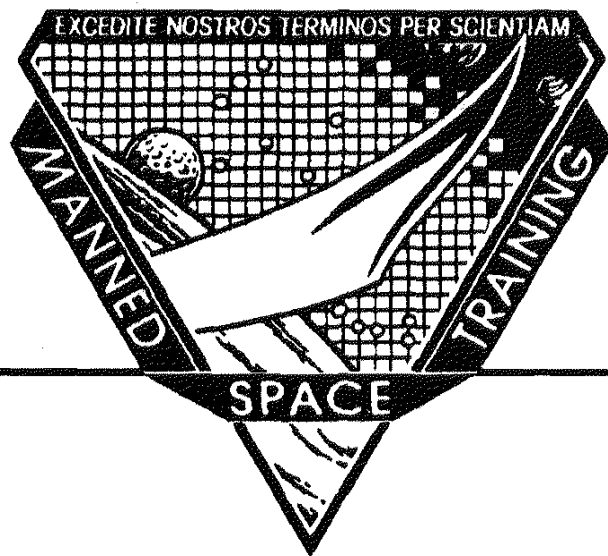


G&C I/O/D 2102A G&C Systems Training Manual

Guidance and Flight Control - Insertion, On-Orbit, and
Deorbit



February 1993

NASA

National Aeronautics and
Space Administration


Lyndon B. Johnson Space Center
Houston, Texas

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**Guidance and Flight Control - Insertion,
On-Orbit, and Deorbit**

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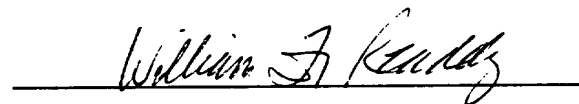
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Foreword

The content of this document was provided by the Control/Propulsion Section, Flight Training Branch, Mission Operations Directorate (MOD), Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA). Technical support was provided by the Rockwell Space Operations Company (RSOC) for the Space Transportation System Operations Contract (STSOC). This document was produced through the MOD Training Center, Flight Training Branch, Training Division, MOD, JSC, with the assistance of the Integrated Documentation Support Department, Omniplan Corporation, STSOC. For additions, deletions, or revisions to the technical content of this document, fill out a JSC form 318 and mail to the document coordinator, Robin Lewis/DT6, or contact the subject matter expert, Bill Lane, at 244-7010/DT66.

This material is for training purposes only and should not be used as a source of operational data. All numerical data, displays, and checklist references are intended only as examples. Consult the applicable Certification Plan outlined in your Flight Operations Support Personnel Training Guide (Blue Book) or the Crew Training Catalog to determine any prerequisites before using this document. This training package should be studied before attending any classroom session or lesson for which this is a prerequisite.

A Training Materials Evaluation is included at the end of this document. Inputs on this sheet will be used to evaluate the lesson material. You do not need to sign the sheet.

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Section 1: Flight Profile Introduction

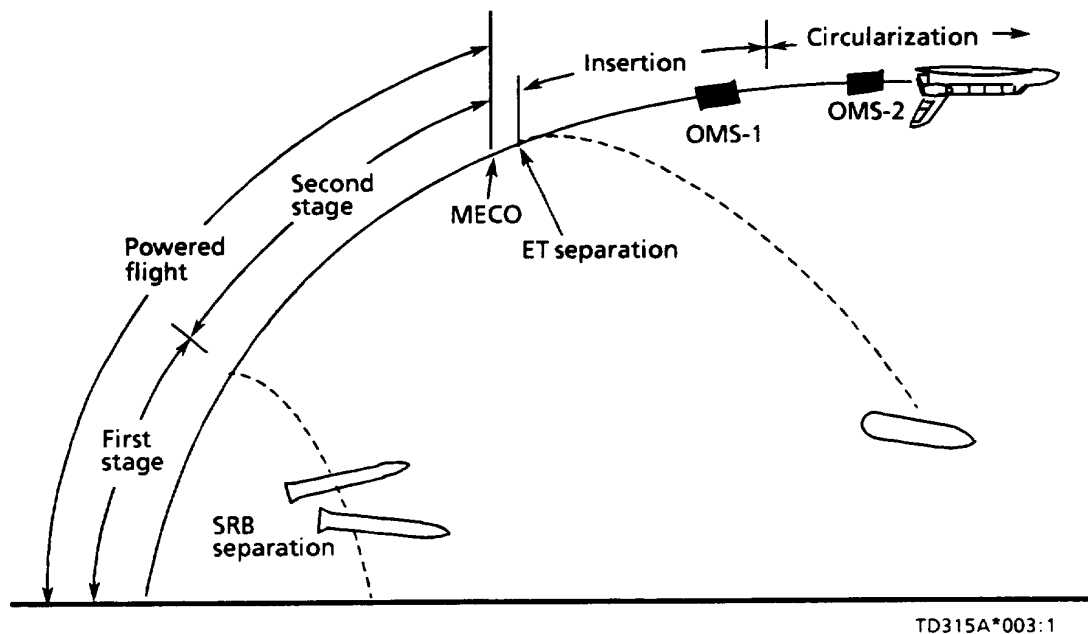
Orbit Insertion

The main sources of energy to put the space shuttle vehicle into orbit come from the solid rocket boosters (SRBs) and the space shuttle main engines (SSMEs). The SRBs burn out and are jettisoned about 2 minutes into the flight, resulting in an Atlantic Ocean splashdown off the coast of Florida (figure 1-1).

At this point, there are two options available to the planners of the flight, direct orbital insertion using main engines or insertion with an orbital maneuvering system (OMS) burn (OMS-1). On STS-1 through STS 41-B, main engine cutoff (MECO) occurred before the shuttle reached orbit. For these flights, insertion was done with the OMS engines. This helped to ensure that there was no danger of the external tank (ET) coming down in a populated area. In fact, all ETs have landed in the middle of the Indian Ocean. STS 41-C was the first direct insertion flight. The trajectory was modified and the SSMEs burned longer, thereby getting the vehicle into a higher orbit and eliminating the need for an OMS-1 burn.

Without a direct insertion ascent, the shuttle would follow the ET back to Earth. For these standard insertion ascents, the OMS-1 burn supplies the additional 200 to 300 ft/s of velocity that is required to place the vehicle in a stable orbit.

Whether or not a direct insertion trajectory is followed, an OMS-2 burn is required to raise the orbital perigee (HP) to an acceptable value. This burn is done at apogee (when the orbiter is at its farthest point from the Earth), which occurs approximately 160° or 35 minutes from the insertion point. The amount of thrust required is dependent on the final orbital altitude desired.



Note: The powered flight phase consists of first and second stages. After MECO there is an orbital insertion maneuver followed by an orbital circularization maneuver for standard insertion ascents.

