN HP OMS 2 & SHALLOW D/O BURN (%)	AOA STEEP D/O BURN (%)	AOA SHALLOW D/O BURN (%)
95	31	11	29	16
90	32	9	27	15
85	33	7	26	13
80	35	9	24	12
75	36	10	22	10
70	38	12	20	8
65	39	13	18	6

ΔV AVAILABLE FOR OMS 2
OMS: 5 FPS/% PER POD
LIFTOFF BLL DN PER POD [134]
MIXED XFD [134]
MAX BLDN (39%) PER POD [192]
AFT RCS: ABOVE AFT QTY 1 [70] (Rev 2)
2 [105] (Rev 2)
FWD RCS: [49] (AVAIL FOR UPHILL IF HP ≥ 70)

Post-ATO (1) OMS Required

OMS-2

After OMS-1 is burned, the OMS-2 TARGETING cue card is checked to determine the appropriate OMS-2 targets. Additionally, the OMS REQUIRED card is used to determine the appropriate abort mode in the event of an OMS propellant shortage or to confirm that sufficient OMS propellant is available for completion of the planned abort mode.

OMS targeting options are complex and vary greatly from flight to flight. For a complete explanation of targets, refer to the Ascent/Aborts Flight Procedures Handbook.

For all AOA aborts, deorbit targets are called up in OPS 1 and carried across the transition to OPS 3. Targets are not loaded until after the OPS 3 transition due to different guidance targeting logic. Where the OMS-1 maneuver (if required) establishes a temporary orbital trajectory, OMS-2 is a deorbit burn.

AOA software computes the amount of excess OMS that may be burned out of plane during the deorbit maneuver. The crew can change this amount through keyboard entries on the OMS MNVR EXEC display.

Once the appropriate AOA OMS-2 targets are loaded, burn TIG may need to be adjusted to correct range from entry interface (REI). The FDF checklist provides the procedure for TIG adjust. The MCC may recommend a TIG that has already been adjusted.

If the key-in AOA targets are used, an AOA target set should still be called up in OPS 1 using Item 35 on the OMS MNVR display to establish the AOA Kalman filter co-variance matrix. The key-in AOA targets can then be entered and ultimately loaded in OPS 3.

Entry

After the OMS-2 burn, the orbiter is maneuvered to an EI-5 attitude, which is similar to the nominal entry attitude. If AOA shallow targets were burned, a prebank will be required to ensure atmospheric capture.

The software transition from OPS 1 to OPS 3 will automatically load landing site data for an AOA. Included are data for the runways shown on the HORIZ SIT SPEC 50, an associated set of TACAN stations, and MLS data for the primary and secondary runways. Potential AOA landing sites are Edwards Air Force Base, California; Kennedy Space Center, Florida; and Northrup Strip, New Mexico. The crew should verify that the appropriate site and runway are selected.

The entry and landing phase of an AOA is similar to the normal entry and landing discussed in Section 7.

6.6 ABORT TO ORBIT

CONTENTS

Powered Flight 6.6-1
OMS-1 ..... 6.6-1
OMS-2 ..... 6.6-1

ATO aborts are designed to achieve a safe orbit that is lower than the nominal orbit. This requires less OMS propellant and allows time for problem evaluation to determine whether an early return is required, or additional burns can be performed to raise the orbit and continue the mission. ATO may be selected for either a performance shortfall or certain systems failures.

Powered Flight

ATO is selected pre-MECO by using the *ABORT MODE* rotary switch or by item entry on SPEC 51. Primarily, pre-MECO ATO selection provides an OMS dump, switches to abort MECO targets (usually the same as nominal), and may enable variable I-Y steering to reduce inclination. The crew monitors ascent performance and keeps abreast of abort mode capability using the NO COMM MODE BOUNDARIES cue card, along with calls from the MCC.

ATO procedures during powered flight, with the exception of the pre-MECO OMS dump, are identical to nominal ascent, which is discussed in Section 7.

OMS-1

If possible, ATO abort is declared after MECO to ensure that other downmode options are available as long as possible. ATO OMS-1 targets are automatically called up if an ATO is declared either pre-MECO or pre-OMS 1. This may be a common target set from which either an AOA deorbit burn or an ATO circularization burn can be performed at OMS-2. The final decision can thus be delayed until after OMS-1 is completed.

OMS-1 targeting is performed using the same procedures and cue cards as AOA. These are discussed in Section 6.5. In order to provide a fuel-efficient ATO or AOA burn, OMS-1 is initiated at time to apogee (TTA) equals 2 minutes, but no earlier than MECO + 2 minutes. If apogee is greater than 6 minutes after MECO, the MPS dump is manually initiated at MECO + 2 minutes.

OMS-2

The ATO OMS-2 burn is performed using nominal Ascent Checklist and cue card procedures. Proper targets are selected and loaded, the Shuttle is maneuvered to burn attitude, and the burn is executed.

After completion of both ATO OMS burns, the orbiter should be in approximately a 105 nm circular orbit. Once this safe orbit is attained, mission operations may be continued for at least 1 day. Additional burns may be used to raise the orbit or the mission may be ended early.

OMS-2 targeting for ATO is very similar to AOA which is discussed in Section 6.5.

6.7 CONTINGENCY ABORT

CONTENTS

Powered Flight 6.7-1
ET Separation 6.7-1
Entry 6.7-2

Contingency aborts are performed when the orbiter's thrust to weight ratio is less than that needed to achieve a safe orbit or an intact abort. The purpose of a contingency abort is to guide the orbiter to a safe gliding flight condition where bailout can be performed. Most of the contingency abort procedures are flown manually and are very dynamic flight modes that take the orbiter to the limits of its structural and flight control envelope. A great deal of training is required to properly execute a contingency abort. For certain cases, especially high altitude and low velocity, the resultant entry may not be survivable.

Contingency abort procedures are outlined on the contingency abort cue cards. These procedures are designed to protect the orbiter from exceeding certain limits:

- c.g. - aft of 1,115 in
- q-bar - 800 psf
- N_z - 3.5 g
- Thermal
- ET SEP - q-bar < 2 psf -4°/sec sep
  q-bar > 2 psf α = -4° sep.

The procedures are separated into CONTINGENCY ABORT and RTLS CONTINGENCY cue cards. They are further subdivided into event timelines and color-coded for easier use. For detailed procedures, the Ascent/Aborts Flight Procedures Handbook should be used. This section describes the basic information applicable to all contingency aborts, and is divided into three major phases: Powered Flight, ET Separation, and Entry.

The PASS is moded to OPS 6 (RTLS) during most contingency abort procedures. OPS 6 provides the OMS/RCS dump capability and entry flight control needed for contingency abort. The BFS does not support contingency aborts since single engine roll control is not available in BFS.

Powered Flight

If any thrust is available, the orbiter is maneuvered to minimize entry sink rate and rolled to a heads-up attitude.

Should two SSMEs fail, the remaining thrust is used to reduce entry sink rate. To do this, the thrust vector is directed to lower the orbiter's altitude and bring the flight path angle to zero before ET separation.

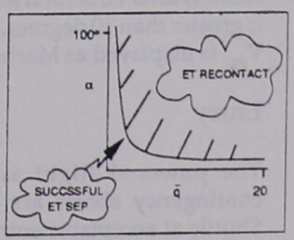
To accomplish this objective, different procedures are used, depending on when the engine failure occurs. At an inertial velocity between 7,000 fps and droop, a vertical thrust vector is used. For earlier failures, when the orbiter has a large positive H-dot, the thrust vector is pointed toward the horizon to prevent further lofting. This increases velocity and helps reduce severity of the entry pullout. However, it may increase heat loads. At inertial velocities greater than DROOP, the orbiter may have enough energy to continue to a downrange site.

Powered flight is also used to dump OMS propellant. This reduces weight and moves the c.g. forward. Reducing weight decreases the peak q-bar during pullout, while more forward c.g.'s reduce elevon and body flap deflection required for pullout. This helps prevent aerosurface saturation and possible actuator stall.

The heads up roll orients the bottom of the orbiter/ET into the velocity vector, which is the proper attitude for ET SEP.

ET Separation

Safe ET SEP is a function of alpha and q-bar. As the Shuttle descends during powered flight, q-bar increases and ET SEP must be performed prior to 10 psf.



At pressures above 10 psf, the ET may recontact the orbiter. Between 2 and 10 psf, the Shuttle must be at a small negative (about -4 degrees) angle of attack to ensure successful separation. This is the same technique used for RTLS ET SEP. At less than 2 psf, larger angles of attack are acceptable, but the -Z translation must be increased to prevent recontact.

High sink rates during many contingency abort scenarios result in rapid entry into the atmosphere and therefore a rapid q-bar buildup. In most of these cases, there is not enough time for an RTLS-type PPD and a normal mated coast separation sequence. A fast SEP is performed instead, which takes about 5 seconds. The separation is commanded while at a high angle of attack and a -4 degrees per second pitch rate. This technique allows separation to be delayed as long as possible and extends the time available for powered flight. It is initiated when EAS is greater than 7 and increasing (q-bar of about 0.7 psf). The ET SEP occurs prior to the 2 psf limit for high alpha separations. Since the Shuttle is near the alpha required for entry, the -4 degrees per second pitch rate needs only to be slowed as the proper alpha is reached. Maneuvering the Shuttle to a negative alpha for separation would require a second pitch maneuver to recover back to the entry alpha.

The pitch rate used for fast SEP is a compromise between a rapid pitchdown and the need to maintain control and slow the rate after SEP.

> CAUTION
>
> Simulations have shown that pitch rates greater than -6 deg/sec may result in loss of control.

The GPCs will automatically mode to MM 602 10 seconds after structural separation, provided alpha is greater than 10 degrees. After MM 602 transition, V_{REL} is displayed as Mach number on the AMI.

Entry

The powered flight and ET SEP portions of contingency aborts are designed to deliver the Shuttle at acceptable entry conditions without loss of control. Entry phases include:

- Alpha recovery
- N_z hold/pullout
- Alpha-Mach
- Bailout.

In general, reducing ET SEP altitude and H-dot will improve entry conditions. Any errors occurring in powered flight or ET SEP will result in more stressful entry.

Alpha Recovery

Upon ET SEP completion, the orbiter is maneuvered to an alpha that maximizes lift and drag in a manner similar to GRTLS. The appropriate alpha is a function of Mach number and trim. A specific alpha in the range of 20 to 60 degrees is called out for each contingency abort procedure.

In some cases, alpha recovery is accomplished by stopping the -4 degrees per second pitch rate at the appropriate alpha. Since the alpha tape on the AMI pegs at 60 degrees, a maximum alpha of 58 degrees is used.

The body flap is set during the alpha recovery phase before the critical pullout begins. The speed brake and body flap affect hinge moment loads on the elevons.

The body flap can be left in AUTO for $M < 4$ (flight specific), or returned to AUTO after N_z hold. The speed brake is usually left in AUTO.

N_z Hold/Pullout

Shuttle H-dot will continue to increase throughout alpha recovery until sufficient q-bar and the resultant lift are developed for equilibrium flight. As lift increases, N_z will also increase. When $N_z = 1.0$, the Shuttle is developing enough lift to support its own weight, and H-dot will begin to decrease. The maximum negative H-dot is a good indicator of the severity of the entry. It is also used to calculate N_z required for pullout, using the equation:

$$N_z \text{ target} = \text{-H-dot}/1000 + 0.5 \text{ at } N_z = 1.0.$$

This N_z target is calculated by the GPCs and displayed on VERT SIT. The N_z hold/pullout is flown in AUTO, which significantly increases chances of survival. N_z target is a compromise between structural limits and q-bar limits. Approximate limits used are 3.1 g and 800 psfs.

Load factor continues to increase until within approximately 0.4 g of N_z target. A pitchdown is then initiated to hold N_z target. The AMI acceleration tape is scaled in g's in MM 602, with 10 = 1 g, 20 = 2 g, and 30 = 3 g. As alpha is reduced while holding a constant g, q-bar will continue to increase until the sink rate is stopped. When H-dot is positive, pullout is complete, and g load is reduced. The crew can then mode the body flap to AUTO and monitor the alpha/mach schedule.

The N_z hold/pullout is the most critical phase of contingency aborts. Even if flown perfectly, some profiles will exceed structural, temperature, or flight control limits. Target N_z must be maintained tightly.

Most regions of the contingency abort profile have adequate flight control margins. However, there are some regions where even flying the maximum structural load factor limit during N_z hold will not prevent q-bar from exceeding 800 psf, stalling the elevons, and losing control.

Loss of control results from a number of factors. In some cases, aerodynamic moments are so large that the orbiter rates cannot be controlled, even at maximum aerosurface deflection and with maximum jet firings. Additionally, in some cases the aerosurface loads are so large that the actuators cannot drive the surfaces. This is called actuator stall. Flight control gains were designed for a maximum q-bar of 375 psf. Sometimes these control problems can be avoided by flying a higher g-level during pullout, but the best technique is to follow the contingency abort procedures explicitly and engage the AUTO system where it has the capability to execute critical maneuvers.

Alpha-Mach

The crew monitors the alpha-mach phase by making sure the vehicle is at the proper alpha for the Mach number. This information is in a table on the Contingency Abort Entry cue card.

Bailout

An attitude hold mode in MM 603 allows the crew to stabilize the orbiter in gliding flight using the AUTO DAP functions. It is activated when Mach is less than 1.0, the *ABORT MODE* rotary switch is placed to *ATO*, and the *ABORT* push button is pressed.

Guidance snapshots current airspeed and roll angle and attempts to hold both constant. The crew should stabilize the orbiterat 185 to 195 KEAS and zero roll angle, then abort ATO and select *PITCH* and *ROLL/YAW AUTO*. If a new airspeed or roll attitude is desired, select CSS, fly to the appropriate parameters, and reselect AUTO.

Once attitude hold is established, a middeck MS depressurizes the crew module using the emergency vent handle. When cabin pressure is equalized, the hatch is jettisoned, the escape pole is extended, and bailout is commenced.

6.8 SYSTEMS FAILURES

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Depending on flight phase, various Flight Data File documents are used to diagnose, correct, and reconfigure malfunctions of orbiter systems.

- Cue Cards
- Pocket Checklists
- Malfunction Book
- Payload Systems.

Dynamic phases of flight, such as ascent and entry, do not allow leisurely identification and correction of malfunctions. The CDR and PLT flip books, along with the Ascent/Entry Systems book are designed to allow quick response to certain critical malfunctions in order to safe the affected system.

Procedures in the Ascent, Orbit, and Entry Pocket Checklists (PCL) are designed to safe critical systems where malfunctions require a response in less than 5 minutes. Three separate books are used, since actions vary significantly depending upon the flight phase.

On orbit, with the exception of certain systems such as cabin pressurization, most malfunctions can be thoroughly investigated and isolated, and backup systems can be activated. The Malfunction Book provides step-by-step procedures that have been developed to allow a very structured, methodical approach to correcting systems failures.

Since each mission is unique, one or more Payload Systems procedures will be flown to allow the crew to troubleshoot various payload malfunctions.

None of these procedures relieve the crew from understanding how various orbiter and payload systems work and what failures may occur. This in-depth knowledge across a broad range of systems allows a well-trained crew to be confident that nearly all credible malfunctions can be handled without compromising safety or mission success.

The philosophy behind all emergency procedures for the orbiter separates into three categories:

- Detect and confirm the malfunction.
- Ensure a safe configuration.
- Attempt to correct the malfunction or reconfigure to optimize remaining systems.

Many orbiter malfunctions are accompanied by some type of caution and warning alarm. These are designed to help the crew identify the system involved and direct them to the correct procedure. Almost all emergency procedures titles reflect either a hardware caution and warning light or a software fault detection annunciation (FDA) message. It is extremely important to confirm the malfunction with whatever data is available. Sources of data may include dedicated displays, related system malfunctions, or an inventory of failed equipment. Mission Control is often able to provide confirmation, since a great deal more data is available on the ground, and highly trained and knowledgeable controllers are dedicated to each system.

Malfunction confirmation may be complicated by previous failures. Also, the caution and warning system cannot distinguish real failures from sensor failures. Thus, identification of the malfunction and selection of the correct procedure are sometimes a difficult. Only through study, training, and practice in simulators can crewmembers develop the capability to quickly and accurately detect and confirm malfunctions in a vehicle as complex as the orbiter.

Once a malfunction has been identified and the proper procedure selected, the crew takes certain well-defined steps to put the orbiter into a safe configuration. An example is pressing the appropriate *MAIN ENGINE SHUT DOWN* push buttons after a second engine failure to establish single engine roll control. Due to the redundancy of most onboard systems, no immediate action should be required for most single and many dual failures. However, if multiple failures occur, there may be very little time to switch to alternative systems or take the necessary steps to prevent loss of control. In multiple failure cases, the crew must keep in mind the interaction of different systems and prioritize their responses.

Most malfunction procedures involve correcting a malfunction to recover lost capability or remaining systems. In general, switching to backup systems, inter-connecting to components of other systems, or securing some remaining systems to reduce heat loads or power consumption are methods used by the crew.

On orbit, it may be possible to perform in-flight maintenance (IFM) to install replacement components or reconfigure systems. An IFM Checklist covers many of these pre-planned activities. A dedicated team of IFM specialists supports each mission and responds to MCC in the event an IFM procedure is contemplated. Mission Control also excels at developing new procedures in real time to deal with unexpected malfunctions. This capability is frequently exercised during simulations.

This section discusses malfunction signatures and confirming cues for some of the malfunctions that may be encountered during training and in flight. Brief summaries of actions required for safing and reconfiguration are also presented. For more detailed malfunction information, refer to Flight Data File books, Flight Procedures Handbooks, and System Workbooks.

APU/Hydraulics

The APU/HYD cue cards and PCL are used to provide response to APU and HYD malfunctions. During ascent, unless the APU or hydraulic failure could cause a catastrophe, the system will not be shut down until after MECO to avoid interrupting hydraulic power to the main engines. Loss of a hydraulic system in powered flight will result in an SSME hydraulic lock-up. Loss of two hydraulic systems in powered flight will result in two SSME hydraulic lock-ups, one of which will have no thrust vector control (TVC).

APU Failure

- Hydraulic pressure goes to zero
- APU speed goes to zero
- APU SPD HI/LOW message
- *MASTER ALARM*
- *APU OVERSPEED/UNDERSPEED* light on F7
- Accumulator pressure decrease to ~ 2600 psia
- *HYD PRESS* light on F7

Specific software and hardware caution and warnings occurring at the time of failure inform the crew if the shutdown was due to an overspeed or underspeed. MCC uses additional telemetry data to confirm the type of shutdown.

To safe the system, the crew performs the APU SHUTDOWN procedures to remove the start command, close fuel tank isolation valves, and remove power from the APU controller. The remaining APUs may be taken to high speed and auto shutdown inhibited, depending upon flight phase. If sensor problems are involved, reconfiguration of PRL may be required.

If APU shutdown was due to an underspeed, a restart may be attempted after completion of the APU COOLDOWN procedure. An APU that shut down due to an overspeed will <u>never</u> be restarted.

Hydraulic System Failure

- Pressure decrease on both CRT and meter (independent sensors)
- APU speed good

- *MASTER ALARM*
- *HYD PRESS* light
- HYD PRESS message
- Accumulator pressure drops to ~ 2600 psia

Two of the three pressure sensors in each hydraulic system can be seen onboard. MCC receives data from all three sensors. If the hydraulic failure is confirmed, the APU will be shut down to prevent additional damage. The remaining APUs may be taken to high speed and auto shutdown inhibited, depending on flight phase.

Partial hydraulic failure due to a degraded pump or line blockage may produce pressure fluctuations. For ascent, the system is allowed to operate as long as sufficient pressure is available to keep a main engine from going into hydraulic lockup (~1200 psi). During other flight phases, the hydraulic system is taken to low pressure in an attempt to restore stable operation and to ensure that the aerosurface switching valve has selected a "good" hydraulic system for aerosurface actuation. If the system is stable in low pressure, the APU is kept running until an appropriate shutdown time. If the system is required for critical functions such as landing, the system may be returned to normal pressure.

Hydraulic Leaks

- Unexpected drop in reservoir quantity
- *SM ALERT*
- SM2 HYD QTY message

During powered flight, the system is left in normal pressure to prevent SSME hydraulic lockup. At other times, the system is taken to low pressure to reduce leak rate. Normal pressure may be reselected if required. MCC determines leak rate and decides whether or not the system may be returned to normal pressure.

APU Fuel/Nitrogen Leaks

- Unexpected decrease in fuel quantity
- *SM ALERT*
- SM2 APU FUEL QTY message
- Difference in fuel quantity among APUs
- Decrease in fuel pressure

Since fuel and nitrogen leaks are indistinguishable until very low levels are reached, crew response is to assume a fuel leak (worst case). No action is required pre-MECO unless the APU shuts down. For other flight phases, the APU is shut down and the fuel tank isolation valves closed to attempt to isolate the leak. If isolated, the APU is only started for critical operations. If non-isolatable, the APU is restarted and run to fuel depletion. This prevents damage in the aft compartment from leaking hydrazine, which is very corrosive.

Water Quantity Low

- Abnormal decrease in water boiler quantity
- *SM ALERT*
- SM2 W/B QTY message

Water spray boiler nitrogen or water leaks, as well as excessive spraying by a faulty water spray boiler controller can cause an abnormal decrease in water boiler quantity.

MCC can detect excessive spraying, but in any case, the crew should switch to the alternate controller. If switching controllers does not work, boiler power is cycled to reduce water usage. MCC will determine when and if APU shutdown is required, depending on mission phase.

For a water leak, switching controllers will not help, and APU cooling will be lost when the quantity reaches zero. The APU will then overheat within 4 minutes. Nitrogen leaks allow cooling for a short time even after water quantity reads zero. W/B QTY is a PVT calculation.

APU Shifts to High Speed

- APU rpm increases to 113%
- APU SPD HI CRT Message
- *SM ALERT*

An APU shift to high speed can be caused by an APU controller electronic malfunction or an open failure of the Primary Control Valve. The crew will take APU control to high-speed to ensure proper controller logic for high-speed control and check for an rpm transducer bias. If rpm does not shift when the controller is taken to high speed, the failure is real. The APU will be shut down as soon as possible post MECO as long as two other APUs are working properly. APU auto shutdown

must not be inhibited on an APU that has shifted to high-speed since auto shutdown via the fuel tank isolation valves is the only protection from APU overspeed if both control valves were to fail open.

Hydraulic Fluid/Lube Oil Overtemp

- High hydraulic fluid temp
- High lube oil temp
- *MASTER ALARM*
- *APU TEMP* light on F7
- *SM ALERT*
- APU TEMP message
- HYD RSVR T message

Excessive hydraulic fluid temperature (> 230° F) or lube oil temperature (> 290° F) are signatures of inadequate cooling. This may be caused by mechanical problems or a water spray boiler malfunction. The crew should switch boiler controllers first. If APU temperatures decrease, then the problem was in the controller. If temperatures continue to rise, APU shutdown may be required.

An APU will run for 4 to 5 minutes without lube oil cooling. Shutdown and restart may be possible if the APU is required for critical maneuvers. Although the system is not limited in run time for excessive hydraulic temperatures, the system may be taken to low pressure or shutdown in order to maintain the hydraulic fluid below limits that may cause system seal degradation if exceeded.

Fuel Tank Valve Overtemp

- High valve temperature
- *SM ALERT*
- FU TK VLV APU message

When the fuel tank isolation solenoid valves are powered open without fuel flow for cooling, excessive heating can occur. High temperatures may cause hydrazine detonation. The crew should verify the fuel tank isolation valve switch is closed, then open the appropriate circuit breaker on panel R2 to remove power from the valve solenoid.

Priority Rate Limiting

- Possible differing hydraulic pressure on CRT and meter
- *SM ALERT*
- PRL DLMA message
- APU accumulator pressure
- APU speed

Pressure (or sensor) differences within a particular hydraulic system may cause the PRL software to be confused. MCC can see all three sensors in each hydraulic system and will assist the crew with proper actions. The first action is to use confirming cues to determine if the APU is running. Once APU status is known, the crew should verify all good systems are selected for PRL by executing appropriate item entries on the OVERRIDE (SPEC 51) display.

Switching Valve Failure

- MCC call
- Control problems

This failure can prevent the hydraulic systems from operating a control surface. The crew can cycle the affected system hydraulic pressure between *LOW* and *NORM* to attempt to reset the valve upon MCC direction. The other option is to deselect one or more hydraulic system in the PRL software and operate on reduced PRL rates. This will reduce the loads on the good APU(s) and enhance flight responsiveness. This procedure is also performed only at MCC direction.

Uncommanded Brake Pressure

- Brake pressure greater than zero in flight
- *SM ALERT*
- SMO BRAKE P message

Since brake pressure is measured downstream of the brake/skid control module, there is no way to determine which hydraulic system is responsible. Therefore, action to isolate higher pressures from the brakes must be taken on both systems

simultaneously. Landing with pressure greater than 200 psi in the braking system can cause the wheels to be locked at touchdown. This will cause one or more tires to fail, resulting in directional control problems and possible loss of control.

The crew should close the appropriate isolation valves, then reopen them after nose gear touchdown. Since hydraulic system 1 supplies power for nosewheel steering, this procedure is modified for certain cases, and isolation valve 1 is reopened at main gear touchdown.

Communications

The orbiter communications system is extensive and complex. A great deal of redundancy exists, and the system has been very reliable. For normal operations, MCC commands system reconfigurations. Loss of communication can occur for reasons other than onboard equipment, such as ground station or satellite problems and antenna blockage. The crew should consider this possibility as well as their current communication mode, comm panel configuration, and position over the ground prior to executing lost communication procedures.

ICOM Lost

- Inability to communicate using ICOM

This problem is investigated by using the built-in redundancy among audio terminal units (ATUs) before troubleshooting hardware. If the problem remains, the audio central control unit (ACCU) is switched to an alternate power source. A different ATU can also be used, or a different headset.

Comm Lost

- ICOM operating properly
- S-band comm lost on multiple panels
- UHF comm status

The crew should first select ACCU alternate power. If this is unsuccessful, S-band PM panel C3 controls are verified and the crew switches the *S-BAND PM CONTROL* switch to *PANEL*, then back to *COMMAND*. This causes the S-Band PM system to attempt to operate as specified by the panel A1L switches. If this corrects the problem, one of the originally selected S-Band subsystems has malfunctioned.

> **CAUTION**
>
> Panel A1L switches must be set up for the current comm mode.

To troubleshoot antenna problems, manual antenna selection is attempted, using the SIGNAL STRENGTH meter and SM OPS 201 ANTENNA display to monitor signal strength. If comm is not restored, the *ANTENNA* rotary switch on panel C3 is returned to *GPC*, and TDRS mode is configured since it provides the greatest coverage.

An in-flight maintenance procedure is available to bypass a completely failed ACCU.

Finally, the procedure provides steps to determine if MCC can uplink to a GNC GPC for state vector updates. If comm is not regained, the crew may have to deorbit without MCC direction to preserve IMU alignment entry limits.

UHF Lost

- Unable to communicate on UHF

The crew first turns off the UHF squelch system to ensure good signal reception, then an alternate ACCU power source is selected.

Three frequencies are available (259.7, 296.8, and GUARD). All should be tried.

Since the UHF antenna is located on the orbiter's belly, a roll to heads up is performed to ensure optimum antenna gain.

Finally, an in-flight maintenance procedure may be performed to bypass the UHF power amplifier. If successful, a low power transmit mode will be available.

Cryo

The cryo O2 and H2 systems provide reactants to the fuel cells from tanks located under the payload bay. The cryo O2 system also supplies oxygen to the crew module for metabolic use and also for direct breathing while using the LES helmets.

Leaks

- *MASTER ALARM*
- *H2 (O2) PRESS* light (F7 matrix)
- *SM ALERT*
- CRYO O2 (H2) message
- CRYO O2 (H2) PRES message
- Decreasing tank pressure
- MCC call

The first step is to determine the location, then troubleshoot the leak. If pressure decreases in only one tank, then a tank leak is indicated. Check valves should prevent the other tanks from losing cryo. Some cryo in the leaking tank may still be usable, depending on the leak rate. Mission duration may be affected.

A pressure decrease in all tanks requires closing the manifold isolation valves to isolate the leak. Once a potential leak area is isolated to a single manifold, additional troubleshooting may allow further isolation to either the PCS system or an individual fuel cell. Should the leak be in the manifold feeding a fuel cell or in the fuel cell itself, a shutdown and powerdown may be required. Mission duration may be affected, depending on leak location and the mission cryo quantity requirements.

Heater Problems

- *MASTER ALARM*
- *H2 (O2) PRESS* light (F7 matrix)
- *O2 HEATER TEMP* light (F7 matrix)
- CRYO O2 (H2) PRES message
- CRYO O2 HTR message
- High tank temperature
- High tank pressure
- High heater temperature

Cryo heaters can fail on, off, or shorted. A shorted O2 heater will cause tripping of the O2 current sensor logic and disable the affected heater. The fail "on" case may result in high tank temperature or pressure, requiring the affected heater to be turned off.

A failed "off" heater can be caused by a control problem or a failure of the heater itself. MCC will normally alert the crew to this condition. Redundant heaters are used if a heater problem is present. For control problems, a manual heater control procedure is used.

Failure of heaters in two tanks indicates a paired logic problem. For this case, each tank's heaters must be operated individually to determine the location of the failure.

Data Processing System

Hardware and software DPS problems are normally detected by monitoring software and annunciated by the caution and warning system. Failure signatures are presented in a table in this section. Once the failure is identified, the appropriate procedure is worked. The impact of a single DPS failure in other systems is normally a loss of redundancy rather than a loss of capability.

Key safing steps in each procedure are used to prevent commands to good systems from bad computers and prevent good computers from using data from bad components. To correct transient errors, an I/O RESET or power cycle is attempted. For port-dependent failures, the port mode procedure may allow communications to be resumed using alternate ports and a different data bus.

During ascent or entry, when certain DPS failures affect more than one flight-critical string, the MULTI DATA PATH cue card is used to identify failure effects and determine crew actions. For some multiple failures, when Flight Rules allow, the DPS system can be reconfigured using the RESTRING cue card. This procedure allows good GPCs to take over flight-critical buses and components that are lost after one or more GPC failures.

FAILURE	CAUTION & WARNING		PROCEDURE	COMMENTS
	HARDWARE	SOFTWARE		
Fail to Sync	GPC light CAM lights	GPC Fail message Down arrow on SYS SUMM	GPC Fail	GPC continues to send commands over data bus
Fail to Halt	BP Output tb BP Mode tb CAM light GPC light CRT Big X Poll Fail	GPC Fail message Down Arrow on SYS SUMM	GPC Fail	Dead GPC, no commands
Fail to Quit	GPC light CAM light CRT Big X	GPC Fail message Down Arrow on SYS SUMM	GPC Fail	Like fail to halt, except talkbacks (tbs)
Generic PFS Fatal Software Error	Fail to quit or halt on all four GPCs		BFS Engage	
Power Fail	Bp Output tb Bp Mode tb CRT Big X Poll Fail	GPC Fail message Down Arrow on SYS SUMM	GPC Fail	Like fail to halt, but no CAM lights or F7 GPC light
I/O Term B fails on		Down Arrow on SYS SUMM for FF and FA FF and FA I/O Error messages	GPC Fail	GPC running, but commands inhibited on flight critical data buses
I/O Term A fails on		Down Arrow on SYS SUMM for PL1 and PL2 PL1 and 2 I/O Error messages	BFS or SM GPC Fail	GPC running, but commands inhibited on payload and launch data buses
MDM I/O Error at MDM	Varies with MDM	I/O Error message Down arrows on PFS SYS SUMM M's on BFS SYS SUMM	MDM I/O Error	GPC good, MDM lost (at least on current port)
MDM I/O Error at GPC	Varies with MDM	PFS I/O Error message BFS BCE String PASS message Down Arrows on PFS for failed MDM M's on BFS SYS SUMM for FF and FA	MDM I/O Error	Port mode may cause loss of other MDM on string
Component comm problems		BCE String x message M's on PFS and BFS SYS SUMM	BCE String X	Use Ref Data book to find parameters lost and verify signature
OI MDM/DSC Fail	Varies with MDM/ DSC	M's on SYS SUMM for MDM L's on SYS SUMM for DSC I/O Error PCM annunciated by BFS for PCM port problem or MDM problem PASS SM machine will annunciate S62 BCE BYP OF X or OA MSG	I/O Error PCM	

DPS Failure Signatures

Set Splits

Since the GPCs run in a redundant set during ascent, entry, and some on-orbit operations, it is possible for one or more PASS GPCs to split apart from the rest of the set and continue running. Various combinations are possible, but in all cases it is imperative to determine if a good PASS set exists. A good set must include:

- 1 IMU
- 2 RGAs
- 2 AAs
- 2 FCS channels.

Restring or BFS engage is required if a good set does not exist.

NOTE

For ascent only, a 2 vs. 2 set split is ridden to MECO unless control problems exist. Post-MECO, the GPC FAIL procedure is worked for the GPCs identified as failed.

BFS Engage

For unrecoverable PASS failures, the BFS is available to take over orbiter control. Monitoring of BFS and GNC systems status prior to engage is required to ensure the BFS is capable of control. For a successful BFS engage, the BFS must have a good nav state and be able to communicate with/command:

- 1 IMU
- 1 RGA
- 1 AA (for 1st stage)
- 2 FCS channels
- 1 TACAN
- 1 ADTA.

BFS Failures

For most transient failures, the BFS will automatically attempt a software restart. If this is successful, operations will continue, and a GPC BITE message will be issued. A Halt transient results in the BFS restarting in OPS 0, and it must be moded to the appropriate OPS by the crew. Total BFS GPC failures present a signature similar to a PASS GPC FAIL. The crew should see barberpole *OUTPUT* and *MODE* talkbacks, a big X on the BFS CRT, and a POLL FAIL message.

Actions for BFS failures are listed in the appropriate FDF procedures. Since the BFS also controls several systems during ascent and entry, the crew may be required to take manual control of communications or ECLSS equipment. The following table lists some commands issued by the BFS:

SYSTEM	COMMAND	MAJOR MODE
ECLSS	FES on	103
	NH3 on	603, 305
COMM	SPC to TDRS	104
	Antenna	Ops 1, 6, 3
	Other SPCs to ground stations for lost comm	Ops, 1, 6, 3

BFS Commands Over Payload Buses

Environmental Control and Life Support System

Environmental control and life support system (ECLSS) malfunction procedures cover the four subsystems of pressurization, air revitalization, active thermal control, and supply/waste water. Since the ECLSS is highly redundant, the normal response to failures is to switch to the alternate system.

Cabin Pressure

- Klaxon
- *MASTER ALARM*
- Cabin pressure meter
- dP/dT meter
- SM SYS SUMM
- High O2 or N2 flow
- *CABIN ATM* light (F7 matrix)

Crew reaction to cabin leaks consists of four basic steps: assess magnitude of the leak, attempt leak isolation through system reconfiguration, power down, and prepare for deorbit.

The crew first closes cabin relief isolation valves and uses available data sources (CRT displays and meters) to verify the leak. If a leak is confirmed, the leak rate determines whether an ascent abort or an emergency deorbit is required. If enough time is available, additional leak isolation procedures are attempted.

An unexpected cabin pressure increase could be caused by either a PCS leak or a malfunction in the PCS control system. Flight Data File procedures are used to secure the PCS and isolate the failure. An early deorbit may be required for a non-isolatable leak to prevent O2 or N2 depletion. PCS leaks may be either internal or external to the crew module.

Pump/Fan Failures

- Rapid drop in flow rate
- Pressure differential in loop
- Rising temperatures
- *MASTER ALARM*
- Hardware caution and warning
- Fault messages

The normal response is to switch to an alternate pump/fan; however, during powered flight only avionics bay fans and freon pumps are switched. This prevents electrical transients. Should avionics bay temperatures exceed limits, activation of the alternate water loop is also permitted.

Water/Freon Leaks

- Decrease in flow rate
- Change in accumulator pressure
- Decrease in pump delta pressure
- *MASTER ALARM*
- Hardware caution and warning
- Fault messages

Depletion of fluid makes the loop unavailable for cooling. An early deorbit should be expected. On ascent, an abort may be required for the loss of 2 H2O loops or 2 Freon loops.

Fire

- Siren
- Master alarm
- *SMOKE DETECTION* lights on panel L1
- Fault messages
- Smoke concentration on CRT display

If a fire is confirmed by checking the smoke concentration on the CRT display, the crew must protect themselves with helmets using the helmet retention assembly (HRA), then take steps to extinguish the fire. Either a built-in or a portable Halon bottle is discharged to extinguish the fire.

Once the fire is under control, the WCS charcoal filter, ATCO, and LiOH canisters are used to clear the cabin atmosphere of combustion products. If the crew cannot purify the atmosphere to a safe level, then an early deorbit will be required, since the orbiter N2 supply is insufficient to maintain cabin PPO2 below flammability limits for more than 4 to 8 hours while the crew is wearing helmets and exhaling oxygen-rich air.

Cooling Loss

Loss of one or more heat rejection systems (radiators, FES, NH3 boiler) requires a reconfiguration to make up for lost cooling capability while troubleshooting. A powerdown may be required. For severe cooling loss, an early deorbit may be performed.

Electrical Power System

The orbiter EPS configuration during all flight phases is for all buses to be powered and operating independently. Payload and other considerations may mandate bus ties during orbit operations. EPS malfunctions that require an immediate response include reactant valves, fuel cells, major dc buses, dc-ac inverters, and ac motors. Cryo-related problems are discussed in the Cryo section.

Shorts

- High amps
- Low volts
- Hardware caution and warning (F7 lights)
- *MASTER ALARM*
- Fault messages
- CRT displays
- F9 meter

For a confirmed short, power is removed from the affected bus. Circuit protection equipment built into the orbiter may also react to large shorts by tripping RPCs, blowing fuses, or popping circuit breakers.

Most bus shorts are characterized by high current and low voltage. Each bus failure has a particular signature that should be learned through practice in failure recognition in the Single System Trainer (SST). It is important to be able to react quickly and correctly to electrical shorts, particularly during critical flight phases.

> **CAUTION**
>
> Never tie a good bus to a shorted bus while executing malfunction procedures.

Bus Losses

- Bus loss ID in FDF
- Fault messages
- Hardware caution and warning

The following table is an abbreviated list of cues for certain bus losses. When the bus loss is confirmed, an attempt may be made to recover the bus, depending on flight phase, criticality, and the type of failure. If the bus cannot be regained, FDF bus loss actions must be completed to reconfigure and safe systems.

BUS	SIGNATURE
Main	*MASTER ALARM* Hardware caution & warning *MAIN BUS UNDER VOLT* light on F7 matrix Fault messages MN volts = 0 CRT loss FC amps = 0
FPC	*MASTER ALARM* Hardware caution & warning *AC VOLTAGE* light, *FUEL CELL PUMP* light Fault messages AC volts = 0 AC amps = 0 MN volts good CRT loss Pump/motors
AC	*MASTER ALARM* Hardware caution & warning *AC VOLTAGE* light, *FUEL CELL PUMP* light Fault messages AC volts low AC amps low Pumps/motors
ESS	*MASTER ALARM* Hardware caution & warning Fault messages ESS volts low Bus loss ID FUEL CELL light on F7 matrix
CNTL	*MASTER ALARM* Fault message CNTL BUS VOLTS CNTL volts low Bus loss ID
Panel/ Sub Bus	Equipment loss Bus loss ID

Abbreviated Bus Loss Signatures

Fuel Cell Reactant Valves

- *MASTER ALARM*
- *SM ALERT*
- *FUEL CELL REAC* light on panel F7
- SM FC REAC message

If the failure is real, the response (an attempt to open the closed react valve) must be quick to prevent fuel cell loss and subsequent main bus loss. For confirmed reactant valve failures, the affected main bus should be tied and the fuel cell must be shut down. If an O2 or H2 reactant valve fails closed, the fuel cell will fail from lack of fuel within 90 or 30 seconds respectively.

Fuel Cell Cooling Loss

- *MASTER*
- *FUEL CELL PUMP* light (F7 matrix)
- FC PUMP message
- FC coolant pump ΔP talkback barberpole

Fuel cell cooling can be lost for several reasons, including: coolant pump failure, AC bus loss, ECU failure, ESS bus loss, or a fuel cell coolant leak. The fuel cell temperature signatures vary with each failure, but in general, the fuel cell must be secured within 9 minutes to prevent stack overheating. To troubleshoot fuel cell cooling problems, use the following rules of thumb, although each is not applicable in all cases.

- With no sensor failures, a STACK T increase should be accompanied by an EXIT T increase.
- If the coolant pump is not running, EXIT T should increase if the H2 pump is running.
- Both EXIT T and STACK T may be static or decrease if neither the coolant pump nor the H2 pump is running.
- Combined coolant/H2 pump failures may be an indication of an ECU malfunction, or an AC problem affecting both motors.
- Steadily increasing STACK T and EXIT T are indications of a real fuel cell cooling problem.

Fuel Cell Internal Short

- Low fuel cell volts
- Low MN volts
- Reduced FC amps
- Increasing STACK T
- Increasing substack delta volts
- Increased reactant flow.

For this case, the MN BUS UNDERVOLTS procedure is used. The fuel cell is shut down after dropping the affected bus. For a confirmed fuel cell short, the main bus may be regained using the BUS TIE procedure.

Fuel Cell Crossover

- *SM ALERT*
- FC DELTA V message
- Increasing STACK T and EXIT T
- Decrease in FC volts

The FC DELTA V procedure is used to bus tie and safe the fuel cell.

Fuel Cell Shutdown

If a shutdown is required due to a failure or malfunction, the FC SHUTDOWN procedure is used. Upon completion, the appropriate LOSS OF 1 FC powerdown should be performed.

Should a second fuel cell shutdown be required, the 2ND FC SHUTDN procedure is used. In this case, some powerdown is required prior to fuel cell shutdown to prevent excessive loads on the single remaining fuel cell. During ascent, one FC cannot support the load of three main buses, so one main bus will have to be dropped. As before, a LOSS OF 2ND FC power down would be performed after the fuel cell is shut down.

Dual Gas Regulator

- *SM ALERT*
- FC COOL P message
- Reduction or increase in coolant loop pressure

Pressure that is either too high or too low will cause the fuel cell to operate incorrectly, and a shutdown will be required. The BUS TIE procedure is used to prevent loss of an MN bus. Time available before shutdown of the fuel cell varies depending upon the severity of the pressure problem.

Powerdowns

Powerdowns are performed to reduce electrical power consumption and reduce heat loads. The appropriate ascent, orbit, or entry FDF procedure is used. These procedures are designed specifically for each flight phase.

Guidance, Navigation, and Control

The most serious failures in GNC systems are those that affect flight control. It is imperative that the crew manage the flight control system properly in a highl augmented vehicle such as the orbiter. Since stability is negative in many flight regimes, failures in the flight control systems can rapidly deteriorate into a loss of control.

FCS Channel

- *MASTER ALARM*
- *FCS CHANNEL* light on panel F7
- FCS CH message
- Down arrow on GNC SYS SUMM
- Down arrows on SPEC 53 CONTROLS display
- MCC call

Due to system redundancy, no action is required for the first failure. A second failure on the same effector requires the crew to place the remaining channels to *OVERRIDE*. This prevents a good channel from being bypassed in the event of a third failure.

Sensor Failures/Dilemmas

- *SM ALERT*
- Fault message
- Down arrow, "?", or M on GNC SYS SUMM
- Down arrow, "?", or M on sensor displays
- OFF flag on dedicated instruments

For single sensor failures or commfaults, redundancy should allow the good systems to continue to provide data without impacting control system performance. A second or third failure may confuse the FDIR selection filter, requiring crew intervention. MCC can generally resolve sensor dilemmas quickly, using the additional data available in the telemetry stream.

Mechanical

Malfunctions in orbiter mechanically actuated systems such as payload bay doors and latches can be electrical, mechanical, or DPS related. Since many of these systems are critical for entry, it is important to understand each system and troubleshoot correctly.

Motor Failure

All orbiter mechanical systems have two motors for redundancy, and all systems can drive with just one motor. Motor failures can occur due to power failures, control logic failures, software failures, or jams. Failure of a single motor doubles actuation time for the system. Failure of both motors precludes actuation. Workarounds, IFM, and, as a last resort, EVA procedures are available to restore capabilities on some systems.

Indicators

Microswitch failures can prevent automatic system operation or give false indications of a malfunction. Individual readouts of paired microswitches on most mechanical systems allow the crew or MCC to determine actual status of the system and its associated talkback indicators.

Main Propulsion System

MPS failures during ascent can cause degraded performance that may result in an abort. Most cue card procedures must be executed quickly to safe systems and protect against additional failures. Close crew coordination is required, especially where an ascent abort must be executed.

Engine Failure

- *MASTER ALARM*
- Red *MAIN ENGINE STATUS* light on panel F7
- SSME FAIL message

- Pc goes to zero
- Change in acceleration
- Guidance transient
- Reduced helium flow. (Helium flow increases during shutdown and then decreases to zero post shutdown).
- MCC call

The most important step following an engine failure is to ensure the GPCs know that an engine has failed. If the SSME FAIL message has not been annunciated, the crew must push the appropriate *MAIN ENGINE SHUT DOWN* push button to mode guidance. Failure of a second engine with limits inhibited requires shutdown buttons to be pushed to enable single engine roll control.

For any SSME failure, the PLT places the *AC BUS SENSOR* switches to the off position. This protects against other electrical failures causing an engine shutdown. AC Bus sensors are also taken off for AC power problems during ascent and entry, and for loss of main engine controller redundancy.

Helium Leak

- *MASTER ALARM*
- MPS HE message
- HE dP/dT > 20
- Down arrow on BFS GNC SYS SUMM 1
- HE tank pressure lower than other engine tanks

Early in ascent, a cue card isolation procedure is used to secure one He leg at a time. If the leak is isolated, the bad valve is kept closed and MCC evaluates He remaining to determine if a safe shutdown will occur at MECO. It may be necessary to interconnect the pneumatic helium system. Failures later in ascent may require a shutdown using the shut down push button only if there is insufficient time for leak isolation. A push button shutdown requires less Helium than a pneumatic shutdown, since hydraulic pressure is used to actuate some SSME valves.

If a leak cannot be isolated, helium from a previously failed engine may be used as a source of additional helium to prevent a second engine failure. The engine will fail when helium is depleted. Limits must be enabled to ensure a safe shutdown. An early crew-initiated shutdown could also be required, depending on leak rate. MCC will analyze leak rate and recommend action if comm is available. Without comm, the crew uses the procedures on the MPS cue card.

Data Path Failure

- Engine Pc goes to zero
- *MASTER ALARM*
- SSME DATA message
- Yellow *MAIN ENGINE STATUS* light on panel F7
- Acceleration cues
- Helium flow
- MCC call

The onboard software automatically inhibits limits for a data path failure. If the engine is still running, the crew re-enables limits and continues monitoring ascent. If the engine has failed, the shutdown push button must be pressed to mode guidance for the engine failure.

Stuck Throttle

- *MASTER ALARM*
- Yellow *MAIN ENGINE STATUS* light on panel F7
- Static engine Pc
- SSME CMD (HYD, ELEC) message
- MCC call

SSME Pc is frozen in its last position for command path failure, loss of a hydraulic system, computer or sensor failures, and drifting valves. Procedures

for these malfunctions are found on the MPS CMD/HYD/ELEC cue card. Engines with command path failures must always be shut down manually using the MPS controller ac power switches. After shutdown, the shutdown push button is depressed to set discretes that allow software to recognize an engine failure. This is called an AC/PB shutdown. A single engine with a hydraulic or electric lockup will be shut down only if first stage performance is low, and three engines are running.

For single stuck throttle, shutdown time varies for nominal ascent, TAL, and RTLS. The engine is usually shut down shortly before normal MECO to preserve the maximum amount of performance.

If two SSME throttles are stuck due to command path failures, they are shut down one at a time near MECO. The MPS *ENGINE POWER* switches (*AC 1*, 2, and 3) must be used for shutdown, followed by the *MAIN ENGINE SHUT DOWN* push buttons (AC/PB shutdown).

Two hydraulic or two electric lockups will cause the orbiter to exceed three g's in the latter part of ascent. One engine is shut down per the cue card or MCC call to prevent vehicle overstress.

Mixed failures require one engine to be shut down near MECO according to the following failure priority:

1. Command
2. Hydraulic
3. Electric.

ET SEP Inhibit

- *MAIN ENGINE STATUS* lights remain on panel F7
- *SM ALERT*
- SEP INH message

This malfunction can be caused by excessive rates or a feedline disconnect failure. If rates are the problem, the crew damps them manually and allows the automatic separation sequence to occur. Feedline disconnect failures require the crew to close the MPS manifold repress valves to prevent loss of Helium, then execute a manual separation 6 minutes after MECO. For performance problems or aborts, a manual separation may be performed immediately.

ET SEP Switch

- *SM ALERT*
- ET SEP MAN message
- ET SEP AUTO message (RTLS)

The software automatically defaults to a crew-initiated ET SEP if this switch fails to *MANUAL*, except for RTLS aborts where the default is *AUTO*. The switch is overridden using an item number on SPEC 51.

MECO Confirm

- No auto ET SEP
- Glareshield DAP lights remain on
- Panel C3 *ORBITAL DAP* lights remain off
- No software mode transition

A failure of the software to confirm MECO prevents an auto ET SEP. The crew can set a MECO confirm flag in the software by simultaneously pushing all three engine shutdown push buttons, providing no other failures have occurred. The MECO confirm flag may also be set by manually moding the software via an OPS 104 PRO. For multiple failures, there are additional methods to set MECO confirm.

Orbital Maneuvering System/ Reaction Control System

Failures in the OMS/RCS are handled using procedures tailored for the current flight phase. For ascent, achieving a safe orbit while maintaining deorbit propellant margins is the primary concern. On orbit, maintaining at least two deorbit capabilities drive the procedures. During entry, vehicle control is paramount.

Leaks

- Helium pressure decrease, propellant quantity decrease
- MCC call
- *MASTER ALARM*

- *OMS* or *RCS* lighton panel F7
- Leak message

Leaks must first be confirmed, using independent CRT and meter indications, since sensor failures may cause false annunciation. Once confirmed, the crew attempts to isolate the leak by securing the affected system. Control requirements drive the procedure to be used.

Helium tank leaks are identified by a continual He pressure decrease after the system has been secured. For this case, propellant is burned from the affected system to achieve blowdown capability. This amount of propellant remaining (39 percent OMS, 22 percent RCS) allows degraded use of the system even though the remaining helium is depleted.

A helium leg leak can be identified by the He pressure stabilizing after the system has been secured. In this case, the helium isolation valves are manually operated to maintain pressure in the propellant tanks.

If propellant tank pressure continues to decrease when the system is secured, a tank leak is indicated (RCS tank leaks in MM 304 are identified by propellant tank pressure diverging from good tank when the system is secured). The system should be used as long as possible, then crossfeed is established to the other system prior to tank depletion. A burn may be performed to deplete the affected propellant tank, preventing leakage into the OMS/RCS pod where the corrosive propellants could damage other systems.

Manifold leaks and leg leaks are indicated by a pressure drop in the individual manifold or manifold pairs after leak isolation. In general, the leaking manifold/leg will be left secured and operations will be continued using the good systems.

Regulator Failed High

- Pressure increase in OMS/RCS system
- *MASTER ALARM*
- *OMS* or *RCS* light on panel F7
- OMS or RCS TK P message

He isolation valves are closed per the appropriate procedure and troubleshooting performed to isolate the bad regulator.

OMS Engine/Propellant Failure

- *MASTER ALARM*
- Drop in OMS Pc and/or increase in OMS injector temperature
- Reduced acceleration
- Down arrow on MNVR display
- OMS ENG PC message
- *OMS* light on panel F7

Depending on flight phase, the appropriate OMS BURN MONITOR cue card is used. Engine oxidizer/fuel inlet pressure is analyzed to determine whether the failure is real and if it was caused by a propellant problem upstream of the engine (PRPLT FAIL) or problems within the engine itself (ENG FAIL).

For engine failures, the remaining propellant can be used by the other engine or the RCS by setting up a crossfeed/interconnect. Propellant failures are more severe, since the remaining propellant is probably unusable. In some cases, where a partial blockage exists, it may be possible to feed the RCS jets using the remaining OMS propellant due to the reduced flow rate requirements.

RCS Jet Failures

- *MASTER ALARM*
- *RCS* light on panel F7
- RCS XJET FAIL message
- GNC SYS SUMM indications
- SPEC 23 RCS display indications

Jets can fail off, on, or leak. False annunciations may also occur.

For a failed "on" jet, the RCS manifold must be quickly secured to prevent propellant depletion. If the failure was real, pressure will decrease in the affected manifold.

Since the RCS jets have a great deal of redundancy, a single failed off jet usually has no major effect. The remaining jets take over per the software jet select priority. MCC will examine the telemetry data to determine whether the failure is a transducer or an actual jet problem. If required, the jet may be reselected so that the DAP will attempt to fire it again.

When a jet fail leak is annunciated, the crew and MCC examine available data to determine if the leak is real or an instrumentation problem. For actual leaks, the appropriate manifold is secured only if the leak is large enough to cause a quantity divergence.

Interconnect/Crossfeed

Crossfeed valves and lines allow crossfeeds between the left and right OMS pods or left and right RCS pods. The crossfeed valves and lines also allow the OMS and RCS systems to be interconnected. Placing the OMS/RCS switches in *GPC* allows the software to automatically reconfigure these valves and establish OMS/RCS interconnects for abort dumps and RCS crossfeed for large RCS leaks. The software will also automatically deselect manifolds and reconfigure the system for DPS and electrical failures for some ascent aborts.

Generally, the automatic reconfiguration can handle single failures and some multiple failures for ascent aborts. The crew must ensure that valves are configured correctly to prevent inadvertent propellant depletion or loss of control.

When the systems are being operated in an interconnect or crossfeed mode, failure isolation becomes much more complex. If conditions permit, it is better to secure the OMS/RCS systems entirely prior to attempting trouble-shooting procedures.

OMS Gimbal

- *MASTER ALARM*
- *OMS TVC* light on panel F7
- OMS GMBL message
- Downmode to secondary gimbal

Either a gimbal failure or its data path cause this annunciation. For either case, operation on the secondary gimbal is initiated. A second gimbal failure may require securing the OMS engine if control problems exist. Should the OMS engine be pointed near the orbiter's c.g., then the RCS and the remaining OMS engine may be able to maintain control.

A gimbal failure that occurs while a burn is not being performed may be overcome if the remaining gimbal system can be used to position the engine through the c.g. Gimbal power is then removed via an item entry on the MNVR display. The procedure protects against additional failures that might make the engine unusable.

6.9 MULTIPLE FAILURE SCENARIOS

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This section briefly describes multiple failures that may be encountered during training. Although the potential for these failures in flight is very low, they allow flight crews and MCC personnel to exercise their knowledge of orbiter systems. For each case,. crew actions are noted after the multiple failure is discussed.

MPS He Leak with APC/ALC Failure

A failure of APC 4 (5,6) or ALC 1 (2,3) causes the A helium isolation valve on the L (C,R) main engine to close. Should a helium leak subsequently occur, and isolation procedures are attempted, closing the B helium isolation valve on the affected engine would result in an unplanned engine shutdown.

With an APC/ALC failure during powered flight, helium leak isolation must not be performed on the affected engine. A helpful cue that an APC has failed is the ullage pressure indication directly below the Helium dp/dt readout on BFS GNC SYS SUMM. With an APC/ALC down, LH2 ullage pressure reads 12.06, and LO2 ullage pressure reads 0.0 beneath the affected engine.

MPS He Leak with Degraded/ Failed SSME

MCC evaluates leak rate to determine if it is acceptable to interconnect to the leaking engine helium supply to avoid a contingency abort. The degraded SSME may be shut down early to extend run time of the engine with a helium leak. Due to insufficient onboard information, the crew must await an MCC call for these cases.

Set Splits/MPS

Certain types of GPC set splits (2V1V1 or 2V2 with additional MPS electronic failures) can cause MPS command and data path problems or inhibit ET SEP. The situation is further complicated on an ascent abort or if any additional DPS or EPS malfunctions have occurred. Should a set split occur, the crew must monitor the engines closely and be ready to back up MECO with the engine power switches. Restring or BFS engage may be required for throttling or ET SEP if hidden failures are present. The MPS multiple data path cue card provides useful information in set split cases even though it is designed to cover only two DPS string failures.

Stuck Throttle in the Bucket

MCC uses the ARD to evaluate uphill capability for this case. Depending on throttle level and actual performance, it may be possible to continue into orbit. If not, downmode preference is TAL followed by RTLS. This is a real time call and can only be made by the MCC.

Second Hydraulic Failure and 1 SSME Failed

Loss of two APUs or hydraulic systems during ascent causes a loss of TVC on one SSME. If another engine fails, the non-gimbaling engine may have to be shut down also to prevent loss of control. Simulations have demonstrated a high probability of control problems with two engines running and one non-gimbaling.

Two APUs/Hydraulic Systems

Loss of two hydraulic systems will affect flight control for landing, since aerosurface rates are reduced. Abrupt maneuvers should be avoided to prevent control system saturation. After main gear touchdown, a 10 KEAS early derotation may prevent a hard nose gear slapdown.

APU 1 and Multiple Prox Box Failures

Either hydraulic system 1 or one of the landing gear proximity boxes is required to deploy the landing gear. APU 1 provides power for hydraulic system 1, which performs hydraulic gear deploy. Pyrotechnic backup is provided by either prox box. One of these three systems is required for a successful gear deploy.

If two of these systems are failed, attempts will be made to recover at least one of them by repowering failed buses, resetting RPCs/circuit breakers, using a hydraulic circulation pump or restarting APU 1. Failure of both prox boxes results in all landing gear talkbacks remaining barberpoled. Gear deployment verification may not be possible via physical cues.

NOTE

Bailout is preferred over a gear up landing attempt.

Two Freon/Water Loops

Loss of cooling capability requires an emergency deorbit. Procedures are contained in the FDF CONTINGENCY DEORBIT PREP or the SYSTEMS AOA books for losses during ascent. It is extremely important to understand the related powerdown procedures for these cases and perform them expeditiously. Successful entry and landing depend on proper execution of the powerdowns.

Total Loss of FES

Complete loss of the FES during ascent requires an emergency payload bay door opening to obtain adequate cooling. Either the BFS or an SM GPC is used, depending on urgency and what other malfunctions are present.

If the FES has failed on orbit, the payload bay doors will be closed as late as safely possible prior to entry. The ammonia boiler will be activated as soon as possible for cooling during entry. Minimum acceleration of 0.05 g is required for ammonia boiler operation. Due to entry heating and lack of cooling with a FES failure, orbiter temperatures will rise to high levels between payload bay door closing and ammonia boiler activation.

Total Loss of FES with BFS Failure

In order to accomplish emergency payload bay door opening with BFS failed, it will be necessary to either IPL a new BFS machine using the BFS GPC IPL procedure in the Ascent Pocket Checklist or transition a PASS GPC to SM OPS 2 using nominal post insertion procedures. MCC and the crew will work together to pick the best course of action depending on the time available, progress through post insertion when failures occur, and other system failures.

Two Fuel Cells

On orbit, all three main buses may be tied upon completion of the LOSS OF 2 FC POWERDOWN. During ascent or entry, the cue card or Pocket Checklist powerdown is performed, but one main bus will remain unpowered to prevent overloading the remaining fuel cell.

Both OMS

RCS is used to perform the remaining ascent and deorbit burns. If RCS is insufficient to accomplish a safe orbit insertion or deorbit, then RCS capability will be used to obtain the best performance possible. A staged deorbit burn using aerobraking to provide some of the deorbit deceleration may be possible.

OMS/RCS Leak with DPS/EPS Failures

Electrical failures affect the capability to operate the motor-driven OMS/RCS valves, and DPS failures affect software commands to the valves. EPS failures especially compromise leak isolation capability. If time permits, the OMS/RCS sliderule is used to determine which valves are operational for various failures. Some workarounds are available.

To work around a tank isolation valve that cannot be closed, the corresponding helium isolation valve should be closed. As pressure decreases in the affected propellant tank, flow will occur preferentially from another higher pressure tank.

During entry after q-bar = 20 psf, to attempt leak isolation, NO YAW JET may be temporarily selected and the entire RCS system secured. Even though some valves may remain open due to DPS/EPS failures, it still may be possible to isolate the leak if no jet fire commands are issued.

NOTE

Although NO Y JET is certified at q-bar = 20 psf, it would be best if the RCS system is not secured until q-bar = 40 psf. Before q-bar = 40 psf, it is possible for a pitch jet to fire. With an RCS system only partially secured due to an EPS failure, evacuated tank legs are possible. This would complicate leak analysis due to a jet firing.

For some control bus failures, it is possible to actuate OMS/RCS valves using GPC commands. The master crossfeed, automatic crossfeed, or a software read/write procedure is used to command the valve.

MDM failures can cause the GPCs to lose RCS status information. This may result in good jets being declared failed or unavailable by the RM software. Using item entries on SPEC 23, it may be possible to override the software to the correct status and regain RCS jets or prevent firing a failed jet or jets on a failed manifold.

Cryo Leak with Failed Manifold Valve

A bus tie and fuel cell shutdown may be required to isolate the leak. The PCS systems may also be secured individually to assist in leak isolation. The manifold valve may be closed if the failed bus can be temporarily powered or an IFM performed. If the valve cannot be closed or the leak isolated, then two fuel cells will be lost when the cryo H2 or O2 is depleted. Emergency deorbit or ascent abort may be required, depending on leak rate.

BFS Self Engage

While this is not a multiple failure per sé, certain failure modes of the Backup Flight Controller and the BFS GPC can put the BFS one failure away from self engage. Should this occur, the crew must be aware that moving the BFS *OUTPUT* switch out of *BACKUP* could result in a self engage.

6.10 SWITCH AND PANEL CAUTIONS

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Because the design of some orbiter controls is very similar, when they are placed in close proximity, inadvertent actuation can occur. Training, along with close attention during high workload tasks, will minimize these problems. This section discusses several potential areas where crewmembers should exercise caution to avoid pitfalls. By being aware that these situations exist, crewmembers can execute time-critical procedures confidently.

MPS Switches

The six *ENGINE POWER* switches and the six *He ISOLATION* switches are located in adjacent rows on panel R2. The switches are very similar except for a yellow band around the six power switches. Caution should be exercised during MPS helium leak isolation or SSME shutdown procedures.

Fuel Cell Reactant Valves

Due to panel design, which represents a schematic of the PRSD and FC systems, the *FUEL CELL REAC* valve switches are arranged in a 1-3-2 order (1 on top, 3 in the middle, 2 on the bottom) on panel R1. Closing the incorrect reactant valve results in the loss of a second fuel cell and possibly two main buses.

CRT Power Switch

The *CRT POWER* switches on panel C2 are adjacent to the *MAJOR FUNC* switch. This makes it relatively easy to power off a CRT when intending to switch major functions.

GPC/MDM

During ascent and entry, these switches on panel O6 are very difficult to reach. They are also very similar in appearance. When executing DPS malfunction procedures, it is important to ensure the correct switch is actuated. One technique is to have the MS2 verify that the CDR has selected the correct switch prior to actuation.

PLB Mech Power/Enable

These switches are located adjacent to each other on panel R13L and perform entirely different functions. Due to their similar nomenclature and same appearance, they are easily confused. The *PL BAY DOOR SYS ENABLE* switches are used during PLBD opening/closing. The *PL BAY MECH PWR SYS* switches are used for other mechanical systems in the PLB (such as radiators, PRLAs, RMS, etc). A careful procedure crosscheck will avoid problems.

HYD Press and APU Controller Power Switches

The *HYD MAIN PUMP* and APU *CNTLR PWR* switches look similar and are in adjacent rows on panel R2. It is easy to confuse these two switches during the APU shutdown procedure or when taking a hydraulic system to LOW PRESS.

OMS Kit

OMS Kit switches are on the left side of panel O8. It is easy to confuse the *OMS KIT* switches with the *LEFT OMS* switches.

6.11 SYSTEMS FAILURE SUMMARY

This section summarizes actual, in-flight failures that have occurred in the Shuttle program. It includes major systems and selected repeat failures important to the crew. The purpose is to give crewmembers a feel for the type and severity of equipment failures and their potential impact on operations. Complete lists of anomalies and failures for both flight and ground operations are available from the Orbiter Project Office. Failures are presented by system, with the mission number identified where the failure occurred.

SYSTEM	FAILURE	CAUSE	MISSION NUMBER(S) WHERE FAILURE OCCURRED
APU/HYD	• APU lube oil temp high • Two APUs underspeed shutdown • APU shifted to high speed • Hydraulic leak on entry • APU underspeed – FCS checkout	• WSB ice • Hydrazine leak and fire • Failed control valve • Leak in pump hose • Valve contamination	• STS–2, 3, 38 • STS–9 • STS–31 • STS–36 • STS–7
COMM	• Loss of KU antenna gimbal and stow control • TAGS Jam	• Loose screw and circuit burnout • Paper jam	• STS–41G • STS–27, 33, 30, 32, 31, 35
CRYO	• O2 Leak	• PCS O2 restrictor installed backwards	• STS–41D
DPS	• BFS failed pre-launch • GPC 1 and 2 failed • GPC 5 failed • GPC 4 failed on orbit • MDM OF3 failed pre-launch • MDM port failure • MDM failure pre-launch	• Failed string tracking • Chip contamination • Engage term errors (32) • Failed to sync; changed on orbit • Component contamination • Power supply fail (34) • I/O errors	• STS–1, 41D • STS–9 • STS–51I, 32, 38 • STS–30 • STS–2 • STS–51G, 34 • STS–40
ECLSS	• FES shutdown	• Ice, temp transducer, or thermal transient	• STS–41G, 51D, 51B, 26, 29, 30, 34, 33, 36, 31, 41
EPS	• Hum Sep signal conditioner B circuit breaker popped • TAGS cable arcing • Fuel cell 1 failed • Fuel cells produced excessive hydrogen	• Wire bundle short • Cable short • H2 pump fail due to blockage • H2 entrainment in new filter screen	• STS–6 • STS–28 • STS–2 • STS–9
GNC	• IMU 1 failed • Spurious IMU accelerometer output • 3 deg/sec vehicle yaw rate during crew sleep • Radar altimeter loss of lock/intermittent lock • TACAN no lock up	• Power supply failed • Accelerometer component shift • Bad state vector uplink • Transmission system malfunction • Low receiver sensitivity	• STS–9 • STS–32, 40 • STS–32 • STS–1, 5, 7, 51A, 51C • STS–1, 5, 7
Mechanical Systems	• PLBD would not close • Brake damage on landing	• Thermal warping • Inadequate brake capacity	• STS–3, 4 • STS–5, 6, 7, 41C, 41G, 51A, 51C, 51D, 61C
MPS	• Pad abort after SSME start • Launch scrub • 14,000 lbs of LO2 drained from ET pre-launch. Launch held due to strange LO2 temp indications in engine • Orbiter/ET/SRB structural breakup • SSME failed (auto shutdown) ATO	• Engine valve slow to open • Various component failures • Operator error • Right SRB lower field joint burnthrough • Failed sensor	• STS–41D • 51E*, 61C, 30, 34, 35 • STS–61C • STS–51L • STS–51F
OMS/RCS	• OMS cracks discovered post flight • Left OMS pod burn through • Loss of verniers • RCS jet failed off • RCS jet failed leak • RCS Reg leak	• Launch stresses • APU detonation and fire • F5L and F5R leak • OX valve failed/clogged Pc tube/ main poppet stuck/He ingestion • Leaks • Helium leaks	• STS–5 • STS–9 • STS–28 • STS–5, 9, 41G, 51G, 51I, 29, 30, 33, 31, 35 • STS–8, 9, 51A, 51C, 51D, 61C, 28, 31 • STS–5, 8, 41G, 61C

* Mission cancelled.

Systems Failure Summary Chart

7. TRAJECTORY MANAGEMENT AND FLIGHT CHARACTERISTICS

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This section presents Space Shuttle flight characteristics and trajectory management during powered flight, on-orbit, re-entry into the atmosphere, approach, landing, and rollout. Some guidance and navigation information is included so the crewmember will be acquainted with the parameters that are important in influencing flight control. Much of the information was supplied by crewmembers who have flown the Space Shuttle. Additional information was derived from simulator runs in the Shuttle Mission Simulator, Shuttle Engineering Simulator, and Vertical Motion Simulator.

For each flight phase (ascent, orbit, entry), manual control techniques are presented, along with information on vehicle handling qualities, performance monitoring, and takeover criteria.

For detailed information on these subjects, consult the appropriate Flight Procedures Handbooks, Flight Data Files, or Flight Rules.

Each subsection discusses the primary controls and displays used during each flight phase. When used, external devices, such as runway lighting, ball-bar, and aimpoints, are integrated with the flight crew techniques in order to present a coordinated picture to the crewmember.

Where the backup flight system (BFS) differs from the primary avionics system software (PASS), (also called primary flight system (PFS)), BFS characteristics are discussed separately. This generally applies to ascent and entry flight phases, since the BFS has limited capability on-orbit.

Each subsection concludes with rules of thumb.

7.1 ASCENT

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Powered Flight

During powered flight, the crew monitors orbiter performance and system status using dedicated displays, CRT displays, and cue cards. This section describes the displays used, the monitoring task, takeover criteria, and manual control.

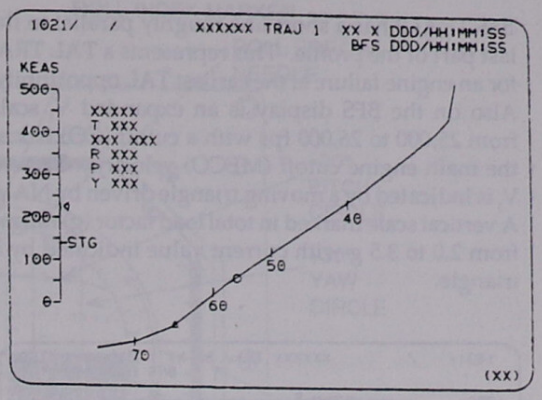
CRT Displays

Several types of CRT displays are used to monitor vehicle performance during powered flight. For a more detailed description of the displays presented here, refer to the Flight Procedures Handbook and DPS Dictionary.

GNC TRAJ Displays

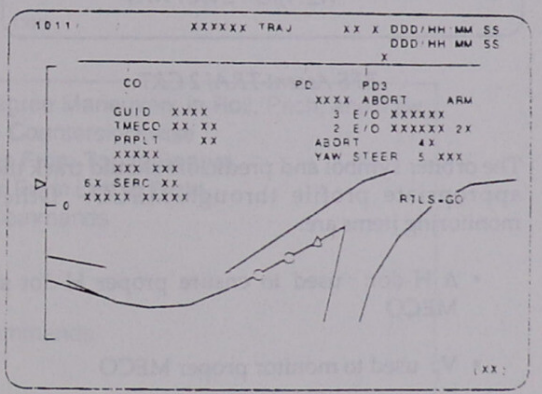
In first stage, BFS ASCENT TRAJ 1 displays a nominal trajectory plot with altitude on the y-axis and relative velocity (V_{REL}) on the X-axis. Altitude scale is from 0 to 170,000 ft and velocity from 0 to 5,000 fps. Tick marks on the profile show attitude director indicator (ADI) pitch attitudes at appropriate reference points. Orbiter state (from NAV) is displayed by a moving triangle with a 20 sec predictor circle. An airspeed scale is marked with speeds, and the current knots equivalent airspeed (KEAS) is shown by a triangle. A staging (STG) tick mark denotes maximum q-bar for SRB SEP.

This display, along with the ascent cue cards, is used to monitor first stage trajectory.



BFS Ascent TRAJ 1 CRT

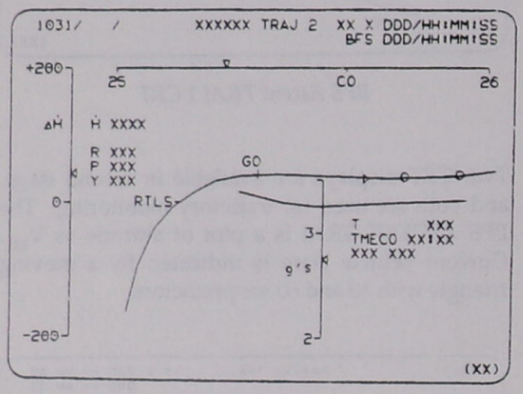
Two CRT displays are available in second stage, and both are used for trajectory monitoring. The PFS ASCENT TRAJ is a plot of altitude vs V_{REL}. Current vehicle state is indicated by a moving triangle with 30 and 60 sec predictors.



PFS Ascent TRAJ

Both altitude and velocity data are supplied by NAV. BFS ASCENT TRAJ 2 is automatically displayed at transition to major mode (MM) 103. The profile represents a nominal second stage ascent with altitude vs inertial velocity (V_I) as the axes. Altitude scale ranges from 140,000 to 525,000 ft and velocity from 5,000 to 26,000 fps. Both PFS and BFS displays have tick marks at the last return-to-launch-site (RTLS) boundary and the point (GO) where no action is required for a single engine failure. The

BFS TRAJ 2 has a short line roughly parallel to the last part of the profile. This represents a TAL TRAJ for an engine failure at the earliest TAL opportunity. Also on the BFS display is an expanded V_I scale from 25,000 to 26,000 fps with a cutoff (CO) tick at the main engine cutoff (MECO) velocity. Current V_I is indicated by a moving triangle driven by NAV. A vertical scale marked in total load factor (g) ranges from 2.0 to 3.5 g with current value indicated by a triangle.



BFS Ascent TRAJ 2 CRT

The orbiter symbol and predictors should track the appropriate profile through MECO. Other monitoring items are:

- Δ H-dot: used to ensure proper H-dot at MECO
- V_I: used to monitor proper MECO
- g: used to monitor throttling.

NOTE

TRAJ DISPLAY titles change to include the abort mode when an ascent abort is executed.

GNC SYS SUMM Displays

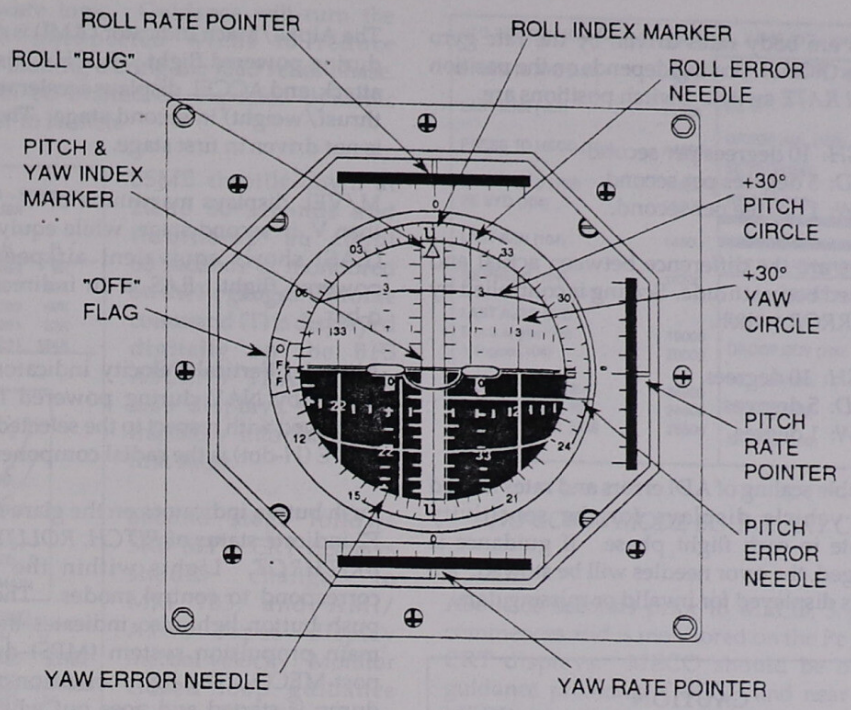
GNC SYS SUMM displays are the principal means of monitoring flight-critical systems. They should be scanned frequently during ascent to verify system status and aid in determining causes for alarms. The BFS also supports a THERMAL display and two SM SYS SUMM displays. These are accessed by placing the BFS CRT *MAJ FUNC* switch to *SM*. These displays should also be scanned frequently to detect impending system problems and are also used to deal with orbiter systems problems during ascent. CRT displays are presented in Appendix B.

OVERRIDE Display

The OVERRIDE display (SPEC 51) allows the crew to deselect/reselect certain line replaceable units (LRUs) to solve a redundancy management (RM) dilemma or to force RM to consider a previously deselected LRU. The OVERRIDE display also contains various software switches that may be used to override dedicated switch failures, controls for OMS and reaction control system (RCS) dumps, and several other additional functions.

Dedicated Displays

Dedicated displays are also used during ascent to monitor Shuttle performance.



Attitude Director Indicator Displays 360-Degree Maneuvers in Roll, Pitch, and Yaw

- Positive Roll Command - Ball Rotates Counterclockwise
- Positive Pitch Command - Ball Rotates From Top to Bottom
- Positive Yaw Command - Ball Rotates From Left to Right
- Error Needle Deflections to Positive Commands
  - Roll - Left
  - Pitch - Down
  - Yaw - Left
- Rate Pointer Deflection to Positive Commands
  - Roll - Right
  - Pitch - Up
  - Yaw - Right

Attitude Director Indicator

Attitude Director Indicator

The attitude director indicator (ADI) displays attitude, rates, and error information and is used in combination with the CRT displays and cue cards. ADI attitude depends upon the position of the *ADI ATTITUDE* switch on panel F6 or F8. Switch positions are:

- *REF*: reference frame based on nominal launch azimuth at lift-off (can be redefined)
- *LVLH*: Earth-referenced pitch/roll
- *INRTL*: referenced to Mean of 1950 (M50) inertial frame (see Section 2.13 for reference frame definitions).

ADI rates are body rates driven by the rate gyro assemblies (RGAs). Scaling depends on the position of the *ADI RATE* switch. Switch positions are:

- *HIGH*: 10 degrees per second
- *MED*: 5 degrees per second
- *LOW*: 1 degree per second.

ADI errors are the difference between actual and commanded body attitude. Scaling is controlled by the *ADI ERROR* switch.

- *HIGH*: 10 degrees
- *MED*: 5 degrees
- *LOW*: 1 degree

The available scaling of ADI errors and rates is used to tailor vehicle displays for the sensitivity appropriate in each flight phase. If guidance is unconverged, the error needles will be stowed. An OFF flag is displayed for invalid or missing data.

> **CAUTION**
>
> ADI malfunctions can occur without tripping the OFF flag. Crosscheck other displays during ascent to confirm performance is appropriate for the displayed attitude.

The horizontal situation indicator (HSI) is used to monitor AUTO guidance and provide information needed by the crew to fly manually. HSIs provide a geometric view of orbiter location with respect to various NAV points. During powered flight, the HSI displays data relative to the target insertion orbit.

North on the compass card is the desired insertion plane. Heading of the body +X axis with respect to desired insertion plane is read at the lubber line. The difference between current heading and north is vehicle yaw. A course pointer indicates heading of V_{REL}, while the course deviation indicator shows estimated sideslip (the angle between body X-axis and V_{REL}). The primary bearing pointer indicates heading to the selected runway for TAL and RTLS aborts only. It is not driven in first stage. Heading of V_I with respect to target insertion plane is indicated by the secondary bearing pointer.

The Alpha/Mach Indicator (AMI) is driven by NAV during powered flight. ALPHA displays angle of attack, and ACCEL displays acceleration (computed thrust/weight) in second stage. The ALPHA tape is not driven in first stage.

M/VEL displays magnitude of V_{REL} in first stage, then V_I in second stage, while equivalent airspeed (EAS) shows equivalent airspeed throughout powered flight. EAS is an indirect indication of q-bar.

Altitude/Vertical Velocity Indicators (AVVIs) are driven by NAV during powered flight. ALT is displayed with respect to the selected runway. ALT RATE (H-dot) is the radial component of V_I.

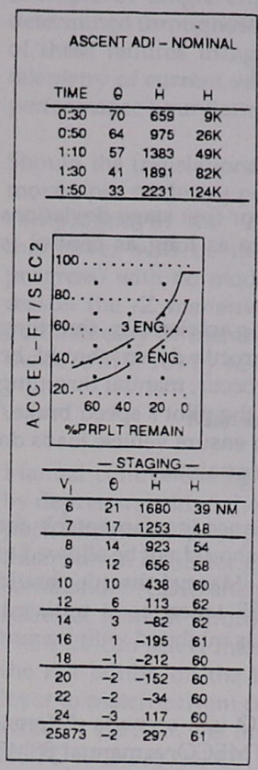
Push button indicators on the glare shield on panel F2 indicate status of *PITCH*, *ROLL/YAW*, and *SPD BK/THROT*. Lights within the push buttons correspond to control modes. The *BODY FLAP* push button light also indicates the status of the main propulsion system (MPS) dump sequence post-MECO. The light comes on when the MPS dump is started and goes out when the dump is complete. All other push buttons extinguish at Space Shuttle main engine (SSME) zero thrust (MECO confirmed +3.75 sec). The *BFC* light illuminates when the BFS is engaged and flashes when the BFS is standalone.

Powered Flight Monitoring

Sequential SSME start is monitored on the chamber pressure (Pc) gauges on panel F7. After solid rocket booster (SRB) ignition (about 7 seconds after SSME start) the orbiter should perform a vertical rise for about 8 seconds, followed by a combination roll, pitch, and yaw maneuver onto the launch azimuth. Roll attitude on the ADI should be 180 degrees upon completion. Switch *ADI ATT* from *REF* to *LVLH* after the roll is complete to obtain proper pitch/roll attitude information. *REF* is used for lift-offs to avoid large ADI movements at the LVLH 90-degree pitch singularity.

Throughout first stage, the crew monitors the parameters listed on the ASCENT ADI cue card (especially attitude) and also vehicle rates. Some deviation of the error needles during first stage can be expected due to load relief, but the error needles may not recenter precisely and veto differences in the load relief flight software and error needle

display software logic. Guidance will turn the vehicle into unexpected winds to reduce aerodynamic loading during the load relief phase. The crew will be briefed on expected dynamic response prior to launch.



ASCENT ADI – NOMINAL

TIME	θ	Ḣ	H
0:30	70	659	9K
0:50	64	975	26K
1:10	57	1383	49K
1:30	41	1891	82K
1:50	33	2231	124K

— STAGING —

V_i	θ	Ḣ	H
6	21	1680	39 NM
7	17	1253	48
8	14	923	54
9	12	656	58
10	10	438	60
12	6	113	62
14	3	–82	62
16	1	–195	61
18	–1	–212	60
20	–2	–152	60
22	–2	–34	60
24	–3	117	60
25873	–2	297	61

ASCENT ADI Cue Card

SSME throttle-down at 20 to 30 seconds and throttle-up at about 60 seconds is monitored on the Pc gauges. Throttle command (T) is displayed digitally on the BFS ASCENT TRAJ, which also displays the only trajectory information in first stage.

Second stage follows SRB SEP. CRT displays should change to MM 103, and AMI/AVVI tapes display inertial velocity. Monitor closed loop guidance convergence by noting that the time of main engine cutoff (TMECO) on the PFS and BFS CRT displays is within a few seconds of the expected MECO time.

The BFS ASCENT TRAJ 2 and the dedicated displays are used to monitor trajectory during second stage. Continue to compare displayed data with the ASCENT ADI cue card. The PFS ASCENT TRAJ is primarily used during an RTLS.

The crew must be continuously aware of the orbiter's abort mode status. Boundaries are monitored by Mission Control Center (MCC) based on tracking data and projected vehicle performance capability as computed by the abort region determinator (ARD) program. Boundaries are transmitted to the crew by the capsule communicator (CAPCOM), but the crew should use the NO COMM MODE BOUNDARY cue card to maintain onboard status if communications with MCC are lost. Boundaries listed on the CONTINGENCY ABORT cue cards should also be monitored.

NEG RETURN (104)	8300	2 ENG BYD (104)	6400
PRESS TO ATO (104)	9300	ABORT TAL BEN	
LAST MRN (104)	11300	EO VI	
PRESS TO MECO (104)	11500	DROOP AML (109)	11400
		SE BYD (109)	
DROOP BYD (109)	11300	SE BEN (109)	
SE BYD (104)	13700		
LAST BEN (104)	14600		
SE PRESS (104)	18200	2 ENG MRN (104)	7000
		ABORT TAL MRN	
LAST AUTO BYD		EO VI	
2 or 3 engine (65)	19000	DROOP GDV (109)	
1 engine (104)	20000	SE BYD (109)	
LAST LATE TAL BYD	24600	SE BEN (109)	
LAST LATE TAL KIN	24900	SE MRN (109)	
LAST LATE TAL HDS	25500		

NO COMM MODE BOUNDARY Cue Card

About 60 seconds prior to MECO, 3 g throttling commences and is monitored on the Pc gauges and CRT displays. MECO should be observed at guidance predicted TMECO and near the design MECO velocity on the AMI. All three red *MAIN ENGINE STATUS* lights on panel F7 will come on for a nominal MECO, and the *ORBITAL DAP* push button lights on panel C3 will illuminate when MECO confirmed is set in the GPC software.

AUTO ET SEP should occur at MECO +18 seconds and is indicated by the red *MAIN ENGINE STATUS* lights going out. A SEP INH message indicates vehicle rate in any axis exceeds 0.7 degrees per second or failure of a feedline disconnect valve to close. For rate exceedance, wait for rates to damp, and separation (SEP) will occur automatically. Feedline disconnect failure is handled using cue card and checklist procedures to perform a delayed ET sep..

After external tank separation (ET SEP), an automatic -Z translation occurs to obtain -4 ft/sec ΔV and move the orbiter away from the external tank. Upon completion, the crew should observe software transition to MM 104 by the appearance of the MNVR displays on the CRTs.

Takeover Criteria

During powered flight, the crew should be prepared to take whatever action is necessary in off-nominal situations in order to preserve safety and mission success. The Flight Rules define potential takeover criteria. These rules are built into the Flight Data File cue cards and checklists.

The most serious situations involve control problems. In many cases, these are time-critical and an FCS downmode (control stick steering (CSS) or BFS engage) must be rapidly performed. Downmode is an onboard decision that may be made for:

- Impending loss of control
- Failure of an expected maneuver to occur
- Unexplained attitude/rate excursions or undamped oscillatory motions.

If the roll maneuver is not initiated as scheduled, auto guidance is considered no-go, and a BFS engage should be performed.

Throughout first stage flight, rate excursions are a parameter requiring crew action. Prior to 90 seconds, if pitch or yaw rates exceed 5 degrees per second, the crew should engage BFS. After 90 seconds, the crew should select CSS, followed, if necessary, by BFS engage.

> CAUTION
>
> With manual throttle control selected, an automatic guided MECO will not occur. To obtain the correct MECO velocity, the main engines must be shut down manually. In low performance cases, a low-level shutdown may occur prior to the planned MECO velocity.

After staging, if TMECO has not converged within 10 seconds, MCC should be consulted. In a NO COMM situation, CSS and manual throttle should be selected.

To avoid violation of range safety limits, CSS takeover may be required. MCC will provide yaw steering commands to allow the crew to fly away from limit lines. Trajectory deviations of such magnitude to require takeover are extremely unlikely. Potential causes are:

- Faulty onboard NAV
- Erroneous guidance
- Launch day winds
- SRB dispersions.

Range safety agreements for first stage deviations allow for limit exceedance as long as control is maintained.

As the orbiter approaches 3-g acceleration, throttling commands and SSME throttle-down should be observed. If this does not occur, manual throttling must be performed using the pilot's speed brake/thrust controller (SBTC) to ensure vehicle loads do not exceed design limit constraints.

Any time the AUTO guidance is unacceptable for vehicle attitude control, it should not be allowed to control the main engines. Manual throttle should be selected whenever CSS takeover is initiated. Automatic guided MECO is inhibited with manual throttles selected.

If MCC predicted TMECO is 2 seconds different than onboard predicted TMECO, a manual SSME shutdown will be initiated on the ground-computed value.

The MCC abort region determinator (ARD) program is the prime tool for determining abort capabilities. The onboard NO COMM MODE BOUNDARIES cue card lists inertial velocity values that define flight design mode boundaries computed prior to flight using predicted ascent performance and including ground rule flight performance reserves. The ARD is a real-time computational system designed to handle:

- One or more SSME failures at any time
- Performance dispersions visible in the vehicle state

- Performance dispersions not visible in the vehicle state

- SSME mixture ratio changes.

Multiple or single engine abort capabilities are determined throughout ascent for any combination of these failures using ground radar tracking or telemetry of current vehicle state. A discussion of performance boundaries is presented in Section 6.

Should the translational hand controller (THC) be moved out of detent post-MECO and prior to the completion of the -Z ET SEP maneuver, the maneuver will be inhibited (terminated if in progress) with no moding to MM 104. If for any reason the -Z maneuver is not completed either automatically or manually, the crew can manually mode to MM 104 by keying in OPS 104 PRO.

Manual Control

Manual control during powered flight is selected by depressing either the *PITCH* or *ROLL/YAW CSS* push button indicator on the eyebrow panel. Any push button indicator gives CSS in all axes to both commander (CDR) and pilot (PLT) RHCs. If CSS is selected, manual throttles should also be selected. The PLT can select manual throttle by depressing the red button on the left SBTC and moving the lever to match current commanded throttle setting within 4 percent. As throttle level is matched, the *AUTO SPD BK/THROT* light on the eyebrow panel will extinguish. When the button is released, SSME throttling is completely controlled by the PLT's SBTC. Pushing the *SPD BK/THROT* push button on the eyebrow panel will return control to auto throttle.

The control system in powered flight is rate control, attitude hold, with a maximum rate of about 12 degrees per second in pitch and roll, and about 6 degrees per second in yaw. With the RHC in detent, attitude is maintained when rates fall below 3 degrees per second. This feature minimizes large attitude overshoots. If both RHCs are out of detent at the same time, the commands are summed.

To fly to a nominal MECO in CSS, the trajectory displays and the ASCENT ADI cue card are the prime tools. Displayed data are only as good as the NAV state, so the crew must confirm NAV state with MCC at takeover. Maintaining roll at 180 degrees and commanding yaw to keep V_I (HSI secondary bearing pointer) on the nose is the most efficient yaw profile. Use the ASCENT ADI cue card to evaluate trends in the pitch axis and to confirm MECO and H-dot.

The BFS ASCENT TRAJ display provides performance information. Keep the current state (triangle) and the two predictors on the TRAJ line and make small (less than 5 degrees) attitude changes. Observe the results prior to making another correction. If BFS guidance is good, BFS digital information can be used to fly the ascent profile.

Since H-dot at MECO is extremely critical, concentrate on controlling H-dot above V_I = 20,000 fps rather than altitude. Attempt to achieve the nominal H-dot shown on the ASCENT ADI cue card. This will result in a nominal H-dot at MECO, although errors of ± 100 fps are usually acceptable.

Whenever the CDR is flying CSS, the PLT should take manual throttle control. Maintain full throttle up to 3 g, then reduce SSME thrust to maintain 3 g. Coordinate with the CDR, since thrust changes affect attitude control. Lead target MECO by about 150 fps to allow for system lag time plus SSME tailoff. Perform manual shutdown by depressing all three shutdown push buttons on panel C3. This procedure should result in achieving desired V_I at MECO.

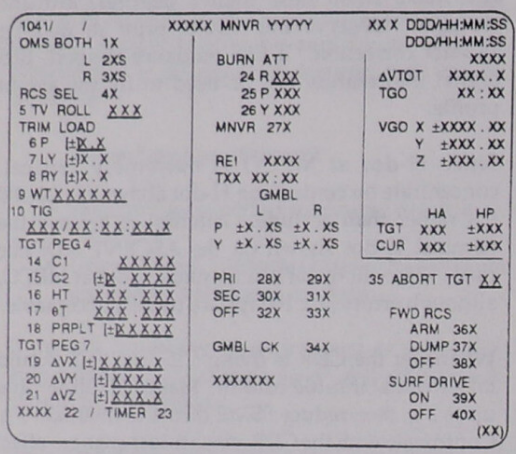
Insertion OMS Burns

Monitoring and Targeting

To monitor insertion OMS burns (OMS 1 and/or OMS 2), the MNVR EXEC display and BFS GNC SYS SUMM 2 are used in addition to the ADI. These displays are available in both PASS and BFS in similar formats. The MNVR EXEC display provides digital data to target and monitor orbital maneuvering system (OMS) burns. MNVR EXEC is an interactive display requiring keyboard inputs from the crew, as well as monitoring prior to and during burns. Current HA and HP are used in conjunction with the OMS 1/2 TGTING cue card to determine which OMS targets should be used. Each

mission has a flight-specific card, which the crew must understand thoroughly. The MNVR display is described in detail in Section 2.18.

After the crew loads the appropriate targets, the GPC software will compute a burn solution. The target set and burn solution can be checked by comparing data on the CRT display with the expected solution listed in the OMS targeting section of the ascent check list or OMS maneuver pads.



MNVR Display

For a quick check, scan ΔVTOT, TGO, apogee altitude (HA) and perigee altitude (HP), burn attitude, and time of ignition (TIG) to make sure they are reasonable. Before executing a burn, automatic maneuvers to the inertial burn attitude may be performed using ITEM 27. Prior to executing the burn, crosscheck the attitude with the ADI and compare PFS and BFS solutions.

NOTE

Burn attitudes on the MNVR display are inertial, and the *ADI MODE* switch must be in *INRTL* for a proper crosscheck of orbiter burn attitude.

The ADI is used for OMS burns in a similar fashion to its use during powered flight. BFS GNC SYS SUMM 2 is used to monitor the OMS system during insertion OMS burns.

Once the targets are loaded, and a solution is available, the crew follows ASCENT CHECKLIST/ OMS Burn cue card procedures to prepare for and execute the burn. When in the correct burn attitude, error needles should be centered, and the ADI inertial attitude and commanded attitude on the MNVR display should match.

CAUTION

Maneuvering to burn attitude should be delayed if the DAP has failed to maintain the orbiter within 10 degrees of the ET SEP attitude during the -Z translation. This will avoid recontact with the ET.

Provided perigee is high enough to remain in orbit for a few revolutions, cutoff conditions of an ascent OMS burn are relatively unconstrained compared to a deorbit burn. Achieving the planned orbit is a mission success issue. Reaching an orbit above minimum HP is a safety issue. For insertion OMS burns, the crew will downmode from 2 OMS to 1 OMS to + X RCS to forward RCS as necessary to reach at least minimum HP. Downmode procedures are listed on the INSERTION OMS BURN cue cards.

Manual Control

Takeover criteria and manual flight characteristics during insertion OMS burns are similar to those encountered during deorbit burns. Refer to Section 7.3 for a more detailed discussion of OMS burn takeover criteria and flight characteristics.

Insertion OMS burns for ascent aborts are discussed in Section 6.2 Some special situations encountered during insertion OMS burns are discussed here.

Backup Flight System

The BFS is unique software contained in a single GPC that supports nominal ascent and most Shuttle aborts. The BFS can be engaged at any time after liftoff. Once engaged, it is irreversible until the orbiter is in orbit or back on the ground.

BFS state vector degrades very rapidly during powered flight if the BFS is standalone, since it is propagated using the last known ΔV from the inertial measurement units (IMUs). Therefore, if the PASS were to fail, BFS engage must be performed within 10 seconds to ensure the vehicle will remain under control.

BFS engage criteria are listed in the Flight Rules and summarized on the DPS cue cards. They include:

- Loss of redundant set
- Loss of PASS capability to control the vehicle due to general purpose computer (GPC)/ multiplexer/demultiplexer (MDM)/LRU failures
- Loss of control due to divergent trajectory
- Roll maneuver not initiated as scheduled.

There are a number of functional differences between the PASS and the BFS:

- No manual control during powered flight.
- No manual throttling.
- BFS does not support contingency aborts.
- No single engine roll control.
- BFS runs pre-engage in parallel with PASS although not in control of the orbiter.
- BFS has only one memory load. Unique ascent and entry requirements are merged into one common set of guidance requirements.
- When BFS is engaged, it takes command of all flight-critical buses.
- Two CRTs are driven unless additional CRTs are assigned with keyboard inputs.
- The BFS can drive all four CRTs simultaneously while the PASS is limited to three.
- The ADI and HSI are the only dedicated displays driven in powered flight. The AMI and AVVI are frozen and display OFF flags.
- Post ET SEP, only AUTO -Z translation is available. In the TRANS DAP, attitude maneuvers are manual only.
- OMS burn attitude must be controlled manually.

Sensory Cues

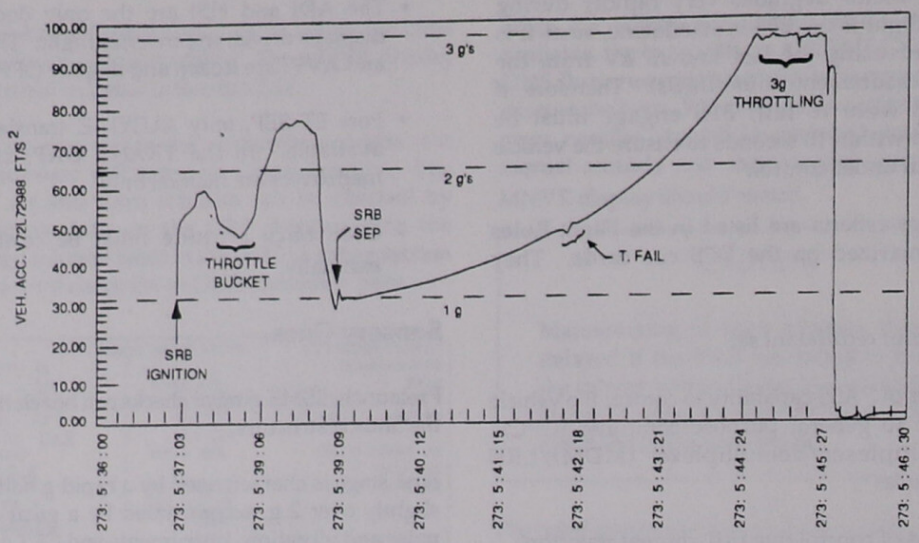
Prelaunch, SSME gimbal checks can be felt through the Shuttle structure.

First stage is characterized by a rapid g buildup to slightly over 2 g, accompanied by a great deal of noise and vibration. Instruments and CRT displays can be monitored, but precise tasks are difficult.

SRB SEP results in a large amount of flame across the windows from the SRB separation motors. When the flame disappears, forward windows appear to be coated with residue, making them nearly opaque at certain Sun angles.

At SRB SEP, g-load undergoes a nearly instantaneous reduction from 2.3 g to 1.0 g, coupled with a significant noise reduction. Since the orbiter is above most of the atmosphere, many crewmembers have remarked that it seems to stop accelerating.

During second stage, g-load builds very gradually until 3 g's are reached and the SSMEs throttle to maintain 3 g.



Vehicle Acceleration During Ascent

A good fit of the pressure suit and harness is very important to avoid discomfort during ascent, particularly at high g loads. Centrifuge runs with actual flight equipment should be performed to ensure proper adjustment.

Some crewmembers report that the eye position in an actual orbiter differs from that encountered in the SMS. Checking seat position in an actual orbiter prior to flight is recommended for first time flight deck crewmembers.

MECO results in g-load decreasing rapidly to zero. Indication of MECO is limited to observing the red SSME status lights, Pc meter readings dropping to 0, and g-reduction.

Some crews have reported an audible thump at ET SEP which could be caused by the explosive severing of the forward attach fitting. Other crews noted that ET SEP had occurred by extinguishment of the SSME status lights.

When the forward RCS jets fire to perform the -Z translation, their ignition is accompanied by a loud boom (just like "cannons" some crewmembers have commented). Aft jets produce a noticeable structural vibration, but no sound. The OMS engines do not produce sounds, but the thrust can be noted by unrestrained objects translating aft in the cabin.

Night launches are a special case. The SRB and SSME plumes appear to reflect off the air molecules and produce a "pulsing" light that is most pronounced through the overhead windows, but can be seen through the front windows also.

Ascent Rules of Thumb

- Monitor roll program on the ADI and BFS ASCENT TRAJ display.
- Before L/O +90 seconds, BFS engage is the crew's only option for loss of guidance and/or control. After 90 seconds, the crew can try CSS.
- Monitor the trajectory on the ASCENT ADI cue card and the PASS and BFS TRAJ displays. The Shuttle bug and predictors should follow the nominal trajectory line. Also monitor the HSI for the inertial velocity to be in the desired orbit insertion plane.
- Monitor guidance convergence by observing PASS and BFS TMECOs converging to expected time.
- If the crew takes CSS, they should take manual throttles. If the crew takes manual throttles, manual shutdown is required unless a low level shutdown occurs due to low performance. The cue for MECO is the BFS MECO cutoff bug or planned MECO V_I minus 150 fps.
- Use OMS 1 TGTING cue card for system problems and OMS 1/2 TGTING cue card for performance problems to determine proper OMS 1 and 2 targets.

7.2 ORBIT

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Translation 7.2-5
Rendezvous/Proximity Operations 7.2-5

Attitude Control

Orbiter attitude is primarily controlled automatically using either inertial attitude hold or track mode. The universal pointing (UNIV PTG) display, combined with the digital autopilot (DAP) display and control panel C3 are used for automatic attitude control. For manual attitude control, the RHC is also used.

Orbit flight control software includes the RCS DAP, OMS TVC DAP, an attitude processor to calculate vehicle attitude, and logic to govern which DAP is selected. Attitudes calculated by the attitude processor are displayed on the ADI and UNIV PTG. Vehicle attitude is used by the DAP to determine attitude and rate errors.

As part of mission planning, an attitude timeline (ATL) is generated. While the Flight Plan is being developed, the ATL is also developed using information about payloads, experiments, and other constraints. An ATL is produced for both the Basic and Final versions of the Flight Plan. When complete, the ATL is incorporated into the Flight Plan, although it is not usually flown. Missions with large numbers of time-critical maneuvers may carry the ATL onboard and use it to perform maneuvers.

Common Attitudes

While each Shuttle mission is unique, some attitudes are frequently used and are briefly described in this section.

Top/Bottom Sun

These are inertial attitudes that point either the +Z or -Z body axis at the Sun. They are normally used for thermal control of payloads. Obviously, a rotation angle about the pointing axis must be defined to constrain the attitude. This is usually flight-specific and is driven by look angles, communications coverage, or other constraints.

Tail Sun

Another inertial attitude, but with the -X axis pointed toward the Sun. This is one of the coldest attitudes.

Nose Sun

Opposite to tail Sun. A semi-cold attitude used to cool the aft section of the orbiter or to warm the nose area, particularly the nose wheelwell.

Deorbit Prep Tail Sun

A special case of the tail Sun attitude designed to "cold soak" the radiators prior to entry. This is a track attitude using body vector of pitch = 184 degrees, yaw = 0 degrees, and OMICRON either 90 or 270 degrees.

Tail Sun Rotation

The coldest attitude for the payload bay. This is an inertial attitude that keeps the -X axis pointed at the Sun while phasing rotation to keep the payload bay pointed away from the Earth. It is used for thermal bending tests or to meet specific payload requirements.

Passive Thermal Control (PTC)

This is another inertial attitude rotation about the + or -X axis, but it maintains the Sun in the Y-Z plane. The result is even warming of the orbiter. PTC is sometimes called the "barbecue" mode. It is used to meet various payload thermal constraints.

Gravity Gradient

A stable attitude controlled by balancing differential gravitational and aerodynamic forces. The RCS is not used. Combined forces are very small, and only a few stable attitudes exist. These are difficult to establish and vary according to altitude, inclination, time of year, and many other variables. Gravity gradient is used to conserve propellant or to inhibit RCS firings during certain payload tests and experiments.

Displays

Attitude data for the attitude processor are provided by the inertial measurement units (IMUs). Rate data are derived from the IMUs by dividing attitude delta by the time interval between attitude measurements.

ADIs provide an analog attitude display relative to three selectable reference frames. These are selectable via the *ADI ATTITUDE* switch. Inertial (*INRTL*) and reference (*REF*) positions represent inertial reference frames. Local vertical, local horizontal (*LVLH*) represents the orbiter in a fixed position relative to a rotating reference frame.

In addition to the forward ADIs, which always operate in the +X sense, the aft ADI may operate in either a -X or -Z sense. Selection is made using the *ADI SENSE* switch. This allows proper orientation, depending on whether the crewmember is viewing through the payload bay (-X) windows (W 9/10) or the overhead (-Z) windows (W 7/8).

The ADIs also display attitude errors that are calculated from the difference between current attitude and required attitude. The error needles are mechanized to indicate a "fly-to" sense. Rate needles are also fly-to. To correct attitude or rate errors, the RHC is deflected in the direction indicated by the needle.

Control

Attitude control on-orbit is provided by the RCS. The RCS is designed to control the orbiter independently in each of three axes. Minimum on/off cycle time for the jets is 80 milliseconds. Vernier jets (25 lb thrust) are normally used on orbit for attitude control since the primary jets (870 lb thrust) use more propellant for fine attitude control. Primary jets are used for translation and higher rate attitude maneuvers. With OI-20, there is also ALT PRCS DAP which uses the primary jets but limits the number, duration, and spacing of primary jet firings to achieve attitude control and loading similar to vernier jets.

For OMS burns, the OMS TVC DAP controls OMS engine gimballing, allowing OMS engine thrust vectors to be independently pointed several degrees in any direction relative to the orbiter c.g. This allows complete attitude control with the OMS engines alone during normal two-engine burns. For single-engine OMS burns, the RCS is used for roll control. The OMS TVC DAP also contains an RCS "wraparound" capability. If the attitude error exceeds 5 degrees in any axis during an OMS burn, RCS jets are fired to correct the attitude.

DAP Configuration

The DAP uses current attitude to determine attitude and rate errors.

Rotation rates and deadbands are functions of DAP configuration. Values may be changed on orbit using SPEC 20 DAP CONFIG. For convenience, each planned DAP configuration is assigned a number. The crew uses these numbers, which are called out in flight data file procedures, to select the proper DAP mode for maneuvers. Typically, DAP A has higher rates and larger deadbands than DAP B. Wide deadbands minimize propellant usage, while smaller deadbands allow more precision in executing maneuvers or holding attitude.

Attitude Control

Rotation and pointing maneuvers are required to achieve correct attitudes for deployments, on-orbit burns, star-tracker operations, thermal control, flyarounds during proximity operations, and pointing.

The RCS controls rotation independently in three axes. Jets are appropriately located and oriented to provide this control. Two independent sets of jets, primary (NORM) and vernier (VERN) are capable of attitude control. Most on-orbit rotation maneuvers are performed with the VERN jets.

The UNIV PTG display is used to control automatic attitude maneuvers input by the crew. By entering data on the UNIV PTG display, the crew can command automatic maneuvers to point a specific body axis at a specified target, maneuver to a predetermined attitude, rotate about a specified body axis, or maintain attitude hold. The UNIV PTG display also shows attitude information, errors, and completion time for current maneuvers. Types of automatic attitude maneuvers are presented in the following summaries.

To perform an automatic maneuver, the crew first enters the required data on the UNIV PTG display for the desired maneuver. To start the maneuver at a set time, that time is also entered on the UNIV PTG display. After checking the data, the crew enters an Item 18, 19, or 20, as appropriate, to start the maneuver. With AUTO DAP selected, an auto maneuver will begin at the set time or as soon as Item 18, 19, or 20 is entered if the maneuver start time is in the past. Item 21 is used to cancel a maneuver.

Maneuver

The maneuver (MNVR) option is used to maneuver the orbiter from current inertial attitude to a new attitude specified on UNIV PTG. AUTO maneuvers are three-axis at the rate specified on SPEC 20. Maximum acceptable error in any axis is the SPEC 20 ATT DEADBAND. Total error, displayed on UNIV PTG, is the difference between required and current attitude. Allowable rate error in any axis is specified by RATE DEADBAND on SPEC 20. When the flight control software determines the orbiter is at the required attitude, attitude hold is initiated.

NOTE

Manually maneuvering away from a commanded attitude is possible. However, the DAP will return the orbiter to the commanded attitude when AUTO is reselected.

Track

The track (TRK) option is by far the most complex in universal pointing software. There are six subcases: orbital object tracking, center of Earth, Earth target, center of Sun, celestial target (e.g., planet, Moon), and navigation star target. Each subcase is selected by a target ID (TGT ID) on UNIV PTG. The TGT ID is the line of sight or target vector from the orbiter c.g. to one of the defined targets.

The track option is used in conjunction with a body vector, which is centered at the orbiter c.g. and is defined by a pitch and yaw combination. These angles are referenced to the orbiter +X axis.

Track software allows the crew to point a specified body vector at one of the defined targets. Attitude is not completely constrained until body orientation about the selected vector has been specified. Rotation about the body vector (which is pointing at the target) is called OMICRON. By selecting a pitch, yaw, and OMICRON, a body vector and the orbiter's orientation with respect to that body vector are specified.

When a TRK option is initiated, TRK software performs a three-axis maneuver at the rate specified by the current DAP, then begins active track of the target. TRK subcases perform the following functions:

Orbital object tracking (TGT ID = 1)

State vectors of the orbiter and another orbiting target are used to determine a relative target vector. The target state vector is maintained by the REL NAV software. This mode is used post-deploy to track a payload. It is also used extensively during rendezvous operations.

NOTE

It is important to have REL NAV (RNDZ NAV) enabled (SPEC 33, ITEM 1) prior to tracking another orbiting body. It is also important to disable a TGT ID = 1 prior to OPS 8 or OPS 3 transition. Although UNIV PTG remains active in OPS 8, REL NAV does not. Excessive fuel usage could occur due to universal pointing chasing a stale state vector.

Center of Earth (TGT ID = 2)

Selected body vector is pointed at the Earth, with orientation specified by OMICRON, and maintained. This is, in effect, an LVLH mode requiring the orbiter to establish a small rotation rate that matches orbital rate. Center of Earth tracking is frequently used on orbit for normal operations that do not require specific attitudes.

Earth target (TGT ID = 3)

Latitude, longitude, and altitude of an Earth target are entered on UNIV PTG. This determines target line of sight from the orbiter. TRK maintains this attitude. Latitude and longitude are entered in

degrees/minutes/seconds. Altitude is entered in nautical miles. Typically, primary jets will be required to maintain this track as the orbiter flies over the target.

Center of Sun (TGT ID = 4)

Present values of right ascension (RA) and declination (DEC) are used to determine line of sight to the center of the Sun. TRK then maintains the proper attitude. RA and DEC on the UNIV PTG display are updated as the Sun RA and DEC change. This mode is used primarily for thermal control.

Celestial target (TGT ID = 5)

RA and DEC of a desired celestial object are entered. TRK will then point the defined body vector at this target and commence tracking it. An astronomical target can be tracked in this mode to point specific instruments. It may also be used during payload deployment to provide illumination or shading.

Navigation star target (TGT ID = 11-110)

TRK software contains the RA and DEC of 100 navigation stars that are defined by a number (11-110). Selecting a particular star and defining a body vector allows TRK to point the body vector at the star and track it. Obviously, this mode can be used for star sightings. It may also be used to point instruments.

Rotation

The rotation (ROT) option takes the body vector defined by pitch and yaw and initiates a rate (specified on DAP CONFIG, SPEC 20) about it.

NOTE

Transitioning to OPS 8 with an active rotation continues the rotation. Ensure correct DISC RATE is selected prior to transition, since neither UNIV PTG nor DAP CONFIG (SPEC 20) is available.

Cancel

Executing the cancel (CNCL) item on UNIV PTG snapshots and maintains current inertial attitude. All other current and future options (MNVR, TRK, ROT) are terminated. CNCL is selected automatically when entering OPS 2 from any OPS except OPS 8. Otherwise, the crew must select CNCL via an ITEM entry.

Manual Attitude Control

The RHC controls roll, pitch, and yaw movements on orbit with the OMS and RCS. Flight characteristics depend totally on DAP configuration. Various DAP configurations have been optimized for certain tasks, using off-line simulation. With the DAP mode in *INRTL*, and *DISC RATE* selected on panel C3 or A6U, deflecting the RHC out of detent fires appropriate RCS jets until an angular rate is achieved in that axis equal to the rate specified in the DAP CONFIG display (SPEC 20). Different rates may be specified for DAP A and B, and for PRI or VERN jets. When the rate is achieved, the jets are turned off until the RHC is returned to detent or deflected in another axis. Jets also fire to maintain attitude or rates within selected DAP CONFIG deadbands. Returning the RHC to detent snapshots the attitude, and jets are fired to stop rates and hold the snapshot attitude.

Deflecting the RHC beyond the soft stop causes jets to fire continuously, producing a constant angular acceleration. When the RHC is repositioned inside the soft stop, jets are turned off, but rates continue until the RHC is returned to detent.

With *PULSE* selected, RHC deflection fires jets to achieve the angular rate change specified on SPEC 20. *PULSE* is also a free drift mode.

For manual rotation maneuvers, modes generally used are:

- *INRTL DISC* for inertial attitude hold and small attitude maneuvers
- *INRTL PULSE* for large manual maneuvers.

High Rate Attitude Maneuvers

To quickly maneuver to attitude in an emergency, a high maneuver rate may be required. Move the RHC to the hard stop until the desired rate is achieved, then hold the RHC out of detent between the soft stop and detent. Lead the desired attitude by returning the RHC to detent to stop the maneuver.

Flying Techniques for COAS Calibrations and COAS IMU Alignments

To perform a COAS calibration or IMU alignment, the orbiter must be maneuvered manually to align the COAS reticle with a pre-selected star. The largest portion of the maneuver will be performed using a coarse control DAP with rates and deadbands selected to minimize maneuver time without exceeding propellant allotments.

Once the star is near the center of the COAS reticle, the crew must switch to a DAP optimized for fine attitude control. A vernier DAP will provide the finest attitude control with minimum fuel consumption.

Patience is very important when attempting to center the star in the COAS reticle. After making an RHC input, wait until movement is noticed, and the star is near the desired position before releasing the RHC. This will minimize jet firings and fuel consumption. The coarse control DAP will usually allow higher maneuver rates than the fine control DAP. The higher rates require more time to start and stop so pilots will notice a requirement to lead RHC inputs when using the coarse control DAP (i.e., return the RHC to the center detent slightly before the star reaches the desired position in the COAS reticle).

Translation

Orbit translation maneuvers can be conducted using the OMS engines or RCS jets. The OMS engines are usually used for larger maneuvers. Burn targets for pre-planned orbit OMS or RCS burns are normally transmitted to the crew from Mission Control. The crew will then load targets and execute the burn at the appropriate time. OMS/RCS burn monitoring and control for orbit burns is similar to that discussed in Section 7.3.

RCS Translation

The RCS is used to control translation when small velocity changes are required. For example, the RCS might be used for the initial maneuvers used to separate from a payload after deploy. In these situations, the CDR/PLT uses the THC and DAP panel to transmit control commands to the GPCs and ultimately to the RCS jets.

Translation flight characteristics depend on DAP panel configuration and the DAP parameters listed on the DAP CONFIG display. DAP parameters are optimized for planned tasks preflight, using off-line simulation.

THC deflection with *PULSE* selected on the *ORBITAL DAP* panel fires jets to cause a velocity change as specified on SPEC 20. Selecting *NORM* allows continuous acceleration as long as the THC is deflected. *HIGH Z* is a submode available for +Z translations only. Selection of this submode fires more jets than *NORM Z* mode.

LOW Z is a submode that allows +Z translations by firing +X and -X jets simultaneously. *LOW Z* translations also affect pitch and roll, since upfiring jets are inhibited. There are significant translational cross-coupling effects in this mode.

Rendezvous/Proximity Operations

Rendezvous and proximity operations require coordinated attitude and translation maneuvers to join with or maintain position relative to another orbiting object. This section covers some of the tasks and problem areas encountered during rendezvous and proximity operations along with some suggested techniques. The normal rendezvous sequence is presented in the orbit mission events summary in Section 5. For a more detailed discussion of Rendezvous/Proximity Operations, refer to the Flight Procedures Handbook.

Plume Impingement

For translations near targets, there is a concern about contamination and also the resultant induced body rates and torques caused by an RCS jet plume striking the target. Certain types of payloads may be sensitive to propellant molecules. For example, a payload with delicate optical equipment could be damaged by an intense blast from an RCS jet at a short distance. Selecting which jets to fire, as well as distance and orientation of the orbiter with respect to the target, may be adjusted to reduce contamination.

Nearly all payloads are sensitive to the overpressure and resultant body rates/torques caused by an RCS jet firing at close range. Usually, a sphere of

influence is identified, and no upfiring jet firings at the target are allowed within it; typically, 200 to 60 feet from the target.

Braking Techniques

Braking is used to reduce relative velocity between the orbiter and a target. Four techniques will be discussed: normal Z, low Z, X axis, and orbital mechanics effects.

Normal Z axis technique uses upfiring jets to generate braking in a +Z direction. Since the jets pointing toward the target provide the braking force, plume impingement is a concern.

Low Z reduces plume impingement by using the cant of the +X jets and scarfing (design of the nozzle) of the -X jets to produce a resultant force in the +Z direction. Jet firing is controlled by the DAP to produce a near zero force in X axis direction. Low Z braking can use up to 12 times the amount of propellant as normal Z. This mode should only be used where plume impingement must be minimized. When in low Z, Y-axis jet firings induce higher closing rates, requiring expensive braking maneuvers.

> **CAUTION**
>
> Due to severe cross-coupling effects, minimize Y-axis translations when flying in low Z mode.

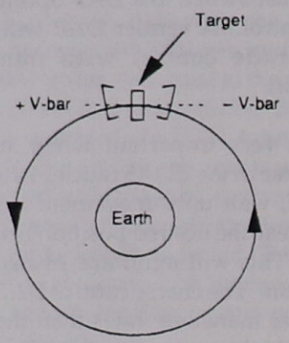
The +X or -X jets can provide braking force, but operational constraints do not normally allow their use. Braking using the forward-firing jets requires large propellant usage from the forward pod. Using the +X jets masks visibility.

Orbital mechanics may provide small separation forces for various approaches. This may be used effectively for plume-sensitive targets and to help minimize propellant usage.

Stationkeeping

Stationkeeping is the technique used to maintain the orbiter at a desired relative position, attitude, and attitude rate with respect to a target vehicle. When stable in a stationkeeping position, the crew has time to obtain navigation information and determine and set up approach maneuvers. Stationkeeping most commonly is performed on the target's velocity vector (V-bar) or the radius vector of the target to the center of the Earth (R-bar).

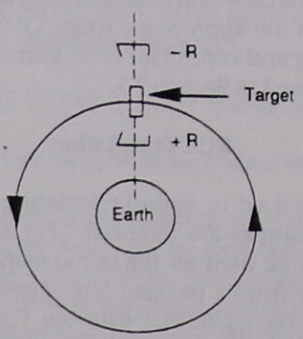
V-bar stationkeeping can be accomplished either ahead of (+V-bar) or behind (-V bar) the target. The only completely stable stationkeeping position is on the target's V-bar.



V-Bar Stationkeeping

This results in the most efficient type of stationkeeping because minimal propellant is required to maintain the orbiter at the same altitude and coplanar with the target. At about 1,000 ft on the V-bar, position can be maintained for about 100 pounds of propellant per orbit, using optimum techniques.

Similarly, R-bar stationkeeping can occur either below (+R-bar) or above (-R-bar) the target.



R-Bar Stationkeeping

This is an unstable configuration, since orbital mechanics effects will result in the orbiter and target changing their relative positions over an extended period of time. R-bar stationkeeping is more complex and requires higher propellant usage. About 0.5 lb/ft per rev, above and beyond V-bar usage, is required.

Stationkeeping position is maintained using the COAS, rendezvous radar, and CCTV triangulation. The crew must judge when attitude and translation corrections are necessary and make corrections manually. Typically, attitude is controlled by UNIV PTG so the crew has only translation corrections to maintain position.

For convenience, stationkeeping operations are classified by range (close in, short, medium, and long). There are significant differences between techniques used at different ranges.

RANGE	DISTANCE
Close in	35 – 200 ft
Short	200 – 1000 ft
Medium	8 miles
Long	40 miles

Stationkeeping Ranges

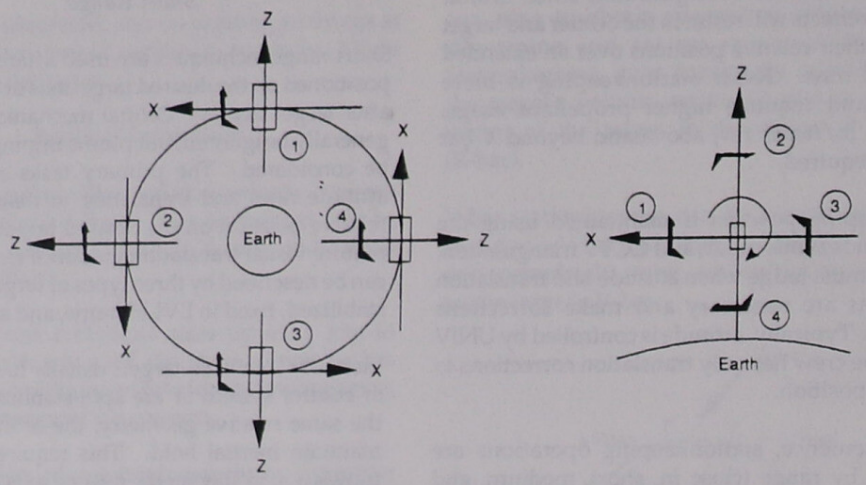
Close In

Close in techniques are required after the orbiter has achieved a stable position near the target. Alignment with the desired target axis may or may not have been completed. Orbital mechanics effects are ignored, and flying is done using a combination of out-the-window and CCTV cues. Most payloads are below the plume's impingement area, so NORM Z operations can be performed. Very large payloads may require use of LOW Z. Also, if the payload drifts too far forward or aft, LOW Z may be required to avoid plume impingement. Close in stationkeeping requires constant attention by the crew. A flyaround or matching the target's rates may be required to effect a capture.

Short Range

Short range techniques are used after the orbiter is positioned on the desired target axis or immediately after target deploy. Orbital mechanics effects can generally be ignored, but plume impingement must be considered. The primary tasks are matching attitude rates and translating to maintain correct relative position on the desired target axis. These require visual translation guidance techniques that can be described by three types of targets: inertially stabilized, fixed in LVLH frame, and arbitrary rate.

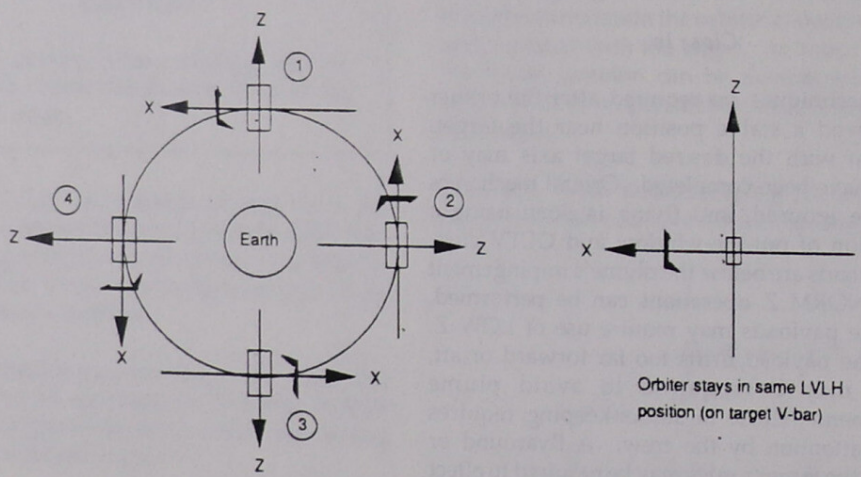
Inertially stabilized targets usually have some type of control system or are spin-stabilized. To keep the same relative geometry, the orbiter must also maintain inertial hold. This requires a constant translation to stay on the desired axis and maintain desired range. Procedurally, UNIV PTG and the DAP are used to automatically maintain inertial hold, while the crew uses the THC to remain on the target axis at the desired range.



Stationkeeping WRT inertially stabilized target

Inertial Stationkeeping

Some targets may be maintaining a constant attitude relative to the LVLH reference frame and therefore rotating in the inertial frame at orbit rate. The target may have an active or passive (gravity gradient) control system.



Stationkeeping WRT target rotating in inertial frame at orbital rate (i.e., target attitude fixed relative to LVLH frame)

LVLH Stationkeeping

The orbiter maintains a fixed position and attitude with respect to the target LVLH reference frame. Procedurally, UNIV PTG or LVLH is used to automatically control attitude, and translation is controlled manually. Since LVLH stationkeeping is much more stable than inertial, fewer translation inputs are required to maintain position.

Should the target lose its control system, causing it to rotate at an arbitrary rate about a principal axis of inertia, stationkeeping becomes more difficult. Either an inertial or LVLH mode may be used, depending on the situation.

Medium Range

Medium range stationkeeping may be required during long-term payload checkout or activation. Operations are usually automatically controlled using NAV state data. The radar should provide relative position information. One AUTO technique, called a "football," attempts to keep the orbiter within some predefined boundary centered at some range on the V-bar. When the orbiter approaches a boundary, a maneuver is performed to drive it back to the center. This is repeated as required. Orbital mechanics effects can be used to maintain the "football" with minimal maneuvering required.

Long Range

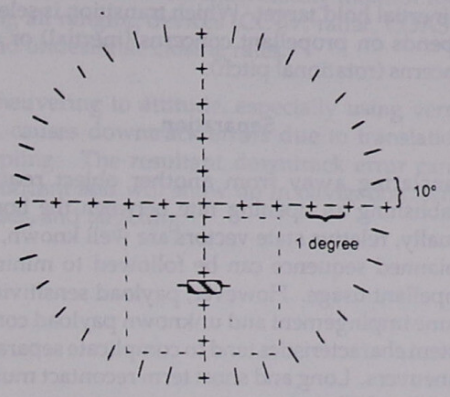
Long range stationkeeping is typically done at 40 nmi. This is usually done to support a possible rendezvous at some later time in the mission (similar to HST deploy). This stationkeeping is usually maintained by ground targeted coeliptic (NSR burns) and is done on the V-bar.

Techniques

Whenever possible, use the DAP and UNIV PTG to automatically maintain attitude. Select vernier jets for attitude control to conserve fuel.

Aim for an "ideal" target position in the -Z COAS reticle. At 1,000 ft, the target should be 2.5 degrees low. This places the orbiter c.g. on the V-bar, since the c.g. is aft of the COAS position. At 500 ft, the target should be at the bottom of the COAS, and at 200 ft, it should be at the bottom of the window.

Translate using the THC to maintain this position. Small inputs and patience are essential. Use the smallest translational pulse size available. Primary jets must be used for translation. Use vernier jets for attitude control. Maintain the payload in an imaginary box about the "ideal" position and translate only when the target moves out of the box.



COAS Sight Picture

This will reduce fuel consumption and take maximum advantage of orbital mechanics effects.

Use radar and REL NAV (SPEC 33) to maintain distance and range rate.

NOTE

The tendency is to focus on keeping target position fixed in the COAS. A good scan and crew coordination are necessary to control range rate and maintain distance.

Transition

Transitions are maneuvers that maintain the orbiter at a constant distance from the target while it moves from one position to another. The orbiter will continue pointing a specified body vector (usually -Z) at the target. In contrast to a flyaround, which requires the orbiter to actually fly around the target in an inertial sense, a transition involves moving the orbiter around the target in a target-centered, rotating LVLH reference frame without regard to the target's inertial attitude. Transitions can be

completed by placing the orbiter in inertial attitude hold with the -Z axis pointed toward the target (inertial stationkeeping), or by pitching the orbiter (tail up or tail down).

Flying a transition from the V-bar to the R-bar in 90 degrees of orbit using a pitch maneuver is equivalent to a 90 degree in-plane flyaround about an inertial hold target. Which transition is selected depends on propellant concerns (inertial) or time concerns (rotational pitch).

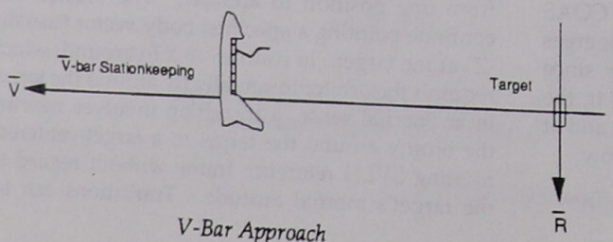
Separation

Translating away from another object requires establishing an opening rate between the bodies. Usually, relative state vectors are well known, and a planned sequence can be followed to minimize propellant usage. However, payload sensitivity to plume impingement and unknown payload control system characteristics tend to complicate separation maneuvers. Long and short term recontact must be considered; therefore, some separation sequences require multiple separation maneuvers. Separation is usually performed in two stages. A small separation burn (< 1 fps) is performed to start opening, then a larger burn is performed when the orbiter is further away. The second burn typically occurs 22 minutes after the first burn.

Cross-Coupling Effects

Since the thrust of the RCS jets is not through the orbiter c.g., commanded translation/rotation maneuvers in one axis tend to induce motion in other axes. This effect is called "cross-coupling," and it can have a significant impact during rendezvous terminal phase and proximity operations.

With the orbiter on the target V-bar, tail-to-Earth, and payload bay toward target, the crew should be aware of cross-coupling effects as follows:



V-Bar Approach

- NORM ROLL: affects every degree of freedom. Much worse in LOW Z than NORM Z.
- LOW Z and NORM ±X: induces significant braking (+Z) translations, requiring closing rate to be reestablished and pitch cross-coupling. May look like translation in the COAS. When flying Prox Ops, use the 1 to 5 Rule: 1 +Z input for every 5 ±X inputs
- NORM -Z: significant +X translation. Same effect in LOW Z.
- LOW Z +Z: major negative pitch if in free drift. In attitude hold, translation pulse loses half its force due to counteraction of attitude firings.
- LOW Z ± Y: in attitude hold, major closing (-Z) rates induced, more than half the size of commanded Y-axis translation.
- ROLL/PITCH Deadbanding: in NORM jets, induces a small opening (+Z) rate. In LOW Z, causes a major closing (-Z rate). Minus pitch also produces a significant +X translation when in LOW Z.
- TAIL ONLY: an off-nominal control mode used to conserve forward RCS propellant. Pitch maneuvers induce a powerful Z translation and a significant +X translation. Yaw induces a powerful Y translation and noticeable X and Z translations. All other control mode effects are identical to normal control (NOSE and TAIL).
- NOSE ONLY: for pitch, translational effects are mirror image of TAIL ONLY, except no X effects. Yaw is also opposite to TAIL ONLY, but significantly reduced.

These effects point out the requirements for patience after performing translation pulses. Crewmembers should observe the line of sight motion after deadbanding (keep ADI rate needles and UNIV PTG in scan) and not be misled by initial line of sight rates. Rotation-induced components must be understood. Techniques are developed through practice in simulation facilities.

Vernier jets, when used for attitude control, induce their own cross-coupling effects. Even though verniers produce much smaller forces than primary jets, their geometry is even more awkward. All vernier firings induce translational cross-coupling of roughly equivalent size in the -Z direction. The firings do not randomly cancel out; rather, they accumulate in one body direction. This can induce significant downtrack errors in orbiter position that are important during rendezvous over long periods of time.

Pitch/yaw deadbanding in LOW Z, or vernier attitude control during PROX OPS can quickly introduce a -Z translation (closing rate). Expending about 35 - 40 lb of RCS propellant to maintain attitude using vernier jets results in a cross-coupling translation of 1 fps in the -Z direction. AVG G on REL NAV (SPEC 33) is not a reliable source for this information, since IMU noise accumulation and much of the cross-coupled acceleration are below the threshold measurement of AVG G. Time required for buildup depends on how stable the orbiter is when attitude hold is initiated. The -Z buildup is significant during close-in stationkeeping and especially during gentle separations. The crew must closely monitor R-dot using all ranging devices (CCTV, radar, COAS) to avoid undesirable closing rates.

Maneuvering to attitude, especially using vernier jets, causes downtrack errors due to translational coupling. The resultant downtrack error can be significant and will show up in navigation, sensor passes, and targeting.

Orbit Rules of Thumb

- In propellant-limited situations, use the following guidelines:
  - Stay in VERN as much as possible.
  - To conserve forward RCS, use TAIL ONLY control mode.
  - During prox ops, when controlling out-of-plane errors, start as early as possible, wait for the node to make inputs to null rates, watch the deadbands, and do not fight orbital mechanics effects.

- TRAJECTORY:
  - NC: sets up 2-rev transfer to Ti (usually retrograde)
  - NCC: 1st Onboard, based on 2 ST Passes, Targets to Ti
  - Ti: 1st to target intercept, uses RADAR Data (usually posigrade)
  - MC1-4: Trim Burns Targeted to intercept
  - OOPN: Usually between MC1 and MC2, Tgt and Orb co-planar (Y = 0)
  - Ti Delay: Football, Posigarde (2 x Ti DVX)
    NEED: New Ti TIG
    LOAD new Base Time
    Start FDF at NCC intermediate solution (may not burn new NCC).

  SOURCE OF ERRORS

  Attitude maneuvers and jet cross coupling
  Burn trims
  Orbiter Vents (APU, FES, etc.)
  Drag uncertainties.

- ST PASSES:
  - DES IMU (Prime sel IMU for Attitude at 2 level)
  - Monitor RESIDS < .05 (Star Lock - BREAK TRACK)
  - 1st PASS:
    Assumes on PROP
    Gives Criteria to select FLTR
  - 2nd PASS:
    Assumes FLTR
    Verify 1st PASS
    Gives Criteria to do FLTR to PROP.

  SOURCE OF ERRORS

  Prime selected IMU going bad
  Star tracker bias
  Maneuvers and length of time since last SV update
  Taking marks on a star
  Either IMU accelerometer going bad.

- RADAR PASS:
  - Use if < 135 k (Range eclipsing)
  - Procedure handles either FLTR or PROP selected
  - Gives criteria to select FLTR -or- to do FLTR to PROP
  - Verifies star tracker passes
  - INH angles during maneuvers to burn attitude
  - RR MODE = ATRK during maneuvers to burn attitude.

  SOURCE OF ERRORS

  Range eclipsing
  EL/AZ greater than 30 deg
  Ku biases (Range).

- TARGETING:
  - Load BASE TIME (Ti TIG) to TGT SET #1
  - Load TGT SET (ITEM 1 +)
  - Verify
  - Compute (ITEM 28)
  - Plot T1 Position
  - MC2 (El Angle for ILOS rates = 0 approach)
    Note Nominal Time
    Compute TIG Change
    TIG will be new BASE TIME
    -3 and +7 limits for lighting.

Orbit Rules of Thumb (continued)

- NAV MANAGEMENT:
  - FLTR to PROP (before taking DATA)
    After new sensor acquisition
    Reacquisition of Sensor Data
  - RNDZ NAV enable creates the PROP
  - Always have a FLTR vector
  - COMM FAULT or suspect bad data INHIBIT then ask questions.
- BURNS:
  - POSIGRADE: TVR = 0
  - RETROGRADE: TVR = 180
  - < 4 - Multi-Axis (DAP:LVLH)
  - > 4 - +X Mnvr to Attitude (DAP:INTL)
  - > 6 - OMS
  - TRANS: NORM until VGO < 1 fps then PULSE
  - VGO Z is negative: Burn Z, X, Y
  - Preliminary solution for NCC and Ti can be considered the PROP solution.
- PTG/DAP MANAGEMENT:
  - -Z target track
  - A/VERN - Attitude hold (.2 deg/sec and 1 deg deadband)
  - B/PRI - Maneuver (.5 deg/sec and 2 deg deadband)
  - TRANS PULSE = .1 RNDZ and .05 Prox Ops
  - Config for VBAR at +RBAR
  - PROX OPS DAP - when stable (VBAR).
- SYSTEMS CONCERNS (single point):
  - GNC GPC FAIL:
    2 required for Ti and PROX OPS
    RNDZ NAV disables at OPS MODE RECALL
    Saves FLTR Vector when RNDZ NAV Disables
    CNCL pointing (TGT ID = 1) before OPS MODE recall
  - MDM FF3:
    Loss of VERN (1-2-3 rule)
    RADAR to NAV panel A2 is still good -Y Tracker
  - MDM FA1 or 2:
    Loss of VERNs (1-2-3 rule)
  - MDM FF1:
    -Z tracker
  - PL 1:
    Auto Ku Pointing (KU MODES: GPC and GDSG lost)
  - Loss of IMU 2 - Restring 1221.
- Expending about 35 to 40 lb of RCS propellant to maintain attitude results in a cross-coupling translation of 1 fps in -Z direction.
- .3 fps posigrade or retrograde = .9 nm downtrack/rev.
- 1 fps posigrade or retrograde =:
  16 kft downtrack/rev
  3.5 kft radial/.5 rev
  .5 nm altitude change (HA or HP).
- 1 fps radial =:
  3.5 kft downtrack/.5 rev
  900 ft radial/.25 and .75 rev (decoupled from the other axis).
- 1 fps Out Of Plane = 900 ft/.5 rev (decoupled from the other axis)
- (SMA error) x (-10) = ft/rev downtrack error.
- High +Z DV for MC2-4 = short trajectory.
- MC2 Positive TIG slip = Early sunrise.
- TGT EL ANG message = Very short case.
- High in COAS = Short traj (subtract from ADI pitch for THETA)

Orbit Rules of Thumb (concluded)

- High at Ti (> 1.4 deg) = MC2 TIG slip should be positive.
- ORB RATE = .06 deg/sec; 4 deg/min; 360 deg/90 min; 1.1 mr/sec.
- Ti done at orbital noon -3 min.
- +Y = South or going South.
- Sep Rate = 10 x delta H.
- (3/2) WΔV for Coeliptic.

7.3 ENTRY

CONTENTS

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Overview of Entry Flying Tasks

The entry phase of flight covers the transition from Earth orbit to the end of landing rollout. Guidance phases for portions of the entry phase are deorbit burn guidance, entry guidance, TAEM guidance, and approach/land guidance.

Monitoring

Crew monitoring of performance is required throughout entry. This subsection presents the information necessary to monitor and control the vehicle during the deorbit burn and entry phases of guidance. This task consists of monitoring vehicle displays to determine if guidance, navigation, and flight control are performing correctly and taking action, if required, to ensure a safe landing. An in-depth knowledge of how these systems work, along with an understanding of the reference trajectory and orbiter flight control system (FCS) will enable crewmembers to recognize off-nominal situations and correct them before serious performance or control problems develop.

Takeover

Takeover rules and criteria are described in the Flight Rules. Interpretation of onboard information will aid the crew in their assessment of when to manually intervene. From the available information, the crew assesses the performance of the automatic guidance system and remains prepared to take over with manual guidance for off-nominal situations. Some of the conditions requiring crew takeover are:

- Navigation errors
- L/D dispersions
- Atmosphere variations
- Winds
- Deorbit execution errors
- GNC failures
- Degraded performance.

Any of these conditions, if left uncorrected, could lead to unrecoverable range problems or loss of vehicle control.

Manual Control

In some instances, the crew will be required to take manual control and fly the orbiter. The Deorbit Burn and Entry sections contain the basic principles for CSS flying, although these portions of the flight profile are normally flown in AUTO. Manual flight control is the normal mode of operation from .96 Mach until the completion of rollout. (This portion of the flight profile is discussed in detail in Section 7.4.) Generally, guidance will be good, even though manual control may be necessary. Self-generated guidance based on navigation information will be discussed, but if guidance is good, flying the error needles in CSS will result in the most consistent tracking of the planned entry trajectory.

Deorbit Burn

Monitoring

Normally, the deorbit burn will be flown in AUTO using both OMS engines. The OMS engines are gimballed to control orbiter attitude in all three axes. Capability exists to downmode from both OMS engines to one OMS engine, to the aft +X RCS jets, or to the forward -X RCS jets. Burn targets are selected to protect for one OMS engine failure at time of ignition (TIG) or at any time during the burn. A single OMS engine can control pitch and yaw, but roll must be controlled by the RCS. There is no separate single-engine control logic for OMS burns. Instead, OMS TVC always commands both engines to gimbal to accomplish the burn, and RCS control (wrap-around) is always available during a one or two engine OMS burn to assist with attitude control. Deorbit burns using the RCS only must be flown manually.

The DEORBIT BURN MONITOR and the DEORBIT BURN FLIGHT RULES cue cards are used to determine the required actions for malfunctions affecting the burn. The philosophy embodied in these cards is to either safely complete the burn or stop the burn above a safe altitude.

OMS Pc LOW OMS ↓ and ENG VLV 1 or 2 < 70%	OMS ENG FAIL
OMS ↓ and ENG VLV 1 and 2 > 70% and FU and OX TK P < 185 (System in Blowdown)	Burn to Pc = 72% then OMS PRPLT FAIL
OX IN P > 227	OMS ENG FAIL
P ≤ 227	OMS PRPLT FAIL
No OMS ↓	SENSOR FAIL
OMS TEMP L R FU IN P ≥ 220 224	OMS ENG FAIL
P ≤ 204 209	OMS PRPLT FAIL
P 205-219 210-223	SENSOR FAIL
OMS OX/FU TK P OX & FU LOW	He PRESS/VAP ISOL (two) – OP
OX LOW	Burn to OMS ↓, then OMS PRPLT FAIL
FU LOW	He PRESS/VAP ISOL (two) – CL Burn to OMS ↓, then OMS PRPLT FAIL
OX & FU HIGH	Cycle He to maint OMS TK P 234-284 Cycle He A(B) to isolate failed leg
OMS GMBL 1st FAIL	Select SEC GMBL (twice)
2nd FAIL	If control problems or high RCS fuel usage: Aft OMS ENG – OFF XFEED if ΔVTOT > 20
RDNT FAIL, 4-WAY OR 2-2 SPLIT or Safe HP: **IMU DLMA** HP > ☐☐	Stop burn, APUs – SHUT DN
or HP < ☐☐ **2 MN DC BUSES**	Continue burn: PASS SET FAIL only – BFS engage PASS SET SPLIT only – √MCC on Restring IMU DLMA – Postburn, desel IMU with "ACC" > 0.03 (PASS & BFS)
GPC1(4)	GPC1(4) MODE – STBY, HALT FF1(4) – OFF, ON L(R) OMS Gimbals – sel SEC
FA1(4)	L(R) OMS Gimbals – sel SEC

Deorbit Burn Monitor Cue Card

ONE-ORBIT LATE AVAILABLE

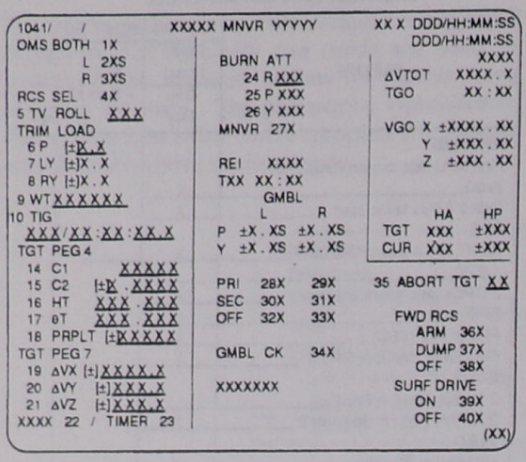
FAILURE	PRE TIG Delay (max) One Orbit	PRE TIG Delay (max) One Day	POST TIG Stop Burn, > Safe HP
APU/HYD			
First APU fails to start (LKBD not avail)	X		
First 2 APUs fail to start	X		
DPS			
RDNT fail, 4-way or 2-2 Split		X	X
1 GPC	X		
2 GPCs (and spare available)		X	
BFS		X	
FF1 or FF2 (KSC)	X		
GPC BITE (Multiple GPCs)		X	
ECLS			
2 Av Bay Fans in Bay 3	X		
2 Av Bay Fans in Bay 1 or 2		X	
ELEC			
H2 Manf or TK leak	X		
2 MN Buses		X	X
MNA, MNA 014 or MNA ALC1 (KSC)	X		
CNTL AB3, CA1 or CA3 (KSC)	X		
CNTL CA1 (No BFS Engage in GPC 3/5)		X	
Multi Φ AC BUS (unshorted)	X		
GNC			
IMU Dilemma		X	X
RHC Dilemma	X		
2 IMUs		X	
3 ADTAs	X		
2 AAs, RGAs, Elevon Pos Fb any surface (if BFS NO-GO)	X		
2 ADTAs, AAs, RGAs, FCS (LKBD not avail)	X		
① Stop Burn > OMS PRPLT FAIL HP Ref: DEL PAD/BURN Card			
OMS			
Prplt Tank	X		X ①
Ignition (neither eng ignites)	X		
Both OMS Eng fail			X
Prplt Lk after LAST LOS	perigee adjust		
AFT RCS			
2 jets, same direction, same pod	X		
Prplt Lk after LAS LOS	X		
1 AFT RCS PROP TK fail	X		
COMM			
MCC GO for DEORBIT not rcvd		X	

ONE-ORBIT LATE NOT AVAILABLE

FAILURE	PRE TIG Delay (max) One Day	POST TIG Stop Burn, > Safe HP
APU/HYD		
First APU fails to start (LKBD not avail)	X	
First 2 APUs fail to start	X	
DPS		
RDNT fail, 4-way or 2-2 Split	X	X
1 GPC		
2 GPCs (and spare available)	X	
BFS	X	
FF1 or FF2 (KSC)	X	
GPC BITE (Multiple GPCs)	X	
ECLS		
2 Av Bay Fans in Bay 3		
2 Av Bay Fans in Bay 1 or 2	X	
ELEC		
H2 Manf or TK leak	X	
2 MN Buses	X	X
MNA, MNA 014 or MNA ALC1 (KSC)	X	
CNTL AB3, CA1 or CA3 (KSC)	X	
CNTL CA1 (No BFS Engage in GPC 3/5)	X	
Multi Φ AC BUS (unshorted)		
GNC		
IMU Dilemma	X	X
RHC Dilemma	X	
2 IMUs	X	
3 ADTAs		
2 AAs, RGAs, Elevon Pos Fb any surface (if BFS NO-GO)	X	
2 ADTAs, AAs, RGAs, FCS (LKBD not avail)	X	
① Stop Burn > OMS PRPLT FAIL HP Ref: DEL PAD/BURN Card		
OMS		
Prplt Tank	X	X ①
Ignition (neither eng ignites)	X	
Both OMS Eng fail		X
Prplt Lk after LAST LOS	perigee adjust	
AFT RCS		
2 jets, same direction, same pod	X	
Prplt Lk after LAS LOS	X	
1 AFT RCS PROP TK fail	X	
COMM		
MCC GO for DEORBIT not rcvd	X	

Deorbit Burn Flight Rules Cue Cards

The ADI error needles are used to monitor guidance and control during deorbit burns; however, the needles may be incorrect due to ADI malfunctions, wrong trim angles, MDM problems, or other failures. Therefore, the body axis burn velocity components (VGO_x, VGO_y, and VGO_z), along with TGO and ΔVTOT, should also be cross checked in the event of ADI display problems.



DEORB MNVR Display

Monitoring the VGOs in addition to the error needles provides insight into the health of guidance during the burn. Noting the VGOs prior to TIG will tell the crew whether guidance thinks the vehicle is in attitude for the burn and whether the OMS burn will ignite at all. Attitude must be within ± 90 degrees of required burn attitude for OMS ignition. If VGO_x is positive, the OMS will probably light and steer the vehicle to the burn attitude.

To monitor burn progress, the crew can watch VGOs, HA, and HP during the burn. The VGOs display how much ΔV is left to go in orbiter body axis coordinates. For any OMS or ± RCS burn, most of the burn should be in the appropriate X direction. HP will gradually increase or decrease depending on whether the OMS burn is posigrade or retrograde. For deorbit burns, HP should always decrease.

NOTE

Propellant-wasting, out-of-plane burns will have larger PEG 7 Delta V_Y (LVLH) components.

OMS burn thrust vector control (TVC) is calculated independently from the ADI error needles.

- OMS TVC gimbals the OMS engines to null vehicle rates and point sensed thrust in the desired ΔVTOT direction.
- ADI error needles display vehicle attitude error from the attitude that would point the net thrust through the c.g., as defined by the trim angles, and in the desired ΔVTOT direction. If trim angles are incorrect, the ADI error needles will not display correct error information.

For a +X RCS burn, the ADI error needles display errors based on an assumed thrust vector aligned 10 degrees down with respect to the orbiter +X axis. Error needles are never correct for a -X RCS burn.

Approaching cutoff, the crew should monitor current HP approaching targeted HP, TGO approaching zero, and ΔVTOT approaching zero. If TGO goes to zero, and the OMS engines do not cut off (chamber pressure zero and engine valves closed), the OMS engine switches should be turned *OFF* to prevent an overburn.

If an early cutoff occurs, the appropriate procedure from the DEORBIT BURN cue card should be executed to achieve deorbit targets. OMS propellant, aft RCS, forward RCS, and prebank may be used to recover the underburn. If the underburn magnitude exceeds RCS and prebank capability, landing site redesignation may be required. For more detailed information on OMS burn downmoding, consult the appropriate Flight Procedures Handbook.

Takeover

Deorbit burns are normally flown in AUTO flight control and are started and stopped by GPC commands. Duration of the burn, as well as maintaining proper attitude during the burn, are the two most important criteria.

NOTE

Attitude changes vary little during a nominal OMS burn, and a downmode from automatic to manual control may not result in noticeable attitude excursions or error needle deflections until late in the burn. Larger than desired residual velocities can result if auto flight control is not reestablished unless the guidance needles are re-centered manually. The *ORBITAL DAP* push buttons on panel C3 should be cross-checked prior to and occasionally

during the deorbit burn to protect against an inadvertent downmode from AUTO to MAN flight control.

Deorbit burns that cut off at a perigee greater than Safe HP will generally be retargeted for another burn one orbit later or up to 24 hours later, since Safe HP orbital lifetime allows the delay. Deorbit burns that cut off at perigee less than Safe HP must be completed to attain acceptable Entry Interface (EI) conditions.

Since deorbit burns are usually large, EI targets will be met within allowable tolerances if post burn residual ΔV is within 2 fps. Specifically, a 2 fps underburn equates to a 30 nm energy error at EI, which is well within guidance capability to converge by Mach 12.

A 5 degree attitude deadband is used in the TRANS DAP. Attitude error or deviation greater than 5 degrees prior to the burn indicates a flight control malfunction. The crew should downmode to MAN DAP and maneuver back to ignition attitude. The deorbit burn attitude is entered in a controlled, timely manner, and the burn can be postponed for an unacceptable attitude error.

Deadband in the TVC DAP is 5 degrees. If ignition has occurred, a manual takeover should be performed for unexplained deviations greater than 5 degrees.

NOTE

Engine out transients may cause a momentary attitude deviation greater than 10 degrees. These transients are an excellent confirmation of an engine out.

Manual Control

Fly the error needles or the ADI REF ball if available. Use the VGO components to determine the correct attitude. During OMS TVC DAP attitude maneuvers, keep rates reasonable (less than 2 degrees per second). Approximate fractions of ΔVTOT depend on the type of burn. If only one OMS engine is used, yaw the vehicle about 10 degrees into the good engine. Normally, manual flight control during an OMS burn requires very few RHC inputs once the guidance needles are centered, and the TVC DAP begins attitude hold.

For an RCS-only burn, the attitude deadband is 3 degrees, and the burn is flown manually using the RHC for attitude control and the THC for the burn with four +X aft RCS jets. One technique for +X RCS burns is to fly the correct attitude as displayed on the MNVR EXEC CRT display, check the VGOs, set a REF ball, pitch up 3 degrees on the ADI, let go of the RHC, and start the burn with the THC. The vehicle will pitch down to the correct attitude, since aft RCS jets are above the c.g., and the 3 degree deadband will hold it there. Another technique is to start the burn with the THC, allow the vehicle to pitch down toward the 3 degree deadband limit, then pitch up 6 degrees to the other side of the deadband. The vehicle will slowly pitch back down and hold the desired attitude.

If error needles or ADI attitude is not available, use VGOs for initial attitude, except change VGO_z to 1/5 ΔVTOT, then use the same burn procedure. The vehicle will pitch down to the correct attitude (VGO_z = 1/6 ΔVTOT), and the DAP will hold it there. The VGO ratio table below lists appropriate ratios of $VGO_{x,y,z}$ to VTOT for different burn maneuvers.

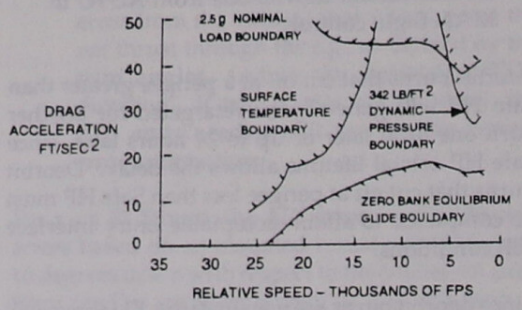
	BOTH OMS	L (R) OMS	+X RCS	−X RCS
VGO_x	1	1	1	−1
VGO_y	0	1/5 (− 1/5)	0	0
VGO_z	1/4	1/4	1/6	1/3

VGO Ratios

One other case is possible if an RCS downmode is required, and the GPCs do not know that the OMS engines are not available. This could be caused by an MDM failure, a commfault, or a GPC failure. For this situation, the vehicle remains in TVC DAP with a 10 degree deadband. Fly to attitude using VGOs, except change VGO_z to 1/5 ΔVTOT. Start the burn. When VGO_z = 1/10 ΔVTOT, pitch up until VGO_z again is 1/5 ΔVTOT. Repeat as necessary. This procedure should keep the vehicle within 3 degrees of desired attitude. Control will be very sloppy, since the DAP is attempting to respond to attitude commands using TVC, while control is being provided by RCS. Keep rates small and lead all maneuvers.

For -X RCS burns, procedures are similar. However, error needles will not display the correct attitude, and the ratio of VGO_z to ΔVTOT must be used to check the burn attitude. Fly to attitude using VGOs, except use VGO_z = 1/4 ΔVTOT, set a REF ball, release the RHC, and start the burn using -X THC. The vehicle will pitch down to the correct attitude, since FWD RCS jets are below the c.g., and the 3 degree deadband will hold it there.

For the 10 degree deadband case, use VGO_z = 1/4 ΔVTOT. When VGO_z = 1/3 ΔVTOT, pitch up until VGO_z is 1/4 ΔVTOT again. Repeat as necessary.



Entry Trajectory Constraints

Entry

Monitoring

During the entry phase, guidance provides steering commands for trajectory control from initial penetration of the atmosphere (about 400,000 ft) at a range of about 4100 nm from the landing site, until TAEM (2500 fps, about 60 nm from landing site at an altitude of about 80,000 ft). The primary objectives of entry guidance are:

- Guide the orbiter along a path that prevents exceeding structural, thermal, and stability design limits.
- Deliver the orbiter to a satisfactory energy state and vehicle attitude at initiation of TAEM guidance.

Entry guidance is based on an analytic solution of the equations of motion defining a drag acceleration profile. Guidance commands, which are based on a control law that ensures damping of oscillatory type trajectory motion, are computed to steer the vehicle to this drag acceleration profile. Entry trajectory constraints are shown in the following chart

Entry navigation (NAV) computes the orbiter's position, velocity, and distance/direction to the landing site. NAV also computes Mach, q-bar, and alpha. There are numerous interfaces between NAV and flight control. The crew optimizes NAV performance by accepting or inhibiting four types of sensed data: drag, TACAN, air data, and MLS. Bad NAV information can cause flight control problems, since NAV information is used to tailor flight control for the varying flight regimes encountered. Mission Control monitors navigation performance during entry using tracking data. TACAN and air data should not be accepted to NAV, or air data accepted to GNC without a go from Mission Control, unless communication capability is lost.

> **WARNING**
>
> Large NAV errors can cause loss of vehicle control, because NAV data are used to select control effectors and set control gains.

Dedicated instruments, CRT displays, and cue cards are available to assist the crew in monitoring entry performance. The ADI, alpha/Mach indicator (AMI), and the altitude/vertical velocity indicator (AVVI) are the primary dedicated instruments for monitoring entry performance. Five entry trajectory CRT displays are available for monitoring entry guidance. Several cue cards are used as references to compare actual and predicted performance.

After the deorbit burn, the crew transitions to MM 303 and maneuvers to the EI-5 attitude that was uplinked with the deorbit targets and voiced up in the DEL PAD.

During the early part of entry, the RCS command lights are a good indication of DAP activity. If the crew transitions to MM 304 at EI-5, the vehicle will be very close to attitude, and only occasional jet firings will occur as attitude drifts back and forth between DAP deadbands. If the crew is late transitioning to MM 304, or if an attitude error has been allowed to develop while working system problems, a large number of jet firings can occur since the entry DAP is very inefficient at low q-bar. Up to 250 lb of RCS propellant can be wasted. Crews should closely check that the orbiter is in the proper attitude prior to MM 304.

From q-bar = 0 to q-bar = 0.5, the RCS is used for attitude control. One-sided pitch jet firings during this period may be an indication of off-nominal aero or an X c.g. problem. Panel trim should not be used to input elevon trim due to weak elevon control power in this regime. At q-bar = 0.5, the elevons become active for automatic trim, and at q-bar = 8.0, the pitch jet trim is terminated. At q-bar = 10, the roll jets are deactivated. Yaw jets continue to fire for bank control until Mach is less than 1.0. Yaw jets should fire from both pods at a similar rate (symmetric firings). Asymmetric jet firings or continuous firing during a roll maneuver are indications of a NAV or control problem. At q-bar = 20, the number of yaw jets that the DAP can fire changes from two to four, and at q-bar = 40, the pitch jets are deactivated.

At q-bar = 50, the RCS *PITCH* and *ROLL* activity lights are reconfigured. Illumination of the *PITCH* light indicates elevon or aileron rate saturation. Three or more yaw jet commands turn on the *ROLL* light. The yaw jets are terminated at Mach 1. Any yaw jet activity below Mach 1 indicates either a Mach error or an MDM malfunction. The *PITCH* jet light will continue to indicate elevon and aileron rate saturation, which may result in the FCS getting out of phase with the vehicle, producing flight path oscillations. If this occurs, selecting CSS and maneuvering less aggressively should be considered.

Orbiter performance during bank maneuvers is the pilot's cue to dynamic stability characteristics. The two most important factors the crew must monitor are *YAW* jet activity lights and roll rate. The first roll command is at 3 deg/sec; subsequent roll reversals are commanded at 5 degrees per second. The rate of roll maneuvers is important to minimize flight path altitude and velocity excursions (phugoiding). Prompt execution of roll commands will minimize the bank angle required to establish the entry profile.

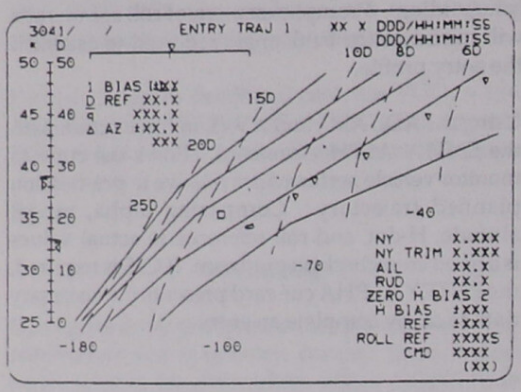
Using the ADI, AMI, and AVVI, in conjunction with the ENTRY ALPHA cue card, allows the crew to monitor vehicle performance relative to pre-mission planned trajectory. Comparing alpha, range, altitude, H-dot, and roll reference to actual values is a good crosscheck on guidance. If CSS is required, the ENTRY ALPHA cue card presents the necessary data to safely complete an entry.

VR	α			R	H	Hrel	Rrel
24.4		40		4184	400		
24		40		2730	255	-44	L85
23		40		2220	245	-60	73
22		40		1850	240	-79	66
21		40		1555	230	-100	63
20		40		1320	225	-117	61
19		40		1130	220	-139	61
18		40		980	210	-162	62
17		40		860	205	-181	62
16		40		760	200	-192	64
15	HI	40	LO	680	191	-204	R64
14	43	42	37	610	189	-127	60
13	43	41	37	540	185	-137	59
12	43	40	37	480	180	-155	57
11	42	39	36	420	170	-197	56
10	41	38	35	367	166	-176	50
9	39	36	33	317	160	-211	46
8	36	34	30	269	153	-245	L41
7	33	32	27	224	145	-269	37
6	29	27	23	180	133	-271	38
5	26	23	20	138	119	-272	40
4	22	19	17	101	105	-263	41
3	19	15	15	72	91	-247	R36
2.5				60	84	-269	
2				49	78	-281	
1.5				37	67	-336	
1				27	52	-272	

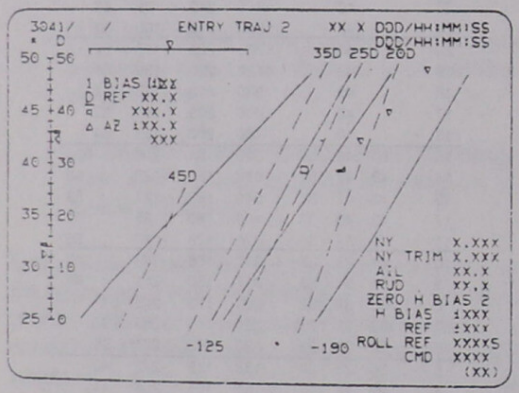
α / MACH — L/D MAX | 17 | 15 | 12 | 3 | 2 | 1 |

ENTRY ALPHA Cue Card

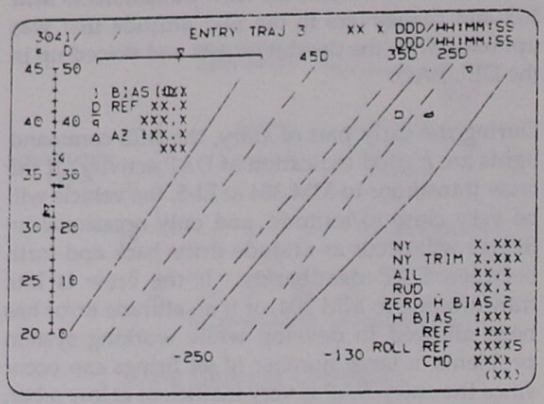
Five CRT displays are also used for entry monitoring or manually flying the orbiter entry. ENTRY TRAJ 1 appears at MM 304 (OPS 304 PRO). TRAJ 2 through 5 appear at predetermined velocity breakpoints. Each display is a continuation of the previous one.



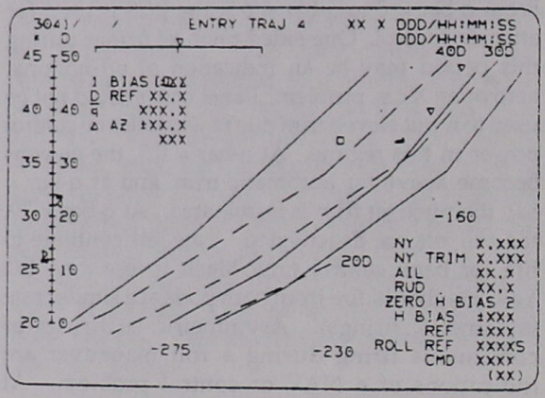
ENTRY TRAJ 1 Display



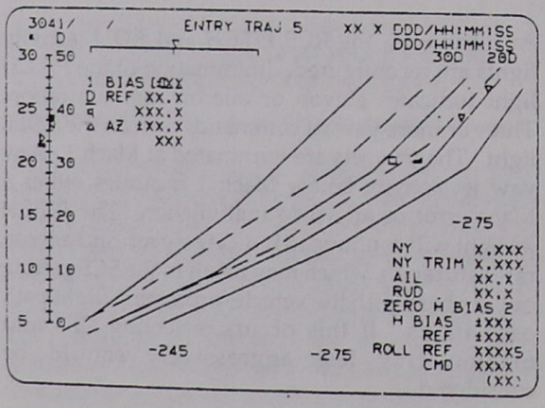
ENTRY TRAJ 2 Display



ENTRY TRAJ 3 Display



ENTRY TRAJ 4 Display



ENTRY TRAJ 5 Display

Monitoring the drag-velocity-range profile involves the drag scale and the dynamic portion of the display. The arrow on the drag scale indicates reference (planned) drag, while the triangle displays current drag.

In the center of the ENTRY TRAJ display is a dynamic trajectory plot of range (X-axis) vs velocity (Y-axis). This display reflects the relationship of drag acceleration and relative velocity as a function of range. The scales on both axes are quadratic. Solid diagonal lines represent the following trajectory guidelines (top to bottom): thermal limit, "half-way" line, nominal energy, 37/20 roll equilibrium glide, and full-lift equilibrium glide. Vertical dashed lines represent nominal constant drag acceleration values and are labeled near the top of each line. TRAJ 4 and 5 represent energy divided by weight (E/W) vs. range.

A Shuttle symbol follows a path through each ENTRY TRAJ display and plots orbiter position relative to the range-velocity plane. As the symbol proceeds down the trajectory lines, it leaves trailers every 15 guidance cycles (28.8 sec), which are used for trend analysis. For ENTRY TRAJ 3, 4, and 5, the trailers are displayed every 8 guidance cycles (15.36 sec). Only six trailers can be displayed at one time.

A guidance box appears upon initiation of closed loop guidance and moves relative to the Shuttle symbol to reflect drag errors ($D-D_{REF}$). The guidance box also generates trailers. Ideally, the nose of the Shuttle symbol will be inside the box, and a dot will be located in every triangle. This indicates converged guidance. The first roll command will be visible on the TRAJ display shortly after the initiation of closed loop guidance. Timely execution of the first roll command will minimize the bank angle required to establish the entry profile.

If the guidance box is to the left of the Shuttle symbol, a positive range potential exists (you will land long) and the guidance trend is toward high energy. The opposite condition indicates a trend toward low energy.

Pitch attitude and alpha are monitored on the ADI, AMI, and ENTRY TRAJ displays. LVLH pitch (theta) is displayed on the ADI, and measured alpha is displayed on the AMI. These parameters should be compared with the values on the ENTRY ALPHA cue card. ENTRY TRAJ displays alpha command (computed by guidance) via an arrow and nav-derived (actual) alpha by a triangle. Normally, these overlay each other. However, guidance can add small biases to the roll and pitch profile to compensate for transient drag errors. If the ADI pitch and roll error needles are centered, and the alpha/drag triangles are offset from the arrow, this is an indication of alpha and/or roll modulation, as guidance seeks to reacquire the reference drag profile.

Roll/bank monitoring is the major task for entry/aerobraking guidance. The primary display for bank angle is the ADI, which is in an LVLH reference frame during entry. Bank is defined as rotation about the stability X axis. Roll is defined as rotation about the body X axis. Unfortunately, the terms are sometimes used interchangeably. ENTRY TRAJ displays provide both roll (bank) reference and roll (bank) command in the digital portion of the display.

NOTE

The ADI displays bank angle in MM 304 and MM 305. This angle is measured about the velocity vector (defined stability axis), not the Shuttle's X axis.

Along the bottom of each ENTRY TRAJ are a series of negative numbers. These indicate reference H-dot values. In the event of a guidance failure, they can be used, in conjunction with the ENTRY ALPHA cue card and the AVVI, as H-dot trend indicators. Also on the AVVI is an altitude acceleration (H-double dot) scale. Roll/bank angle, H-dot, and H-double dot must be correlated to converge drag and maintain the drag profile.

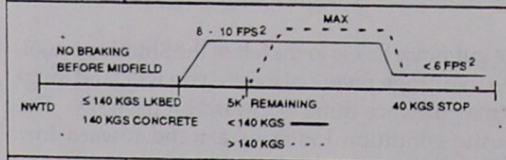
Heading error is defined as delta azimuth (DEL AZ or ΔAZ on the ENTRY TRAJ displays) and is the angle between the velocity vector and the great circle direction to the runway. DEL AZ is displayed on the HSI as the difference between the primary bearing pointer and the lubber line. There is also a digital value of DEL AZ on the ENTRY TRAJ displays. Bank angle controls drag, and therefore energy, during entry. Because the bank angle causes the orbiter to continually turn, a crossrange capability of 750 nm can be obtained. This gives the orbiter the advantage of using landing sites that are

not directly under the orbital groundtrack. Roll reversals are performed to keep DEL AZ within limits. The velocities at which the reversals occur are a function of crossrange.

Initiation of a roll/bank reversal is indicated by a flashing Shuttle symbol and phugoid damper bar on the ENTRY TRAJ and a full scale deflection of the roll error needle on the ADI. The first roll reversal will occur at a DEL AZ of 10.5 degrees. Subsequent roll reversals occur at a DEL AZ of 17.5 degrees.

The ENTRY MANEUVERS cue card itemizes important events that the crew must monitor during entry. This is a flight-specific cue card, since each entry trajectory is somewhat different. Off-nominal activities are indicated by asterisks (*). Crew action items are keyed to velocity. Items to be verified only are marked with a check (√).

FLIGHT CONDITIONS	MANEUVER
EI-5	√LVLH ATT GNC, OPS 304 PRO * PREBANK ☐☐☐ (90° if AOA-S) * If previous OMS OX TK or He TK or RCS OX TK leak: G51 VENT DOORS - OP PTI - ENA at EI-5 when applicable
EI-3	√FWD RCS MANF ISOL 1,2,3,4 - CL (OP if FWD RCS PTIs SCHED)
$\bar{q}$ = 1	(AOA) HYD MN PUMP PRESS (three) - NORM
*Guidance Box *@ $\bar{q}$ ~ 8 or D ~ 3	CLOSED LOOP GUIDANCE ____:____:____ * If PREBANK, rollout PREBANK * * & follow first ROLLCMD (usually * * zero) at 3°/sec (TIME CRITICAL) * * When ROLL = ROLLCMD, go AUTO *
D = 11	√DRAG H (FORCE if editing)
V = 19K	DOUBLE TOGGLE (√OVHD) √MPS/TVC ISOL VLV - CL
V = 15K	√NAVAIDS (I/O RESET if reqd) * If ELS: UHF MODE - G T/R *
ΔAz - 10.5°	FIRST ROLL REVERSAL (15254) ☐☐☐☐☐
V = 12K	RAD BYP VLV MODE (two) - AUTO CNTLR LOOP (two) - AUTO B(A) * If no YAW JET, begin lateral trim * * monitoring *
V = 10K	√SPDBK to 81% * If three yaw jets failed on same side: * * Perform remaining roll reversals in * * R/Y - CSS *

FLIGHT CONDITIONS	MANEUVER
V = 7K	√TACAN status
V - 5K	ADTA PROBES - DEPLOY(√HEAT) Begin AIL and RUD trim monitoring
M = 4	Begin $\dot{H}$ monitoring (√ < 500 fps)
M = 2.7	√APUs HUD PWR (two) - ON
	* If M < 2.5; P CSS for ADTA to G&C incorp *
M = 2.0	Ensure ADTA to G&C else √ Theta limits
M = 0.9	P, R/Y - CSS as reqd √SPDBK CMD vs POS √R FLT CNTLR - ON √NWS - GPC
M = 0.7	√HYD LG ISOL 1,2 - OP
h = 15K	√MLS
h = 10K	√A/L, LES VISORS - DOWN (KSC)
MAIN GEAR TOUCHDOWN	SPDBK - 100%
NOSE GEAR TOUCHDOWN	SRB SEP - MAN/AUTO and depress pb √Auto Load Relief
	
STOP	Go to ENT C/L, POST LANDING PROCEDURES, 5-1

ENTRY MANEUVERS Cue Card

Automatic program test inputs (PTIs) may be included as part of entry trajectories to obtain flight data from which aerodynamic coefficients can be extracted postflight. These data are used to further define the aerodynamic characteristics of the Shuttle, help expand the operational envelope, and reduce aero data base uncertainty. PTIs are executed automatically by the entry DAP and are input into the flight controls downstream of gains and filters so that a known control deflection or jet firing can be made. The crew enables PTIs on SPEC 50, and flight control must be in AUTO. Execution of PTIs is monitored on the SPI and GNC SYS SUMM 1 for control deflections and by the RCS activity lights for jet firings. Normal vehicle performance parameters must be continuously monitored also to ensure there is no degradation introduced due to PTIs.

Takeover

The entry trajectory is normally flown in AUTO until subsonic, when the crew downmodes to CSS. Upon moding the GPCs to MM 304, dedicated displays and ENTRY TRAJ CRT displays become available. DAP controls for the AEROJET DAP are located on each eyebrow panel. Manual takeover can be executed using the push buttons or by moving the RHC more than 7 degrees out of detent.

NOTE

During entry, downmoding to CSS is separate for the pitch axis and roll/yaw axes. It is possible to be in CSS pitch control and AUTO roll/yaw or vice versa.

Drag Error

The flight rule criterion for CSS takeover for drag error is actual drag minus drag command greater than 3 ft/sec^2. There are several indications of off-nominal drag presented on the TRAJ displays. If actual drag is larger than reference drag, the triangle will be above the arrow on the drag scale, and the guidance box will be behind the Shuttle symbol, showing a negative range potential. If this error were allowed to continue, the Shuttle trailers would indicate the vehicle dropping below the nominal guideline toward the 0 degree bank boundary. The drag error must be corrected before the target moves outside the vehicle footprint. In this case, take CSS and decrease the bank angle to cause drag to decrease toward reference drag.

As bank angle changes, so does altitude acceleration. As an approximation, 1 degree change in bank produces 0.7 ft/sec^2 change in H-double dot. Large bank errors cause corresponding errors in H-dot, allowing a phugoid to develop more quickly. The crew should closely monitor H-double dot when flying entry in CSS.

If actual drag is less than reference drag, the triangle will be below the arrow on the drag scale and the guidance square will move ahead of the Shuttle symbol, showing a positive range potential. The trailers will indicate the vehicle moving to the left toward the thermal limit boundary. The correction in this case would be to increase bank. A deviation of this type could be expected if the first roll command is not executed when commanded by guidance. Prompt execution of roll commands at the proper rate will minimize the bank angle required to establish the entry profile.

If both pitch and roll/yaw are in CSS, the task of maintaining drag equal to reference drag becomes more difficult due to angle of attack and bank angle interaction. Oscillations in alpha cause drag transients, which cause bank oscillations. A 1 degree change in alpha produces a 1.7 ft/sec^2 drag change, which is equal to an 8 degree roll change.

Low L/D

Using the ENTRY TRAJ display, if ROLL REF displays a down arrow (a fault message will also be generated) prior to the first bank reversal, this is an indication of a low L/D condition. Since the orbiter uses drag modulation for ranging, L/D control is a major factor in the ranging problem. To protect against TAEM interface targets moving out of the entry footprint, the crew should select R/Y CSS and initiate the first bank reversal when DEL AZ = 5 degrees. AUTO flight control may be reengaged after completion of the first bank reversal.

Ground Controlled Approach

NAV errors detected by Mission Control that result in trajectory dispersions uncorrectable by AUTO guidance by Mach = 4 or in greater than 10 nm

range error at TAEM interface require the crew to downmode to CSS and manually correct the trajectory. In extreme cases, a ground controlled approach (GCA) may be required. Redesignating to another runway or to the straight-in heading alignment cone (HAC) may also solve the problem. MCC will evaluate the entry trajectory to ensure it is within the orbiter's capability to reach an acceptable runway during TAEM.

Failed Yaw Jets

Failure of three yaw jets on the same side after the first roll reversal requires the crew to perform subsequent roll reversals in CSS.

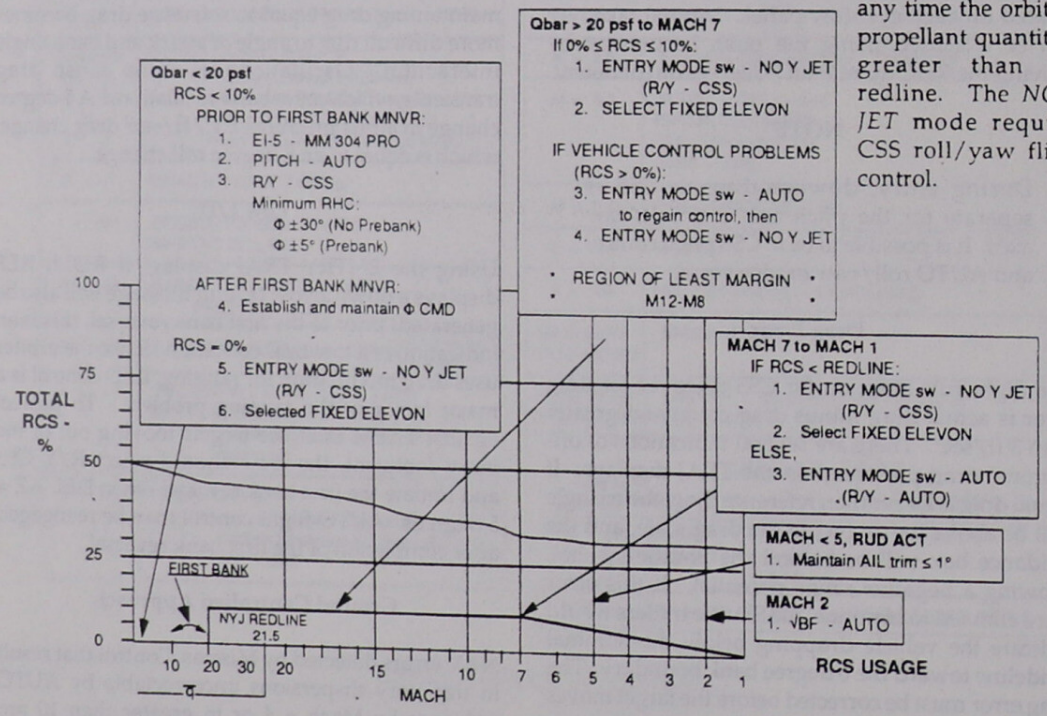
> **WARNING**
>
> Abrupt maneuvers may exceed reduced yaw jet control margin and result in loss of vehicle control.

Undesirable Transients

Prior to any event capable of introducing an unwanted transient into the flight control system, such as a delta state update that includes a velocity component, the crew should select CSS to prevent undesirable transients. Automatic flight control may be reengaged upon completion of the event and reconvergence of the guidance needles.

RCS Critical Entry (No Yaw Jet)

RCS CRITICAL ENTRY is a flight-specific cue card used to determine if an RCS critical situation exists. If possible, enough propellant should be saved to fly the entire entry profile using nominal flight control. An expected usage rate line is provided for information. This reflects expected propellant consumption for an AUTO entry, including PTIs. The no yaw jet entry mode (*NO Y JET*) redline is 10 percent from MM 304 to Mach 7, decreasing to 0 by Mach 1. If propellant falls below this line, the crew should go to *NO Y JET* entry mode. Below Mach 7, the crew can reselect AUTO entry mode any time the orbiter's propellant quantity is greater than the redline. The *NO Y JET* mode requires CSS roll/yaw flight control.



RCS CRITICAL ENTRY Cue Card

If below the *NO Y JET* redline from EI-5 to q-bar = 20, select R/Y CSS and minimize bank inputs prior to closed loop guidance. After the first bank, the crew can select *NO Y JET* and the flight-specific elevon schedule which sets the elevons farther down.

From q-bar = 20 until Mach 1, the crew will select *NO Y JET* when below the redline and select the flight-specific elevon schedule.

The rudder becomes active at Mach 5 and should take over yaw trim. Monitor aileron trim to assure it remains within 1 degree of neutral. This will prevent an aileron/rudder force fight and degraded aileron control. If bank oscillations develop, or ailerons seem ineffective and any RCS propellant remains, select AUTO entry mode, and use RCS jets to reestablish control. Once control is reestablished, *NO Y JET* entry mode can be reselected.

The body flap may have been manually driven up to improve aileron trim effectiveness at higher Mach numbers. Below Mach 2, reselect body flap AUTO and allow the body flap to drive the elevons back on schedule.

Trim Saturation and Control Oscillations

Trim saturation and dynamic oscillatory problems requiring downmode to CSS are covered by the TRIM/OSC cue card.

JETS OPPOSE ROLL, INCR RATE
DURING ROLL REVERSAL (Alpha Error)
1. R/Y - CSS,
   DECR ROLL RATE ≤ 5°/sec
2. When Φ = ΦCMD:
   R/Y - CSS or AUTO

AIL TRIM SAT (±3°)
POSSIBLE ROLL - OFF:
1. BF - UP to lower ELEV until M < 2;
   then BF - AUTO
2. M12 to M8 decr α to α limit
   M6 to RUD TRIM act incr α to α limit

HIGH FREQ OSC OR SURFACE/JET LIMIT CYCLE
1. P, R/Y - CSS
2. ENTRY MODE - LO GAIN
   If returning payload > 10K lb:
   2: GNC 51 OVERRIDE
   ALT FILTER - ITEM 21
   3: BFS, GNC 51 OVERRIDE
   ALT FILTER - ITEM 21
3. After OSC stops:
   ENTRY MODE - AUTO
   P, R/Y - AUTO

TRIM/OSC Cue Card

The DAP uses alpha to compute body axis roll and yaw rates, then coordinates yaw/roll axes to provide pure stability axis bank maneuvers. If the alpha error is large enough, it can cause serious DAP problems, especially if yaw control authority is reduced by yaw jet failures. Alpha errors may be caused by NAV errors, but the largest potential source of error is winds. High altitude winds can cause alpha errors of 2-3 degrees. Large bank overshoots with poor damping may result.

The worst case involves banking from a bottom wind into a top wind. As the maneuver is started, the crew will see lots of jet firings to initiate the bank and a sluggish bank rate. Passing wings level, jet firings and bank rate will be nominal. As bank increases in the new direction, bank rate will begin to increase from 5 degrees per second with a large number of jet firings to damp the rate.

> **CAUTION**
>
> Bank rates greater than 6 degrees per second with reduced yaw jet authority and alpha errors may be difficult to control.

Early recognition of alpha error (by the sluggish bank rate) will enable the crew to take over and prevent a more serious problem from developing. As the bank rate needle on the ADI reaches 5 degrees per second, downmode to R/Y CSS and maintain 5 degrees per second until 20 degrees past wings level. Then slowly reduce bank rate to approach bank command at about 2 degrees per second. Stop the bank rate and reselect AUTO.

Aileron trim saturation is defined as trim being driven to the limit of 3 degrees. Two possible causes are: Y c.g. offset greater than 3 inches, or off-nominal aerodynamics.

The result is an increased dependence on yaw jets for trim. The implications are serious, since propellant consumption can increase dramatically, and a loss of control is possible due to a roll off that full RHC deflection will not stop. Therefore, it is highly desirable to maintain the elevons in an optimum position for lateral trim.

To recover, raise the body flap, which will cause elevon trim to move downward, making the ailerons more effective. Ensure that the body flap is returned to AUTO at Mach 2.

Decreasing alpha between Mach 12 and 8, or increasing alpha from Mach 6 to Mach 5 is usually the fastest technique for stopping a divergent roll-off tendency. This also helps aileron control power and has the added benefit at lower altitudes of reducing q-bar in a trim saturation situation. Reducing q-bar reduces the total unbalancing moment from an offset c.g. and also makes the yaw jets proportionally more effective since the jet torques are constant while the aero torques are decreased.

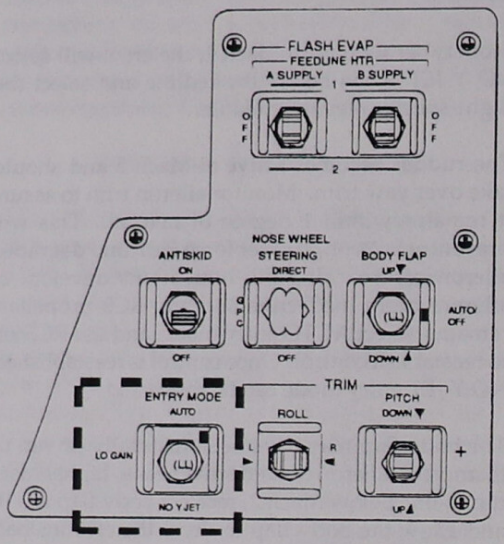
> WARNING
>
> Exceeding limits on the ENTRY ALPHA cue card may result in loss of directional control or violation of vehicle thermal limits.

After the rudder becomes active at Mach 5, the rudder trim should take over yaw trim. As the rudder starts doing the yaw trim job, the aileron trim will start to decrease. Lower the nose to reestablish alpha command. Using the roll panel trim, trim aileron trim to less than 1 degree.

The DAP includes bending filters in all axes that protect the DAP from coupling with the orbiter structure in a resonant oscillation. These filters incorporate appropriate gain and phase margins to prevent cross-coupling. If the bending filter constants were wrong, it could be possible to excite bending instability.

Symptoms are a very high frequency oscillation, accompanied by airframe vibration caused by oscillation of the aero surfaces. The crew may observe these oscillations on the SPI or the ADI rate needles. A yaw jet limit cycle may also occur.

Any bending instability should be stopped by selecting CSS in P and R/Y, selecting *LO GAIN* on the *ENTRY MODE* switch on panel L2and verifying that the proper bending filters have been selected on SPEC 51. The oscillations should stop immediately. Reselect P and R/Y AUTO, and return the *ENTRY MODE* switch to *AUTO*.



ENTRY MODE Switch on Panel L2

Manual Control

The crew can take CSS control using the PBIs on the glare shield panels or by moving the RHC out of detent in P or R/Y. Downmoding is by axis, but it is very inefficient to fly P CSS and R/Y AUTO, since guidance controls drag via bank angle, and any alpha errors will result in the AEROJET DAP attempting to correct drag by changing bank angle. One degree of alpha deviation may require 4 to 8 degrees of roll. Each bank correction requires firing at least two yaw jets to start the bank and two jets to stop it. The result is considerable unnecessary RCS propellant usage, but the AUTO system can be used to maintain drag control while the crew deals with a pitch control problem. R/Y CSS and P AUTO is a valuable mode if manual bank reversals are required, or the crew must deal with a control problem.

WARNING

If possible, do not downmode to CSS without consulting MCC. Deviations from the desired entry drag profile can cause violation of thermal limits or failure to reach the planned landing site.

In MM 304, prior to closed-loop guidance, allow alpha to deadband ± 3 degrees and bank to drift ± 10 degrees. This can save up to 200 lb of RCS propellant.

After closed loop guidance, the first bank command should be in the direction of the landing site (primary bearing pointer on the HSI). This maneuver is usually done in AUTO. If CSS is required, move the RHC to about half deflection, watch the roll rate needle on the ADI, and bank at about 3 degrees per second. Check the roll command on the ENTRY TRAJ CRT display. As bank angle approaches roll command, slow the rate to arrive at zero with the RHC in detent and with the roll error needle centered. Keep the pitch error needle centered throughout the bank maneuver. Prompt execution of the first roll command will minimize the bank angle required to establish the entry profile.

To fly the most fuel-efficient entry, hawk the guidance needles, and always center the pitch needle first. Keep rates small and try not to start and stop the rate more often than necessary. Minimize the number of discrete RHC movements to reduce unnecessary RCS jet firings. Overly aggressive control during entry can cause depletion of available RCS propellant. The *MED* position of the *ADI ERROR* switch is recommended for entry.

Roll reversals occur as a function of DEL AZ, which in turn will vary with crossrange. The first roll reversal occurs at a DEL AZ of 10.5 degrees. Subsequent reversals occur when DEL AZ reaches 17.5 degrees. The Shuttle symbol on the TRAJ display will flash when NAV determines a roll reversal is required. Use the guidance error needles, if available, for the reversal.

Use 5 degrees per second bank rate between ± 30 degrees bank, and adjust as necessary when approaching the desired bank angle. Increasing alpha to the upper limit will help control drag during the reversal. A good cue for stopping the roll reversal maneuver is H-double dot passing through zero. Returning the RHC to detent at this point will result in a smooth reduction in bank rate with final bank angle very close to roll command. A 5 degree per second roll rate will minimize altitude and velocity excursions (phugoiding) during the reversal, while preserving adequate control margins. A gentle roll reversal at less than 5 degrees per second roll rate can require the use of large bank angles to recapture the entry profile.

CAUTION

Monitor DEL AZ carefully when flying R/Y CSS, especially at lower velocity. Azimuth errors can quickly make it impossible to reach the desired landing area using nominal entry profile.

A good instrument crosscheck of actual drag (DACT), reference drag (DREF), bank angle, H-dot, and H-double dot is required when flying a CSS entry. Decreasing the bank angle will decrease DACT and vice versa, but H-dot and H-double dot must be used to control rate of change. Small bank angle changes are quickly reflected in H-double dot, making this a very useful parameter. Keep changes in H-double dot small (< 5 fps^2) and never peg the H-double dot needle.

The following is a summary of tasks required during a CSS entry:

- Fly scheduled alpha per the cue card or CRT ENTRY TRAJ to maintain DACT = DREF.
- Bank as required to maintain H-dot = H-dot REF.
- Perform roll reversals based on DEL AZ (10.5 degrees for first reversal, 17.5 degrees for subsequent reversals).
- Keep H-dot less than -400 fps. The fuselage compartment venting constraint is -480 fps to prevent structural failure (below 100,000 ft).

No Yaw Jet/RCS Critical Entry

The entry profile can be flown without yaw jets using the no yaw jet mode of the DAP. Flight control uses sideslip to control bank angle, at high angles of attack, and sideslip can be generated just as effectively by the elevons as by the yaw jets. When *NO Y JET* is selected, the DAP command path gain to the ailerons is initially set to -0.7 rather than the nominal -0.1. This means that in response to a roll command, the FCS gives seven times the normal aileron input. In response to a right roll command, the orbiter begins to simultaneously roll left and yaw right, which creates a left sideslip and ultimately a right roll due to the roll-due-to-yaw stability derivative.

When flying no yaw jet entry, use smooth, slow RHC inputs. Expect some lag in response and lead control inputs. Once the proper attitude is established, roll control is usually good with few required inputs. Roll maneuvers in no yaw jet can be difficult. If possible, delay transition to no yaw jet until after established in the required attitude after the first bank command, as called for by procedures. When performing roll reversals it is important to use the recommended 5 degrees/sec roll rate to minimize altitude and airspeed fluctuation (phugoiding). This also minimizes the bank angle required to establish the entry profile. A gentle roll maneuver at less than 5 degrees per second may feel more comfortable, but the trajectory dispersions it will cause will make the ride uncomfortable later. Reverse bank as required to keep DEL AZ within normal entry limits.

To initiate a bank in *NO Y JET*, make a small, steady RHC deflection in the proper direction. When bank rate is established, slowly increase the RHC command to achieve the desired rate. For rollout, lead the target bank angle by about 30 degrees. Avoid abrupt RHC inputs and be patient. Attempt to hold the bank error near zero to minimize pitch/bank interaction. This allows full alpha modulation capability for roll reversals.

As alpha decreases during entry, roll becomes less effective at creating beta, and the yaw due to aileron inputs becomes less adverse. The CDR or PLT may notice a reduction in bank control authority as angle of attack decreases during entry.

The most critical region of a *NO Y JET* entry is between Mach 12 and Mach 8, where control margins are smallest. Precise alpha and bank angle control are critical in this region. If control problems are encountered at any velocity, and RCS control is still an option, reenable the yaw jets by returning the *ENTRY MODE* switch to *AUTO*. Once control is restored, and the orbiter is in a stable attitude, return to the *NO Y JET* mode.

At Mach 5 the rudder becomes active and can be used to help with yaw control. Monitor aileron trim closely and trim ailerons manually to keep aileron trim near zero. This will cause flight control to input rudder for roll trim. In training simulators, bank control in *NO Y JET* seems easier to most pilots after the rudder becomes active. Elevon gains in *NO Y JET* are equal to the gains with *AUTO* entry mode selected after Mach 3.8. The major difference at this point is use of the yaw jets.

Off Nominal Trajectory Control

Should the orbiter be outside the CRT-displayed nominal energy envelope, for whatever reason, corrections are necessary to recover. Both the high and low energy cases are discussed from a manual control point of view.

High Energy Recovery

If the orbiter symbol is above the display envelope, thermal limits will be exceeded in order to make the planned runway. In some cases, it may be possible to redesignate to another landing site further downrange. For survival reasons, the solution is to preserve vehicle integrity until MCC can help with a GCA. Guidance is of marginal use for either bank attitude or drag. ENTRY TRAJ background displays based on navigation parameters are the only valid information.

The basic problem in this case is too much energy to bleed off in the distance remaining to the landing site. The solution is to fly the maximum allowable drag consistent with velocity and stay just inside the thermal limits. In practice, this is very difficult to do manually. Use of AUTO flight control or the phugoid damper display are two options available. More detailed manual procedures to accomplish this are under investigation (August '91).

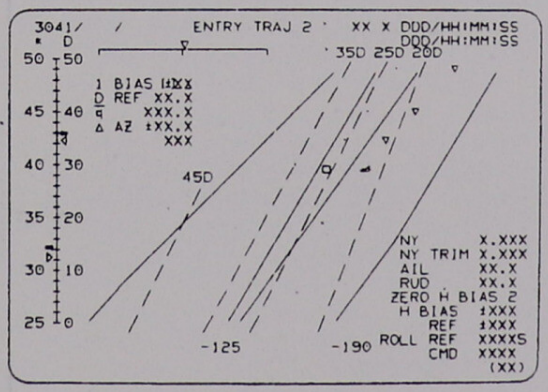
Low Energy Recovery

The orbiter symbol dropping below the max L/D line presents the opposite case. The problem is too little energy to make the landing site. Since the ENTRY TRAJ displays are based on flying the design alpha profile, flying the lower alpha limit from the ENTRY ALPHA cue card should allow the orbiter to "climb" back into the trajectory limit guidelines. A wings-level attitude should be maintained unless correcting for DEL AZ. Flying this profile may result in a higher q-bar and higher structural temperature after landing.

CAUTION

When using manual control techniques, control problems may result if q-bar limits are exceeded.

One option to safely recover from a low energy situation is to follow guidance until headed toward WP1 (DEL AZ of zero), downmode to P and R/Y CSS, and fly wings level. When past the peak heating region, fly the lower alpha limit. Detailed low energy entry procedures, called alpha stretch, are currently applicable only for TAL entry. They call for a reduction in alpha to 34 or 31 degrees, depending on inclination, after peak heating, followed by modulation of bank angle to control DEL AZ. More information on the alpha stretch procedure is contained in the Flight Data File and the Flight Procedures Handbook.



ENTRY TRAJ 2 Display

Backup Flight System

The backup flight system (BFS) is capable of performing nearly all of the primary flight system functions (controlled by PASS software) during deorbit, entry, approach, and landing. This section presents the major differences, from the flight crew viewpoint, between the two systems. Differences in handling qualities between the PASS and the BFS are very small in the training simulators, and no large differences are expected if BFS is engaged onboard the orbiter. A moderate control transient should be expected when BFS is engaged.

Deorbit

Automatic maneuvers are not available in BFS. The crew must manually fly to deorbit burn attitude using the error needles, MNVR EXEC display, and ADI attitude. The TRANS DAP supports both *DISC RATE* and *PULSE* modes, but all three axes are switched when *DISC RATE* or *PULSE* is selected. During the burn, attitude must be maintained manually using the ADI error needles and REF ball. Upon completion of the burn, the maneuver to EI-5 attitude is a manual maneuver.

Entry

BFS does not support PTIs. Upon entering MM 304, flight control mode is CSS through landing/rollout.

The BFS maintains only one state vector during entry. Redundancy management is performed on most systems, but in a simpler manner than PASS. BFS is also set up to accept air data to GNC immediately upon engage. If air data has not been previously accepted in PASS, the crew should inhibit air data to GNC upon BFS engage.

Sensory Cues

During the night portion of an entry, the glowing plasma sheath around the vehicle can be observed through the orbiter windows. The pulsing light has not interfered with tasks inside the vehicle. The plasma glow is less visible during daylight portions of entry and may not be noticeable.

Returning from orbit, some crewmembers have reported increased sensitivity to g as it builds during entry. One crewmember observed that "when you hit a quarter g on entry, it seems like two g's in the T-38." Crewmembers should be aware that their ability to perform entry tasks may be degraded from that experienced in the SMS during training.

Bank reversals on entry will feel different than pure roll maneuvers in a conventional aircraft due to the orbiter's entry angle of attack. Pilots will probably notice the yaw rate required during the bank change as much as the roll rate. Some mission specialists have stated that they could barely feel the roll reversals.

At high Mach numbers, a slight vehicle buffet may be noticed as well as some light structural vibration as dynamic pressure increases during entry.

Ground Controlled Approach

Although GCA techniques are available, they are emergency alternatives only. Control should be quickly returned to autoguidance when conditions permit.

During entry, trajectory is monitored via the Tracking and Data Relay Satellite (TDRS) and ground radars. Should the trajectory diverge and approach energy limits, a GCA will be performed.

MCC, via the CAPCOM, will provide the crew with bank attitude, heading, airspeed, and speed brake information. The crew must maintain the orbiter within g, q-bar, and H-dot limits.

GCAs are divided into three phases, based on energy: high velocity (Mach 10 - Mach 3), TAEM (Mach 3 - Mach 0.9), and final approach.

Criteria for electing to perform a GCA depend upon autoguidance capability to achieve a nominal trajectory by Mach 5.