Figure 1-1.—Nominal ascent profile.

On Orbit

Once the shuttle has achieved a stable orbit, the payload bay doors are opened, and the flight-specific operations begin (figure 1-2). Depending on the mission objectives, it may be necessary to schedule OMS and/or reaction control system (RCS) translation burns as well as RCS attitude maneuvers. Satellite deployments, rendezvous operations, and Earth observation experiments often require orbital changes or adjustments.

Deorbit

The purpose of a deorbit burn is to reduce the vehicle's orbital velocity, thereby decreasing its energy, which allows it to reenter the Earth's atmosphere. To control the entry, deorbit guidance targets the vehicle to a point where the range and velocity of the orbiter allow a safe landing at the desired site. The point that the shuttle is targeted is called entry interface (EI). It is the height above the Earth where the atmosphere is considered to end and space begins. This point lies approximately 400,000 feet above sea level.

To decrease orbital velocity, the vehicle is turned around so that the OMS engines point in the direction of travel (thrusting opposite to the velocity vector) and fire until the desired result is achieved. After a deorbit burn of about 2.5 minutes, the vehicle is turned around again and placed in the best possible attitude for EI. After EI, the orbiter essentially becomes a glider, conserving energy or bleeding it off via banks, or S-turns, until a safe landing can be made (figure 1-2).

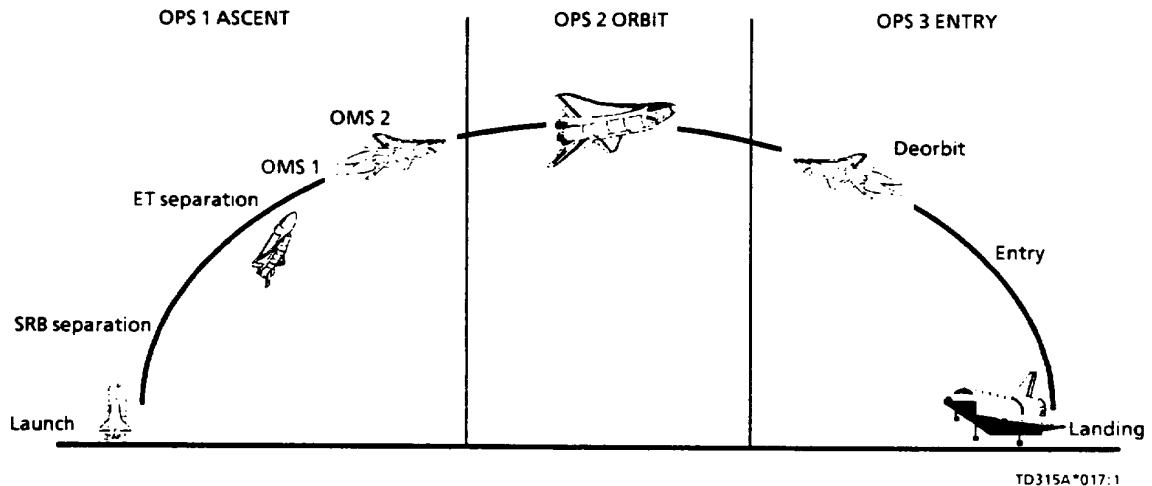


Figure 1-2.– Typical mission profile.

The Role of Guidance, Navigation, and Flight Control

Simply stated, navigation equipment and software keep track of where the orbiter is located, guidance computes where it needs to be to satisfy mission requirements, and flight control gets it there.

Since the requirements and needs vary from one flight phase to another, guidance, navigation, and control (GN&C) is different for different parts of the mission. For example, when on orbit, guidance target parameters related to the launch site are useless; whereas during ascent, they are essential. Similarly, the small vernier (VERN) RCS jets are not needed while the main engines are thrusting since the effect would be insignificant. Without vernier jets on orbit, however, the pointing accuracy of the orbiter would not be sufficient to achieve many of the objectives that the payload users demand. To conserve badly needed computer space, software is written to conform to the specific needs of the mission timeline. Table 1-1 shows the types of GN&C for each flight phase.

Table 1-1.– GN&C types by flight phase.

Flight Phase	MM	Navigation	Guidance	Control
Ascent – Precount	901	–	–	–
Terminal count	101	–	–	–
First stage (SRB ignition)	102	Asc. ¹ super-G (T-8s)	1st stage	Ascent DAP ²
Second stage (SRB separation)	103	Asc. super-G	PEG ³ 1	Asc. (until MECO)/ TRANS ⁴ DAP
Orbit insertion – OMS 1 ⁵ (– Z translation complete)	104	Asc. super-G	PEG 4, 7	TRANS DAP
OMS 2 ⁶	105	Asc. super-G	PEG 4, 7	TRANS DAP
Coast phase	106	Asc. super-G	–	TRANS DAP
Orbit – Orbit coast	201	Orb super-G/RNDZ ⁷	UNIV PTG	Orbit DAP
Maneuver EXEC	202	Orb super-G/RNDZ	UNIV PTG/ PEG 7	Orbit DAP
FCS ⁸ checkout	801	Orb super-G/RNDZ	UNIV PTG	Orbit DAP
Deorbit – Predeorbit coast	301	Entry super-G	–	TRANS DAP
Deorbit EXEC	302	Entry super-G	PEG 4, 7	TRANS DAP
Preentry monitor	303	Entry super-G	–	TRANS DAP
Entry – Entry monitor	304	Entry super-G	Entry	Aerojet DAP
TAEM ⁹ /landing (TAEM interface)	305	Preland super-G (MLS ¹⁰)	TAEM (M = 2.5)	Aerojet DAP
Aborts – RTLS ¹¹ second stage (RTLS abort)	601	RTLS super-G	PEG 5	Ascent DAP
Glide RTLS 1 (– Z translation complete)	602	RTLS super-G	PEG 5	GRTLS ¹² DAP
Glide RTLS 2 (TAEM interface)	603	RTLS super-G	TAEM (M = 3.2)	GRTLS DAP

¹Asc - Ascent.

²DAP - Digital autopilot.

³PEG - Powered explicit guidance.

⁴TRANS - Transition.

⁵OMS 1 - First OMS burn (not used nominally in a direct insertion ascent).

⁶OMS 2 - Second OMS burn (or first OMS burn in a direct insertion ascent).

⁷RNDZ - Rendezvous.

⁸FCS - Flight control system.

⁹TAEM - Terminal area energy management.

¹⁰MLS - Microwave landing system.

¹¹RTLS - Return to launch site.

¹²GRTLS - Glide portion of an RTLS.

Section 2–A: Guidance, Navigation, and Control Overview

Objectives

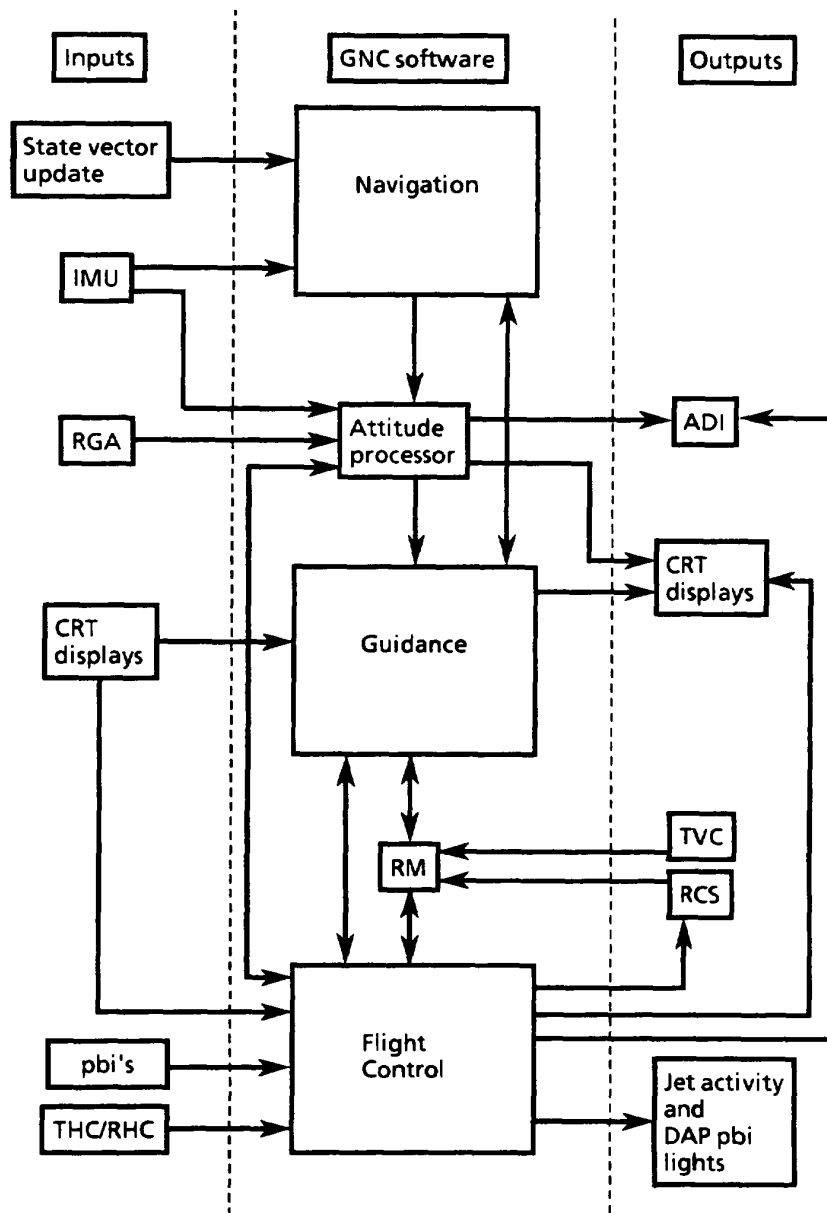
After completing this section, you should be able to

- Identify the purpose of navigation
- Define a state vector
- State when inertial measurement unit (IMU) data is not incorporated for use in state vector propagation
- State what can be done to improve/update the onboard state vector
- Name the software that maintains the orbiter state vector
- Identify the components that compute the orbiter state vector and the algorithm that is used
- Identify the components and software modules that receive attitude-related data from the attitude processor

Figure 2-1 shows how guidance, navigation, and flight control software interfaces with the crew and with hardware devices. The left side shows the inputs, while the outputs are on the right side. The center section shows schematically how the various programs are tied together.

In this section, the diagram is examined from a software point of view. By knowing what information is being passed from one module to another and what sort of calculations are performed to process that information, you will acquire a better understanding of why the orbiter behaves as it does. Subsequent sections of this document cover crew displays, controls, and procedures, all of which hinge on this software.

A word of caution, figure 2-1 has been simplified to increase readability and to maximize the clarity of the presentation. As a result, it is lacking some of the detail contained in other diagrams. If software modules or interface lines appear to be missing, it is because the author felt that such information is not essential to understand the subject matter and, in fact, may actually hinder you from learning the important parts. (See the reference guide in appendix A for a list of documentation on this subject.)



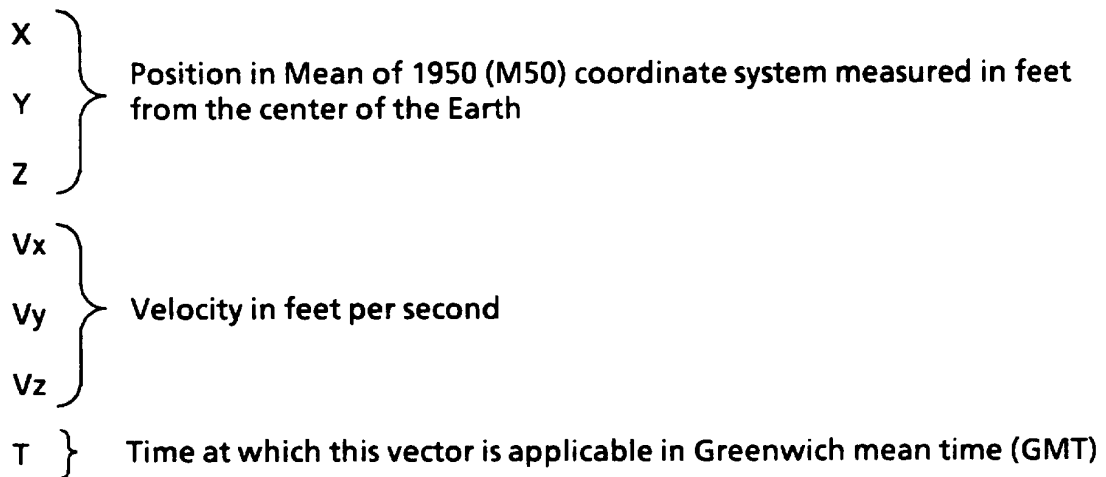
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Figure 2-1.— Guidance, navigation, and flight control software interfaces.

Navigation

To perform insertion, orbit, and deorbit maneuvers, there must be accurate data for the orbiter's location and velocity with respect to the Earth for use by guidance and control. This is the task of the shuttle's navigation (nav) software.