In the high velocity phase, MCC provides bank magnitude information to control drag and bank direction to control crossrange. To keep workload under control, fly roll/yaw CSS and pitch, speed brake, and body flap AUTO.

During TAEM, a more conventional technique of heading to control ground track and airspeed to control energy is used. Fly both pitch and roll/yaw in CSS. Perform turns using 30 degrees bank angle unless MCC requests a steeper bank. Control airspeed by modulating alpha and bank angle.

Final approach GCAs are similar to traditional airplane GCAs. Heading information controls alignment with the runway centerline, and position information references glide slope. Speed brake is used to control airspeed.

Off-nominal energy situations could be caused by incorporating erroneous navigation data into guidance or selecting an incorrect landing site. If this is the case, the GCA will be used to control the entry profile until NAV can be updated via a ground uplink or a manual state vector update. Once the NAV state is correct, MCC will terminate the GCA and call for a return to AUTO flight control.

Entry Rules of Thumb

- 2 OMS: TGO ≈ ΔVTOT/2.
- 1 OMS: TGO ≈ ΔVTOT.
- RCS: TGO ≈ 1.7 x ΔVTOT.
- As an approximation, 1 degree of bank change produces 0.7 ft/sec^2 H-dot change. Large bank errors cause corresponding errors in H-dot, allowing a phugoid to develop more quickly.
- A 1 degree change in alpha produces a 1.7 ft/sec^2 drag change, which is equal to an 8 degree roll change.
- Prior to the first bank, monitor vehicle attitude at 0 degrees bank and 40 degrees alpha.
- First bank (flight path angle capture) should occur at a drag acceleration of approximately 3 fps^2 and/or q-bar of approximately 8 psf.
- Monitor the trajectory on the ENTRY ALPHA cue card, and the PASS and BFS TRAJ displays:
  - The Shuttle bug superimposed on guidance box superimposed on nominal trajectory line
  - Actual drag equal to reference drag
  - Appropriate bank angle, H-dot, range and altitude.
- For an off-nominal trajectory, check that guidance is working to put the guidance box back on the Shuttle bug (zero range error) within the trajectory envelope.
- Attempt to contact MCC before taking CSS.
- If you must take CSS:
  - Control range by controlling drag.
  - Control drag by controlling H-dot.
  - Control H-dot by controlling H-double dot.
  - Control H-double dot by controlling bank angle.
  - Control everything slowly by small corrections.

7.4 TERMINAL AREA ENERGY MANAGEMENT AND APPROACH, LANDING, AND ROLLOUT

CONTENTS

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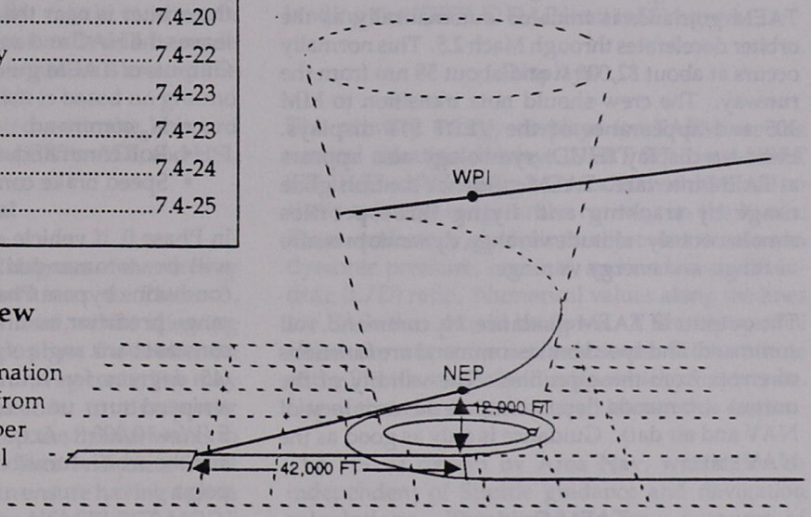
Definition and Overview

This section presents information required to pilot the orbiter from a velocity of 2,500 feet per second, where terminal area energy management (TAEM) begins, all the way through approach, landing, and rollout on the runway. TAEM guidance provides information to the pilot and guides the orbiter until the transition to approach/landing guidance at an altitude of 5,000 to 10,000 feet. Derotation and rollout logic take over after the orbiter touches down on the runway. Procedural information for the TAEM and approach/landing guidance phases are contained in the Entry Checklist and cue cards. Pilots often refer to the flight phase from .95 Mach to touchdown as the approach and landing phase of flight. This is the phase of flight in which the crew normally controls the vehicle manually (CSS) and in which the Shuttle Training Aircraft operates. By this definition, the approach and landing portion of the trajectory includes both subsonic TAEM guidance and the approach/landing guidance regions.



HAC Profile

TAEM and approach/landing guidance trajectories allow the orbiter to handle a large variety of dispersions. Certain specified ground rules and constraints such as weight, c.g., aerodynamic limits, distance past runway threshold, velocity, altitude rates, lateral rates, and energy margin must be observed to ensure guidance is capable of directing the orbiter to a safe landing. Mission Control monitors these limits closely. Carefully following guidance commands will generally provide the crew the best chance for coping with environmental dispersions.

The TAEM and approach and landing trajectories are divided into five segments that are jointly designed to allow the orbiter to land safely: heading alignment cone (HAC), prefinal geometry, outer glide slope (OGS), preflare, inner glide slope (IGS), and final flare. This section presents information for monitoring and takeover during the early portions of TAEM and then details the manual flying tasks during each segment of the trajectory.

General information on handling qualities, flight control surfaces, priority rate limiting (PRL), winds, limits, BFS, sensory cues, and autoland is presented at the end of this section.

Terminal Area Energy Management

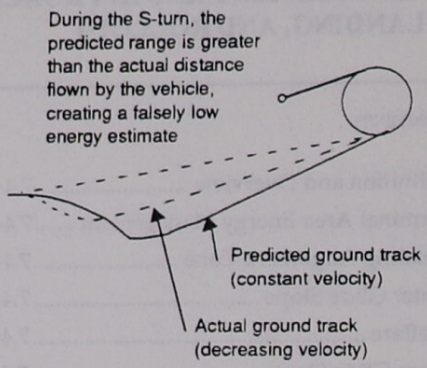
Monitoring

TAEM guidance is initiated automatically as the orbiter decelerates through Mach 2.5. This normally occurs at about 82,000 ft and about 58 nm from the runway. The crew should note transition to MM 305 and appearance of the VERT SIT displays. Head-up display (HUD) symbology also appears at TAEM interface. TAEM guidance controls glide range by tracking and flying three profiles simultaneously: altitude vs range, dynamic pressure vs range, and energy vs range.

The outputs of TAEM guidance, N_z command, roll command, and speed brake command are functions of errors from these profiles. The validity of the output commands depends upon the accuracy of NAV and air data. Guidance is only as good as the NAV state.

TAEM Guidance

TAEM guidance operates by phases. Phase 0 (S-Turn), if required, dissipates energy by turning away from the HAC until energy conditions allow a nominal approach. Phase 1 (Acquisition) turns the orbiter until its ground track is tangent to the applicable HAC.



S-Turn Profile

Phase 2 (Heading Alignment) follows the HAC until the orbiter is near the runway centerline. Phase 3 leaves the HAC and acquires the runway centerline. Outputs of TAEM guidance are:

- N_z command
- Roll command
- Speed brake command.

In Phase 0, if vehicle energy is too high, an S-turn will be commanded. Low or nominal energy conditions bypass Phase 0. During the S-turn, the range predictor assumes that the orbiter will fly a constant bank angle of 30 degrees for end-of-mission (45 degrees for return to launch site), constant airspeed turn until energy decreases to nominal E/W + 10,000 ft. Acquisition phase is then resumed, and the orbiter turns back toward the HAC tangency point.

Obviously, energy dissipation rate during an S-turn depends on geometry. For high DEL AZ, ending the S-turn at nominal E/W + 10,000 ft may not always deliver the orbiter precisely onto the nominal E/W versus range profile. Monitor the E/W triangle on the VERT SIT display during an S-turn. When the triangle overlays the + 8,000 ft mark on the scale, the S-turn is terminated. If a large DEL AZ is building up, the E/W triangle will accelerate as it travels down toward nominal. Manual intervention may be necessary if the dissipation rate is too large.

CAUTION

Energy can be dissipated very rapidly. Ensure a high energy condition exists (MCC or visual) prior to initiating an S-turn.

Tracking the HAC

Guidance uses an algorithm for bank command that is a function of vehicle error with respect to HAC radius (ΔR) and the rate of change of distance to the center of the HAC (Δ R-dot). Primary and secondary bearing pointers are referenced to the HAC tangency point and HAC center respectively as computed by Area Nav. Wind magnitude affects HAC tracking, as does the arc length around the HAC, since relative wind angle change during HAC tracking is large. Flying the guidance commands and monitoring energy status will normally result in smooth tracking. Routine energy status calls will be made by the CAPCOM at 90 degree intervals around the HAC. This information, which is based on ground tracking, should be integrated with the onboard energy status displayed on the CRTs, ADI, and HSI.

Prefinal

When the orbiter is within 12 degrees of the runway centerline, guidance transitions to Phase 3. Smoothly rolling the wings level, while allowing for any crosswind, should position the orbiter on the OGS. Overshooting the runway centerline may cause the glide slope needle to disappear momentarily. Guidance thinks the orbiter wants to go around another HAC. This will clear itself momentarily, but the crew can ensure having a glide slope indicator by placing the *HSI SELECT MODE* switch on panel F6 or F8 to *APPROACH*. This will force the glide slope indicator to display deviation from final approach glide path.

Pitch and Roll Commands

TAEM guidance uses normal (Z-axis) acceleration (N_z) feedback from the accelerometer assemblies (AAs) to determine errors from the guidance pitch command. These pitch errors are scaled and displayed on the ADI and HUD. Auto flight control attempts to zero out the N_z errors, and with good guidance, a pilot flying CSS pitch will do the same thing by following the error needles. If N_z feedback is inaccurate, pitch guidance needles and pitch auto flight control will be degraded. Accelerometer problems will not affect CSS pitch control.

Pitch commands are constrained by q-bar limits during pre-final and by both q-bar and E/W during approach and land. The N_z term is filtered to constrain rate of change of E/W to provide further insurance that vehicle q-bar limits are not exceeded. The logic in the pitch channel results in a control system that causes the vehicle to appear to fly airspeed as a function of energy.

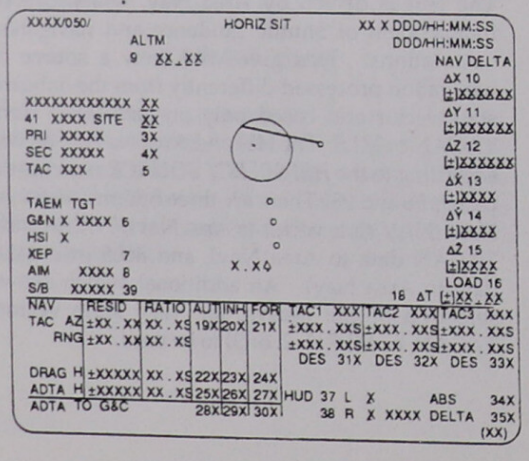
TAEM roll commands are a function of lateral position (groundtrack) error. Guidance scales the errors and displays them on the ADI and HUD. Roll commands are constrained to control H-dot. During heading alignment phase, the DAP limits roll command to 60 degrees. The glide return to landing site (GRTLS) DAP limit is 55 degrees.

Displays

The primary energy displays for TAEM are the vertical situation displays (VERT SIT 1 and VERT SIT 2). The VERT SIT plot is scaled with altitude on the Y-axis and range to the runway on the X-axis. Three trajectory guidelines represent maximum dynamic pressure, nominal, and maximum lift-to-drag (L/D) ratio. Numerical values along the lines are EASs that should be flown. A Shuttle symbol shows current range versus altitude. Pitch attitude of the Shuttle symbol indicates vehicle descent rate. Use of theta limits is discussed later in this section.

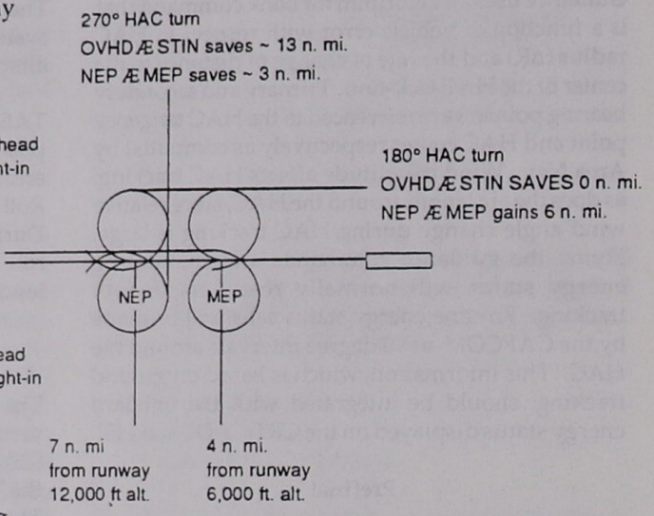
The HSI is driven by Area Nav, which can be independent of Shuttle guidance and navigation calculations. This gives the crew a source of navigation processed differently from the onboard state vector and based only on data taken from TACAN or MLS. The HSI and Area Nav are driven according to the *HSI SELECT SOURCE* switches on panels F6 and F8. There are three options available: *NAV* (NAV state vector to Area Nav), *TACAN* (raw TACAN data to Area Nav), and *MLS* (raw MLS data to Area Nav). An additional switch allows selection of the individual NAV state vector, TACAN, or MLS (1, 2, or 3) to be used.

Instead of the HAC inverted cone geometry, Area Nav defines (and the HSI displays) the HACs as 15,500 ft radius cylinders. This causes the HSI and guidance ground track information to differ slightly. During TAEM, the HSI primary bearing pointer indicates the bearing toward the HAC intercept point called way point 1 (WP1), and the secondary bearing pointer indicates bearing to the center of the HAC (WP2). Range displayed in the HSI DME windows corresponds to range to the runway via the HAC (PRI MILES) and range to the HAC center (SEC MILES). Range to the runway can be varied by moving the HAC using ITEM 6 and 7 on SPEC 50. The HAC is an imaginary inverted cone tangent to the runway centerline at 12,000 ft altitude and nominally centered about a point 42,400 ft from the runway threshold. For low energy situations, the crew can shift the HAC to a point 24,000 ft from the threshold by executing ITEM 7. The point where the HAC is tangent to the runway centerline is called the entry point. For a nominal HAC configuration, the entry point is called the nominal entry point (NEP). Executing ITEM 7 repositions the HAC to a minimum entry point (MEP), which is tangent to the runway centerline at 6,000 ft.



HORIZ SIT Display (SPEC 50)

ITEM 6 allows selection of an overhead (OVHD) approach or a straight-in (STRT) approach. This allows the crew to position the HAC on either side of the runway centerline. OVHD/STRT and NEP/MEP can be combined to define four HACs that are available to the crew for energy management purposes. Guidance is always initialized to the OVHD NEP HAC.



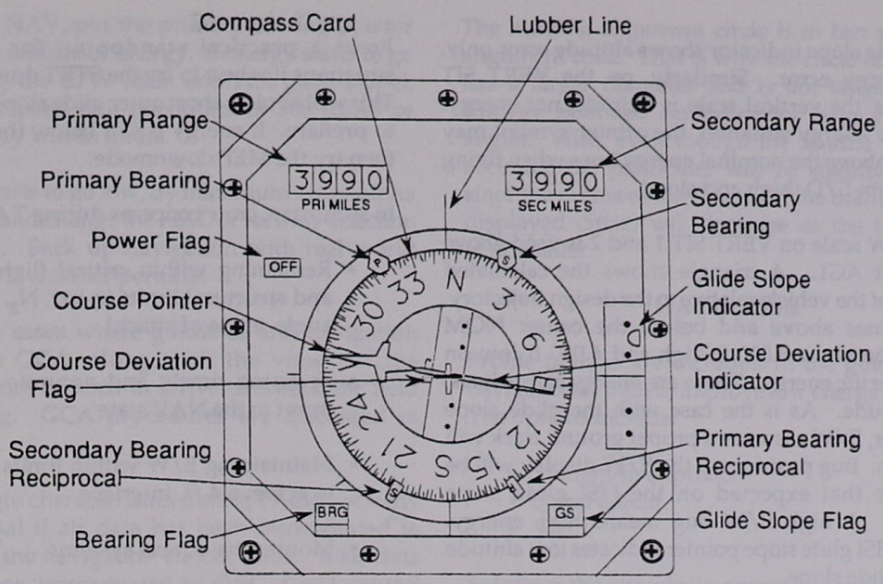
HAC Turns

NOTE

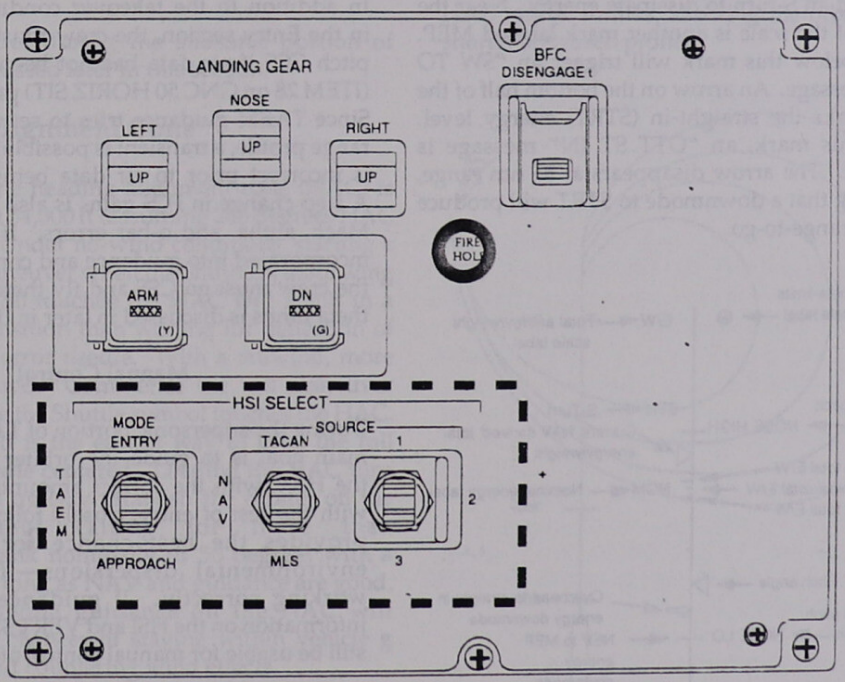
Within 35 nm of the runway, switching between OVHD/STRT is not recommended. The heading error generated by a downmode could nullify any energy gains.

The glide slope indicator on the HSI displays calculated altitude error computed by Area Navigation. Note that this is not a guidance computation. The scale is 2,500 ft per dot until Area Nav transitions to Approach (usually within 2.5 degrees of Course Deviation), then it becomes 500 ft per dot. Crewmembers can force this scale change by selecting *APPROACH* on the *HSI SELECT MODE* switch on panel F6 or F8.

Data presented by the glide slope indicator are calculated assuming the orbiter will fly from its present position, over the proper ground track trajectory, to touchdown.



Horizontal Situation Indicator

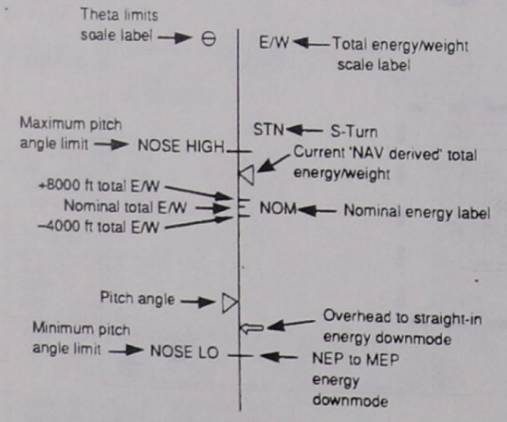


HSI SELECT Switches on Panel F6 and F8

The glide slope indicator shows altitude error only, not energy error. Similarly, on the VERT SIT displays, the vertical scale is altitude, not energy. In a low energy situation, the orbiter symbol may appear above the nominal energy lines when flying maximum L/D (high and slow).

The E/W scale on VERT SIT 1 and 2 is used above 20,000 ft AGL. A triangle shows the calculated energy of the vehicle relative to the design trajectory. Wide lines above and below the center NOM indication show 8,000 ft high and 4,000 ft low on total specific energy. These are energy status lines, not altitude. As is the case with the glide slope indicator, E/W assumes a proper ground track will be flown. Bug position on the E/W display will be opposite that expected on the HSI glide slope display. A high E/W bug means high energy. A high HSI glide slope pointer indicates low altitude on the glide slope.

Above the nominal energy marks is a mark labeled STN (S-turn). When vehicle energy, represented by the triangle, is above the STN mark, guidance will command an S-turn to dissipate energy. Near the bottom of the scale is another mark labeled MEP. Energy below this mark will trigger an "SW TO MEP" message. An arrow on the bottom half of the scale marks the straight-in (STRT) energy level. Below this mark, an "OTT ST IN" message is triggered. The arrow disappears at 35 nm range, signifying that a downmode to STRT will produce a longer range-to-go.



E/W Scale on VERT SIT 1

From a practical standpoint, for low energy situations it is best to try the STRT downmode first. This will avoid a short outer glide slope (OGS) prior to preflare. If energy is still below the MEP mark, then try the MEP downmode.

In summary, crew concerns during TAEM are:

- Remaining within critical flight control and structural limits (q-bar, N_z, beta, roll angle, angle of attack)
- Ensuring timely and accurate data are input to the NAV state
- Maintaining E/W within limits required to achieve A/L interface
- Monitoring critical systems
- Keeping pace with increasing workload.

Takeover

In addition to the takeover conditions discussed in the Entry section, the crew must downmode to pitch CSS if air data has not been taken to G&C (ITEM 28 on GNC 50 HORIZ SIT) prior to Mach 2.5. Since TAEM guidance tries to set up an altitude/range profile, a transient is possible if NAV altitude is incorrect prior to air data being incorporated. A step change in FCS gains is also possible due to Mach, alpha, and q-bar errors. If air data is not incorporated into guidance and control by Mach 2, the crew must go CSS and fly theta limits. Flying theta limits is discussed in later in this section.

Manual Control

During the supersonic portion of TAEM, the pilot's main goal is to guide the orbiter to the edge of the HAC with the correct amount of energy. As with the rest of entry, closely following guidance provides the best chance for coping with environmental dispersions—if guidance is working correctly. If guidance is bad, NAV information on the HSI and VERT SIT displays may still be usable for manual control of the trajectory.

With good NAV, put the primary bearing pointer on the nose and check energy. If energy starts to go high (using the E/W scale and HSI glide slope), increase airspeed to a maximum of 300 KEAS or S-turn to stay within limits.

If energy starts to go low, fly maximum range alpha (max L/D) and change the HAC or runway selection if required. Back up navigation with real world visual cues if weather permits.

In extreme cases where guidance and navigation are bad, a GCA, along with the view out the windows, can be used to arrive overhead the field for landing. GCA procedures are discussed in Section 7.3.

Vehicle flight characteristics during TAEM are fairly conventional if air data has been incorporated to G&C, and the navigation state is good. If air data has not been incorporated to G&C, flight control may be degraded slightly. Pilots should maneuver with caution and observe theta limits on the VERT SIT displays if flying CSS without air data information.

Manual control during the subsonic portion of TAEM is discussed later in this section.

Heading Alignment Cone

Nominally, the heading alignment cone (HAC) is intercepted at 34,000 ft (assuming 240 degrees HAC turn angle). Under no-wind conditions, starting a gentle roll maneuver when the Shuttle symbol wing tip on SPEC 50 touches the HAC will result in a smoother transition than waiting for deflection of the ADI roll error needle. With a tailwind, more lead is required. Commence the roll maneuver slightly before the Shuttle symbol touches the HAC. A proper lead is the easiest way to keep the roll guidance needle centered. Leading the HAC turn correctly will quickly establish the orbiter on the HAC without calling for more than 45 degrees bank nominally or 50 degrees with a tailwind. As long as NAV and guidance are good, closely following guidance on the HAC will optimize the chances of staying within vehicle g limitations and countering wind effects.

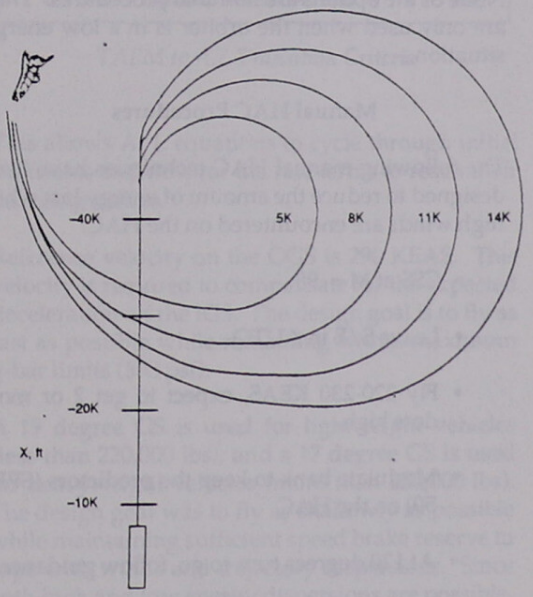
The heading alignment circle is in fact a heading alignment cone. That is why the circle on SPEC 50 has a larger diameter and is not tangent to the runway extended centerline for large HAC turn angles. Also, even though the Shuttle symbol is accurate, the predictors will be slightly in error, since the radius of the cone (and the diameter of the displayed circle) will decrease as the turn angle gets smaller.

HAC Options

Profile options are included in the guidance and navigation system to improve low energy situations. The options include:

- Straight-in approach
- Spiral adjust
- MEP.

Selecting the straight-in approach option on SPEC 50 will reduce the HAC turn angle to 180 degrees or less. When guidance and navigation compute a low energy state, the second option, spiral adjust, is invoked automatically by TAEM guidance. The HAC radius shrinks, allowing the orbiter to fly a shorter approach profile.



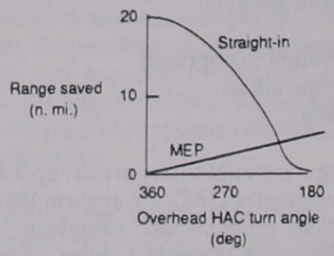
Groundtrack Plot of Spiral Adjust

NOTE

A spiral adjust will only occur if the HAC turn angle is greater than 90 degrees.

The MEP option moves the HAC center point 3 nm closer to the runway. MEP is selected by ITEM 7 on SPEC 50.

Range savings using these options vary as a function of HAC turn angle.



Range Saved vs HAC Turn Angle

None of the options are nominal procedures. They are only used when the orbiter is in a low energy situation.

Manual HAC Procedures

The following manual HAC techniques have been designed to reduce the amount of energy lost when high winds are encountered on the HAC:

- CSS at M = .95.
- Leave S/B in AUTO.
- Fly 220-230 KEAS, expect to get 2 or more dots high.
- Modulate bank to keep the predictors (SPEC 50) on the HAC.
- At 120 degrees turn to go, follow guidance.

Energy loss is reduced by flying higher than guidance is commanding while horizontal ground track remains the same. This procedure must only be used when requested by the ground, based on energy predictions and the altitude at which approach and transition is expected to occur.

Default Air Data and Theta Limits

If air data has not been incorporated to G&C by Mach 1.5, default air data values will be used to set flight control parameters. Default air data should insure adequate flight control for a safe landing, although flying qualities may be slightly degraded.

Theta limits are a set of pitch attitude limits intended to keep vehicle attitude within a reasonable range for flight control. Vehicle pitch attitude, as well as the NOSE HI and NOSE LO limits, is displayed on the VERT SIT display. A 50-degree bank angle limit is imposed when flying theta limits. With no air data to G&C, theta limits apply from 1,500 fps (2,000 fps operational constraint) until established on the outer glide slope and below 10,000 ft altitude.

WARNING

Operationally, do not exceed 50 degrees angle of bank during theta limits. Bank angles greater than 57 degrees will exceed maximum and/or minimum theta limits.

When flying theta limits, the speed brake may be manually managed (below M = .95 only) to control energy if the auto mode is not sending the proper commands. For example, if flying the nose low limit to correct a high energy situation, the speed brake should be full open. At 5,000 ft, the speed brake should be set to the value uplinked in the DEL PAD.

WARNING

No warning is provided when pitch attitude limits are exceeded. Crewmembers should closely monitor theta limits to prevent loss of control.

If using default air data and flying theta limits on the HAC, Mach may be less than 1.0 while V_{REL} (true ground speed) is still greater than 1,000 fps if a tailwind is present. In this situation, default Mach will be greater than 1.0, and a 30 degree bank angle limit is imposed by guidance. Following guidance in this case will result in being blown off the HAC, creating an extremely low energy situation. If in AUTO speed brake, energy may be further degraded since the high q-bar based on high V_{REL} in default air data will deploy the speed brake as the vehicle is blown outside the HAC.

CAUTION

Default air data and a tailwind combination can rapidly cause a low energy situation, requiring aggressive corrections. This is one of the situations where the crew will take the last ADTA data, if available, rather than fly theta limits.

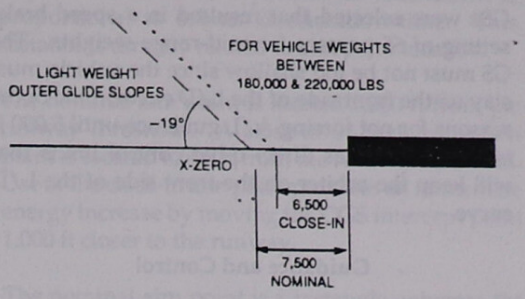
Continuing around the HAC, the tailwind becomes a headwind on final, which may require maximum L/D to make the runway.

Outer Glide Slope

The outer glide slope (OGS) is an equilibrium glide path that provides sufficient energy at preflare for a safe landing. Sufficient energy includes:

- Enough energy to compensate for deceleration between preflare and touchdown
- Providing the pilot with adequate time on the IGS to make final corrections
- Allowing a minimum of 5 seconds of stable flight time on the IGS.

In order to provide sufficient energy at preflare, the OGS design must handle both high and low energy dispersions over the entire weight span of the orbiter. The OGS is a sloped-line segment that intercepts the ground at the aim point.



OGS Profile

Time to correct trajectory dispersions is provided by the altitude at which the OGS is acquired. Nominally, this occurs at 12,000 ft. Transition from TAEM to A/L guidance normally occurs at 10,000 ft, but if the transition criteria have not been satisfied by 5,000 ft, A/L transition is forced.

TAEM TO APPROACH/LAND TRANSITION CRITERIA		
10,000 FT		5,000 FT
< 4 DEG	FLIGHT PATH ANGLE ERROR	< 0.5 DEG
< 1000 FT	CROSSRANGE ERROR	< 100 FT
< 1000 FT	ALTITUDE ERROR	< 50 FT
< 24 PSF	DYNAMIC PRESSURE ERROR	< 24 PSF

TAEM to A/L Transition Criteria

This allows A/L equations to cycle through initial transients and time for the rate terms to reach their damping values.

Reference velocity on the OGS is 290 KEAS. This velocity is required to compensate for the expected deceleration on the IGS. The design goal is to fly as fast as possible while remaining within maximum q-bar limits (300 psf).

A 19 degree GS is used for lightweight vehicles (less than 220,000 lbs), and a 17 degree GS is used for heavyweight vehicles (more than 220,000 lbs). The design goal was to fly as shallowly as possible while maintaining sufficient speed brake reserve to cope with winds and trajectory dispersions. Since both high and low energy dispersions are possible,

GSs were selected that resulted in a speed brake setting of 65 percent for mid-range weights. The GS must not be too shallow since the vehicle must stay on the front side of the L/D curve. One of the reasons for not forcing A/L guidance until 5,000 ft is that TAEM has direct q-bar control limits that will keep the orbiter on the front side of the L/D curve.

Guidance and Control

Guidance attempts to maintain the reference airspeed of 290 KEAS and either the 19 degree or 17 degree GS reference by computing a normal acceleration command to guide the orbiter along the OGS trajectory. The N_z command is converted to a pitch command and displayed on the ADI and HUD. If the pitch command results in a velocity that is different than 290 KEAS, the speed brake responds to correct the velocity error.

Leaving the speed brake in AUTO allows guidance to reposition it, as required, to maintain the reference velocity.

The body flap, if in AUTO, is commanded to retract to the trail position (0 degrees) on the first A/L guidance pass.

Navigation

Upon receiving good data from the ground-based microwave landing system (MLS), preland navigation is begun. Unlike entry NAV, preland NAV maintains only one state vector, but executes twice as fast (every 1.92 sec vs 3.84 sec).

The MLS provides extremely accurate azimuth, range, and elevation, which correct the onboard NAV state. Allowable errors are about 5 ft altitude, 21 ft downtrack, and 17 ft crosstrack when processing MLS data.

NOTE

Both range and azimuth data "good" flags are required to process MLS data. Without an elevation data "good" flag, azimuth and range will still be processed, but if either the azimuth or the range data "good" indicator is lost, all MLS processing will cease.

If MLS data are lost for any reason (above 1,500 ft) after processing has begun, TACAN and ADTA information will again become available to NAV until 1,500 ft and 500 ft respectively. If MLS data are lost below 1,500 ft, ADTA processing is not possible.

NOTE

With TACAN data in FORCE mode, MLS data cannot be processed.

Smart Speed Brake Logic

To control orbiter touchdown energy, the speed brake is retracted at 3,000 ft to a value calculated by onboard guidance that will target the remaining velocity profile to a fixed touchdown energy. The calculated speed brake position is a function of:

- Wind speed
- Vehicle weight
- Velocity error
- Density altitude
- Aimpoint (if applicable)
- Short field (if applicable).

This position is maintained until 500 ft where the A/L guidance calculates an adjustment to the retract angle. This adjustment is based on any changes in winds and predicted density altitude since the 3,000 ft calculation. No more adjustments are made until touchdown. The 500 ft adjustment altitude was selected because the time to fly from 3,000 to 500 ft is approximately the same time it takes to fly from 500 ft to touchdown. This allows time for the adjustment to have an effect on the vehicle energy state.

When the close-in aim point is selected, 1,000 ft are directly added to the downrange total. The idea is to keep the same touchdown energy target even though the geometry has been shifted in by 1,000 ft. This lets the vehicle respond to atmospheric conditions that required the close-in aim point.

Selecting the short field option on SPEC 50 also adds 1,000 ft to the downrange total. However, in this case, the target touchdown energy is changed. The short field option is used to subtract energy from the trajectory and will decrease rollout distances by 1,000 ft. This option is usually selected

for transoceanic abort landing (TAL) runways of less than 13,000 ft length in order to maintain a 2,000 ft rollout margin.

The maximum allowable speed brake command at 500 ft is 50 degrees, due to degradation of orbiter handling qualities near touchdown. This maximum limit is not invoked when short field option is selected.

After the speed brake setting is adjusted at 500 ft, the guidance command remains constant until the weight-on-wheels signal is sent to the GPCs. When this signal is latched, the speed brake is commanded to full open.

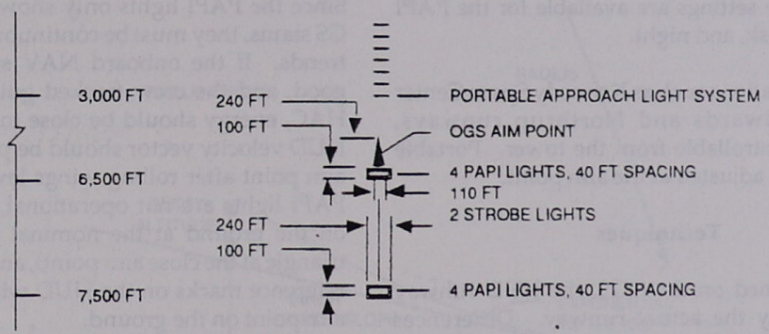
Visual Aids

Aim Points

The OGS aim point location was determined by energy requirements for landing and geometry constraints for transition between the two glide slopes. Distance from preflare to touchdown is proportional to orbiter deceleration time. This distance is directly related to aim point location.

The nominal aim point is located 7,500 ft from the runway threshold. A close-in or high wind aim point is located 6,500 ft from the runway threshold. Use of the close-in aim point provides an immediate energy increase by moving the OGS intercept point 1,000 ft closer to the runway.

The nominal aim point is a rectangle, whereas the close-in aim point is a triangle. Colors are chosen to contrast with the local terrain. Aimpoints on lakebeds and light-color terrain are usually black. For tree- or vegetation-covered terrain, aimpoints are usually white. A dark background is preferred for the precision approach path indicator (PAPI) lights, which are placed on each aimpoint.

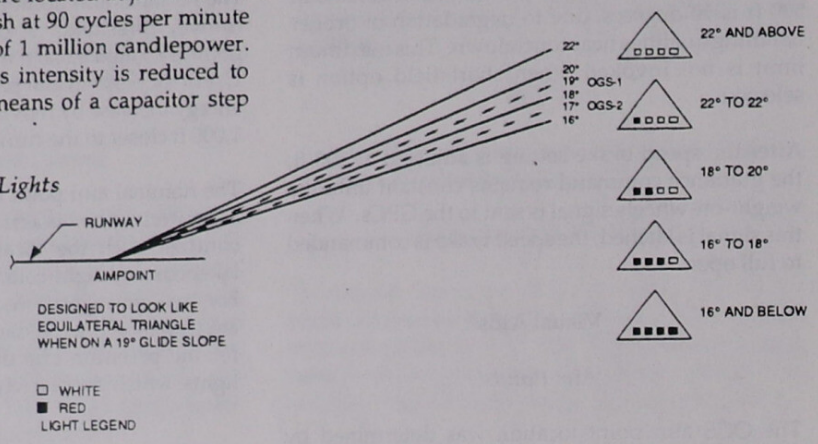


Aim Points

To enhance the flight crew's ability to acquire the aim points and PAPI lights, a strobe light system is installed at the close-in aim point. Six high-intensity, directional strobe lights are located adjacent to the aim point. The lights flash at 90 cycles per minute (cpm) with an intensity of 1 million candlepower. For night operations, this intensity is reduced to 10,000 candlepower by means of a capacitor step and red filter.

PAPI Lights

The PAPI lights define the OGS. On a nominal approach, the crew should see two red and two white lights (19 degree GS). For heavyweight landings, a 17 degree GS is flown (three red and one white PAPI).



PAPI Light Diagram

Three intensity settings are available for the PAPI lights: day, dusk, and night.

At fixed installations such as Kennedy Space Center and some Edwards and Northrup runways, intensity is controllable from the tower. Portable PAPIs must be adjusted at the aim point.

Techniques

When established on the OGS, the HUD runway should overlay the actual runway. Differences indicate the amount of NAV error. If the overlay is good, then NAV and guidance should be good, and declutter level one or two may be selected and the guidance symbol followed. If excessive NAV error exists, declutter but do not follow guidance. The HUD gamma reference marks should lie next to the aim point if guidance is correct.

Without a HUD, use the ADI error needles as long as the NAV state is good. With MLS data, the NAV state will generally be very good. Use of TACAN only will produce errors requiring the pilot to fly the OGS primarily using the HUD and external references.

Since the PAPI lights only show an instantaneous GS status, they must be continuously monitored for trends. If the onboard NAV state is reasonably good, and the crew tracked guidance around the HAC, energy should be close to nominal, and the HUD velocity vector should be positioned near the aim point after rolling wings level on final. If the PAPI lights are not operational, use the rectangle on the ground at the nominal aim point (or the triangle at the close aim point), and align the gamma reference marks on the HUD with the appropriate aim point on the ground.

Night approaches should be considered instrument approaches. Due to lack of outside references, bank control is more difficult. Sink rate is not apparent until after preflare.

When flying a manual speed brake approach, maintain 285-290 KEAS on the OGS, then close the speed brake at 2,500 ft. If speed brake settings are known, the pilot not flying the approach should set the speed brake at 3,000 ft and 500 ft.

High energy conditions are best corrected by deploying the speed brake to 100 percent. S-turns on final are not recommended because the turn dissipates an uncontrollable amount of energy leading to a low energy condition.

For low energy cases, close the speed brake and fly the wings level max L/D of 10.5 degrees alpha. Push over no later than 4,000 ft in order to have enough energy to preflare.

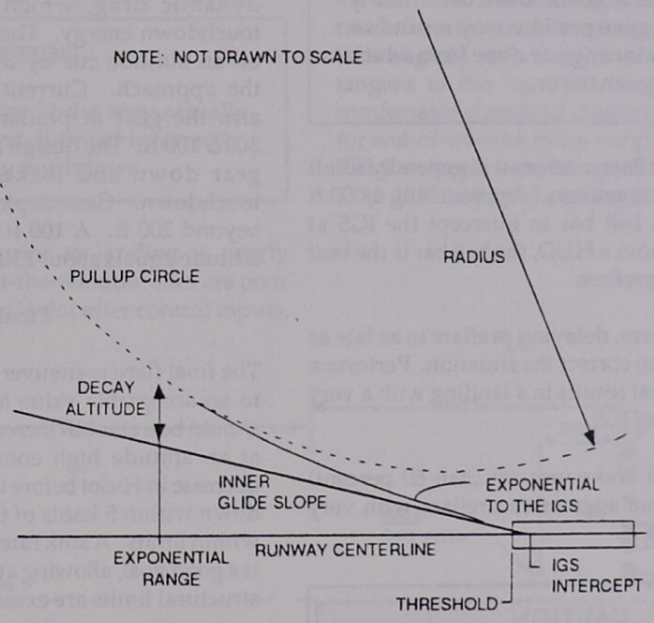
> **CAUTION**
>
> Entering preflare with less than 240 KEAS does not allow enough energy to rotate the nose to a safe touchdown attitude.

With speed brake stuck closed, lowering the landing gear early results in equivalent drag of 40 - 45 percent speed brake.

Stuck open speed brake can be compensated for by flying a steeper OGS with an adjusted aimpoint closer to the runway.

Preflare

The preflare maneuver is used to transition from the OGS to the IGS. Flight path geometry is a sector of a circle tangent to the OGS and an exponential to the IGS. H-dot of about 190 fps must be reduced to less than 3 fps at touchdown. Preflare reduces H-dot to about 12 fps, with the remainder taken out in final flare. Pullup is about 1.25 g.



Preflare Geometry

Since the speed brake is retracted at 3,000 ft and preflare nominally occurs at 1,750 ft, the orbiter's velocity will increase to about 300 KEAS. As flight path angle nears the minimum steady state value (minus 12 degrees), velocity will begin to decrease.

Techniques

There is a strong tendency, especially with inexperienced pilots, to be too aggressive in the preflare or to anticipate the maneuver, ending up high and slow. This tendency is aggravated at night, when closure rate and depth perception cues are reduced.

> CAUTION
>
> The preflare is a gentle maneuver. Early and/or aggressive preflare may result in a high and slow inner glide slope from which a hard landing can occur.

Utilizing the HUD flare markers will generally result in good preflare maneuvers. Approaching 1,000 ft to 800 ft, use the ball bar to intercept the IGS at about 300 ft. Without a HUD, the ball bar is the best reference during preflare.

For low energy cases, delaying preflare to as late as 1,000 ft may help to correct the situation. Perform a flare maneuver that results in a landing with a very minimal amount of IGS.

Stuck open speed brake (greater than 60 percent) will require a more aggressive preflare with very little time on the IGS.

> CAUTION
>
> Failure to anticipate the rapid airspeed decay during preflare with stuck open speed brake (more than 60 percent) may result in high sink rate landings.

Use crab angle to control drift due to crosswind during the preflare. A significant change in crab angle during preflare should be expected due to the large change in airspeed and altitude during the maneuver.

Inner Glide Slope

Transition to the IGS begins at 300 ft. Once the landing gear is deployed, and the orbiter is on the IGS, deceleration is fairly constant at 4 KEAS per sec. Each additional second the orbiter remains airborne results in a 4 knot slower touchdown velocity. The 1.5 degree IGS was designed to give the pilot at least 5 sec of stable flight before final flare.

Once stabilized on the inner glide slope, since the orbiter is decelerating, some pitch attitude changes will be required to maintain the desired trajectory.

Landing Gear

The landing gear creates a great deal of aero dynamic drag, which can significantly alter touchdown energy. The landing gear is deployed on an altitude cue by the pilot who is not flying the approach. Current flight procedures are to arm the gear at preflare and lower the gear at 300 ± 100 ft. The design requirement is to have the gear down and locked at least 5 sec before touchdown. Gear deploy should not be delayed beyond 200 ft. A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy.

Final Flare

The final flare maneuver reduces H-dot on the IGS to an acceptable value at touchdown. Final flare should be a smooth increase in pitch attitude started at an altitude high enough to result in a timely decrease in H-dot before touchdown. Strive to touch down within 5 knots of target speed with sink rate within limits. A sink rate of 3 feet per second or less is a good goal, allowing ample margin before vehicle structural limits are exceeded.

Maximum H-dot at touchdown was designed to protect the main gear struts from unacceptable loadings. Each strut can withstand up to 207,000 lbs, although the actual H-dot limit varies from 6 to 9 fps as a function of vehicle weight.

A very important factor in reducing H-dot is the powerful aerodynamic ground effect of the orbiter. This effect grows as altitude decreases, increasing L/D by about 25 percent. Minimize RHC inputs prior to touchdown, and expect ground effect to cushion sink rate.

The 1.5 degree IGS used by guidance is a compromise. It does not require a large maneuver to land, yet maintains a reasonable ground clearance when coming out of preflare.

Techniques

A negative handling quality of the orbiter is that initial vehicle response to pitch control inputs is backwards from the desired performance. This is due to relative locations of the c.g., aerodynamic center, control surfaces, and the pilot's seat. For example, a pitch up command from the RHC causes an upward elevon deflection. The up elevon initially causes a decrease in lift (approximately 2,000 lb per degree), and the wheels actually move closer to the ground at a faster rate. The expected positive lift increment will not occur until the orbiter has rotated to a higher angle of attack.

> **CAUTION**
>
> Attempting to reduce H-dot may actually increase the rate, and, if timed incorrectly, can result in an early touchdown.

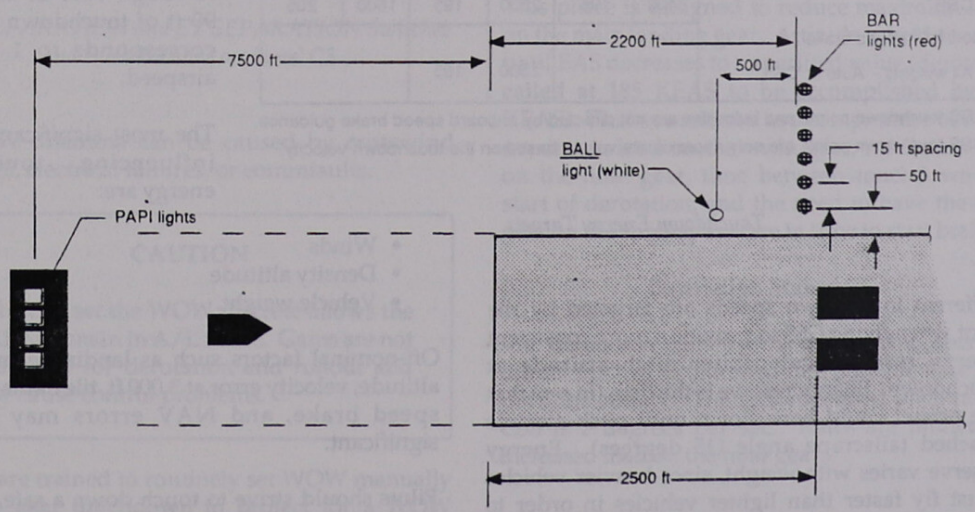
Pilot eye height just prior to landing is nearly constant. Therefore, out-the-window cues are poor indicators of actual H or H-dot after control inputs.

The HUD should be used to monitor pitch attitude and make precise adjustments both on the IGS and for final flare. For no-HUD approaches, use the far end of the runway or the horizon, since pitch attitude changes are very difficult to see due to a lack of references.

A "bang-bang" technique of pitch attitude corrections on the IGS has proven to be effective for some pilots. Small pitch inputs are made, and the RHC is quickly returned to detent. After each input (or series of inputs for larger corrections), wait until the effect is apparent before making another correction. This technique is less effective as landing weight increases.

Ball Bar

The ball bar defines a 1.5 degree GS. Overlaying the center of the ball across the center of the bar results in a threshold crossing height of 26 ft. This feels slightly high to most pilots. Flying the ball tangent to the top of the bar results in a more comfortable threshold crossing height of 15 to 18 ft for end-of-mission gross weights and 10 to 15 ft for RTLS weights. In training, pilots should strive for a 15 to 20 ft threshold crossing height.



Ball Bar Geometry

Touchdown rectangles on the runway surface may also be used. The leading edges of the marks are 2,500 ft from the threshold, and the marks are 200 ft long and 40 ft wide. Aiming the orbiter straight toward the marks from ball bar intercept until final flare results in good IGS control and safe threshold crossing heights. This technique is especially helpful for no-HUD approaches.

For the final flare, matching digital altitude and digital airspeed on the HUD (40, 240 . . . 30, 230 . . . 20, 220) will result in a smooth maneuver from the IGS to touchdown.

Touchdown

A/L trajectory was designed to result in touchdowns about 2,500 ft past the runway threshold at a safe speed and sink rate. Speed brake control logic targets a touchdown at 195 KEAS and 2,500 down the runway for all vehicle weights.

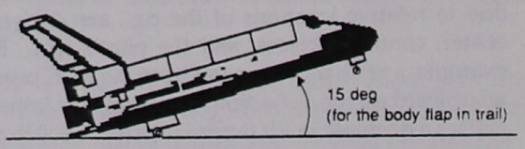
GUIDANCE MODE	VEHICLE WEIGHT					
	< 200 K		200 K – 220 K		> 220 K	
	T/D Point (ft)	T/D Speed (KEAS)	T/D Point (ft)	T/D Speed (KEAS)	T/D Point (ft)	T/D Speed (KEAS)
Nominal guidance – all aim points						
• Auto	2500	195	2500	195	2500	195
• CSS*	3400	195	2500	195	1600	205
Short field speed brake						
• All weights – Auto or CSS*			1500	195		

* CSS touchdown points and velocities are not directed by onboard speed brake guidance. CSS touchdown points are only approximate values based on the touchdown velocity.

Touchdown Energy Targets

Different touchdown speeds are targeted by the pilot when flying CSS to provide a more consistent energy reserve and orbiter pitch attitude at touchdown. Energy reserve is the time (in sec) that the orbiter could have flown until pitch attitude reached tailscrape angle (15 degrees). Energy reserve varies with weight, since heavier vehicles must fly faster than lighter vehicles in order to produce aerodynamic lift equal to weight. Consistent energy reserve and consistent pitch attitude are very important factors that help pilots land with sink rates within vehicle limits. CSS target touchdown speed is 195 KEAS for weights less than 220,000 lbs and 205 KEAS for weights greater than 220,000 lbs.

$$\text{ENERGY RESERVE} = \frac{V_{\text{Tailscrape}} - V_{\text{Touchdown}}}{\text{Deceleration}_{\text{Avg}}}$$



TAILSCRAPE — The maximum pitch attitude (deg) the vehicle can land at and not scrape the tail (body flap).

ENERGY RESERVE — The time (sec) the vehicle could have continued flying after touchdown until the tailscrape condition.

Energy Reserve/Tailscrape

Since the speed brake (in AUTO) still targets for 2,500 ft at 195 KEAS touchdown energy regardless of weight, touch-down distances for lighter vehicles will be longer and for heavier vehicles will be shorter. A rough rule of thumb is 90 ft of touchdown distance corresponds to 1 knot of airspeed.

The most significant factors influencing touchdown energy are:

- Winds
- Density altitude
- Vehicle weight.

Off-nominal factors such as landing gear deploy altitude, velocity error at 3,000 ft, tile damage, stuck speed brake, and NAV errors may also be significant.

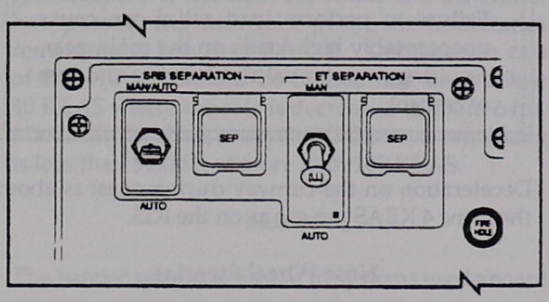
Pilots should strive to touch down a safe distance down the runway, within 5 knots of the targeted airspeed, with sink rate within limits, and negligible lateral drift. A sink rate of 3 feet per second or less

is a good goal for training. Minimal RHC activity prior to touchdown is desired to preclude pilot induced oscillations and high main gear loads.

For crosswind landings, use crab angle to control drift. Maintain the required crab angle all the way to touchdown.

Weight on Wheels Discretes and Flight Control Moding

At touchdown, both weight on wheels (WOW) discretes must be set for at least 1 second to properly mode flight control for derotation and rollout. If both main gear discretes are not set within 7.2 sec, a WOW DILEMMA will be annunciated. The crew can set the WOW discrete manually by selecting the *SRB* or *ET SEPARATION MAN* mode and depressing the appropriate push button. To avoid derotation transients, this action is deferred until after nose gear touchdown.



SRB SEPARATION and ET SEPARATION Switches and Push Buttons on Panel C3

A WOW dilemma can be caused by crosswind landings, electrical failures, or commfaults.

> **CAUTION**
>
> Failure to set the WOW discrete allows the DAP to remain in A/L mode. Gains are not optimized for derotation and rollout and may cause control problems.

Crews are trained to routinely set WOW manually at nose gear touchdown to protect for a WOW discrete failure. If a manual *SEP* push button is depressed at main gear touchdown in order to clear a WOW DILEMMA, the rollout discrete will be set when pitch attitude decreases below 0 degrees.

Flight software performs other checks to ensure the WOW discrete is not set while the orbiter is still airborne.

The WOW discrete also sets flat turn and HUD discretes, which cause mode changes in the aerojet DAP. Setting WOW also modes the pitch channel to AUTO for auto load relief. In the roll/yaw channel, when WOW is set, rudder trim freezes, aileron trim freezes, and auto load balancing becomes active. Auto load balancing uses aileron commands generated through the roll channel to balance loads on the main tires. These commands are computed as a function of true airspeed, lateral acceleration, and vehicle yaw rate. Also at main gear touchdown, lateral acceleration feedback and rudder trim loops are opened. In CSS, pitch axis information drives only the ADI error needles.

Derotation

There are two phases of the derotation portion of orbiter landings: attitude hold and the derotation maneuver itself. Both are important and are discussed separately for clarity.

Attitude Hold

This phase is designed to reduce maximum loads on the main landing gear. Attitude is held constant until EAS decreases to a specified value (derotation called at 185 KEAS to be accomplished by 180 KEAS). This was selected as a compromise between maximum load on the main gear, maximum load on the nose gear, time between touchdown and start of derotation, and the need to have the nose gear on the runway surface in time to start braking.

Derotation Maneuver

The derotation maneuver is designed to decrease orbiter pitch at a controlled rate until the nose gear is on the surface. The recommended pitch rate in CSS is 2 degrees per sec. Rates are limited by increased load on the nose gear.

Executing a smooth derotation requires good crew coordination and must be practiced in the simulator. The pilot not flying the approach and landing should call out airspeeds, with a "derotate" statement at 185 KEAS. A positive nosedown command must be input and held with the RHC to generate the desired 2 degrees per sec pitch rate. When pitch rate is established, callouts of "down at 2, down at 1-1/2,..." are very helpful in maintaining a constant rate until nose gear touchdown. The pitch rate needle on the ADI is the best source of this information.

Heavy gross weight landings on lakebeds (high rolling friction coefficient) are the most difficult to control.

CAUTION

Do not delay derotation, especially on lakebeds at heavy gross weight. Loss of elevon effectiveness can cause hard nose gear slapdowns and possible structural damage.

Derotation must be commenced at the proper speed and the pitch rate maintained throughout the maneuver. Attempts to significantly slow or stop the pitch down rate can cause a dangerous PIO.

Rollout

Two phases of rollout are coast and braking. Rollout margin and brake energy limits are defined to ensure the orbiter can stop prior to the end of the runway. Generally, high-energy rollout margin is considered to be 2,000 ft and is measured either from the end of the runway or the end of the usable overrun. Brake energy is limited to 42 M ft-lb (carbon brakes) for end of mission landings. If predicted brake energy exceeds these values, runway redesignation will be considered.

Shorter abort site runways will have a barrier to protect against brake failures. Note that crosswinds directly increase resulting brake energy when differential braking is used for lateral control during rollout.

Short field speed brake may be selected on SPEC 50 to achieve required rollout margin or brake energy limits. This software logic adjusts the speed brake retract function to target a touchdown point 1,000 ft closer to the runway threshold (1,500 ft vs. 2,500 ft).

Coast

Coast phase begins when the nose gear has been on the ground for 13 software cycles (2.08 sec). This sets the weight on nose gear (WONG) signal. Elevons are moved automatically from the position required to control derotation to 10 degrees down in order to reduce loads on the main landing gear. The crew should monitor auto load relief on the SPI. If it does not occur, manual load relief should be initiated.

WARNING

Failure to perform load relief can cause unacceptably high loads on the main gear, resulting in potential tire failures and loss of control.

Deceleration on the runway during coast is about the same 4 KEAS per sec as on the IGS.

Nose Wheel Steering

HUD rollout discrete and groundspeed enable are nominally set at nose gear touchdown. Nose wheel steering is available once groundspeed enable is set. Three modes are available:

1. OFF: No steering commands; nose wheels caster.
2. DIRECT: Rudder pedal deflection tied to nose wheel steering angle. No N_y damping but commands passed through a parabolic shaper to limit deflection at high groundspeed.
3. GPC: Rudder pedal deflections incorporated as biases to N_y feedback.

NOTE

With the improved NWS system, direct NWS is deleted and a second GPC mode is added. This second mode is wired differently than the first mode and therefore adds some redundancy.

The DIRECT mode should only be used as a backup to GPC on the lakebed surface in the presence of tire failure, since it is overly sensitive to control inputs. GPC mode should not be used if N_y feedback is zero fault tolerant (two AAs failed or commfaulted). This avoids exposure to another AA failure.

Braking

The start of braking is normally determined by groundspeed, although distance remaining on the runway is also considered. Braking begins when groundspeed is less than 140 KEAS and the orbiter has passed the midfield point, or if distance remaining is less than 5,000 ft. Deceleration rate of 8 to 10 fps should be maintained until below 40 KEAS where the rate is decreased to about 6 fps. Maximum braking is applied if distance remaining is less than 5,000 ft at more than 140 KEAS.

Barrier

The barrier system is similar to systems used aboard aircraft carriers to recover damaged airplanes. It consists of a net, positioning system, and energy absorbers. The net is made of vertical nylon straps that are bundled together at the top and bottom. The orbiter nose passes through the vertical straps, which then catch on the wings, pulling the net down from the positioning stanchions. The straps spread out uniformly over the wings and provide a distributed retarding load.

On each side of the runway, two spools of nylon tape are attached to the side of the net. As the orbiter pulls the net, the spools unwind, paying out tape. The spools are mounted on water turbines that convert kinetic energy into heat. The system is capable of stopping a 260,000 lb orbiter that engages the net at 100 KEAS.

Barriers are placed about 800 ft from the end of the runway overruns on short abort runways (less than 12,000 ft).

Some damage will occur to gear doors, probes, and tiles during barrier engagement. The crew module and fluid systems will remain intact.

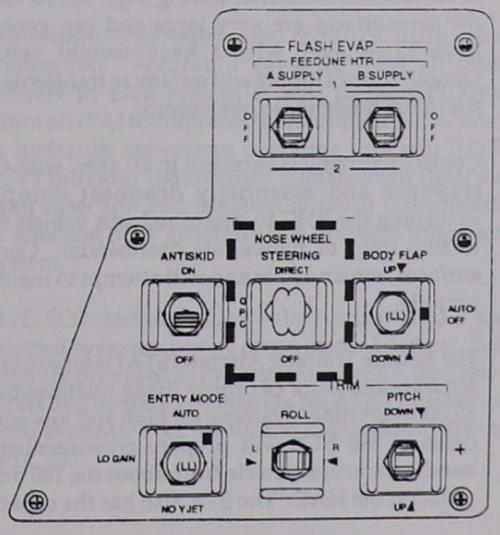
Barrier systems are portable and can be transported via C-130 aircraft and stored at landing sites. Set up time is about 6 hours, using an eight person crew. The stanchions can be raised or lowered in about 10 sec.

To engage the barrier, try to be as slow as possible and as close to the runway centerline as possible. Nose wheel steering or differential braking may be required to keep the vehicle on the runway.

Techniques

Nose wheel steering (NWS) should be used for directional control and brakes used for stopping unless differential braking is required. NWS operations in *GPC* are crisp and responsive with no tendency to overshoot or overcontrol. In *DIRECT* mode, the NWS is very sensitive, and care must be taken to avoid overcontrol.

The *NOSE WHEEL STEERING* switch on panel L2 has an extension device mounted on the shaft to make it easier to locate. The commander should make it a habit to locate this switch during rollout and be prepared to downmode the NWS to *DIRECT* or *OFF* if a failure occurs.



NOSE WHEEL STEERING Switch on Panel L2

With NWS in *GPC* or *DIRECT*, the orbiter will tend to turn into a crosswind during rollout. With NWS in caster (*OFF*), the orbiter will tend to turn away from a crosswind.

If a tire failure occurs during rollout, the orbiter will turn toward the failed tire. When the turning moments due to crosswind and tire failure are in the same direction, large control inputs will be required to maintain runway centerline. When the turning moments are in opposite directions, smaller control inputs will be required, and pilots must be careful not to overcontrol.

Rollout performance is best demonstrated in the Vertical Motion Simulator (VMS) at NASA Ames Research Center. NWS and tire failures are realistically modeled, allowing crewmembers to experience actual orbiter dynamics while making corrections. Crew coordination and skills are practiced in the Shuttle Mission Simulator (SMS). Crewmembers should ensure that different rolling friction coefficients and wind conditions are seen, as well as appropriate system failures that disable or downgrade the NWS system.

Handling Qualities

The Space Shuttle DAP is a rate command system. When the RHC is moved from detent, aerosurfaces are deflected to command a bank or pitch rate. Due to control requirements during high speed flight, the aerosurfaces are very large and can generate large rates, even with a heavyweight vehicle. Smooth control inputs will minimize transients and the initial tendency to overcontrol.

Control harmony is excellent in all axes, with crisp response and essentially deadbeat damping. Returning the RHC to detent reduces vehicle rates to zero (plus or minus rate deadbands). Control surfaces remain active and will attempt to maintain attitude.

The Shuttle Training Aircraft (STA) is an extremely accurate simulator of orbiter flying qualities below 35,000 ft altitude. Training for high and low energy cases in the STA will prepare crewmembers to handle the actual vehicle from about the 180 degree point on the HAC. The STA also has the capability to demonstrate navigation state errors up to 6,500 ft short, 2,000 ft long, and 1,200 ft laterally from the desired touchdown point.

Elevons

During subsonic flight, all four elevons are commanded up and down simultaneously for pitch control. For roll control, the elevons are commanded differentially, similar to ailerons on a conventional aircraft.

Body Flap

The body flap is used to trim the elevons during entry and A/L. When guidance transitions to the A/L phase, the body flap is commanded to trail. Normally, the body flap is operated in AUTO. If the body flap is not in AUTO, the crew should return to AUTO or manually position the body flap to trail at A/L transition.

> **CAUTION**
>
> The body flap is a large control surface and exerts a powerful pitching moment on the vehicle. Proper positioning is required to ensure adequate control margins.

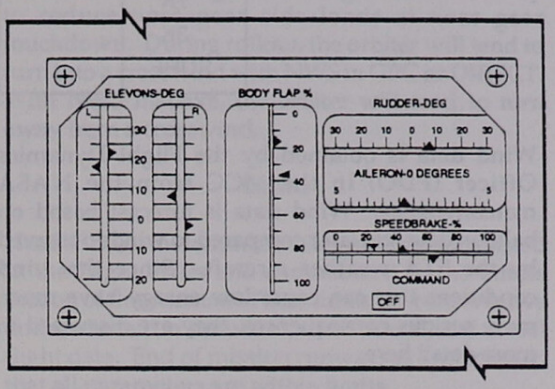
Speed Brake

Although energy is controlled primarily by bank angle and the resulting drag in hypersonic and supersonic flight, the speed brake is the primary energy control device in subsonic flight. A/L guidance modulates the speed brake to control q-bar, when operated in AUTO. Speed brake position is constrained to a lower limit of 15 degrees to prevent physical binding of mechanical linkages when the rudder is deflected.

It is important to take manual control of the speed brake if guidance or NAV is questionable. For example, erroneous air data could cause flight control to generate erroneous position commands, resulting in high or low energy or a flight control transient at a critical moment. At 3,000 ft AGL, the speed brake is closed automatically to a computed value based on wind, weight, density altitude, velocity error, and short field option. At 500 ft

AGL, guidance can command a final adjustment of the speed brake position based on density altitude and wind velocity.

The speed brake is normally operated in AUTO throughout Approach and Landing. Speed brake position and command are displayed on the surface position indicator (SPI) and the HUD.



Surface Position Indicator

WARNING

The speed brake is a very powerful drag device. Overlooking a stuck speed brake or neglecting to retract the speed brake when operating in MAN can result in dangerously low energy.

Rudder

Corrected body roll rate is used in the DAP yaw channel as a yawing rate error to generate rudder commands. This essentially provides turn coordination. Rudder pedal deflection serves only to bias the N_y feedback. Since rudder deflection is largely a function of the automatic stability loops, crewmember rudder pedal input should not be required prior to touchdown.

Trim

Automatic trim loops in the Shuttle flight control system work very well, and although manual capability is available, it is not usually required in the approach and landing flight phase. One exception is after a BFS engage. In this case, the trim values initialize at zero, and the pilot can help the flight control system return to a trimmed condition more quickly by trimming manually.

Priority Rate Limiting

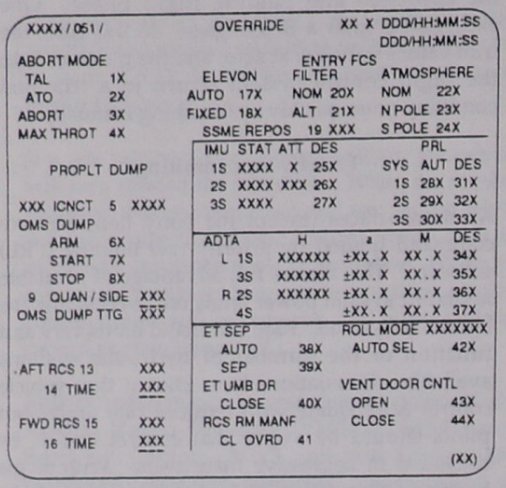
All aerosurfaces (except the body flap) are rate command limited by priority rate limiting (PRL) software. This allows full advantage of available hydraulic system power while not overloading the hydraulic systems. Rate command limits vary as a function of the number of hydraulic systems available. Simulations have shown that vehicle control is adequate with reduced rate limits, but pilots should be aware that control could be degraded in aggressive maneuvers. With single hydraulic system rate limits, touchdown should be about 10 knots fast and derotation 10 knots early to prevent elevon saturation and high nose gear slapdown loads.

HYD SYSTEMS	ELEVONS	AILERONS	SPEED BRAKE	RUDDER
1	13.9	13.9	3.8	7.0
2	20.0	20.0	10.86	12.0
3	20.0	20.0	10.86	14.0

PRL Rate Limits in Degrees

Automatic PRL normally requires little crew interaction. Hydraulic pressure from all three sensors in each system is sent to the GPCs via flight aft (FA) multiplexer/demultiplexers (MDMs). A hydraulic subsystem operating program (HYD SOP) provides redundancy management (RM) for fault detection and isolation of failed transducers. A selection filter generates one pressure from each system.

HYD SOP declares a hydraulic system failed if the selected system pressure drops below 1,760 psi. Fail flags are provided to PRL software, which then rate-limits aerosurface commands based on number of good systems. PRL status and management are on SPEC 51.



PRL STAT/MGMT ON OVERRIDE SPEC 51 Display

Utilizing item numbers, the crew can place PRL in automatic systems management, deselect a system, or invoke manual systems management. A failed system is indicated by a down arrow in the system status column. Failed systems are not used by PRL. Loss of hydraulic pressure information can cause a PRL dilemma and a question mark (?) is displayed next to the affected system. When a dilemma is declared, PRL leaves the system status as it was prior to the dilemma. The crew can then either manually deselect or reselect the system after determining its real status using other cues.

Wind Effects on Trajectory

Winds affect the orbiter's capability to fly the desired HAC trajectory and can result in high or low energy situations if not handled correctly. Since the onboard navigation and guidance systems cannot predict winds, the crew must be prepared to anticipate high wind conditions and compensate for them. Information on wind speed and direction is passed to the crew prior to the deorbit burn. This information is updated as required during entry. Data is provided for the following altitudes:

Wind Data Table

ALTITUDE	HAC POSITION
50K	
38K	270
28K	180
20K	90
12K	FINAL
7K	
3K	
SURF	

Wind data is obtained by the Flight Dynamics Officer (FDO) in the MCC from the NASA meteorologists. Wind data is forecast based on balloon data and later compared to winds observed by the STA weather aircraft. Since the wind conditions that can cause low energy have much more serious consequences, they are discussed in more detail here.

Constant Headwind

For a given reference airspeed, any headwind greater than zero will result in less kinetic energy (less ground speed) than the no wind or tailwind case.

Sudden Headwind Increase

For a given initial energy state, a headwind shear will cause more drag and greater energy loss, until the pilot compensates for the immediate drag increase.

Tailwind Below 50 Feet

Tailwinds, or reduction in headwinds, are normally favorable in a glider because of the reduction of drag. However, at less than about 50 ft, the beneficial effects of drag reduction, integrated over such a short period of time, are outweighed by the sudden loss of available energy caused by the instantaneous decrease in KEAS. Large sink rates and hard landings may result.

Crosswinds

Use crab angle to control lateral drift due to crosswind from outer glide slope intercept until touchdown. Expect a noticeable change in crab angle during preflare and on the inner glide slope due to the large changes in velocity and the change in wind speed as altitude decreases.

Post touchdown, align the fuselage with the runway to reduce nose gear side loads at nose gear touchdown. During rollout, the orbiter will tend to turn into a crosswind with NWS in GPC or DIRECT. With NWS inactive, the orbiter will tend to turn away from a crosswind.

Limits

Headwind, tailwind, and crosswind limits are listed in the Flight Rules and summarized in the Limits section of this manual. These limits are conservative and are based on simulator, wind tunnel, and actual flight data. End of mission runways are selected so that all parameters are within limits.

Backup Flight System

The backup flight system (BFS) is capable of performing nearly all of the primary flight system functions during TAEM, approach, and landing. This section presents the major differences, from the flight crew viewpoint, between the two systems. Differences in handling qualities between the PASS and the BFS are very small in the training simulators, and no large differences are expected if BFS is engaged onboard the Shuttle. A moderate control transient should be expected when BFS is engaged.

The BFS does not support PTIs. Flight control mode is CSS from engage through landing rollout.

The BFS maintains only one state vector during entry. Redundancy management is performed on most systems, but in a simpler manner than PASS. BFS is also set up to accept air data to GNC immediately upon engage. If air data has not been previously accepted in PFS, the crew should inhibit air data to GNC after BFS engage.

The HUD is not supported in BFS. MLS is not supported. Guidance terminates in BFS at 2,000 ft, and ADI error needles are stowed.

Off-Nominal Approaches

This section briefly summarizes the procedures used to correct problems typically encountered during STA training. More detailed information is available in the Approach and Landing Flight Procedures Handbook.

Navigation Errors

A bad navigation state can put the orbiter in a high or low energy condition. If the error is detected early in entry or TAEM, Mission Control will declare a GCA and provide guidance to the landing site until the navigation state can be corrected with a state vector uplink or manual state vector update. If errors are observed after the field is in sight, pilots can use visual cues in addition to MCC calls to fly to the runway.

Low Energy

If the orbiter is more than about one dot low (using HSI glide slope scale) on the glide slope when subsonic, pilots should check that the speed brake is closed, taking manual control if necessary. Next, transition to the angle of attack for best glide range, about 10 to 12 degrees. Hold this angle of attack until slightly above the nominal trajectory, and then lower the nose to accelerate and fly the nominal glide path. Once established on the glide path with speed increasing, check that the speed brake is back in AUTO and operating properly.

If not back on energy by 5,000 feet altitude, the nose must be lowered to achieve a speed of at least 240 KEAS for a safe transition to the touchdown attitude. A delayed gear deploy and slow touchdown may be required to reach the runway. Gear deploy lower than 200 feet is not recommended.

Depending on the portion of the trajectory where the low energy situation is observed, it may be possible to select MEP or turn inside the HAC toward the landing runway to reduce energy requirements.

High Energy

If more than about one dot high on energy during subsonic flight, ensure the speed brake is deployed to 100 percent, and lower the nose to increase airspeed. Maximum airspeed should be limited to 300 KEAS although flight rules allow slightly higher speeds for short periods of time. Carefully observe g-limits when flying the HAC at high speed.

> **CAUTION**
>
> A high energy situation can rapidly become a low energy situation if g-limitations and high speed combine with wind effects to take the orbiter outside of the HAC.

Once back on the nominal trajectory, ensure the speed brake is in AUTO or manually adjusted for the proper airspeed and complete the approach using normal procedures.

Stuck Speed Brake

Procedures for stuck speed brake approaches vary with speed brake setting and are summarized in the following table. These procedures depend on detection of the stuck speed brake prior to the HAC where energy can be adjusted more easily without using the speed brake

SB SETTING (STUCK)	TAEM	A/L	AIMPOINT
> 60	FLY 1 – 2 dots high throughout TAEM	< 220 K: 25° GS > 220 K: 21° GS	*4,000 ft
40 – 60	AUTO P, R/Y	Fly needles	CLSE
30 – 40	Fly 1 – 2 dots low Mtn EAS < 300	15° GS	CLSE
< 30	AUTO P, R/Y At M < .95 deploy gear	Fly needles	CLSE

* Aim 1/2 way between 7,500 aim point and threshold.

Stuck Speed Brake Procedures

Early Gear Deploy

If the gear is deployed early, pilots should manually close the speed brake. If possible, shift to the close aim point, adjust glide path to enter the preflare with slightly more than nominal energy, and delay preflare initiation slightly. A slow touchdown may be required to reach the runway surface in extreme cases.

Manual HAC Techniques

Manual HAC techniques are used to prevent excess energy loss or high-g on the HAC due to high winds. Closely following guidance normally provides the best chance of coping with environmental dispersions, and manual HAC techniques should only be used if requested by Mission Control.

To perform the manual HAC procedures, go CSS at Mach = 0.95 with speed brake in AUTO. Fly an airspeed of 220 to 230 KEAS, and follow guidance roll commands to keep the predictor dots on the HAC (SPEC 50). At 120 degrees of HAC turn to go, resume following pitch and roll guidance.

Sensory Cues

Most crewmembers report a fairly smooth ride throughout TAEM to landing, with the exception of some buffet during the transonic region. On final, the orbiter responds very little to turbulence in comparison to the STA due to the orbiter's higher wing loading.

When returning from orbit, crewmembers should be aware of the potential for some change in vestibular sensations. Head movements will tend to make these changes more noticeable. Flight crewmembers should avoid exaggerated head movements during landing to reduce the possibility of disorientation.

Sun glare and residue on the windows from the SRB separation motors can reduce visibility during landing.

Gear deploy causes very little structural vibration and may be difficult to detect.

The orbiter landing gear absorbs touchdown loads very well, and for low sink rate landings, it may be difficult to feel touchdown. The first cue to the mission specialists that the orbiter has landed may be the beginning of derotation followed by nose gear touchdown. For some flights, depending on runway surface, vehicle weight, and center of gravity, derotation and nose gear touchdown could be quite dramatic.

After returning from orbit, crewmembers need to be aware that some degree of decreased balance and coordination, as well as dizziness, may be experienced when getting out of their seats. Studies are in progress to quantify these effects and improve current countermeasures. At present, crewmembers should exercise caution when leaving their seats and preparing for egress.

Autoland

Although the orbiter has been certified for hands-off automatic landings, this capability has not been verified. Simulations indicate that performance is acceptable under reasonable wind conditions for most weight and c.g. combinations.

Although the orbiter may be flown in AUTO for the entire approach and landing, CSS control until MLS acquisition is recommended. This is due to possible transients as the NAV state is updated by MLS data. A runway equipped with MLS is required for autoland.

Based on SMS and STA data, the autoland system tightly controls azimuth and elevation tracking during the approach. Corrections may be abrupt if not close to the nominal trajectory when AUTO is selected.

As with any automatic control system, the crew's task is to monitor the approach and take over manually if performance is not acceptable or to recover from system failures. Since there is no onboard independent monitor, the crew's visual perception of the approach determines takeover criteria. This may differ somewhat among crewmembers and requires a significant number of automatic approaches in the SMS and STA to achieve a reasonable level of proficiency. Both the HUD and ADI should be monitored during the approach. Splitting crewmember duties between the pilots has proven to be an effective method of monitoring autoland performance.

CAUTION

Pilots must use extreme care when executing a manual takeover from automatic flight control after commencement of pre-flare. Very little time exists before touchdown to damp vehicle attitude transients which may be induced by the takeover.

Techniques

After OGS intercept, MLS acquisition, and A/L transition, engage *AUTO PITCH* and *ROLL/YAW*. Attempt to have ADI error needles centered or tracking toward the center position prior to engagement. Should a takeover be required, the *CSS PITCH* and *ROLL/YAW* push buttons should be used to downmode. This avoids undesirable transients caused by a "hot-stick" downmode. Takeover should be performed only during stable flight conditions, if possible. A manual takeover on the OGS or IGS is much less demanding than during a dynamic phase of the approach such as preflare.

With good autoland performance, the crew should only be required to lower the gear at 300 ft and apply brakes after nose wheel touchdown. Rollout guidance is provided by the MLS and lateral control by the NWS.

RWY	MLS	PAPI 7500 FT (NOMINAL)	PAPI 6500 FT (CLOSE-IN)	MARKING 7500 FT ■	AIM PT. 6500 FT ▲	BALL BAR	TACAN (PRIMARY)	TACAN (BACKUP)	REMARKS
EDW 17L	√ JR CH 6	√	√	√	√	√	EDW 111 (SS)	PMD 92 (SS)	
EDW 23L	—	•	•	√	√	•			Threshold & TD MK
EDW 35R	—	•	•	√	√	•			Threshold & TD MK
EDW 05R	—	—	—	—	√	•			Threshold & TD MK
EDW 15	√ JR CH 6	√	√	√	√	√			Threshold & TD MK XENON
EDW 33	—	•	√	√	√	√			Threshold & TD MK
EDW 22	√ SR CH 8	√	√	√	√	√			XENON **
EDW 04	—	√	√	√	√	√			Underrun unusable/ displaced threshold XENON **
EDW 18L	—	•	•	√	√	•			Threshold & TD MK XENON **
KSC 15	√ SR CH 8	√	√	—	(1)	√	TTS 59Y (DS)	COF 97 (DS)	XENON
KSC 33	√ SR CH 6	√	√	—	(1)	√			XENON
NOR 17	√ JR CH 6	√	√	√	√ (1)	√	SNG 121Y (SS)	HMN 92 (SS)	XENON
NOR 23	—	√	√	√	√	√			
NOR 35	—	√	—	√	√	√			
NOR 05	—	—	—	√	√	—			
BEN 36	√ SR CH 6	√	√	√	√ (1)	√	BEN 118 (DS)	CBA 116 (DME)	XENON
BEN 18	—	√	√	√	√ (1)	√			
MRN 20	√ SR CH 6	√	√	—	(1)	√	MRN 100 (SS)	AOG 23 (DS)	Barrier 800 ft from end of overrun, XENON **
ZZA 30	√ SR Ch 6	√	√	—	(1)	√	ZZA 64 (DS)	MLA 58 (DME)	Barrier 800 ft from end of overrun, XENON **
BYD 32	√ 2JRS CH 6	√	√	—	(1)	√	BYD 121Y (DS)	BJ 76 (DME)	Barrier 800 ft from end of overrun, XENON **
HNL 08R	√ JR CH 6	—	—	—	(1)	√	HNL 95	CKH 86	Barrier 800 ft from end of Rwy, XENON **
GUA 06L	√ JR CH 6	—	√	—	(1)	√	UAM 54	UNZ 100	Barrier 800 ft from end of overrun, XENON **

NOTE

THIS CHART REFLECTS CAPABILITIES AND CONFIGURATIONS WHICH ARE DEPENDENT ON MISSION CHARACTERISTICS; i.e., INCLINATION, AND DAY VS NIGHT RTLS, TAL, AOA CASES. • SURVEYED POINTS WHERE PAPI LIGHTS/BALL BAR CAN BE INSTALLED. (1) AIM POINT IDENTIFICATION LIGHT SYSTEM (APILS) AVAILABLE. ** XENON lights can be installed at these locations for mission requirements. AIM POINT MARKING @ 6500 FT IS A TRIANGLE, 7500 FT MARKING IS A RECTANGLE. (2) SINGLE GENERATOR ONLY. (DS) REFERS TO DUAL STRING TACAN TRANSPONDERS, (SS) IS A SINGLE STRING UNIT.

Navaids/Landing Aids Hi/Lo Inclination

Terminal Area Energy Management and Approach, Landing, and Rollout Rules of Thumb

- A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy. Gear deploy should not be delayed past 200 feet altitude.
- 90 ft of touchdown distance corresponds to 1 knot of airspeed.
- TAEM guidance uses pitch to control range, bank angle to control ground track, and speed brake to control q-bar.
- Overhead HAC with NEP allows the most downmode options for energy.
- Fly theta limits at Mach 2 (NLT Mach 1.5) if air data is not incorporated to G&C. Maximum bank angle is 50 degrees. Speed brake should be controlled manually when flying theta limits.
- Manual HAC techniques are only used when requested by Mission Control. To execute the manual HAC procedure, fly 220 - 230 KEAS and follow roll commands. At 120 degrees turn to go, resume flying pitch and roll guidance.
- For an early gear deploy, immediately close the speed brake.
- OGS is 19 degrees lightweight (< 220,000 lbs) and 17 degrees heavyweight (> 220,000 lbs). Aimpoint is 7,500 ft nominal and 6,500 close-in. Touchdown speed is 205 knots heavyweight and 195 knots lightweight and short field speed brake.
- At main gear touchdown, manually deploy the speed brake. Start derotation at 185 KEAS at approximately 2 degrees per sec. At nose gear touchdown, manually back up WOW.
- During training, pilots should strive for a threshold crossing height of 15 to 20 feet on nominal approaches. Touchdown goals are airspeed within 5 knots of the target value, sink rate within structural limits, negligible lateral drift, and minimal RHC activity. A good target value for sink rate is 3 fps or less, insuring ample margin before violating limits.
- With NWS in *GPC* or *DIRECT*, the orbiter will tend to turn into a crosswind. With NWS *OFF*, the orbiter will tend to turn away from a crosswind.
- If the orbiter is landing with a known failed tire, the second tire on that axle is expected to fail during derotation at the point of maximum loading.
- If both main gear tires fail on one side, the orbiter will tend to turn toward that side. The turning moment due to crosswind can either reinforce or reduce this effect.
- If the turning moments due to tire failure and crosswind are in the same directions, large control inputs will probably be required.
- If the turning moments due to tire failure and crosswind are in opposite directions, the control inputs required to counteract tire failure will be reduced. In this situation, pilots must be careful not to overcontrol. A good rule of thumb is to be more cautious with the rudder pedal, matching the crosswind turning tendency.
- Flight Rules call for landing with an existing crosswind on the same side as a known or expected bad tire.

8. INTEGRATED OPERATIONS

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The most successful teams are those who have learned to work together and know each other's responsibilities, strengths, and weaknesses. In a system as complex as the Space Shuttle, the Mission Control Center (MCC), the Launch Control Center (LCC), and the flight crew must work as an integrated team with each part supporting and contributing to the performance of the other.

Each team member must be completely aware of his or her responsibilities and realize that safety and mission success depend on proper coordination among team members. The duties and coordination functions discussed in this section are typical of the responsibilities assigned by the CDR andthe Flight and Launch Directors. Specific assignments will vary from mission to mission.

Preplanned decisions which have been approved by the Shuttle Program are published in the Flight Rules and Launch Commit Criteria. These are designed to minimize the amount of real time discussions when off-nominal situations occur. The Flight Rules also serve as the basis for real time decisions. Rules are developed using system performance capabilities documented in the Shuttle Operational Data Book (SODB), along with program certified capability. Where circumstances do not allow staying within the operating base (SODB + certified capability), the Mission Management Team may choose to take any necessary action to ensure the safety of the crew and Shuttle.

During prelaunch and flight operations, the Mission Management Team (MMT) chairman is responsible for near real time policy decision. The launch team and the flight teams consult with the MMT chairman as soon as possible whenever operations outside the Shuttle operating base are required.

8.1 FLIGHT CREW DUTIES AND COORDINATION

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Dynamic Flight Phases

For a Shuttle flight crew to work well together, each crewmember needs to have his or her job clearly defined. This definition includes the tasks assigned and when they are to be performed. Individual responsibilities will be assigned by the mission commander based on mission requirements. One way in which duties might be divided for dynamic flight phases is summarized in the following table.

POSITION	PRIMARY	SECONDARY
CDR	Trajectory/Nav Abort Boundaries * DPS ECLSS Nominal Timeline Navaids ** Mission Success Mission Safety Voice Transmissions to MCC	Communications Flight Control Channels OMS RCS Contingency Abort Boundaries *
PLT	MPS EPS APU/HYD OMS RCS Flight Control Channels	Trajectory/Nav Navaids ** Mission Success Mission Safety Voice Transmissions to MCC
MS2	Overhead Panels Overhead Gauges Communications	Abort Boundaries * Navaids ** Nominal Timeline Reference Data
MS1	Contingency Abort Boundaries * Photography Reference Data	Nominal Timeline Overhead Panels Overhead Gauges
MS3	Stowage Middeck Panels/Actions	Photography

* Ascent only
** Entry only

Flight Crew Duties for Dynamic Flight Phases

It is critical for the crew to lay out responsibilities early during training and follow their plan. As malfunctions occur, the division of responsibilities may change. For example, the PLT may have to concentrate on the trajectory while the CDR deals with an ECLSS malfunction. To ensure the trajectory is being monitored, especially during the early portion of crew training, the CDR could verbally ask the pilot to watch the gauges. As training progresses, crews gain an understanding of when another crewmember requires assistance and usually provide backup without being asked.

Another way crews work together is to monitor keyboard entries and switch throws. By allowing someone else to check a keyboard entry before it is fed to the GPCs or check that the correct switch is being actuated before it is moved, crewmembers can greatly reduce the chance of errors. For crewmembers to provide a good crosscheck for each others' activities, they must remain together as they work nominal and malfunction procedures. Calling out page numbers, procedural titles, and step numbers will help everyone follow through the procedures.

During dynamic flight phases, or any time when dealing with several malfunctions, it may be best to divide into groups or detail individuals to separate tasks to successfully deal with all problems in a timely manner. The CDR usually takes the lead in assigning tasks. As the proficiency of crews increases, crewmembers often assume responsibility without being formally assigned by the CDR. Whenever groups/individuals begin working separate problems, they should attempt to periodically update the other members of the crew on their progress. This is especially critical when the problems being worked are interrelated. The CDR and PLT must exercise care to ensure that at least one member of the crew monitors the vehicle trajectory and maintains awareness of the nominal timeline when their attention is drawn to different problems.

Orbit Phase

On orbit tasks are usually less time critical and responsibilities are redistributed as necessary. It is important that more than one crewmember is trained for each flight task to protect for the occasion when the prime crewmember might be ill or busy

with another task. Mission specialists usually assume the prime responsibility for major payload activities. For Spacelab flights, the senior mission specialist will be assigned as the Payload Commander and charged with successful payload operations. The following table lists a sample division of duties for the orbit phase.

POSITION	CDR	PLT	MS1	PS1	MS2	MS3	PS2
EVA 1					X		
EVA 2						X	
IVA		X					
MEDIC	2				1		
IFM		1			2		
EARTH OBS		2			1		
PHOTO/TV		2			1		
Prime Payload	2	1					
Secondary Payloads			X	X			
DTO XXX	1					2	
DSO XXX						1	2

1 Prime
2 Backup

On-Orbit Division of Responsibilities

Intercom Protocol

During ascent or entry most crews have a standard protocol of voice callouts to help them keep track of mission events. Typical callouts and associated displays for ascent and entry are listed in the following tables.

MET	EVENT	CALLOUT
00:00	SRB Ignition	CDR: Lift-off/102
00:30	Throttle Bucket	PLT: Throttle down
01:00	Throttle Up	PLT: Three at 104
02:12	SRB Sep	CDR: Pc < 50, Sep, 103, TMECOs converged
03:00		MS2: EVAP OUT T coming down
08:00	MECO -30 sec	CDR: Coming up on MECO
08:32	MECO	CDR: MECO, MECO confirm, ET sep, 104, check targets
10:32	MECO +2:00	PLT: Dump/start

Ascent Displays and Callouts

EVENT	CREWMEMBER	CALL
MLS to state vector	MS	MLS
10 k ft	PLT	10,000 ft
A/L	MS	Approach and Land, BF trail
~5 k	PLT	Radar Altimeter
4 k	PLT	4,000
	CDR	Arm the gear
	PLT	Gear is armed
3 k ft	PLT	3,000
	MS	Boards ____%
2 k ft	PLT	2,000
	CDR	Preflare
1 k ft	PLT	1,000 ____ knots (PLT call max EAS in preflare)
500 ft	PLT	500
400 ft	MS	Boards ____%
300 ft	CDR	Gear down
	PLT	Gear coming
200 ft	MS	Gear is down
~ 50 ft	PLT	____ ft, ____ knots (steady rhythm)
~40 ft		
~ 30 ft		
~20 ft		
~ 10 ft		
~5 ft		
TD		Touchdown, boards open
185 kts		185/175, derotate
140 kts		140 knots
130 kts		____ knots, ____ fps (decel reading)
120 kts		
110 kts		
100 kts		
90 kts		
80 kts		
70 kts		
60 kts		
50 kts		
40 kts		
30 kts		
20 kts		

Landing Comm Protocol

8.2 WORKING WITH MISSION CONTROL

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Air to Ground Voice Communications...8.2-1
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To work well together, the flight crew and MCC must be aware of each other's capabilities. Integrated simulations where members practice their roles on an actual mission are one way in which the team members learn about each other. Another way is for members of the flight crew to observe in MCC during integrated simulations and for Flight Controllers to ride along and observe flight crews operating in the Shuttle Mission Simulator (SMS).

MCC Resources

While visiting MCC, crewmembers will notice that an immense amount of downlist data is available for Flight Controllers to analyze the performance of orbiter systems and follow mission activities. The downlist data is formatted on various displays with orbiter DPS keyboard entries, fault messages, and switch discretes available, as well as numerical parameters. Many of the parameters in the down list data stream are not displayed on board the orbiter. The flight control team also has access to inputs from the customer, direction from NASA management, weather observations and forecasts, engineering test data and analysis, systems performance histories, and radar tracking data.

To properly utilize this data, personnel are divided into groups concentrating on specific vehicle systems or operational functions with each group led by a Flight Controller. The Flight Controllers pass information and recommendations over the intercom voice loops to the Flight Director. The Flight Director uses the information to make decisions on the proper conduct of the mission, and manages the flow of information to the crew via the CAPCOM or uplink commands.

Operations Monitoring and Control

Optimum MCC performance depends on successful receipt of telemetry and tracking data. Orbiter DPS or instrumentation failures, as well as communications failures, can quickly degrade the amount of assistance available from the ground. If possible, the CAPCOM will inform the crew whenever downlist data is lost or regained.

To track the crew's progress through the nominal timeline, Flight Controllers observe individual crew keyboard entries and switch throws via MCC displays. It is usually possible for the ground to follow the crew's progress without voice calls, but an occasional status call can be helpful. The crew can also help the ground by closely following the nominal timeline and by loading maneuvers with future start times well before they are required.

MCC will try to anticipate points in the timeline where an MCC go is required for the crew to proceed, and call before the crew reaches that point. If the crew reaches a point where an MCC go is required before MCC calls, they should ask for a go.

When malfunctions occur, the controllers in MCC will usually see a trend develop in their data before the crew hears an on-board alarm. Whenever possible, and especially on orbit, MCC will attempt to warn the crew and advise a course of action before a fault message occurs. For failures which occur more rapidly, the crew will see a fault message first and the ground will see the problem a few seconds later in the telemetry data stream. After a few seconds to diagnose the problem, the responsible Flight Controller will advise the Flight Director on the proper course of action. On direction from the Flight Director, the CAPCOM will then relay the necessary information to the crew. Usually this transmission will include instruction to follow a procedure in the flight

data file, specific switch actions, or information on why a false alarm occurred. CAPCOMs will strive to use the precise FDF procedural titles and the same switch nomenclature listed on orbiter panels to minimize confusion. If the situationpermits, the CAPCOM will also try to pass to the crew the rationale for the decisions which have been made, especially those involving resources not available to the crew.

Air-to-Ground Voice Communications

Flight crews should be aware that the monitoring of crew voice calls is given very high priority in MCC. Whenever the crew calls on air-to-ground, all discussions cease on the Flight Director's loop in order to concentrate on the crew's transmission. Crew calls to inform MCC of fault messages or advise the ground on progress through normal procedures can interrupt information flow in MCC. Advisory calls on progress through nominal procedures should be reserved for periods of reduced communications activity or for when the ground is having problems with downlist data. For confirmation of non-critical system problems, one plan that works well is to wait 15 to 20 seconds after the appearance of a non-critical fault message before calling the ground. This allows the ground time to digest the problem and call the crew, without interruption. Waiting for MCC to make the first call when non-critical fault messages occur should result in the quickest possible problem confirmation.

Of course, flight crew calls can be extremely helpful when MCC is experiencing data problems or when failures occur which require immediate attention. A crew call in these instances will focus MCC's attention on the problem brought up by the crew. Following are some appropriate calls to MCC which are not specifically required by procedure:

- Acknowledging MCC transmissions.
- Reporting deviations from the timeline or from a procedure.
- Beginning/Ending post insertion, deorbit prep, or major payload activities.
- Beginning/Ending malfunction pro-cedures. (This call is generally not made for critical malfunctions or during periods of high workload.)
- Beginning major DPS reconfigurations or cockpit switch configurations.
- Shutting down a main engine, APU, or fuel cell, or taking electrical buses off line unless previously directed by MCC.
- To report engine failure, fire, DPS set splits, or flight control problems. (These problems may not be immediately apparent in downlist data.)
- Reporting any problem the crew desires MCC to give immediate attention.
- Calling MCC prior to MDM port mode/ power cycle.
- Changing Telemetry formats.
- Switching to alternate ACCU or PCMMU.
- Reporting headset, CCU, or ATU problems.

If practical, flight crews should obtain MCC confirmation of a malfunction before working a malfunction procedure. By the same token, crews should call MCC whenever beginning a malfunction procedure or deviating from the nominal timeline without MCC direction, if the pace of activities and communication status permits. During periods of high activity, MCC will assume that the flight crew is prioritizing problems and automatically working the necessary malfunction procedures as problems arise. In these cases, MCC will save voice confirmation and direction to work malfunction procedures for the most critical problems.

To minimize verbiage and confusion, standard phraseology is frequently used in calls between the orbiter and MCC. Some of these calls are summarized in the table on the next page. Standard abort mode boundary calls are presented in Section 6, Emergency Procedures.

CALL	MEANING
Roger	Your transmission has been received.
Wilco	Will comply with received instructions.
Say again/repeat	Repeat your last transmission.
Read back	Repeat the list of information just transmitted.
Good read-back	The information just repeated was correct.
Stand by	Wait, we will have an answer or be ready to listen shortly.
Stand by on the xx procedure	Wait, we will have a plan of procedure/action soon, do not execute the xx procedure.
Hold . . .	Stop executing the mentioned procedure at the current step.
You are go for . . .	You have permission to execute . . .
The xx system is go	The xx system is working adequately.
Expect ratty comm due to . . .	Expect degraded communication due to . . .
. . . in the blind	We can't hear you, but we're transmitting, hoping that you can hear us.
Lost data	MCC has lost vehicle downlink data, expect reduced MCC troubleshooting assistance.
Regained data	MCC has regained downlist data.
. . . UHF only	MCC or orbiter transmitting or receiving on UHF only. May also mean loss of orbiter downlink data.
Comm check	Voice communication check, acknowledge and describe quality of transmission.
LOS	Loss of signal/without comm. Sometimes used to mean star/object no longer in view.
AOS	Acquisition of signal/good comm. Sometimes used to mean star/object in view.
Abort . . .	Execute the . . . abort mode. MCC will also uplink an abort light.
Take TACAN	Accept TACAN for use by NAV software.
Take Air Data	Accept Air Data information for use by NAV and GNC software.
Go . . . CSS	Take pitch and/or roll/yaw CSS as called.
Go . . . Auto	Return to Auto Pitch and/or Roll/Yaw flight control. For Orbit Ops, select Auto DAP.
Check DAP . . .	Ensure the DAP mode matches the mode mentioned in call.

Standard Air-to-Ground Voice Calls

Unplanned downmodes to manual flight control should be discussed with MCC if time and flight control performance permit.

Aborts or redesignation of landing site/runway should only be performed at the direction of MCC if air-to-ground communication is available. If air-to-ground communication is not available, or if mission safety is in question, the CDR assumes ultimate authority for mission decisions. In this case, the crew will use on board procedures and flight rule summaries to take whatever action is required to safely conclude the mission.

Telemetry Uplink

In addition to voice communication, MCC has the capability to electronically uplink information to the orbiter. This capability is frequently used to reduce crew workload, uplink large amounts of information, or to uplink information where accuracy is critical. Crews may request that MCC uplink information rather than using a voice transmission if they feel it would be beneficial and if sufficient time exists for the ground to prepare the uplink. In extreme cases, MCC also has the capability to uplink keyboard entries to the orbiter GPCs in the form of DEU equivalent uplinks. Common uplink information is shown below:

- Communication system configuration commands.
- State vector updates.
- Table Maintenance Block Updates (TMBU) to alter software caution and warning limits.
- IMU compensation.
- OMS burn targets.
- Alternate landing site information.
- Teleprinter or TAGS messages for daily execute packages. Contains flight plan and procedural changes, amplifying information, news from home, systems, and consumables status.
- Unscheduled Teleprinter or TAGS messages containing information not conveniently passed using voice transmission.