The navigation software maintains an accurate estimate of the orbiter's inertial (INRTL) position and velocity in the form of a seven-element "state vector." The seven elements include:



(See the NAV 2101 workbook for more information about coordinate systems and state vectors.)

During accelerated flight, the IMUs supply the information to calculate this vector. The onboard vector may be updated or replaced with a vector based on data obtained from tracking devices. During entry, other onboard sensors are used. Since this training manual is concerned only with the flight phases of insertion, orbit, and deorbit, entry sensors are not discussed here.

When rendezvous navigation is active, the software also keeps track of a state vector for the target. Based on the assumption that the target state vector is accurate, nav can improve its estimate of the orbiter state vector relative to the target by incorporating data from one of the three external sensors designed for this purpose. These are the rendezvous radar (RR), star tracker (ST), and the crew optical alignment sight (COAS).

Once nav has computed a state vector, it is sent to guidance for use in calculating burn target solutions. The state vector also is used by various cathode-ray tube (CRT) displays and meters, where it is converted into forms which the crew finds useful for flying the vehicle.

State Vectors

Because the vehicle's location changes with respect to the Earth as it orbits, the state vector is constantly changing, and nav is continually having to recompute it. This is done in the general purpose computers (GPCs) via an algorithm known as "super-g navigation."

Super-g Algorithm

1. Given the state vector and gravitational acceleration from the last cycle, a new position vector is estimated using either modeled drag acceleration or IMU-sensed acceleration.
2. The gravity at the new position is calculated.
3. Using the change in gravity from the past to the current cycle, the position and velocity vectors are recomputed.

The modeled acceleration referred to above uses a simple gravity equation and IMU data when the IMU-sensed acceleration is above a certain threshold level. This happens only on ascent (powered flight) or during an OMS or RCS burn. Because the IMUs are actual measuring instruments, they not only sense ΔV s due to legitimate accelerations, but those due to vehicle vibrations and other unwanted motions as well (the software corrects for sensed ΔV s due to rotations since it knows how far off the center of gravity (c.g.) the IMUs are located). These noise outputs tend to degrade the state vector if not eliminated. For this reason, when the vehicle acceleration is below the required ΔV threshold, IMU data is not used and a more sophisticated gravity model, also incorporating drag effects, is used.

In operational sequence (OPS) 201 or 801 when some of the RCS burns may not produce enough acceleration for the IMUs to detect, the crew has the option to turn "average g" (AVG G) on or off via a CRT item entry (SPEC 33, item 5). When it is turned on, IMU data is used when the magnitude of the sensed acceleration is enough to exceed the threshold level. When AVG G is turned off, IMU data is not incorporated.

In OPS 202, AVG G is automatically turned on so that sensed acceleration from an OMS burn is incorporated. The crew may not turn AVG G off in OPS 202, but the ΔV threshold test is active.

During dynamic flight phases, guidance and flight control need the state vector and attitude data often, especially for driving dedicated displays (tapes and meters). Unfortunately, the nav software takes a long time (3.84 seconds) to compute a state vector. (The time required for a computation is called a "nav cycle.") To supply data more quickly, a software module called User Parameter Processing (UPP) is

used to supply state vectors at a higher rate between nav cycles by using a simplified (but less accurate) propagation scheme. UPP updates its vectors with the regular nav-computed vector whenever one becomes available. The data from UPP is then made available to guidance, flight control, and crew displays.

Vector Selection

In primary avionics software system (PASS) OPS 1, 2, 6, and 8, nav propagates one state vector based on data from all three IMUs as determined by the IMU redundancy management (RM) scheme. (See the RM Functional Subsystem Software Requirements (FSSR) or the IMU Training Manual for additional information.) In OPS 3, however, a separate state vector is propagated from each IMU. The vector which is used by nav is then created by taking the best components from each. As a result, the OPS 3 state vector, which is probably the most critical, has a lesser chance of being "polluted" by bad sensor data.

State Vector Updates

The flight controllers in the Mission Control Center (MCC) have the capability to monitor the onboard state vector as computed by nav. In addition, they can monitor tracking data from ground-based radar. By comparing the two, they can see what sort of errors are accumulating. Errors in the onboard state vector are inherent in the propagation scheme and grow with time, following a fairly predictable pattern. The MCC evaluates these errors and may uplink a correction factor called a "delta state update" (if in powered flight) or a new state vector (if in coasting flight) into the system. The crew can perform delta state updates in OPS 1, 3, or 6, using the Horizontal Situation (HORIZ SIT) display (SPEC 50) or new state vector updates in OPS 2 or 8 with the GPC MEMORY display.

BFS – State Vectors

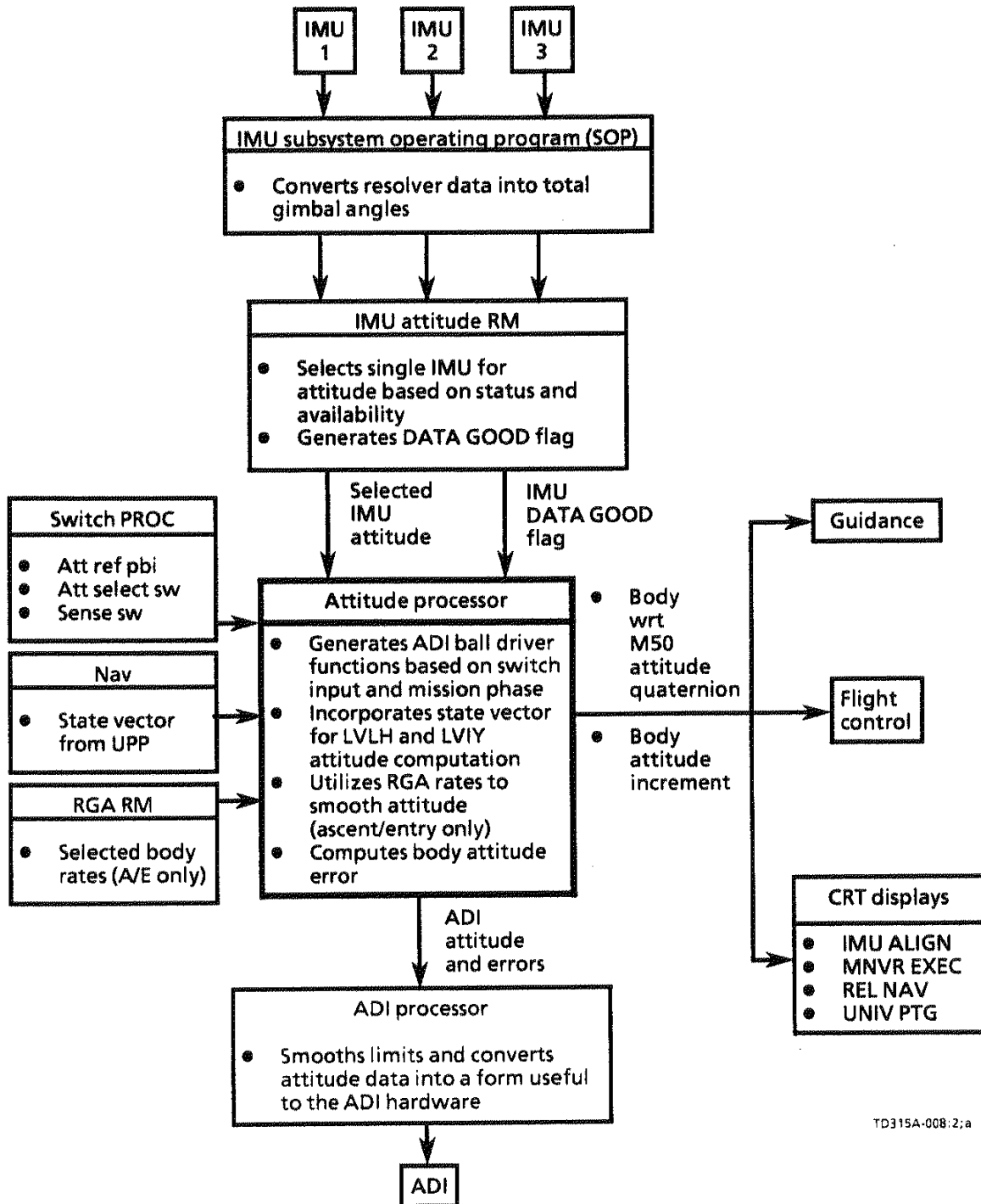
When the backup flight system (BFS) is not engaged, it is very important that it keep a current state vector propagating in case it is needed. Unlike the PASS, the BFS uses only one state vector during all mission phases in which it is active (there is no OPS 2 in BFS). Periodically during a nominal mission, a PASS to BFS state vector transfer is done to ensure that the BFS state vector is kept up to date on all the various corrections that are applied to the PASS. This transfer capability is available in OPS 1, 3, and 6 via SPEC 50 (HORIZ SIT). It is also possible to uplink a new or delta state vector update directly to the BFS.

Attitude Processor

The attitude processor (ATT PROC) derives attitude-related data for use by guidance, flight control, and crew displays, as well as by the attitude direction indicator (ADI) as shown at the bottom and on the right side of figure 2-2. Using data from a software-selected IMU, it computes the vehicle roll, pitch, and yaw attitude in an inertial coordinate system. For local vertical, local horizontal (LVLH) attitude processing, the vehicle state vector must also be taken into account.

During ascent and entry, when it becomes necessary to compute the attitude more frequently than the IMUs can provide data, rate gyro assembly (RGA) data is used to propagate the attitude between the IMU attitude measurements. This means that the vehicle attitude is updated approximately 12 times per second during ascent and insertion and about 6 times per second on entry, as opposed to only once per second on orbit when the RGAs are turned off.

The other task of the ATT PROC is to process the vehicle roll, pitch, and yaw rates from SRB and orbiter rate gyro's. In OPS 2 and 8, these rates are derived in the on-orbit DAP from successive attitude measurements, while in OPS 1 and 3, the rates are derived from RGA measurements. Such information is used by various software modules as well as for driving the ADI rate needles.



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Figure 2-2.- Functions of the ATT PROC.

Section 2-A: Questions

1. The purpose of nav is: (choose one)
 - a. To maneuver the orbiter to the required position in space
 - b. To determine where the orbiter must be to satisfy target requests
 - c. To keep track of where the orbiter is located
2. A state vector is defined as an accurate estimate of the orbiter inertial _____ and _____.
3. The _____ software maintains the orbiter state vector.
4. The _____ compute the orbiter state vector using an algorithm known as super-g nav.
5. When is IMU data not incorporated for use in state vector propagation?
6. What can be done to improve/update the onboard state vector?
7. Which components or software modules receive attitude-related data from the attitude processor?
 - a. IMU
 - b. ADI processor
 - c. Guidance
 - d. CRT displays
 - e. Flight control

Section 2–A: Answers

1. c. The purpose of nav is to keep track of where the orbiter is located.

Page 1-3 (The Role of Guidance, Navigation, and Flight Control)

2. A state vector is defined as an accurate estimate of the orbiter inertial position and velocity.

Page 2-3 (Navigation)

3. The navigation software maintains the orbiter state vector.

Page 2-3 (Navigation)

4. The general purpose computers (GPCs) compute the orbiter state vector using an algorithm known as super-g nav.

Page 2-4 (State Vectors)

5. IMU data is not incorporated for use in state vector propagation when the sensed accelerations are below certain threshold levels. Nor is the data used in OPS 201 or 801 when AVERAGE G (SPEC 33 item 5) is turned off.

Pages 2-4 (State Vectors)

6. To improve/update the onboard state vector

- a. The MCC can send delta or new state vector uplinks.
- b. The crew can perform delta state updates via the HORIZ SIT (SPEC 50) display or new state vector updates via GPC read/write.
- c. The BFS state vector can be updated from the PASS via a PASS/BFS state vector transfer or directly with new or delta state updates.

Page 2-5 (State Vector Updates)

7. b, c, d, and e. The ADI processor, guidance, CRT displays, and flight control receive attitude-related data from the attitude processor.

Page 2-6 (Attitude Processor)

Section 2–B: Purpose of Guidance

Objectives

After completing this section, you should be able to

- Describe the differences between powered explicit guidance (PEG) 4 and PEG 7 burns
- State when the transition (TRANS) digital autopilot (DAP) is active
- State when the thrust vector control (TVC) DAP is active
- State the purpose of the phase plane

Guidance

As previously mentioned, the function of navigation software is to answer the question, "Where am I?" Guidance's purpose is to determine where we want to be and how best to get there. Using the state vector from nav, the vehicle attitude from ATT PROC, the crew target information inputs to the Maneuver (MNVR) display (covered in detail later in this manual), and the control effector inputs (OMS gimbals and RCS jets for the insertion, orbit, and deorbit flight phases), guidance calculates how long and in what direction engines must burn to achieve the desired result. Guidance also supplies the attitude error information to flight control, CRT displays, and to the ADI error needles during insertion and deorbit. Although most burns and attitude maneuvers are "guided" (that is, employ software which utilizes knowledge of where the vehicle is with respect to where the crew wants it to be), there are times when the crew may want to perform simple burns or maneuvers without guidance. During the flight phases of insertion, orbit, and deorbit, such burns can be done only manually with RCS jets, using the translation hand controller (THC) for translations or the rotation hand controller (RHC) for rotations. OMS burns are always guided.