8.3 PRE-LAUNCH

CONTENTS

Flight Crew 8.3-1
Mission Control Center 8.3-1
Launch Control Center 8.3-1

Pre-launch activities begin at KSC with the start of the launch countdown. For purposes of discussing responsibilities of the flight crew as they relate to the LCC and MCC teams, pre-launch is considered to start upon flight crew arrival at KSC.

Flight Crew

Crew activities at KSC are outlined in a letter promulgated by the Director of Flight Crew Operations Directorate (FCOD). All activities are coordinated by the FCOD Vehicle Integration Test Office. Each mission has different timelines, and activities vary among pilots, mission specialists, and payload specialists.

The flight crew is subject to Health Stabilization Plan restrictions. These limit direct contact to a small group of individuals who are especially badged as Primary Contacts. Thus, exposure of the crew to communicable diseases with short incubation periods is minimized.

Typical activities for the flight crew at KSC include:

- Shuttle systems briefing
- Countdown status briefing
- STA flights
- Weather briefing
- FDF review
- Preflight physical exam
- Equipment checks
- T-38 flights.

Unless mission requirements dictate a different timeline, the crew will arrive at KSC 3 days prior to launch. Circadian shifts are performed during this period, except for flights requiring large shifts and 24-hour operations. Those crews start their circadian shift prior to departing Houston.

Crew activities are conducted per a relaxed timeline until the actual launch day, when the schedule is tightly controlled. Basically, crew members are responsible for their scheduled events.

Mission Control Center

The MCC is in a monitor mode during most of the launch countdown. Active participation is required for communication checks, weather coordination, and inputs to the MMT on Shuttle systems anomalies.

Flight controllers and MCC support personnel are responsible for their own readiness for flight. This includes console and computer systems configuration and checks. All necessary materials required to support flight operations are positioned. The MCC shift teams usually begin their circadian shift during the countdown.

Launch Control Center

LCC personnel man consoles around the clock once the launch countdown commences. Each Shuttle and ground system is monitored by one or more members of the launch team. The countdown is managed by an Orbiter Test Conductor (OTC) who has responsibility for accomplishment of all steps listed in the countdown Operations and Maintenance Instructions (OMI). Pre-launch OMIs implement checkout requirements designed to demonstrate operation of all testable subsystems within prescribed limits. The launch countdown OMI is performed under strict quality control. Any deviation is documented and must be accounted for, either by repair, replacement, or a waiver from the MMT. In certain areas, launch may be permitted with equipment losses provided they are well understood to be isolated occurrences and not symptomatic of a generic problem.

LCC responsibilities include the conduct of the countdown OMI under the OTC's direction, systems monitoring, test and checkout, recording any deviations, making recommendations on system problems, and ensuring any violations of the Launch Commit Criteria are brought to the attention of the Launch Director.

The launch team resides in one of the firing rooms of the Launch Control Center building at KSC.

8.4 LAUNCH

CONTENTS

Flight Crew 8.4-1
Mission Control Center 8.4-2
Launch Control Center 8.4-2

Shuttle launches are complex interactive tasks where each member of the LCC, MCC, and flight crew performs an integral part. For purposes of discussing responsibilities of each element, launch activities are considered to start at flight crew ingress into the Shuttle.

Flight Crew

The flight crew enters the orbiter about 2 hours 45 minutes before launch. Prior to ingress, final weather and systems briefings are conducted and the crew dons their Launch/ Entry Suits (LESs).

Ingress is accomplished with the assistance of a suit technician and an astronaut support person (ASP). These individuals are part of the closeout crew who perform final Shuttle checks on the launch pad.

Upon completion of ingress, activities are governed by the FDF Ascent Checklist which summarizes crew tasks from the countdown OMI. These activities are presented in Section 5.

Crew responsibilities include responding to LCC and MCC requests per the checklist. Emergency procedures are discussed in Section 6.

As the launch countdown progresses, crew-members will be asked to configure certain systems and make various keyboard entries. This direction will come from the OTC via air-to-ground loops. The NTD may also communicate with the crew via air-to-ground loops, especially if an off-nominal situation occurs. MCC inputs are voiced to the crew by the CAPCOM, who also utilizes the air-to-ground loops. The crew normally uses air-to-ground to respond to LCC or MCC calls during the launch count.

The LCC has the capability to transmit to the crew using A/G 1, A/G 2, or A/A loops. Normally, only one loop is used at a time. The MCC transmits simultaneously on all three loops. Occasionally, this may result in an echo due to different time delays. The crew should report this phenomena to MCC since the delays can be adjusted in real time to remove the echo. Normally the LCC OIS 212 oop, which is used for the direction of launch activities, will be patched into the A/G loop for the crew to monitor.

The LCC also has the capability to talk and listen on ICOM 1 and ICOM 2. Transmission on these loops is restricted to a small number of consoles in the Firing Room. If the LCC enables a patch, ICOM conversation can be received by the entire launch team. This patch is normally disabled. ICOM is used only as an emergency backup to the A/G and A/A loops. The ICOM loops are routed through the T-0 umbilical. A/G and A/A loops are RF transmissions through the MILA ground station.

Weather aircraft observations may be patched directly into one of the RF loops if necessary. This will allow the Shuttle crew to communicate directly with the weather aircraft crew.

Certain other consoles in the LCC have the capability to transmit directly to the crew. These include the Launch Director, Landing Recovery Director, and Shuttle Operations Director.

All voice loops are continuously recorded. This includes both ICOM loops, all 3 RF loops, and all LCC/MCC channels.

The maximum time the crew will remain in the Shuttle is 5 hours 15 minutes, excluding safing and egress time in the event of a launch scrub. This allows 2-1/2 hours of hold time after the earliest planned launch time.

Prior to actuation of any Shuttle switches or controls other than those called out in the checklist, the crew should inform the OTC. This will prevent the LCC team from recording an

unplanned configuration change which could cause a launch hold. This is particularly important in the final minutes of the countdown.

Mission Control Center

The MCC Flight Director is responsible for calling a launch "hold" for all problems that jeopardize the ability to safely monitor and recover the Shuttle and crew after launch. This includes problems in:

- MCC
- Spacecraft tracking and data network
- Landing area facilities
- Abort landing area weather.

In addition, the Flight Director is responsible for overall control of the MCC command uplink capability.

Individual flight controllers are responsible for monitoring their systems and interfacing in real time with their counterparts in the LCC.

Launch Control Center

The LCC Launch Director is responsible for giving the launch team the final go for launch . A formal poll of all elements is taken by the chairman of the MMT during a planned countdown hold at T-9 minutes. If all elements are go, the Launch Director is given permission to proceed with the launch countdown.

The Launch Director is also responsible for making a decision on weather acceptability at the launch pad for ascent trajectory.

When the countdown clock is restarted at T-9 minutes, all operations are under control of a computer system called the Ground Launch Sequencer (GLS). Shuttle systems are automatically configured and monitored by the GLS.

Preplanned hold points for troubleshooting are available in the final 9 minutes of the countdown. These hold points, called GLS milestones, allow the countdown clock to be restarted without recycling back to some previous time. GLS milestones are shown in the table below.

TIME TO LAUNCH	EVENT
9 min	GLS sequence start
7 min 30 sec	Access arm retract
5 min	APU start
4 min	Purge sequence 4
2 min 55 sec	LOX pressurization
1 min 57 sec	LH2 terminate replenish
31 sec	Go for RSLS auto sequence

If a hold command is issued between T-9 minutes and T-31 seconds, the countdown clock will be restarted upon successful resolution of the problem without a "go" survey made of all elements. After T-31 seconds, only a cutoff is available. Cutoff will result in a recycle to T-20 minutes. Depending on launch window, another launch attempt may be possible.

At T-31 seconds, the GLS issues a command to the onboard GPC Redundant Set Launch Sequencer (RSLS) software. This command, GO FOR AUTO SEQUENCE START, enables the RSLS to reconfigure certain onboard systems such as the vent doors, start the main engines, and issue the SRB ignition commands. Throughout this period, the GLS continuously monitors various system parameters and will issue an automatic cutoff should the Launch Commit Criteria be violated.

If a cutoff command is issued, the RSLS will automatically shift control back to the GLS. A program is then automatically started, which safes the Shuttle systems. If this GLS safing program does not run automatically, then LCC controllers safe the systems manually by issuing appropriate commands.

Throughout the countdown, individual LCC controllers are responsible for monitoring their systems and executing commands per the countdown OMI. Any deviations or anomalies are reported to the OTC.

8.5 ASCENT

CONTENTS

Flight Crew 8.5-1
Mission Control Center 8.5-1

The ascent flight phase starts at SRB ignition and continues through OMS-2 cutoff. This is one of the most dynamic phases of a Shuttle flight.

Flight Crew

The flight crew is responsible for monitoring vehicle performance and systems and executing procedures on the nominal timeline. Flight crew and MCC coordination is most critical in this phase of flight due to the time critical nature of most activities. General crew and MCC coordination is discussed in Section 8.1 and 8.2.

Mission Control Center

The Flight Director is responsible for overall direction of Shuttle flights from SRB ignition until crew egress after landing. The Flight Director, after analysis of the flight condition, may choose to take any necessary real time action required to ensure the safety of the crew and Shuttle.

MCC has the prime responsibility for abort mode determination, since the Abort Region Determinator (ARD) program can assess Shuttle abort capabilities inreal time. Data from independent ground radar tracking, along with telemetry of the current onboard state, is used in the ARD.

Each flight controller on the MCC team has specific responsibilities based on discipline. For example, the Booster Officer monitors SRB, SSME, and MPS performance and informs the Flight Director of malfunctions and recommended actions.

Many voice loops are used within the MCC. All controllers have a responsibility to monitor the Flight Director loop and air-to-ground loops, in addition to their own internal and external communication loops. Since the workload can be quite high during off-nominal situations, the crew can help by minimizing air-to-ground calls when possible. Also, allowing time for the MCC to formulate an action, coordinate it among several disciplines, and transmit it back to the crew prior to making additional transmission will aid in MCC/crew teamwork.

8.6 ORBIT

CONTENTS

Flight Crew 8.6-1
Mission Control Center 8.6-1

The orbit flight phase starts at OMS-2 cutoff and continues through deorbit burn ignition. Nearly all mission objectives are accomplished during the orbit phase.

Flight Crew

The crew is responsible for monitoring vehicle systems and executing the nominal timeline. Operation of primary and secondary payloads is the major user of available time. This is the most benign portion of a Shuttle mission in that time is usually available to perform in-depth troubleshooting of any malfunctions. Crews and MCC will take advantage of the available time to thoroughly troubleshoot malfunctions. General crew and MCC coordination is discussed in Sections 8.1 and 8.2.

Execution of on-orbit tasks as called out in the Flight Plan and other FDF documents is the responsibility of the crew. Some tasks must be accomplished on a very strict timeline. Deployment of a payload or experiment operations fall into this category. Other activities are not time-critical. For example, crew exercise can be accomplished on a not-to-interfere basis.

Based on preflight assignments and training, each crewmember will have certain responsibilities. Most crews designate backup crewmembers for critical activities. These backup crewmembers receive nearly all of the training that the prime crewmember receives. This policy provides the necessary redundancy which might be required in the event of unforeseen circumstances such as an injured crewmember or an unplanned contingency. A typical list of duty assignments is shown in Section 8.1.

Mission Control Center

The MCC is responsible for onboard navigation maintenance. Adequate navigation and maneuver definition will be maintained onboard to provide runway landing capability after loss of communication. The Flight Rules specify navigation state requirements.

Individual flight controllers monitor onboard systems and make recommendations to the Flight Director for any changes or reconfiguration. In some cases, uplink commands may be used to perform certain tasks such as antenna management or limit changes (to prevent nuisance alarms).

The Flight Activities Officer and the Payloads Officer are responsible for tracking the Flight Plan and payload activities, respectively. When there is a remote Payload Operations Control Center (POCC), responsibility for the major payload activity, such as Spacelab, resides with the POCC Director. Other payloads, such as middeck experiments, are still controlled by the MCC Payloads Officer. Changes to the Flight Plan, updates to the orbiter attitude and pointing, and replanning are the responsibility of the Flight Activities Officer.

The Integrated Communications Officer (INCO) in the MCC is responsible for operation of the MCC and Shuttle command system. Status of the communications link and the command system is included in this responsibility. The INCO is the designated control point and representative of the Flight Director for approval of all types of commands, including those sent to payloads. With the exception of routine communications systems commands and non-hazardous commands, most command uplinks directly affect the systems being used by the flight crew for control of the orbiter or payload. To ensure that the flight crew has current Shuttle and payload system status, should communications be lost, MCC has a responsibility to inform the flight crew when command uplinks are transmitted. Typically, several hundred commands are sent during each mission. The majority of these are transparent to the crew and do not require coordination.

8.7 ENTRY

CONTENTS

Flight Crew 8.7-1
Mission Control Center 8.7-1

The second dynamic phase of a Shuttle mission is entry. For purposes of discussing team responsibilities, entry activities are considered to start at deorbit burn ignition and continue through rollout.

Flight Crew

The crew is responsible for monitoring vehicle trajectory and systems and execution of the nominal timeline. The pace of activities during entry is generally not as severe as that experienced during ascent until the beginning of TAEM. Depending on inclination and altitude, communication with MCC may not be available for the deorbit burn and part of entry. Crews should be mentally prepared to carry out mission activities without MCC assistance during the deorbit burn and early portion of entry.

Crew duty assignments during entry are similar to those for ascent. General crew coordination and working with MCC are discussed in Sections 8.1 and 8.2.

Mission Control Center

MCC has the prime responsibility for deorbit burn targets. Factors in the selection include Shuttle systems status, consumables, c.g. control, weather, and other landing site information. Although the crew has onboard capability to generate deorbit targets in an emergency, the MCC team, with their extensive capability, will normally calculate and uplink planned targets.

Upon completion of the deorbit burn, MCC is responsible for monitoring the entry trajectory and status of the onboard systems. Should a malfunction occur and be confirmed by the MCC, the crew is expected to work the appropriate cue card or pocket checklist procedure with no further direction. Activities outside the published procedures will be requested by the MCC.

If the trajectory diverges and approaches energy limits, the Flight Dynamics Officer will perform a GCA. Procedures are discussed in Section 7.

The communication workload during entry is similar to ascent with numerous loops in use. The crew can help to simplify the process by minimizing air-to-ground calls and allowing time for the MCC to develop a coordinated decision.

8.8 POST LANDING

CONTENTS

Flight Crew 8.8-1
Mission Control Center 8.8-1
Launch Control Center 8.8-1

Postlanding activities start at completion of rollout and continue through crew egress. The LCC and convoy commander have certain responsibilities during this phase.

Flight Crew

After wheels stop, crew activities are controlled by the FDF Entry Checklist which summarizes crew procedures from the post landing OMI. Normal activities include Shuttle safing and systems reconfiguration for extended power up. These are described in Section 5, Normal Procedures.

The crew responds to MCC requests for activities outside the normal procedures. For example, certain reconfiguration procedures might be modified due to previous systems failures.

Communications with the convoy commander are established shortly after wheels stop. The convoy commander controls post landing activities in the vicinity of the Shuttle and can pass information on hazardous situations to the flight crew.

Mission Control Center

The MCC retains responsibility for orbiter systems until crew egress or ground support equipment (GSE) cooling activation, whichever occurs later. At this time the Flight Director hands over control to the Ground Operations Manager (GOM). Should MCC voice and telemetry be lost, or if an emergency crew egress is required, handover to the GOM will be accomplished ASAP.

While the MCC is controlling ground operations, flight controllers are responsible for monitoring their systems and interfacing in real time with their counterparts in the LCC.

Launch Control Center

Until handover, the LCC monitors the progress of Shuttle safing and reconfiguration. LCC data monitoring is available to the GOM if loss of MCC system insight and communications capability occurs. In this case, handover will occur ASAP in order for normal post landing operations to continue. Should LCC monitoring capability be lost, the MCC will continue to support until LCC capability is regained or the Shuttle is powered down.

Once handover is complete, the GOM and OTC have responsibility for all Shuttle activities. The OTC coordinates completion of post landing procedures and preparation for turnaround operations.

9. PERFORMANCE

CONTENTS

9.1 Ascent 9.1-1
9.2 Orbit 9.2-1
9.3 Entry 9.3-1

This section contains information regarding the performance capability of the Space Shuttle during ascent, on orbit, and during entry (EI to wheels stop). Some performance related material is also included. The information presented is accurate but is usually derived from representative 28.5 and 57 degree missions. It is not intended for mission planning. The information is presented only for the purpose of broadening the crew's fundamental understanding of the vehicle's performance capabilities during each flight phase under the stated conditions. Mission specific questions or requests for more detailed explanations should be referred to the appropriate Flight Design and Dynamics Division (DM) personnel.

9.1 ASCENT

CONTENTS

Payload 9.1-1
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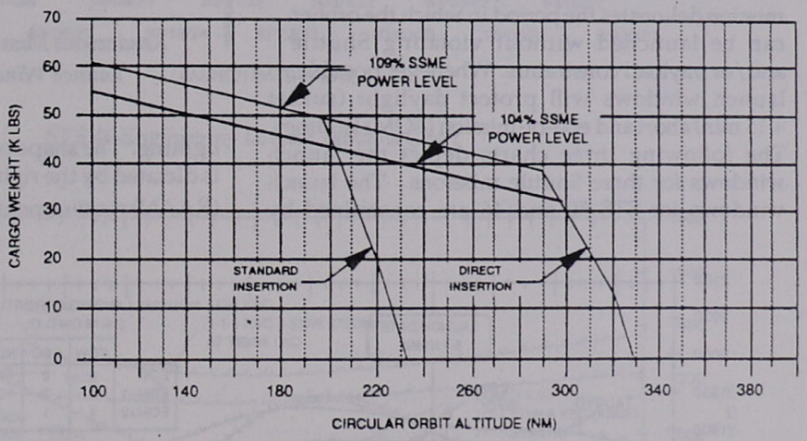
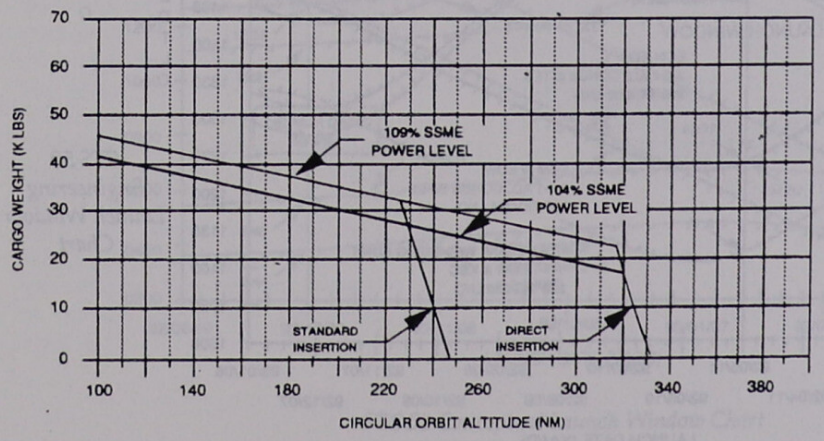
Payload

The graphs below indicate the maximum weight payload that can be launched to a particular circular orbit with a 28.5 or 57 degree inclination. Also shown is the higher altitude capability of a direct insertion versus standard insertion mission profile, as well as the performance increase available using 109 percent versus 104 percent main engine power.

Cargo Weight vs. Circular Orbital Altitude 28.5 Degree Inclination

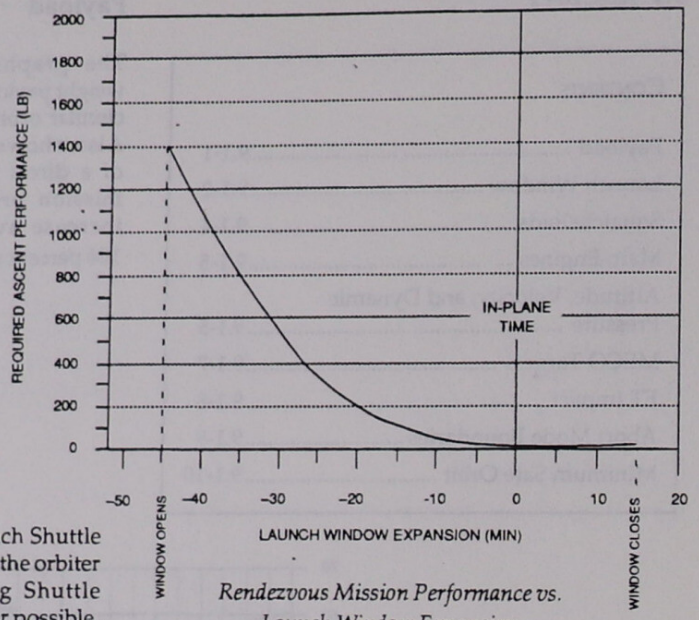




Cargo Weight vs. Circular Orbital Altitude 57 Degree Inclination

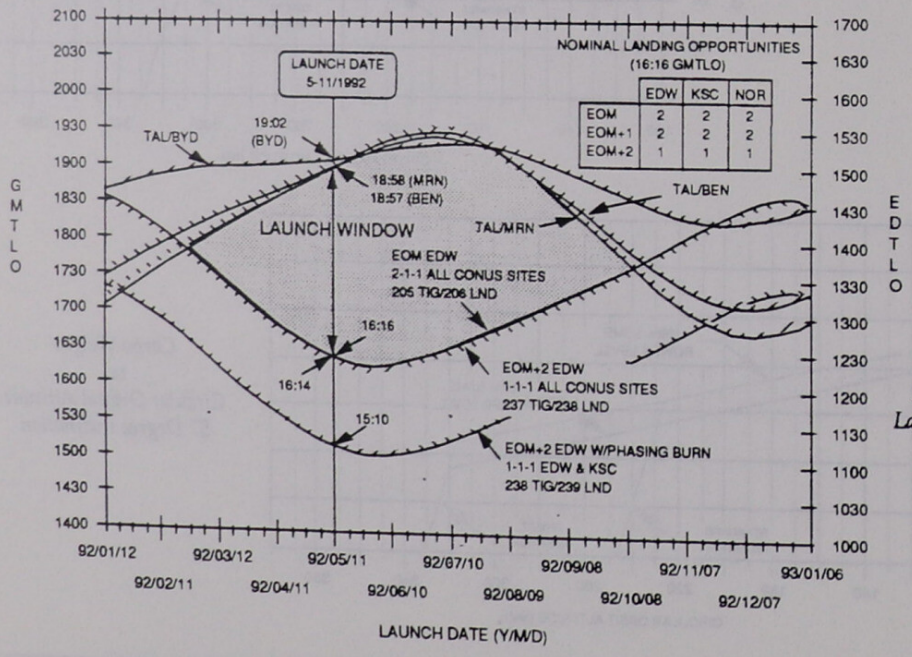
Launch Window

The launch window for a rendezvous mission must satisfy several constraints. A major factor determining the window is ensuring that the orbiter having sufficient performance (plus reserves) to achieve a coplanar orbit. The chart at the right (for a 28.5 degree mission) indicates the additional performance required if the launch occurs prior to the "in-plane" time. The window for a 57 degree mission is approximately 15 minutes (such a rendezvous has not been required).

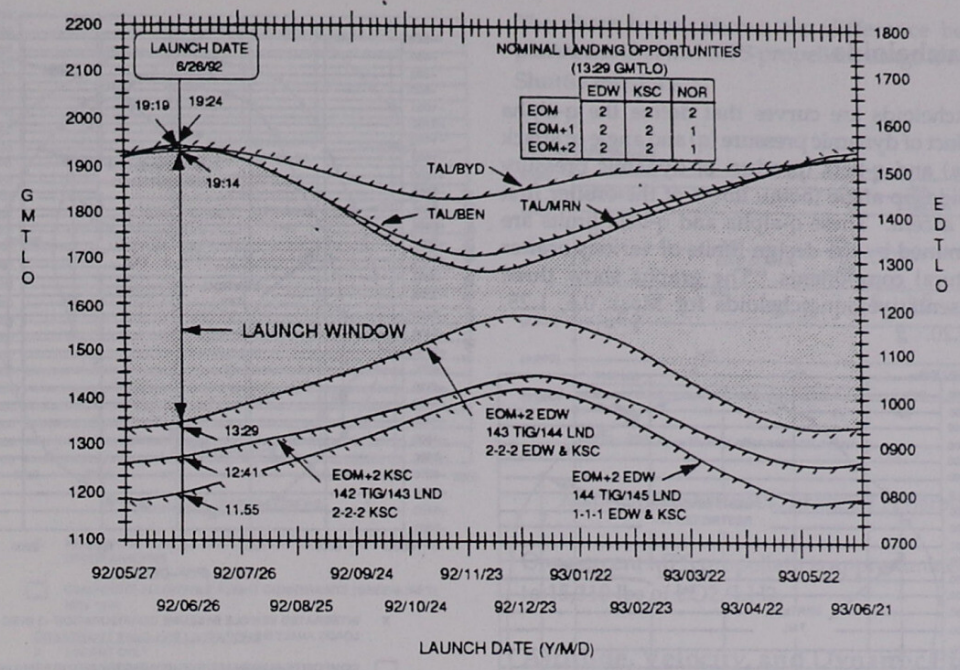


Rendezvous Mission Performance vs. Launch Window Expansion

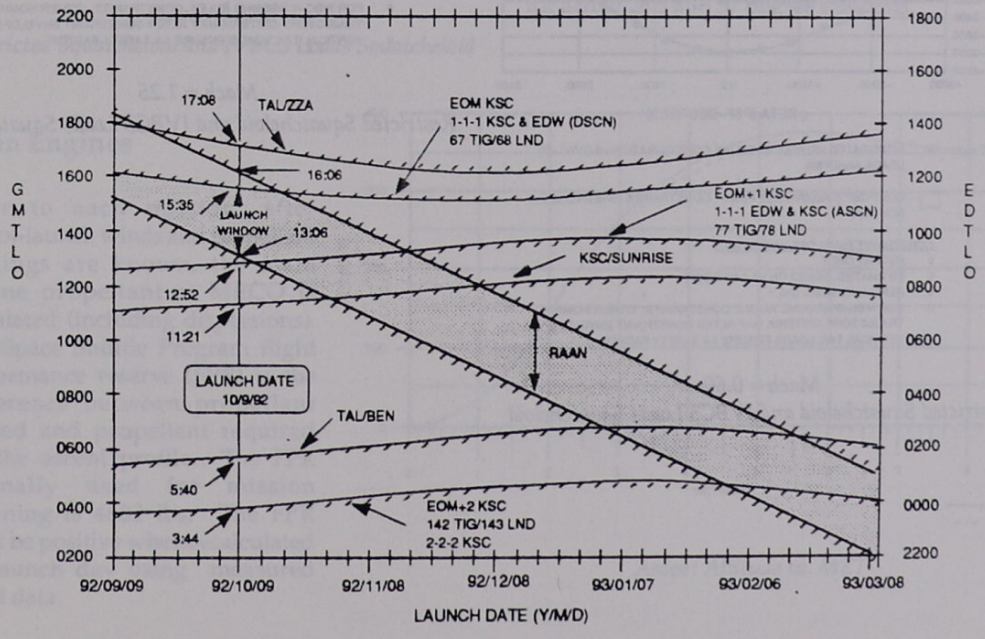
The launch window developed for each Shuttle mission delineates the period in which the orbiter can be launched without violating Shuttle and/or payload constraints. Whenever possible, launch windows will protect daylight (sunset + 15 min) abort and end-of-mission (EOM) landings. The following three charts depict the launch windows for three Shuttle missions. The launch windows for STS 50 and 46 are constrained by lighting. The shape of the STS 53 launch window is dictated by the right ascension ascending node (RAAN) requirements of the mission payload.



STS 50 Engineering Launch Window Chart



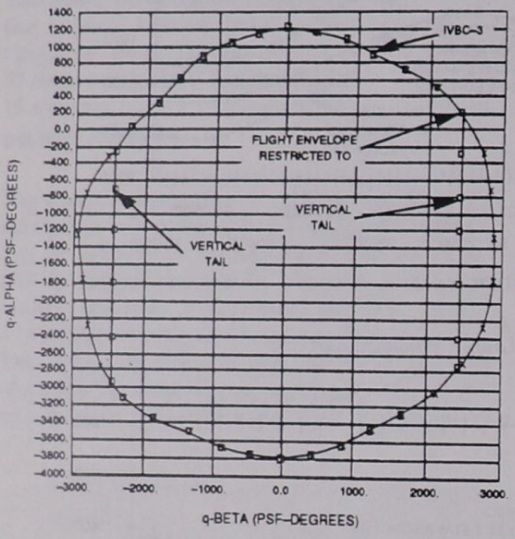
STS 46 Engineering Launch Window Chart



STS 53 Conceptual Launch Window Chart

Squatcheloids

Squatcheloids are curves that define the q-alpha (product of dynamic pressure (q) and angle of attack (alpha) and q-beta (product of dynamic pressure and sideslip angle (beta)) limits of the orbiter first stage ascent. These q-alpha and q-beta limits are determined by the design limits of various orbiter structural components. The graphs show three representative squatcheloids for Mach 0.6, 1.25, and 2.20.

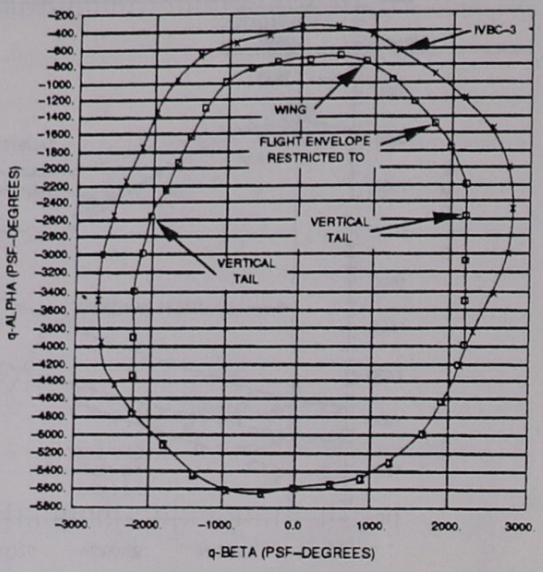


X INTEGRATED VEHICLE BASELINE CONFIGURATION –3 (IVBC –3) LOADS ANALYSIS

☐ COMPOSITE ALLOWABLE FLIGHT CONSTRAINTS (GREENLINES), NOV 1989

CONSTRAINT ENVELOPE LIMITATIONS
- 0 ASCENT ONLY
- 0 ESTIMATED, BASED ON V6.0 MARGINS
- 0 AERO SURFACES ONLY
- 0 FOR IVBC–3 GROUND RULES, CONSTRAINTS: OTHER NOMINAL TRAJECTORY CRITERIA MAY ALTER CONSTRAINT ENVELOPE
- 0 VERTICAL TAIL LOADS ENSURE 1.4 SAFETY FACTOR

Mach = 0.60
Restricted Squatcheloid and IVBC3 Loads Squatcheloid



X INTEGRATED VEHICLE BASELINE CONFIGURATION –3 (IVBC –3) LOADS ANALYSIS

☐ COMPOSITE ALLOWABLE FLIGHT CONSTRAINTS (GREENLINES), NOV 1989

CONSTRAINT ENVELOPE LIMITATIONS
- 0 ASCENT ONLY
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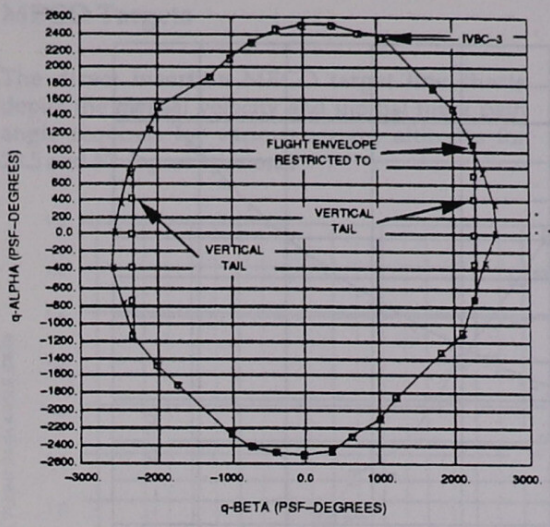
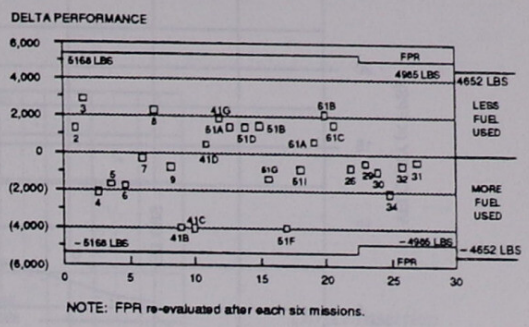
- 0 AERO SURFACES ONLY
- 0 FOR IVBC–3 GROUND RULES, CONSTRAINTS: OTHER NOMINAL TRAJECTORY CRITERIA MAY ALTER CONSTRAINT ENVELOPE
- 0 VERTICAL TAIL LOADS ENSURE 1.4 SAFETY FACTOR

Mach = 1.25
Restricted Squatcheloid and IVBC3 Loads Squatcheloid



Mach = 2.20
Restricted Squatcheloid and IVBC3 Loads Squatcheloid

The chart below shows the difference between planned and actual MPS propellant usage for several Shuttle missions.



Main Engine Actual vs. Predicted Performance

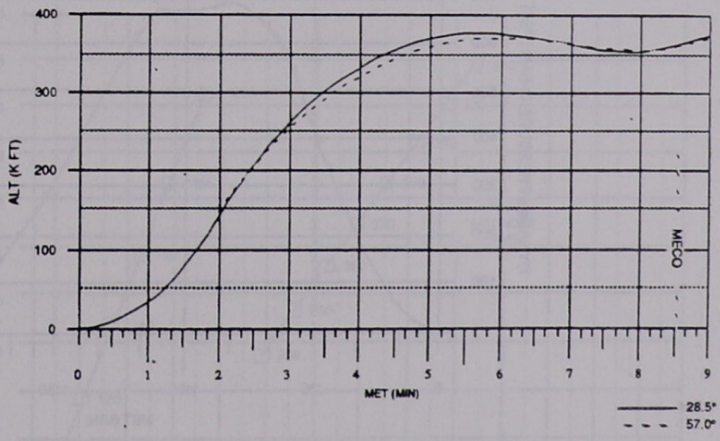
One percent MPS propellant is approximately equal to 15,310 lbs of LO2/LH2.

Altitude, Velocity, and Dynamic Pressure

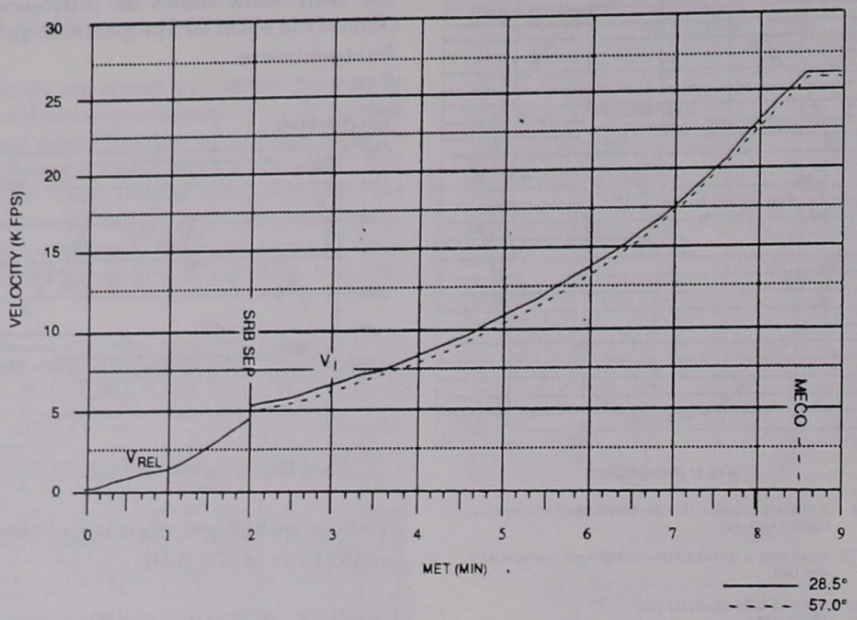
The following three charts depict ascent altitude, velocity, and dynamic pressure as a function of MET for actual 28.5 and 57 degree missions.

Main Engines

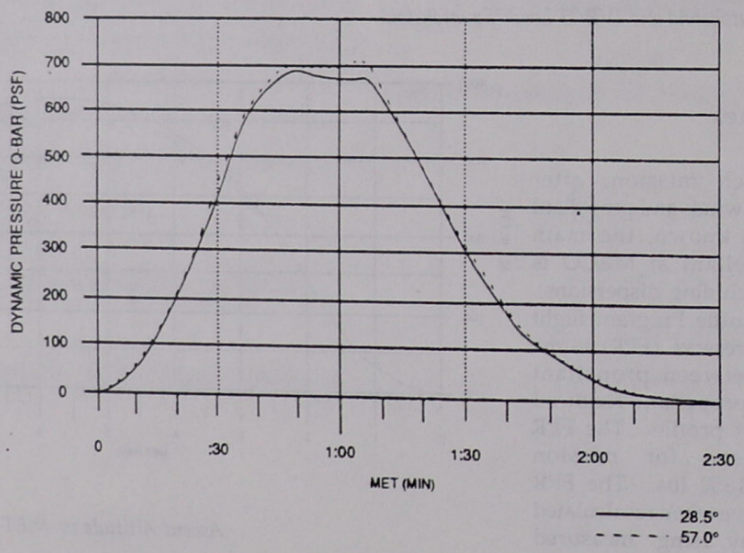
Prior to each mission, after day-of-launch winds and propellant loadings are known, the main engine propellant at MECO is calculated (including dispersions). The Space Shuttle Program flight performance reserve (FPR) is the difference between propellant loaded and propellant required for the ascent profile. The FPR normally used for mission planning is 4652 lbs. The FPR must be positive when recalculated on launch day using measured wind data.



Ascent Altitude vs. MET



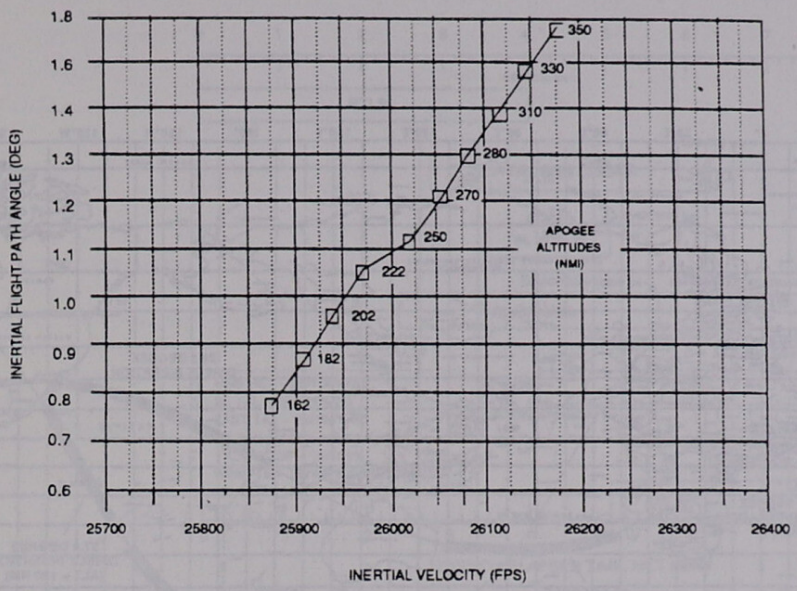
Ascent Velocity vs. MET



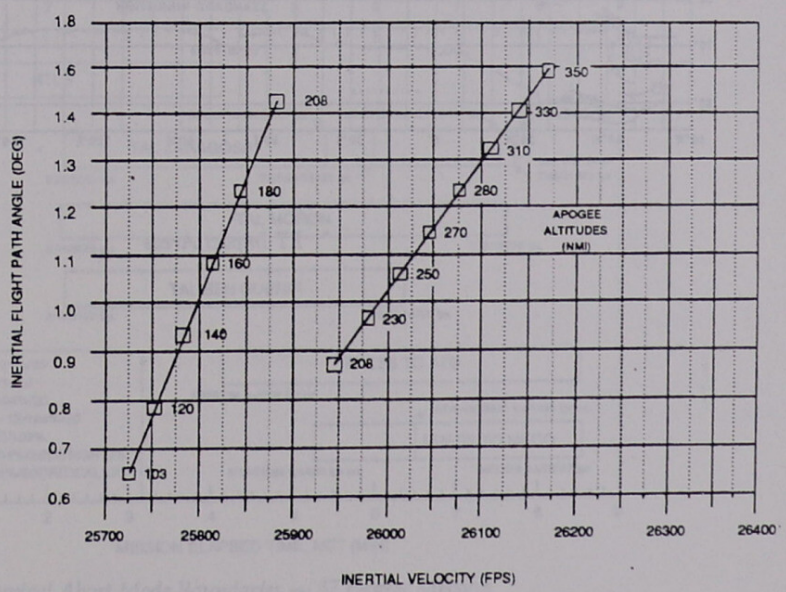
Ascent Dynamic Pressure vs. MET

MECO Targets

The direct insertion MECO target line charts depict the inertial velocity and inertial flight path angle required for various apogee altitudes for 28.5 and 57 degree missions.



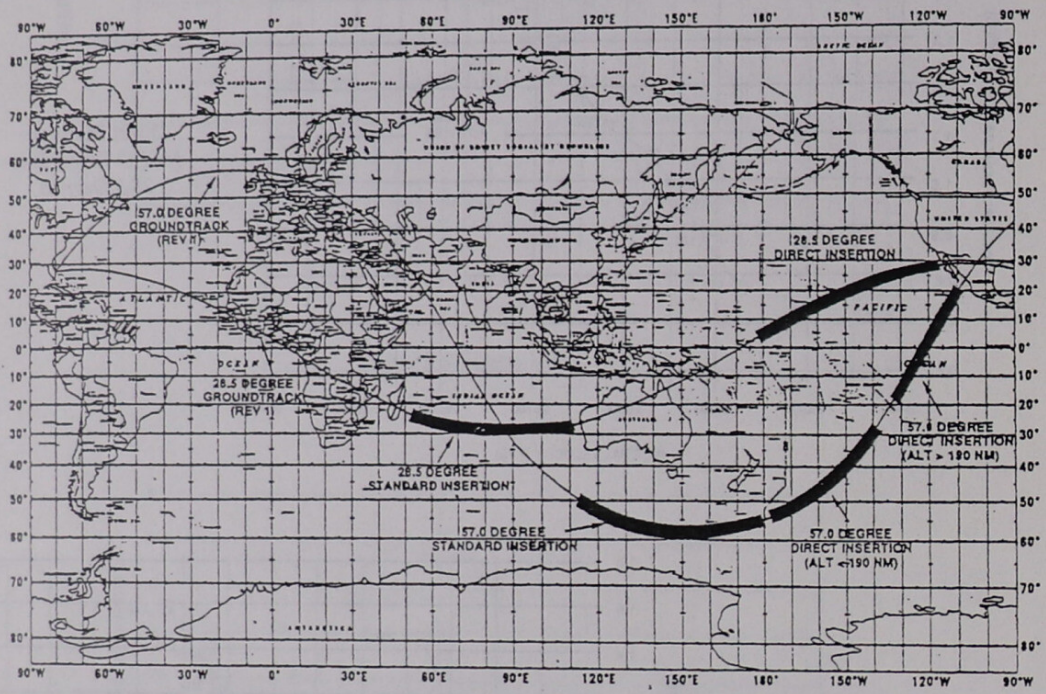
Direct Insertion MECO Target Line 28.5 Degrees



Direct Insertion MECO Target Line 57 Degrees

ET Impact

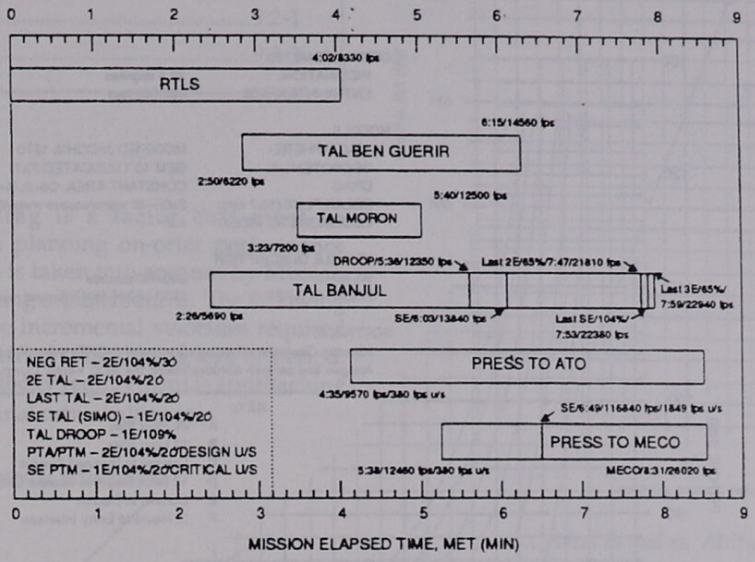
The following map shows the projected ET impact areas for 28.5 and 57 degree (<190 and >190 nm) standard and direct insertion missions given nominal performance and a nominal ET separation.



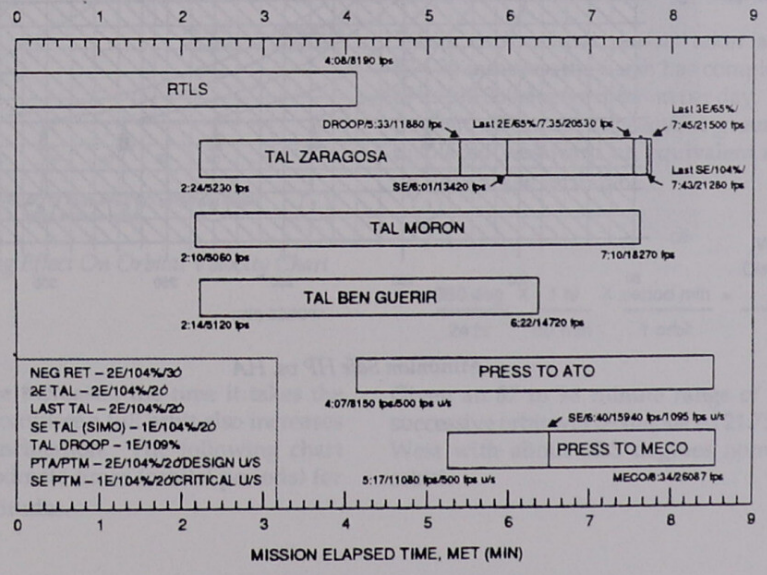
ET Impact Areas

Abort Mode Boundaries

Abort Mode Boundary charts are computed for each mission depicting the abort options available from launch until MECO. Two TAL site capability is required (three preferred), and no abort gaps are permitted for single engine out contingencies. The MET/inertial velocity on the left of each abort bar gives the earliest time and velocity possible for the successful use of that abort mode. The MET/inertial velocity on the right of the bars indicates the last opportunity for that mode.



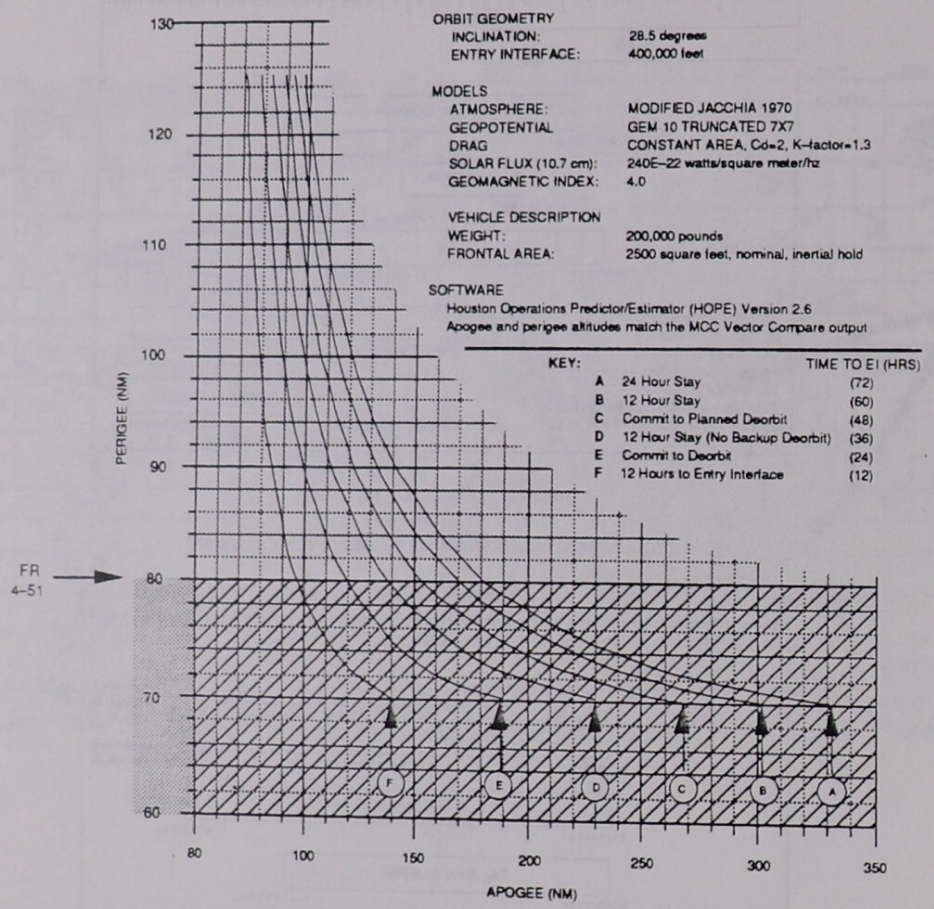
Typical Abort Mode Boundaries — 28.5 Degree Mission



Typical Abort Mode Boundaries — 57 Degree Mission

Minimum Safe Orbit

If the orbiter is inserted into an off-nominal orbit, Mission Control will insure that the vehicle has sufficient orbital lifetime. The lowest perigee that will guarantee the minimum orbital lifetime is a function of apogee and the delta time to the next prime deorbit opportunity. Reference Flight Rule 4-51 for more details. The following chart shows approximate time on orbit versus apogee and perigee for low inclination insertion.



Minimum Safe HP vs. HA

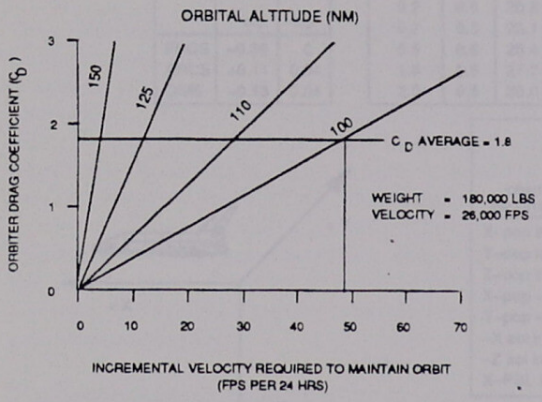
9.2 ORBIT

CONTENTS

Drag 9.2-1
Period 9.2-1
Perturbations 9.2-1
OMS/RCS 9.2-2

Drag

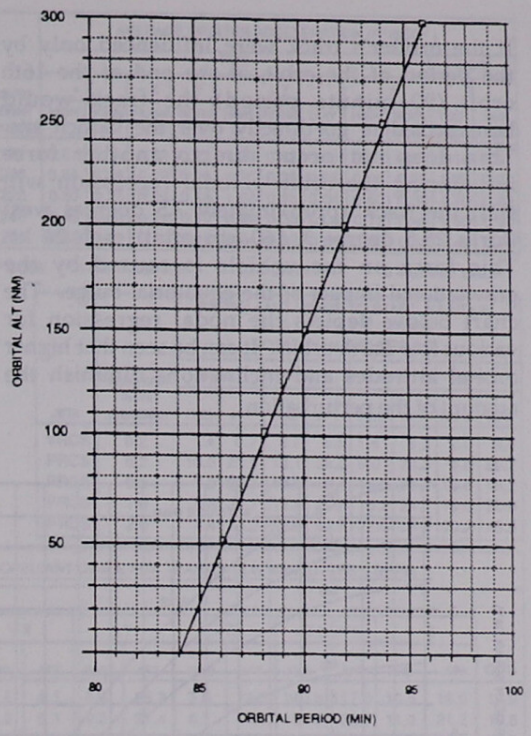
Aerodynamic drag is a factor that must be considered when planning on-orbit performance capabilities. This is taken into account by Mission Control in evaluating orbital lifetime. The following chart indicates the incremental velocities required to maintain a specified orbit during a 24 hr period. Notice that the velocity requirement is approaching 0 at 160 nm (nominal orbital altitude).



Aerodynamic Drag Effect On Orbital Velocity Chart

Period

As orbital altitude increases, the time it takes the Space Shuttle to complete a full orbit also increases independent of inclination. The following chart plots these approximate times (orbital periods) for various orbital altitudes.



Orbital Period vs. Altitude

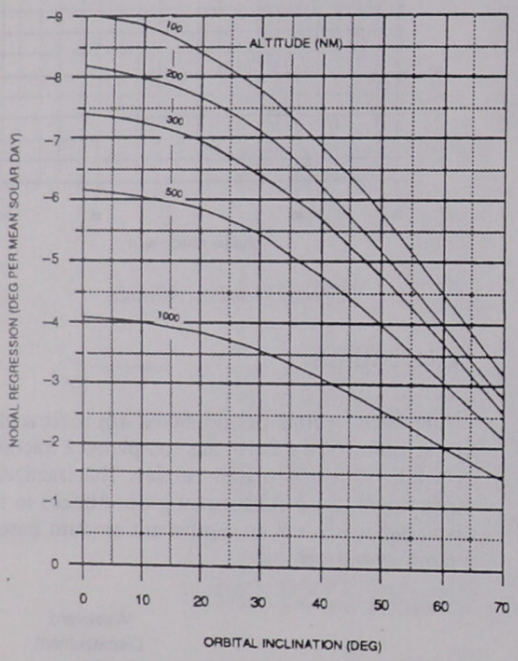
Perturbations

While each orbital period takes approximately 87 - 96 minutes, the Earth has completed a fraction of its full 360 degree rotation per day. That fractional portion will cause subsequent groundtracks to be displaced westward an equivalent amount based on this simple formula:

$$\frac{360 \text{ deg}}{24 \text{ hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{\text{period min}}{1 \text{ orbit}} = \frac{\text{Westward Displacement deg}}{1 \text{ orbit}}$$

Given an 87 to 96 minute range of periods, each successive orbit will be displaced 21.75 to 24 degrees West with about 22.5 degrees nominal (160 nm orbit).

If the orbiter's track were influenced only by the period of the orbit, at the end of the 16th orbit (90 minute period) the track would be expected to go directly over the launch site. This does not occur due to another force influencing the orbit. Nodal regression will shift the track approximately 7.5 degrees west (for a 28.5 degree X 160 nm orbit) each 24 hr. This force on the vehicle is caused by the gravitational impact of the equatorial bulge. The chart below depicts the nodal regression for various low Earth orbits. It can be seen that higher orbital altitudes and inclinations diminish the amount of the perturbation.



Nodal Regression

OMS/RCS

On orbit, the vehicle's performance capability is dictated by the amount of usable OMS/RCS propellant minus that amount required for deorbit, entry, and reserve. This performance capability can be maximized by using the most efficient burns possible for mission accomplishment and attitude/altitude control. The charts on the next page provide a convenient "quick look" method for determining the performance penalty for OMS/RCS use.

1% OMS = 130 lbs propellant

1% RCS = 22 lbs propellant

ORBITER WEIGHT (1000 LB)	AVERAGE ORBITER ACCELERATION (FT/SEC^2) RCS +X HIGH 1	+X NORM 2	−X NORM 1,2	±Y NORM 1,2	+Z HIGH 2	+Z NORM 1,2	+Z LOW 2	−Z HIGH 3	−Z NORM 1,2	OMS TWO ENG	OMS ONE ENG
180	0.61	0.31	0.32	0.22	1.29	0.43	0.05	0.98	0.61	2.14	1.07
200	0.55	0.28	0.29	0.20	1.16	0.39	0.05	0.88	0.55	1.93	0.97
220	0.50	0.25	0.26	0.18	1.06	0.35	0.04	0.80	0.50	1.75	0.88
240	0.46	0.23	0.24	0.17	0.99	0.33	0.04	0.72	0.46	1.60	0.80
260	0.42	0.21	0.22	0.16	0.94	0.32	0.04	0.65	0.42	1.48	0.74

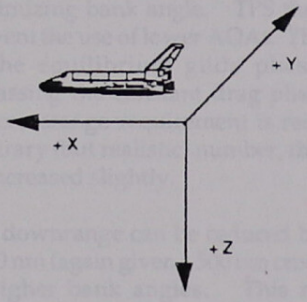
DAP CODE 1 = TRANSITION 2 = ON ORBIT 3 = ET SEP ONLY

AVERAGE ORBITER ACCELERATION (DEG/SEC^2) ROTATION MANEUVER	NORM PRCS	LOW PRCS FWD	LOW PRCS AFT	YRCS
± Roll	0.923			0.021
+ Pitch	1.230	0.696	0.534	0.019
− Pitch	0.851	0.478	0.373	0.008
± Yaw	0.703	0.449	0.242	0.014

JETS	ROTATION RATE (DEG/SEC)	PROPELLANT USAGE TO START, MAINTAIN, AND STOP A 115 DEGREE ROTATION MANEUVER (LB) ROLL FWD	ROLL AFT	PITCH FWD	PITCH AFT	YAW FWD	YAW AFT	3-AXIS FWD	3-AXIS AFT
VRCS	0.2	1.4	5.7	2.0	6.5	1.6	8.3	2.0	9.6
PRCS	0.2	10.3	23.9	13.1	28.3	9.0	20.3	8.8	20.2
PRCS	0.5	8.2	20.7	10.0	19.4	10.2	21.0	10.6	18.2
PRCS	1.0	6.8	23.7	12.9	22.4	13.2	24.1	16.5	26.9
PRCS	2.0	6.4	34.2	22.0	32.7	21.0	36.6	30.2	45.5

ORBITER C.G. SHIFT FOR OMS/RCS USAGE	INCHES/100 LB $X_{c.g.}$	INCHES/100 LB $Y_{c.g.}$
FRCS	−0.36	0
ARCS	+0.11	0.04
OMS	+0.13	0.04

ORBITER WEIGHT (1000 LB)	PROPELLANT USAGE FOR TRANSLATION MANEUVERS (LB/FPS) RCS +X FWD	+X AFT	−X FWD	−X AFT	±Y FWD	±Y AFT	+Z FWD	+Z AFT	+Z (LOW) FWD	+Z (LOW) AFT	−Z FWD	−Z AFT	OMS
0.2	0.5	20.8	19.6	4.1	8.6	25.2	7.5	12.5	140.0	117.0	10.5	18.9	17.9
0.2	0.5	23.1	21.8	5.1	9.3	27.4	8.1	14.1	159.0	132.0	11.3	21.2	19.8
0.5	0.5	25.4	24.0	6.1	10.0	29.6	8.7	15.7	178.0	147.0	12.1	23.5	21.8
1.0	0.5	27.7	26.2	7.1	10.7	31.8	9.3	17.3	197.0	162.0	12.9	25.8	23.8
2.0	0.5	30.0	28.4	8.1	11.4	34.0	9.9	18.9	216.0	177.0	13.7	28.1	25.8



ORBITER ORIENTATION	PRIMARY RCS THRUSTERS PROPELLANT USAGE (LB/HOUR) (ATTITUDE DEADBANDS = 3.5 DEG/AXIS) 100 NM FWD	100 NM AFT	120 NM FWD	120 NM AFT	150 NM FWD	150 NM AFT	200 NM FWD	200 NM AFT	300 NM FWD	300 NM AFT
X–pop inertial	10.5	20.2	10.2	19.8	9.8	19.3	9.3	18.6	8.8	18.0
Y–pop inertial	11.0	24.0	10.2	19.9	9.4	17.7	8.4	15.7	7.6	14.6
Z–pop inertial	8.6	21.0	8.6	20.2	8.6	19.3	8.6	18.5	8.6	18.0
X–pop –Z–LV	9.8	21.2	9.3	20.8	8.4	20.4	7.3	19.8	6.0	19.0
Y–pop –Z–LV	10.3	18.0	10.1	17.8	9.8	17.5	9.5	17.1	9.1	16.5
–X sol inertial	10.4	20.8	10.4	20.4	10.4	19.9	10.4	19.4	10.4	19.0
–Z sol inertial	10.0	19.9	10.0	19.9	10.0	19.9	10.0	19.9	10.0	19.9
X–PSL PTC	9.3	19.0	9.3	19.0	9.3	19.0	9.3	19.0	9.3	19.0

ORBITER ORIENTATION	VERNIER RCS THRUSTERS PROPELLANT USAGE (LB/HOUR) (ATTITUDE DEADBANDS = 1.0 DEG/AXIS) 100 NM FWD	100 NM AFT	120 NM FWD	120 NM AFT	150 NM FWD	150 NM AFT	200 NM FWD	200 NM AFT	300 NM FWD	300 NM AFT
X–pop inertial	3.0	11.6	1.5	5.7	0.9	3.8	0.7	3.0	0.6	2.8
Y–pop inertial	1.9	6.3	1.6	4.7	1.5	4.5	1.4	4.3	1.3	3.9
Z–pop inertial	2.9	11.5	2.0	8.1	1.6	6.8	1.5	6.5	1.4	5.9
X–pop –Z–LV	4.1	13.3	1.6	5.1	0.7	1.3	0.4	0.6	0.4	0.4
Y–pop –Z–LV	0.5	1.0	0.5	0.8	0.5	0.7	0.5	0.6	0.5	0.5
–X sol inertial	2.9	10.6	2.2	7.7	1.8	6.7	1.8	6.5	1.8	6.1
–Z sol inertial	3.6	8.8	2.6	5.5	2.3	4.8	2.2	4.7	2.2	4.5
X–PSL PTC	5.6	10.9	4.8	7.2	4.2	4.9	3.8	3.4	4.3	3.6

ENGINE	SPECIFIC IMPULSE (SEC)	THRUST PER ENGINE (LB)	PROP FLOW RATE (LB/SEC)	PROP MIXTURE RATIO (OX/FU)
OMS	313.2	6000	19.16	1.65
PRCS	280.0	870	3.11	1.60
VRCS	265.0	24	0.09	1.60

OMS/RCS Estimated Performance

9.3 ENTRY

CONTENTS

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Entry History 9.3-2
Entry RCS Data 9.3-4
Rollout/Braking 9.3-4
Rollout History 9.3-6

Downrange/Crossrange

TAL, emergency deorbit, or a waveoff to the secondary landing site can result in mission critical assessments of the orbiter's downrange and crossrange capabilities. Once the orbiter has committed to its descent, only a carefully flown profile can put it on the runway safely.

The orbiter begins entry at EI (400,000 ft) on average 4,176 nm from the landing site. Given a crossrange situation of about 500 nm (414 nm being the average), the vehicle has the ability to stretch that descent approximately 800 nm downrange by minimizing bank angle. TPS thermal constraints prevent the use of lower AOAs. The orbiter remains in the equilibrium glide phase longer, likely bypassing the constant drag phase altogether. If the crossrange requirement is reduced below this arbitrary (but realistic) number, the downrange can be increased slightly.

The downrange can be reduced by approximately 1,100 nm (again given a 500 nm crossrange) by flying at higher bank angles. This results in higher temperatures on the TPS as the vehicle descends more quickly into the atmosphere. TPS thermal constraints are the initial limiting factor in this profile. As the vehicle descends into denser air, downrange capability is limited by "g" (~ Mach 16) and eventually q-bar (~ Mach 5).

In the event of an emergency deorbit, the orbiter's crossrange capability becomes a significant factor. The following charts list the disperse and undispersed crossrange limits for 28.5 and 57 degree missions at the stated entry weights. The dispersed crossrange limits protect for 3 sigma entry dispersions. However, for an emergency deorbit, the crew could deorbit to a landing site that is within the undispersed crossrange limit if there were no site within the dispersed limit.

APPROACH DIRECTION	RANGE NM
Ascending, left	753
Descending, left	753

Dispersed Crossrange Limits 28.5 Degree, 160 nm Orbit, 197 k lb

APPROACH DIRECTION	RANGE NM
Ascending, left	815
Descending, left	815

Undispersed Crossrange Limits 28.5 Degree, 160 nm Orbit, 197 k lb

APPROACH DIRECTION	RANGE NM
Ascending, left	774
Ascending, right	828
Descending, left	781
Descending, right	818

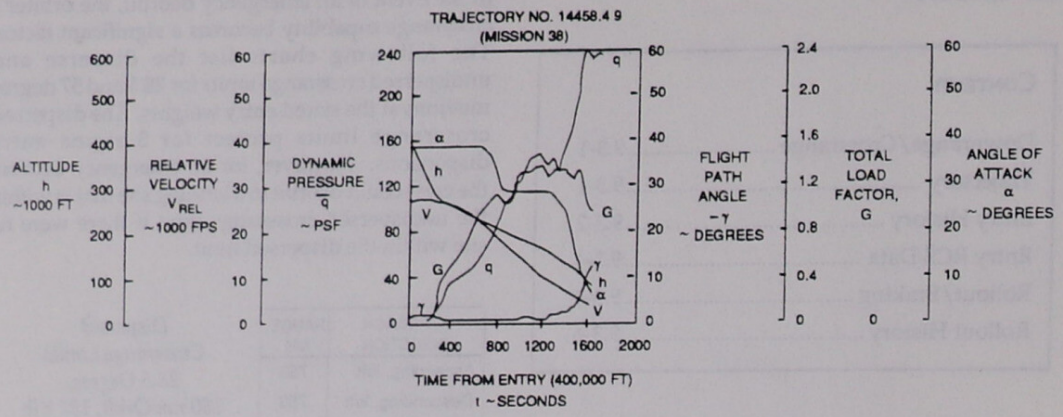
Dispersed Crossrange Limits 57 Degree, 160 nm Orbit, 217 k lb

APPROACH DIRECTION	RANGE NM
Ascending, left	850
Ascending, right	904
Descending, left	857
Descending, right	894

Undispersed Crossrange Limits 57 Degree, 160 nm Orbit, 217 k lb

Trajectory

The following chart plots nominal performance in terms of altitude, V_{REL}, q-bar, flight path angle, g, and alpha against time from EI.



Orbiter Entry Trajectory

Entry History

The following table lists flight history performance and performance related data for the first 43 Space Shuttle missions.

MISS. SEQ. NO.	STS NO.	ORB. OV	ORBIT INCL/ALT (DEG/NM)	ENTRY INTERFACE				CROSS RANGE (NM)	MAX. LOAD FACTOR (g)	MAX. DYN. PRESS. (PSF)	FIRST ROLL REV. VEL. (FPS)	TERM. AREA ENERGY MGMT			APPROACH AND LANDING			
				WT (K LB)	VELOCITY (FPS)	FLIGHT PATH ANGLE (DEG)	RANGE (NM)					INTER-FACE RANGE (NM)	LOAD FACTOR (g)	MAX. DYN. PRESS. (PSF)	INTER-FACE ALT. (FT)	GLIDE SLOPE (DEG)	VEL. (KEAS) MAX.	VEL. (KEAS) OVER THLD
1	1	102	40/145	197	25,731	−1.19	4,372	228	1.60	217	18,310	58.9	1.70	286	10,000	20	315	250
2	2	102	38/137	207	25,726	−1.17	4,474	63	1.61	215	20,297	59.7	1.93	280	5,000	19	276	206
3	3	102	38/128	209	25,656	−1.13	4,136	276	1.62	220	17,784	59.1	1.54	295	10,000	19	302	232
4	4	102	28.5/160	211	25,797	−1.28	3,817	581	1.77	241	11,461	59.4	1.46	278	10,000	19	295	215
5	5	102	28.5/160	204	25,758	−1.24	4,036	580	1.59	219	11,397	59.8	1.59	280	10,000	19	298	216
6	6	099	28.5/153	191	25,755	−1.24	4,045	378	1.53	207	15,808	59.9	1.41	257	10,000	19	293	213
7	7	099	28.5/160	205	25,771	−1.25	4,040	738	1.59	220	7,143	59.6	1.65	305	8,834	19	295	232
8	8	099	28.5/160	205	25,649	−1.12	4,037	519	1.54	223	12,900	58.9	1.56	281	5,000	19	309	226
9	9	102	57/135	221	25,969	−1.18	4,349	69	1.60	243	21,581	59.9	1.52	280	10,000	17	295	203
10	41B	099	28.5/165	203	25,752	−1.20	4,137	524	1.57	220	12,957	59.4	1.59	289	10,000	19	292	218
11	41C	099	28.5/190 x 250	198	25,998	−1.52	4,089	381	1.54	216	16,208	59.4	1.43	293	10,000	19	313	234
12	41D	103	28.5/160	203	25,776	−1.26	4,112	474	1.54	206	14,072	60.0	1.42	265	10,000	19	299	227
13	41G	099	57/190	204	25,684	−1.12	4,308	614	1.54	241	11,927	60.2	1.40	285	10,000	19	296	216
14	51A	103	28.5/160	209	25,869	−1.35	4,141	486	1.56	225	14,063	60.5	1.46	285	10,000	19	299	217
15	51C	103	28.5/185	197	25,855	−1.32	4,144	380	1.54	211.8	16,118	60.1	1.50	281	10,000	19	293	223
16	51D	103	28.5/245 x 160	200	25,955	−1.45	4,064	518	1.59	211.1	13,573	60.9	1.40	294	10,000	19	301	215
17	51B	099	57/109	214	25,857	−1.26	4,264	274	1.57	241.6	18,500	59.1	1.50	282	10,000	19	300	219
18	51G	103	28.5/190	206	25,850	−1.34	4,050	694	1.58	217.7	8,680	59.3	1.60	218	5,000	19	301	—
19	51F	099	50/106 x 170	218	25,813	−1.19	4,221	603	1.58	235.6	11,537	59.7	1.54	290	10,000	19	306	244
20	51I	103	28.5/190	198	25,829	−1.31	4,004	692	1.58	215.3	8,626	59.7	1.56	274	10,000	19	307	204
21	51J	104	28.5/254	192	26,023	−1.55	3,986	432	1.54	—	—	—	1.9	312	5,000	19	296	—
22	61A	099	57/175	215	25,830	−1.19	4,345	69	1.55	241	22,257	59.8	1.3	319	10,000	19	303	231
23	61B	104	28.5/190	206	24,882	−1.35	4,106	533	1.54	232	13,172	59.1	1.4	286	10,000	19	293	224
24	61C	102	28.5/175	211	25,815	−1.31	4,154	661	1.56	224	9,480	59.2	1.43	292	10,000	19	311	233
25	51L	099	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	26	103	28.5/160	194	25,790	−1.25	4,117	383	1.56	203	15,774	60.0	1.3	288	10,000	19	297	219
27	27	104	57/240	192	25,121	−1.50	4,220	520	1.61	206	14,564.6	60.2	1.4	294	10,000	19	297	211
28	28	103	28.5/160	195	25,787	−1.23	4,163	384	1.54	207	15,852	60.1	1.6	287	10,000	19	307	218
29	29	104	28.85/160	193	25,788	−1.22	4,155	350	1.56	207	16,452	60.08	1.50	287	9,957	19	295	206
30	30	102	57/160	201	25,803	−1.11	4,332	186	1.54	213	19,494	58.8	1.6	295	10,000	19	299	224
31	34	104	34.3/160	196	25,784	−1.19	4,156	496	1.54	219	13,653	60.1	1.7	286	10,000	19	305	220
32	33	103	28.5/302 x 126	195	25,998	−1.48	4,068	226	1.52	215	16,988	60.2	1.5	301	10,000	19	300	211
33	32	102	28.5/175	230	25,823	−1.25	4,317	372	1.62	253	16,293	58.8	1.7	295	10,000	17	300	230
34	36	104	62/115 x 132	188	25,713	−1.18	4,338	255	1.57	204	18,520	59.5	1.9	325	5,000	19	298	218
35	31	103	28.5/330	190	26,120	−1.61	4,121	420	1.60	205	15,905	60.2	1.54	279	10,000	19	299	194
36	41	103	28.45/160	198	25,762	−1.20	4,147	492	—	212.7	13,639	60.0	1.67	291	9,777	19	306	224
37	38	104	28.5/115 x 142	191	25,729	−1.16	4,146	3	1.57	207	20,816	60.3	1.42	273	9,819	19	301	218
38	35	102	28.45/190	226	25,858	−1.32	4,266	426	1.58	245.8	15,406	59.15	1.59	279	8,052	17	300	217
39	37	104	28.5/243	191	24,612	−1.40	4,175	375	1.57	205	16,455	59.0	1.66	276	5,048	19	288	161
40	39	103	57/140	212	25,765	−1.06	4,502	616	1.57	246.5	11,543	60.2	1.50	295	9,862	19	302	222.1
41	40	102	39/146 x 157	228	25,772	−1.23	4,339	211	1.56	245.4	18,904	58.9	1.70	298	10,014	17	311	218.6
42	43	104	28.5/160	TBS	———	———	———	———	———	———	———	———	1.40	294	9813	19	295	TBS
43	48	103	57/292	TBS	———	———	———	———	———	———	———	———	1.50	286	9956	19	297	TBS

Orbiter Entry Trajectory

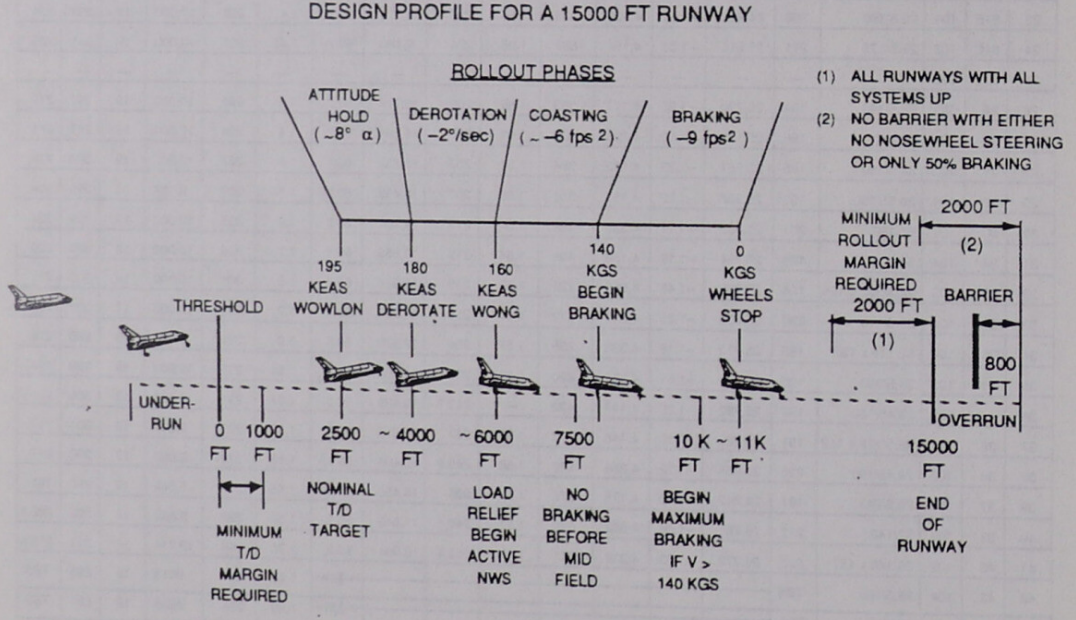
Entry RCS Use Data

Typically, the orbiter deorbits with approximately 50 percent aft RCS (ARCS) propellant in each pod (~ 1,100 lbs). RCS propellant use during entry averages about 13 percent (600 lbs) of full ARCS tanks. Certain missions are selected to conduct Program Test Inputs (PTIs) which are modifications to flight control software to collect entry performance data. In addition to nominal RCS use, other jet firings are used to collect RCS PTI data or to correct for aerosurface PTIs. Missions conducting PTIs will typically use in excess of 23 percent (1,000 lbs) of full ARCS tanks during entry. The chart on the right shows the predicted ARCS usage and the actual flight usage for selected missions. Analysis of actual versus predicted use is underway.

FLT	INCLINATION	PREDICTED ARCS USAGE (LB)	ACTUAL FLIGHT ARCS USAGE (LB)	PERCENT AFRCS	PTI ARCS/ FRCS
32	28.5	827.4	1340	30	ARCS
31	28.5	1113.0	1095	25	ARCS
41	28.5	488.5	855	19	FRCS
35	28.5	1157.6	1036	24	ARCS
37	28.5	876.9	1240	28	ARCS
39	57	846.9	1070	24	ARCS
40	39	756.1	870	20	ARCS
43	28.5	441.6	1020	23	FRCS
48	57	405.4	553	13	FRCS

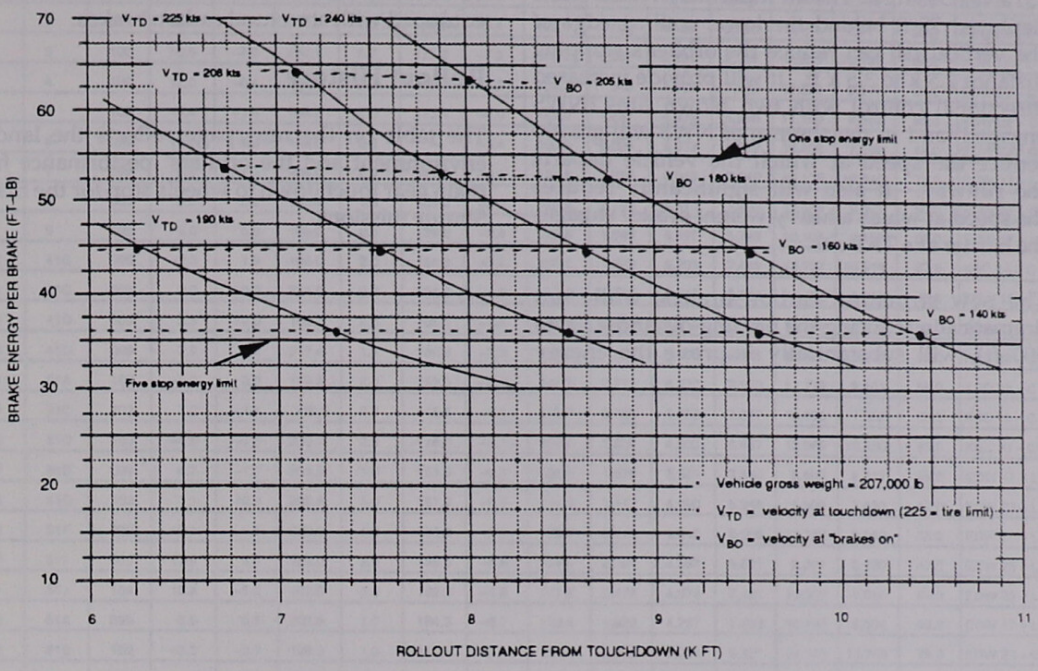
Rollout/Braking

The design rollout chart depicts a nominal touchdown to wheels stop profile for a 15 k ft runway.



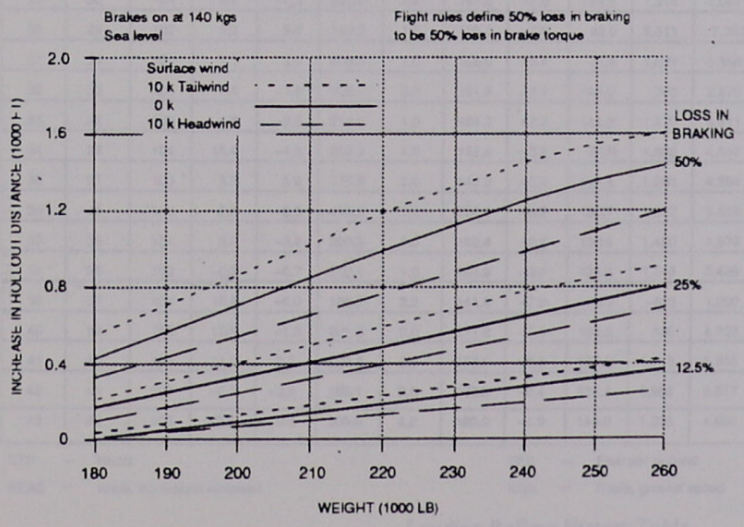
Design Rollout Phases

The following chart depicts the rollout distances and brake energies required to stop a 207 k lb orbiter using different touchdown and "brake on" speeds.



Rollout Distance/Brake Energy

The following chart depicts the increase in landing rollout for three levels of diminished braking.



Loss of Braking

Although the data are still being reduced and analyzed, some general comments can be made about the impact of the new drag chute (STS 49, OV 105). The 40 ft partially reefed chute deployed 75 ft behind the lower trailing edge of the vertical tail can reduce the orbiter's stopping distance 2.5 k to 3.5 k ft. It will provide increased directional control with two blown tires (NWS engaged) and in the absence of NWS will greatly reduce the speed at which the vehicle departs the runway. It also will significantly reduces the speed at which a heavy weight orbiter engages the barrier at a TAL site.

The new structural carbon brakes, while not dramatically reducing the braking distance (300 to 500 ft), will substantially improve the energy absorption capability over the beryllium/carbon brakes. Vibration induced brake damage and heat damage (including heat induced blown tires) should be virtually eliminated. All four orbiters are now equipped with structural carbon brakes.

Rollout History

The table on the next page reflects the landing environment and the orbiters' performance from main gear touchdown to wheels stop for the first 43 Shuttle missions.

FLT NO.	STS NO.	OV	[+] HEAD/ [–] TAIL WIND (KTS)	CROSS-WIND [L+, R–] (KTS)	MAIN GEAR TOUCH DOWN (KEAS)	MAIN GEAR SINK (FPS)	NOSE GEAR TOUCH DOWN (KEAS)	NG PITCH (DEG/ SEC)	BRAKES ON (KGS)	DISTANCE FROM THRESHOLD (FT)				TOTAL		RUNWAY (L, C)
										MAIN GEAR TOUCH DOWN	NOSE GEAR TOUCH DOWN	BRAKES ON	STOP	ROLLOUT (FT)	ROLLOUT (SEC)	
1	1	102	0.0	0.0	183.4	.8	147.5	–4.8	105.0	6,053	9,152	12,025	15,046	8,993	60.0	EDW 23 – L
2	2	102	16.4	7.4	194.3	1.0	145.6	–4.4	109.0	780	4,429	5,780	8,491	7,711	50.0	EDW 23 – L
3	3	102	10.9	–7.0	224.1	5.7	175.0	–7.2	149.0	1,092	6,261	8,159	14,829	13,737	84.0	NOR 17 – L
4	4	102	12.0	–0.4	200.1	2.0	164.9	–3.2	133.2	948	4,988	7,839	10,826	9,878	64.0	EDW 22 – C
5	5	102	–1.4	–1.4	199.0	1.0	173.4	–4.0	167.0	1,637	4,675	5,286	11,190	9,553	63.0	EDW 22 – C
6	6	099	15.9	8.5	194.0	2.0	—	–3.4	136.0	2,026	4,972	5,072	19,206	7,180	49.0	EDW 22 – C
7	7	099	6.5	–2.7	206.0	2.5	161.5	–4.4	124.5	2,726	6,843	7,040	13,176	10,540	75.0	EDW 17 – L
8	8	099	5.3	2.8	194.4	1.6	165.0	–3.7	154.3	2,793	5,515	7,403	12,164	9,371	50.0	EDW 22 – C
9	9	102	–3.0	0.0	185.0	2.5	139.0	–8.5	126.0	1,849	5,897	6,749	10,105	8,456	53.0	EDW 17 – L
10	41B	099	–2.3	1.9	195.0	2.0	154.0	–7.4	136.0	1,922	5,703	7,448	12,737	10,815	67.0	KSC 15 – C
11	41C	099	0.0	0.0	214.0	2.0	134.0	–4.0	110.0	1,912	7,167	8,538	10,628	8,716	48.0	EDW 17 – L
12	41D	103	3.5	–2.0	199.1	2.0	155.1	–4.8	106.5	2,510	6,713	10,018	12,780	10,270	60.0	EDW 17 – L
13	41G	099	7.9	1.4	217.4	1.8	166.9	–2.6	113.0	959	5,505	8,986	11,592	10,633	59.0	KSC 33 – C
14	51A	103	–5.0	0.0	189.5	2.0	153.0	–4.0	141.6	2,718	6,370	7,550	12,179	9,461	58.0	KSC 15 – C
15	51C	103	7.9	–1.4	186.0	0.7	145.8	–3.4	116.7	2,753	5,752	7,677	10,105	7,352	50.0	KSC 15 – C
16	51D	103	–4.5	–7.8	203.0	2.8	176.0	–5.1	156.0	1,639	4,303	6,667	12,069	10,430	63.0	KSC 33 – C
17	51B	099	4.7	–1.7	203.8	1.0	151.0	–6.1	106.0	1,576	5,528	7,589	9,893	8,317	59.0	EDW 17 – L
18	51G	103	1.1	10.9	202.8	5.0	157.9	–6.9	154.2	1,117	4,990	5,248	8,590	7,433	42.0	EDW 23 – L
19	51F	099	9.1	4.1	203.9	4.0	163.8	–6.1	126.2	3,713	6,912	9,059	12,282	8,569	55.0	EDW 23 – L
20	51I	103	17.9	1.4	189.0	2.0	156.0	–4.8	114.0	2,101	4,384	5,571	8,201	6,100	47.0	EDW 23 – L
21	51J	104	10.8	–5.2	192.0	3.0	162.0	–4.8	117.2	2,476	4,873	7,421	10,532	8,056	65.0	EDW 23 – L
22	61A	099	0.9	0.3	202.6	1.0	164.3	–6.7	110.9	1,829	4,767	7,923	10,133	8,304	49.0	EDW 17 – L
23	61B	102	–3.3	–3.7	189.3	1.0	149.5	–3.1	126.4	2,386	5,909	9,321	13,145	10,759	78.0	EDW 22 – C
24	61C	099	0.9	–0.4	217.3	1.0	157.0	–2.7	138.4	1,525	5,987	7,831	11,727	10,202	59.0	EDW 22 – C
25	51L	099	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	26	103	–1.7	1.0	188.0	1.0	148.0	–4.0	134.0	2,569	5,671	6,750	10,020	7,451	49.4	EDW 17 – L
27	27	104	0.3	2.0	195.0	1.0	158.0	–3.8	134.0	1,469	4,423	5,908	8,592	7,123	43.0	EDW 17 – L
28	29	103	5.7	1.9	207.0	2.9	166.0	–1.7	130.0	1,195	5,027	7,550	10,534	9,339	52.7	EDW 22 – C
29	30	104	4.9	–6.3	202.2	2.4	167.0	–2.0	138.0	1,314	5,088	6,028	11,609	10,295	64.3	EDW 22 – C
30	28	102	5.2	3.0	159.0	1.0	130.0	–7.6	82.0	5,311	7,393	9,776	11,326	6,621	46.5	EDW 17 – L
31	34	104	1.1	3.9	200.5	1.0	156.0	–3.4	77.6	1,871	5,355	10,063	11,548	9,677	60.4	EDW 23 – L
32	33	103	7.8	–1.6	202.7	3.0	161.8	–2.9	148.0	740	2,670	4,856	8,504	7,764	46.1	EDW 04 – C
33	32	102	1.9	–3.5	210.6	1.0	164.7	–2.2	141.3	1,870	6,611	8,096	12,601	10,731	62.2	EDW 22 – C
34	36	104	15.4	–4.3	202.2	1.0	152.9	–3.8	97.0	1,622	4,862	6,405	9,522	7,900	52.9	EDW 23 – L
35	31	103	3.7	5.9	179.8	3.0	142.2	–2.9	118.6	1,291	4,564	6,718	10,165	8,874	60.7	EDW 22 – C
36	41	103	2.3	–2.0	193.9	1.0	153.6	–2.3	135.7	2,637	6,328	7,713	10,913	8,276	49.2	EDW 22 – C
37	38	104	3.2	–3.8	200.2	1.0	162.4	–2.6	130.5	1,480	4,579	6,966	10,512	9,032	56.5	KSC 33 – C
38	35	102	–0.7	–0.7	202.1	1.0	164.9	–3.4	134.4	1,748	5,489	8,465	12,195	10,447	57.7	EDW 22 – C
39	37	104	15.9	–6.0	166.2	2.3	141.9	–7.3	93.6	–623	1,200	3,197	5,741	6,364	55.9	EDW 33 – L
40	39	103	12.0	–1.0	221.0	2.0	171.2	–2.5	136.5	168	4,723	6,316	9,403	9,235	55.5	KSC 15 – C
41	40	102	11.8	2.3	203.8	2.0	153.6	–3.5	135.2	1,615	5,915	7,323	11,018	9,403	54.6	EDW 22 – C
42	43	104	–0.7	–3.9	199.1	2.0	163.3	–2.4	132.5	1,986	5,517	8,243	11,876	9,890	58.9	KSC 15 – C
43	48	103	+2.9	+0.8	203.0	4.2	160.0	–1.9	145.0	1,235	4,882	6,715	10,619	9,384	—	EDW 22 – C

KTS — Knots
KEAS — knots, equivalent airspeed
FPS — Feet per second
KGS — Knots, ground speed
L — Lakebed
C — Concrete

Landing Rollout History Table

Performance Rules of Thumb

ASCENT

Ascent Performance Margin
Management Reserve Req. (lbs)
Pre Flight Design Requirements Document = 3500
Flight Design Requirements Document = 2500
Cargo Integration Review = 1500
Flight Planning Stowage Review = 1500
FPR = 4652

ORBIT

1 hr launch delay = change in orbital noon by 4 minutes

Ascending node
28.5 deg – 1st ascending node is @ Long = 173.38 East
57 deg = 121.55 West

MISCELLANEOUS

Orbiters
OV101 – Enterprise
OV102 – Columbia
OV103 – Discovery
OV104 – Atlantis
OV105 – Endeavor
OV102 weighs 7000 lbs more than OV103/104

Min planned flt duration = 96 hours

Max/Min Beta Angle
Max = 23.5 + orbital inclination
Min = 23.5 – orbital inclination

Time
CDT = GMT – 5 hr
CST = GMT – 6 hr
Daylight savings time from 1st Sunday in April to last Sunday in October

DESCENT

EOM Elevon Schedules
FWD if Xcg < 1092
MID if 1092 < Xcg < 1100
AFT if Xcg > 1100

Xcg Limits
FWD = 1076.7 in (RTLS = 1079.0 in)
AFT = 1109.0 in
CONT AFT = 1119.0 in

D/O Delta V's
Descending approach is worst case ΔV
90 deg prebank will decrease ΔV ~ 10 ft/s (function of altitude)

If Xcg > 1091.5: 1 in Xcg = 2.2 miles
If Xcg < 1091.5: 1 in Xcg = 1.1 miles
As Xcg increases (more aft), XR decreases
1 nm XR = 5780 lbs EI weight
1 nm XR = 4.38 nm D/O altitude
As altitude and weight increase, XR increases
As inclination increases, XR increases (non-linear)
As temp increases, XR increases (non-linear)

Touchdown speeds
185 kts if TD weight < 200 k lbs
195 kts if 200 K lbs < TD weight < 220 k lbs
205 kts if TD weight > 220 k lbs

195 kts for all weights if shortfield speedbrake guidance mode is used

Mass Moment
MM = TD Weight * (1172.3 – Xcg)/12
If MM > 1.4 M ft-lbs Concrete desire
If MM > 1.55 M ft-lbs Concrete required
Note: If TD Xcg not known, use Xcg @ M = 3.5 + 1.5 in

Landing Weight Limits
EOM 230 k lbs
RTLS 240 k lbs *
TAL 240 k lbs *
AOA 240 k lbs *

Noctilucent Clouds
If Inc > 50, do not enter on descending opportunity June through August.

RENDEZVOUS

1 deg of phasing/hour = 10 nm of Δheight
1 deg of phasing = 60 nm
17.5 ft/s burn changes other side of orbit 10 nm
440 ft/s burn will change plane by 1 deg of wedge
1 deg of ΔRAAN occurs for each relative lap

PROPELLANT

1 deg of plane change = 440 ft/s

OMS philosophy
1 ft/s = 2.8 lbs OMS @ 220 k lbs ~1/6%
1.78 ft/s = 1 nm

Maximum OMS load
OV102 = 25156 lbs
OV103/4 = 25064 lbs
Min = 10800 lbs
Max OMS ballast = 4000 lbs
1% OMS = 130 lbs/side

Hard Ballast
OV102 – can be installed in the aft compartment
OV103/104 – Bay 13

RCS philosophy
1 ft/s = 25 lbs (+ X) or 35 – 40 lbs (multi axis) @ 220 K lbs
Max burn = 250 sec = 55 fps
Full FRCS = 2446 lbs
ET blowdown offload = 2225 lbs
Min FRCS – 1862 lbs
Full ARCS = 4970 lbs (over 100%)
1% ARCS = 22 lbs/side

INTERCONNECT logic
If OMS < 14,000 lbs, I/C off
If OMS > 17,000 lbs, I/C on
If 14 K < OMS < 17 k, analysis req.

ECS – N2

OV102
6.28 lbs/day for 4 person crew @ 14.7 psi
. add .114 lbs/day for additional crewman
4.35 lbs/day for 4 person crew @ 10.2 psi
add .079 lbs/day for additional crewman

OV103/4
5.28 lbs/day for 4 person crew @ 14.7 psi
add .114 lbs/day for additional crewmember
3.66 lbs/day for 4 person crew @ 10.2 psi
add .079 lbs/day for additional crewmember

	Dry wt	Fully loaded wt
N2	83 lbm	143 lbm

EPS

.09 lbm Hydrogen = 1 kwh
.7 lbm Oxygen = 1 kwh
.07 lbm Oxygen/hour = cabin leak rate

	Dry wt	Fully loaded wt
H2	227 lbm	319 lbm
C2	215 lbm	996 lbm

* Orbiter Engineering Memo VE3-90-096.

APPENDIX A: PANEL DIAGRAMS

CONTENTS

Forward
F1 ..... A-2
F2 ..... A-2
F3 ..... A-2
F4 ..... A-2
F5 ..... A-3
F6 ..... A-4
F7 ..... A-5
F8 ..... A-6
F9 ..... A-7

Overhead
O1 ..... A-8
O2 ..... A-9
O3 ..... A-10
O5 ..... A-11
O6 ..... A-12
O7 ..... A-13
O8 ..... A-14
O9 ..... A-15
O13 ..... A-16
O14 ..... A-17
O15 ..... A-18
O16 ..... A-19
O17 ..... A-20
O19 ..... A-20

Left
L1 ..... A-21
L2 ..... A-22
L4 ..... A-23
L5 ..... A-24
L9 ..... A-24
L11 ..... A-25
L15 ..... A-26

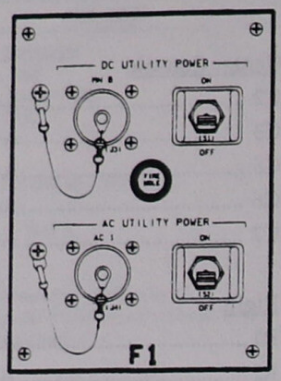
Center Console
C2 ..... A-27
C3 ..... A-28
C5 ..... A-29
C6 ..... A-29
C7 ..... A-29

Right
R1 ..... A-30
R2 ..... A-31
R4 ..... A-32
R6 ..... A-32
R10 ..... A-33
R11U A-34
R11L A-34
R12U A-35
R12L A-35
R13U A-36
R13L A-37
R15 ..... A-38

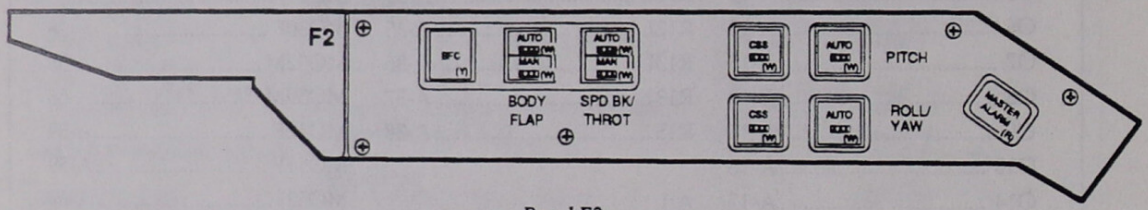
Aft
A1U A-39
A1L A-40
A1R A-41
A2 ..... A-42
A3 ..... A-42
A4 ..... A-43
A6U A-43
A6L A-44
A7U A-44
A7L A-45
A8U A-46
A8L A-47
A11 ..... A-47, 48
A12 ..... A-49
A13 ..... A-49, 50
A14 ..... A-50
A15 ..... A-51

Middeck
MA73C A-52
MD24K A-53
MD44F A-53
ML18F A-53
ML26C A-53
ML31C A-54
ML86B A-55
MO10W A-56
MO13Q A-57
MO29J A-58
MO30F A-58
MO32M A-58
MO39M A-58
MO42F A-59
MO51F A-59
MO52J A-60
MO58F A-60
MO62M A-61
MO69M A-61
WCS A-61
Teleprinter A-62

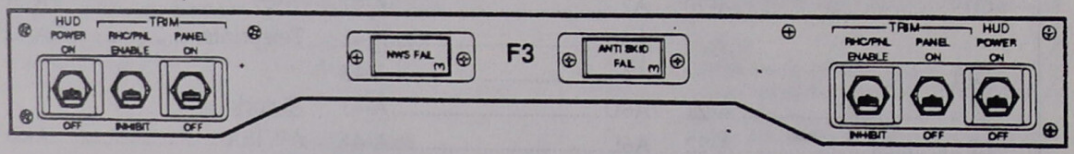
Airlock
AW18A A-63
AW18D A-63
AW18H A-64
AW82B A-65
AW82D A-65
AW82H A-66



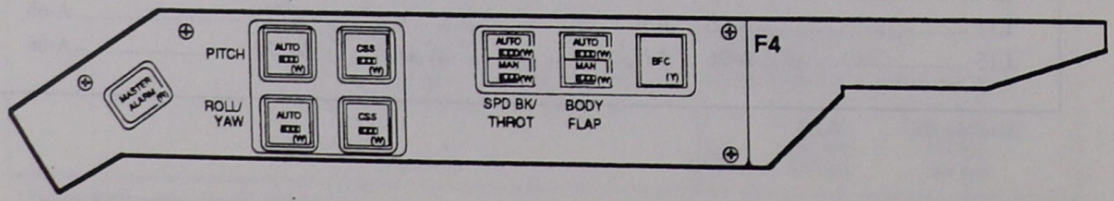
Panel F1



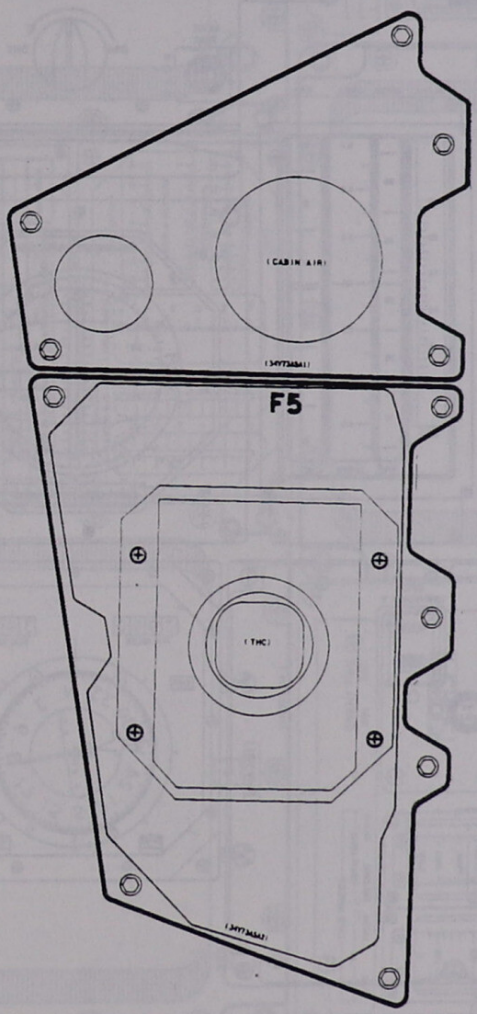
Panel F2



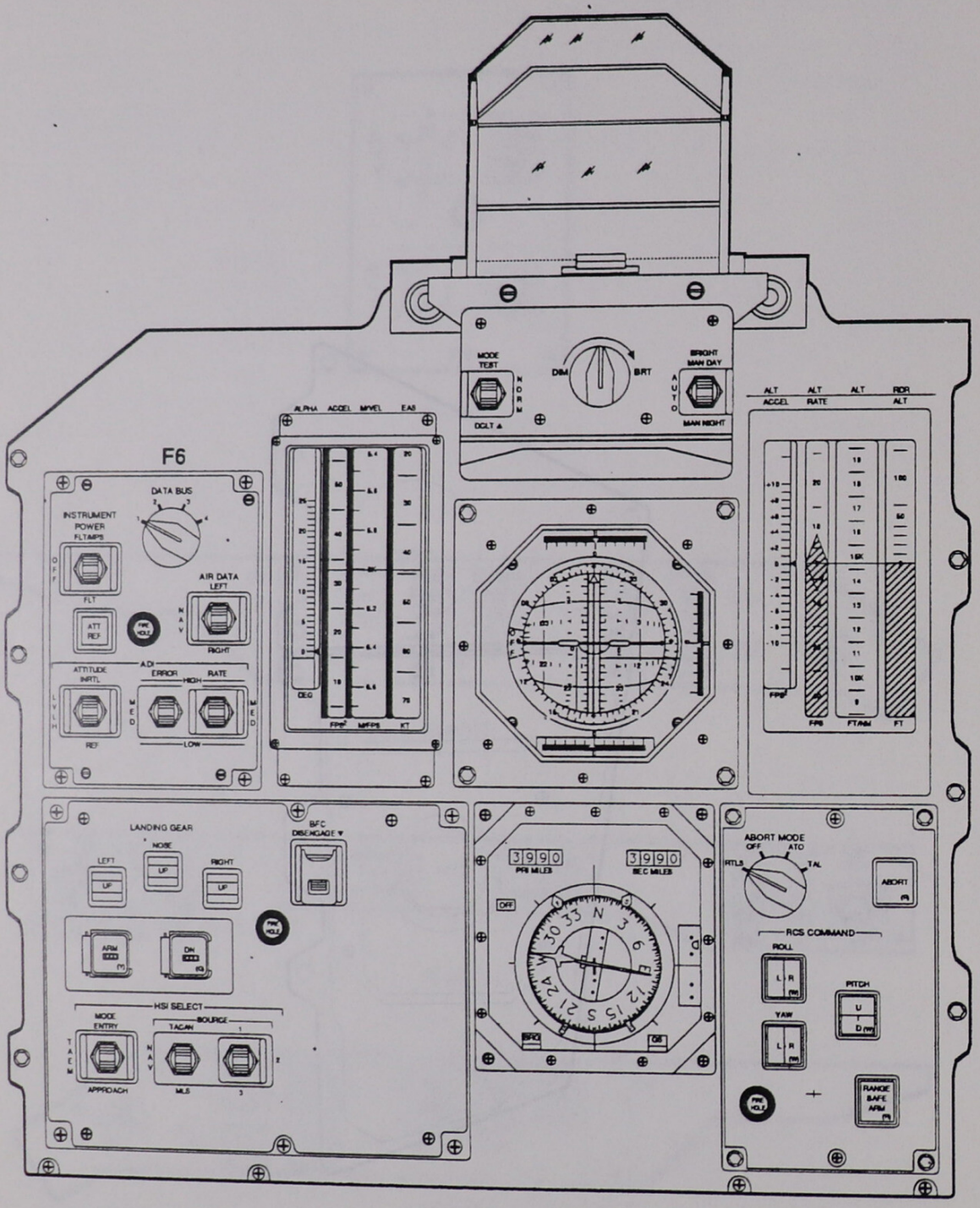
Panel F3



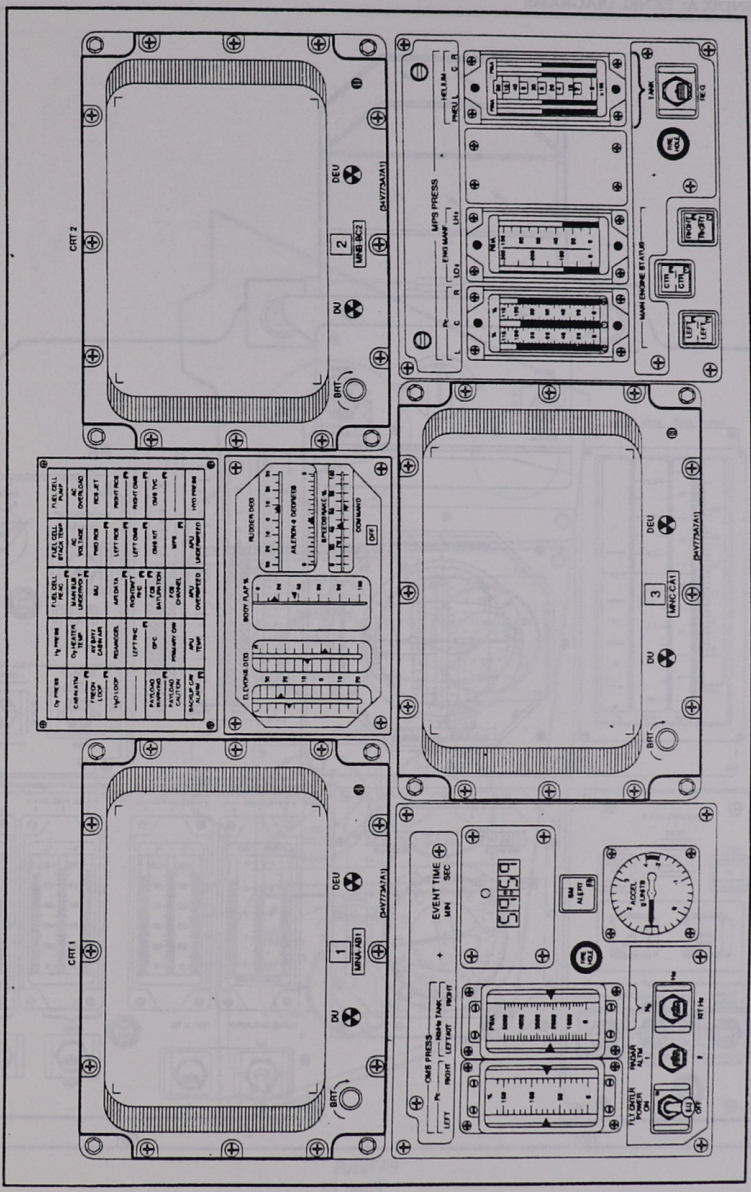
Panel F4



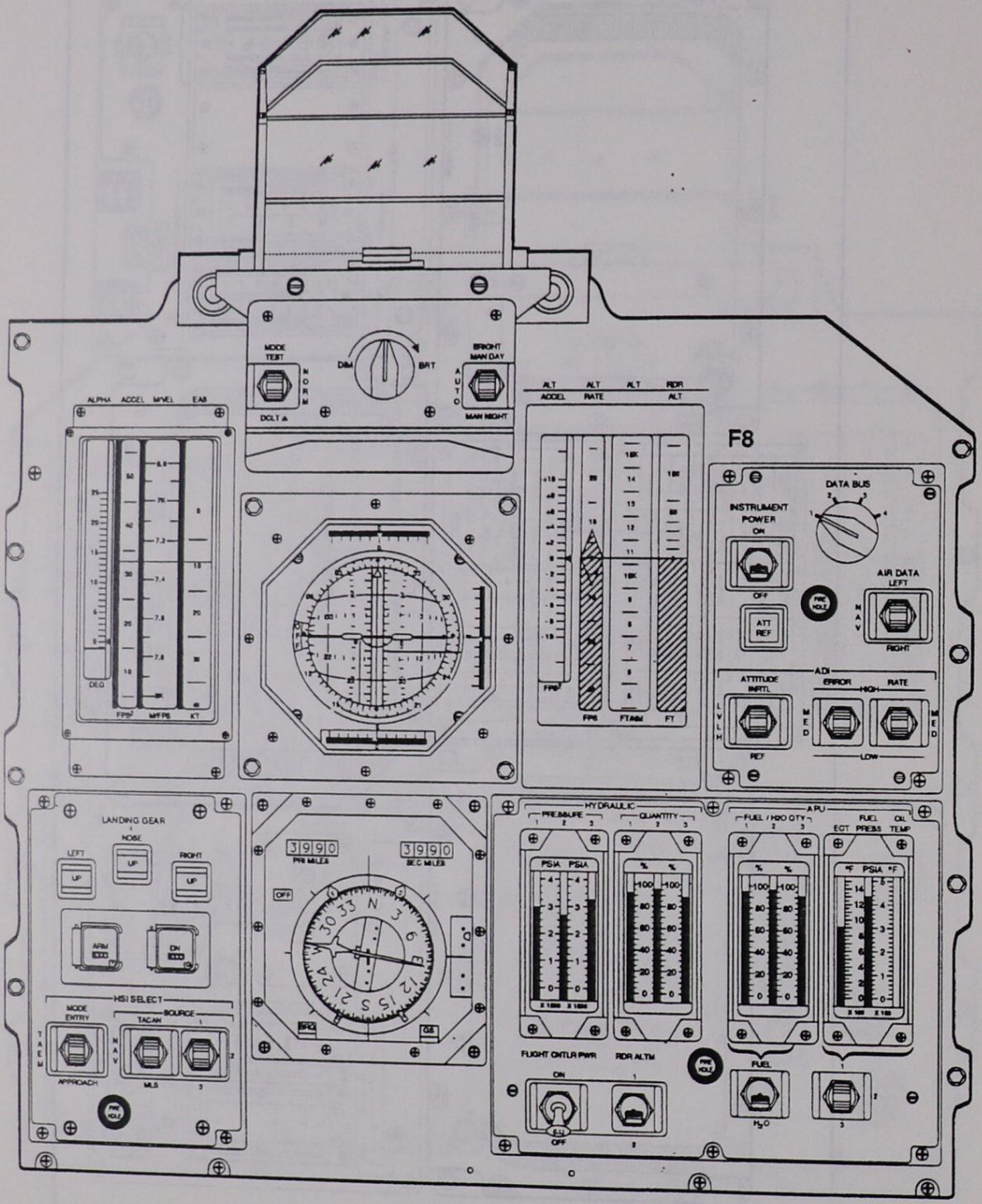
Panel F5


F6
DATA BUS
INSTRUMENT POWER FLT/MPS
AIR DATA LEFT
RIGHT
ATT REF
ATTITUDE INRTL
ADI ERROR
RATE
HIGH
LOW
REF
ALPHA
ACCEL
MVEL
EAS
DEG
FPS
MPPS
KT
MODE TEST
DBM
BRT
BRIGHT MAN DAY
AUTO
NORM
DCLT
MAN NIGHT
ALT ACCEL
ALT RATE
ALT
RDR ALT
FPS
FT/MIN
FT
LANDING GEAR
NOSE
LEFT
RIGHT
UP
DN
ARM
BFC DISENGAGE
HSI SELECT
MODE ENTRY
APPROACH
SOURCE
TACAN
MLS
PRI MILES
SEC MILES
OFF
ABORT MODE
OFF
ATO
RTLS
TAL
ABORT
RCS COMMAND
ROLL
PITCH
YAW
L
R
U
D
RANGE SAFE ARM

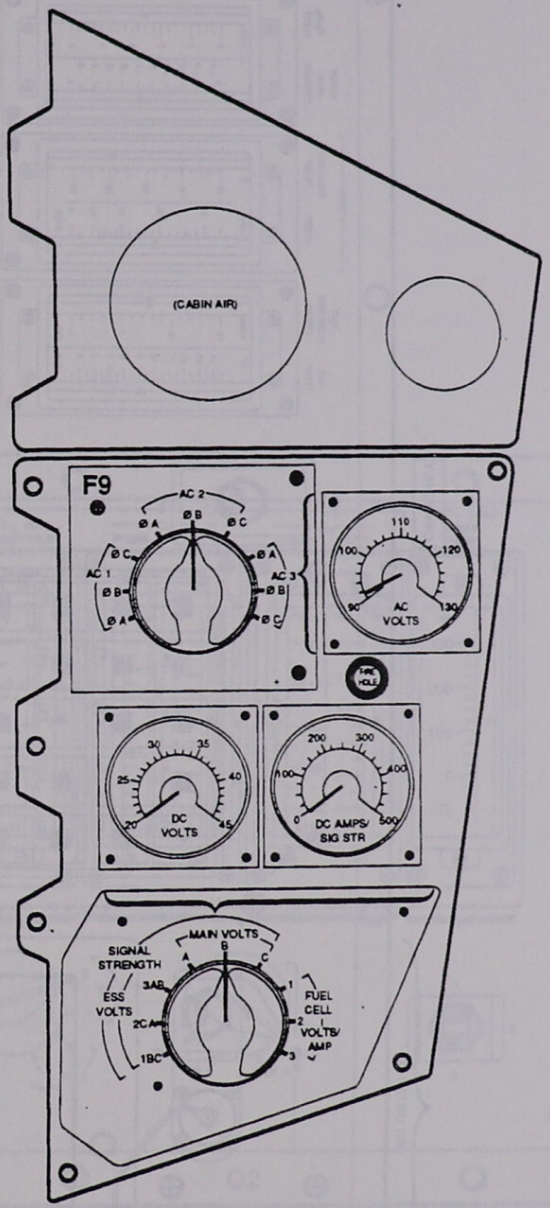
Panel F6



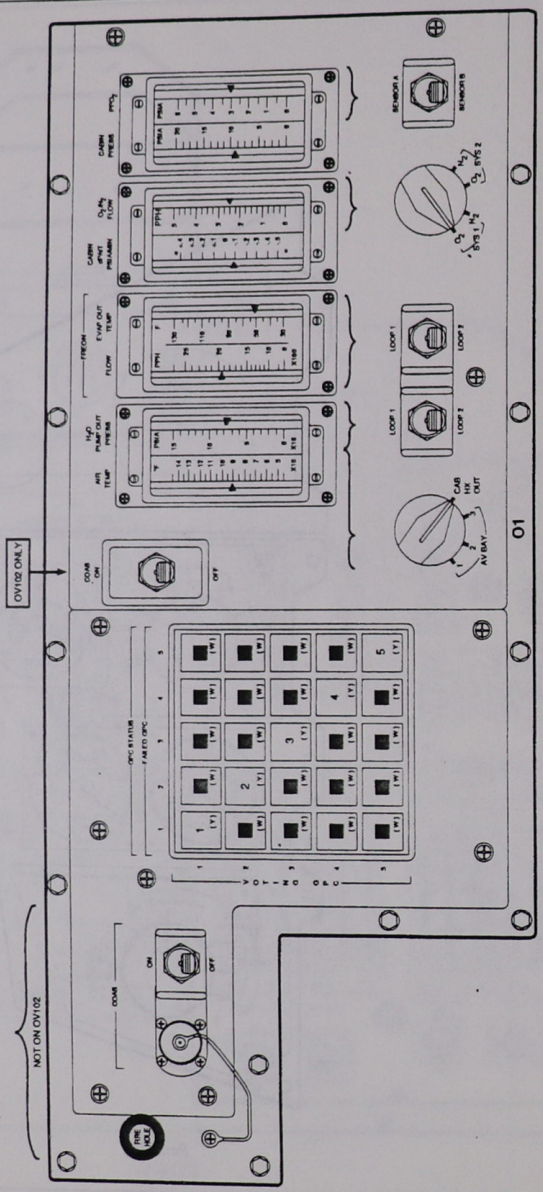
Panel F7


F8
MODE TEST
DIM
BRT
BRIGHT MAN DAY
MAN NIGHT
DCLT
ALPHA ACCEL MVEL EAS
ALT ACCEL
ALT RATE
ALT
RDR ALT
INSTRUMENT POWER
ON
OFF
ATT REF
DATA BUS
AIR DATA LEFT
RIGHT
ADI
ATTITUDE INRTL
ERROR
RATE
HIGH
LOW
REF
LANDING GEAR
NOSE
LEFT
RIGHT
UP
ARM
DN
HSI SELECT
MODE ENTRY
SOURCE
TACAN
APPROACH
MLS
HYDRAULIC
PRESSURE
QUANTITY
PSIA
APU
FUEL / H2O QTY
FUEL PRESS
OIL TEMP
EGT
FLIGHT CNTLR PWR
RDR ALTM
FUEL
H2O
ON
OFF

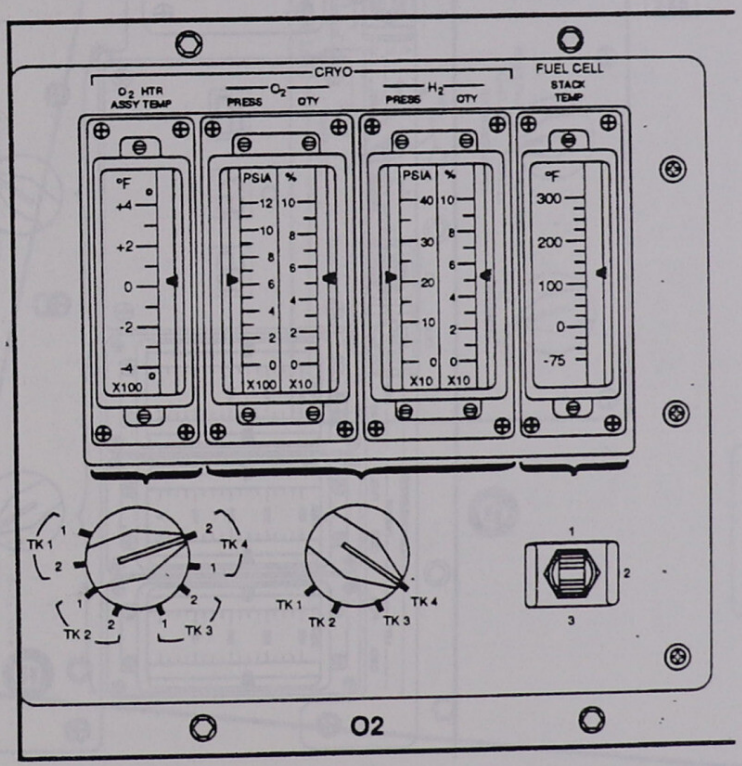
Panel F8


(CABIN AIR)
F9
AC 2
ØA
ØB
ØC
AC 1
AC 3
AC VOLTS
110
100
120
90
130
DC VOLTS
30
35
25
40
20
45
DC AMPS/ SIG STR
200
300
100
400
0
500
MAIN VOLTS
A
B
C
SIGNAL STRENGTH
ESS VOLTS
3AB
2CA
1BC
1
2
3
FUEL CELL VOLTS/ AMP

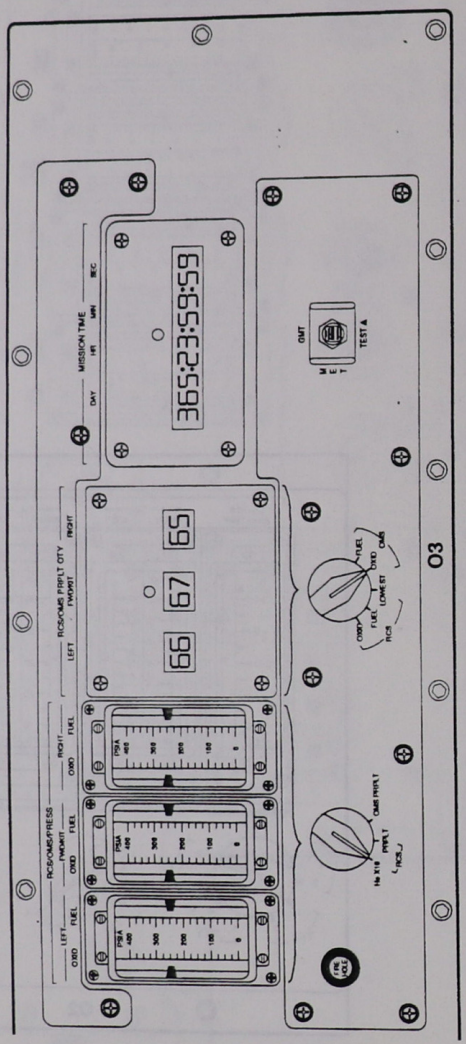
Panel F9


01
OV102 ONLY
NOT ON OV102
COMM
ON
OFF
CABIN PRESS
CABIN ΔP/ΔT PRESS/RATE
FROM EVAP OUT TEMP
FLOW
H2O PUMP OUT PRESS
AVI TEMP
LOOP 1
LOOP 2
LOOP 3
SENSOR A
SENSOR B
AV BAY
OPC STATUS
FAULTY OPC
OPC 1 TO OPC 5

Panel O1


CRYO
FUEL CELL
O_2 HTR ASSY TEMP
O_2 PRESS
O_2 QTY
H_2 PRESS
H_2 QTY
STACK TEMP
°F
+4
+2
0
-2
-4
X100
PSIA
%
12
10
8
6
4
2
0
X100
X10
40
30
20
X10
300
200
100
-75
TK 1
TK 2
TK 3
TK 4
O2

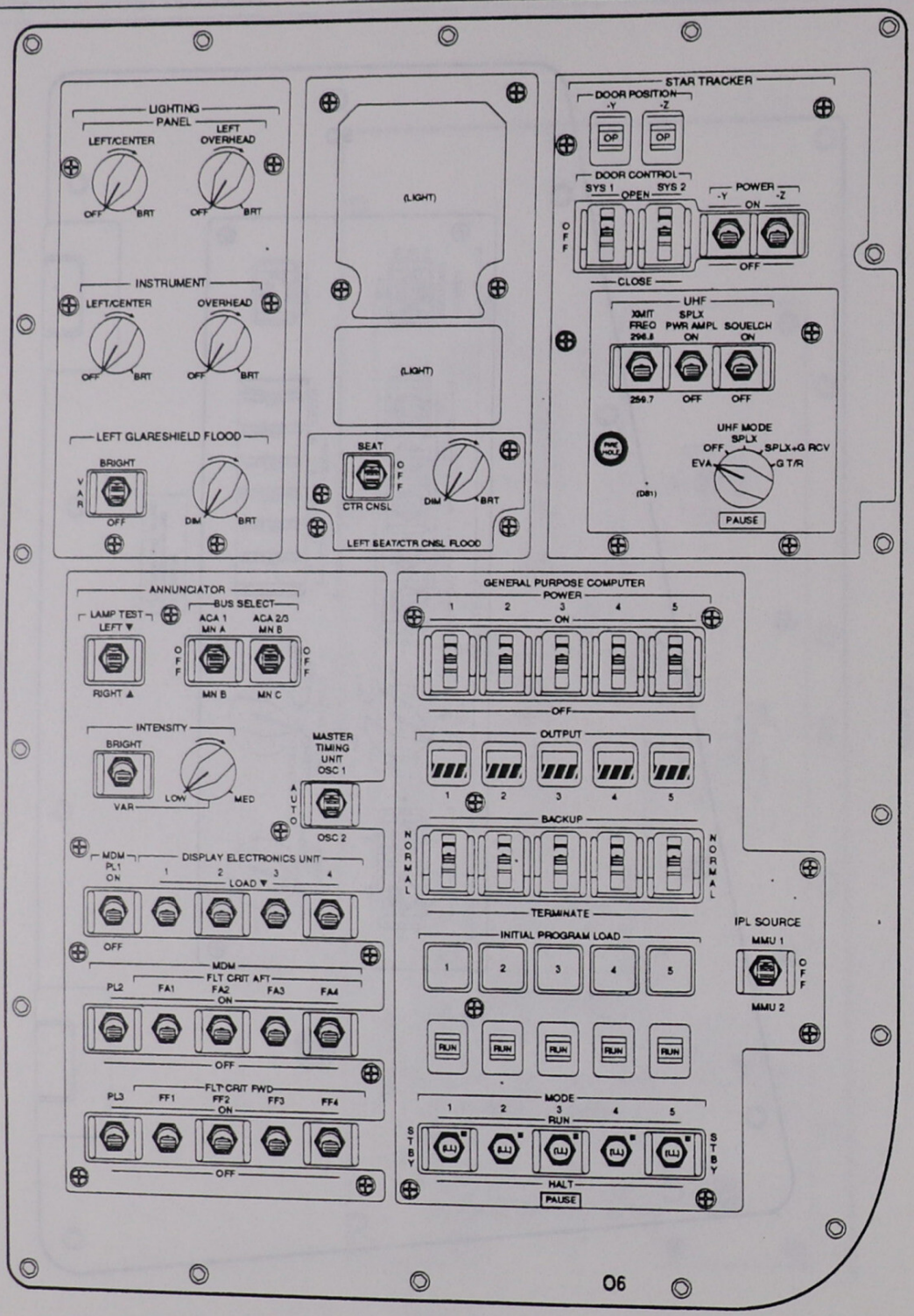
Panel O2


RCS/OMS/PRESS
LEFT
RIGHT
OXID
FUEL
PSIA
MISSION TIME
DAY
HR
MIN
SEC
365:23:59:59
66
67
65
RCS/OMS PRPLT QTY
LEFT
RIGHT
OUT
TEST
03

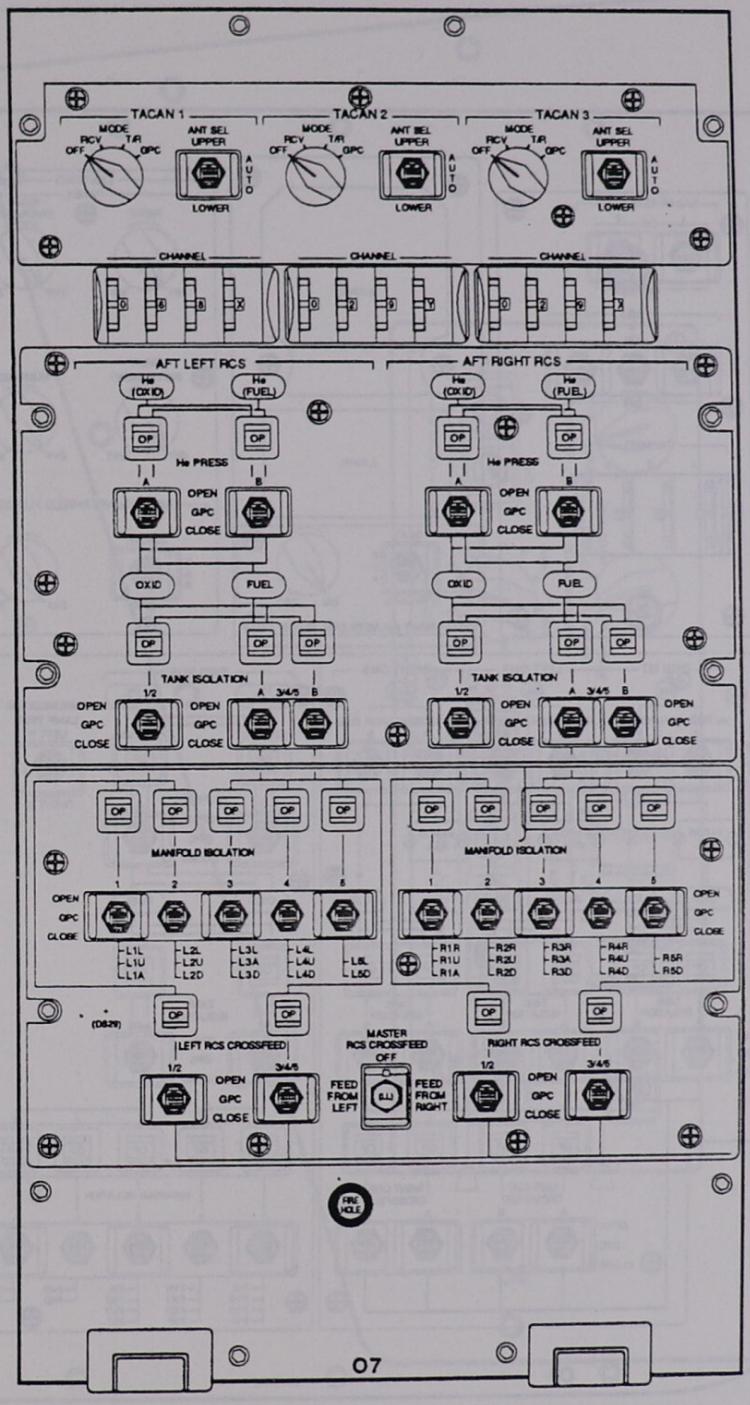
Panel O3

LEFT AUDIO
TACAN ID
ON
OFF
VOX SENS
MIN
MAX
A/G
A/A
ICOM
T/R
RCV
OFF
POWER
AUD/TONE
CONTROL
NORM
RIGHT
XMIT/COM MODE
PTT/VOX
PTT/HOT
PTT/PTT
VOX/VOX
VOLUME
TACAN
PAGE
FIRE HOLE
O5

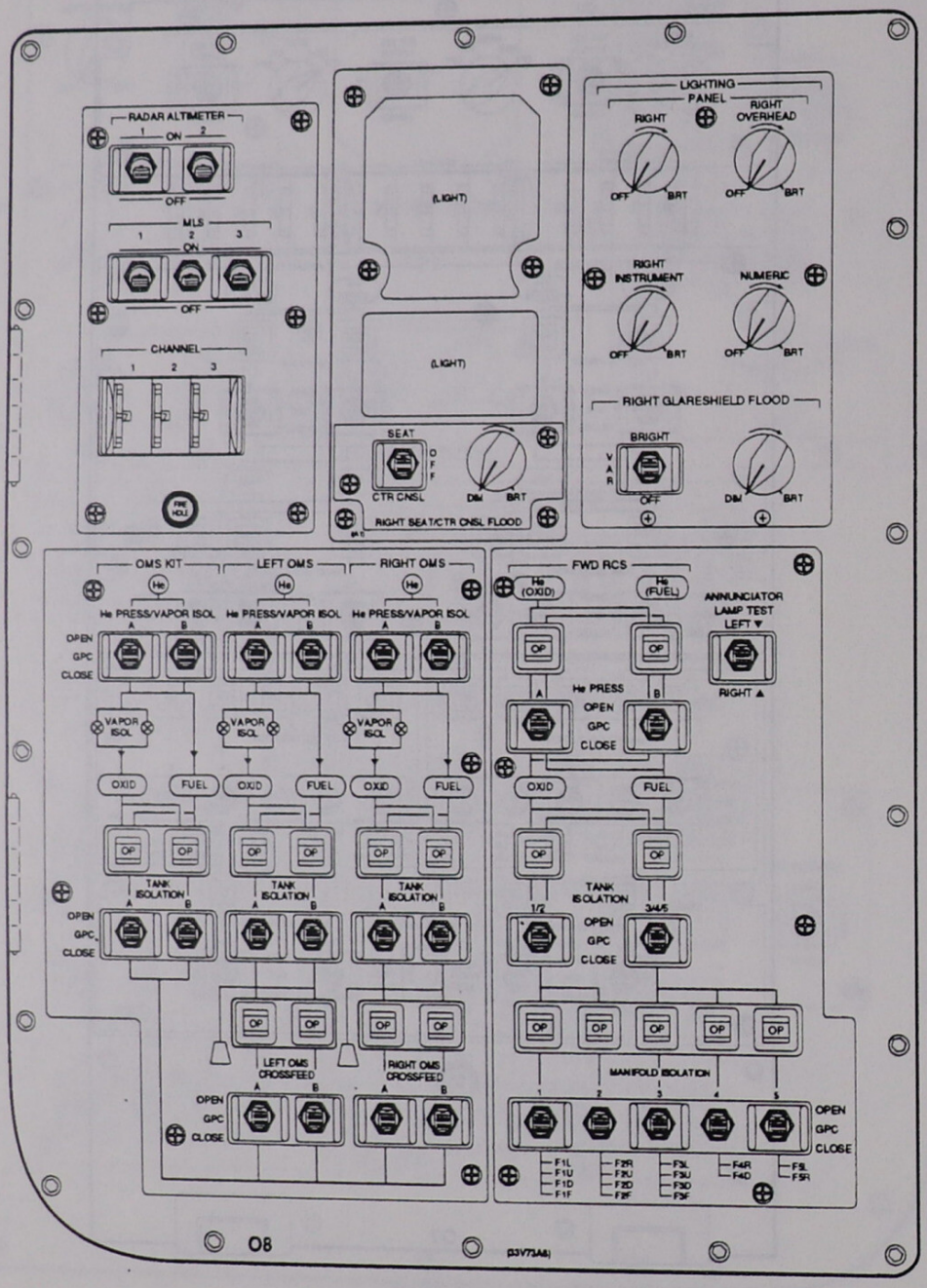
Panel O5


LIGHTING
PANEL
LEFT/CENTER
LEFT OVERHEAD
OFF
BRT
INSTRUMENT
LEFT/CENTER
OVERHEAD
LEFT GLARESHIELD FLOOD
BRIGHT
VAR
OFF
DIM
BRT
(LIGHT)
SEAT
CTR CNSL
LEFT SEAT/CTR CNSL FLOOD
STAR TRACKER
DOOR POSITION
-Y
-Z
OP
DOOR CONTROL
SYS 1
OPEN
SYS 2
CLOSE
POWER
ON
UHF
XMIT FREQ
SPLX PWR AMPL
SQUELCH
UHF MODE
SPLX
SPLX+G RCV
G T/R
EVA
PAUSE
ANNUNCIATOR
LAMP TEST
LEFT
RIGHT
BUS SELECT
ACA 1 MN A
ACA 2/3 MN B
MN B
MN C
INTENSITY
BRIGHT
VAR
LOW
MED
MASTER TIMING UNIT OSC 1
OSC 2
MDM
DISPLAY ELECTRONICS UNIT
PL1
LOAD
MDM
FLT CRIT AFT
PL2
FA1
FA2
FA3
FA4
FLT CRIT FWD
PL3
FF1
FF2
FF3
FF4
GENERAL PURPOSE COMPUTER
POWER
OUTPUT
BACKUP
NORMAL
TERMINATE
INITIAL PROGRAM LOAD
RUN
MODE
STBY
HALT
IPL SOURCE
MMU 1
MMU 2
06

Panel O6


TACAN 1
TACAN 2
TACAN 3
MODE
RCV
T/R
OFF
GPC
ANT SEL
UPPER
LOWER
AUTO
CHANNEL
AFT LEFT RCS
AFT RIGHT RCS
He (OXID)
He (FUEL)
He PRESS
OPEN
GPC
CLOSE
OXID
FUEL
TANK ISOLATION
MANIFOLD ISOLATION
LEFT RCS CROSSFEED
MASTER RCS CROSSFEED
OFF
RIGHT RCS CROSSFEED
FEED FROM LEFT
FEED FROM RIGHT
FIRE VALVE
07

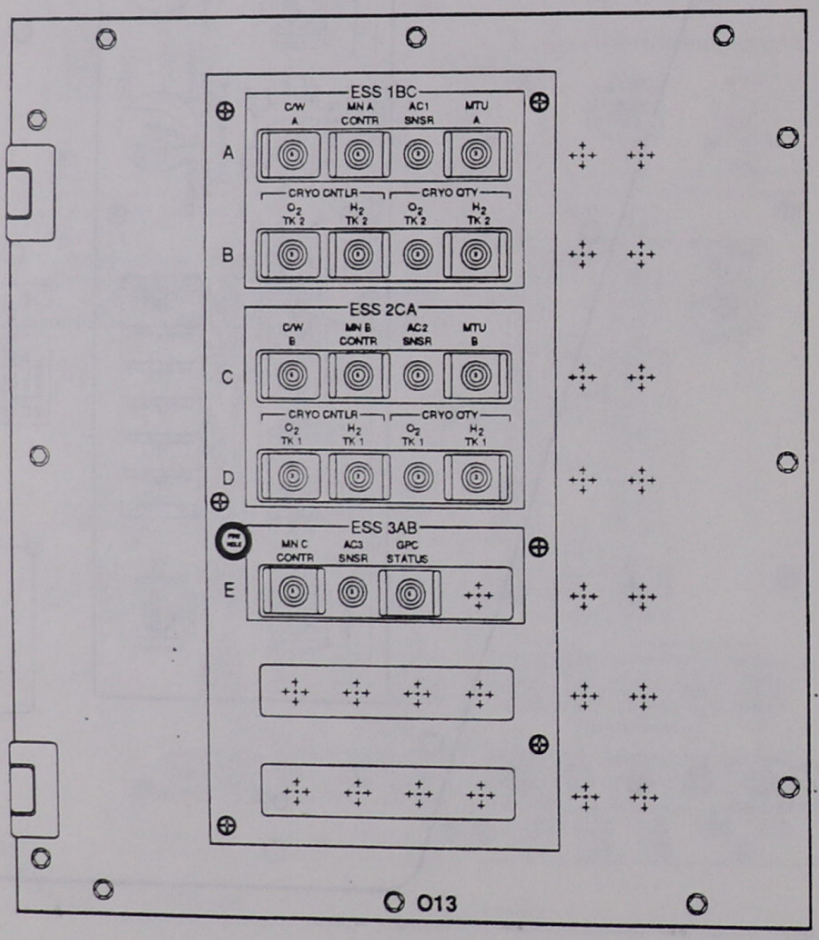
Panel O7


RADAR ALTIMETER
ON
OFF
MLS
ON
OFF
CHANNEL
(LIGHT)
(LIGHT)
SEAT
CTR CNSL
RIGHT SEAT/CTR CNSL FLOOD
LIGHTING
PANEL
RIGHT
RIGHT OVERHEAD
RIGHT INSTRUMENT
NUMERIC
RIGHT GLARESHIELD FLOOD
BRIGHT
OMS KIT
LEFT OMS
RIGHT OMS
He PRESS/VAPOR ISOL
VAPOR ISOL
OXID
FUEL
TANK ISOLATION
LEFT OMS CROSSFEED
RIGHT OMS CROSSFEED
FWD RCS
He (OXID)
He (FUEL)
ANNUNCIATOR LAMP TEST
LEFT
RIGHT
He PRESS
MANIFOLD ISOLATION
OPEN
GPC
CLOSE
O8

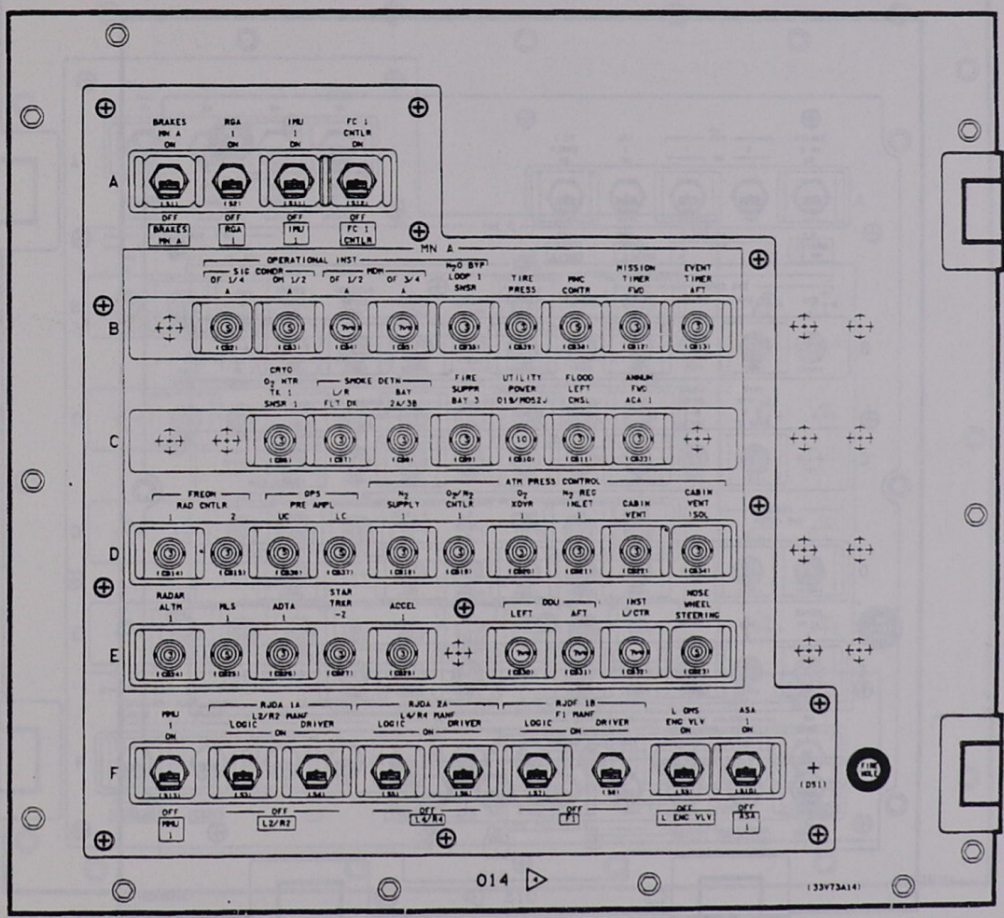
Panel O8

RIGHT AUDIO
POWER
AUD/TONE
OFF
A/G
1
2
A/A
T/R
ICOM
A
B
RCV
OFF
VOX SENS
MIN
MAX
TACAN ID
ON
1
2
OFF
3
VOLUME
A/G
1
2
ICOM
A/A
A
B
TACAN
PAGE
XMIT/COM MODE
PTT/VOX
PTT/PTT
PTT/HOT
VOX/VOX
CONTROL
NORM
LEFT
FIRE HOLE
O9
ACTIVATION
O9 R AUD PWR - AUD/TONE
all other pwrs - as req'd
R/L COMM PWR - as req'd

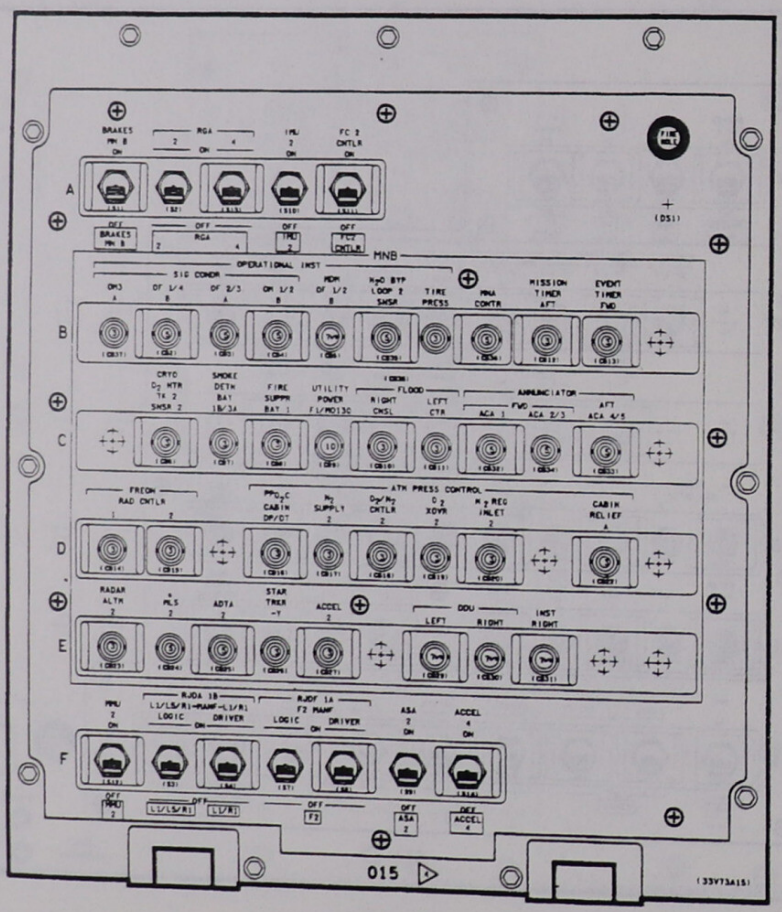
Panel O9


ESS 1BC
C/W A
MN A CONTR
AC1 SNSR
MTU A
A
CRYO CNTLR
CRYO QTY
O2 TK 2
H2 TK 2
O2 TK 2
H2 TK 2
B
ESS 2CA
C/W B
MN B CONTR
AC2 SNSR
MTU B
C
CRYO CNTLR
CRYO QTY
O2 TK 1
H2 TK 1
O2 TK 1
H2 TK 1
D
ESS 3AB
MN C CONTR
AC3 SNSR
GPC STATUS
E
O13

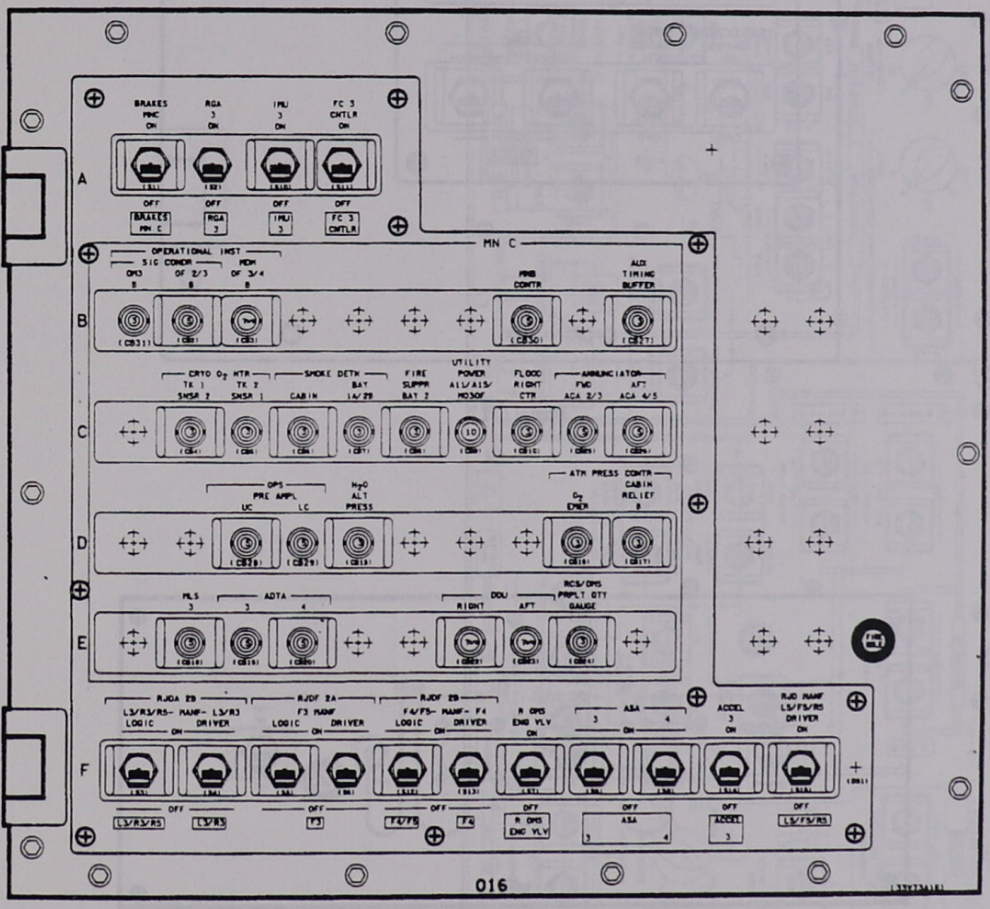
Panel O13



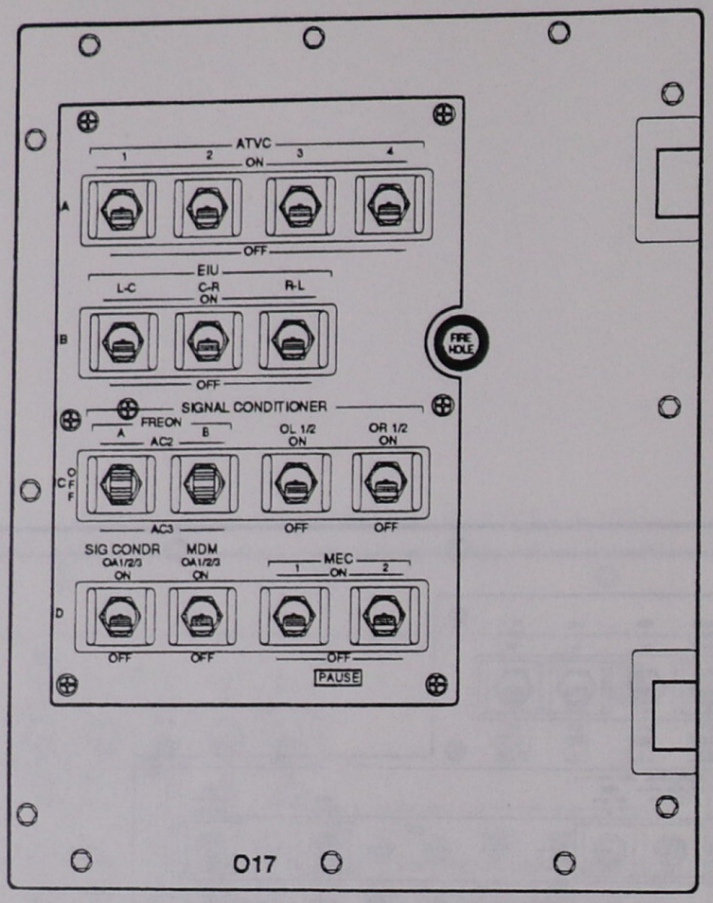
Panel O14



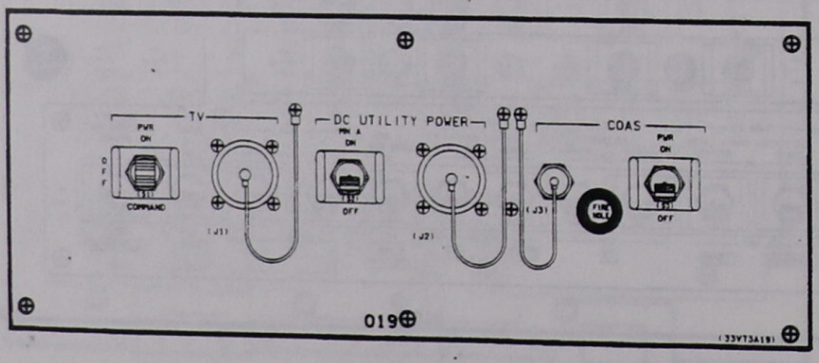
Panel O15



Panel O16



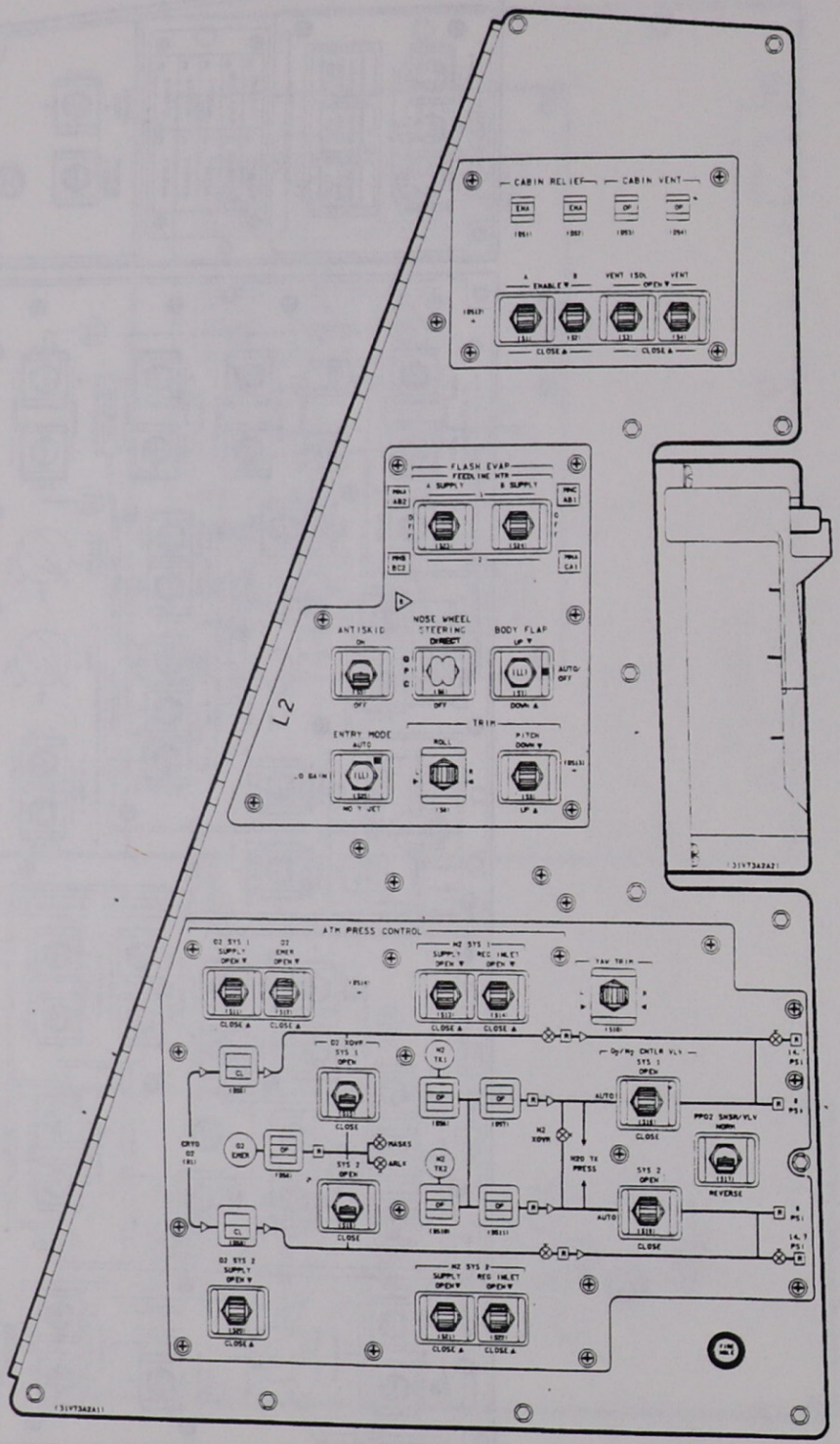
Panel O17



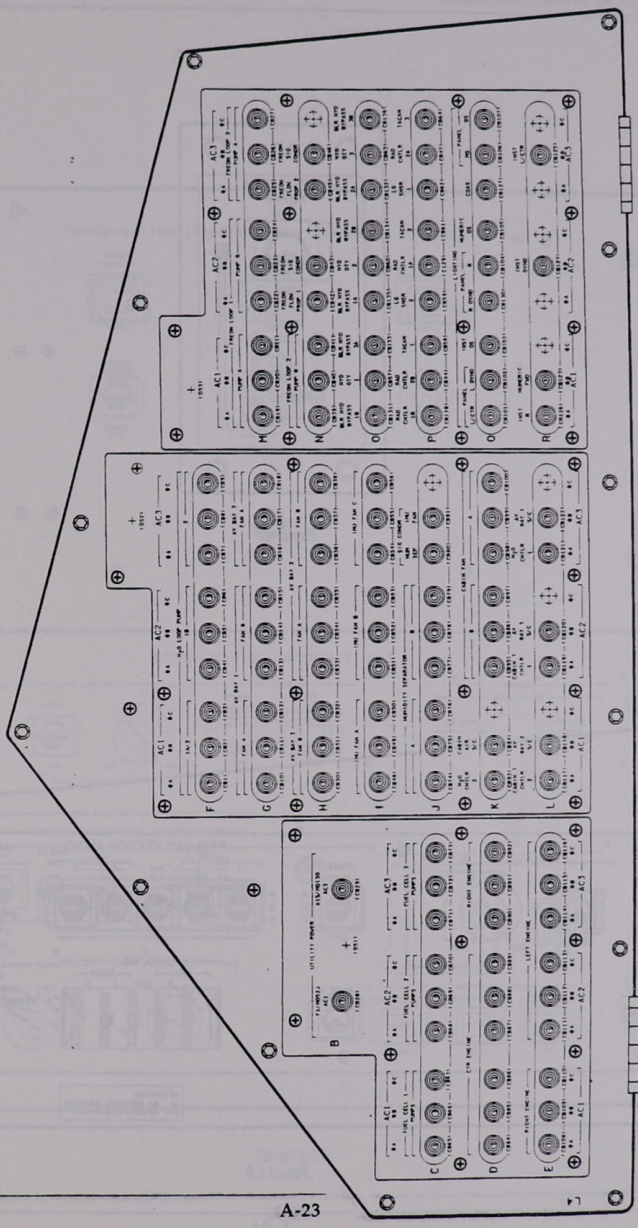
Panel O19

L1
CABIN HX
H2O CHILLER
LCG HX
HUMIDITY SEP
WASTE H2O
CABIN TEMP
COOL
WARM
CABIN TEMP CNTLR
CABIN FAN
FLT DECK AVIONICS
AV BAY 3 FAN
AV RACK CP
AV BAY 2 FAN
AV BAY 1 FAN
H2O PUMP
LOOP 1 BYPASS
LOOP 2 BYPASS
DECR
MAN INCR
MODE
AUTO
LOOP 1
LOOP 2
QPC
ON
OFF
AFT HX
FWD HX
DRCP
INTERCHANGER
AFT CP
PAYLOAD HX
KGH
FLOW PROP VLV
PAYLOAD HX A
PAYLOAD HX B
HYD HX
FC HX
MID CP
FREON PUMP
NORM
RADIATORS
RAD CONTROLLER
OUT TEMP
RAD
MAN SEL
RAD FLOW
BYPASS
H2O TK
ALTERNATE PRESS OPEN
CLOSE
FLASH EVAP CONTROLLER
PRESS
TEMP
A SPLY
B SPLY
HI LOAD EVAP ENABLE
TOPPING EVAP
HI LOAD EVAP
TOPPING EVAPORATOR HEATER
L NOZZLE HTR
DUCT
HI LOAD DUCT HTR
N2 BOILER
N2 CONTROLLER
PRESS
RECON
FIRE SUPPRESSION
AV BAY 1
AV BAY 2
AV BAY 3
ARM
SAFE
AGENT DISCH
SMOKE DETECTION
CABIN
PAYLOAD
L FLT DECK
R FLT DECK
SENSOR RESET
CIRCUIT TEST

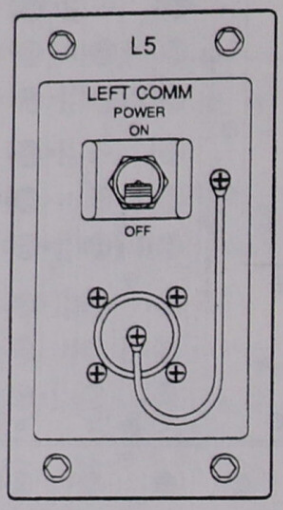
Panel L1


CABIN RELIEF
CABIN VENT
ENA
ENA
OP
OP
A
B
VENT ISOL
VENT
ENABLE
OPEN
CLOSE
CLOSE
FLASH EVAP
FEEDLINE HTR
A SUPPLY
B SUPPLY
ANTISKID
NOSE WHEEL STEERING
BODY FLAP
ON
DISARM
UP
OFF
OFF
DOWN
AUTO/ OFF
TRIM
ENTRY MODE
AUTO
ROLL
PITCH
DOWN
L2
ATM PRESS CONTROL
O2 SYS 1 SUPPLY
O2 EMER
N2 SYS 1
SUPPLY
REG INLET
YAW TRIM
O2 XOVR SYS 1
N2 TK1
O2/N2 CNTLR VLV SYS 1
OPEN
CLOSE
AUTO
N2O TK PRESS
PPO2 SNSR/VLV
NORM
REVERSE
CRYO O2
O2 EMER
MASKS
ANLY
SYS 2
OPEN
CLOSE
N2 TK2
O2 SYS 2 SUPPLY
N2 SYS 2
SUPPLY
REG INLET
CLOSE
CLOSE

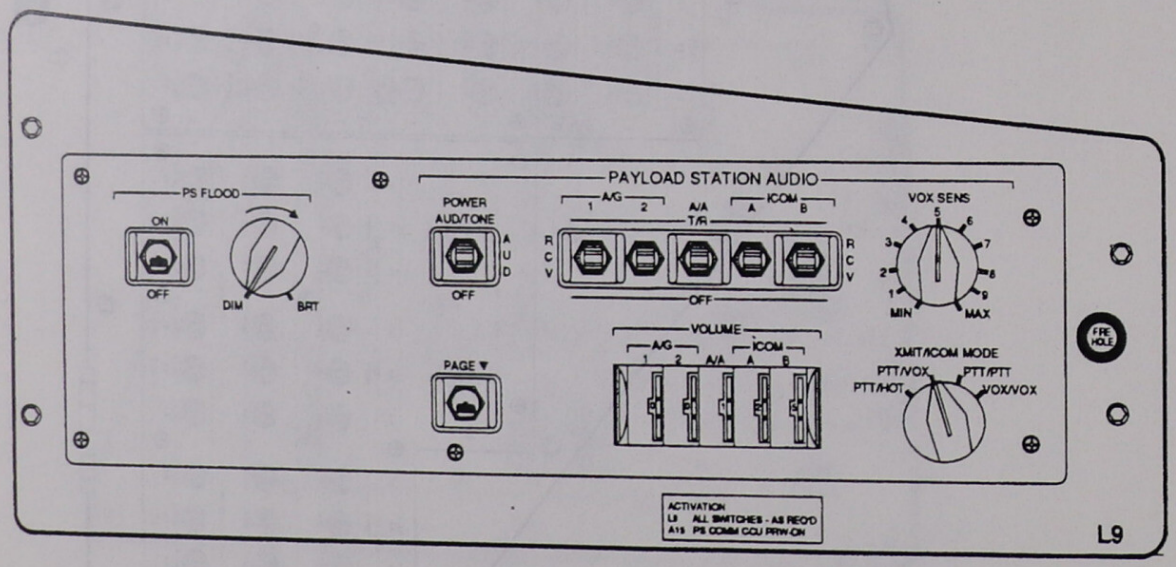
Panel L2



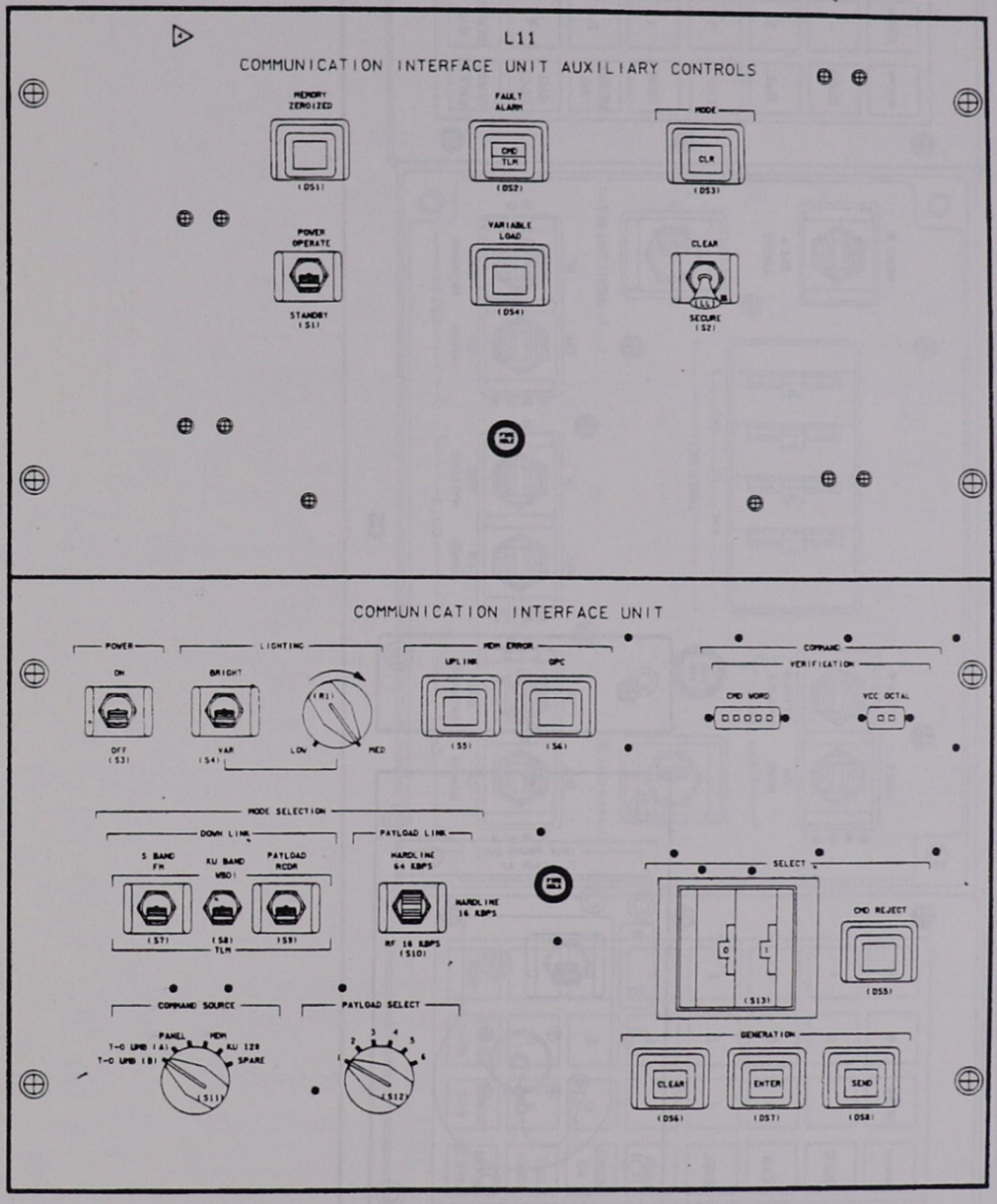
Panel L4



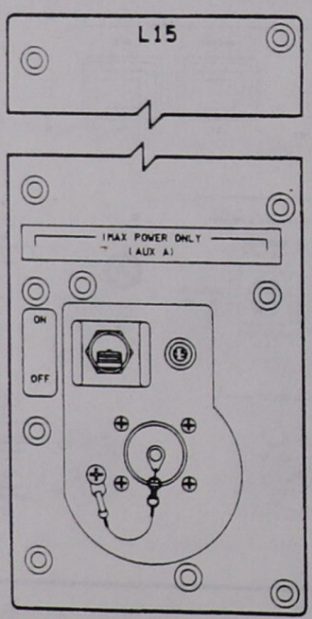
Panel L5



Panel L9


L11
COMMUNICATION INTERFACE UNIT AUXILIARY CONTROLS
MEMORY ZEROIZED
(DS1)
FAULT ALARM
CMD
TLM
(DS2)
MODE
CLR
(DS3)
POWER OPERATE
STANDBY
(S1)
VARIABLE LOAD
(DS4)
CLEAR
SECURE
(S2)
COMMUNICATION INTERFACE UNIT
POWER
ON
OFF
(S3)
LIGHTING
BRIGHT
VAR
(S4)
LOW
MED
MDM ERROR
UPLINK
DPC
(S5)
(S6)
COMMAND VERIFICATION
CMD WORD
VCC OCTAL
MODE SELECTION
DOWN LINK
PAYLOAD LINK
S BAND FM
KU BAND VSO
PAYLOAD RCDR
(S7)
(S8)
TLM
(S9)
HARDLINE 64 KBPS
HARDLINE 16 KBPS
RF 16 KBPS
(S10)
SELECT
(S13)
CMD REJECT
(DS5)
COMMAND SOURCE
PANEL
MDM
T-0 UMB (A)
T-0 UMB (B)
KU 128
SPARE
(S11)
PAYLOAD SELECT
(S12)
GENERATION
CLEAR
ENTER
SEND
(DS6)
(DS7)
(DS8)

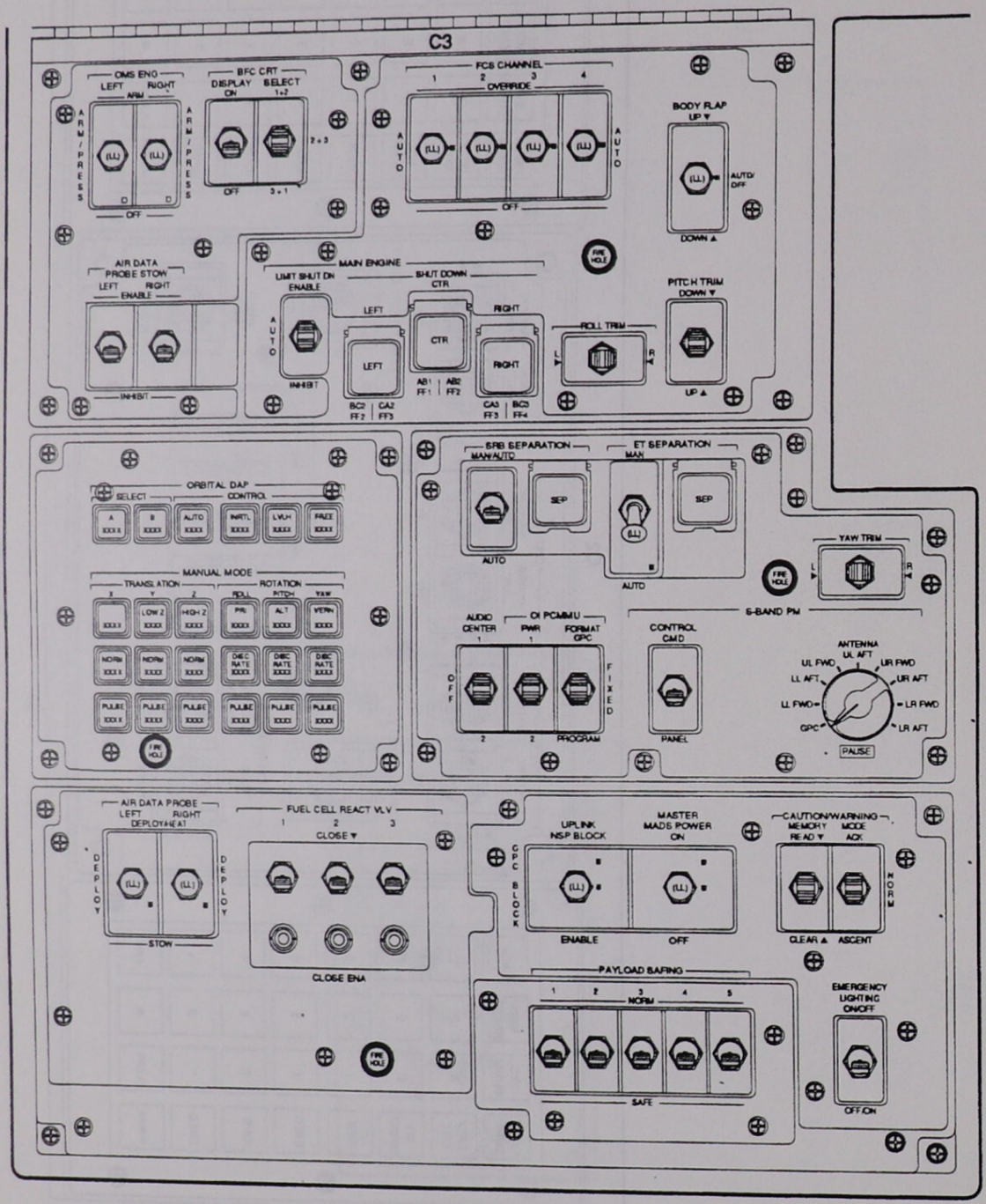
Panel L11



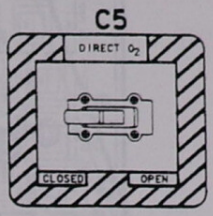
Panel L15

C2
CRT 1
CRT 3
CRT 2
POWER ON
MAJ FUNC GNC
STBY
OFF
PL
LEFT CRT SEL
RIGHT CRT SEL
TIMER SET
MIN
SEC
EVENT TIMER
MODE UP
CONTROL START▼
DOWN
TEST▲
STOP▲
TIMER SET▼
RESET▲
FAULT SUMM
SYS SUMM
MSG RESET
ACK
GPC/ CRT
I/O RESET
ITEM
EXEC
OPS
SPEC
RESUME
CLEAR
PRO

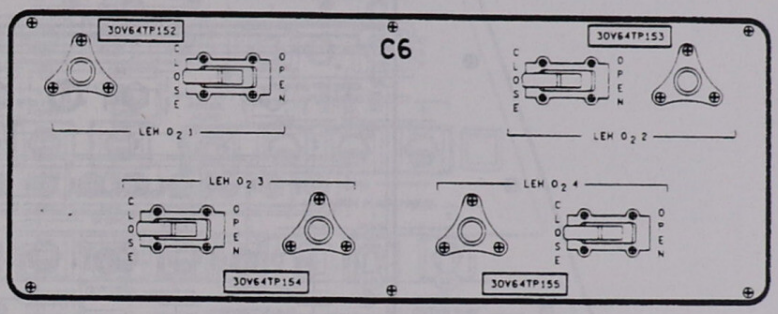
Panel C2


C3
OMS ENG
LEFT
RIGHT
ARM
ARM/PRESS
OFF
BFC CRT
DISPLAY SELECT
ON
1+2
2+3
OFF
3+1
FCS CHANNEL
1
2
3
4
OVERRIDE
AUTO
OFF
BODY FLAP
UP
AUTO/OFF
DOWN
AIR DATA PROBE STOW
LEFT
RIGHT
ENABLE
INHIBIT
MAIN ENGINE
LIMIT SHUT DN
ENABLE
SHUT DOWN
CTR
LEFT
RIGHT
INHIBIT
BC2 | CA2
FF2 | FF3
AB1 | AB2
FF1 | FF2
CA3 | BC3
FF3 | FF4
ROLL TRIM
PITCH TRIM
DOWN
UP
FIRE HOLD
ORBITAL DAP
SELECT
CONTROL
AUTO
INRTL
LVLH
FREE
MANUAL MODE
TRANSLATION
ROTATION
ROLL
PITCH
YAW
LOW 2
HIGH 2
PULSE
SRB SEPARATION
MAN/AUTO
SEP
ET SEPARATION
MAN
AUTO
YAW TRIM
S-BAND PM
AUDIO CENTER
OI PCMMU
PWR
FORMAT GPC
OFF
FIXED
PROGRAM
CONTROL CMD
PANEL
ANTENNA
UL AFT
UL FWD
UR FWD
LL AFT
UR AFT
LL FWD
LR FWD
GPC
LR AFT
PAUSE
AIR DATA PROBE
LEFT
RIGHT
DEPLOY/HEAT
DEPLOY
STOW
FUEL CELL REACT VLV
CLOSE
CLOSE ENA
UPLINK
NSP BLOCK
ENABLE
MASTER
MADS POWER
ON
OFF
GPC BLOCK
CAUTION/WARNING
MEMORY
READ
MODE
ACK
NORM
CLEAR
ASCENT
PAYLOAD SAFING
NORM
SAFE
EMERGENCY
LIGHTING
ON/OFF

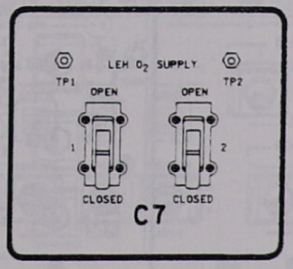
Panel C3



Panel C5



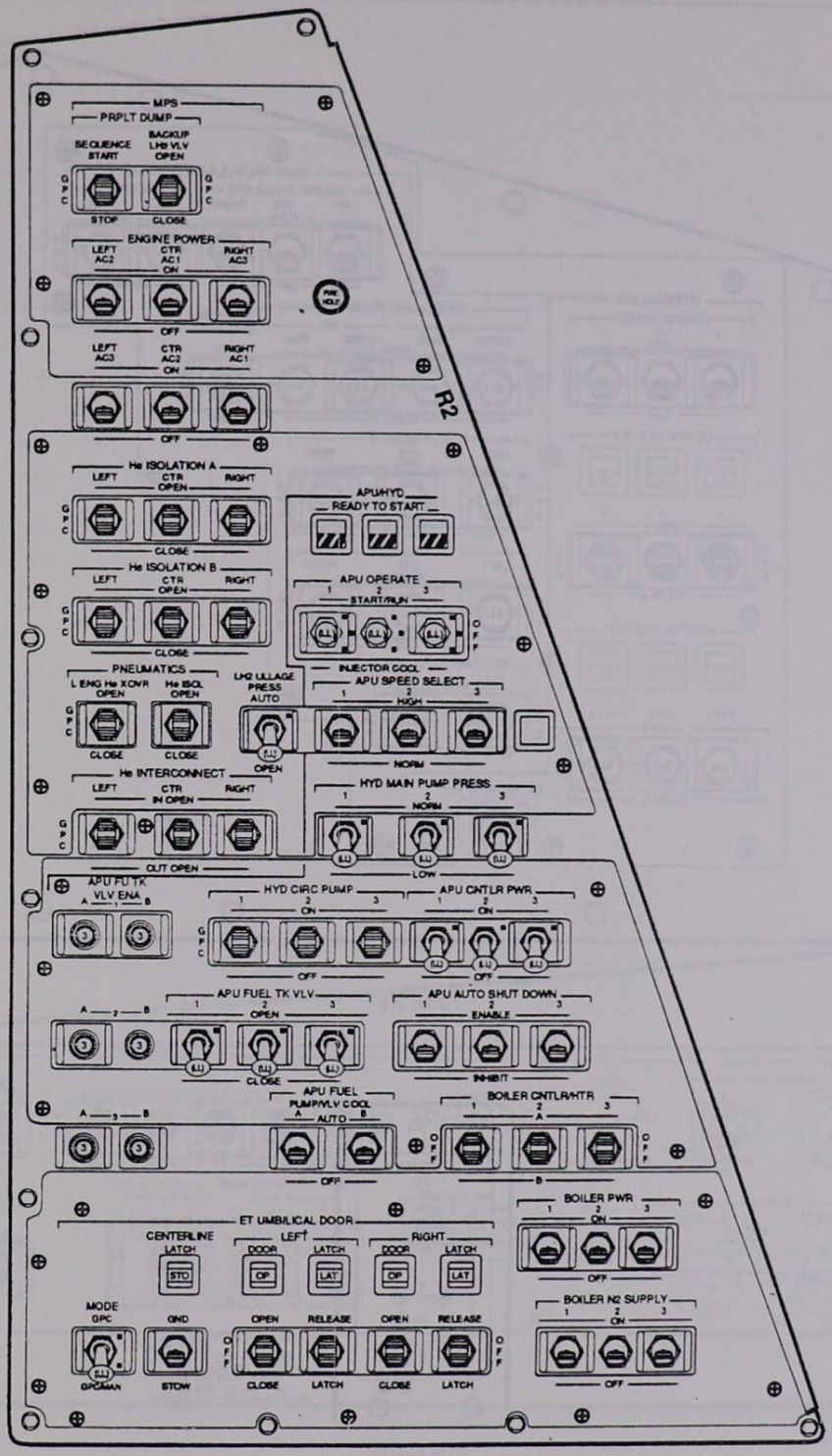
Panel C6



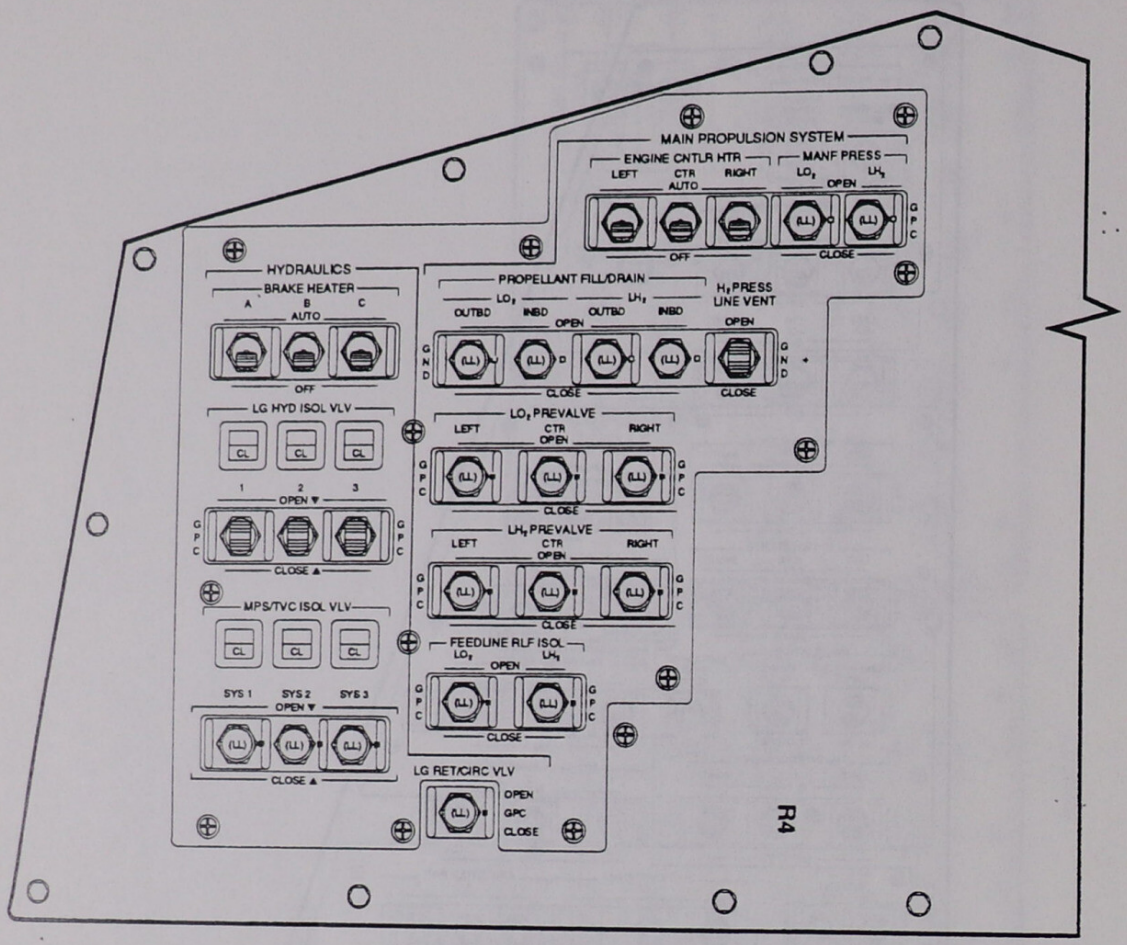
Panel C7

POWER DISTRIBUTION
CONTROL BUS PWR
ESS BUS SOURCE
FC/MAIN BUS
MN BUS TIE
INV PWR
INV/AC BUS
AC CONTR
AC BUS SNSR
R1
CRYO
O2 MANIFOLD VLVS
FUEL CELL 1 REAC
H2 MANIFOLD VLVS
FUEL CELL 3 REAC
FUEL CELL 2 REAC
O2 TK1 HEATERS
O2 TK2 HEATERS
O2 TK3 HEATERS
H2 TK1 HEATERS
H2 TK2 HEATERS
H2 TK3 HEATERS
FUEL CELL
CABIN
AUX
AFT

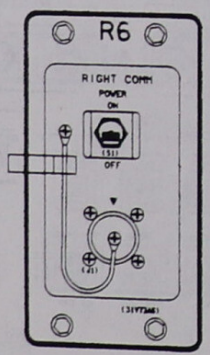
Panel R1


MPS
PRPLT DUMP
SEQUENCE START
BACKUP LH2 VLV OPEN
STOP
CLOSE
ENGINE POWER
LEFT AC2
CTR AC1
RIGHT AC3
ON
OFF
LEFT AC3
CTR AC2
RIGHT AC1
R2
He ISOLATION A
LEFT
CTR
RIGHT
OPEN
CLOSE
He ISOLATION B
APU/HYD
READY TO START
APU OPERATE
START/RUN
PNEUMATICS
L ENG He XOVR
He ISOL
LH2 ULLAGE PRESS
AUTO
APU SPEED SELECT
HIGH
NORM
INJECTOR COOL
He INTERCONNECT
IN
OUT
HYD MAIN PUMP PRESS
LOW
APU FU TK VLV ENA
HYD CIRC PUMP
APU CNTLR PWR
APU FUEL TK VLV
APU AUTO SHUT DOWN
ENABLE
INHIBIT
APU FUEL PUMP/VLV COOL
BOILER CNTLR/HTR
ET UMBILICAL DOOR
CENTERLINE LATCH
LEFT DOOR LATCH
RIGHT DOOR LATCH
BOILER PWR
BOILER N2 SUPPLY
MODE
GPC
GND
OPEN
RELEASE
GPC/MAN
STOW
CLOSE
LATCH

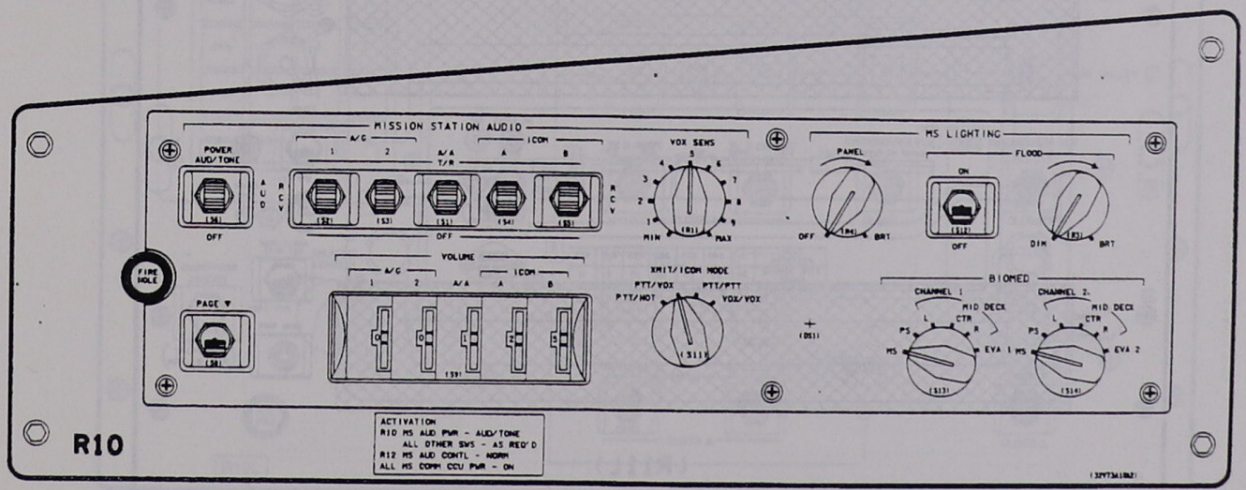
Panel R2



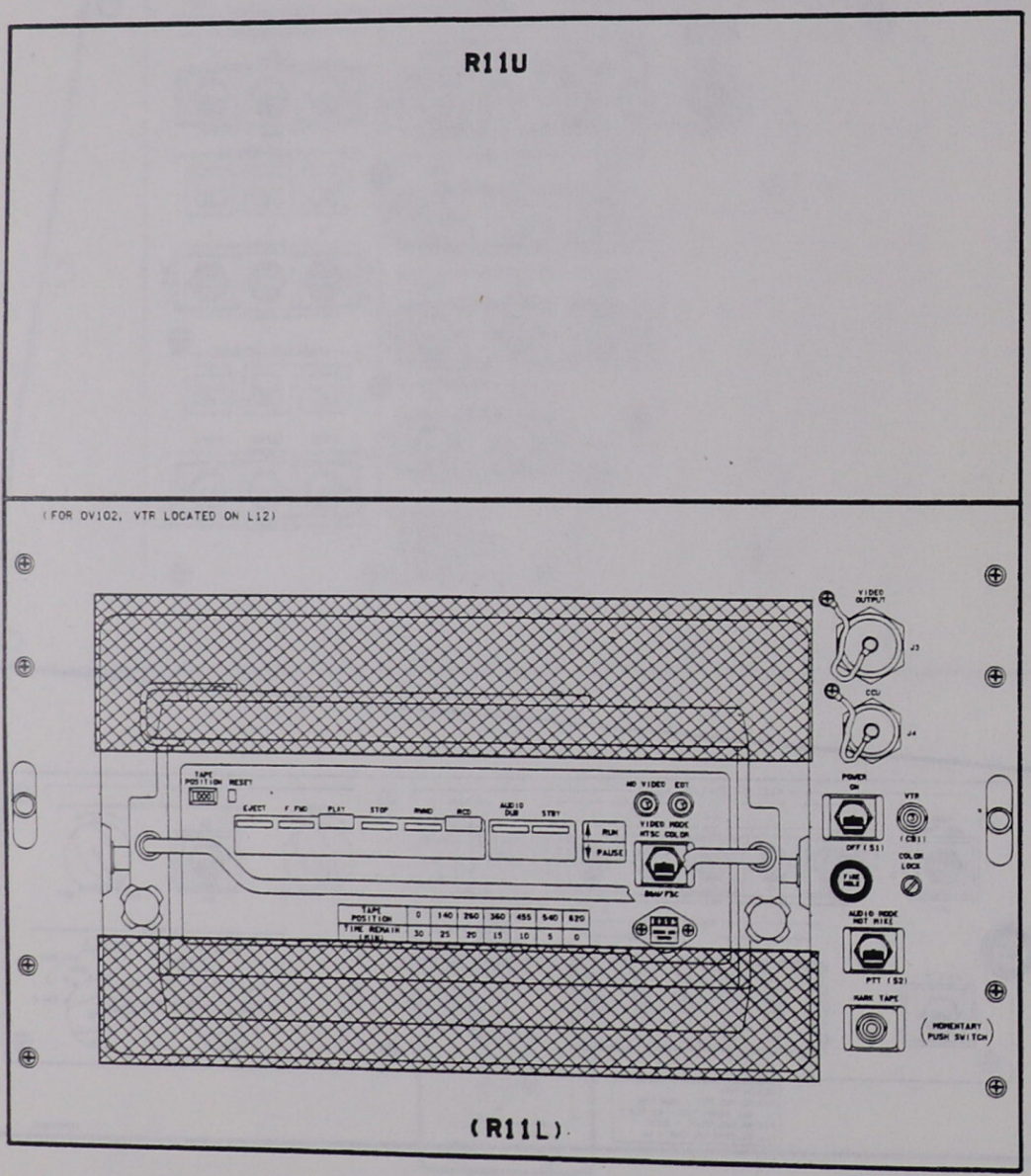
Panel R4



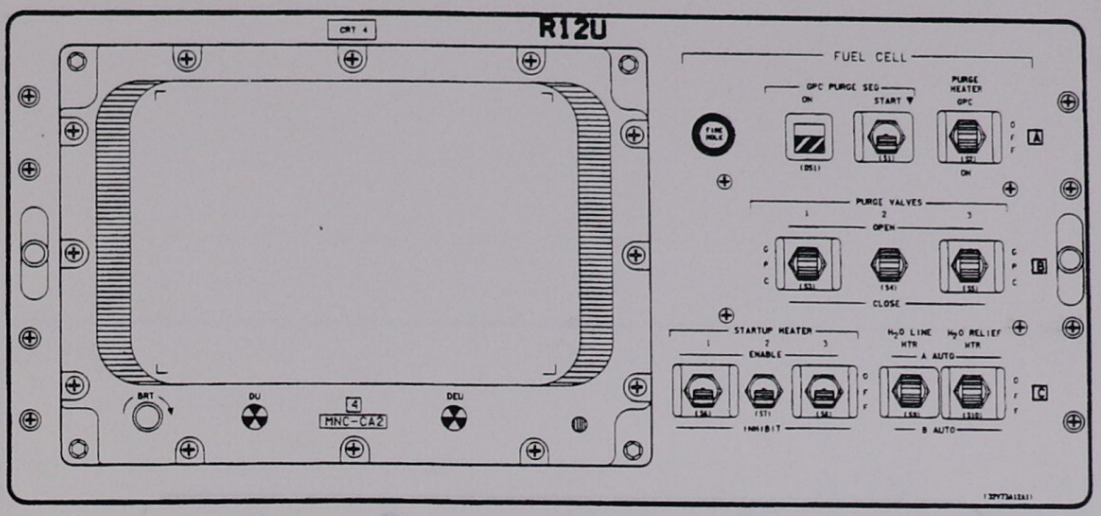
Panel R6


MISSION STATION AUDIO
POWER AUD/TONE
OFF
A/G
ICOM
1
2
A/A T/R
A
B
AUD RCV
OFF
VOLUME
VOX SENS
MIN
MAX
XMIT/ICOM MODE
PTT/VOX
PTT/PTT
PTT/HOT
VOX/VOX
MS LIGHTING
PANEL
OFF
BRT
FLOOD
ON
DIM
BIOMED
CHANNEL 1
CHANNEL 2
MID DECK
CTR
L
R
PS
MS
EVA 1
EVA 2
FIRE HOLE
PAGE
R10
ACTIVATION
R10 MS AUD PWR - AUD/TONE
ALL OTHER SWS - AS REQ'D
R12 MS AUD CONTL - NORM
ALL MS COMM CCU PWR - ON