Insertion/Deorbit Guidance

Insertion and deorbit guidance is based on two mutually exclusive schemes. The next few paragraphs cover these two schemes in detail, when they are used as well as the how and why of their operation.

PEG 4 Vs. PEG 7 Guidance

When the guidance schemes for the shuttle were developed, two basic programs were produced for use on the insertion, orbit, and deorbit flight phases. These are called PEG routines 4 and 7 (other PEG numbers are used in different flight phases). PEG 4 guidance, also called linear terminal velocity constraint (LTVC) guidance, achieves a specified relationship between the horizontal and vertical velocity components at a certain position in orbit. This guidance scheme can accept OMS engine failures, once they are recognized as such, and make appropriate compensations so that the original targets of the burn are still met.

To maximize the efficiency of an insertion or deorbit burn, PEG 4 has the capability to burn in an arc instead of in a straight line as the orbiter passes around the Earth. However, this capability is not currently being used.

PEG 7 guidance (also called external ΔV) is an "open loop" system. This means that there is no target position vs. current position feedback, since guidance is trying to achieve a desired delta velocity in the X, Y, and Z LVLH reference frame. The OMS engines fire until the original delta V requirements are met or the engines are shut down due to failures. As a result, anything but a nominal burn (that is, engine failure, gimbal problems, steering dispersions, and so forth) could lengthen the burn time such that the net effective delta V will have been imparted further downrange than intended, thereby causing the target to be missed.

Since PEG 4 guidance is "closed loop" and relates the orbiter position to the Earth, it is well suited for orbital insertion and deorbit. Once in space, however, the orbiter's relationship to the Earth becomes less critical, while the success of rendezvous operations depends on achieving certain positive or negative velocities with respect to other orbiting objects. Apogee or perigee adjustments can be made simply by adding or subtracting velocity from the current orbital velocities. For these reasons, PEG 7 guidance, an "open loop" scheme, is used on orbit. In fact, PEG 4 is not available in OPS 2.

PEG 4 Calculations

The following steps show the calculations that guidance goes through to converge on a burn solution. In an effort to keep this clear and simple, the steps have been translated from equations into words. If you wish to see a more rigorous approach to this subject, read the section of the Onorbit/Deorbit Guidance FSSR entitled "Powered Explicit Guidance Task (PEG TSK)" in section 4.5.5.

1. The TARGET STATE is calculated based on CRT inputs of altitude (HT), down-range angle (θ), C1, and C2 (the definition of these parameters is given in the MNVR display section of this manual).

2. The **CURRENT STATE** comes from nav software.
3. The time of ignition (TIG) state (or position of the orbiter when the burn begins) is extrapolated by UPP from the **CURRENT STATE** and TIG.
4. To get a starting point, guidance begins with the **PREDICTED C/O (cutoff) STATE = TIG STATE**. (This is clearly impossible since it implies that the burn takes no time at all.)
5. The **REQUIRED C/O VELOCITY** which will satisfy the targets is computed next. The C/O state is not the same as the target state because the vehicle should stop burning sometime before the target is reached and coast the rest of the way.
6. $V_{MISS} = \text{REQUIRED C/O VELOCITY} - \text{PREDICTED C/O VELOCITY}$ (these velocities are part of the state vectors calculated in steps 4 and 5).
7. Velocity to go (VGO) = $V_{MISS} + VGO$ from the previous cycle (initially $VGO = \text{zero}$).
8. Burn time (TGO) is calculated from VGO using the basic rocket equation.
9. The predicted C/O state is now recomputed based on the addition of the following three vectors:
 - Current state
 - Theoretical burn state
 - Gravity effects
10. Steps 5 through 9 are repeated until V_{MISS} is less than 1 percent the value of VGO. At this point, guidance is converged, and the target solution is displayed. If a solution is not reached after six iterations (this should take only a few seconds), the burn attitude (BURN ATT), target apogee (TGT HA), and target perigee (TGT HP) are not displayed, while total change in velocity ($\Delta VTOT$), TGO, and VGO show the last computed value before guidance stopped iterating. If this happens, recheck the targets because something is probably wrong with them.

Orbit Guidance

On-orbit guidance can be divided into three basic types. Refer to figure 2-3 for the displays that are used to execute on-orbit guidance. First, the MNVR EXEC display in OPS 202 can be used to execute external ΔV (PEG 7) burns just as they are done

for insertion or deorbit. Second, that same display can be used for executing rendezvous maneuvers, which come in two varieties. Third, there exists universal pointing software, available in major mode (MM) 201 and active until overridden in MM 202 or MM 801. This software provides the capability to set up and execute a wide variety of RCS attitude maneuvers and tracking options.

For on-orbit maneuvers, there is a guidance scheme which is used exclusively for rendezvous and proximity operations (PROX OPS). This capability is enabled via the ORBIT TGT display (SPEC 34) but executed on the ORBIT MNVR EXEC display (OPS 202). Once the onboard computations are made, using target state and time information, the result is a set of delta V's: V_x , V_y , and V_z for PEG 7 on the MNVR display and can be executed just as any other PEG 7 burn.

The burn ΔV 's can be derived by two methods. The Lambert method compares the M50 state vector of the orbiter with the M50 state vector of the target and is used for most rendezvous operations. The Clohessy-Wiltshire (C&W) equations, on the other hand, are used primarily for PROX OPS and are considered a simplified version of Lambert targeting. In the C&W scheme, the relative state of the orbiter with respect to a target-centered coordinate system is used to derive the required ΔV 's. Of the two methods, Lambert is the more complex, accurate, and time-consuming method (it usually takes between 30 seconds and 2 minutes for a solution to be reached).

Universal pointing guidance uses the UNIV PTG display available only in OPS 201 to set up and initiate automatic RCS maneuvers. With this display, the crew can execute inertial attitude maneuvers, track specified targets with a selected axis of the vehicle, or rotate the orbiter in any orientation. All these options are covered later in this manual.

Flight Control

The role of flight control is to assimilate maneuver requests from guidance or from crew inputs and convert them into signals which cause the orbiter's gimbals, aerosurfaces, or RCS jets to respond in the manner appropriate to the flight phase conditions (figure 2-4).