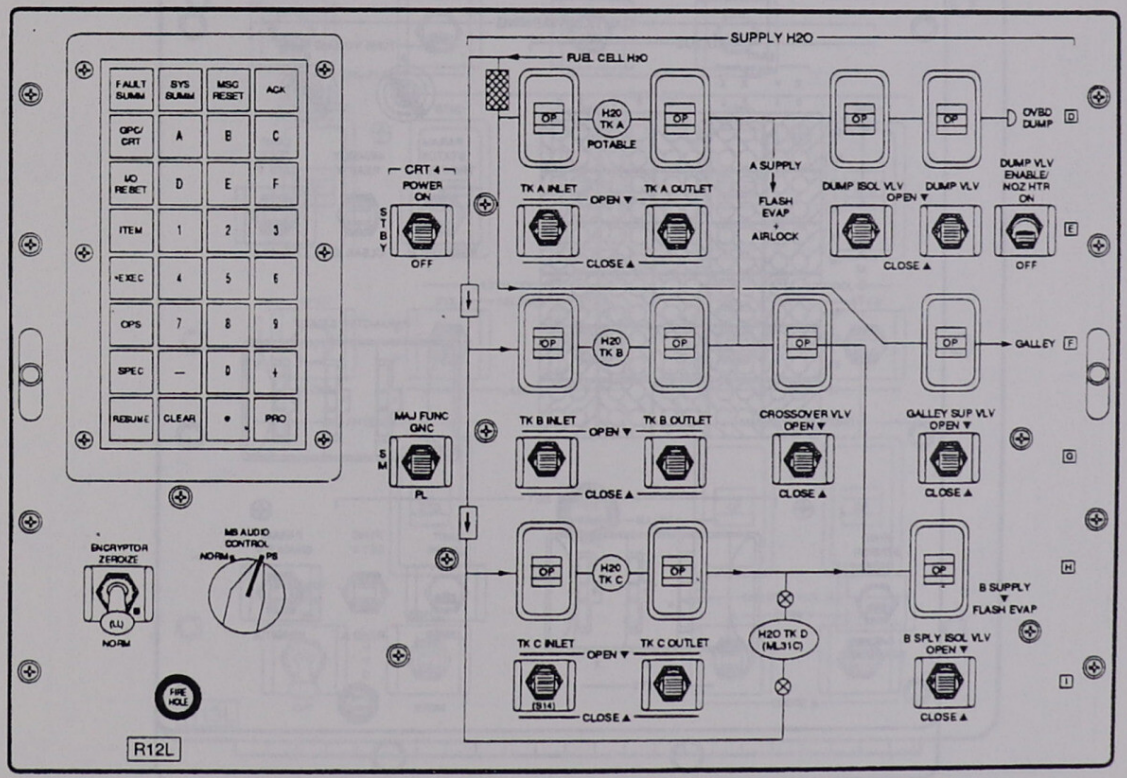
Panel R10



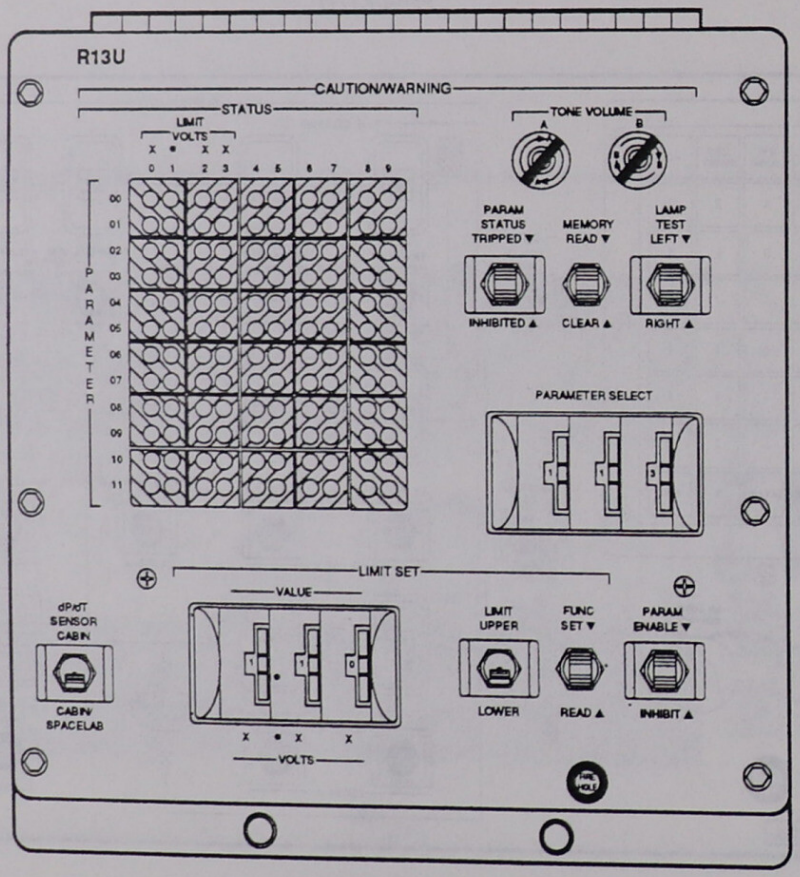
Panels R11U and R11L



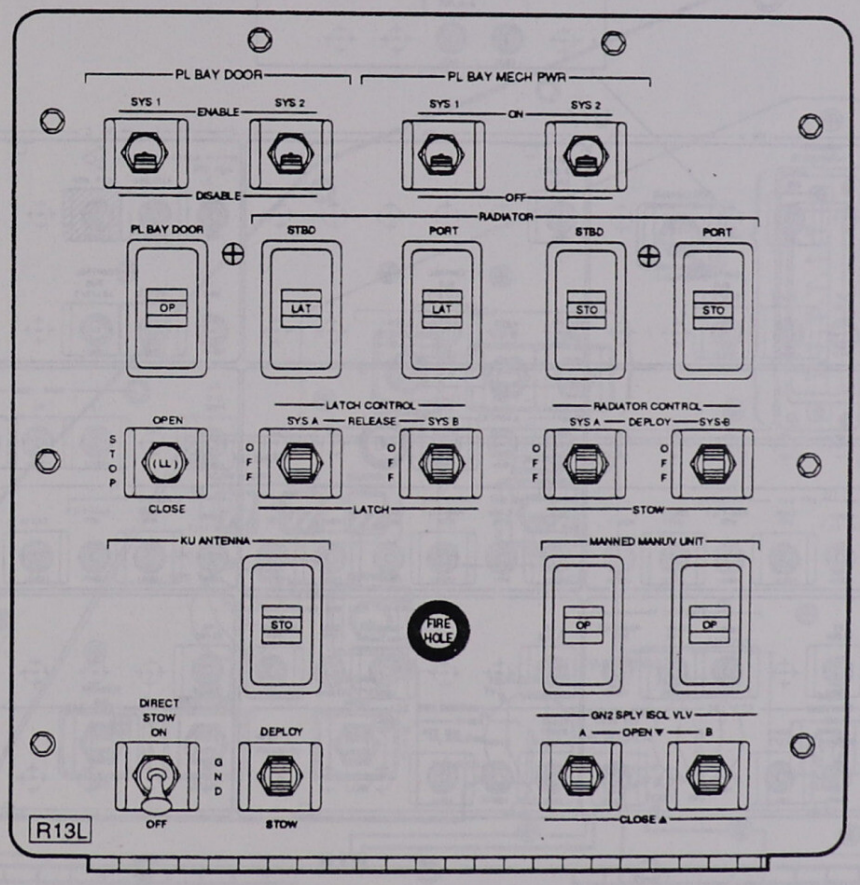
Panel R12U



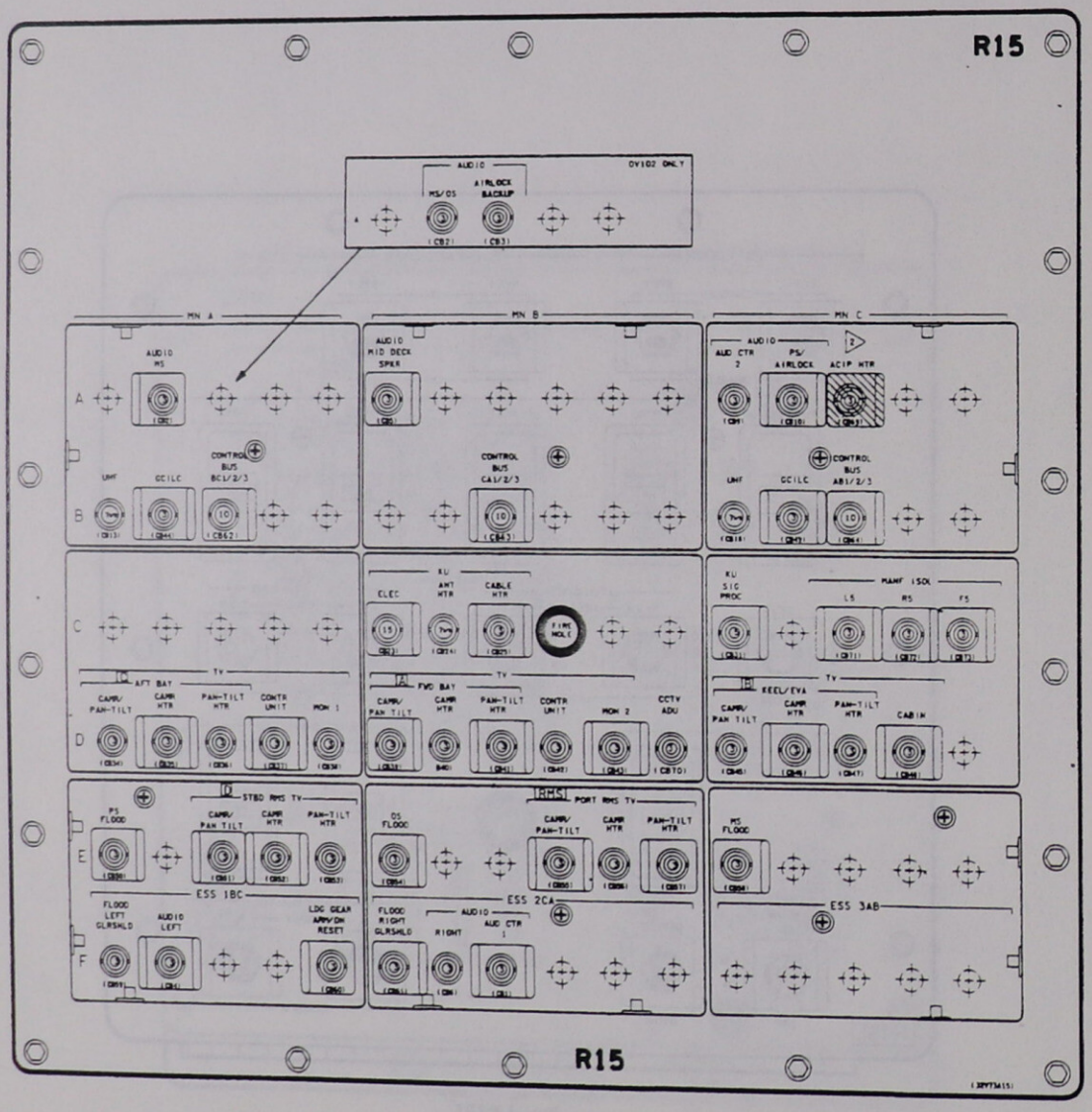
Panel R12L


R13U
CAUTION/WARNING
STATUS
LIMIT VOLTS
X • X X
0 1 2 3 4 5 6 7 8 9
PARAMETER
00
01
02
03
04
05
06
07
08
09
10
11
TONE VOLUME
A
B
PARAM STATUS TRIPPED ▼
MEMORY READ ▼
LAMP TEST LEFT ▼
INHIBITED ▲
CLEAR ▲
RIGHT ▲
PARAMETER SELECT
LIMIT SET
VALUE
dP/dT SENSOR CABIN
CABIN SPACELAB
LIMIT UPPER
FUNC SET ▼
PARAM ENABLE ▼
LOWER
READ ▲
INHIBIT ▲
X • X X
VOLTS

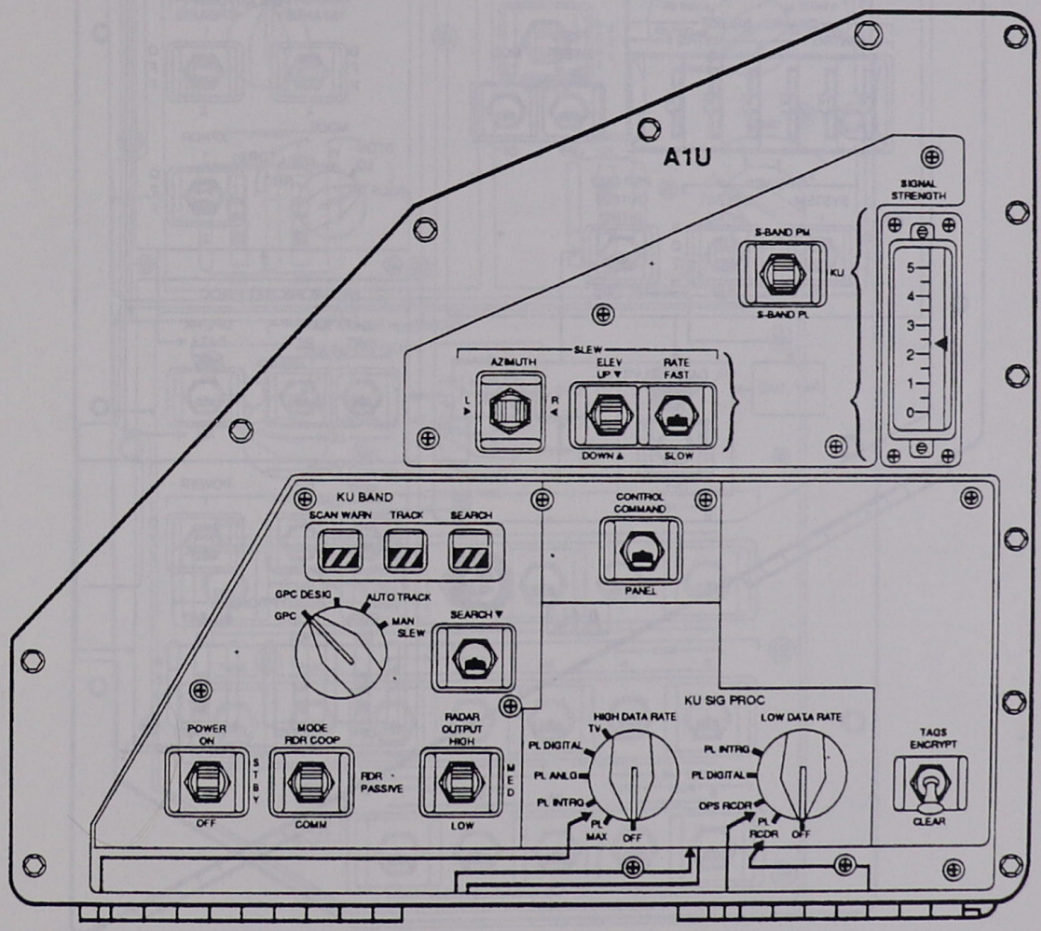
Panel R13U


PL BAY DOOR
PL BAY MECH PWR
SYS 1
ENABLE
SYS 2
DISABLE
SYS 1
ON
SYS 2
OFF
RADIATOR
PL BAY DOOR
OP
STBD
LAT
PORT
LAT
STBD
STO
PORT
STO
LATCH CONTROL
SYS A
RELEASE
SYS B
RADIATOR CONTROL
SYS A
DEPLOY
SYS B
OPEN
STOP
CLOSE
OFF
LATCH
STOW
KU ANTENNA
STO
FIRE HOLE
MANNED MANUV UNIT
OP
OP
DIRECT STOW
ON
OFF
GND
DEPLOY
STOW
GN2 SPLY ISOL VLV
A
OPEN
B
CLOSE
R13L

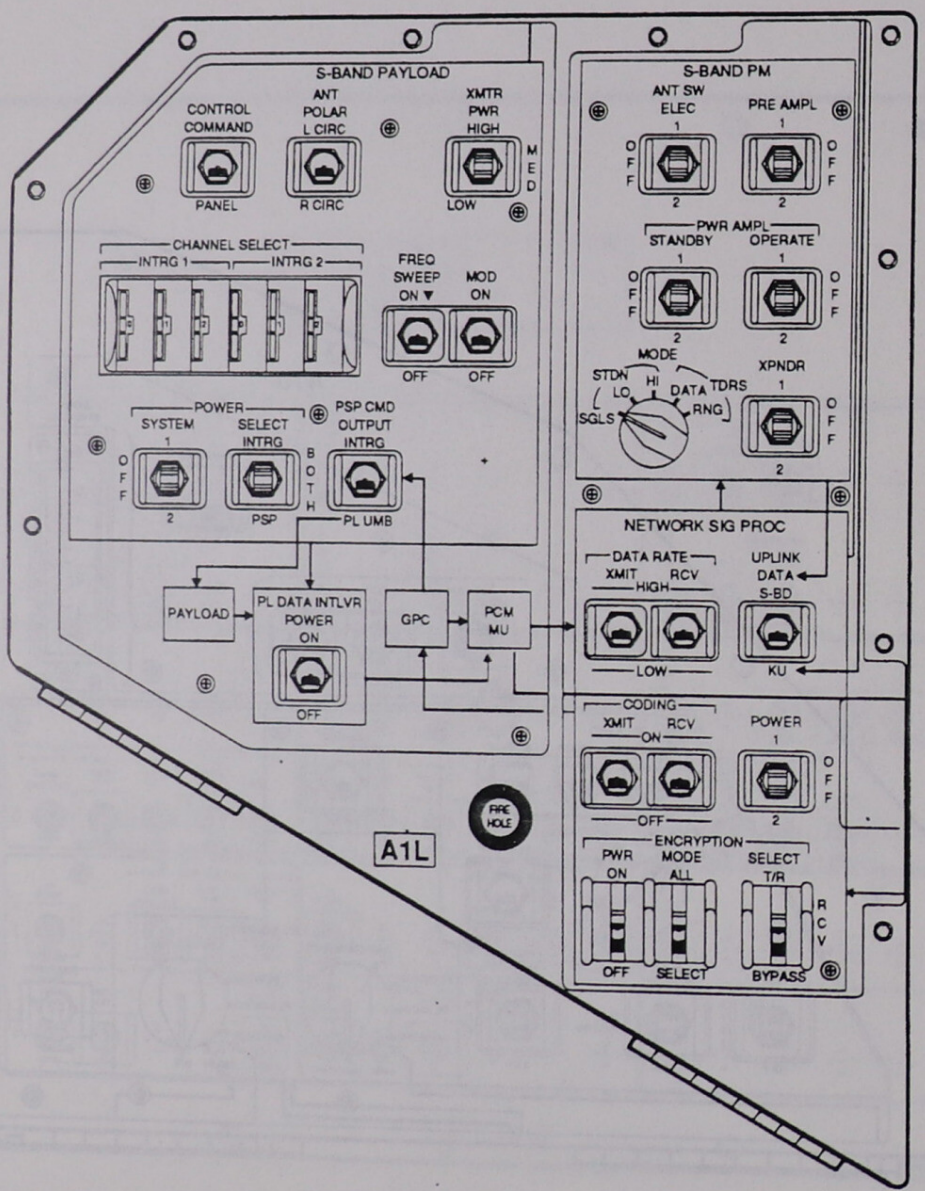
Panel R13L


R15
AUDIO
AIRLOCK BACKUP
MS/OS
OV102 ONLY
MN A
MN B
MN C
AUDIO
MS
AUDIO
MID DECK SPKR
AUDIO
AUD CTR 2
PS/ AIRLOCK
ACIP HTR
CONTROL BUS BC1/2/3
CONTROL BUS CA1/2/3
CONTROL BUS AB1/2/3
UHF
GCILC
KU ANT HTR
CABLE HTR
KU SIG PROC
MANF ISOL
LS
RS
FS
AFT BAY
FWD BAY
KEEL/EVA
CAMR/ PAN TILT
CAMR HTR
PAN-TILT HTR
CONTR UNIT
MON 1
MON 2
CCTV ADU
CABIN
STBD RMS TV
PORT RMS TV
PS FLOOD
OS FLOOD
MS FLOOD
ESS 1BC
ESS 2CA
ESS 3AB
FLOOD LEFT GLRSHLD
AUDIO LEFT
LDG GEAR ARM/DN RESET
FLOOD RIGHT GLRSHLD
AUDIO RIGHT
AUD CTR 1
R15

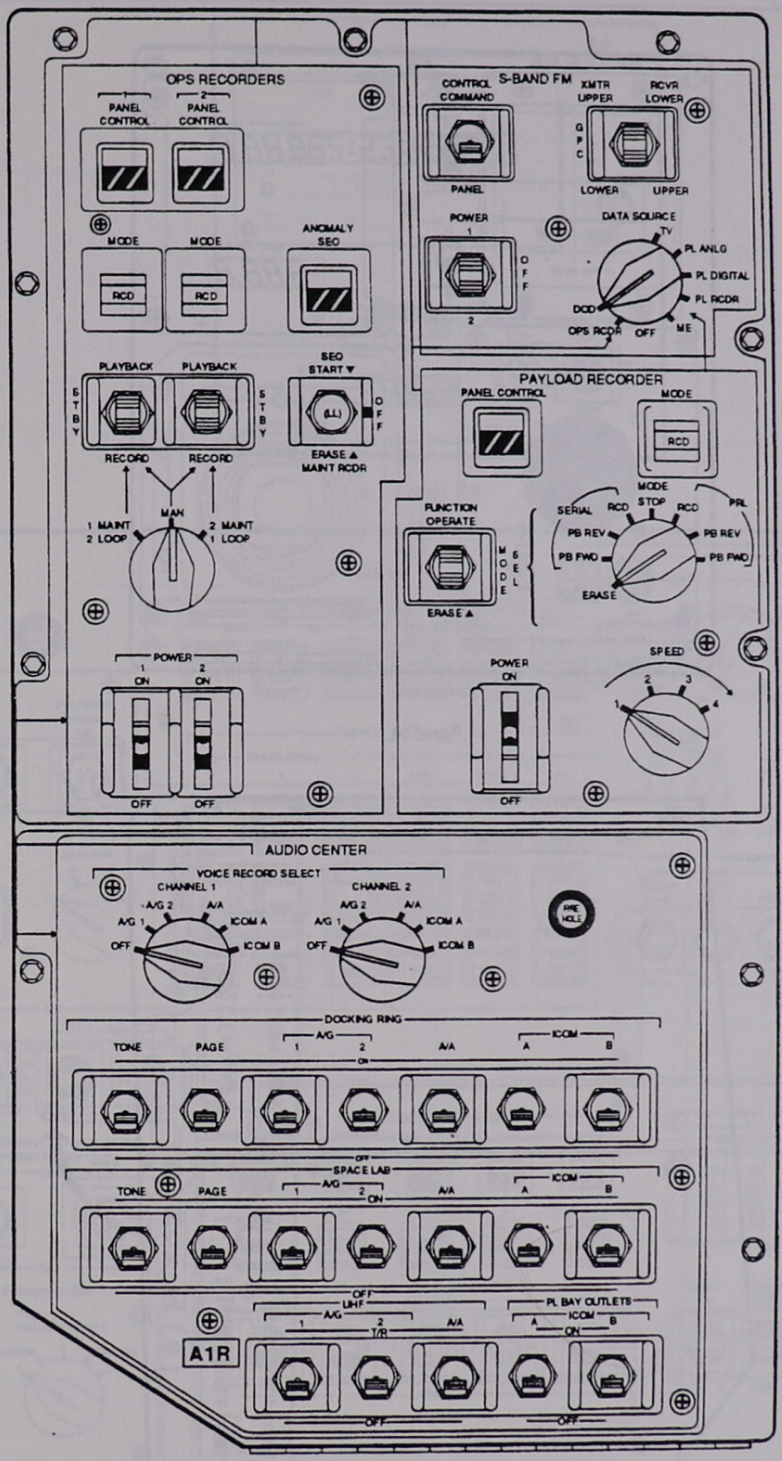
Panel R15


A1U
SIGNAL STRENGTH
S-BAND PM
KU
S-BAND PL
SLEW
AZIMUTH
ELEV
RATE
UP
FAST
DOWN
SLOW
KU BAND
SCAN WARN
TRACK
SEARCH
CONTROL COMMAND
PANEL
GPC DESIG
AUTO TRACK
GPC
MAN SLEW
SEARCH
KU SIG PROC
HIGH DATA RATE
LOW DATA RATE
TV
PL DIGITAL
PL ANLG
PL INTRG
PL MAX
OFF
OPS RCDR
PL RCDR
TAGS ENCRYPT
CLEAR
POWER ON
OFF
MODE RDR COOP
COMM
RDR PASSIVE
STBY
RADAR OUTPUT HIGH
LOW
MED

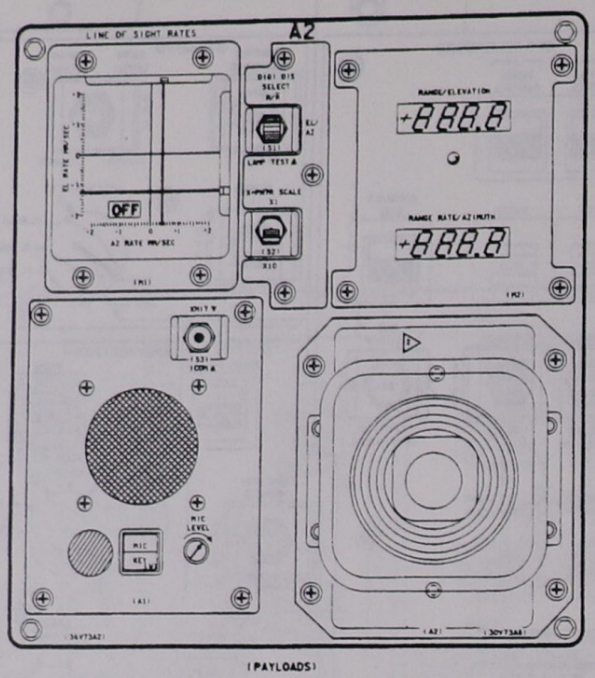
Panel A1U


S-BAND PAYLOAD
CONTROL COMMAND
PANEL
ANT POLAR L CIRC
R CIRC
XMTR PWR HIGH
LOW
MED
CHANNEL SELECT
INTRG 1
INTRG 2
FREQ SWEEP ON
MOD ON
OFF
OFF
POWER
SYSTEM SELECT INTRG
PSP CMD OUTPUT INTRG
OFF
BOTH
PSP
PL UMB
PAYLOAD
PL DATA INTLVR POWER ON
OFF
GPC
PCM MU
FIRE HOLE
A1L
S-BAND PM
ANT SW ELEC
PRE AMPL
PWR AMPL
STANDBY
OPERATE
MODE
STDN
LO
HI
DATA
TDRS
RNG
SGLS
XPNDR
NETWORK SIG PROC
DATA RATE
XMIT
RCV
HIGH
LOW
UPLINK DATA S-BD
KU
CODING
XMIT
RCV
ON
OFF
POWER
ENCRYPTION
PWR ON
MODE ALL
SELECT T/R
OFF
SELECT
BYPASS
RCV

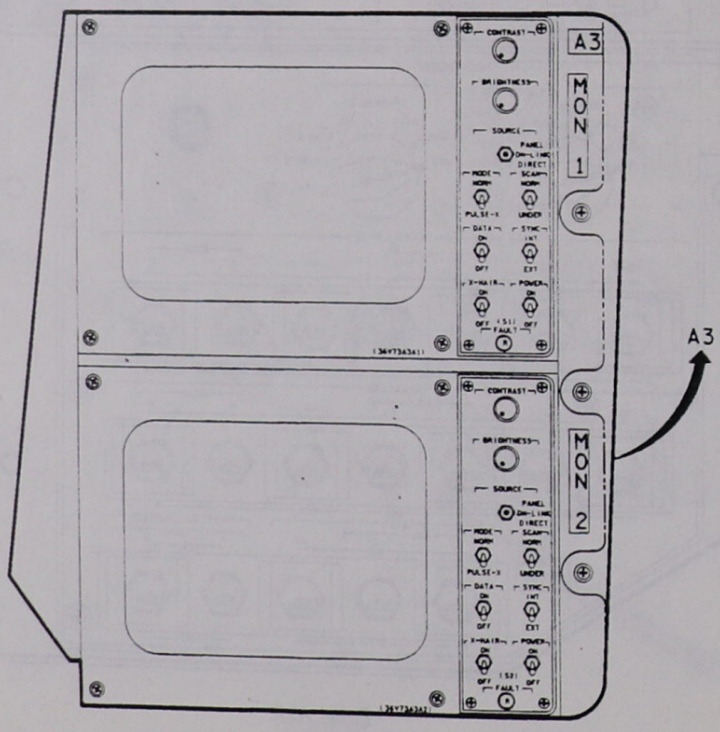
Panel A1L


OPS RECORDERS
PANEL CONTROL
MODE
RCD
ANOMALY SEQ
PLAYBACK
STBY
RECORD
ERASE
MAINT RCDR
MAN
1 MAINT 2 LOOP
2 MAINT 1 LOOP
POWER
ON
OFF
S-BAND FM
CONTROL COMMAND
PANEL
XMTR UPPER
RCVR LOWER
LOWER
UPPER
DATA SOURCE
TV
PL ANLG
PL DIGITAL
PL RCDR
DCD
OPS RCDR
ME
PAYLOAD RECORDER
FUNCTION OPERATE
ERASE
SERIAL
STOP
PB REV
PB FWD
PRL
SPEED
AUDIO CENTER
VOICE RECORD SELECT
CHANNEL 1
CHANNEL 2
A/G 1
A/G 2
A/A
ICOM A
ICOM B
DOCKING RING
TONE
PAGE
ICOM
SPACE LAB
UHF
T/R
PL BAY OUTLETS
A1R

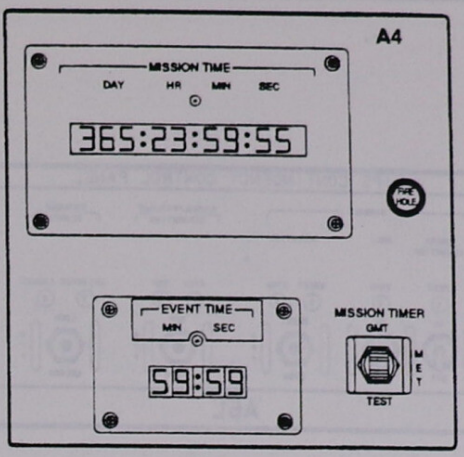
Panel A1R



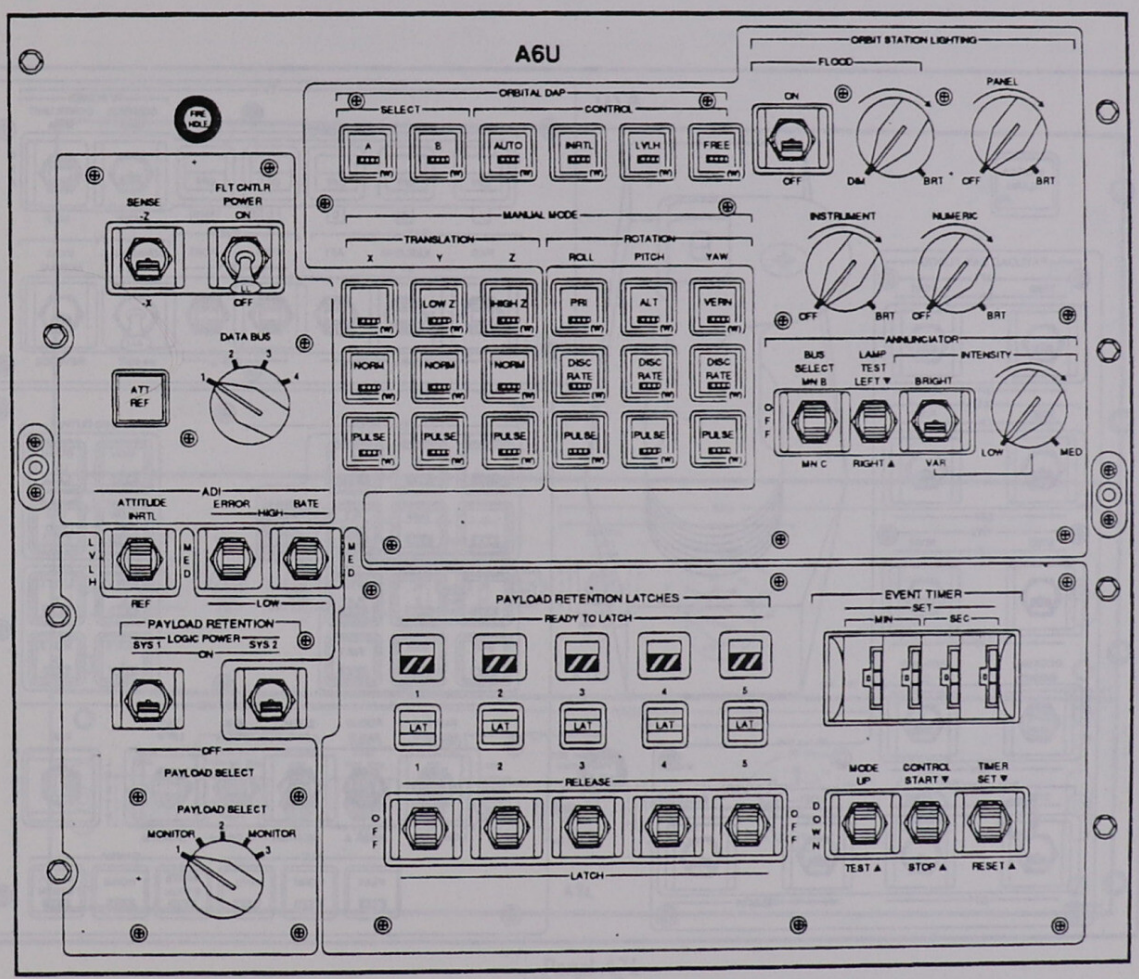
Panel A2



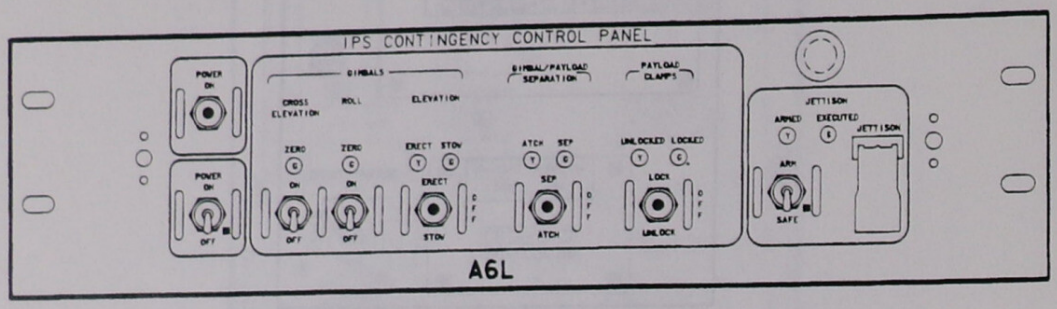
Panel A3



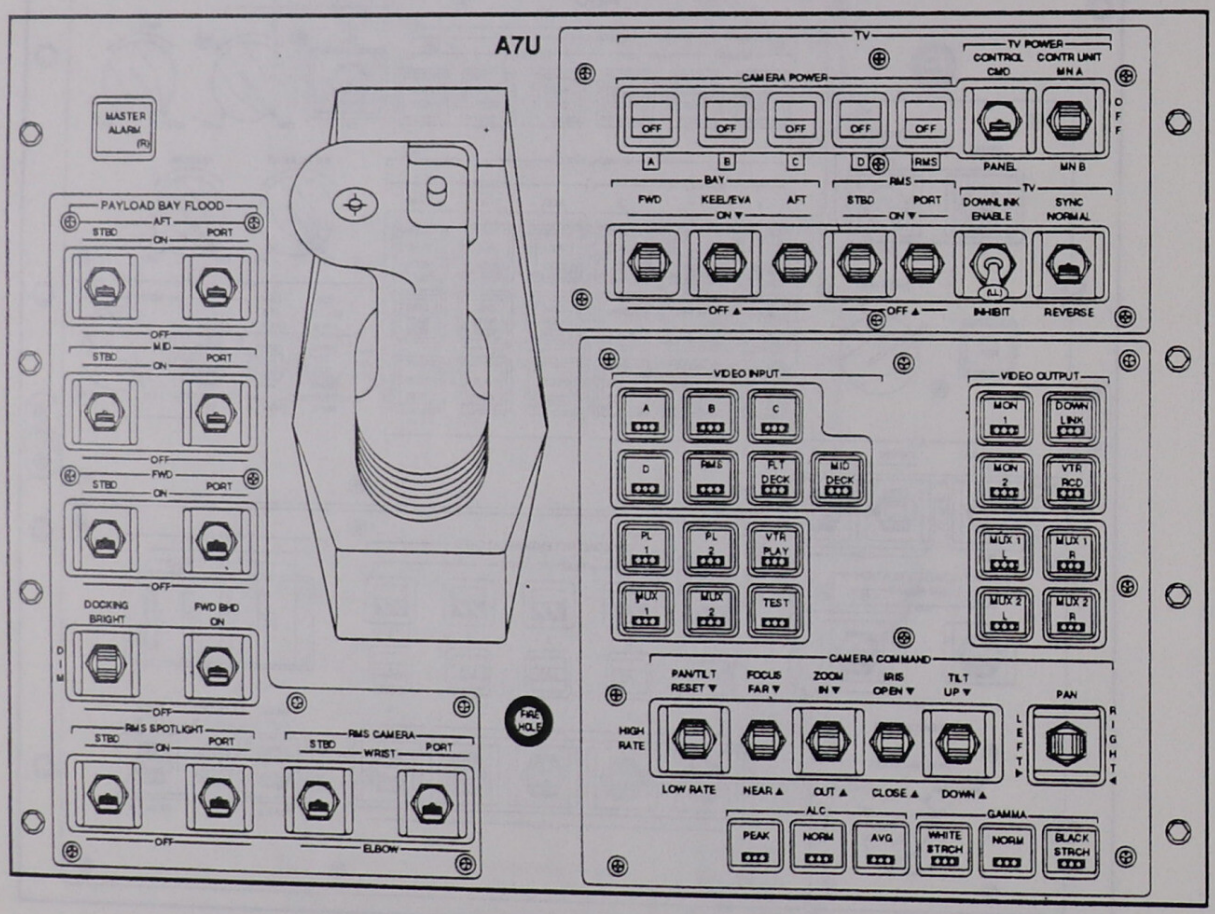
Panel A4



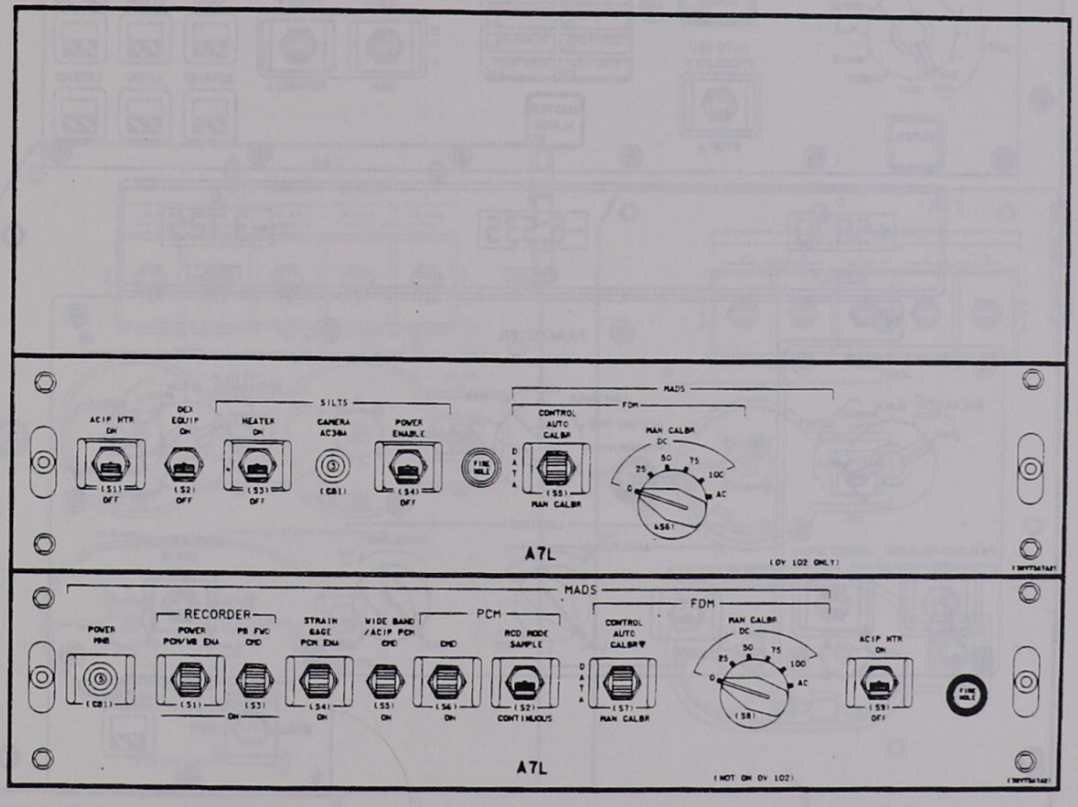
Panel A6U



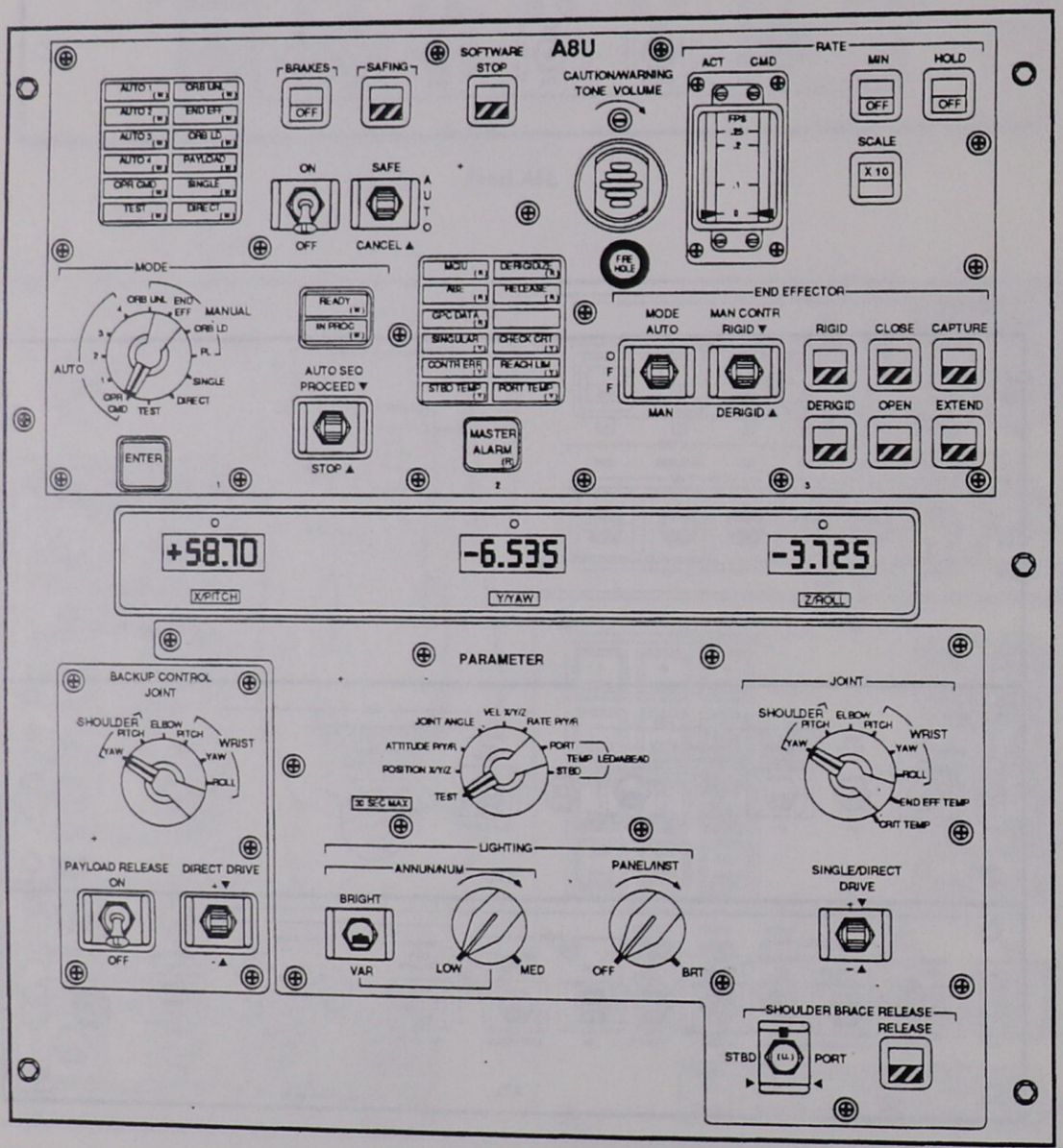
Panel A6L



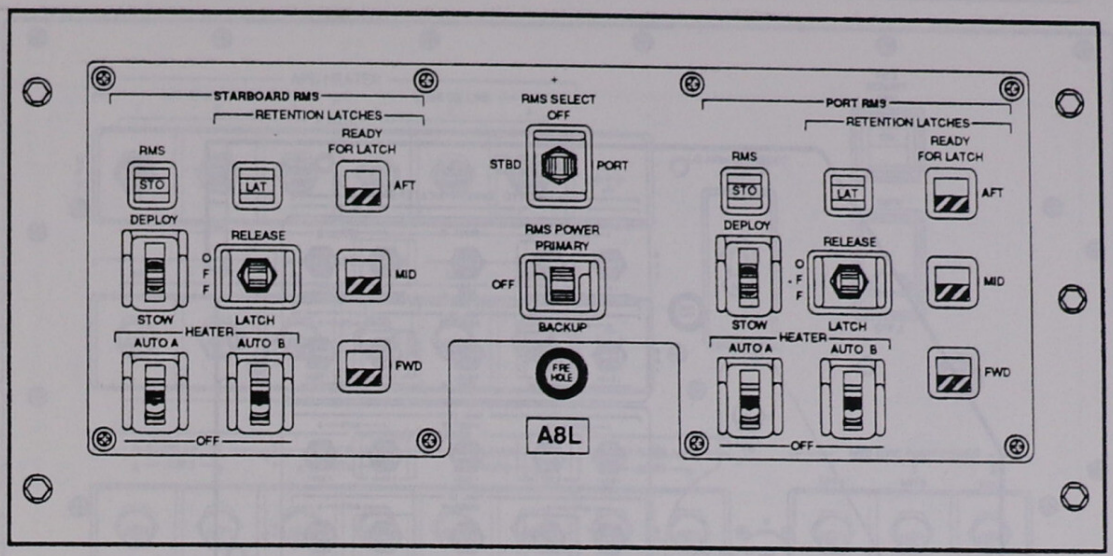
Panel A7U


SILTS
ACIP HTR
ON
(S1)
OFF
DCU
EQUIP
ON
(S2)
OFF
HEATER
ON
(S3)
OFF
CAMERA
AC30A
(CB1)
POWER
ENABLE
(S4)
OFF
FINE
WELT
MADS
FDM
CONTROL
AUTO
CALBR
DATA
(S5)
MAN CALBR
MAN CALBR
DC
25
50
75
100
0
AC
(S6)
A7L
(DV 102 ONLY)
MADS
RECORDER
POWER
MNB
(CB1)
POWER
PCM/WB ENA
(S1)
PB FWD
CMD
(S3)
ON
STRAIN
GAGE
PCM ENA
(S4)
ON
WIDE BAND
/ACIP PCM
CMD
(S5)
ON
PCM
CMD
(S6)
ON
RCD MODE
SAMPLE
(S2)
CONTINUOUS
FDM
CONTROL
AUTO
CALBR
DATA
(S7)
MAN CALBR
MAN CALBR
DC
25
50
75
100
0
AC
(S8)
ACIP HTR
ON
(S9)
OFF
FINE
WELT
A7L
(NOT ON DV 102)

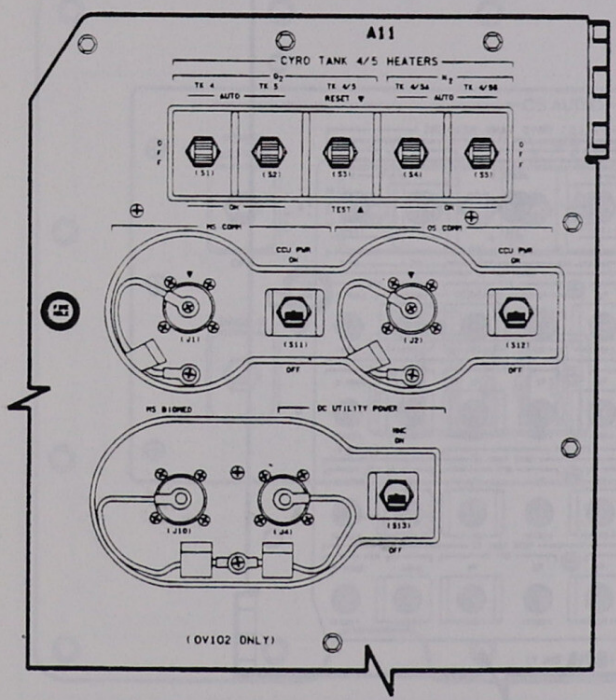
Panel A7L


A8U
SOFTWARE STOP
BRAKES
SAFING
OFF
ON
SAFE
CANCEL
AUTO
CAUTION/WARNING TONE VOLUME
RATE
ACT
CMD
MIN
HOLD
SCALE
X10
FIRE HOLD
MODE
MANUAL
AUTO
READY
IN PROC
AUTO SEQ PROCEED
STOP
ENTER
MASTER ALARM
END EFFECTOR
MODE AUTO
MAN CONTR RIGID
MAN
DERIGID
RIGID
CLOSE
CAPTURE
OPEN
EXTEND
+58.70
-6.535
-3.725
X/PITCH
Y/YAW
Z/ROLL
PARAMETER
BACKUP CONTROL JOINT
SHOULDER PITCH
ELBOW PITCH
WRIST YAW
WRIST ROLL
PAYLOAD RELEASE ON
DIRECT DRIVE
JOINT ANGLE
VEL X/Y/Z
RATE P/Y/R
ATTITUDE P/Y/R
POSITION X/Y/Z
PORT TEMP
STBD TEMP
LEDABEAD
TEST
30 SEC MAX
JOINT
END EFF TEMP
ORIT TEMP
LIGHTING
ANNUN/NUM
BRIGHT
VAR
LOW
MED
PANEL/INST
OFF
BRT
SINGLE/DIRECT DRIVE
SHOULDER BRACE RELEASE
RELEASE
STBD
PORT

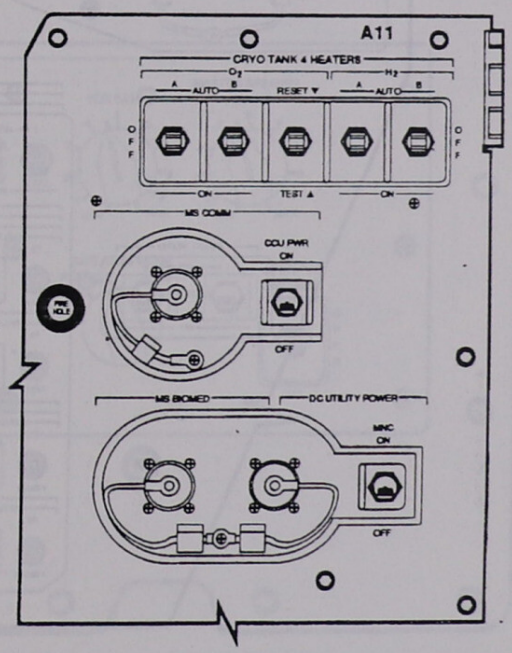
Panel A8U



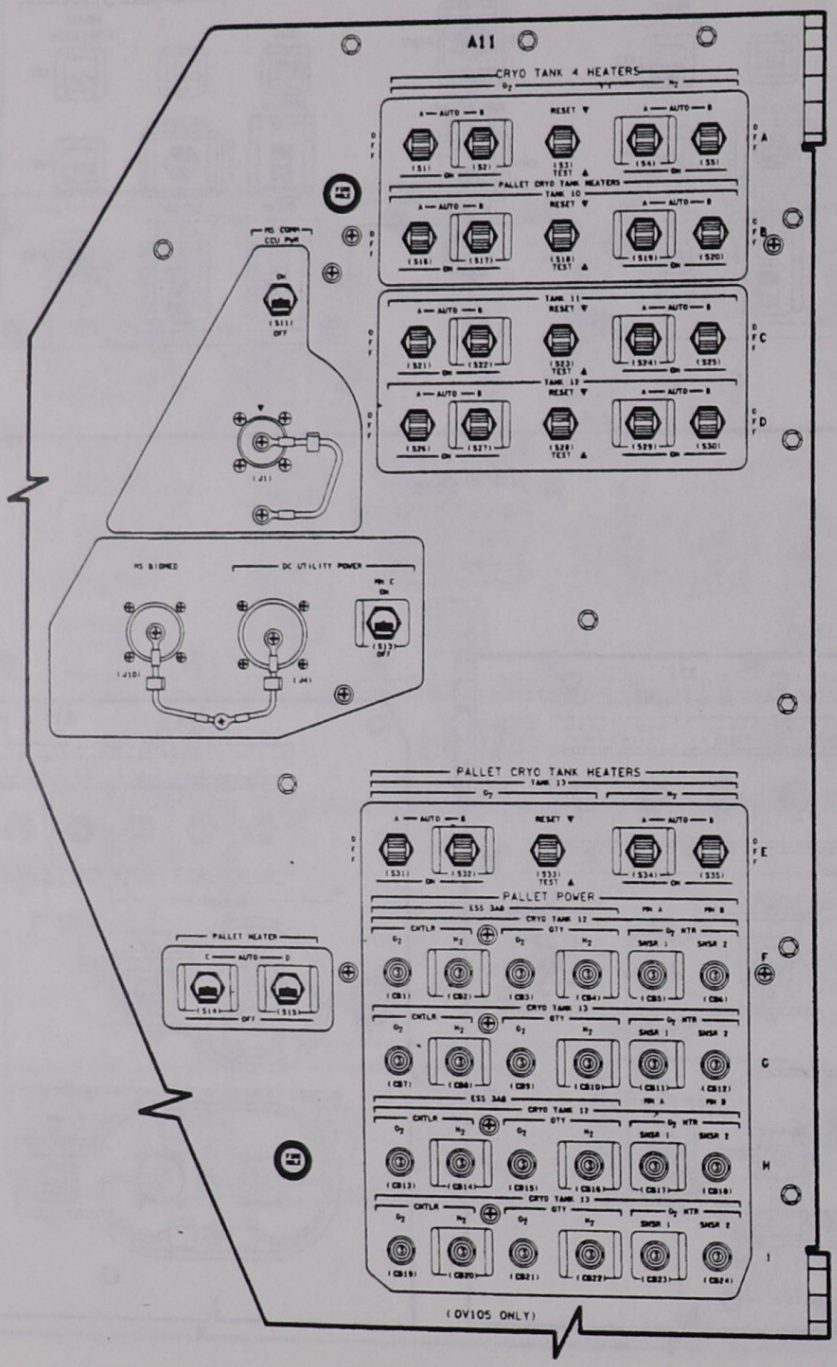
Panel A8L



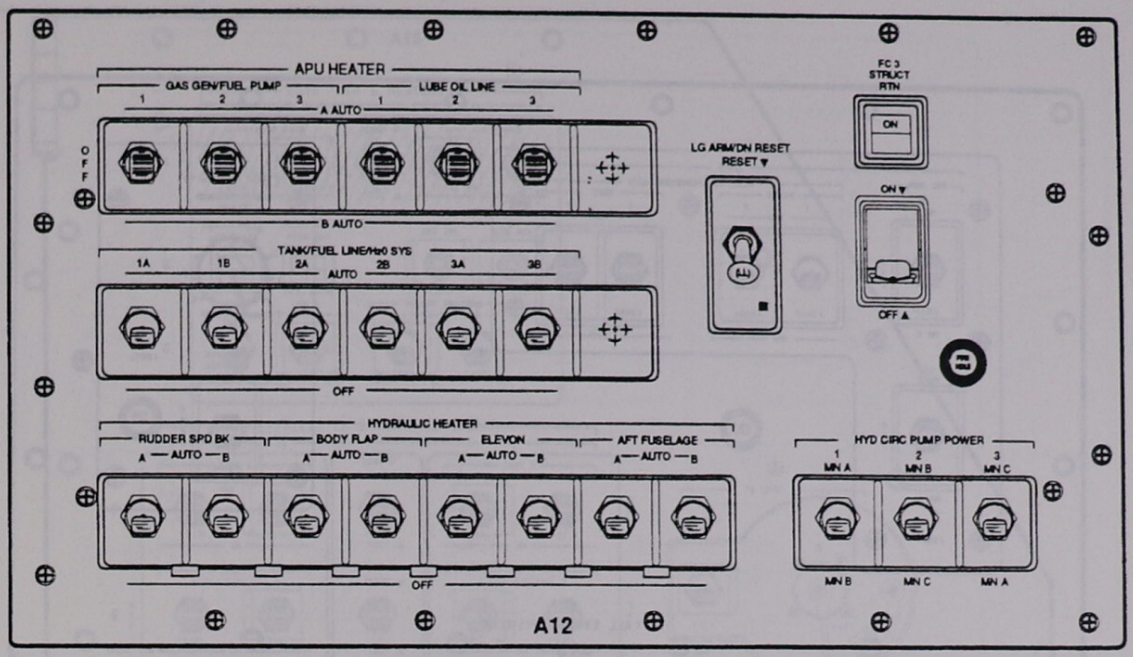
Panel A11 (OV102 only)



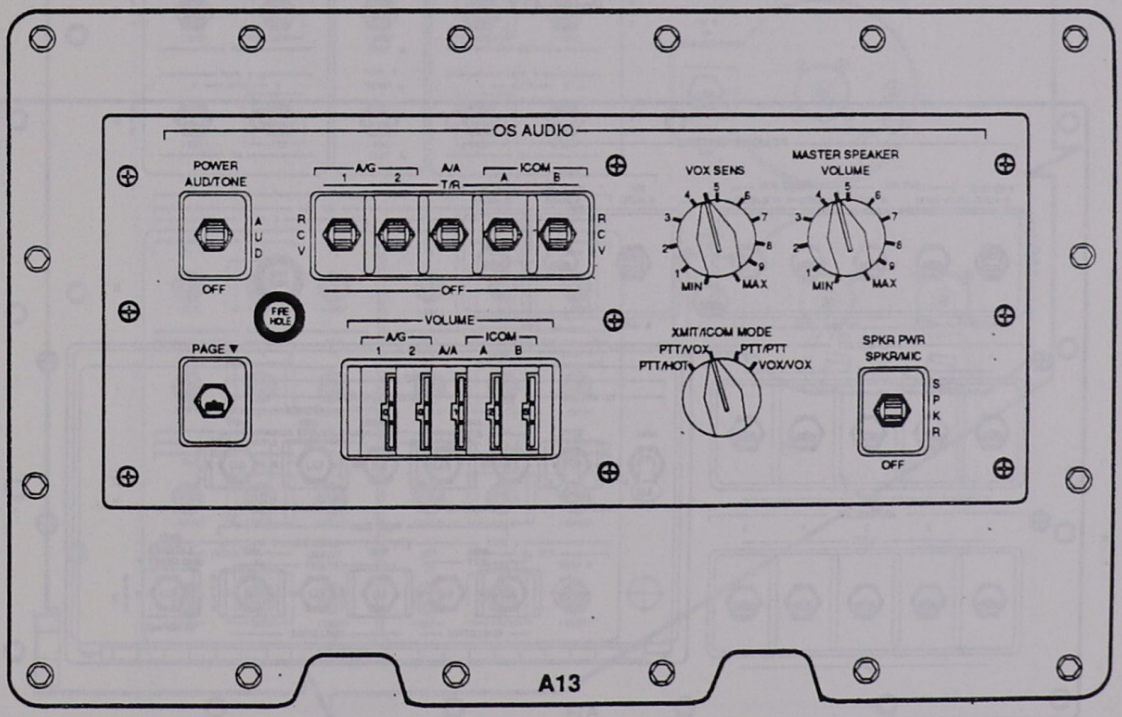
Panel A11 (OV103 and OV104 only)



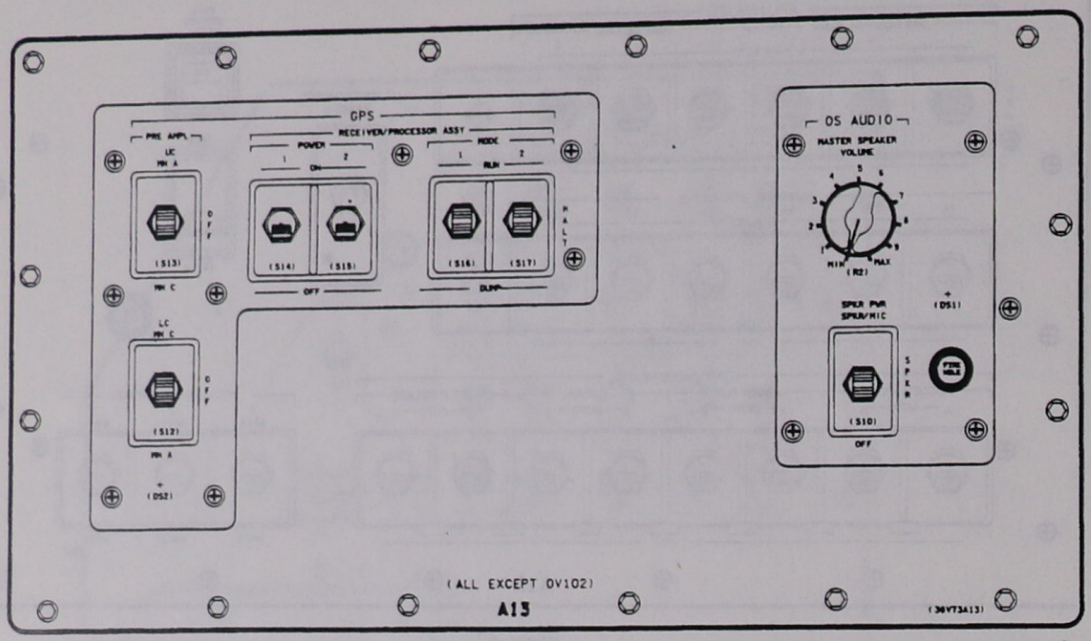
Panel A11 (OV105 only)



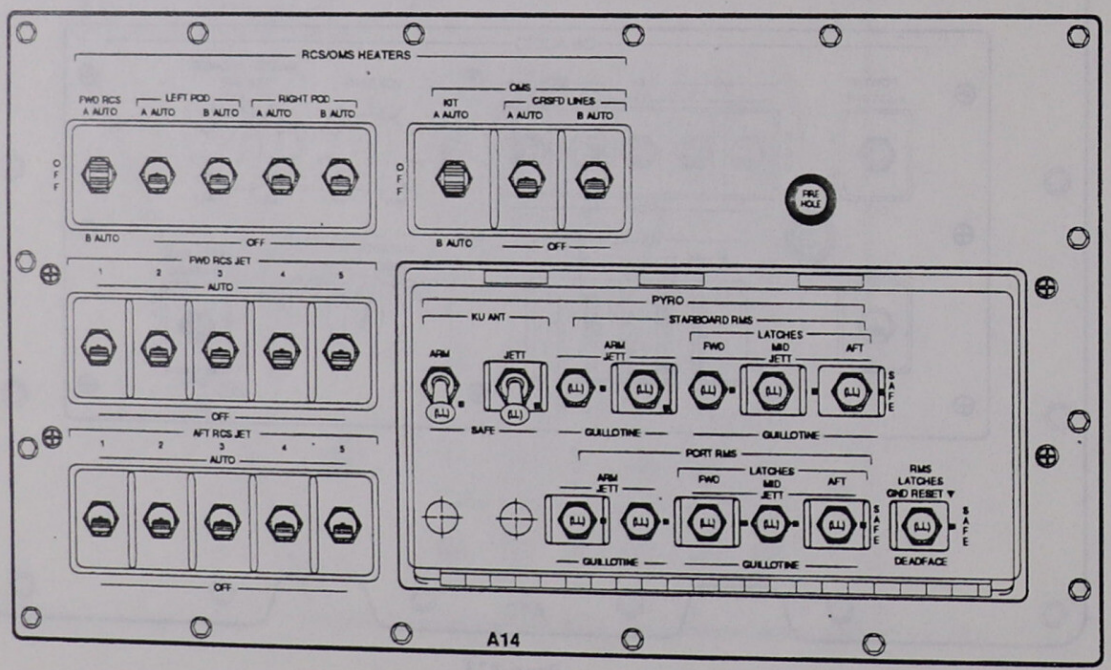
Panel A12



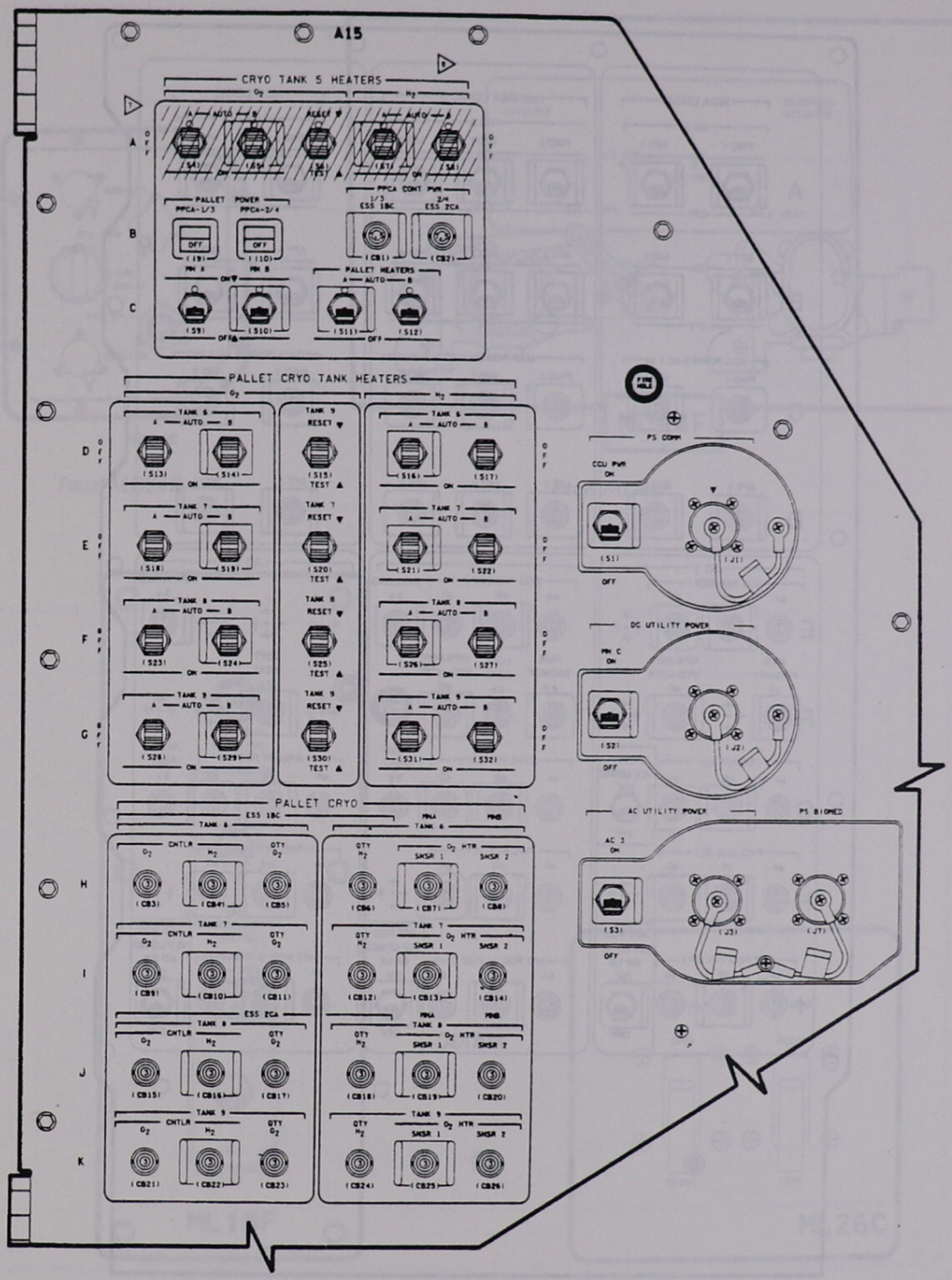
Panel A13



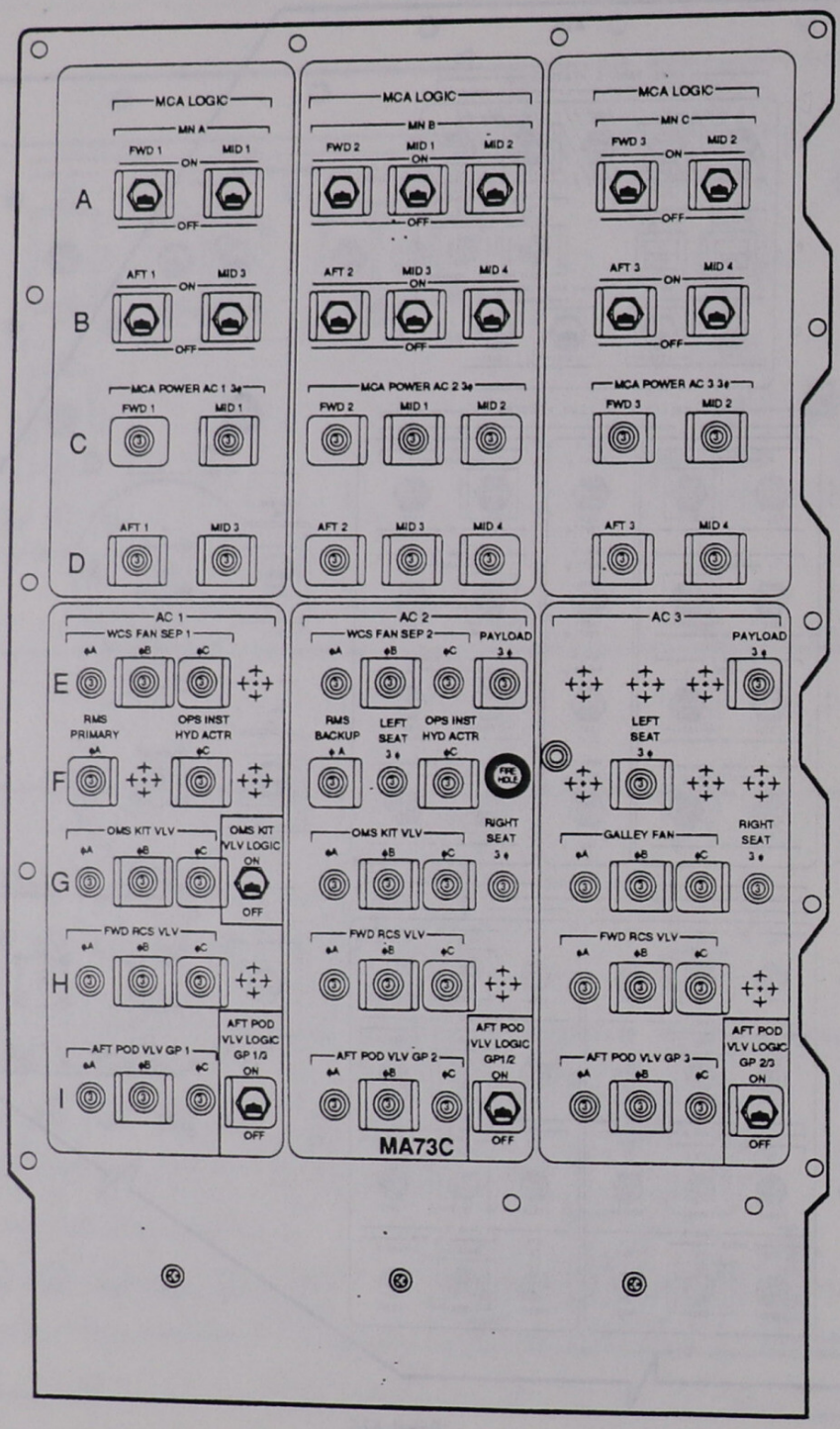
Panel A13



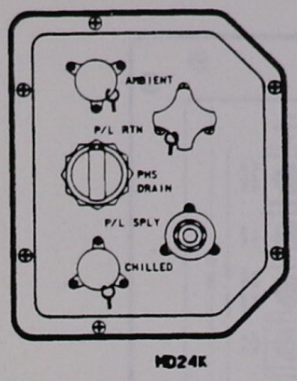
Panel A14


A15
CRYO TANK 5 HEATERS
PALLET CRYO TANK HEATERS
PALLET CRYO
PS COMM
DC UTILITY POWER
AC UTILITY POWER
PS BIOMED

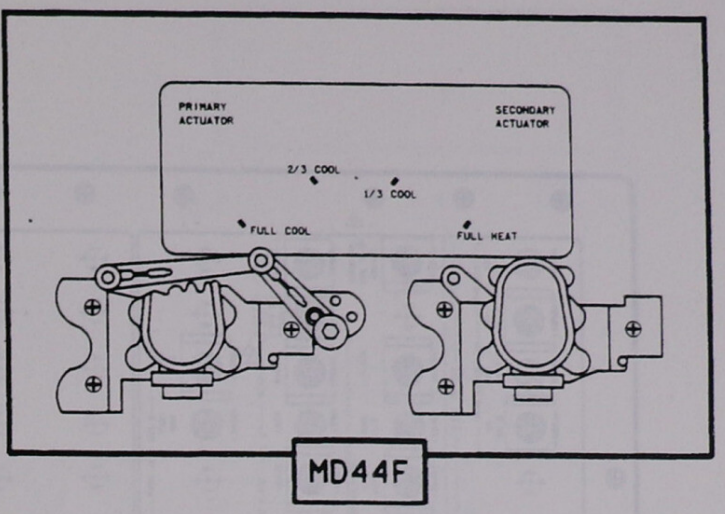
Panel A15


MCA LOGIC
MN A
FWD 1
MID 1
ON
OFF
A
AFT 1
MID 3
B
MCA POWER AC 1 3φ
C
D
MCA LOGIC
MN B
FWD 2
MID 1
MID 2
AFT 2
MID 3
MID 4
MCA POWER AC 2 3φ
MCA LOGIC
MN C
FWD 3
MID 2
AFT 3
MID 4
MCA POWER AC 3 3φ
AC 1
WCS FAN SEP 1
φA
φB
φC
E
RMS PRIMARY
OPS INST HYD ACTR
F
OMS KIT VLV
OMS KIT VLV LOGIC
G
FWD RCS VLV
H
AFT POD VLV GP 1
AFT POD VLV LOGIC GP 1/3
I
AC 2
WCS FAN SEP 2
PAYLOAD
3φ
RMS BACKUP
LEFT SEAT
RIGHT SEAT
FIRE WALL
AFT POD VLV GP 2
AFT POD VLV LOGIC GP1/2
MA73C
AC 3
GALLEY FAN
AFT POD VLV GP 3
AFT POD VLV LOGIC GP 2/3

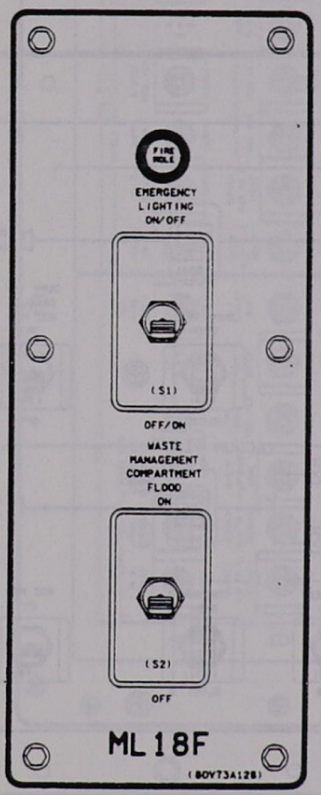
Panel MA73C



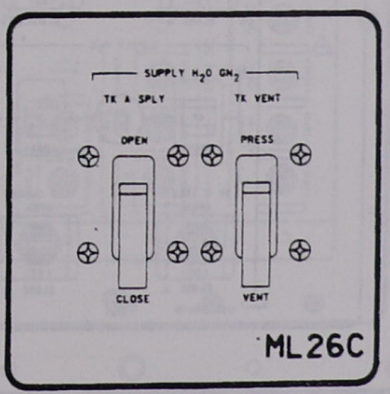
Panel MD24K



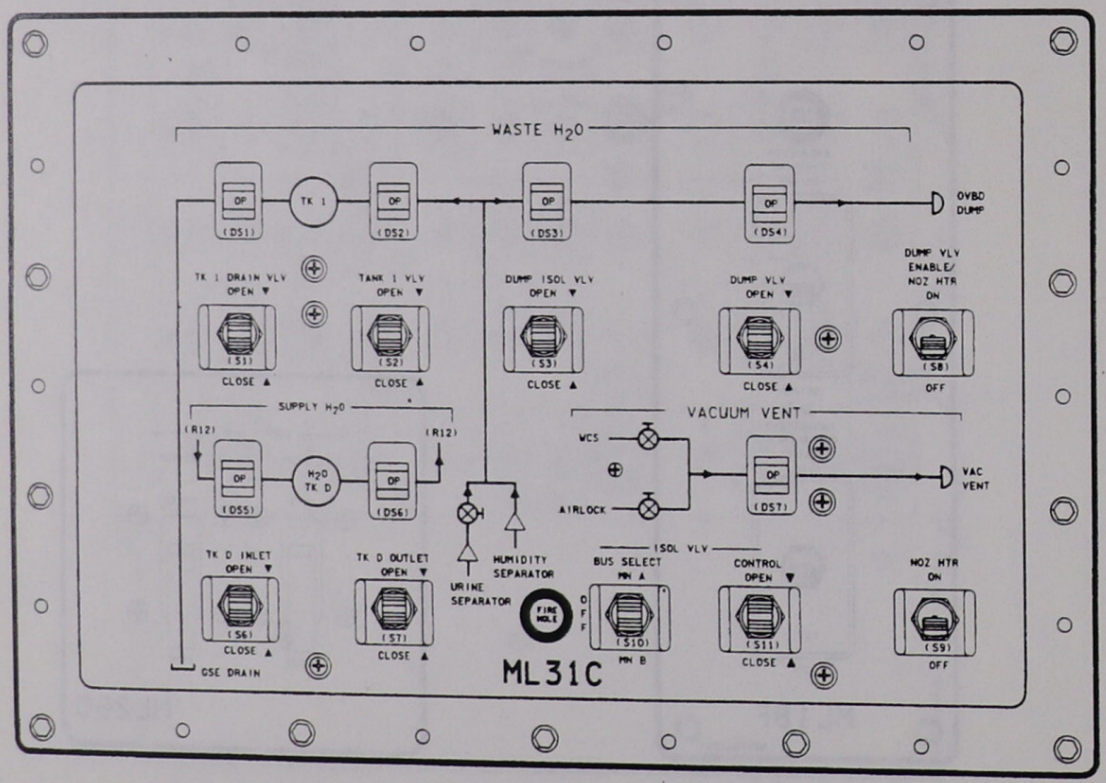
Panel MD44F



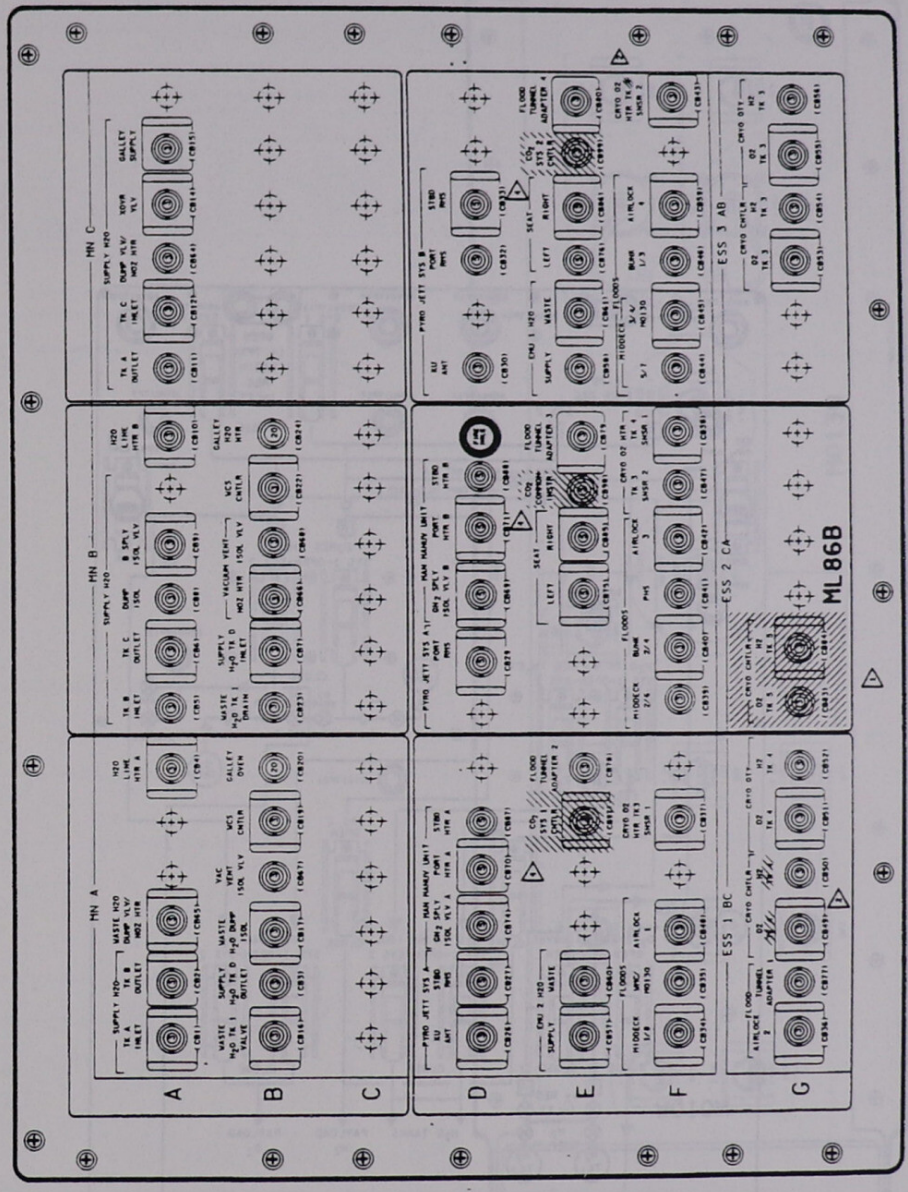
Panel ML18F



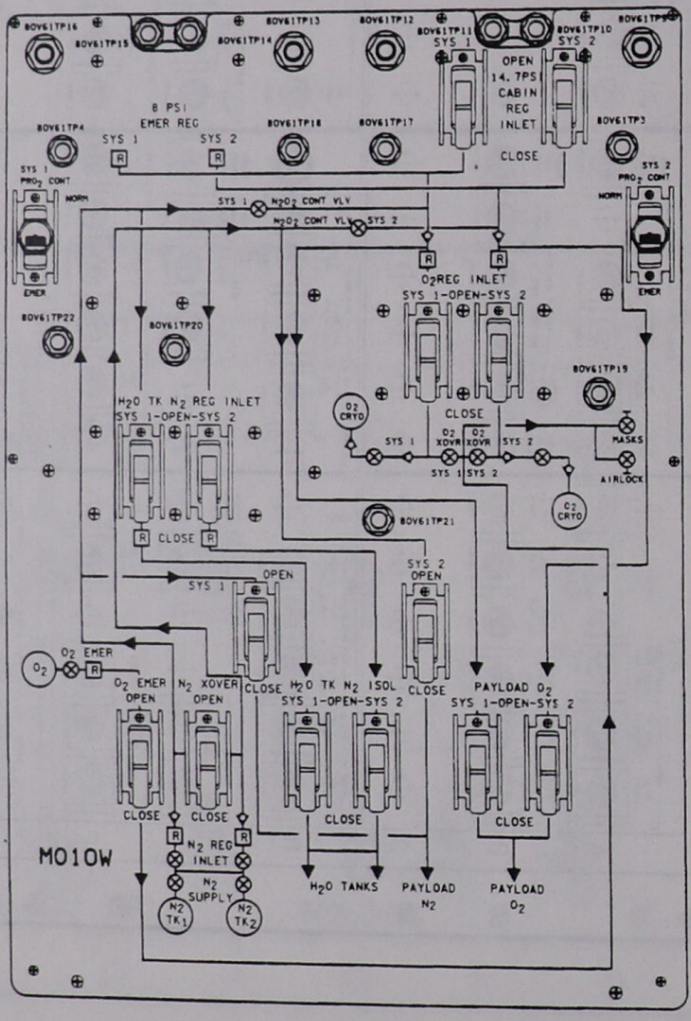
Panel ML26C


WASTE H2O
OP
(DS1)
TK 1
(DS2)
(DS3)
(DS4)
OVBD DUMP
TK 1 DRAIN VLV OPEN
TANK 1 VLV OPEN
DUMP ISOL VLV OPEN
DUMP VLV OPEN
DUMP VLV ENABLE/ NOZ HTR ON
(S1)
(S2)
(S3)
(S4)
(S8)
CLOSE
OFF
SUPPLY H2O
(R12)
H2O TK D
(DS5)
(DS6)
(DS7)
VACUUM VENT
WCS
AIRLOCK
VAC VENT
ISOL VLV
TK D INLET OPEN
TK D OUTLET OPEN
URINE SEPARATOR
HUMIDITY SEPARATOR
BUS SELECT
CONTROL OPEN
NOZ HTR ON
(S6)
(S7)
(S10)
(S11)
(S9)
FIRE MOLE
OFF
MN A
MN B
GSE DRAIN
ML31C

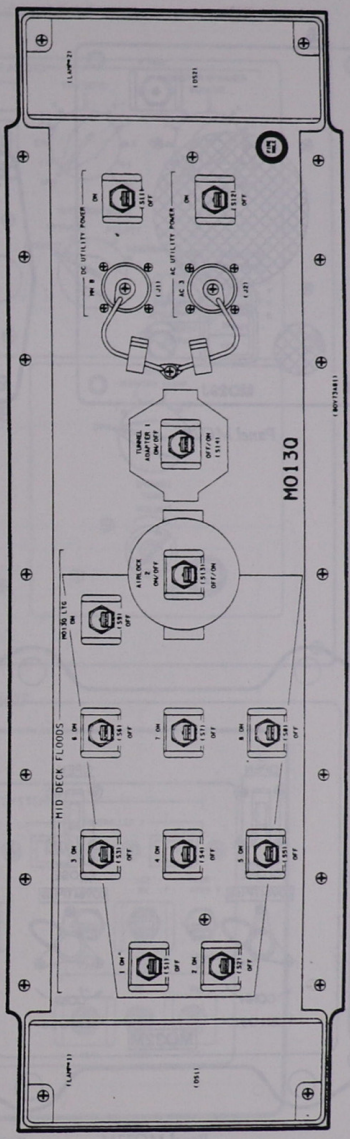
Panel ML31C



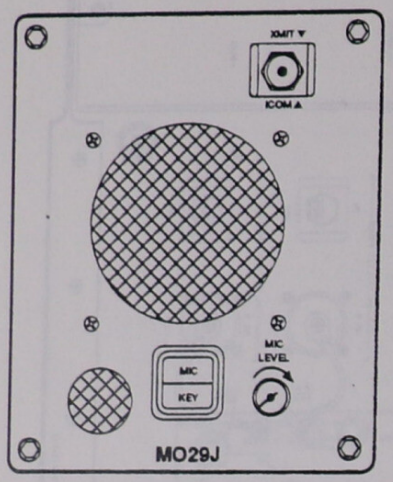
Panel ML86B


8 PSI
EMER REG
SYS 1
SYS 2
OPEN
14.7PSI
CABIN
REG
INLET
CLOSE
SYS 1
PRO2 CONT
NORM
EMER
SYS 2
PRO2 CONT
NORM
EMER
SYS 1 N2O2 CONT VLV
N2O2 CONT VLV SYS 2
O2 REG INLET
SYS 1-OPEN-SYS 2
H2O TK N2 REG INLET
SYS 1-OPEN-SYS 2
CLOSE
O2 CRYO
SYS 1
O2 XOVR
O2 XOVR
SYS 2
MASKS
AIRLOCK
SYS 1 SYS 2
O2 CRYO
CLOSE
OPEN
SYS 2
OPEN
O2 EMER
O2
O2 EMER
OPEN
N2 XOVER
OPEN
CLOSE
H2O TK N2 ISOL
SYS 1-OPEN-SYS 2
CLOSE
PAYLOAD O2
SYS 1-OPEN-SYS 2
CLOSE
CLOSE
CLOSE
CLOSE
N2 REG
INLET
N2
SUPPLY
N2
TK1
N2
TK2
MO10W
H2O TANKS
PAYLOAD
N2
PAYLOAD
O2

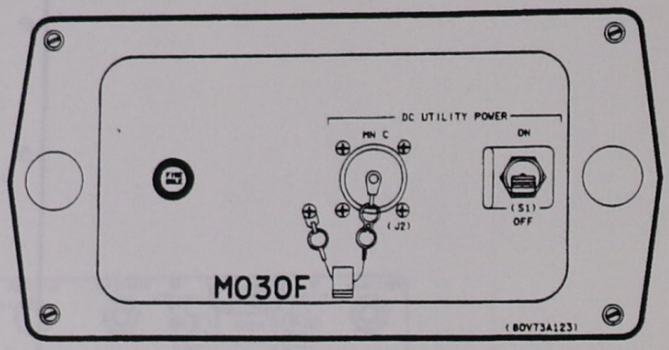
Panel MO10W


M0130
MID DECK FLOODS
AIRLOCK 2 ON/OFF
TUNNEL ADAPTER 1 ON/OFF
DC UTILITY POWER
AC UTILITY POWER

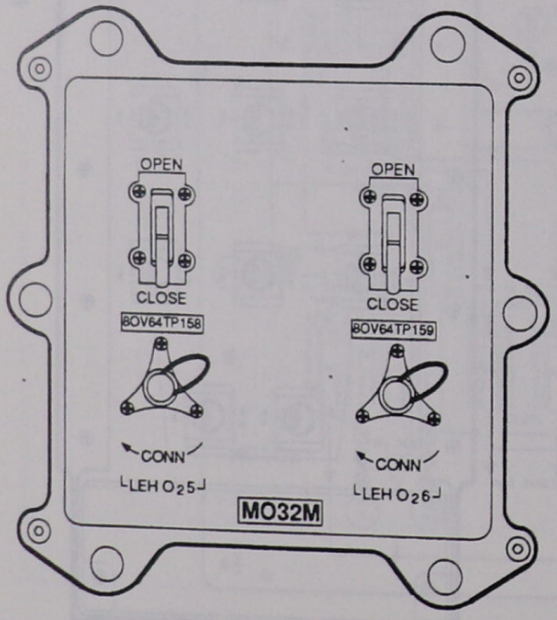
Panel M013Q



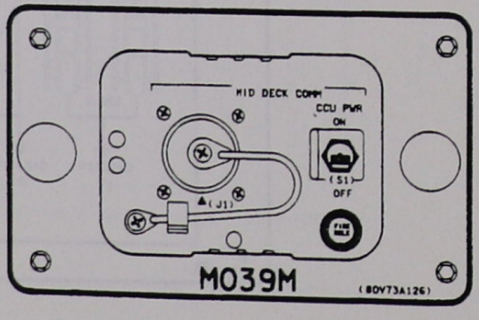
Panel MO29J



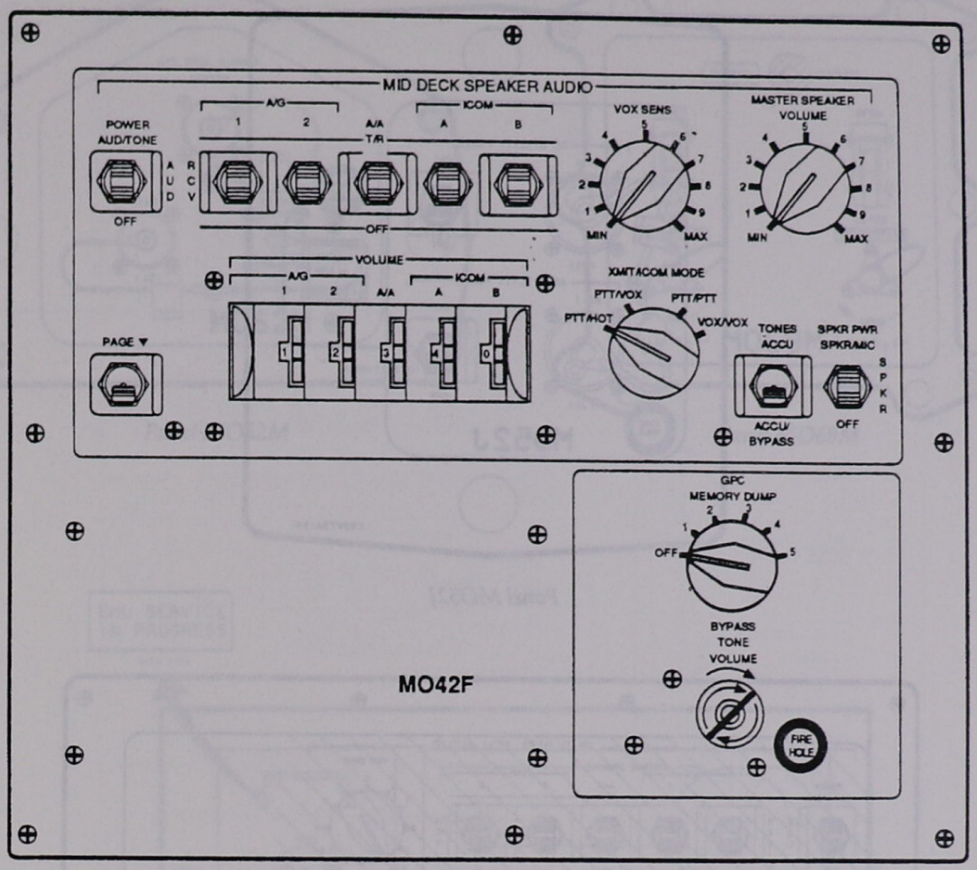
Panel MO30F



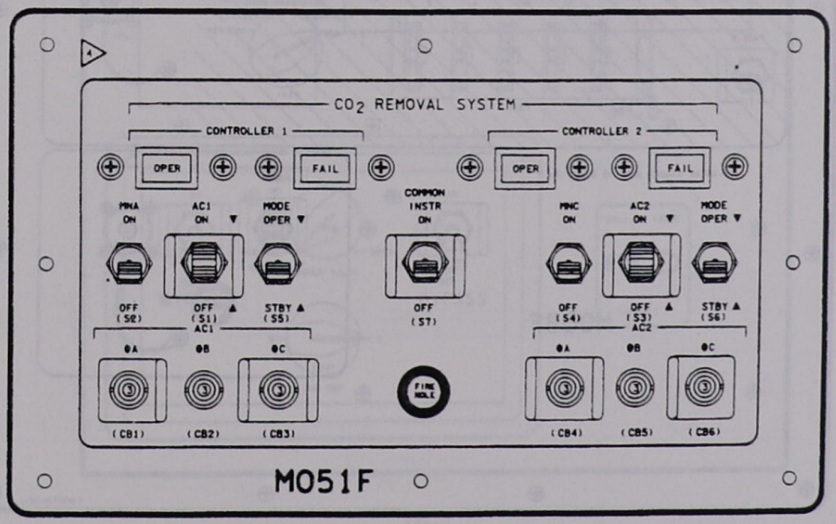
Panel MO32M



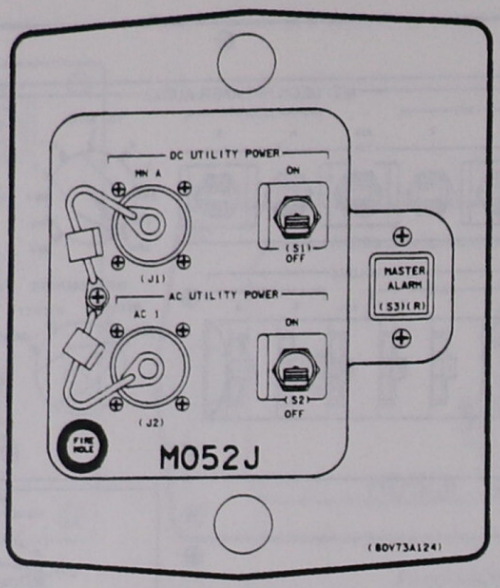
Panel MO39M



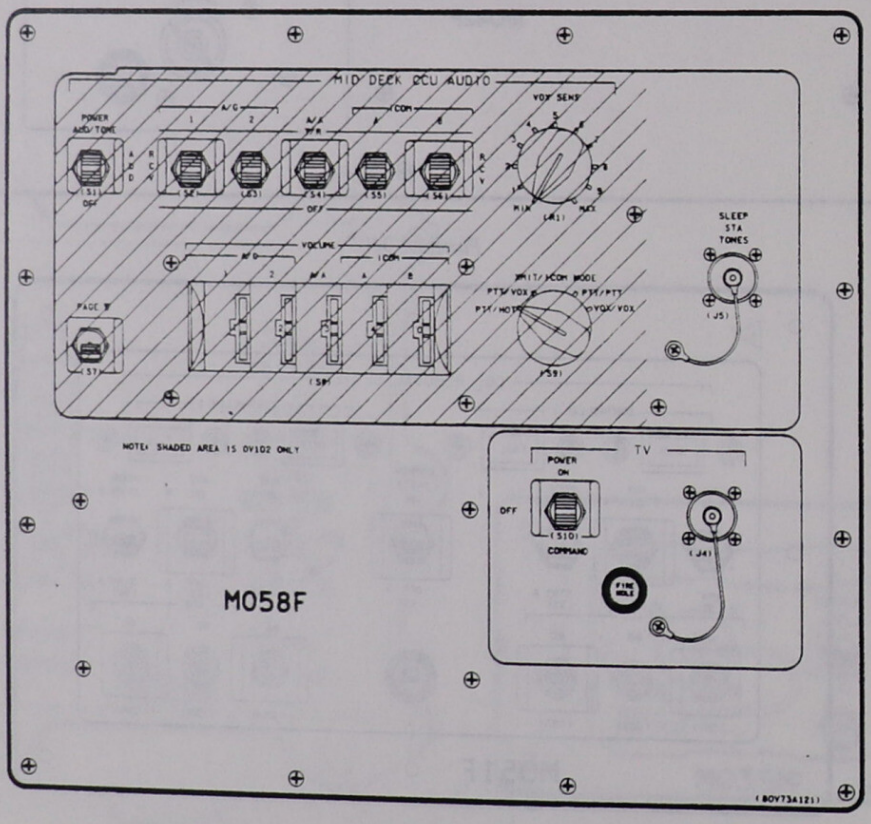
Panel MO42F



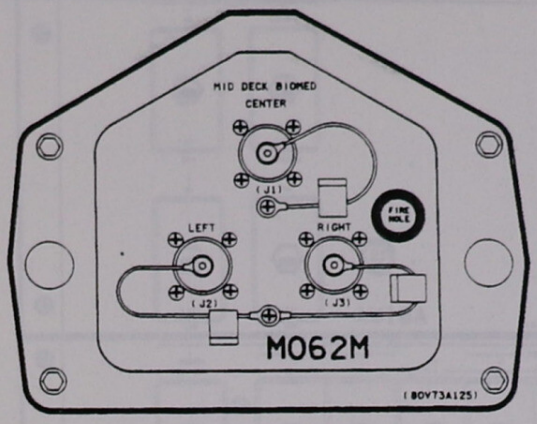
Panel MO51F



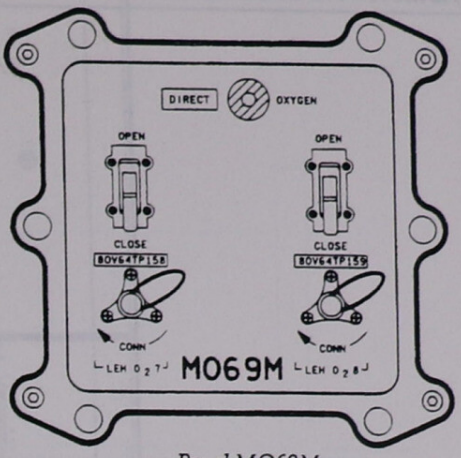
Panel MO52J



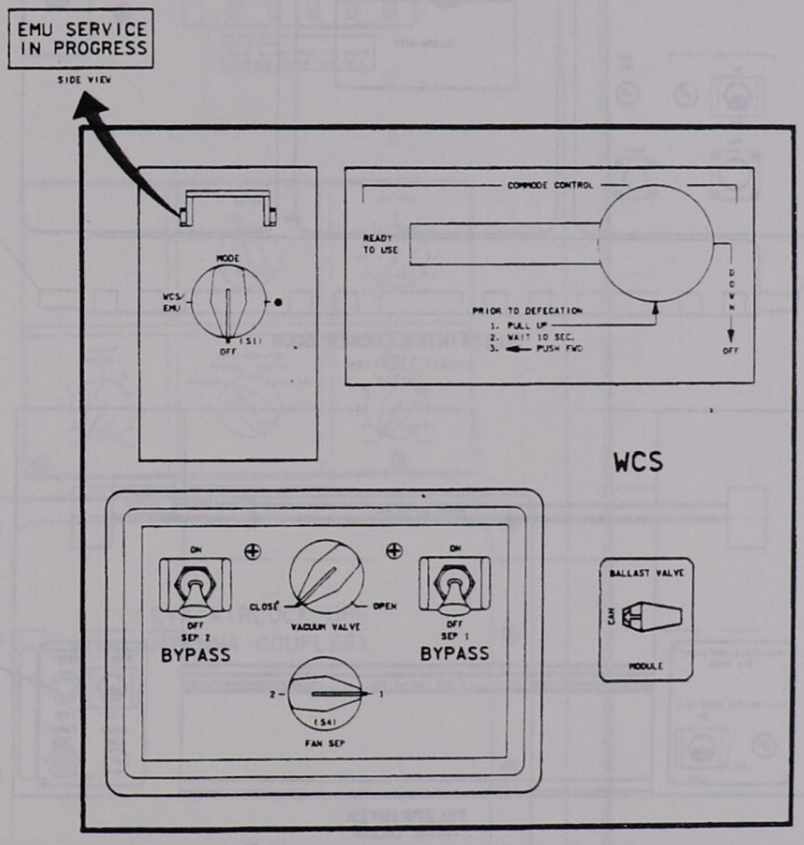
Panel MO58F



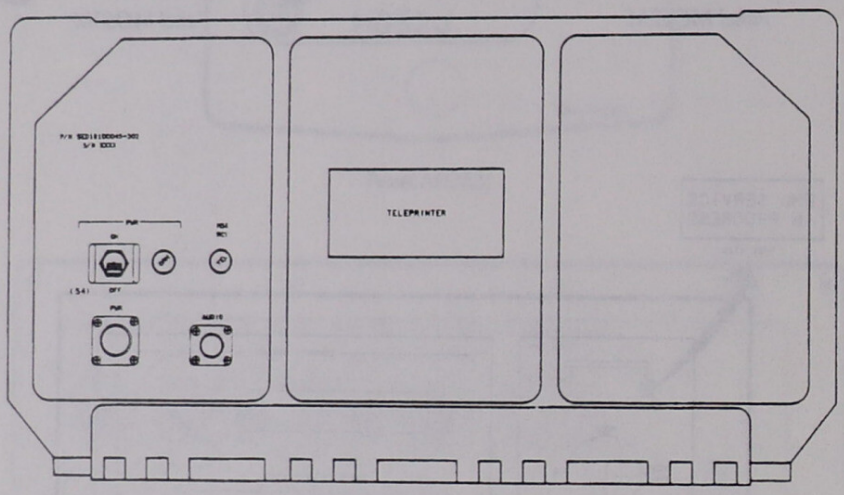
Panel MO62M



Panel MO69M

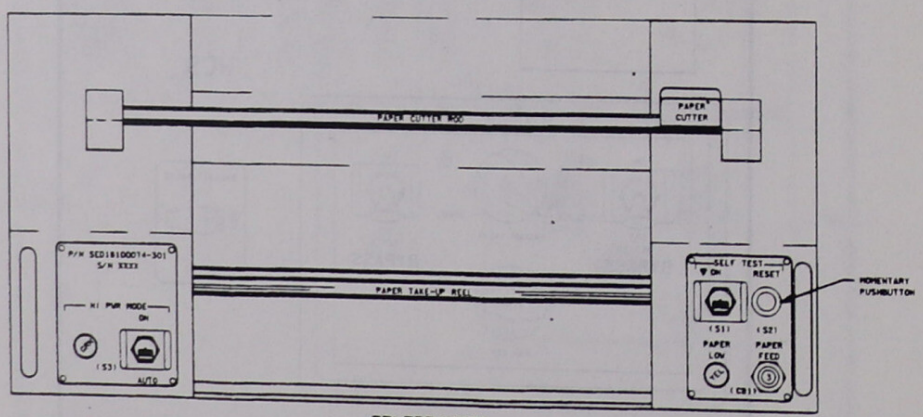


WCS



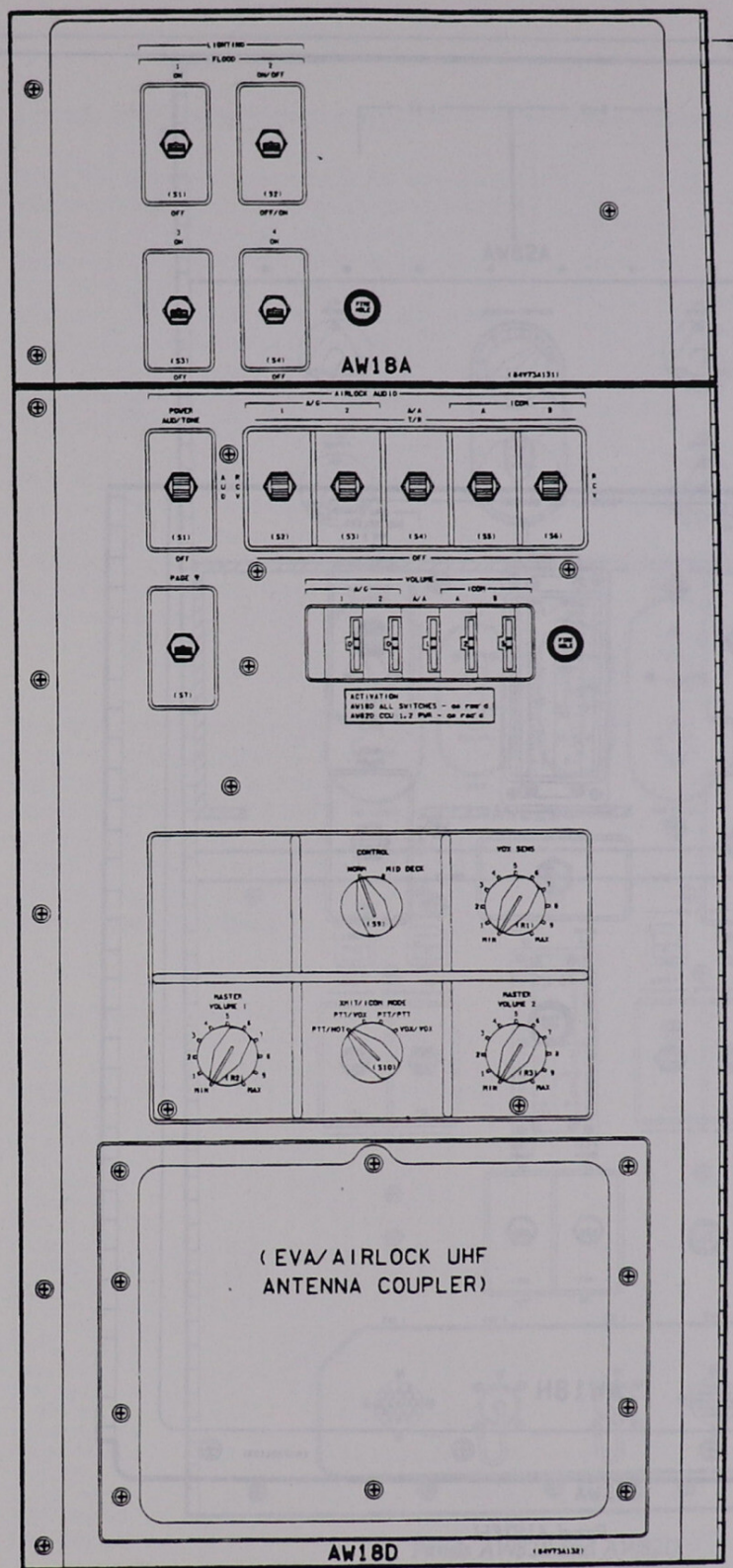
TELEPRINTER LOCKER DOOR

LOCKER LOCATION

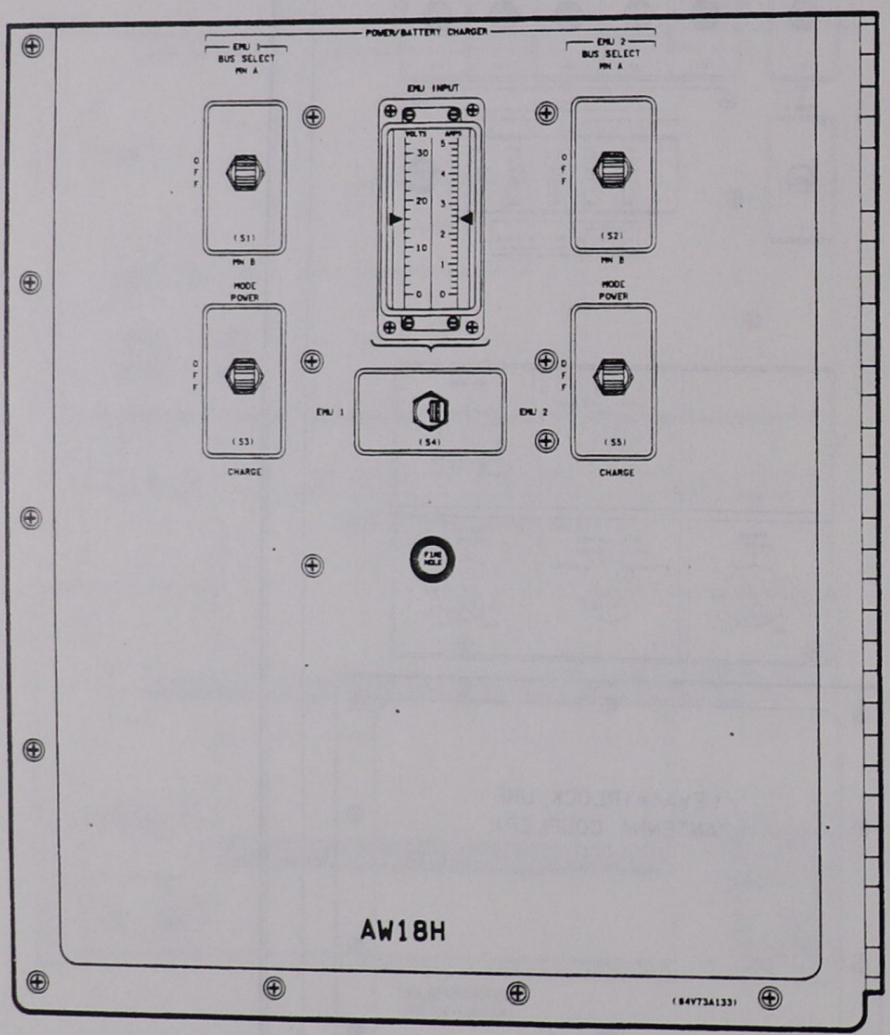


TELEPRINTER
INSIDE LOCKER

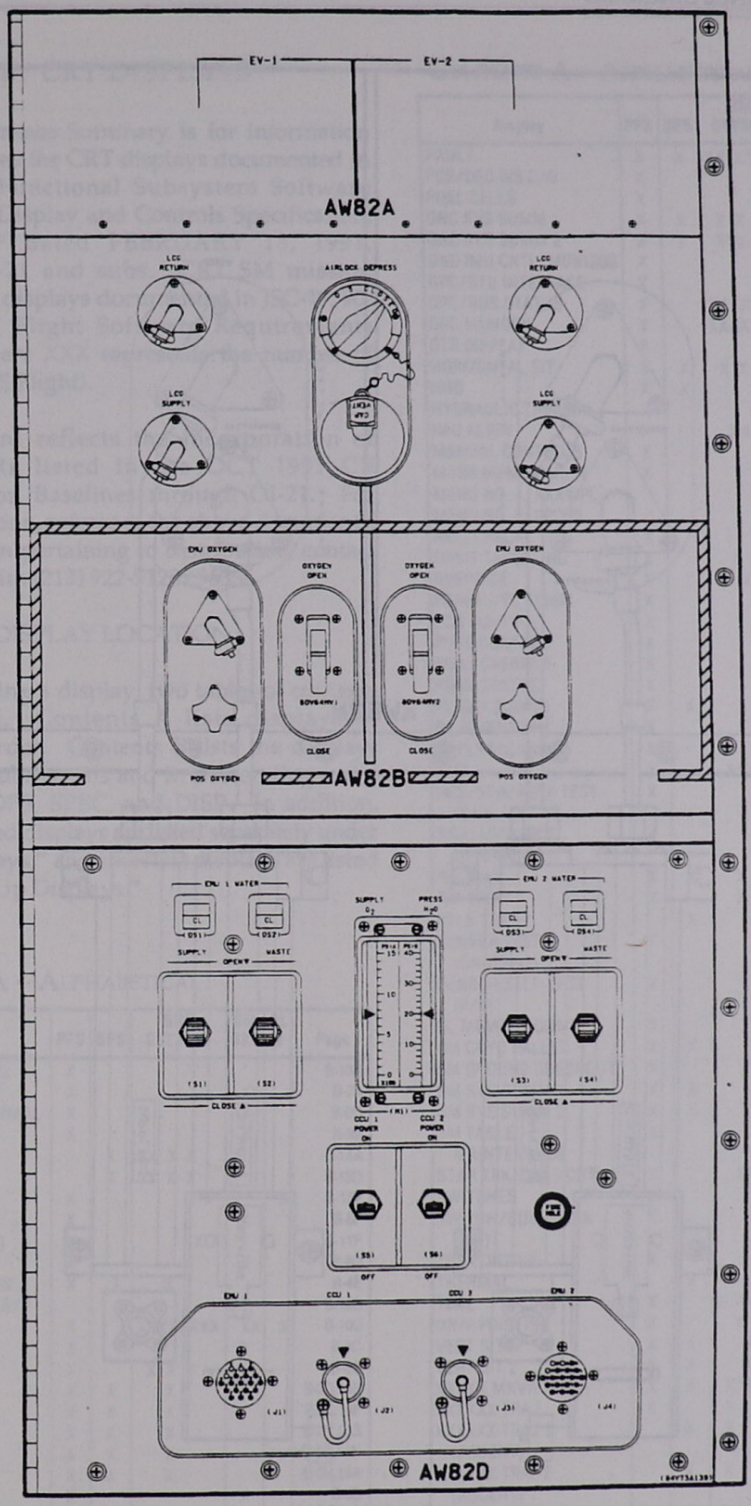
Teleprinter



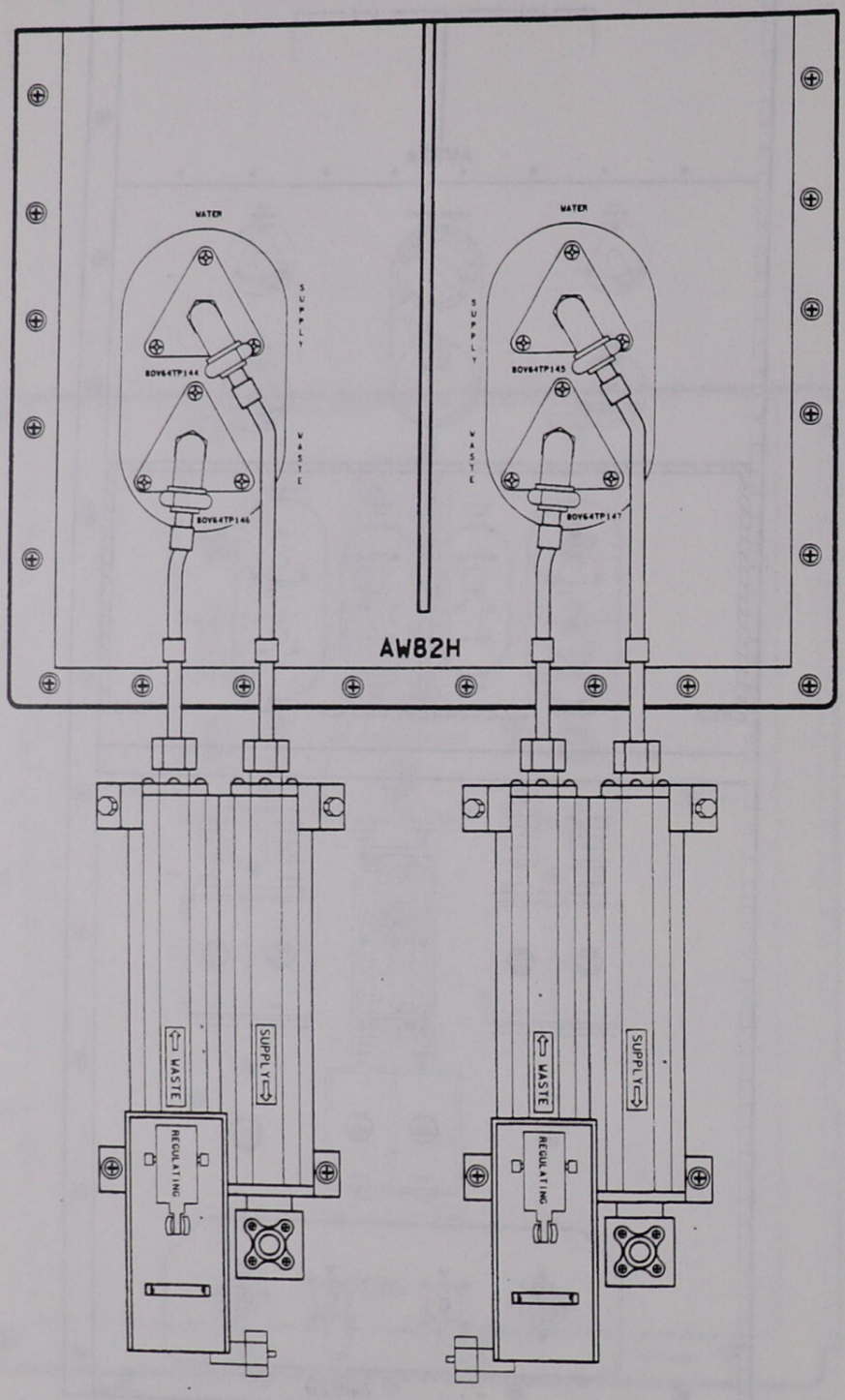
Panels AW18A and AW18D


POWER/BATTERY CHARGER
EMU 1 BUS SELECT PRI A
EMU 2 BUS SELECT PRI A
EMU INPUT
VOLTS
AMPS
OFF
(S1)
PRI B
(S2)
MODE POWER
(S3)
CHARGE
EMU 1
(S4)
EMU 2
(S5)
FINE HOLE
AW18H
(84Y73A133)

Panel AW18H



Panels AW82B and AW82D


WATER
SUPPLY
WASTE
BOV64TP144
BOV64TP146
WATER
SUPPLY
WASTE
BOV64TP145
BOV64TP147
AW82H
WASTE
SUPPLY
REGULATING
WASTE
SUPPLY
REGULATING

Panel AW82H

APPENDIX B: CRT DISPLAYS

This CRT Reference Summary is for information only. It provides the CRT displays documented in the Level C Functional Subsystem Software Requirements Display and Controls Specification, STS 83-0020F dated FEBRUARY 13, 1991, effectivity OI-21 and subs. CRT SM mission reconfigurable displays documented in JSC-19590-XXX Level C Flight Software Requirements document (where XXX represents the number of the specific OPS Flight).

This document reflects the incorporation of approved CRs listed in the OCT 1991 CR Implementation Baselines through OI-21. For detail information, reference the above documents. For information pertaining to distribution, contact J. Cox or P. Smith (213) 922-5128/5636.

DISPLAY LOCATION

To aid in locating a display, two tables of contents are provided. Contents A lists displays in alphabetical order. Contents B lists the displays according to subsystems and in descending order of hierarchy OPS, SPEC, and DISP. In addition, three IPL-related displays are listed separately under "Special Displays," and six HUD displays are listed under "Head-Up Displays."

CONTENTS A – ALPHABETICAL

Display	PFS	BFS	GNC 0123689	SM 024	PL 9	Page
ACTUATOR CONTROL	X		X			B-13A
ANTENNA	X			XX		B-7A
APU/ENVIRON THERMAL	X			X		B-9D
APU/HYDRAULIC	X			X		B-9B
BFS MEMORY		X	XX X X	X		B-14A
BFS OVERRIDE		X	X X X			B-15D
BUS/BTU STATUS	X		X		X	B-12F
COMM/RCDR	X			X		B-8F
CONTROLLERS (RM)	X		X			B-11F
CRYO SYSTEM	X			X		B-8D
DAP CONFIGURATION	X		X			B-4E
DEU STAND-ALONE S/T						B-13C
DPS UTILITY	X		XXXXXXXX	XX	X	B-10D
ELECTRIC	X			X		B-8C
CONTROLS	X		X X X			B-5G
ENTRY TRAJ 1	X	X	X			B-3D,14E
ENTRY TRAJ 2	X	X	X			B-3E,14F
ENTRY TRAJ 3	X	X	X			B-3F,14G
ENTRY TRAJ 4	X	X	X			B-3G,14H
ENTRY TRAJ 5	X	X	X			B-3H,15A
ENVIRONMENT	X			X		B-8B
EVA/MMU/FSS	X			XX		B-8G

CONTENTS A – ALPHABETICAL (continued)

Display	PFS	BFS	GNC 0123689	SM 024	PL 9	Page
FAULT	X	X	XX*X*X**	X**	**	B-10F,15E
FCS/DED DIS C/O	X		X			B-11A
FUEL CELLS	X			X		B-8E
GNC SYS SUMM 1	X	X	X*X X*			B-5H,15F
GNC SYS SUMM 2	X	X	X*X X*			B-6A
GND IMU CNTL/MONITOR	X		X			B-12D
GPC/BTU INTERFACE	X		X			B-12H
GPC/BUS STATUS	X		XXXXXXXX	XX	X	B-10G
GPC MEMORY	X		XXXXXXXX	XXX	XX	B-10C
GTS DISPLAY	X		X		X	B-12A
HORIZONTAL SIT	X	X	X X X			B-5D,15C
HUD	X	X				B-17A,17F
HYDRAULIC THERMAL	X			X		B-9C
IMU ALIGN	X		XX			B-4F
MANUAL CONTROLS	X		X			B-13B
MASS MEMORY R/W	X			XX	X	B-11B
MENU NO. 1, XXXXIPL						B-10A
MENU NO. 2, GPCIPL						B-10B
NWS CHECK	X		X			B-11H
ORBIT TARGETING	X		X			B-5C
OVERRIDE	X		X X X			B-5E
PCMMU/PL COMM	X		X	XX		B-7E
PCS CONTROL	X			XX		B-7G
PDRS CONTROL	X			XX		B-7H
PDRS OVERRIDE	X			XX		B-8A
PDRS STATUS	X			X		B-9F
PL BAY DOORS	X	X		X**		B-7B
PL RETENTION	X			XX		B-9G
PRPLT THERMAL	X			X		B-9E
RCS	X		XXXX X			B-4H
RCS/RGA/ADTA TEST (P/F)	X		X			B-12C
RGA/ADTA/RCS ON-ORBIT	X		X			B-11D
REL NAV	X		X			B-5B
RM ORBIT	X		X			B-5A
RTLS TRAJ 2		X	X			B-15B
SENSOR TEST (ON-ORBIT)	X		X			B-11C
SENSOR SELF-TEST (P/F)	X		X			B-12B
SL MEMORY DUMP	X		X			B-12G
SM CRYO PALLET	X	X		X**		B-9H,16A
SM GROUND CHECKOUT	X			XX		B-7F
SM SYS SUMM 1	X	X		X**		B-8H,15G
SM SYS SUMM 2	X	X		X**		B-9A,15H
SM TABLE MAINTENANCE	X			X		B-7C
STAR TRK/COAS CNTL	X		XX			B-4G
SWITCHES	X		X			B-11G
SWITCH/SURF FDBK (RM)	X		X			B-11E
TCS CONTROL	X		X			B-12E
THERMAL		X		X		B-14B
TIME	X		X X XX	XX	X	B-10E
UNIV POINTING	X		X			B-3C
VERT SIT 1	X	X	X X			B-4A,4C
VERT SIT 2	X	X	X X			B-4B,4D
XXXXX MNVR YYYYY	X	X	X*X			B-3B
XXXXXX TRAJ	X		X X			B-3A
XXXXXX TRAJ 1 (ASCENT)		X	X			B-14C
XXXXXX TRAJ 2 (ASCENT)		X	X			B-14D

* = INDICATES PFS ONLY AVAILABILITY

CONTENTS B – OPS DISPLAYS

OPS No.	Display	PFS	BFS	GNC	SM	PL	Page
0001	GPC MEMORY	X		X			B-10C
0001	BFS MEMORY		X	X			B-14A
0001	THERMAL		X		X		B-14B
1011	XXXXXX TRAJ	X		X			B-3A
1011	XXXXXX TRAJ 1		X	X			B-14C
1021	XXXXXX TRAJ	X		X			B-3A
1021	XXXXXX TRAJ 1		X	X			B-14C
1031	XXXXXX TRAJ	X		X			B-3A
1031	XXXXXX TRAJ 2		X	X			B-14D
1041	XXXXX MNVR YYYYY	X	X	X			B-3B
1051	XXXXX MNVR YYYYY	X	X	X			B-3B
1061	XXXXX MNVR YYYYY	X	X	X			B-3B
2011	ANTENNA	X			X		B-7A
2011	UNIV PTG	X		X			B-3C
2021	PL BAY DOORS	X	X		X		B-7B
2021	XXXXX MNVR YYYYY	X	X	X			B-3B
3011	XXXXX MNVR YYYYY	X	X	X			B-3B
3021	XXXXX MNVR YYYYY	X	X	X			B-3B
3031	XXXXX MNVR YYYYY	X	X	X			B-3B
3041	ENTRY TRAJ 1	X		X			B-3D
3041	ENTRY TRAJ 1		X	X			B-14E
3041	ENTRY TRAJ 2	X		X			B-3E
3041	ENTRY TRAJ 2		X	X			B-14F
3041	ENTRY TRAJ 3	X		X			B-3F
3041	ENTRY TRAJ 3		X	X			B-14G
3041	ENTRY TRAJ 4	X		X			B-3G
3041	ENTRY TRAJ 4		X	X			B-14H
3041	ENTRY TRAJ 5	X		X			B-3H
3041	ENTRY TRAJ 5		X	X			B-15A
3051	VERT SIT 1	X	X	X			B-4A
3051	VERT SIT 2	X	X	X			B-4B
4011	ANTENNA	X			X		B-7A
6011	XXXXXX TRAJ	X		X			B-3A
6011	RTLS TRAJ 2		X	X			B-15B
6021	VERT SIT 1	X	X	X			B-4A
6021	VERT SIT 1 (GRTLS)	X		X			B-4C
6031	VERT SIT 1	X	X	X			B-4A
6031	VERT SIT 2	X	X	X			B-4B
6031	VERT SIT 2 (GRTLS)	X		X			B-4D
8011	FCS/DED DIS C/O	X		X			B-11A
9011	MASS MEMORY R/W	X			X	X	B-11B
9011	GPC MEMORY	X		X			B-10C

SPECIAL DISPLAYS

Display	Page
XXXXIPL MENU NO. 1	B-10A
GPCIPL MENU NO. 2	B-10B
DEU STAND-ALONE SELF-TEST	B-13C

HEAD-UP DISPLAYS

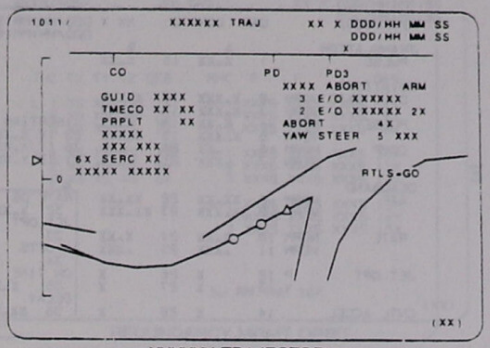
Display	Page
FORMAT 1 PRE-WOW (70,650 FT)	B-17A
FORMAT 1 PRE-WOW (100 FT)	B-17B
FORMAT 1 AFTER WOW	B-17C
FORMAT 2 PRE-WOW	B-17D
OPS 8 LOW	B-17E
OPS 9 LOW	B-17F

CONTENTS B – SPEC AND DISP DISPLAYS

Spec No.	Display	PFS	BFS	GNC	SM	PL	Page
001	DPS UTILITY	X		X	X	X	B-10D
002	TIME	X		X	X	X	B-10E
006	GPC/BUS STATUS	X		X	X	X	B-10G
018	GNC SYS SUMM 1	X		X			B-5H
018	GNC SYS SUMM 1		X	X			B-15F
019	GNC SYS SUMM 2	X	X	X			B-6A
020	DAP CONFIG	X		X			B-4E
021	IMU ALIGN	X		X			B-4F
022	S TRK/COAS CNTL	X		X			B-4G
023	RCS	X		X			B-4H
025	RM ORBIT	X		X			B-5A
033	REL NAV	X		X			B-5B
034	ORBIT TGT	X		X			B-5C
040	SENSOR TEST	X		X			B-11C
041	RGA/ADTA/RCS	X		X			B-11D
042	SWITCH/SURF	X		X			B-11E
043	CONTROLLERS	X		X			B-11F
044	SWITCHES	X		X			B-11G
045	NWS CHECK	X		X			B-11H
050	HORIZ SIT	X		X			B-5D
050	HORIZ SIT		X	X			B-15C
051	OVERRIDE	X		X			B-5E
051	BFS OVERRIDE		X	X			B-15D
053	CONTROLS	X		X			B-5G
060	SM TABLE MAINT	X			X		B-7C
062	PCMMU/PL COMM	X			X		B-7E
063	PL BAY DOORS	X	X		X		B-7B
064	SM GROUND CHECKOUT	X		X			B-7F
066	ENVIRONMENT	X			X		B-8B
067	ELECTRIC	X			X		B-8C
068	CRYO SYSTEM	X			X		B-8D
069	FUEL CELLS	X			X		B-8E
076	COMM/RCDR	X			X		B-8F
077	EVA-MMU/FSS	X		X	X		B-8G
078	SM SYS SUMM 1	X	X		X		B-15G
079	SM SYS SUMM 2	X			X		B-9A
079	SM SYS SUMM 2		X		X		B-15H
085	MASS MEMORY R/W	X			X	X	B-11B
086	APU/HYD	X			X		B-9B
087	HYD THERMAL	X			X		B-9C
088	APU/ENVIRON THERM	X			X		B-9D
089	PRPLT THERMAL	X			X		B-9E
090	PCS CONTROL	X				X	B-7G
094	PDRS CONTROL	X			X		B-7H
095	PDRS OVERRIDE	X			X		B-8A
096	PDRS STATUS	X			X		B-9F
097	PL RETENTION	X		X		X	B-9G
099	FAULT	X		X	X	X	B-10F
099	FAULT		X	X	X	X	B-15E
100	GTS DISPLAY	X		X		X	B-12A
101	SENSOR SELF-TEST	X		X			B-12B
102	RCS/RGA/ADTA TEST	X		X			B-12C
104	GND IMU CNTL/MON	X		X			B-12D
105	TCS CONTROL	X		X			B-12E
106	MANUAL CONTROLS	X		X			B-13B
110	BUS/BTU STATUS	X		X		X	B-12F
111	SL MEMORY DUMP	X		X		X	B-12G
112	GPC/BTU I/F	X		X			B-12H
113	ACTUATOR CONTROL	X		X			B-13A
168	SM CRYO PALLET	X			X		B-9H
168	SM CRYO PALLET		X	X			B-16A

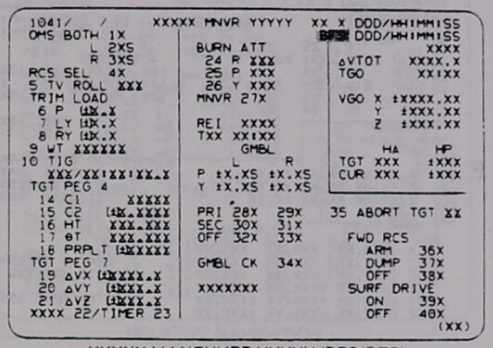
GUIDANCE, NAVIGATION, and CONTROL (GN&C)

A



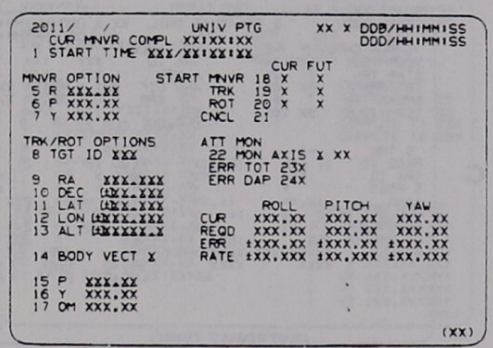
XXXXXX TRAJECTORY

B



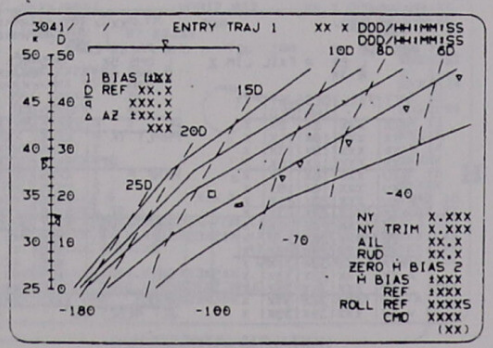
XXXXX MANEUVER YYYYY (PFS/BFS)

C



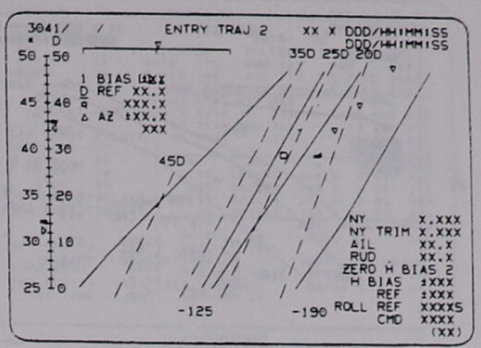
UNIVERSAL POINTING

D



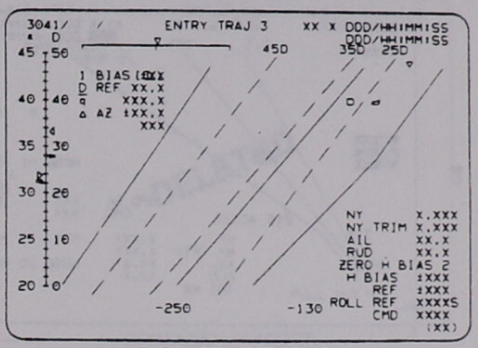
ENTRY TRAJECTORY 1

E



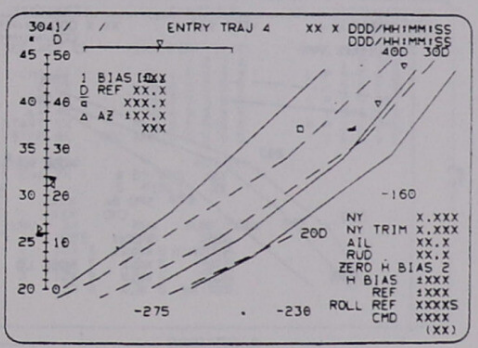
ENTRY TRAJECTORY 2

F



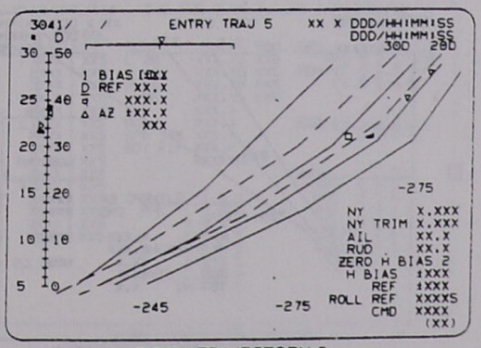
ENTRY TRAJECTORY 3

G



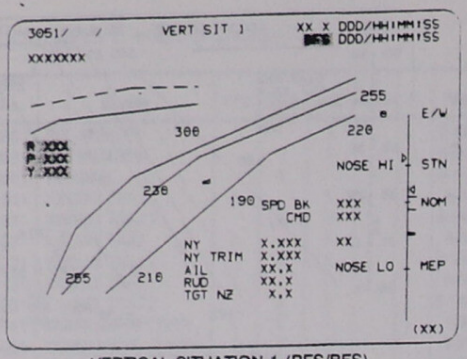
ENTRY TRAJECTORY 4

H



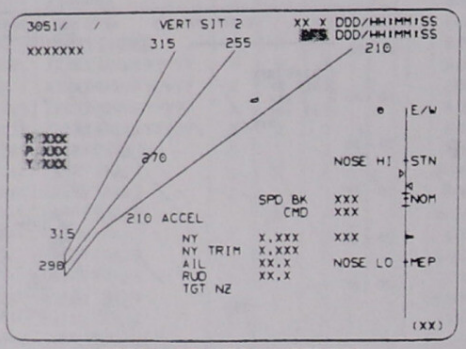
ENTRY TRAJECTORY 5

A



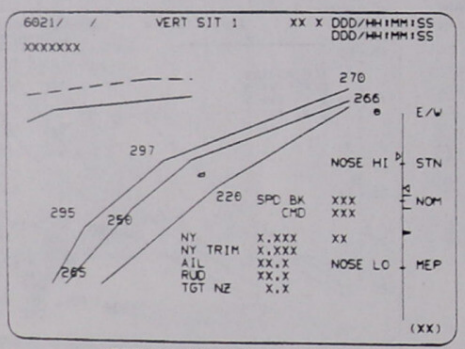
VERTICAL SITUATION 1 (PFS/BFS)

B



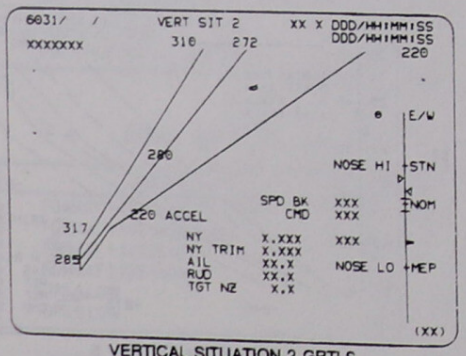
VERTICAL SITUATION 2 (PFS/BFS)

C



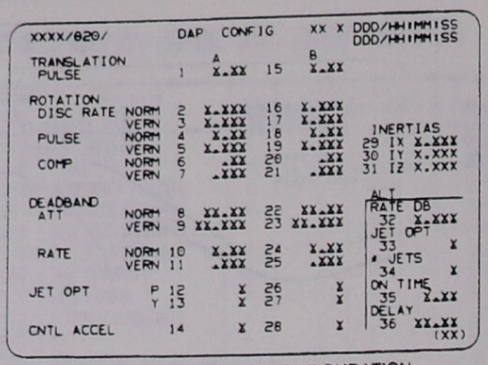
VERTICAL SITUATION 1 GRTLS

D



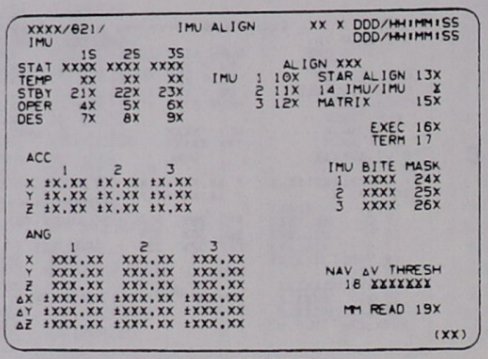
VERTICAL SITUATION 2 GRTLS

E



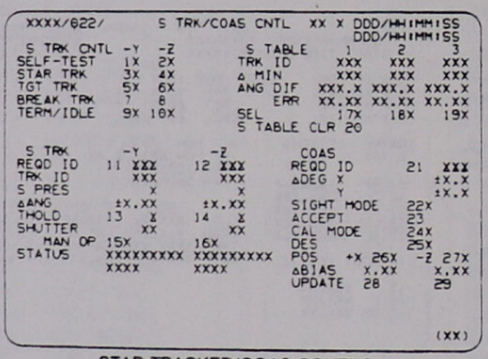
DIGITAL AUTOPILOT CONFIGURATION

F



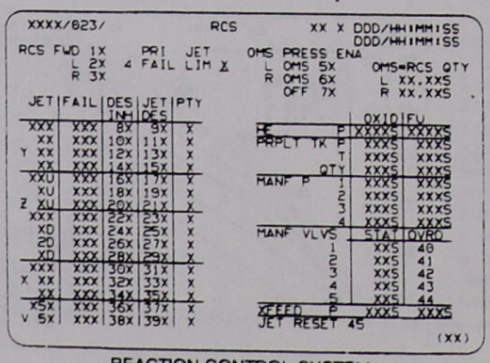
IMU ALIGNMENT

G



STAR TRACKER/COAS CONTROL

H



REACTION CONTROL SYSTEM

A

```
XXXX/025/          RM ORBIT          XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS

  THC TX TY TZ DES    RHC  R    P     Y     DES

  L 1 XS XS XS  1X    L  1 XXXS XXXS XXXS  7X
    2 XS XS XS  2X       2 XXXS XXXS XXXS  8X
    3 XS XS XS  3X       3 XXXS XXXS XXXS  9X

  A 1 XS XS XS  4X    R  1 XXXS XXXS XXXS 10X
    2 XS XS XS  5X       2 XXXS XXXS XXXS 11X
    3 XS XS XS  6X       3 XXXS XXXS XXXS 12X

                      A  1 XXXS XXXS XXXS 13X
                         2 XXXS XXXS XXXS 14X
                         3 XXXS XXXS XXXS 15X


                      SW RM INH 16X
                                          (XX)
```

REDUNDANCY MGMT ORBIT

B

```
XXXX/033/          REL NAV           XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS

 RNDZ NAV ENA 1X   SV UPDATE          AVG G ON     5X
 KU ANT   ENA 2X     POS XX.XX        ΔVX      ±XX.XX
 MEAS     ENA 3X     VEL XX.XX        ΔVY      ±XX.XX
          NAV                         ΔVZ      ±XX.XX
 SV SEL 4 XXXX     RR XXXX            ΔVTOT    XXX.XX
 RNG  XXXX.XXX  RNG  XXXX.XXXS        RESET COMPNT 6
 R    ±XXXX.XX  R    ±XXXX.XXS              TOT 7
 e       XXX.XX  EL      ±XXX.XS   SV TRANSFER
 Y       ±XX.XX  AZ      ±XXX.XS   FLTR MINUS PROP
 Ẏ       ±XXX.X  ωP      ±XX.XS      POS      XX.XX
 NODE XX:XX:XX   ωR      ±XX.XS      VEL      XX.XX
          FILTER                     FLTR TO PROP  8X
 S TRK 12X   RR 13X   COAS 14X       PROP TO FLTR  9X
 STAT XXXXXXXXX  OFFSET X ±X.X       ORB  TO TGT  10X
      XXXX          Y ±X.X           TGT  TO ORB  11X
 SLOW RATE    15X                    EDIT OVRD
 COVAR REINIT 16X    MARK HIST       AUT  INH  FOR
          RESID  RATIO ACPT  REJ     17X  18X  19X
 RNG    ±XX.XX   X.X  XXX   XXS      20X  21X  22X
 R      ±XX.XX   X.X  XXX   XXS      23X  24X  25X
 V/EL/Y ±X.XX    X.X  XXX   XXS
 H/AZ/X ±X.XX    X.X  XXX   XXS
                                          (XX)
```

RELATIVE NAVIGATION

C

```
XXXX/034/          ORBIT TGT         XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
 MNVR     TIG        ΔVX    ΔVY    ΔVZ    ΔVT
 XX X X/XX:XX:XX   ±XXX.X  ±XX.X  ±XX.X  ±XXX.X
                           PRED MATCH= XXXXXXX

 INPUTS                              CONTROLS
 1 TGT NO              XX            T2 TO T1    25
 2 T1 TIG  X/XX:XX:XX                XXXX        26
 6   EL          XXX.XX              COMPUTE T1 28X
 7   ΔX/DNRNG  UXXX.XX               COMPUTE T2 29X
 8   ΔY        UXXX.XX
 9   ΔZ/ΔH     UXXX.XX
10   ΔẊ        UXXX.XX
11   ΔẎ        UXXX.XX
12   ΔŻ        UXXX.XX
13 T2 TIG  X/XX:XX:XX             ORBITER STATE
17   ΔT        UXXXX.X          XXX/XX:XX:XX.XXX
18   ΔX        UXXX.XX             X ±XXXXX.XXX
19   ΔY        UXXX.XX             Y ±XXXXX.XXX
20   ΔZ        UXXX.XX             Z ±XXXXX.XXX
21 BASE TIME X/XX:XX:XX          VX ±XX.XXXXXX
                                 VY ±XX.XXXXXX
                                 VZ ±XX.XXXXXX
                                          (XX)
```

ORBIT TARGETING

D

```
XXXX/050/          HORIZ SIT         XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
PTI   XXX 1   ALTM                          NAV DELTA
 INDEX XX     9? XX.XX                      ΔX 10
      XXX                                   UXXXXXX
                                            ΔY 11
XXXXXXXXXXX XX                              UXXXXXX
41 XXXX SITE XX                             ΔZ 12
PRI XXXXX     3X                            UXXXXXX
SEC XXXXX     4X                            ΔX 13
TAC XXX       5                             UXXXX
                                            ΔẎ 14
TAEM TGT                                    UXXXX
GIN X XXXX 6                                ΔŻ 15
MSI X                                       UXXXX
XEP          7                              LOAD 16
AIM   XXXX 8          X.X δ                 UXXXX
S/B  XXXXX 39                          18 AT UXX.XX
NAV  RESID RATIO AUTO INH FOR  TAC1 XXX TAC2 XXX TAC3 XXX
TAC AZ ±XX.XXX.XS 19X 20X 21X  ±XXX.XXS ±XXX.XXS ±XXX.XXS
   RNG ±XX.XXX.XS              ±XXX.XXS ±XXX.XXS ±XXX.XXS
                               DES 31X  DES 32X  DES 33X
DRAG H ±XXXX.XXX.XS 22X 23X 24X
ADTA H ±XXX.XXX.XS 25X 26X 27X  UD 37 L X      ABS   34X
ADTA TO GFC        28X 29X 30X     38 R X XXXX DELTA 35X
                                          (XX)
```

HORIZONTAL SITUATION

E

```
XXXX/051/          OVERRIDE          XX X DDD/HH MM SS
                                     DDD/HH MM SS
ABORT MODE                    ENTRY FCS
 TAL        1X      ELEVON    FILTER    ATMOSPHERE
 ATO        2X   AUTO  17X    NOM 20X     NOM    22X
 ABORT      3X   FIXED 18X    ALT 21X     N POLE 23X
 MAX THROT  4X   SSME REPOS 19 XXX       S POLE 24X

                 IMU STAT ATT DES              PRL
    PROPLT DUMP    1S XXXX  X  25X          SYS AUT DES
                   2S XXXX XXX 26X            1S 28X 31X
XXX ICNCT 5 XXXX   3S XXXX    27X            2S 29X 32X
OMS DUMP                                     3S 30X 33X
  ARM       6X   ADTA      H        α     M      DES
  START     7X     L 1S  XXXX.XX  ±XX.X  X.XX    34X
  STOP      8X       3S  XXXXXX  ±XX.X  X.XX    35X
9 QUAN/SIDE XXX    R 2S  XXXXXX  ±XX.X  X.XX    36X
OMS DUMP TTG XXX     4S  XXXXXX  ±XX.X  X.XX    37X
                 ET SEP                  ROLL MODE XXXXXX
                   AUTO      38X         AUTO SEL  42X
AFT RCS 13  XXX    SEP       39X
  14 TIME   &&&  ET UMB DR               VENT DOOR CNTL
                   CLOSE     40X         OPEN      43X
FWD RCS 15  XXX  RCS RM MANF             CLOSE     44X
  16 TIME   &&&    CL OVRD   41
                                          (XX)
```

OVERRIDE

F

```
6021/052/          CONT ABORT        XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
 DUMP START 1X
      STOP  2X


                    DELETED


                                  PULL OUT NZ
                                          (XX)
```

CONTINGENCY ABORT

G

```
XXXX/053/          CONTROLS          XX X DDD/HH:MM:SS
                                     DDD/HH:MM:SS
SEC ACT CK     AERO PORT STAT          SSME PORT STAT
                      1 2 3 4                 1 2 3 4
  CH1 1X     L OB  1 S S S S       L P  1 S S S S
      2 2X      IB  2 S S S S          Y  2 S S S S
      3 3X   R IB  3 S S S S       C P  3 S S S S
      4 4X      OB  4 S S S S          Y  4 S S S S
START 5X      RUD  5 S S S S       R P  5 S S S S
 STOP 6X  SPD BRK  6 S S S S          Y  6 S S S S

 NEG STIM          ACT/CH
  ENA 7X     8 BYPASS  XX
             9 RESET   XX

LRU   AA       RGA    SURF FDBK
      DES      DES      DES
 1   10X S    14X S    18X S
 2   11X S    15X S    19X S
 3   12X S    16X S    20X S
 4   13X S    17X S    21X S
                                          (XX)
```

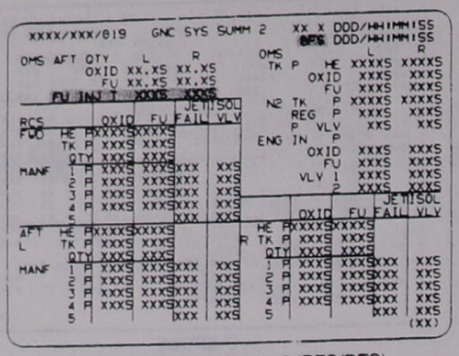
CONTROLS

H

```
XXXX/XXX/018  GNC SYS SUMM 1       XX X DDD/HH:MM:SS
                                   DDD/HH:MM:SS
RCS | JET|SOL
MAN|FAIL|V                SURF      POS      MOM
 P |XXX | XXS          L OB      XXX.XS   XXS
   2XXX | XXS             IB      XXX.XS   XXS
   3XXX | XXS          R IB      XXX.XS   XXS
   4XXX | XXS             OB      XXX.XS   XXS
   5XXX | XXS          AIL       XXX.X
 L 1XXX | XXS          RUD       XXX.X
   2XXX | XXS          SPD BRK   XXX.X
   3XXX | XXS          BDY FLP   XXX.X
   4XXX | XXS                    XXXXXX
   5XXX | XXS
 R 1XXX | XXS
   2XXX | XXS          CNTLR  1  2  3
   3XXX | XXS          RHC  L S  S  S
   4XXX | XXS               R S  S  S
   5XXX | XXS               A S  S  S
                        THC  L S  S  S
                             A S  S  S
                        SBTC L S  S  S
                             R S  S  S

DPS              1  2  3  4  5
      GPC        S  S  S  S  S
MDM   FF         S  S  S  S  S
      FA         S  S  S  S  S

FCS CH           1  2  3  4
                 S  S  S  S

NAV              1  2  3  4
      IMU        S  S  S  S
      ACC        S  S  S  S
      RGA        S  S  S  S
      TAC        S  S  S  S
      MLS        S  S  S  S
      ADTA       S  S  S  S
                                          (XX)
```

GNC SYSTEM SUMMARY 1

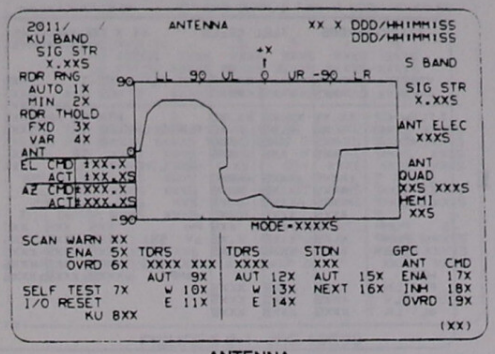
A



GNC SYSTEM SUMMRY 2 (PFS/BFS)

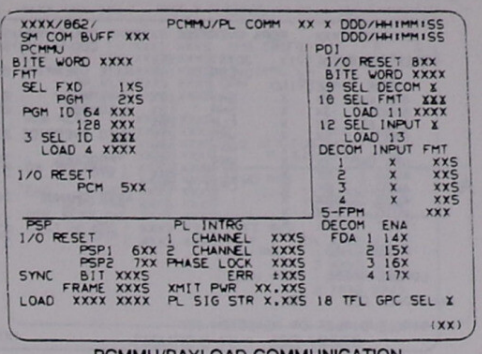
SYSTEMS MANAGEMENT (SM)

A



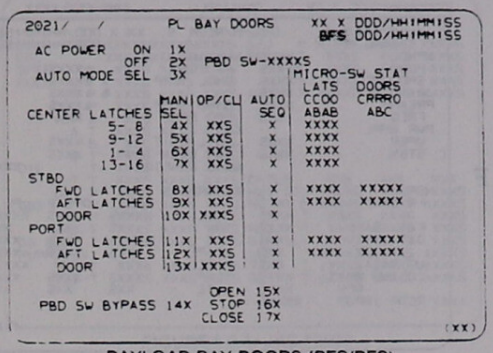
ANTENNA

E



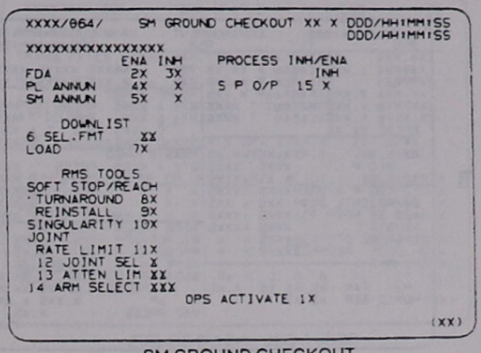
PCMMU/PAYLOAD COMMUNICATION

B



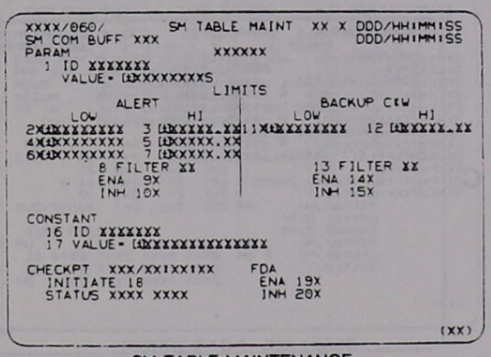
PAYLOAD BAY DOORS (PFS/BFS)

F



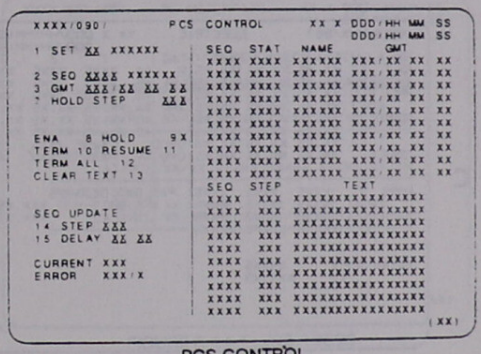
SM GROUND CHECKOUT

C



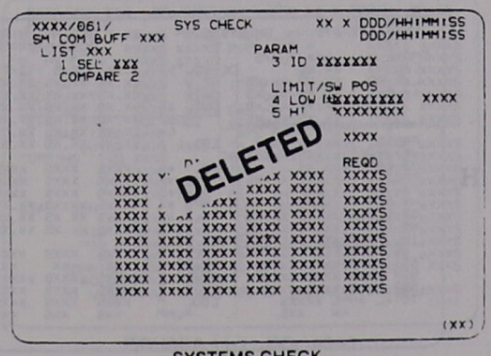
SM TABLE MAINTENANCE

G



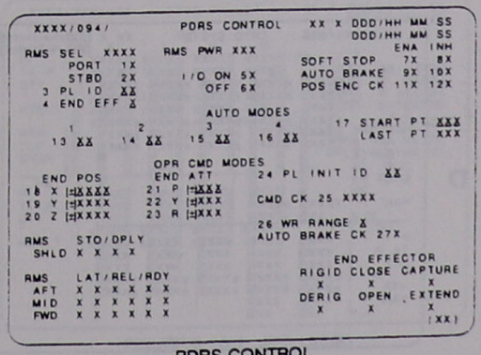
PCS CONTROL

D



SYSTEMS CHECK

H



PDRS CONTROL

A

```
xxxx/095/xxx    PDRS OVERRIDE        xx x DDD/HH:MM:SS
                                          DDD/HH:MM:SS

MODE OVERRIDE  1X    JOINT      SEL
                     OVERRIDE   17X   RATE OVERRIDE 26X
  MODE     SEL IND
 ORB UNL   2X   X        SHY   18X     VERNIER    27X
 SINGLE    3X   X        SHP   19X     COARSE     28X
 END EFF   4X   X        ELP   20X
 ORB LD    5X   X        WRP   21X   AUTO OVERRIDE 29X
 PL        6X   X        WRY   22X
 OPR CMD   7X   X        WRR   23X     PROCEED    30
 AUTO 1    8X   X        EE T  24X     STOP       31
 AUTO 2    9X   X        CRIT T 25X
 AUTO 3   10X   X                    AXIS CHANGE  32X
 AUTO 4   11X   X
 TEST     12X   X                      THC        33X
                                       RHC        34X
 ENTER    13

LOADED RATES   14X

STOWED OPS     15X

SINGLE/DIRECT DR REASSIGN 16X
                                                  (XX)
```

PDRS OVERRIDE

B

```
xxxx/xxx/066      ENVIRONMENT      xx x DDD/HH:MM:SS
                                          DDD/HH:MM:SS
          CABIN                  AV BAY  |  2   3
dP/dT ±.XXS CABIN P XX.XS  TEMP     XXXXS XXXXS XXXXS
PPO2        AIRLK P XX.XS  FAN   dP X.XXS X.XXS X.XXS
   A X.XXS FAN   dP X.XXS  SUPPLY H2O
   B X.XXS HX OUT T XXXS  QTY A XXXS  PRESS     XXXS
   C X.XXS CABIN  T XXXS        B XXXS  DMP LN T XXXS
PPCO2 XX.XS                     C XXXS  NOZ  T A XXXS
                                        D XXXS       B XXXS
O2 FLOW        X.XS  X.XS   WASTE  H2O
  REG P        XXXS  XXXS  QTY |XXXS  PRESS     XXXS
N2 FLOW        X.XS  X.XS                DMP LN T XXXS
  REG P        XXXS  XXXS                NOZ  T A XXXS
O2/N2 CNTL VLV  XXS   XXS                          B XXXS
H2O TK N2 P    XXXS  XXXS            VAC VT NOZ T XXXS
N2 QTY         XXXS  XXXS  CO2 CNTLR        1XS   2XS
EMER O2 QTY    XXXS        FILTER dP          X.XXS
     REG P XXXXS           PPCO2              XX.XS
                           TEMP               XXX.XS
          A  B  C   dP     BED A PRESS     XX.XS XX.XS
IMU   FAN XS XS XS  X.XS    B PRESS     XX.XS XX.XS
HUMID SEP XS XS             dP          X.XXS X.XXS
                          VAC PRESS           X.XS
                                              (XX)
```

FIGURE 6.1-1. JSC-19590

C

```
xxxx/xxx/067      ELECTRIC         xx x DDD/HH:MM:SS
                                          DDD/HH:MM:SS
 DC       1/A   2/B   3/C   |AC          1     2     3
VOLT  FC XX.XS XX.XS XX.XS  |V    φA  XXXS  XXXS  XXXS
      MN XX.XS XX.XS XX.XS  |     φB  XXXS  XXXS  XXXS
PCA FWD  XX.XS XX.XS XX.XS  |     φC  XXXS  XXXS  XXXS
     AFT XX.XS XX.XS XX.XS  |AMP  φA XX.XS XX.XS XX.XS
CNTL AB  XX.XS XX.XS XX.XS  |     φB XX.XS XX.XS XX.XS
     BC  XX.XS XX.XS XX.XS  |     φC XX.XS XX.XS XX.XS
     CA  XX.XS XX.XS XX.XS  |OVLD      XXS   XXS   XXS
ESS      XX.XS XX.XS XX.XS  |O/U V      XXS   XXS   XXS

AMPS  FC  XXXS  XXXS  XXXS  |PAYLOAD DC AMPS
     FWD  XXXS  XXXS  XXXS  |   AFT B       XXX.XS
     MID  XXXS  XXXS  XXXS  |       C       XXX.XS
     AFT ±XXXS ±XXXS ±XXXS

TOTAL AMPS     XXXXS
      KW       XXX.XS
                                              (XX)
```

FIGURE 6.2-1. JSC-19590

D

```
xxxx/xxx/068      CRYO SYSTEM      xx x DDD/HH:MM:SS
                                          DDD/HH:MM:SS
                    TK
 O2          1     2     3     4     5
 TK P     XXXXS XXXXS XXXXS XXXXS XXXXS
 QTY      XXXS  XXXS  XXXS  XXXS  XXXS
 T        ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
 HTR T  1 ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
        2 ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
 HTR  1A     S     S     S     S     S
 CUR  1B     S     S     S   4/5S    S
 SNSR 2A     S     S     S     S     S
      2B     S     S     S   4/5S    S
 MANF P  XXXXS XXXXS
   VLV   XXS   XXS
 N2
 P        XXXS  XXXS  XXXS  XXXS  XXXS
 TK P     XXXS  XXXS  XXXS  XXXS  XXXS
 QTY      XXXS  XXXS  XXXS  XXXS  XXXS
 T        ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
 HTR T    ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
 MANF P    XXXS  XXXS
    VLV    XXS   XXS
                                          (XX)
```

FIGURE 6.3-1. JSC-19590

E

```
xxxx/xxx/069      FUEL CELLS       xx x DDD/HH:MM:SS
                                          DDD/HH:MM:SS
                    FC
                  1   2   3
VOLTS        XX.XS XX.XS XX.XS  H2O RLF LINE T    XXXS
AMPS         XXXS  XXXS  XXXS        NOZ T A    XXXS
                                             B    XXXS
FLOW O2      XX.XS XX.XS XX.XS      HTR SW       XXXS
     H2       X.XS  X.XS  X.XS  PURGE LN  O2 T   XXXS
REAC O2       XXS   XXS   XXS        H2 T1      XXXS
     H2       XXS   XXS   XXS           T2      XXXS
                                  H2O LINE  PH    XXS
STACK T     ±XXXS ±XXXS ±XXXS
EXIT  T      XXXS  XXXS  XXXS
COOL  T      XXXS  XXXS  XXXS                FC
        P    XXXS  XXXS  XXXS                1   2   3
   PUMP      XXS   XXS   XXS   PH           XXS XXS XXS
H2 PUMP                        ΔV  SS1     XXXS XXXS XXXS
  READY      XXXS  XXXS  XXXS      SS2     XXXS XXXS XXXS
                                   SS3     XXXS XXXS XXXS
H2O                              ΔAMPS   ±XXXS±XXXS±XXXS
PRI LN T     XXXS  XXXS  XXXS
   VLV T     XXXS  XXXS  XXXS
ALT LN T     XXXS  XXXS  XXXS
                                          (XX)
```

FIGURE 6.4-1. JSC-19590

F

```
XXXX/XXX/076      COMM/RCDR        xx x DDD/HH:MM:SS
 S-BAND PM                                DDD/HH:MM:SS
XPND          XXXS   KU-BAND
MODE          XXXXS   PA TEMP          ±XXXS
SPD SPEC      XXXS   GMBL TEMP    A ±XXXS
RANGING       XXXS              B ±XXXS
PREAMP        XXXS   GYRO TEMP      ±XXXS
FREQ          XXS    SPD SPEC       XXX
PWR AMPL             CCTV
OPER          XXXS   CNTL UNIT      XXXS
STBY          XXXS   CAM OVER-TEMP  XXXS
                     GCIL CONFIG            XXXS

NSP                  RECORDERS
FR SYNC  1    XXXS                OPS 1  OPS 2  PL
         2    XXXS   MODE          XXXXS  XXXXS  XXXXS
FAIL SAFE     XXXS   TRK           XXS    XXS    XXS
DATA XMIT     XXS    DIR           XXXS   XXXS   XXXS
   RCV        XXS    ±TAPE         XXXS   XXXS   XXXS
UL DATA       XXS    TAPE          XXXX   XXXX   XXXX
CODING XMIT   XXXS   TEMP          XXXS   XXXS   XXXS
   RCV        XXXS   BITE          XXS    XXS    XXS
RCDR INPUT    XXXXS
                                          (XX)
```

FIGURE 6.5-1. JSC-19590

G

```
XXXX/XXX/077      EVA-MMU/FSS      xx x DDD/HH:MM:SS
                                          DDD/HH:MM:SS
 MMU/FSS
TEMPS                 PORT    STBD
TOGGLE VLV FSS  L   ±XXXS   ±XXXS
                R   ±XXXS   ±XXXS
            MMU L   ±XXXS   ±XXXS
                R   ±XXXS   ±XXXS
GN2 TANK BARREL L   ±XXXS   ±XXXS
                R   ±XXXS   ±XXXS
CNTL ELECT ASSY     ±XXXS   ±XXXS
                                          (XX)
```

FIGURE 6.6-1. JSC-19590

H

```
XXXX/XXX/078      SM SYS SUMM 1    xx x DDD/HH:MM:SS
                                          DDD/HH:MM:SS
SMOKE        1/A   2/B
CABIN        XX.XS
L/R FD       XX.XS XX.XS
AV BAY  1    XX.XS XX.XS
        2    XX.XS XX.XS
        3    XX.XS XX.XS
      CABIN
PRESS        XX.XS
dP/dT-EQ  ±.XXS±X.XXXS
O2 CONC   XXX.XS
PPO2         X.XXS X.XXS
FAN  dP      X.XXS
HX OUT T     XXXS
O2 FLOW      XX.XS XX.XS
N2 FLOW      XX.XS XX.XS
IMU FAN   AXS BXS CXS
  ΔV  FC1   FC2   FC3
SS1  XXXS  XXXS  XXXS
SS2  XXXS  XXXS  XXXS
SS3  XXXS  XXXS  XXXS
TOTAL AMPS XXXXS
      KW     XXS

DC VOLTS          1/A   2/B   3/C
  FC             XX.XS XX.XS XX.XS
  MAIN           XX.XS XX.XS XX.XS
  CNTL AB        XX.XS XX.XS XX.XS
       BC        XX.XS XX.XS XX.XS
       CA        XX.XS XX.XS XX.XS
  ESS            XX.XS XX.XS XX.XS
AC
  VOLT  φA       XXXS  XXXS  XXXS
        φB       XXXS  XXXS  XXXS
        φC       XXXS  XXXS  XXXS
  AMPS  φA      XX.XS XX.XS XX.XS
        φB      XX.XS XX.XS XX.XS
        φC      XX.XS XX.XS XX.XS
FUEL CELL
  AMPS           XXXS  XXXS  XXXS
  REAC VLV       XX    XX    XX
  STACK T      ±XXXS ±XXXS ±XXXS
  EXIT  T        XXXS  XXXS  XXXS
  COOL  P        XXXS  XXXS  XXXS
     PUMP        XXS   XXS   XXS
                                          (XX)
```

FIGURE 6.7-1. JSC-19590

A

```
XXXX/XXX/079      SM SYS SUMM 2   XX X DDD/HHIMMISS
                                  DDD/HHIMMISS

          CRYO TK   1      2      3      4      5
       H2 PRESS   XXXS   XXXS   XXXS   XXXS   XXXS
       O2 PRESS  XXXXS  XXXXS  XXXXS  XXXXS  XXXXS
       HTR  T1    ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS
            T2    ±XXXS  ±XXXS  ±XXXS  ±XXXS  ±XXXS

 APU          1      2      3     | HYD          1      2      3
TEMP EGT   XXXXS  XXXXS  XXXXS   | PRESS     XXXXS  XXXXS  XXXXS
 B/U EGT   XXXXS  XXXXS  XXXXS   | RSVR T     XXXS   XXXS   XXXS
 OIL  IN    XXXS   XXXS   XXXS   |      P     XXXS   XXXS   XXXS
      OUT   XXXS   XXXS   XXXS   |    QTY     XXXS   XXXS   XXXS
SPEED   %  XXXS   XXXS   XXXS   |     W/B
FUEL QTY   XXXS   XXXS   XXXS   | H2O QTY    XXXS   XXXS   XXXS
 PMP LK P   XXS    XXS    XXS   | BYP VLV    XXXS   XXXS   XXXS
OIL OUT P  XXXS   XXXS   XXXS   |
                                | THERM CNTL     1      2
  AV BAY                        | H2O PUMP P                XXXS   XXXS
TEMP          XXXS   XXXS   XXXS | FREON FLOW                XXXXS  XXXXS
FAN ΔP      X.XXS  X.XXS  X.XXS | EVAP OUT T                XXXS   XXXS

                                                          (XX)
```

FIGURE 6.8-1. JSC-19590

B

```
XXXX/XXX/086          APU/HYD      XX X DDD/HHIMMISS
                                   DDD/HHIMMISS
 APU          1      2      3     HYD          1      2      3
B/U   EGT  XXXXS  XXXXS  XXXXS  B/U    P   XXXXS  XXXXS  XXXXS
EGT         XXXXS  XXXXS  XXXXS  RSVR   T   XXXS   XXXS   XXXS
SPEED   %   XXXS   XXXS   XXXS         P   XXXS   XXXS   XXXS
FUEL  QTY   XXXS   XXXS   XXXS       QTY   XXXS   XXXS   XXXS
    TK P    XXXS   XXXS   XXXS  ACCUM P   XXXXS  XXXXS  XXXXS
   OUT P    XXXS   XXXS   XXXS
TK VLV A     XXS    XXS    XXS
     A T     XXXS   XXXS   XXXS
       B     XXS    XXS    XXS
     B T     XXXS   XXXS   XXXS  W/B          1      2      3
OIL    T     XXXS   XXXS   XXXS
   OUT T     XXXS   XXXS   XXXS  CNTLR       XXX    XXX    XXX
   OUT P     XXXS   XXXS   XXXS  H2O QTY     XXXS   XXXS   XXXS
GBX    P     XXXS   XXXS   XXXS  N2     P   XXXXS  XXXXS  XXXXS
    N2 P     XXXS   XXXS   XXXS        T    XXXS   XXXS   XXXS
   BRG T     XXXS   XXXS   XXXS  REG    P   XXXS   XXXS   XXXS
GG BED T     XXXS   XXXS   XXXS  BYP VLV    XXXS   XXXS   XXXS
PUMP/VLV                         VENT   T  ±XXXS  ±XXXS  ±XXXS
    PMP T    XXXS   XXXS   XXXS  TANK   T  ±XXXS  ±XXXS  ±XXXS
    VLV T    XXXS   XXXS   XXXS  BLR    T  ±XXXS  ±XXXS  ±XXXS

                                                          (XX)
```

FIGURE 6.9-1. JSC-19590

C

```
XXXX/XXX/087        HYD THERMAL    XX X DDD/HHIMMISS
                                   DDD/HHIMMISS
                                  | CIRC PUMP CONTROL
 HYD          | 1  |  2  |  3    | LINE TEMPS | 1  |  2  |  3
CIRC PMP P | XXXS | XXXS | XXXS | ELEVON  LOB±XXXS±XXXS±XXXS
PMP BDY  T |±XXXS±XXXS±XXXS |       LIB±XXXS±XXXS±XXXS
RSVR     T |±XXXS±XXXS±XXXS |       RIB±XXXS±XXXS±XXXS
ACCUM    P |XXXXS XXXXS XXXXS |      ROB±XXXS±XXXS±XXXS
HX IN    T |±XXXS±XXXS±XXXS | RUD/SB  PDU±XXXS±XXXS±XXXS
   OUT   T |±XXXS±XXXS±XXXS |         FUS±XXXS±XXXS±XXXS
                                BDYFLP  PDU±XXXS±XXXS±XXXS
 SW VLV      PR    S1    S2           FUS±XXXS±XXXS±XXXS
ELEV L OB   3XS   1XS   2XS  L BRAKE  WHL     ±XXXS±XXXS
        IB   2XS   1XS   3XS           FUS     ±XXXS±XXXS
     R  IB   3XS   1XS   2XS  R BRAKE  WHL±XXXS±XXXS±XXXS
        OB   2XS   1XS   3XS           FUS±XXXS±XXXS±XXXS
RUD/SPDBK   1XS   2XS   3XS  NG      UPLK±XXXS
                                   MFUS ±XXXS
 TIRE PRESS                        MFUS ±XXXS
MG     LEFT        RIGHT          MG L   UPLK±XXXS
 IB XXXS XXXS XXXS XXXS           MG R   UPLK±XXXS
 OB XXXS XXXS XXXS XXXS             FUS±XXXS
NG  XXXS XXXS XXXS XXXS

                                                          (XX)
```

FIGURE 6.10-1. JSC-19590

D

```
XXXX/XXX/088  APU/ENVIRON THERM XX X DDD/HHIMMISS
                                  DDD/HHIMMISS
 FREON LOOP      1      2       |                 1      2
ACCUM QTY      XXXS   XXXS      | H2O LOOP                XXXS   XXXS
FREON FLOW     XXXXS  XXXXS     | PUMP OUT P              XXXXS  XXXXS
PL HX FLOW     XXXXS  XXXXS     |      OUT T              XXXXS  XXXXS
AFT CP FLOW     XXXS   XXXS     |           ΔP            XXXXS  XXXXS
RAD IN T        XXXS   XXXS     | ICH FLOW                XXXXS  XXXXS
RAD OUT T       XXXS   XXXS     |      OUT T              XXXXS  XXXXS
EVAP OUT T      XXXS   XXXS     | CAB HX IN T             XXXXS  XXXXS
 EVAP TEMP    DUCT   NOZ        | ACCUM QTY               XXXXS  XXXXS
HI LOAD INBD XXXS               |  APU FUEL T | 1      2      3
       OUTBD XXXS   XXXS        | TK SURF     | ±XXXS  ±XXXS  ±XXXS
TOPPING  FWD XXXS               | TK HTR      | ±XXXS  ±XXXS  ±XXXS
       AFT XXXS                 | TEST LN 1   | ±XXXS  ±XXXS  ±XXXS
         L XXXS   XXXS          | TEST LN 2   | ±XXXS  ±XXXS  ±XXXS
         R XXXS   XXXS          | FEED LN     | ±XXXS  ±XXXS  ±XXXS
EVAP FDLN T   A      B          | PUMP IN     | ±XXXS  ±XXXS  ±XXXS
       FWD XXXS   XXXS          |  DRN LN 1   | ±XXXS  ±XXXS  ±XXXS
       MID 1 XXXS   XXXS        |  DRN LN 2   | ±XXXS  ±XXXS  ±XXXS
       MID 2 XXXS   XXXS        |  OUT        | ±XXXS  ±XXXS  ±XXXS
       AFT XXXS   XXXS          |  BYP LN     | ±XXXS  ±XXXS  ±XXXS
   TOPPING XXXS   XXXS          | GG SPLY LN XXXS   XXXS   XXXS
     ACCUM XXXS   XXXS          |
   HI LOAD XXXS   XXXS          | H20 LN INJ±XXXS ±XXXS ±XXXS
                                                          (XX)
```

FIGURE 6.11-1. JSC-19590

E

```
XXXX/XXX/089     PRPLT THERMAL    XX X DDD/HHIMMISS
                                  DDD/HHIMMISS
    POD          L      R
OMS TK      OX XXXS XXXS
            FU XXXS XXXS   OMS CRSFD    L      R      C
ENG I/F     OX XXXS XXXS   XFD       OX XXXS XXXS XXXS
            FU XXXS XXXS       GMBL LN XXXS XXXS
       OX VLV XXXS XXXS    DRN       OX XXXS XXXS
       FU INJ XXXS XXXS

WEB KEEL    1 XXXS XXXS
            2 XXXS XXXS                    FU     OX
     Y      OB XXXS XXXS   BLD AFT FUS XXXS XXXS
            UP XXXS XXXS         PL BAY XXXS XXXS
OX DRN PNL  1 XXXS XXXS
            2 XXXS XXXS   FWD RCS      FU     OX
ENG     COVER XXXS XXXS        LINE T1 XXXS XXXS
   SERV PNL   XXXS XXXS              T2 XXXS XXXS
GSE SERV PNL  XXXS XXXS
TEST HE/OX  1 XXXS XXXS   AFT RCS      L      R
            2 XXXS XXXS   MANF 1    OX XXXS XXXS
                          DRN PNL    1 XXXS XXXS
                                     2 XXXS XXXS
                          VERN PNL   1 XXXS XXXS
                                     2 XXXS XXXS
                                                (XX)
```

FIGURE 6.12-1. JSC-19590

F

```
XXXX/XXX/096        PDRS STATUS    XX X DDD/HHIMMISS
                                   DDD/HHIMMISS
RMS SEL: XXXX

                      X/P          Y/Y          Z/R
TRANS RATES ACT   ±XX.XXS      ±XX.XXS      ±XX.XXS
            CMD   ±XX.XX       ±XX.XX       ±XX.XX
ROT RATES   ACT   ±XX.XXS      ±XX.XXS      ±XX.XXS
            CMD   ±XX.XX       ±XX.XX       ±XX.XX
POSITIONS   ACT   ±XXXXXS      ±XXXXXS      ±XXXXXS
ATTITUDES   ACT   ±XXX.XS      ±XXX.XS      ±XXX.XS

JNT ANGLES: SY: ±XXX.X   SP: ±XXX.X   EP: ±XXX.X
            WP: ±XXX.X   WY: ±XXX.X   WR: ±XXX.X

FAULTS:  SY SP EP WP WY WR   MCIU:        CHECK CRT:
REACH LIM X  X  X  X  X  X     GADC X       DC/MCIU X
ABE- TACH X  X  X  X  X  X     MCPC X       EXT FS  X
 SDA BITE X  X  X  X  X  X     ICF  X       EE FLAG X
 SPA +28V X  X  X  X  X  X                  EEEU    X
 SPA COMM X  X  X  X  X  X   ABE:           EE CMOS X
 UPC BITE X  X  X  X  X  X     COMM X       MCIU HC X
CONTR ERR X  X  X  X  X  X                  TMP CAT X
CACH1-CMS X  X  X  X  X  X

                                                (XX)
```

FIGURE 6.13-1. JSC-19590

G

```
XXXX/XXX/097      PL RETENTION     XX X DDD/HHIMMISS
                                   DDD/HHIMMISS

                 LATCH 1  LATCH 2  LATCH 3  LATCH 4  LATCH 5
                 AB/AB    AB/AB    AB/AB    AB/AB    AB/AB
PL SEL 1
 RDY-FOR-LAT     XX       XX       XX       XX       XX
     LAT/REL     XX/XX    XX/XX    XX/XX    XX/XX    XX/XX

PL SEL 2
 RDY-FOR-LAT     XX       XX       XX       XX       XX
     LAT/REL     XX/XX    XX/XX    XX/XX    XX/XX    XX/XX

PL SEL 3
 RDY-FOR-LAT     XX       XX       XX       XX       XX
     LAT/REL     XX/XX    XX/XX    XX/XX    XX/XX    XX/XX

                                                (XX)
```

FIGURE 6.14-1. JSC-19590

H

```
XXXX/XXX/168      CRYO PALLET      XX X DDD/HHIMMISS
                                   DDD/HHIMMISS
                      TK
  O2          6      7      8      9
P          XXXXS  XXXXS  XXXXS  XXXXS  PALLET T
TK P       XXXXS  XXXXS  XXXXS  XXXXS      STBD  A  ±XXXS
QTY         XXXS   XXXS   XXXS   XXXS      STBD  B  ±XXXS
T          ±XXXS  ±XXXS  ±XXXS  ±XXXS      PORT  A  ±XXXS
HTR T 1    ±XXXS  ±XXXS  ±XXXS  ±XXXS      PORT  B  ±XXXS
       2   ±XXXS  ±XXXS  ±XXXS  ±XXXS
HTR   1A       S      S      S      S  PALLET VOLTS
CUR   1B       S      S      S      S      PPC1 MNA XX.XS
SNSR  2A       S      S      S      S      PPC2 MNB XX.XS
      2B       S      S      S      S
  H2
P          XXXS   XXXS   XXXS   XXXS
TK P       XXXS   XXXS   XXXS   XXXS
QTY         XXXS   XXXS   XXXS   XXXS
T          ±XXXS  ±XXXS  ±XXXS  ±XXXS
HTR T      ±XXXS  ±XXXS  ±XXXS  ±XXXS

                                                (XX)
```

FIGURE 6.18-1. JSC-19590

SYSTEM LEVEL

A

```
                    XXXX IPL MENU (1) XX X DDD/HH MM SS
                                        DDD/HH MM SS
PASS1   1X    PASS5   9X
BFS1    2X    BFS5   10X    STP/PURGE CYC CNT   XXXXX
PASS2   3X    PASS6   11X   ERROR/MSG CODE        XXX
BFS2    4X    BFS6   12X    ERROR/MSG CODE CNT  XXXX
PASS3   5X    PASS7   13X   TOTAL ERR/MSG CNT    XXXX
BFS3    6X    BFS7   14X    MSGS STILL IN LIST    XXX
PASS4   7X    PASS8   15X
BFS4    8X    BFS8   16X            MCDS BITE
                                      MODE   XXXX
17 DEU FORMAT LOAD X                  BSR1   XXXX
                                      BSR2   XXXX
START GPC SELF TEST 18X               SWSW   XXXX
STOP  GPC SELF TEST 19X
START DEU SELF TEST 20X
STOP STP ON ERROR   24X
CONTINUE STP ON ERR 25X
INHIBIT CKPT LOAD   26X
```

IPL MENU NO. 1 (PFS/BFS)

B

```
                    GPC IPL MENU (2) XX X DDD/HH MM SS
                                        DDD/HH MM SS
17 DEU FORMAT LOAD X          STP/PURGE CYC CNT XXXXX
                              ERROR/MSG CODE       XXX
START GPC SELF TEST 18X       ERROR/MSG CODE CNT XXXX
STOP  GPC SELF TEST 19X       TOTAL ERR/MSG CNT  XXXX
START DEU SELF TEST 20X       MSGS STILL IN LIST  XXX
STOP STP ON ERROR   24X
CONTINUE STP ON ERR 25X              MCDS BITE
INHIBIT CKPT LOAD   26X                MODE XXXX
                                       BSR1 XXXX
                                       BSR2 XXXX
                                       SWSW XXXX

OLD PSW   XXXX XXXX XXXX XXXX
REGISTER 0-3  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
  SET 0   4-7  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

REGISTER 0-3  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
  SET 1   4-7  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX

FLOATING 0-3  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
 PT REGS 4-7  XXXXXXXX XXXXXXXX XXXXXXXX XXXXXXXX
MAJ=XXXXX  MIN=XX SCHEDWRD=XXXXXXXX  CLOCK1=XXXXX
                                                (XX)
```

GPCIPL MENU NO. 2

C

```
0001/   /          GPC MEMORY          XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS
MEM/BUS CONFIG     READ/WRITE  XXX
1 CONFIG XX(XX)     DATA 20X  BIT SET 22X  SEQ ID 24
2 GPC X X X X X     CODE 21X  BIT RST 23X  WRITE  25
                    26 ENG UNITS XXX       HEX 27X
STRING 1   7 X      ADD ID   DESIRED   ACTUAL
       2   8 X     28 XXXXX  29 XXXX  ±XXXXXXXXXXX
       3   9 X     30 XXXXX  31 XXXX  ±XXXXXXXXXXX
       4  10 X     32 XXXXX  33 XXXX  ±XXXXXXXXXXX
    PL 1/2 11 X     34 XXXXX  35 XXXX  ±XXXXXXXXXXX
                    36 XXXXX  37 XXXX  ±XXXXXXXXXXX
     CRT 1 12 X     38 XXXXX  39 XXXX  ±XXXXXXXXXXX
         2 13 X
         3 14 X    MEMORY DUMP              STORE   MC=XX
         4 15 X     40 START ID  XXXXX       45 CONFIG XX
                    41 NO WORDS  XXXXXX      46 GPC X
  LAUNCH 1 16 X   * 42 WDS/FRAME XXX         STORE 47
         2 17 X     DUMP  43
      MM 1 18 X
         2 19 X    44 DOWNLIST GPC X        MM AREA
                     OPS 0 ENA 49  X          PL  52 X
OPS 3 UPLK 50X                                GNC 53 X
OPS 3 INIT 51      ERR LOG RESET 48           SM  54 X
                                                (XX)
```

GPC MEMORY

D

```
XXXX/001/          DPS UTILITY          XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS
MMU ASSIGN          PORT ASSIGN
    1   2                PRI  SEC          VL CNTL
  GNC 1X  2X    STRING 1  15X  16X         AUTO 35X
   SM 3X  4X           2  17X  18X          ENA 36X
   PL 5X  6X           3  19X  20X          INH 37X
OPS 0 7X  8X           4  21X  22X
                    PL 1/2  23X  24X      IPL SOURCE SW
MMU STATUS                                  MASK 38X
  1 XXX
  2 XXX             VAR PARAM ID LIST
                     25 XXXX
MMU SOURCE/BUS       26 XXXX                 G3 ARCHIVE
  GPC/MMU   9X       27 XXXX                   LOAD    48X
  MMU/MMU  10X       28 XXXX                   RETRIEVE 49X
  GPC/LDB  11X       29 XXXX
                     30 XXXX                GROUND OPS
CKPT RETRV           31 XXXX              GSE POLL ENA 50X
      ENA 12X        32 XXXX                SM GSE INH 51X
                     33 XXXX                SM C/O ENA 52X
RTC                  34 XXXX               GNC C/O ENA 53X
 13 XXXX XXXX                              BFC C/O ENA 54X
 CMD 14                                     ALT PL9 TB 55X
                                                (XX)
```

DPS UTILITY

E

```
XXXX/002/              TIME          XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS
MISSION TIME                          TONE
  GMT 1X                               3  XX:XX:XX MSN T
  MET 2X                               6  XX:XX:XX
CRT TIMER                            20 [#XX:XX:XX CRT T
  9 SET [#XX:XX:XX
  START 12    STOP 13
  14 START AT XX:XX:XX MSN T         23 DURATION  XX
  17 COUNT TO XX:XX:XX MSN T

MTU
  24 GMT Δ [#XXX/XX:XX:XX.XXX
  28 MET Δ [#XXX/XX:XX:XX.XXX
     UPDATE 32                    MET RESET 33

GPC TIME                                        GPC
                      GMT          | TRY |  1 XX
  MTU ACCUM 1 | XXX/XX:XX:XX.XXXS  |  34 |  2 XX
            2 | XXX/XX:XX:XX.XXXS  |  35 |  3 XX
            3 | XXX/XX:XX:XX.XXXS  |  36 |  4 XX
          GPC | XXX/XX:XX:XX.XXXS  |  37 |  5 XX

  TIME SYNC 38                                  (XX)
```

TIME

F

```
XXXX/XXX/099           FAULT         XX X DDD/HH:MM:SS
                                           DDD/HH:MM:SS

  CRT        FAULT        C/W   GPC      TIME
  ID

  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX
  XXX  XXXXXXXXXX  XXXX   X    XXXXX  XXX/XX:XX:XX

                                                (XX)
```

FAULT

G

```
XXXX/XXX/006     GPC/BUS STATUS     XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
        GPC | 1S  | 2S  | 3S  | 4S  | 5S
       MODE | XXXX| XXXX| XXXX| XXXX| XXXX
        OPS | XX  | XX  | XX  | XX  | XX
STRING 1 FF | XS  | XS  | XS  | XS  | XS
         FA | XS  | XS  | XS  | XS  | XS
       2 FF | XS  | XS  | XS  | XS  | XS
         FA | XS  | XS  | XS  | XS  | XS
       3 FF | XS  | XS  | XS  | XS  | XS
         FA | XS  | XS  | XS  | XS  | XS
       4 FF | XS  | XS  | XS  | XS  | XS
         FA | XS  | XS  | XS  | XS  | XS

      PL 1  | XS  | XS  | XS  | XS  | XS
         2  | XS  | XS  | XS  | XS  | XS
  LAUNCH 1  | XS  | XS  | XS  | XS  | XS
         2  | XS  | XS  | XS  | XS  | XS
   CRT   1  | XS  | XS  | XS  | XS  | XS
         2  | XS  | XS  | XS  | XS  | XS
         3  | XS  | XS  | XS  | XS  | XS
         4  | XS  | XS  | XS  | XS  | XS

                                                (XX)
```

GPC/BUS STATUS

VEHICLE UTILITY

A

```
8011/   /        FCS/DED DIS C/O   XX X DDD/HH:MM:SS
                                      DDD/HH:MM:SS

 DED DIS              MODE LT          AVG G  ON  9X
FWD 1X  HIGH 3X       ON   7X
AFT 2X  LOW  4X       OFF  8X
        FLAG 5X
        OFF  6X

                   SURF DR  START 10X  STOP 11X

 BODY FLP DES
VLV 1 XXX 12X
    2 XXX 13X    SURF          CMD     POS    1 2 3 4
    3 XXX 14X    ELEV L  OB   XXX.X   XXX.XS  S S S S
                         IB   XXX.X   XXX.XS  S S S S
  SEC ACT CK         R  IB   XXX.X   XXX.XS  S S S S
CH 1  15X               OB   XXX.X   XXX.XS  S S S S
CH 2  16X            RUD        XXX.X   XXX.XS  S S S S
CH 3  17X            SPD BRK    XXX.X   XXX.XS  S S S S
CH 4  18X            BDY FLP      XX    XXX.X
STOP  19X
POS STIM                                 SEC ACT
  ENA 20X                              21 BYPASS  XX
                                       22 RESET   XX

                                                 (XX)
```

FCS DEDICATED DISPLAY CHECKOUT

E

```
XXXX/042/          SWITCH/SURF          XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
        |ORIDE|DES      |ORIDE|DES
      1 1| XS | 1X    3 1| XS | 7X
      2  | XS | 2X      2  | XS | 8X
FCS   3  | XS | 3X      3  | XS | 9X
CH  2 1  | XS | 4X    4 1  | XS | 10X
      2  | XS | 5X      2  | XS | 11X
      3  | XS | 6X      3  | XS | 12X

          P                R/Y              SPD BRK BDY FLP
        |AUT|CSS|        |AUT|CSS|          AUT MAN  AUT DES
      L | XS| XS|        | XS| XS|          XS  XS   XS  13X
FCS   2 | XS| XS|        | XS| XS|          XS  XS   XS  14X
MODE  3 |XS |XS |        |XS |XS |          XS  XS   XS  15X
      R 1 | XS| XS|        | XS| XS|          XS  XS   XS  16X
        2 | XS| XS|        | XS| XS|          XS  XS   XS  17X
        3 | XS| XS|        | XS| XS|          XS  XS   XS  18X

                                        SPD BDY
        | L OB | L IB | R IB | R OB |  RUD  BRK FLP
SURF  1|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXS XS|19X
      2|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXS XS|20X
      3|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXS XS|21X
      4|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXX.XS|XXS XS|22X
                                                 (XX)
```

RM SWITCHES/SURFACES FEEDBACK

B

```
9011/   /        MASS MEMORY R/W   XX X DDD/HH:MM:SS
SM COM BUFF XXX                       DDD/HH:MM:SS
DESIRED ACTUAL  DESIRED ACTUAL
 1  XXXX  XXXX   21 XXXX  XXXX          SELECT
 2  XXXX  XXXX   22 XXXX  XXXX  MMU 1          40X
 3  XXXX  XXXX   23 XXXX  XXXX  MMU 2          41X
 4  XXXX  XXXX   24 XXXX  XXXX  42 S/W SYSTEM   X
 5  XXXX  XXXX   25 XXXX  XXXX  43 PHASE       XXX
 6  XXXX  XXXX   26 XXXX  XXXX  44 LOAD BLK     XXX
 7  XXXX  XXXX   27 XXXX  XXXX  45 OFFSET    XXXXX
 8  XXXX  XXXX   28 XXXX  XXXX  46 NUMBER      XX
 9  XXXX  XXXX   29 XXXX  XXXX  47 PATCH ID  XXXX
10  XXXX  XXXX   30 XXXX  XXXX    VIOLATE     XXX
11  XXXX  XXXX   31 XXXX  XXXX  READ LOAD BLK  48X
12  XXXX  XXXX   32 XXXX  XXXX  MERGE          49X
13  XXXX  XXXX   33 XXXX  XXXX  WRITE LOAD BLK 50X
14  XXXX  XXXX   34 XXXX  XXXX  COMPARE        51X
15  XXXX  XXXX   35 XXXX  XXXX  STATUS       XXXX
16  XXXX  XXXX   36 XXXX  XXXX    ERROR CODE    X
17  XXXX  XXXX   37 XXXX  XXXX  REGISTER A    XXXX
18  XXXX  XXXX   38 XXXX  XXXX             B   XXXX
19  XXXX  XXXX   39 XXXX  XXXX  MM VERSION  XX.XX
20  XXXX  XXXX   CHECKSUM XXXX  DUMP VIA DL    52X

                                                 (XX)
```

MASS MEMORY READ/WRITE

F

```
XXXX/043/          CONTROLLERS          XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
        |T|X|Y|T|Z|DES                    |R |P |Y |DES
      1|X|S|X|S|S| 1X                   1|XXS|XXS|XXS|53X
      2|X|S|X|S|S| 2X                   2|XXS|XXS|XXS|54X
THC   3|X|S|X|S|S| 3X      BDY FLP      3|XXS|XXS|XXS|55X
      1|X|S|X|S|S| 4X        LEFT DES   1|XXS|XXS|XXS|56X
      2|X|S|X|S|S| 5X      L|XS|XS|19X RHC 2|XXS|XXS|XXS|57X
      3|X|S|X|S|S| 6X  SW   2|XS|XS|20X    3|XXS|XXS|XXS|58X
      1|XXS| 7X             R|XS|XS|21X    1|XXS|XXS|XXS|59X
      2|XXS| 8X               2|XS|XS|22X  2|XXS|XXS|XXS|60X
      3|XXS| 9X                            3|XXS|XXS|XXS|61X
SPD   1|XXS|10X                          L|1| XS| XS|  |62X
BK  R 2|XXS|11X                          RHC 2| XS| XS|  |63X
      3|XXS|12X                          TRIM R1| XS| XS|  |64X
      1|XXS|13X                            2| XS| XS|  |65X
      2|XXS|14X                          L|1| XS| XS| XS|66X
RUD   3|XXS|15X                          PNL 2| XS| XS| XS|67X
PED   1|XXS|16X                          TRIM R1| XS| XS| XS|68X
      2|XXS|17X                            2| XS| XS| XS|69X
      3|XXS|18X

                                                 (XX)
```

RM CONTROLLERS

C

```
XXXX/040/          SENSOR TEST          XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
          DES STAT  RNG      AZ      EL
MLS 1   1X XXXX XX.XS  ±X.XXS X.XXS
      2 2X XXXX XX.XS  ±X.XXS X.XXS
      3 3X XXXX XX.XS  ±X.XXS X.XXS

          DES STAT  RNG     AZ
TAC 1   4X XXXX  X.XS XXX.XXS
      2 5X XXXX  X.XS XXX.XXS
      3 6X XXXX  X.XS XXX.XXS

          DES STAT  ALT
RA  1   7X XXXX XXXXS
      2 8X XXXX XXXXS

          DES       Y         Z
AA  1   9X      ±XX.XS    ±XX.XS
      2 10X     ±XX.XS    ±XX.XS
      3 11X     ±XX.XS    ±XX.XS
      4 12X     ±XX.XS    ±XX.XS

            START 13X  STOP 14X

                                                 (XX)
```

SENSOR TEST

G

```
XXXX/044/          SWITCHES             XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
                          ENTRY ROLL MODE
                          LOW  NO
                          GAIN Y/J DES
                        1  XS   XS  1X
                        2  XS   XS  2X
                        3  XS   XS  3X
                        4  XS   XS  4X

                                                 (XX)
```

SWITCHES

D

```
XXXX/041/          RGA/ADTA/RCS         XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
   DES STAT     R        P        Y
R1  1X XXXX  ±XX.XS   ±XX.XS   ±XX.XS
G2  2X XXXX  ±XX.XS   ±XX.XS   ±XX.XS
A3  3X XXXX  ±XX.XS   ±XX.XS   ±XX.XS
 4  4X XXXX  ±XX.XS   ±XX.XS   ±XX.XS

   DES STAT     PS      P*C      P*U      P*L       T
A1  5X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
D3  6X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
T2  7X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
A4  8X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS

TEST   HI 9X   LOW 10X   STOP 11X

                RCS DRIVERS

   RJDF   12X    TEST EXEC 15X    TEST XXXX
   RJDA-A 13X    CONTINUE  16X    JET   XXX
       -B 14X    STOP      17

                                                 (XX)
```

RGA/ADTA/RCS

H

```
XXXX/045/          NWS CHECK            XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
          SYS  HYD PRESS
          SEL  HIGH   ENABLE   CURRENT    POSITION
NWS1  XS   XS     A XS      XX.XXS     A XX.XXS
                  B XS                 B XX.XXS
                                       C XX.XXS
NWS2  XS   XS     A XS      XX.XXS
                  B XS

STIMULI
ENABLE                1X
RIGHT TURN (+)        2X
LEFT TURN  (-)        3X
STOP                  4X

                                                 (XX)
```

NWS CHECK

A

```
XXXX/100/          GTS DISPLAY      XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS

HDA CONTROL                DED DISP
  ENA 1X  INH 2X             FWD  18X   AFT 19X  DRIVE 24X
                             HIGH 20X   LOW 21X
CSL/RML TEST                 FLAG 22X   OFF 23X
 UF1 3X UF4 6X
 UF2 4X UF5 7X           CRIT MEC CMDS     ELEV LMT SEL
 UF3 5X IFA 8X             ENA  25X                HORZ  27X
 9 FAIL GPC SEL X          INH  26X                VERT  28X
 TEST EXEC 10X                                     OWPS  29X
 RESET     11X
                          SL COMM      SSC      EXC
                            CH A ENA   30X      35X
DL FORMAT                      B ENA   31X      36X
    12 SEL  XX                 DSBL    32X      37X
     LOAD 13X
                          MDM TESTS
                            RTRN CHW 33 XXXX 38 XXXX
GSE POLL ENA  14X           RTRN MSG 34 XXXX 39 XXXX

PASS/BFS XFER 15          COUPLER
                            STATE    XXXX     XXXX
RJD TOGGLER                 ERR CD     XX       XX
  ON 16X  OFF 17X

                                                (XX)
```

GENERAL TEST SUPPORT

E

```
XXXX/105/          TCS CONTROL      XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
1 SELECT ID XX          NAME XXXXXXXX      ECP  ERROR XXX
MM READ 2 XXXX          STATUS   XXXX      ERROR CODE XXX
  STEP   XXXXX          TIME XX:XX:XX      BITE       XXXX
  STOP     3          4 STOP AT XXXXX      CANCEL        5
  RESUME   6          7 RSM AT  XXXXX      CLEAR MSGS    8

   TIME                    TEXT
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX:XX:XX     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                          (XX)
```