During insertion, on orbit, and deorbit, the OMS gimbals and RCS jets are the only active "effectors." In addition to sending commands to these effectors, flight control also smooths the output signals and limits them so that guidance does not issue commands which may exceed structural limitations.

```

1041/ OMS 1 MNVR EXEC 5 000/00:00:28
OMS BOTH 1* BFS 000/00:01:00
  L 2 BURN ATT
  R 3 24 R 335
RCS SEL 4 25 P 179
5 TV ROLL 180 26 Y 347
TRIM LOAD MNVR 27
6 P [+ ] 0.4 REI
7 LY[- ] 5.7 TX 15:02
8 RY[+] 5.7 GMBL
9 WT 244025 L R
10 TIG 0/ 0:10:28.0 P +2.0 +0.5
TGT PEG 4 Y -5.4 +6.8
14 C1 0
15 C2 [+ ] 0.0000 PRI 28* 29*
16 HT 134.000 SEC 30 31
17 OT 140.000 OFF 32 33
18 PRPLT [ ] 0 GMBL CK 34
TGT PEG 7
19 ΔVK [ ] 158.0
20 ΔVY [ ] 0
21 ΔVZ [ ] 0
LOAD 22/TIMER 23

```

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```

2021/034/ ORBIT TGT 1 003/22:58:38
000/00:01:00
MNVR TIG ΔVX ΔVY ΔVZ ΔVT
XX X X/XX:XX:XX ±XXX.X ±XX.X ±XX.X ±XXX.X
PRED MATCH XXXXXX
CONTROLS
1 TGT NO XX T2 TO T1 25
2 T1 TIG X/XX:XX:XX LOAD 26
6 EL [±]XXX.XX COMPUTE T1 27X
7 ΔX/ΔWRNG [±]XXX.XX COMPUTE T1 28X
8 ΔY [±]XXX.XX
9 ΔZ/ΔH [±]XXX.XX
10 ΔX [±]XXX.XX
11 ΔY [±]XXX.XX
12 ΔZ [±]XXX.XX
13 T2 TIG X/XX:XX:XX
17 ΔT [±]XXX.XX
18 ΔX [±]XXX.XX
19 ΔY [±]XXX.XX
20 ΔZ [±]XXX.XX
21 BASE TIME X/XX:XX:XX
ORBITER STATE
XXX/XX:XX:XX
X ±XXXXX.XXX
Y ±XXXXX.XXX
Z ±XXXXX.XXX
VX ±XX.XXXXXX
VY ±XX.XXXXXX
VZ ±XX.XXXXXX
(XX)

```

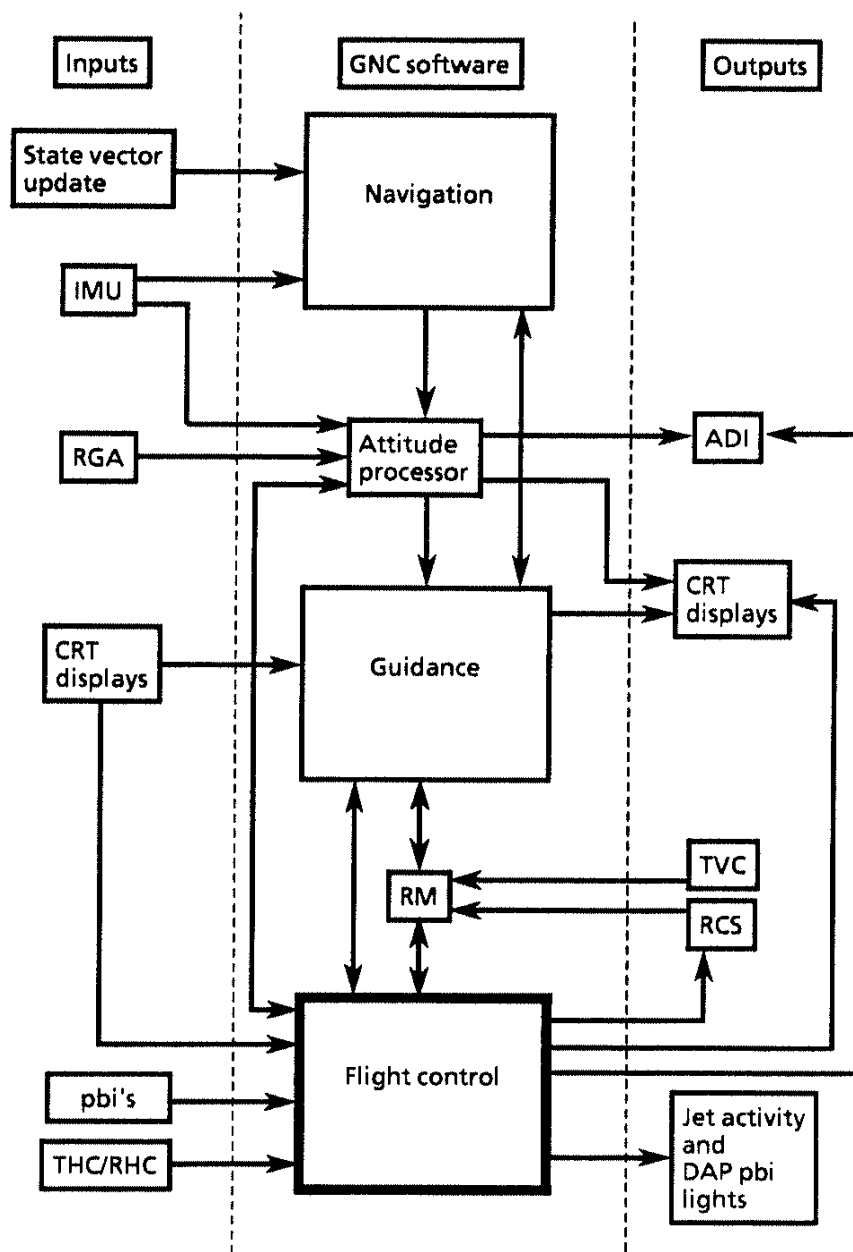
```