TCS CONTROL

B

```
XXXX/101/       SENSOR SELF-TEST   XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS

   ENA STAT  RNG    AZ       EL
M1  1X XXXX XX,XS  ±X,XXS  X,XXS
L2  2X XXXX XX,XS  ±X,XXS  X,XXS
S3  3X XXXX XX,XS  ±X,XXS  X,XXS

   ENA STAT  RNG    AZ
T1  4X XXXX  X,XS XXX,XXS
A2  5X XXXX  X,XS XXX,XXS          TEST CONTROL:
C3  6X XXXX  X,XS XXX,XXS            START      13X
                                     AUTO SEQ   14X
   ENA STAT  ALT                     TERM       15X
R1  7X XXXX XXXXS
A2  8X XXXX XXXXS                      INH ALL  16X

   ENA          Y          Z
A1  9X      ±XX,XS     ±XX,XS
A2 10X      ±XX,XS     ±XX,XS
 3 11X      ±XX,XS     ±XX,XS
 4 12X      ±XX,XS     ±XX,XS

                                                (XX)
```

SENSOR SELF-TEST

F

```
XXXX/110/          BUS/BTU STATUS     XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
                  B T O P                 B T O P
          FF1P    X X X X LF1P    X X X X
MODE X     1S     X X X X  1S     X X X X PMU      X X X X
MC   X     2P     X X X X LA1P    X X X X EIU1A    X X X X
MF   XX    3S     X X X X  1S     X X X X    1B    X X X X
     XX    3P     X X X X PM1P    X X X X    1C    X X X X
CPU XX     3S     X X X X  1S     X X X X    1D    X X X X
           4P     X X X X LL1P    X X X X    2A    X X X X
          FF4S    X X X X  1S     X X X X    2B    X X X X
PRI/SEC FA1P      X X X X  2P     X X X X    2C    X X X X
 PORTS     1S     X X X X  2S     X X X X    2D    X X X X
           2P     X X X X LR1P    X X X X    3A    X X X X
PRI 1X     2S     X X X X  1S     X X X X    3B    X X X X
SEC 2X     3P     X X X X  2P     X X X X    3C    X X X X
           3S     X X X X  2S     X X X X EIU3D    X X X X
           4P     X X X X MCIU    X X X X MEC1A    X X X X
          FA4S    X X X X                 1B       X X X X
          MMU1    X X X X LDIUP   X X X X    1C    X X X X
             2    X X X X      5  X X X X    1D    X X X X
          DEU1    X X X X PF1P    X X X X    2A    X X X X
             2    X X X X  1S     X X X X    2B    X X X X
             3    X X X X  2S     X X X X    2C    X X X X
             4    X X X X  2P     X X X X MEC2D    X X X X
                                                (XX)
```

BUS/BTU STATUS

C

```
XXXX/102/      RCS/RGA/ADTA TEST XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
RCS DRIVERS

  RJDF   1X    START TEST 4X  STAT XXXX
  RJDA-A 2X    CONT       5X  JET   XXX
      -B 3X    TERM       6   STEP    X

SENSORS                                   TEST CONTROL:
                                            HIGH START  15X
   ENA STAT      R          P          Y     LOW START  16X
R1  7X XXXX  ±XX.XS     ±XX.XS     ±XX.XS   AUTO SEQ   17X
G2  8X XXXX  ±XX.XS     ±XX.XS     ±XX.XS   TERM       18X
A3  9X XXXX  ±XX.XS     ±XX.XS     ±XX.XS
 4 10X XXXX  ±XX.XS     ±XX.XS     ±XX.XS   INH ALL    19X

   ENA STAT  P*C      PS       P*U       P*L       TT
A1 11X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
D3 12X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
T2 13X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS
A4 14X XXXX XX.XXXS XX.XXXS XX.XXXS XX.XXXS XXX.XXS

                                                (XX)
```

RCS/RGA/ADTA TEST

G

```
XXXX/111/       SL MEMORY DUMP     XX X DDD/HH:MM:SS
SM COM BUFF XXX                           DDD/HH:MM:SS

SL COMP SEL
  SS  1X
  EXP 2X
SL COUPLER
  SEL A 3X
      B 4X
5 START ADD  XXXX
6 LENGTH     XXXXX
DUMP 7 XXXX

WORDS ACQ XXXXX
FAIL PHW  XXXX
      AW  XXXXX
LAST ADD  XXXX

                                                (XX)
```

SPACELAB MEMORY DUMP

D

```
XXXX/104/      GND IMU CNTL/MON   XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
IMU        1          2          3
X    1 XXX.XX   4 XXX.XX   7 XXX.XX    SEL IMU 1 16X
Y    2 XXX.XX   5 XXX.XX   8 XXX.XX            2 17X
Z    3 XXX.XX   6 XXX.XX   9 XXX.XX            3 18X

     O  XXX.XX     XXX.XX     XXX.XX   ATT DET     19X
     M  XXX.XX     XXX.XX     XXX.XX   HNGR CAL A  20X
     I  XXX.XX     XXX.XX     XXX.XX            B  21X
    IR  XXX.XX     XXX.XX     XXX.XX            C  22X
  V  X  ±XX.XX     ±XX.XX     ±XX.XX   PREFLT CAL  23X
     Y  ±XX.XX     ±XX.XX     ±XX.XX   GYROCOMP    24X
     Z  ±XX.XX     ±XX.XX     ±XX.XX     XXXX  XXXX
  VRSS   XX.XX       XX.XX      XX.XX   INERTIAL    25X
                                       PLAT POS    26X
BI MDW    XXXX       XXXX       XXXX   TERM/IDLE   27X
II S/W      XX         XX         XX
TSTAT       XX         XX         XX   28 MM WRITE  X
                                          READ     29X
PWR ON       X          X          X   MM STATUS XXXX
I/O          S          S          S
STBY       10X        11X        12X   30 SITE SEL  X
OPER       13X        14X        15X   ACTUAL     XXX
                                                (XX)
```

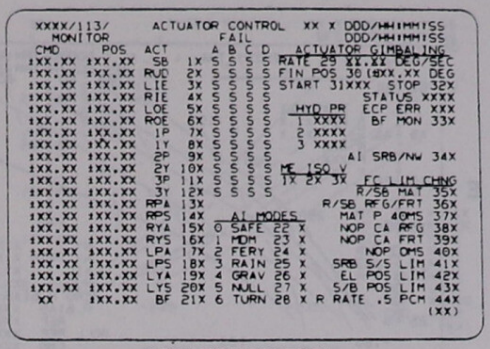
GROUND IMU CONTROL/MONITOR

H

```
XXXX/112/        GPC/BTU I/F      XX X DDD/HH:MM:SS
                                          DDD/HH:MM:SS
  BTU SELECTION     TEST STATUS
FF1 1X  PCMMU 12X        XXXX   MDM OUTPUT TEST
  2 2X  MMU1  13X  BTU ITEM XX      MODULE XX
  3 3X     2  14X  STEP XXXXXX
  4 4X  MEC1  15X  RDW    XXXX   ANALOG OUTPUTS
FA1 5X     2  16X  BCE STAT RG     0 ±X.XX  1 ±X.XX
  2 6X  EIU1  17X     XXXXXXXX     2 ±X.XX  3 ±X.XX
  3 7X     2  18X                  4 ±X.XX  5 ±X.XX
  4 8X     3  19X  PORT SEL 1 31X  6 ±X.XX  7 ±X.XX
PF1 9X  DDU  20X          2 32X   8 ±X.XX  9 ±X.XX
  2 10X MCIU  21X                 10 ±X.XX 11 ±X.XX
        CMD   22X                 12 ±X.XX 13 ±X.XX
        SRB   23X                 14 ±X.XX 15 ±X.XX
ALL      DES
MDMS 11X ALL   24X                DISCRETE OUTPUTS
                                  CHANNNEL 0  XXXXXX
         LEVEL 1    25X           CHANNNEL 1  XXXXXX
TEST     LEVEL 2    26X           CHANNNEL 2  XXXXXX
         MDM OUTPUT 27X
CONTROL  TERMINATE  28
         CONTINUE   29          BTU CYCLIC BITE 30X

                                                (XX)
```

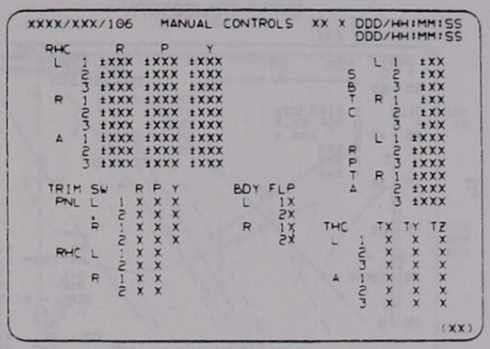
GPC/BTU INTERFACE

A



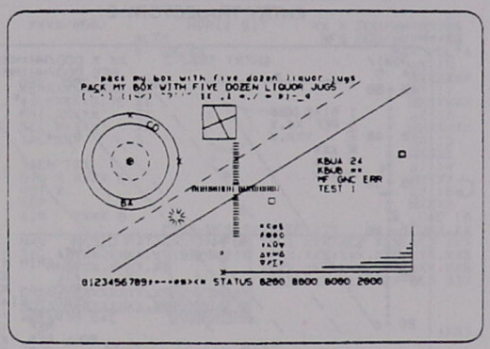
ACTUATOR CONTROL

B



MANUAL CONTROLS

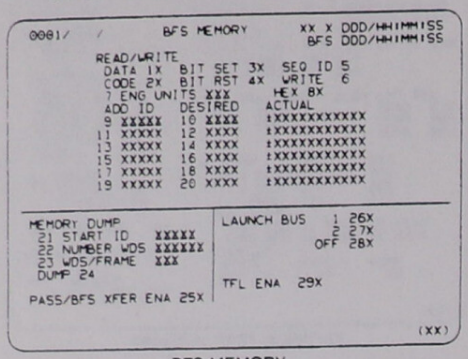
C



DEU STAND-ALONE SELF TEST

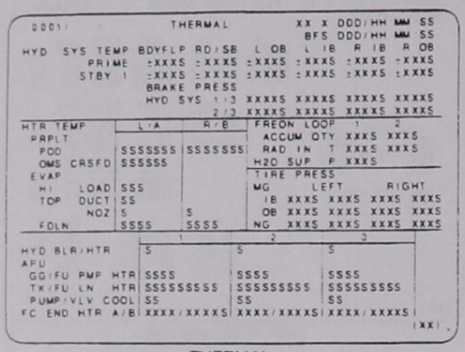
BACK-UP FLIGHT SYSTEM (BFS)

A



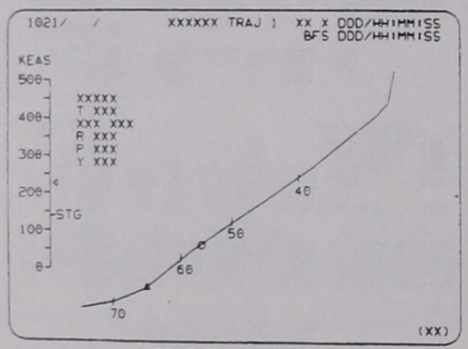
BFS MEMORY

B



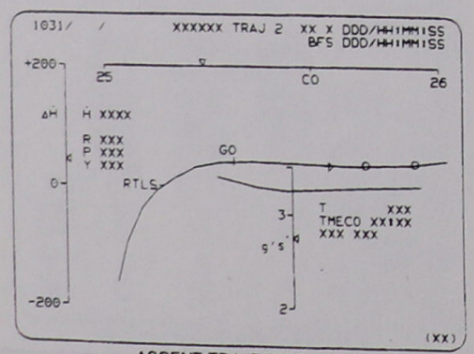
THERMAL

C



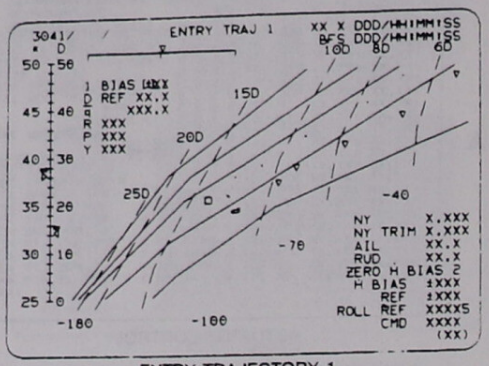
ASCENT TRAJECTORY 1

D



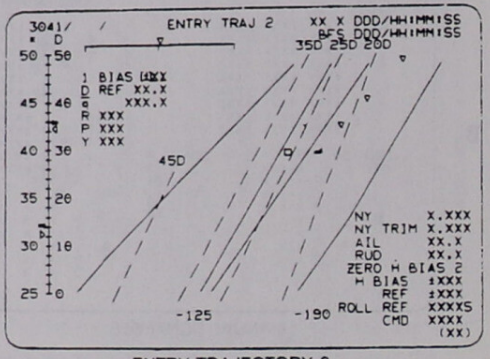
ASCENT TRAJECTORY 2

E



ENTRY TRAJECTORY 1

F



ENTRY TRAJECTORY 2

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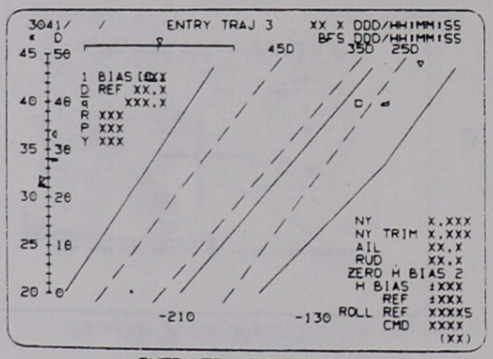
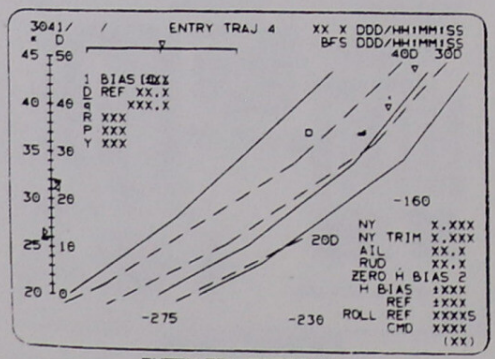


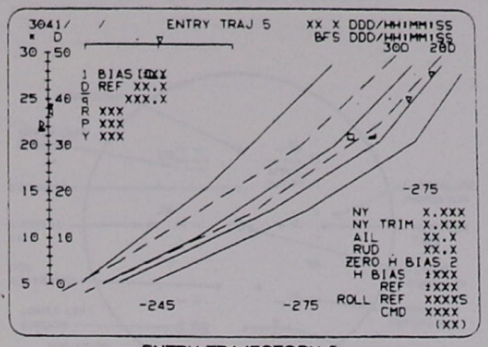
ENTRY TRAJECTORY 3

H



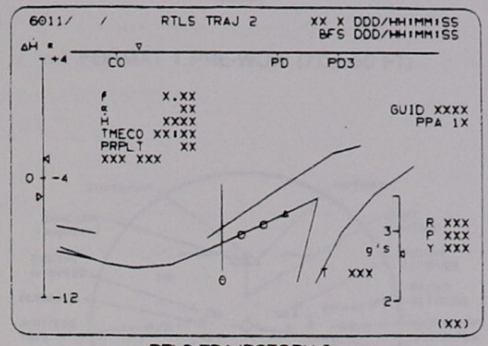
ENTRY TRAJECTORY 4

A



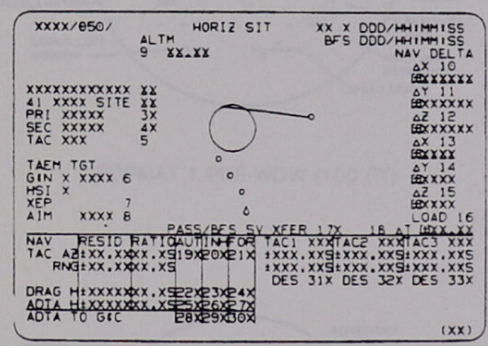
ENTRY TRAJECTORY 5

B



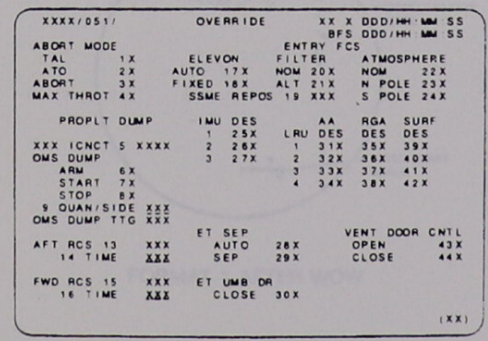
RTLS TRAJECTORY 2

C



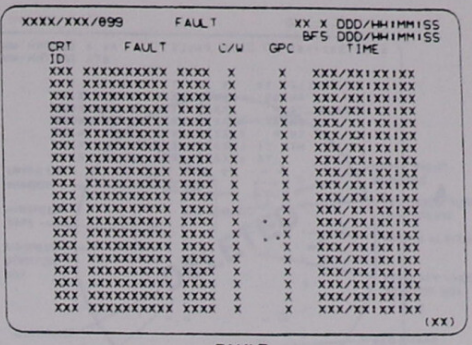
HORIZONTAL SITUATION

D



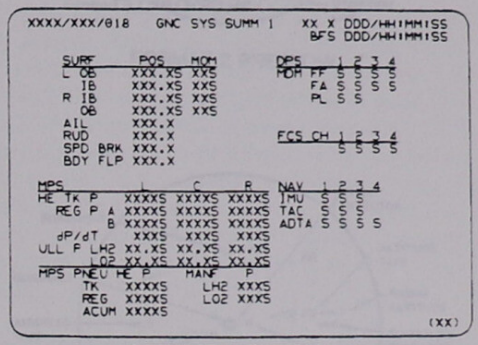
BFS OVERRIDE

E



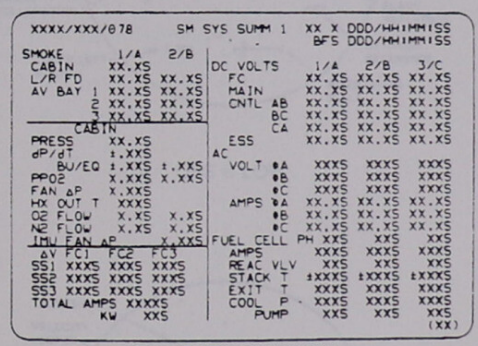
FAULT

F



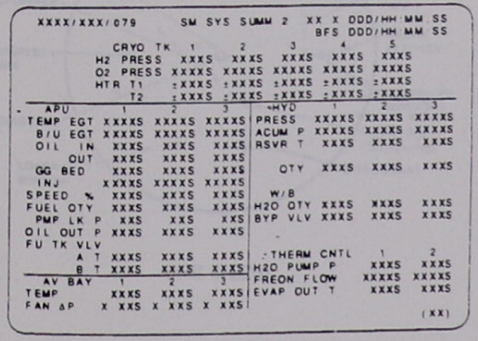
GNC SYSTEM SUMMARY 1

G



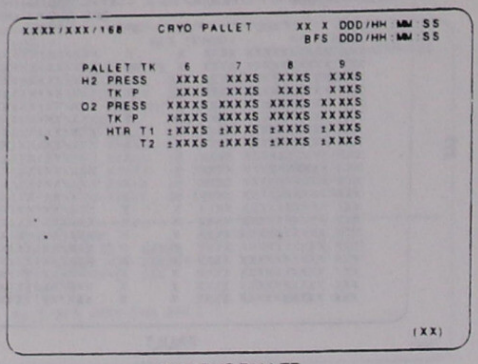
SM SYSTEM SUMMARY 1

H



SM SYSTEM SUMMARY 2

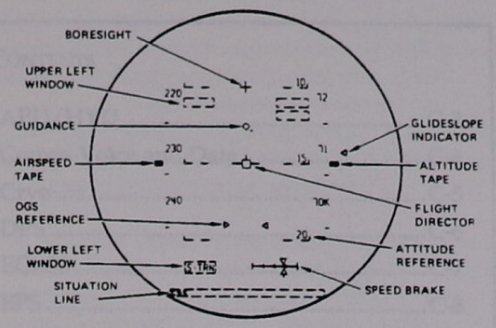
A



SM CRYO PALLET

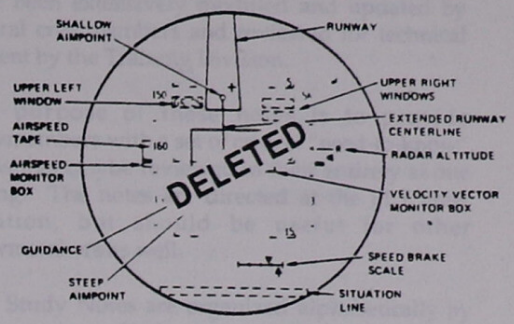
HEAD-UP DISPLAY (HUD)

A



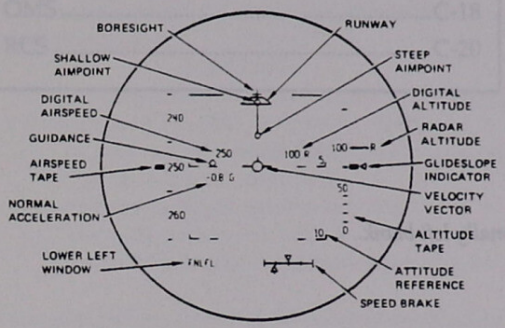
FORMAT 1 PRE-WOW (70,650 FT)

D



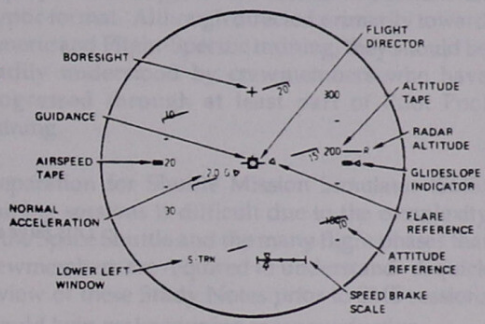
FORMAT 2 PRE-WOW

B



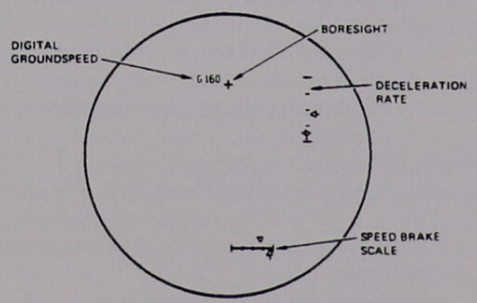
FORMAT 1 PRE-WOW (100 FT)

E



OPS 8 LOW

C



FORMAT 1 AFTER WOW

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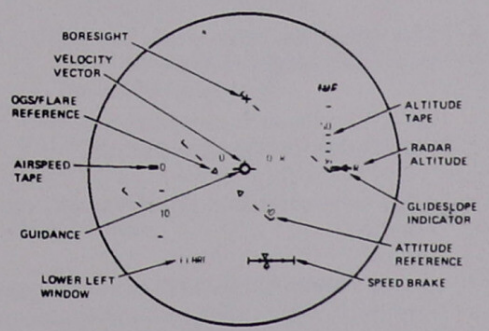

OPS 9 LOW

APPENDIX C: STUDY NOTES

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DPS C-6
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This appendix contains a set of study notes originally developed by Ron Grabe in September 1989. They have been extensively modified and updated by several crewmembers and reviewed for technical content by the Training Division.

The purpose of these notes is to provide crewmembers with a set of critical "need-to-know" items that can be reviewed in their entirety at one sitting. The notes are directed at the PLT crew position, but should be useful for other crewmembers as well.

The Study Notes are organized alphabetically by major system. Under each system heading, notes on critical subsystems and malfunctions are presented. The text is written in Flight Data File shorthand using switch nomenclature and CRT display terminology, which results in a somewhat cryptic format. Although directed primarily toward Generic and Flight-Specific training, they should be readily understood by crewmembers who have progressed through at least part of Pilot Pool training.

Preparation for Shuttle Mission Simulator (SMS) training sessions is difficult due to the complexity of the Space Shuttle and the many flight phases that crewmembers are required to understand. A quick review of these Study Notes prior to SMS sessions should help make training more productive.

APU/HYD

General

- Ascent: all APUs will be kept running through MECO if possible.
  - Loss of one APU means hydraulic lock on one engine.
  - Loss of two APUs means 2 SSMEs in hydraulic lock plus loss of TVC for one SSME.
- Entry
  - Pre-TAEM, a sick APU (high oil temperature, high hydraulic temperature, pump leak P, H_2O leak) may be manually shut down, cooled down, and restarted near Mach 1 to support landing.
  - Post-TAEM, APUs will generally be kept running except for high oil temperature. An APU will be shut down for high oil temperature if Mach > 1. A gearbox failure for high oil temperature is not catastrophic.

Auto Shutdown

- Controller will issue an auto shutdown command, if auto shutdown is enabled, for RPM less than 80% or above 129% (auto shutdown is inhibited for the first 9.5 seconds after start to allow turbine spinup).
- Auto shutdown closes secondary fuel control valve and fuel tank valves.
- An APU with an underspeed shutdown is a candidate for cooldown and restart.
- APUs with overspeed shutdown will not be restarted.
- If auto shutdown inhibited and APU speed is confirmed above 129%, manual shutdown is required as soon as possible.

Single APU Loss

- APU 1 means loss of nose wheel steering (OI-21 and subs, hydraulic system 2 can also be used for nose wheel steering).
- Single APU loss will not affect braking (loss of APU 3 plus either 1 or 2 means half brakes).

Switching Valves

- Supply either primary or one of two back-up hydraulic systems to the aerosurface actuators.
- Valve status only visible on SPEC 86 (SM OPS 2).
- During FCS checkout, check active hydraulic system selected.

Fuel Tank

- Supply supports about 110 minutes of operations (AOA).
- Nitrogen pre-charge required for start-up.
- Pressure displayed on panel F8 meter.
- Quantity (CRT and meter) is a PVT calculation.
- Isolation valves must be closed (de-powered) when APU is not running. No fuel cooling of solenoid valves.
  - Post APU shutdown, if fuel tank valve temperature high, pull circuit breakers.
  - Solenoid short may overtemp valves while APU is still running. Pull circuit breaker for second valve in parallel. Will keep APU running.

Fuel Pump

- Gear driven pump delivers fuel under pressure post start.
- "APU PUMP LK P" shows build-up of leaking oil or fuel in catch bottle. Bottle relieves overboard.

Cooling

- GG bed cooled by separate H_2O injection system for re-start. H_2O system not used during normal ops.
- Cooling required for 3.5 minutes in *INJECTOR COOL* prior to start. If no cooling of GG injector apparent, do not perform re-start.
- If APU not started immediately following cool-down, injector temperature will rise again rapidly.
- Common tank for all APUs. Cooling capacity is 21 minutes.
- Fuel pump and fuel control valves are cooled by *APU PUMP/VALVE COOLING*. Two separate systems (A and B), each with its own water supply.
- Water spray boiler cools hydraulic and lube oil.
  - Bypass valve isolates hydraulic cooling feature when not required.
  - Two controllers (A and B) use common water lines but have different spray logic.
  - Water quantity should not decrease during ascent. Pre-charge in H_2O boiler immerses oil lines. No spraying until MET about 11:00.

Hydraulic Accumulator

- Maintains pressure of about 2600 psi when APU not running (hydraulic pressure still about 65 psi).
- Prevents hydraulic pump cavitation.
- Low accumulator pressure on orbit indicates nitrogen leak or internal priority valve or unloader valve failure.

Circulation Pump

- Two-stage pump. First stage low pressure, high volume. Second stage high pressure, low volume. High pressure fluid can be diverted to repress accumulator. Otherwise, high pressure fluid mixes with low pressure fluid.
- On orbit, automatically turns on (when pressure < 1960 psi) to maintain accumulator pressure.
- Circ pumps keep hydraulic fluid moving for thermal conditioning on orbit. Automatically turn on for low hydraulic line temperatures.
- Only one circ pump operates at a time in GPC control for electrical loads considerations. The system with low accumulator pressure has higher priority than the system with low hydraulic line temperatures. For thermal reasons, two circ pumps at a time are OK if needed to recharge two accumulators.

Priority Rate Limiting

- Gets 3 hydraulic pressure inputs from each system.
- Crew can see 2 of the inputs on BFS SYS SUMM and F8 meter. MCC has access to all three inputs.
- Crew can also see hydraulic accumulator pressure which PRL doesn't see.
  - Use hydraulic accumulator pressure and RPM to resolve dilemma.
  - Accumulator pressure = 3000 means hydraulic system OK.
- PRL will show down arrow if declaring system down.
- SPEC 51 data:
  - AUT* means auto logic is active
  - DES* means manual deselection (toggle to reselect).

- For PRL ? and system good, leave auto logic selected.
  - Subsequent transducer fail may require deselect of auto logic and a manual deselect or reselect.
- For PRL down arrow and system good, deselect auto logic to reinstate hydraulic system into PRL.

Manual Shutdown

- Used to back up auto shutdown.
- Controller power off protects against uncommanded hot re-start.
- Must identify over or underspeed shutdown prior to controller power off (caution and warning light extinguished).

Ready-To-Start Talkback Gray

- Low press selected.
- H_2O spray boiler ready.
- APU fuel isolation valves open.
- GG bed temperature > 190 degrees.
- APU speed below 80%.
- Underspeed immediately after start is probably caused by 9.5 second timer failure. Auto shutdown is normally disabled during first 9.5 seconds of start. *AUTO SHUTDOWN* to *INHIBIT* may allow start.

Comm-Voice Data

General

- *PANEL/CMD* on panel C3 switch passes S-band control to system selected on aft panel. One step total reconfiguration to alternate system.
- Normally, INCO manages system on LRU by LRU basis. All LRUs are system 1/system 2 redundant.

ACCU

- Routes all audio to ATUs.
- No voice (ICOM and A/G), switch ACCUs.
- CDR and PLT can talk to each other on same ATU without an ACCU.

Antenna Electronics Unit

- Switches antenna per GPC or RTC command.
- BFS commands for ascent and entry.
- SM GPC command on orbit with BFS in *STBY* or *HALT*.
- Commands routed to antenna electronics 1/2 over PL MDM 1/2. No cross-strapping capability.
- Manual selection available with loss of auto select.

Ascent/Entry Configuration

- S-band system 2 active in STDN mode.
  - STDN sites prime for comm.
  - On orbit, 1 to 2 hour call up.
- A/G 1 and A/G 2 selected simo.
- UHF T/R on A/A loop.
- TDRS available post-MECO on ascent and TAL.
  - On ascent, stored program command will mode to TDRS.
  - Active S-band system switches automatically if INCO does not clear command, or if BFS fails.

- Manual reconfiguration of back panel to TDRS may be required post-MECO to restore comm if S-band failure, ground site failure, or BFS command failure occurs late in powered flight.

Encryptor, Transponder, and Power Amp

- In-line LRUs.
- Power amp and preamp not required if reconfigured to STDN low mode.
- Encryption is normally on uplink only.
  - Encryptor dedicated to one NSP. Not selectable separately.
  - Bypass selected for encryption failure.

NSP

- Processes uplink and downlink (voice, commands, and data), except UHF which bypasses NSP.
- Failure means no S-band voice, commands or data to/from ground.
  - "I/O ERROR NSP X" where X = active FF MDM (1 or 3). Could be just command failed. Check data/voice with MCC.

Cryo

General

- Separate transducers for CRT digitals and overhead meters.
- CRT data goes off scale low for big leaks.

Heaters

- Each tank has A and B heaters.
- Separate controls/logic for O_2 and H_2 heaters.
- O_2 heaters have two elements with two current sensors per heater.
- Crew insight into sensor status in OPS2 only.
- If any current sensor trips (short), that heater is disabled.
- Heater logic (applies separately to O_2 and H_2)
  - Both tanks in a ganged pair must have low P before heaters in either tank are turned on.
  - Only one high P is needed to turn both heaters off.
  - During leak isolation, pressure in good tank may prevent heaters in leaking tank from coming on with both tanks' heaters enabled.
  - Control points for heaters:

    H_2 tank 1 and 2 pressure = 203 to 223

    O_2 tank 1 and 2 pressure = 811 to 846
  - Tank 3, 4, and 5 set points slightly higher so tank 3, 4, and 5 will preferentially feed on orbit with all tanks in *AUTO*.

Leaks

- First step in ascent and entry cryo leak procedure is to determine number of tanks with pressure decreasing.
  - Only one tank leaking, leave configuration as is (manifold isolation valves open). Leak is a tank leak. Isolating tank will starve its fuel cell.
  - If all tanks decreasing, close manifold valves to isolate leak. Must react quickly for large multi-tank leaks.
  - If leak internal to fuel cell 3, need to reopen manifold valves ASAP. Manifold 3 does not have a relief valve.

DPS

General

- It is important to be able to identify GPC failures, for MCC has little insight. Crew information affects MCC analysis and planning for subsequent failures (both DPS and non DPS).

- When using the *GPC MODE* switch, remove your hand between positions. On past missions, there have been problems with the switch being in two positions at the same time. Research is ongoing. This problem can occur on other orbiter switches also. It is good practice to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.

- Always clear fault message line as soon as messages have been seen. This will avoid missing annunciations of subsequent failures.

- Resume SPECs and DISPs from CRTs when not in use or prior to switching to another major function on that CRT.

- Hard assign CRTs (both PASS and BFS) via PASS CRT keyboard (BFS will DK listen). Dual CRT commanders can be caused by trying to assign a CRT to BFS that a PASS GPC is still driving.

BFS Engage

- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both *MODE* and *OUTPUT* talkbacks are barberpole). If not, take the offending GPC to *HALT* (or power it off) immediately to avoid I/O problems on the flight critical strings.

Restringing

- Deassign CRTs from Fail To Sync GPCs and reassign to good GPCs to avoid inadvertent entries.

- Before OPS transitions and restrings, verify the NBAT. Check proper *MAJOR FUNCTION* and GPC switch configuration.

- Ensure the correct memory configuration is displayed prior to making NBAT changes.

- Dynamic flight

  - Use the cue card.

  - Must take failed GPC to *STBY*, *HALT* prior to OPS MODE RECALL.

  - Must deselect IMU on failed GPC for OPS 3 restring, then follow OPS MODE RECALL with NAV DELTA ZERO and IMU RESELECT.

  - Deselect surface feedbacks prior to OPS MODE RECALL. Reselect following OPS MODE RECALL.

  - Follow OPS MODE RECALL with BFS I/O RESET (or PRO to OPS 3 if TAL).

  - Avoid assignment of all three CRTs to the same GPC, especially on orbit.

  - Keep hands off of everything during OPS transitions, especially switches and CRT keyboards.

- Rules

  - Powered flight. Recover stuck throttle if necessary for uphill performance.

  - Post MECO, pre ET SEP. Recover jets for SEP.

  - Pre OMS-1. Recover single OMS ignition capability (delay burn). Regain critical system insight (if engagable BFS still available). Maintain single fault tolerance.

  - Entry. Regain vent door commands. Regain string 1 or 2 for nose wheel steering. Maintain ASA command and body flap command.

  - In general, port moding is preferred over restring to regain lost capability.

  - Prior to EI-5, restring for any failed GPC.

Set Split

- 2 on 2 ascent split
  - Maintain CRT interface with both sets.
  - If both sets have an IMU and FCS channels, ride to MECO. MCC will then advise which is good set.
  - FCS channels remain in *AUTO*.
  - *ET SEP* to *MANUAL* for post-MECO, pre-SEP restring.
  - Set up G1 (G3 if TAL) NBATS for both sets.
  - Monitor tapes driven by both sets.
  - Be prepared for BFS engage if sets begin force fight or total set split.
- 2 on 1 on 1
  - Treat simplex machines as failed GPCs.
  - BFS engage required on ascent for MPS commands if simplex machines can't be taken to *HALT*.
- BFS engage decisions for set splits
  - On seeing multiple GPC faults and CAM lights, call "SET SPLIT".
  - Check BFS and PASS GNC SYS SUMM.
  - If BFS tracking 2 PASS GPCs, check them for 1 IMU, 2 FCS channels, 1 RGA, and 1 AA. Minimum for good PASS set. BFS engage will be required for MPS commands on ascent if simplex computer is failed to sync and cannot be taken to *HALT*.
  - If BFS standalone, check PASS if time permits. Time available is based on NAV state without IMU data:

    Powered flight - 10 seconds
    Entry - 45 seconds
    Orbit - plenty of time.

- Distribute CRTs among different GPCs. On orbit ensure all CRTs are not assigned to the SM GPC. Loss of this GPC loses PASS CRT interface.

ECLSS

General

- During ascent, only switch avionics bay fans and freon pumps. Water pumps may be switched if avionics bay temps are increasing out of limits.
- NH_3 Boiler A/B control based on temperature in freon loop 1/2.
  - If no flow in freon loop, must use NH_3 boiler corresponding to good loop.
  - If slightly degraded flow in loop with NH_3 boiler selected, undertemp may result in degraded loop, if NH_3 boiler controlling based on temp in good loop. Select NH_3 boiler for loop with degraded flow.

Cabin Pressure

- First reaction to cabin leak is to close cabin relief isolation valves one at a time.
- Double check leak indications with MCC. May be due to cabin expansion or thermal effects.
- N_2/O_2 leak into cabin will cause rise in cabin pressure and for O_2 leak, PPO_2 will also rise (O_2 concentration available on orbit).
- dP/dT on meter and CRT come from dP/dT sensor.
- EQ dP/dT is calculated from cabin pressure sensor by BFS and standardized to a 14.7 cabin. EQ dP/dT is used when available to make ascent abort decisions for cabin leak. Backup dP/dT is also calculated from cabin pressure, but not standardized for a 14.7 cabin.

EPS

General

- Do not reset popped circuit protection device (RPC or circuit breaker) without consulting MCC.
- For critical actions, MCC may call for momentary reset of failed control or essential bus while crew holds switch for affected system in desired position (three finger trick).

AC Bus

- Surge on AC bus can cause main engine controller to trip off line. Avoid actuation or switching of AC powered equipment during powered flight unless called for in malfunction procedures.
  - Loads that can be switched in powered flight:

    Avionics bay fans
    Freon pumps
    H_2O loops (only for an avionics bay temp high)

- AC bus sensors *OFF* on ascent to protect SSMEs for:
  - Loss of first engine
  - Loss of SSME controller redundancy on any engine
  - Loss of a single AC phase (takes down an SSME controller on two engines)
  - When AC bus sensors are *OFF*, no hardware caution and warning lights will illuminate (no AC VOLTS or AC OVERLOAD light).
- AC voltage high
  - Ride until MECO unless volts exceed 130, or affected main engine controllers are lost.
  - Trip bus off line with *AUTO TRIP* selection on bus sensor.
- AC phase shift/phase-to-phase short (three-phase motors stop)
  - Verified by multi-phase amps high.
  - Multiple three-phase motors fall off line, fuel cell pump, Freon pump, H_2O pump.
  - Take individual phases off line separately to find bad phase.
- If AC bus sensor in *AUTO TRIP*, AC phase will be automatically disconnected for either an AC overload or high AC volts.
- If AC bus sensor in *MONITOR*, will get hardware caution and warning, but will not get AUTO TRIP feature.
- AC bus sensor uses different transducer than one feeding F9 meter or CRT.
- AC bus sensor needs to see rapid rise or delta amps to issue an AC OVERLOAD indication.

Bus Tie Actions

- If re-establishing power to a main bus (main bus volts < 20), always unpower the AC inverters before tying to a good bus (prevents surges). Use long form bus tie procedure on cue card.
- If a tie results in a short, immediately untie.
- Never tie 3 main buses during powered flight. OK post-MECO, on orbit, and entry.
- Never tie into a short.
- Payload primary bus can be used to tie Main B to Main C (back door bus tie), or connect FC3 to Main C.
- Unless absolutely necessary, do not bus tie in first stage.

Fuel Cell

- Coolant pump and H_2 pump both driven by same AC bus and both pumps controlled by fuel cell ECU and *START/STOP* switch.

- Coolant pump draws 0.5 amps, H_2 pump draws 0.3 amps.
- Coolant pump delta P indication
  - Ground can see immediately if loss of fuel cell coolant pump is real (stop/start to check run current not required).
  - No comm, can stop fuel cell and check for 0.8 amp drop. This indicates both pumps were running (bad sensor). Restart gives full recovery (should see 0.8 amp increase).
- *START* switch sends pump start commands
  - Pressure should be sensed in 3 seconds. *Delta P* talkback goes gray.
  - *READY FOR LOAD* talkback requires 30 second timer and good heaters.
  - Delta P relay failure may prevent fuel cell ECU from latching on fuel cell start command. *DELTA P* talkback won't stay gray. OK to hold *START* switch in *START*. After 30 seconds, second relay should latch command on (can release *START* switch).
- Coolant pump failure stagnates coolant loop
  - Stack T measured at outlet of stack. May actually decrease immediately after coolant pump failure.
  - Exit T measured in H_2/H_2O loop.
  - If H_2 pump running, exit T will progressively increase after coolant pump failure.
  - Nine minutes of run time available after coolant pump failure, assuming normal fuel loading.
- O_2 is entirely consumed. H_2 is circulated continuously through power section and condenser.
  - H_2O is drawn out of stack by mixing with H_2.
  - H_2O is separated at the H_2/H_2O pump.
  - Dual gas regulator maintains proper pressure of reactants (about 60 psia). O_2 pressure feeds coolant loop accumulator.
  - Dual gas regulator problem indicated by COOL P HIGH/LOW. Tie buses and monitor fuel cell for degradation.
  - If O_2 reactant valve closes, coolant pressure will drop.
- Failure of the H_2/H_2O pump will lead to fuel cell flooding since water is not removed.
  - Ascent and entry: PH status fail followed by slow degrade and exit temperature decreasing may be first signatures of flooding.
  - Indicated on orbit by H_2 pump status fail.
- Crossover (uncontrolled O_2 and H_2O mixing)
  - Highly unlikely to happen rapidly without warning signs.
  - Fuel cell delta volts increasing is a warning.
  - PH high may occur, but not necessarily.
  - Fuel cell degradation will eventually occur.
- Separate PH sensor for each fuel cell and common sensor in H_2O manifold.
  - PH fail may indicate pending breakdown of Fuel Cell matrix (fuel cell crossover). Potential explosive mixing of H_2 and O_2.
  - High fuel cell delta volts provides confirming cue.
  - Assume matrix failure for PH fail and bus tie as soon as possible. Problem may be an H_2/H_2O pump failure.
  - Common PH sensor can confirm individual fuel cell sensor. Will annunciate about 10 minutes after individual fuel cell PH (common PH only seen by crew on orbit).

- In normal configuration, redundantly powered loads are load shared.
  - Hot running fuel cell (real STACK T high) will grab more than its share of the load. Indication is high amps.
  - Flooding (real EXIT T low) will cause fuel cell to shed load.
- Water output of all fuel cells feeds common manifold.
  - Water expulsion for fuel cell is preferentially: Tank A (primary), Tank B (alternate), Dumped overboard (relief).
  - *FC H_2O LINE HTR* controls heaters on each fuel cell primary and alternate path.
  - *FC RELIEF LINE HTR* controls heaters on each fuel cell relief line.
  - Each fuel cell relief line merges into one common manifold that vents H_2O overboard.
- Purge process pumps extra O_2 and H_2 through fuel cell.
  - Removes contaminants.
  - Excess O_2 and H_2 dumped overboard. All three fuel cell purge lines merge into one O_2 and one H_2 manifold.
  - Purge only one fuel cell at a time.
- Nominal load is 7 kw per fuel cell. For powerdown operations, 13 kw OK on one fuel cell for 4 hours.

Main Bus Short

- Fuel cell will overheat in time. Amps high, fuel cell and main volts low.
  - Short before the fuel cell main bus switch will have high amps and will not drop when fuel cell is isolated from main bus. Fuel cell and main volts will remain low. Should be treated like a fuel cell short.
  - Fuel cell internal short. Amps low, fuel cell and main volts low.
  - Fuel cell inadvertent disconnect. Amps low (should be zero), fuel cell volts greater than 32, main volts near zero. OK to attempt reconnect.

GNC

BCE STRG X "D" Fail

- Will commfault feedback on affected FCS channel.
- Command path on that channel will remain good.
- Ports will not pop unless feedback goes bad under "D" failure.

Body Flap Commands

- Go out on FCS channels 1, 2, and 3 only.
- Each channel uses separate hydraulic system.
- FDIR is QMVS.

FCS Channels

- Each channel equally supplies every actuator (TVC and aerosurface).
- Each channel should get same command from GPCs.
- Never have more active channels on one GPC than another
- Position feedbacks on aerosurfaces for each channel.
  - Feedbacks go to FDIR to determine surface position for GPC computations.
  - Feedbacks also used individually in closed loop servo to position each FCS channel's input to actuator. Inputs are summed hydraulically.

- Port bypass, or port pop, is an electro-mechanical means to remove bad command/avoid force fights. Feedback deselection is a software means to avoid a bad input into the selection filter.

- A bad feedback will result in a bad actuator input for that FCS channel. Result will be a port pop (bypass), removing input.

- Single port pop with no other failures: no action.

- Two failures on any surface/TVC actuator. Take good channels to *OVERRIDE*. Protects remaining two channels from port pop if a force fight develops (wrong channel might port pop). Take 2 seconds between switch throws to *OVERRIDE*.

- All port pop indications should be verified with MCC.

- If verified, single port pops may be bypassed in software on SPEC 53. Allows taking channel to *OVERRIDE* later if subsequent failures on other channels.

- Feedback deselection on SPEC 53 deselects all feedbacks on channel, and terminates FDIR on all aerosurfaces.

- If there are two failures on the same actuator, take the remaining FCS channels to *OVERRIDE*.

- Feedback RM for aerosurfaces.

  - PASS uses first 3 inputs (channels 1, 2, and 3).

  - RM will throw out a bad feedback and substitute channel 4.

  - RM shuts down after first manual or auto deselect, including commfault.

  - PASS FDIR will never pass a commfaulted feedback.

  - PASS may lose control if 3 feedbacks erroneous due to combination of commfaults, channels off, or bad feedbacks on individual surface.

  - Any *OFF* channel should have feedbacks deselected. If channel is recovered, reselect feedback after channel is taken to *ON*.

  - Always maintain two good commands and one good feedback on each aerosurface.

  - In OPS 6, only works in MM 602 and 603.

- BFS feedback RM.

  - Selection filter uses feedbacks on all four channels.

  - No redundancy management.

  - Only manual downmoding of selection filter.

  - Selection filter uses IMVS.

- ASA power fail.

  - Results in all ports bypassed and zero voltage feedback input to GPCs.

  - Deselect feedbacks on channel with an ASA power fail if failure is confirmed. On board signature is not conclusive.

FCS Channel Switches

- *OFF* bypasses ports on all actuator inputs for given FCS channel (turns off command). Also sends zero voltage feedback to FDIR.

- *AUTO* allows port popping to bypass bad FCS channel.

- *OVERRIDE* inhibits port pop on associated channel.

- Pause between all FCS channel switch position changes. Switches are break before make. Switch actuation can result in momentary loss of channel.

FDIR

- PASS FDIR for the RGAs, AAs, and aerosurfaces terminates after the first failure, and crew management of the selection filter is required. For the BFS selection filter, crew management is always required. Proper selection filter management is required for proper control.

GPC and MDM Failures

- Take associated FCS channel *OFF*.
- Removes what may be a command latched at the MDM.
- Also requires deselection of feedback (SPEC 53). Feedback to GPCs would be zero voltage if I/O restored.

IMU

- SPEC 21 shows IMU status.
  - OFF, BITE, blank in status field.
  - Mode designated by *: STBY (caged) or OPER (operate)
- GPC send operate command through FF MDMs.
  - IMU returns status (operate discrete) over FF MDM card A.
  - IMU returns digital data over FF MDM serial I/O card
  - STBY and power off conditions available on SPEC 21 after "BCE STRG X IMU", but not after FF MDM lost.
- GPC or FF MDM port failure.
  - IMU will maintain operate command. Commands and output of MDMs are latched at last value.
  - IMU will operate without pulse torquing compensation. Should maintain reasonable align up to 15 minutes.
- FF power cycle.
  - KT-70: Must complete in < 1 second to avoid caging IMU.
  - HAINS: IMU can maintain OPER CMD LATCH for approximately 8 seconds.
- FF power fail.
  - IMU loses operate command and goes to STBY (upon recovery of I/O).
  - In STBY IMU spins down and cages.
  - FF 1,2,3 power failure signature (following "I/O ERROR FF X") is loss of SSME Pc tape (ascent). Deselect IMU PASS and BFS after FF power fail (IMU will come back caged when I/O regained.).
- BCE STRG IMU.
  - Could be result of IMU losing power. SPEC 21 (orbit and entry only) shows IMU status OFF, mode STBY.
  - Could be loss of IMU data to the FF MDM (serial I/O card down). Status and data blank on SPEC 21. Mode will still show operate, received over card A.
- Standby mode.
  - If IMU has moded to STBY, it will begin startup sequencing if power and I/O are restored.
  - KT-70: Transient power fail results in 3 minute spin down, followed by startup sequence, which cages the IMU.
  - HAINS: Transient power fail, no 3 minute timer. Only startup sequence which cages IMU (approximately 1 minute).
  - When IMU completes startup sequence (caged), it will mode to operate and be available to selection filter (PASS and BFS). Hence any caged IMU should be deselected (PASS and BFS).

- PASS selection filter.
  - Any IMU not commfaulted (M) or deselected is a candidate.
  - An IMU in STBY is not a candidate.
  - Attitude selection is MVS at 3 level.
  - Downmode or upmode to 2 level. Maintain previously selected if available. Otherwise lowest numbered IMU.
  - Velocity is MVS at 3 level (component basis). Averaged at 2 level.
- PASS RM.
  - Either attitude or velocity fail removes IMU from selection filter.
  - PASS will not RM fail an IMU for a BITE (H/W or S/W) at 3 level.
  - IMU with BITE will fail RM if dilemma at 2 level.
  - If IMU miscompare at 2 level and PASS sees no BITE, IMU dilemma declared. Manual deselection required to break dilemma. Use MCC or deselect IMU. BFS is prime selecting to break tie.
- BFS RM and selection
  - Only commfaults, power loss, hardware BITE, and manual deselect will remove an IMU from candidacy.
  - Selection is MVS at 3 level.
  - Once downmoded to 2 level, BFS will only upmode to 3 level if taken through OPS 0 and up to OPS 3.
  - Selection on downmode to 2 level is lowest numbered IMU.
  - At 2 level, BFS can be taken off lowest numbered IMU with deselect followed by reselect.
  - BFS uses first deselected, last reselected logic after MVS broken.
  - IMU deselected for H/W BITE will not be upmoded if other IMUs lost.
  - Can only recover IMU with a H/W BITE if it is IMU 3 and the BFS is moded through OPS 0 (and IMUs 1 and 2 are deselected).
  - BFS will stay on an IMU with a H/W BITE if it is already on that IMU, and all others are not candidates.
- IMU dilemma
  - If MCC comm available, ask MCC which IMU to deselect (PASS and BFS).
  - No comm, deselect lowest numbered IMU in PASS. BFS will use lowest numbered.
  - Let NAV run to determine which IMU is better.

Navaids

- For TACAN and ADTA management, talk to MCC before incorporating. Without communication, use the NO COMM TACAN MGMT and ADTA MGMT cue card.

SBTC/RHC

- During ascent, only the PLT SBTC is active. To get manual throttles, the PLT must depress the takeover button and then match the commanded throttle setting.
- During entry, both SBTCs are active. Manual speed brake control is selected by depressing the takeover button.
- For ascent, manual RHC control is available only in PASS and must be both PITCH and ROLL/YAW axes.
- For entry, manual RHC control is available in either PITCH or ROLL/YAW in PASS. BFS is always manual.

Instrumentation

General

- MDM loss results in parameters showing Ms.
- Signal conditioner loss shows data on respective parameters as L. . .
- Loss of OI MDM does no affect data to meters, but some digital data may be lost. DSC loss will affect most meters.
- OI DSC loss section of REF DATA is accurate only for DSC parameters, not MDMs.

Data

- Runs through signal conditioners and/or MDMs
  - Data from OI MDMs goes through PCMMU for most SM data.
  - PCMMU swap reads alternate ports on OI MDMs.
  - OR, OL, and OF DSCs (GNC data) go directly through MDMs to GPCs.

Mechanical Systems

General

- ET doors and latches, vent doors, star tracker doors, air data probes, payload bay doors and latches, RMS latching gear, and payload retention latches are powered by dual AC motors linked through a differential.
  - One motor fail results in double actuation time. Actuation times are listed in the FDF.
  - Most actuators have dual microswitch pairs for open and close indications.
- Failed mid motor controllers or popped circuit breakers on MA73C are a frequent cause of payload bay door, ET door, or vent door single motor ops. Chart in post insertion book lists circuit breakers and motors affected.

Payload Bay Doors

- *PL BAY DOOR SYS ENABLE* switches only enable payload bay doors. Other systems in payload bay use *PAYLOAD BAY MECH POWER* switches to allow operation.
- "PAYLOAD BAY DOOR CONFIG" message means a microswitch is indicating differently than required by software for auto operations. Can occur any time during auto open/close sequence. May require manual door operation.
- "PAYLOAD BAY SEQUENCE FAIL" message caused by failure of proper microswitch indications within single motor actuation time. Can occur during auto sequence.

ET Doors

- Close automatically in OPS 304 if TAL flag is set in software. Always double check doors closed before AOA OPS 3 transition or TAL flag set before late TAL OPS3 transition. No software backup to close doors in OPS 3 without TAL flag set. Only available in OPS 1.

MPS

General

- Propellant (PRPLT) numbers on ASCENT TRAJ display calculated by guidance, not measured directly from tank.
- SSME will consume about 4% propellant per engine per minute at 104% throttles.
  - Total fuel consumption 1% every 5 seconds with 3 engines.
- Consumption is 2.5% per engine per minute at 65% throttles.
  - Total fuel consumption 1% every 8 seconds with 3 engines.
- Actual throttle setting in bucket will vary with SRB performance.

- Loss of an APU will cause hydraulic lockup. CMD PATH fail message post-MECO is possible. No action required.

- Engine power switches are close to SSME helium isolation valves switches and look similar.

- Selection of manual maximum throttles (109%) is not to be taken lightly. Estimated risk is increased by a factor of ten.

Command Path

- Command path failures require a manual shutdown with AC switches. This will create a data path fail.

- Engine with command path fail will not get guided shutdown command nor will it get pushbutton shutdown command.

Data Path

- Must determine engine and command status.
  - Loss of acceleration indicates engine down.
  - Helium dP/dT > 40 for a few seconds, then zero indicating engine shutdown.
- If SSME down, use push button to mode guidance, then AC bus sensor OFF.

- Assume bad command path until throttling is observed. No comm – assume command path.

- Engine shutdown auto *ENA/INH* logic inhibits shutdown for redline exceedance (limits) for a data path failure. *ENA/AUTO* resets limits to ENABLE. Crew has no indication of actual limit status. MCC does have status.

- Engine with data path fail will get a shutdown command if GPCs see other 2 SSME's with Pc < 30%. Two Pc < 30 plus data path sets MECO confirm. MECO confirm will shut down engine if still running behind data path, even if before guided MECO.

- Engine with a data path fail will not display a red status light after engine shutdown (pre-BFS engage).

Engine Failure

- First priority is to ensure GPCs recognize it.
  - Check for CRT message "SSME FAIL L (C, R)". If no message, depress pushbutton.
- When time permits, *AC BUS SENSORS - OFF*.
- If second SSME fail:
  - Check interconnect for single engine roll control.
  - Contingency abort actions if appropriate.

Entry

- MPS configuration for entry allows auto purge of MPS lines.

- If MPS caution and warning during entry, assume aft compartment overpress, close helium regs. Helium reg fail high and subsequent venting could be catastrophic.

- MPS caution and warning for low helium reg not expected for normal entry. Might occur on RTLS due to additional helium usage.

Helium Leaks

- Non-isolatable leak requires interconnect at 1150 psi.
  - Use previously failed SSME helium supply, if available.
  - Interconnect to pneumatics results from *IN-OPEN*.
  - Return all helium interconnect valves to *GPC* post-MECO.
- Non-isolatable leak may require SSME manual shutdown using pushbutton. Helium available may not support zero-g shutdown at MECO.
  - Shutdown must be with pushbutton (hydraulic cutoff) to conserve helium.

- Helium interconnect may be called for to allow SSME to run to MECO. Interconnect may be well before 1150 psi cue.

- Crew assumes shutdown is required at velocity on MPS cue card unless MCC advises that helium is adequate for zero-g shutdown.

- If MPS helium reg pressure starts to drop due to helium depletion, limits must be enabled to prevent catastrophic main engine shutdown (given the proper scenario).

- MPS pneumatic helium leak with leak in accumulator requires steps to repress accumulator at TMECO minus 30 seconds.

- Loss of ALC 1, 2, 3/APC 4, 5, 6 causes the A helium isolation valve to close for the corresponding engine.

  - Helium leak isolation must not be attempted on the affected engine.

  - MPS H_2/O_2 ullage pressure indications on GNC SYS SUMM display will go to 12.0↓/0.0 for engine with ALC/APC failure.

Manual Shutdown

- Required for manual throttles, command path, and some stuck throttle cases.

- Low level cutoff will still work in manual throttle mode if command path is good.

- If any doubt about shutdown function, use AC switches and follow with push buttons to inform GPCs of shutdown.

- Shutdown with AC switches no-ops the MPS dump for affected SSME. Manual inerting may be required.

- When manual SSME shutdown is required, use the AC switches followed by the push button except for:

  - Shutdown with push button(s) only for manual MECO.

  - Shutdown with push button for helium leak.

  - Use push button to mode guidance when GPCs don't know SSME is already down.

Manual Throttle

- CSS requires manual throttle, which requires manual shutdown.

  - Shutdown press to MECO cases at target V_r.

  - Shutdown TAL and RTLS cases at BFS cutoff cue. This cue is based on NAV and indicates cutoff when on R-V line.

- Any manual MECO (push buttons or AC switches plus push buttons), depress 3 push buttons to ensure MECO confirmed.

- Secondary shutdown cue is PASS/BFS TMECO on TRAJ display.

MECO Confirmed Flag

- Set by any of the following:

  - Three shutdown commands with engine safing flags set (no data failures, 3 Pc's < 30%).

  - One data path plus 2 Pc's < 30%.

  - Manually depress 3 push buttons. PASS sets MECO confirm for three push buttons pushed separately or together. BFS needs to see all three push buttons depressed simultaneously. Can power cycle any FF MDM associated with bad control bus (printed near push button).

  - OPS 104 PRO (OPS 602 PRO will not set MECO confirm).

  - Fast sep.

Net Positive Suction Pressure

- Requirement for engines down.

- If two engines are running, throttling at 3-g will bring good engines below 91% (OK for shutdown).
- Single engine press to TAL, ATO, or MECO
  - Manual throttle back to 65% at 2% propellant remaining.
  - Manual cutoff at guidance cue required.
  - If low level sensors uncovered, fuel depletion cutoff will be commanded.
  - NPSP requirements will be protected.

Pc Gauges

- Data for Pc gauges and status lights:
  - Left: FF2
  - Center: FF1
  - Right: FF3
- Pc on gauge goes to zero for MDM power fail. Freezes for port failure.

Status Lights

- Amber = data path, electronic (fuel flow or Pc sensors) or hydraulic lockup.
- Red = engine in shutdown or redline exceedance.
- Second engine fail with limits inhibited may show amber plus "MPS ELEC" message in SMS. Likely cues "real world" are data path fail and loss of acceleration. Red light for limit exceedance also possible.

SSME Push Buttons

- Control two functions, shutdown and GPC recognition.
- Push button shutdown requires good command path and no push button faults. Command path fail takes out push button for shutdown.
- GPC recognition of SSME fail (to mode guidance) may be accomplished with push button if no switch faults.
  - FF/push button fault: must create data path fail with AC switches and depress push button.
  - Control bus fault: AC switches (data path), power cycle associated FF MDM, depress push button.
  - BFS requires good FF and control bus to mode guidance.

Stuck Throttles

- Command paths always require manual shutdown.
- Two stuck hydraulic or electric, shutdown highest priority hydraulic (based on TVC loss).
- One hydraulic or electric, only shutdown with three engines running, uphill, and performance low.
- Stuck throttle shutdown cues of 23K, 22.5K and 24.5K for three engine uphill, TAL, and two engine uphill correspond roughly to 30 seconds before MECO.

OMS

General

- Standard insertion OMS-1 burn at MECO+2 is critical.
  - Take status of OMS engines post-MECO following FA/GPC failures coupled with ALC/MN or CNTL bus failures.
  - If one engine not available, re-target for single engine burn.
  - Restring not allowed by flight rules to regain dual OMS engine capability if 4 +X jets still available for redundancy.
  - Underspeed at MECO, always burn OMS-1 at TTA = 2 for optimum efficiency.

- For large underspeed at MECO (> 500 fps), supplement a single OMS engine with 4 RCS +X jets.

- TAL is preferred abort if dual prop fail is recognized in time.

- Gauging active only with at least one OMS engine burning. Otherwise, overhead and aft quantity readings dormant.

- Overhead gauging ceases actual measurement between 45 and 30%.

  - Software routine decrements quantity with engine burning. Only accurate for straight feed operations.

  - Pick up accurate readings when aft probes active below 30% prop.

- If only one pod prop is available and 2 engines, feeding both engines from one pod is certified.

Burn Cues

- PASS MNVR display decrements TTG 2 seconds per display update.

- BFS MNVR display decrements TTG 1 second per display update.

- At ignition

  - Check Pc.

  - Check ball valves = 100%.

  - Check fuel injector temperatures = about 200 degrees.

  - Monitor engine inlet pressures.

Delta V Available

- 1% OMS prop (either side or total) = 6 fps delta V.

- 1% RCS (either side or total) = 1 fps delta V.

- 2 fps required for 1 nm HP change.

DPS Failures

- FA 3(4) failures commfault L(R) *ARM/PRESS* switches.

  - Guidance will not downmode to 1 OMS or RCS burns when switch turned off.

  - Guidance needles in error.

  - DAP remains in TVC DAP on downmode to RCS.

- Set split or IMU dilemma, terminate burn if above safe HP. Determine bad IMU post burn by which IMU accel is not zero.

Thrust Loss

- At first indication of OMS thrust loss (usually Pc low), check for OMS engine down arrow. PASS requires Pc low and loss of acceleration for down arrow.

- BFS shows down arrow with loss of Pc only. Pc transducer fail will give false engine down cue.

- Check for ball valve fail. If not confirmed and ignition path is good, must assume prop fail. Cue card procedure will identify engine or prop fail.

- Orbiter will initially yaw into dead engine and then yaw into good engine.

- No hurry to turn bad engine off. Know without doubt which engine is down before moving switch.

- Ensure prop or engine fail identified.

- Simple OMS engine fail, crossfeed at 1/2 delta V.

  - Protect aft quantity. Crossfeed at 3% minimum.

  - Maintain good flow path to prop source.

  - For OMS-1 with large delta V, interconnect failed OMS to RCS and supplement with 4 +X RCS.

- For prop fail, consider engine lost. Use cue card to determine proper course of action.
- If both engines down, complete burn with RCS.
  - Interconnect good OMS prop to RCS, note OMS helium pressure, convert to burn time, and time RCS burn.
  - FA failures may cause only 2 +X jets available. Required burn time is almost doubled.
  - OMS gauging not active without an OMS engine burning.
  - Must protect RCS system from helium ingestion at OMS prop depletion.
  - For any prop failure, isolate bad prop from crossfeed lines.

Leaks

- Tank leaks must be confirmed with decreasing inlet pressure.
  - Tank leaks may be isolated by closing tank isolation valves.
  - If inlet pressures goes to zero and tank stable, inlet line leak.

Gimbals

- Trim for 2 engine burns has parallel thrust vectors.
- Single engine burn trim is through CG.
- Gimbals move to trim position 15 seconds prior to TIG.

Nitrogen System

- Used to open ball valves and supply purge post burn.
- If N_2 tank fail, but good reg P available, save engine for deorbit.
- If reg P fails, ball valves will close and engine will fail.

OMS Dumps

- Time the dump. System failures can prevent automatic cutoff.

RCS

General

- Talkbacks get hardware fuel and oxidizer inputs (no MDMs involved).
  - Inputs must agree for open or close indication.
  - Miscompare results in barberpole.
- Quantity calculations are PVT determination based on helium in prop tank.
  - PASS calculation allows for substitution of inputs.
  - If any helium leakage, prop calculation will be erroneous.

Crossfeed

- Master crossfeed available in PASS OPS 1, 3, and 6.
  - *TANK ISOL* and *CROSSFEED* switches must always be returned to *GPC* to protect master crossfeed sequence.
  - Master crossfeed selection valves have simo jet firing limit, even if auto crossfeed not used (all OPS, both PASS and BFS).
- Auto crossfeed sequence in PASS OPS 1, 3, and 6.
  - Initiates crossfeed in response to low pressure in prop tank.
  - Protects against helium reg fail low (primarily for ET SEP).

Dumps

- OMS prop interconnected dumps
  - Smart interconnect handles FA MDM and EPS failures for intact dumps.
  - Dump time compensated for inactive manifolds.
  - No smart interconnect for contingency dump or single engine roll control until OI-21.
  - If second engine fails with intact dump underway, do not start contingency dump. Leave smart interconnect configuration as is.
- ATO dump
  - Interconnect inhibit may be required before abort selection. Time the dump. System failures can prevent automatic OMS cutoff.

Heaters

- Pod heater, crossfeed line heaters, and jet thruster heaters (by manifold) on panel A14.
- Turned on post insertion. Some heaters redundant and switchable.

Interconnect

- RCS crossfeed requires check of left to right tank pressures.
- OMS to RCS interconnect requires low delta pressure and OMS tank pressure higher than RCS tank pressure.
- OMS PRES ENABLE must be toggled off when breaking interconnect. Computation assumes OMS prop feeding when L or R OMS has *.

Jet Availability

- Monitor on SPEC 23.
- Software considers a jet available (no DES*) unless:
  - Deselected by RM.
  - Manifold status in software = closed.
  - Manual DES item entry.
- RM will not deselect more than jet deselect limit.
  - Intialized at 2 per pod.
  - Limit does not apply to manual deselect or vernier jets.

Jet RM

- BFS RM is inactive (display and PASS monitor), unless engaged.
- Any detected RCS fault lights RCS JET caution and warning light.
- For jet fail ON, RM does not auto deselect.
- Jet fail OFF, RM does auto deselection (PASS). Only if first fail OFF and not previous fail ON (BFS).
- Fail LEAK results in PASS auto deselect. Not available in BFS.

Leaks

- Isolation during ascent and entry
  - Always confirm decreasing helium pressure (CRT and meter) before isolating.
  - Confirm talkbacks reflect switch throws.
  - Reselect *GPC* position of *TANK ISOL* and *XFEED* switches.
  - Monitor prop remaining. Crossfeed before quantity reaches zero.
  - Helium leaks invalidate quantity computations.

- Auto crossfeed may be used to open/close valves if manual switch functions lost due to control bus failures.

- Confirmed jet fail LEAK, do not reselect jet since leaking prop will probably freeze in jet.

- RCS secure for leak isolation performed from manifolds up. When re-opening, must ensure prop supply before manifolds opened.

Manifold RM

- Software looks at open and close discretes.

- Any indeterminate combination results in "CL?".

- Crew can override manifold status on SPEC 23.

- SPEC 51, ITEM 7 overrides all manifolds in hardware "?" to open. No effect on manifold with commfaults.

- RCS RM loss occurs with "BCE STRG X B" (forward), or "BCE STRG X D" (aft). Manifold goes CL?.

Manual Reselection

- ITEM entry to remove * in DES column.

- Will not work if deselect due to manifold closure.

- Does not reset RM. Jet will not RM fail for same fault.

- DES INH item reprioritizes jets and disables RM auto deselect. Does not reselect jet.

- Double DES INH resets jet RM (toggling RM).

- ITEM 45 resets RM of all available jets at once. No effect on deselected jets.

On Orbit Burns

- Normally 2 jet burns.

- Will downmode to 1 jet burn if no jets available on one side.

OPS 1 and 3 Burns

- Aft RCS burns use 4 jets and downmode to 3, 2, and 1.

- Forward RCS burns use 3 jets and downmode to 2 and 1.

- Asymmetric +X burns require a lot of propellant for attitude control.

Tank Press High

- Indication of helium reg failure.

  - Close both helium regs to minimize helium loss.

  - Monitor low prop tank pressure and repress to protect manifold pressure. Jets will fail OFF if manifold pressure < 190.

Valves

- Prop valves are AC with control bus for switch power. Will operate on 2 phases if 1 phase lost.

- Helium valves are DC with control bus for switch power.

Vernier Jets

- Two side-firing forward jets.

- Two side-firing aft, two down-firing aft.

- Only aft side-firing jet can be lost and still have vernier mode (may still be lost for RMS loaded operations).

APPENDIX D: RULES OF THUMB

This appendix is a compilation of the rules of thumb from the body of this manual. Topics are organized alphabetically keyed on commonly used acronyms and abbreviations.

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APU/HYD

- APU fuel usage rates vary with loading, but average 1% per minute (3 to 3.5 lbs/minute). Usage rates are reduced by about half if the hydraulic main pump is taken to low pressure (*HYD MAIN PUMP PRESS* switch on panel R2 set to *LOW*), as is done during the abort once around deorbit coast period.
- The APU injector cooling tank shared by all three APUs contains enough water for 21 minutes of continuous flow. This is enough for six complete 3.5-minute hot restart injector cooling cycles.
- If all water spray boiler cooling is lost to the lube oil after an APU reaches full operating temperatures, only 4 to 5 minutes of operating time are available before bearing seizure occurs.

Ascent

- Monitor roll program on the ADI and BFS ASCENT TRAJ display.
- Before L/O +90 seconds, BFS engage is the crew's only option for loss of guidance and/or control. After 90 seconds, the crew can try CSS.
- Monitor the trajectory on the ASCENT ADI cue card and the PASS and BFS TRAJ displays. The Shuttle bug and predictors should follow the nominal trajectory line. Also monitor the HSI for the inertial velocity to be in the desired orbit insertion plane.
- Monitor guidance convergence by observing PASS and BFS TMECOs converging to expected time.
- If the crew takes CSS, they should take manual throttles. If the crew takes manual throttles, manual shutdown is required unless a low level shutdown occurs due to low performance. The cue for MECO is the BFS MECO cutoff bug or planned MECO V_I minus 150 fps.
- Use OMS 1 TGTING cue card for system problems and OMS 1/2 TGTING cue card for performance problems to determine proper OMS 1 and 2 targets.

CCTV System

- When the VCU is powered on, the crew must wait 10 seconds before any CCTV commands can be accepted. This time is used to initialize the VCU.
- Always wait at least 4 seconds after powering off a camera before powering it back on. This gives the iris enough time to fully close.
- Always wait at least 4 seconds after switching from the RMS wrist camera to the RMS elbow camera before switching back to wrist, and vice versa. This gives the iris enough time to fully close.
- When ejecting VTR tapes, always wait at least 10 seconds after selecting *STOP* before you attempt to eject the tape. Never unpower the VTR while it is in a mode other than *STOP*. Either of these will result in tape breaking or fouling.
- Never leave a payload bay camera in a manual mode (either semi- or full) while in direct sunlight or any bright light. Damage to the camera will result.
- If neither you nor Mission Control is using a camera for extended periods, power it off to conserve energy and to keep it cool.

Communications System

- When the TDRS has an elevation of greater than +70 degrees or less than –60 degrees relative to the orbiter (as shown on OPS 201), there is a risk of degraded communications as the orbiter nose or tail blocks line of sight between the orbiter antenna and the TDRS.
- Power amplifiers are specified to have a minimum power output of 100 watts. Flight experience has shown that a good downlink can be sustained with a power output of 65 watts.
- Payload interrogator output power, when in low power mode, will read zero. This measurement is meaningless as the output power is too small to be output by the instrumentation system.

C/W System

- The *SENSOR RESET* switch on panel L1 should be pressed when smoke concentration goes below 1.8. This prevents masking of alarms.
- When panel R13U is not in use, the *PARAMETER SELECT* thumbwheels should be set to a value greater than 119.
- Crewmembers should reset fault messages as quickly as possible after review to avoid covering other messages.
- The fault summary should be reviewed regularly to avoid missed fault messages.

DPS

- Always deassign CRTs from fail to sync GPCs and reassign to good GPCs to avoid inadvertent entries (NBATs/restrings, burn targets, etc.).
- Before OPS transitions and restrings, always verify the appropriate NBAT is what you want it to be; never assume that it is correct! Also check the proper major function and GPC switch configuration.
- Make sure you have the correct memory configuration called up before you start making NBAT changes.
- During OPS transitions, keep "hands off" everything, including all switches and CRT entries.
- Always clear the Fault Message line as soon as you have seen the message; otherwise, you will likely miss subsequent annunciations from other failures.
- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both *MODE* and *OUTPUT* talkbacks are barberpole). If not, take the offending GPC to *HALT* (or if this doesn't work, power it *OFF*) immediately to avoid I/O problems on the flight critical strings.
- It is a very good idea to resume SPECs and DISPs from CRTs when not using them or before going to another major function on that CRT.
- It is important to be able to identify GPC failures, for Mission Control has little insight. The information you provide will affect Mission Control analysis and its ability to plan for subsequent failures (both DPS and non DPS).
- Always hard assign CRTs (both PASS and BFS) via PASS CRTs (BFS will DK listen). You can cause dual CRT commanders if you try to assign BFS a CRT that a PASS CRT is still driving.
- Always distribute your CRTs among different GPCs. On orbit, always be sure SM is not on all CRTs at the same time; if you lose SM, you also lose PASS CRT interface.
- When using the *GPC MODE* switch, always take your hand off between positions. On past missions there have been problems with the switch being in two positions at the same time; at the time of writing, this is still being researched. This problem can occur on other orbiter switches too. It is a good idea to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.
- The *CRT SEL* switch should always be checked before making a keyboard entry, and data should always be checked on the CRT scratch line before it is entered.

ECLSS

NOTE

Numbers presented here are for typical orbit power and heat loads and may vary significantly depending on attitude and power loading.

- Supply water tanks fill at about 1.5 percent per hour depending on fuel cell load (.8 lb/kW hr + 16 lb over 1%; 14 kW typical orbit power load).
- Water tanks empty at about 100 percent per hour for a water dump, about 50 percent per hour when using the FES high load evaporator for cooling with payload bay doors closed, and about 16 percent per hour when using the FES topping evaporator for supply water dumps on orbit with the doors open.

- On-orbit cold soak is good for 20 to 30 minutes of cooling. Prelaunch Freon conditioning is good for 2 to 3 minutes of cooling.
- NH_3 boiler supply is good for 25 minutes of ground cooling.
- A single cryo O_2 tank is good for about 2 to 3 days of orbit usage depending on crew size and power level. H_2 tanks are sized to match O_2 usage.
- A single LiOH canister is usable for about 48 man-hours.

Entry

- 2 OMS: TGO ≈ ΔVTOT/2.
- 1 OMS: TGO ≈ ΔVTOT.
- RCS: TGO ≈ 1.7 x ΔVTOT.
- As an approximation, 1 degree of bank change produces 0.7 ft/sec^2 H-dot change. Large bank errors cause corresponding errors in H-dot, allowing a phugoid to develop more quickly.
- A 1 degree change in alpha produces a 1.7 ft/sec^2 drag change, which is equal to an 8 degree roll change.
- Prior to the first bank, monitor vehicle attitude at 0 degrees bank and 40 degrees alpha.
- First bank (flight path angle capture) should occur at a drag acceleration of approximately 3 fps^2 and/or q-bar of approximately 8 psf.
- Monitor the trajectory on the ENTRY ALPHA cue card, and the PASS and BFS TRAJ displays:
- The Shuttle bug superimposed on guidance box superimposed on nominal trajectory line.
  - Actual drag equal to reference drag.
  - Appropriate bank angle, H-dot, range and altitude.
- For an off-nominal trajectory, check that guidance is working to put the guidance box back on the Shuttle bug (zero range error) within the trajectory envelope.
- Attempt to contact MCC before taking CSS.
- If you must take CSS:
  - Control range by controlling drag.
  - Control drag by controlling H-dot.
  - Control H-dot by controlling H-double dot.
  - Control H-double dot by controlling bank angle.
  - Control everything slowly by small corrections.

EPS

- *Never* close a circuit breaker or reset an RPC found out of configuration without MCC coordination.
- Loss of cooling to a fuel cell requires crew action within 9 minutes to prevent a catastrophic loss of crew/vehicle due to possible fuel cell fire and explosion.
- Any interruption of continuous ac power during ascent may result in the loss of main engine controller redundancy. Reconfiguration of ac powered equipment prior to MECO should be avoided.
- *Never* connect or reconnect power to a known shorted or failed component; this includes switch throws, circuit protection device resets, or bus ties.
- Fuel cell run limit prior to shutdown for loss of cooling is 9 minutes at a 7 kW nominal load. Run time varies inversely with fuel cell load.
- Three oxygen and hydrogen tanks are good for up to 8 days on orbit; five oxygen and hydrogen tanks are good for up to 12 days on orbit; eight oxygen and hydrogen tanks are good for up to 18 days on orbit. Duration varies with crew complement and power load.
- A fuel cell hydrogen pump uses 0.3 amps/AC phase; a coolant pump uses 0.5 amps/AC phase.

EVA

- Always use "make before break" tether protocol.
- Don't use the glove as a hammer.
- EVA crewmember must remain tethered at all times.

- Slow and deliberate motion provides much greater stability than quick, jerky motions.
- Body positioning is 90 percent of the task.
- Each EVA crewmember should check out his or her own EMU.

GNC

- The PASS FDIR for the RGAs, AAs, and aerosurfaces terminates after the first failure. After the first failure, crew management of the selection filter is required. For the BFS selection filter, crew management is always required. Proper selection filter management is required for proper control.
- For FCS channel management:
  - Never have more active channels on one GPC than another.
  - If there are two failures on the same actuator, take the remaining FCS channels to *OVERRIDE*.
  - Always maintain two good commands and one good feedback on each aerosurface.
  - Delay 2 seconds between switch throws when moving FCS *CHANNEL* switches to *OVERRIDE*.
  - Port bypass, or port pop, is a mechanical means to avoid force fights; feedback deselection is a software means to avoid a bad input into the selection filter.
- For ascent, only the pilot's SBTC is active. To get manual throttles, the pilot must depress the *TAKEOVER* button and then match the commanded throttle setting. Manual rotational control is available only in PASS and must be both pitch and roll/yaw.
- For entry, both SBTCs are active. To get manual speed brake, the CDR or pilot must depress the *TAKEOVER* button. Manual rotational control is available in either pitch or bank in PASS, and required in both axes in BFS.
- For TACAN and ADTA management, talk to MCC before incorporating.
- Without communication, the crew will use the NO-COMM TACAN MGMT and ADTA MGMT cue card.

Landing/Deceleration System

- Landing gear should not be deployed at equivalent airspeeds greater than 297 knots.
- ± 1 knot of touchdown speed corresponds to ± 100 feet of distance.

Lighting System

- Power consumption of cockpit lighting can be as much as 1 to 2 kW with all lights on.
- When payload bay floodlights are turned off, they should remain unpowered for 10 to 16 minutes prior to repowering.

Mechanical Systems

- Always use a timer when operating mechanical systems, noting either dual or single motor time. Do not continue driving if greater than the single motor time has elapsed without the mechanism reaching the desired state.

MPS

- Direct insertion MECO is usually close to 8 minutes 30 seconds.
- For three engines at 104 percent, fuel consumption is about 1 percent propellant/5 seconds. For three engines at 65 percent, fuel consumption is about 1 percent/8 seconds.
- An SSME will consume approximately 4 percent propellant per engine per minute at 104 percent. Propellant remaining is displayed on the ASCENT TRAJ display and is a guidance-calculated number.
- When an engine fails, the helium dP/dT is greater than 40 for several seconds, due to engine shutdown, and then it goes to zero. This is a good crosscheck to confirm engine shutdown.
- The selection of max throttle is not to be taken lightly. It increases the risk of catastrophic failure of an SSME by 10 times.
- Five ways to set MECO confirmed are: three Pc's less than 30, two Pc's less than 30 plus one data path failure, three SSME PBs, OPS 104 PRO, and FAST SEP.

- PASS will downmode a commfaulted *MAIN ENGINE SHUT DOWN* push button and allow the push button to safe an engine under a data path failure. BFS does not allow this. If a *MAIN ENGINE SHUT DOWN* push button is commfaulted in BFS, it is inoperative.
- An OPS 602 PRO does not set MECO confirmed.
- BFS requires all three *MAIN ENGINE SHUT DOWN* push buttons SIMO to set MECO confirmed; PASS only requires to see the PBs once.
- To shut an engine down, both contacts on the *MAIN ENGINE SHUT DOWN* push button must be good. If one contact is commfaulted, the button can be used to set the safing flag on an engine that failed under a data path failure. If a contact is power-failed, the button is inoperative unless it is commfaulted.
- An SSME command path failure must always be shut down manually with the A/C switches and PBs.
- An SSME FAIL C (L, R) message indicates that the GNC software has recognized an engine shut down. Two of these messages will enable single engine roll control mode.
- An engine in data path failure will never display a red *MAIN ENGINE STATUS* light, pre-engage.
- There are no direct indications to the crew of limit shutdown enable/inhibit status. The status is available to Mission Control, or it can be deduced by the crew.
- Limits must be enabled on an engine when the helium regulator pressure begins to decay due to a helium leak. An SSME will almost certainly fail catastrophically if there is insufficient helium, and limit shutdown is inhibited.
- Manual shutdown of hydraulically or electrically locked SSME is dependent on which issues the performance call, due to low-level C/O sensor timing.
- Actual throttle levels on the first stage throttle bucket can vary due to SRB thrust level dispersions. This is an artifact of "first stage adaptive guidance."
- Loss of an APU means hydraulic lockup. SSME CMD C (L, R) messages are possible post-MECO. No action is necessary.
- 23 k, 22.5 k, and 24.5 k V_I are about 30 seconds before MECO on the three-engine uphill, TAL, and two-engine uphill cases respectively. Note that V_I indication is lost to the crew post-engage.
- *MPS ENGINE POWER* switches look very similar to *He ISOLATION* switches and are located close together on panel R2. ***Use caution.***
- Shutdown with A/C switches will always cause a data path failure.
- Loss of ALC 1, 2, 3 (APC 4, 5, 6) will cause SSME helium isolation A to close on the C, L, R SSME with no direct indication to the pilot. Do not attempt subsequent helium leak isolations.

OMS

- 1 percent of OMS propellant

  = 6 fps ΔV

  = 3 n.m. ΔHp

  = 130 lbs (80 lbs oxidizer, 50 lbs fuel)

  uses 40 psi of helium for long burns.
- One OMS engine causes approximately 1 fps^2 acceleration.
- For OMS ignition, there must be power and command to at least one coil on both control valves.
- OMS TVC requires an enable discrete from the FF MDM, and commands from the FA MDM.
- FUEL INJECTOR TEMP message may be a signature of a bad temperature transducer or a fuel blockage.
- CHAMBER PRESSURE message may be a signature of a bad pressure transducer or an oxidizer blockage.
- There are several failures that inop OMS FDI (FA MDM commfault or Pc transducer failed high).
- Always check redundant sources to confirm any malfunction.

- An OMS engine failure post-MECO should be signified by a down arrow on the MNVR display.
- Max blowdown on the OMS is approximately 39 percent.
- 1,000 lbs of OMS (approximately 8 percent) moves the X c.g. 1.5 inches aft and the Y c.g. 0.5 inches left or right.
- Max OMS quantity for landing = 21 percent.

Orbit

- In propellant-limited situations, use the following guidelines:
  - Stay in VERN as much as possible.
  - To conserve forward RCS, use TAIL ONLY control mode.
  - During prox ops, when controlling out-of-plane errors, start as early as possible, wait for the node to make inputs to null rates, watch the deadbands, and do not fight orbital mechanics effects.
- TRAJECTORY:
  - NC: sets up 2-rev transfer to Ti (usually retrograde)- NCC: 1st Onboard, based on 2 ST Passes, Targets to Ti
  - Ti: 1st to target intercept, uses RADAR Data (usually posigrade)
  - MC1-4: Trim Burns Targeted to intercept
  - OOPN: Usually between MC1 and MC2, Tgt and Orb co-planar (Y = 0)
  - Ti Delay: Football, Posigarde (2 x Ti DVX)

    NEED: New Ti TIG

    LOAD new Base Time

    Start FDF at NCC intermediate solution (may not burn new NCC).

  SOURCE OF ERRORS

  Attitude maneuvers and jet cross coupling

  Burn trims

  Orbiter Vents (APU, FES, etc.)

  Drag uncertainties.

- ST PASSES:
  - DES IMU (Prime sel IMU for Attitude at 2 level)
  - Monitor RESIDS < .05 (Star Lock - BREAK TRACK)
  - 1st PASS:
    Assumes on PROP
    Gives Criteria to select FLTR
  - 2nd PASS:
    Assumes FLTR
    Verify 1st PASS
    Gives Criteria to do FLTR to PROP.

  SOURCE OF ERRORS

  Prime selected IMU going bad

  Star tracker bias

  Maneuvers and length of time since last SV update

  Taking marks on a star

  Either IMU accelerometer going bad.

- RADAR PASS:
  - Use if < 135 k (Range eclipsing)
  - Procedure handles either FLTR or PROP selected
  - Gives criteria to select FLTR -or- to do FLTR to PROP
  - Verifies star tracker passes
  - INH angles during maneuvers to burn attitude
  - RR MODE = ATRK during maneuvers to burn attitude.

  SOURCE OF ERRORS

  Range eclipsing

  EL/AZ greater than 30 deg

  Ku biases (Range).

- TARGETING:
  - Load BASE TIME (Ti TIG) to TGT SET #1
  - Load TGT SET (ITEM 1 +)
  - Verify
  - Compute (ITEM 28)

- Plot T1 Position
- MC2 (El Angle for ILOS rates = 0 approach)

  Note Nominal Time

  Compute TIG Change

  TIG will be new BASE TIME

  –3 and +7 limits for lighting.

- NAV MANAGEMENT:
  - FLTR to PROP (before taking DATA) After new sensor acquisition Reacquisition of Sensor Data
  - RNDZ NAV enable creates the PROP
  - Always have a FLTR vector
  - COMM FAULT or suspect bad data INHIBIT then ask questions.
- BURNS:
  - POSIGRADE: TVR = 0
  - RETROGRADE: TVR = 180
  - < 4 - Multi-Axis (DAP:LVLH)
  - > 4 - +X Mnvr to Attitude (DAP:INTL)
  - > 6 - OMS
  - TRANS: NORM until VGO < 1 fps then PULSE
  - VGO Z is negative: Burn Z, X, Y
  - Preliminary solution for NCC and Ti can be considered the PROP solution.
- PTG/DAP MANAGEMENT:
  - -Z target track
  - A/VERN - Attitude hold (.2 deg/sec and 1 deg deadband)
  - B/PRI - Maneuver (.5 deg/sec and 2 deg deadband)
  - TRANS PULSE = .1 RNDZ and .05 Prox Ops
  - Config for VBAR at +RBAR
  - PROX OPS DAP - when stable (VBAR).
- SYSTEMS CONCERNS (single point):
  - GNC GPC FAIL:

    2 required for Ti and PROX OPS

    RNDZ NAV disables at OPS MODE RECALL

    Saves FLTR Vector when RNDZ NAV Disables

    CNCL pointing (TGT ID = 1) before

    OPS MODE recall
  - MDM FF3:

    Loss of VERN (1-2-3 rule)

    RADAR to NAV panel A2 is still good -Y Tracker
  - MDM FA1 or 2:
    Loss of VERNs (1-2-3 rule)
  - MDM FF1:

    -Z tracker
  - PL 1:

    Auto Ku Pointing (KU MODES: GPC and GDSG lost)
  - Loss of IMU 2 - Restring 1221.
- Expending about 35 to 40 lb of RCS propellant to maintain attitude results in a cross-coupling translation of 1 fps in -Z direction.
- .3 fps posigrade or retrograde = .9 nm downtrack/rev.
- 1 fps posigrade or retrograde =:

  16 kft downtrack/rev

  3.5 kft radial/.5 rev

  .5 nm altitude change (HA or HP).
- 1 fps radial =:

  3.5 kft downtrack/.5 rev

  900 ft radial/.25 and .75 rev (decoupled from the other axis).
- 1 fps Out Of Plane = 900 ft/.5 rev (decoupled from the other axis)
- (SMA error) x (-10) = ft/rev downtrack error.
- High +Z DV for MC2-4 = short trajectory.
- MC2 Positive TIG slip = Early sunrise.
- TGT EL ANG message = Very short case.

- High in COAS = Short traj (subtract from ADI pitch for THETA)
- High at Ti (> 1.4 deg) = MC2 TIG slip should be positive.
- ORB RATE = .06 deg/sec; 4 deg/min; 360 deg/90 min; 1.1 mr/sec.
- Ti done at orbital noon -3 min.
- +Y = South or going South.
- Sep Rate = 10 x delta H.
- (3/2) WΔV for Coeliptic.

PDRS

- Whenever there are both talkbacks and CRT displays that reflect microswitch status, they should ALWAYS both be checked during any operation affecting them.
- Whenever troubleshooting RMS malfunctions in the long-form MAL book, always READ AHEAD. The MALs have a knack for having page breaks in extremely bad locations, and if you don't know what you're supposed to look for before you turn the page, you could be in trouble.
- The hand controllers are rate-proportional and are extremely sensitive. They should be held in such a way that you can control the full range of inputs without ever stopping to rearrange your hand. Care must be taken to not overcontrol the inputs. A good practice is to slowly and steadily input a desired command, wait patiently until you see the reactions of that command on the arm, and as the desired motion is achieved, slowly back off the input. Ideally, you should reach the axis detent at the same time the arm achieves the desired position and attitude.
- MPM motion may cease during deployment or stowage before the expected microswitches are made. This is due to the fact that the last part of travel in either direction is when the overcenter lock is locking. Therefore, don't turn off the *PORT RMS* switch when visible motion stops. Wait for the microswitches.
- Practice safety habits, the most important of which are brakes on, then power off (if required) for abnormal joint response and use EE CC for abnormal EE ops during the specified conditions.
- During arm cradling, periodically check all joint angles to make sure that joints that you have already aligned to zero have not moved. During soft stop, position hold does not work; therefore, external forces can move joints out of desired alignment.
- CCTV cameras have a tendency to malfunction at the most inconvenient times. Expect this and know how to perform all operations without cameras.
- Develop a scan pattern that encompasses window, CCTV, and panel status.
- Never rotate the *MODE* switch through *DIRECT* while the brakes are on. This actually puts the arm in mode, and sets you up for a possible runaway if a *SINGLE/DIRECT DRIVE* switch failure occurs or is present.
- Verify the *RATE* switch setting by feel and talkback status. This should be done EVERY TIME prior to moving the arm, regardless of mode.
- Make sure you know the proper definitions of "cradling," "stowing," and "berthing."
- Rates for berthing/unberthing: Usually maintain rates at about 0.4 to 0.5 ft/sec between Z = 414 and -438. For Z < -438 (away from the bay), rates can be increased somewhat.
- For berthing or unberthing of payloads with keel trunnions: the keel pin enters/exits the AKA when the longeron trunnions are at the top of the built-in 8-inch PRLA guides.

RCS

- 1% RCS prop = 1 fps ΔV.
- 1% RCS prop = 22 lbs.
- 1,000 lbs of ARCS prop moves X c.g. 1.2 in, X c.g. $\pm$ 0.4 in.
- 1,000 lbs of FRCS prop moves X c.g. -3.5 in.
- ARCS max blowdown qty 24%.
- FRCS max blowdown qty 22%.
- Loss of a single downfiring vernier jet is loss of vernier mode.
- If fuel tank pressure is 20 psi higher than the oxidizer tank pressure, then verniers are no-go.

- Always secure the RCS from the manifolds to the helium tanks.
- Always open the RCS from the helium tanks to the manifolds.

TAEM

- A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy. Gear deploy should not be delayed past 200 feet altitude.
- 90 ft of touchdown distance corresponds to 1 knot of airspeed.
- TAEM guidance uses pitch to control range, bank angle to control ground track, and speed brake to control q-bar.
- Overhead HAC with NEP allows the most downmode options for energy.
- Fly theta limits at Mach 2 (NLT Mach 1.5) if air data is not incorporated to G&C. Maximum bank angle is 50 degrees. Speed brake should be controlled manually when flying theta limits.
- Manual HAC techniques are only used when requested by Mission Control. To execute the manual HAC procedure, fly 220 to 230 KEAS and follow roll commands. At 120 degrees turn to go, resume flying pitch and roll guidance.
- For an early gear deploy, immediately close the speed brake.
- OGS is 19 degrees lightweight (< 220,000 lbs) and 17 degrees heavyweight (> 220,000 lbs). Aimpoint is 7,500 ft nominal and 6,500 close-in. Touchdown speed is 205 knots heavyweight and 195 knots lightweight and short field speed brake.
- At main gear touchdown, manually deploy the speed brake. Start derotation at 185 KEAS at approximately 2 degrees per sec. At nose gear touchdown, manually back up WOW.
- During training, pilots should strive for a threshold crossing height of 15 to 20 feet on nominal approaches. Touchdown goals are airspeed within 5 knots of the target value, sink rate within structural limits, negligible lateral drift, and minimal RHC activity. A good target value for sink rate is 3 fps or less, insuring ample margin before violating limits.
- With NWS in *GPC* or *DIRECT*, the orbiter will tend to turn into a crosswind. With NWS *OFF*, the orbiter will tend to turn away from a crosswind.
- If the orbiter is landing with a known failed tire, the second tire on that axle is expected to fail during derotation at the point of maximum loading.
- If both main gear tires fail on one side, the orbiter will tend to turn toward that side. The turning moment due to crosswind can either reinforce or reduce this effect.
- If the turning moments due to tire failure and crosswind are in the same directions, large control inputs will probably be required.
- If the turning moments due to tire failure and crosswind are in opposite directions, the control inputs required to counteract tire failure will be reduced. In this situation, pilots must be careful not to overcontrol. A good rule of thumb is to be more cautious with the rudder pedals, matching the crosswind turning tendency.
- Flight Rules call for landing with an existing crosswind on the same side as a known or expected bad tire.

ASCENT

Ascent Performance Margin
Management Reserve Req. (lbs)
Pre Flight Design Requirements Document = 3500
Flight Design Requirements Document = 2500
Cargo Integration Review = 1500
Flight Planning Stowage Review = 1500
FPR = 4652

ORBIT

1 hr launch delay = change in orbital noon by 4 minutes

Ascending node
28.5 deg – 1st ascending node is @ Long = 173.38 East
57 deg = 121.55 West

MISCELLANEOUS

Orbiters
OV101 – Enterprise
OV102 – Columbia
OV103 – Discovery
OV104 – Atlantis
OV105 – Endeavor
OV102 weighs 7000 lbs more than OV103/104

Min planned flt duration = 96 hours

Max/Min Beta Angle
Max = 23.5 + orbital inclination
Min = 23.5 – orbital inclination

Time
CDT = GMT – 5 hr
CST = GMT – 6 hr
Daylight savings time from 1st Sunday in April to last Sunday in October

DESCENT

EOM Elevon Schedules
FWD if Xcg < 1092
MID if 1092 < Xcg < 1100
AFT if Xcg > 1100

Xcg Limits
FWD = 1076.7 in (RTLS = 1079.0 in)
AFT = 1109.0 in
CONT AFT = 1119.0 in

D/O Delta V's
Descending approach is worst case ΔV
90 deg prebank will decrease ΔV ~ 10 ft/s (function of altitude)

If Xcg > 1091.5: 1 in Xcg = 2.2 miles
If Xcg < 1091.5: 1 in Xcg = 1.1 miles
As Xcg increases (more aft), XR decreases
1 nm XR = 5780 lbs EI weight
1 nm XR = 4.38 nm D/O altitude
As altitude and weight increase, XR increases
As inclination increases, XR increases (non-linear)
As temp increases, XR increases (non-linear)

Touchdown speeds
185 kts if TD weight < 200 k lbs
195 kts if 200 K lbs < TD weight < 220 k lbs
205 kts if TD weight > 220 k lbs

195 kts for all weights if shortfield speedbrake guidance mode is used

Mass Moment
MM = TD Weight * (1172.3 – Xcg)/12
If MM > 1.4 M ft-lbs Concrete desire
If MM > 1.55 M ft-lbs Concrete required
Note: If TD Xcg not known, use Xcg @ M = 3.5 + 1.5 in

Landing Weight Limits
EOM 230 k lbs
RTLS 240 k lbs *
TAL 240 k lbs *
AOA 240 k lbs *

Noctilucent Clouds
If Inc > 50, do not enter on descending opportunity June through August.

RENDEZVOUS

1 deg of phasing/hour = 10 nm of Δheight
1 deg of phasing = 60 nm
17.5 ft/s burn changes other side of orbit 10 nm
440 ft/s burn will change plane by 1 deg of wedge
1 deg of ΔRAAN occurs for each relative lap

PROPELLANT

1 deg of plane change = 440 ft/s

OMS philosophy
1 ft/s = 21.8 lbs OMS @ 220 k lbs ~1/6%
1.78 ft/s = 1 nm

Maximum OMS load
OV102 = 25156 lbs
OV103/4 = 25064 lbs
Min = 10800 lbs
Max OMS ballast = 4000 lbs
1% OMS = 130 lbs/side

Hard Ballast
OV102 – can be installed in the aft compartment
OV103/104 – Bay 13

RCS philosophy
1 ft/s = 25 lbs (+ X) or 35 – 40 lbs (multi axis) @ 220 K lbs
Max burn = 250 sec = 55 fps
Full FRCS = 2446 lbs
ET blowdown offload = 2225 lbs
Min FRCS – 1862 lbs
Full ARCS = 4970 lbs (over 100%)
1% ARCS = 22 lbs/side

IINTERCONNECT logic
If OMS < 14,000 lbs, I/C off
If OMS > 17,000 lbs, I/C on
If 14 K < OMS < 17 k, analysis req.

ECS – N2

OV102
6.28 lbs/day for 4 person crew @ 14.7 psi
add .114 lbs/day for additional crewman
4.35 lbs/day for 4 person crew @ 10.2 psi
add .079 lbs/day for additional crewman

OV103/4
5.28 lbs/day for 4 person crew @ 14.7 psi
add .114 lbs/day for additional crewmember
3.66 lbs/day for 4 person crew @ 10.2 psi
add .079 lbs/day for additional crewmember

	Dry wt	Fully loaded wt
N2	83 lbm	143 lbm

EPS

.09 lbm Hydrogen = 1 kwh
.7 lbm Oxygen = 1 kwh
.07 lbm Oxygen/hour = cabin leak rate

	Dry wt	Fully loaded wt
H2	227 lbm	319 lbm
C2	215 lbm	996 lbm

* Orbiter Engineering Memo VE3-90-096.

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