2011/ / UNIV PTG XX X 000/HH:MM:SS
CUR MNVR COMPL XX:XX:XX 000/HH:MM:SS
1 START TIME XXX/XX:XX:XX
MNVR OPTION START MNVR 18 X X CUR FUT
6 R XXX.XX TRK 19 X X
6 P XXX.XX ROT 20 X X
7 Y XXX.XX CNCL 21
TRK/ROT OPTIONS ATT MON
8 TGT ID XXX 22 MON AXIS X XX
ERR TOT 23X
9 RA XXX.XXX ERR DAP 24X
10 DEC [±]XX.XXX
11 LAT [±]XX.XXX ROLL PITCH YAW
12 LON [±]XXX.XXX CUR XXX.XX XXX.XX XXX.XX
13 ALT [±]XXXXX.X REQD XXX.XX XXX.XX XXX.XX
ERR ±XXX.XX ±XXX.XX ±XXX.XX
14 BODY VECT X RATE ±XX.XXX ±XX.XXX ±XX.XXX
16 P XXX.XX
18 Y XXX.XX
17 OM XXX.XX
(XX)

```

TD315*052

Figure 2-3.- On-orbit guidance displays.



10315*034 2

Figure 2-4.- Flight control process.

The DAP is the heart of the flight control software. It is composed of several software modules which interpret maneuver requests, compare the requests to what the vehicle is actually doing, and generate commands for the appropriate effectors as needed to satisfy the requests. There are different DAPs for different flight phases (five in all) and various modes and submodes of operation within each.

During insertion and deorbit, the TRANS DAP is running. It takes over from the ascent DAP in OPS 103 when the "MECO CONFIRM" flag is set in the software. (The conditions which set this flag can be found in the Sequencing FSSR.) This means that the TRANS DAP is in effect for ET separation (SEP) and the automatic - Z translation maneuver which follows. The TRANS DAP continues to run through MMs 104, 105, and 106 and resumes again for deorbit (MMs 301, 302, and 303). The orbit DAP is active only in MMs 201, 202, and 801. The other three DAPs, ascent, aerojet, and the glide portion of a return to launch site (GRTLS), are not used in insertion, on orbit, or deorbit and are not covered in this manual.

<u>MM</u>	<u>Active DAP</u>
102	Ascent
103 (pre-MECO)	Ascent
103 (post-MECO)	Transition
104	Transition
105	Transition
106	Transition
201	Orbit
202	Orbit
801	Orbit
301	Transition
302	Transition
303	Transition
304	Aerojet
305	Aerojet
601	Ascent
602	GRTLS
603	GRTLS

The Thrust Vector Control Digital Autopilot

Both TRANS and orbit DAPs are always in one of two modes, RCS or TVC. These are referred to as the RCS mode or RCS DAP and the TVC mode or TVC DAP. Usually, they are in the RCS mode which means that the only effectors in use are the RCS jets. For the DAP to be in the TVC mode, the following conditions must be met:

1. An ON command is being sent to one or both of the OMS engines.
2. In orbit DAP only, the IMU DATA GOOD flag must be set to ON (good). That is, there is at least one good IMU from which attitude data can be derived.

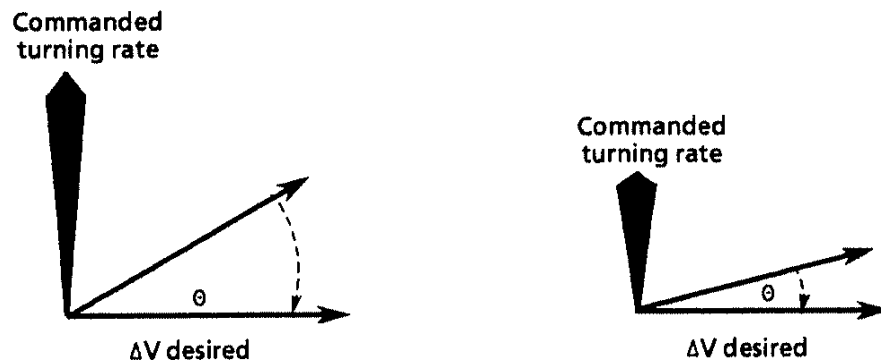
The following conditions are necessary for an engine ON command to be generated:

- The engines (L, R, or both) must be selected on the MNVR EXEC display in OPS 104, 105, 202, or 302.
- The execute (EXEC) key must be pressed after the word EXEC flashes on the MNVR display.
- The designated TIG must have been reached.

When these conditions are satisfied, the burn commences and the TVC mode is in effect until cutoff occurs; the OMS ENG switches are turned off; the IMU DATA GOOD flag is set "bad"; or the crew transitions to the next major mode.

The TVC DAP is a "rate command system." Every second, guidance calculates a desired direction for delta V needed to achieve the target condition. The IMUs measure the delta V sensed since the last guidance cycle. The cross product of these two vectors, multiplied by a constant (K), is the angular rotation rate vector for turning delta V achieved into delta V desired. Another way to put this, the commanded turning rate is proportional to the sine of the angle between the two vectors: achieved and desired delta V (figure 2-5).

$$\text{Rate command} = (\Delta V_{\text{des}} \times \Delta V_{\text{ach}})$$



TD315A*010:2:a

Figure 2-5.— Commanded turning rate.

When delta V desired and delta V achieved are in the same direction, the sine of the angle between them is zero and the commanded turning rate is zero. To produce a turning rate of zero, the gimbals must be pointed to provide a net thrust through the c.g.

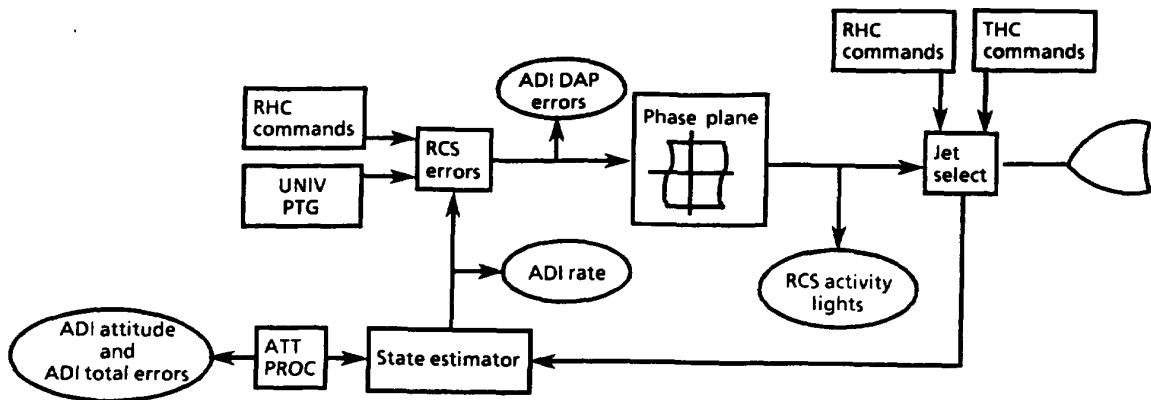
When the TVC mode is active, RCS jets may be required to perform in either of two ways. First, if only one engine is being used, vehicle roll cannot be controlled by any combination of gimbal pitch and yaw. RCS jets are utilized, therefore, to control any roll commands that are generated. Second, whether there are two engines selected or only one, RCS jets may perform a "wraparound" function. This means that if the control authority of the gimbals is not adequate to keep the rate or attitude deadbands within the specified TVC limits, RCS jets fire as needed to correct the errors. This might occur if there was degradation in the OMS gimbal which prevents it from slewing properly or if the vehicle is significantly out of burn attitude for a PEG 4 burn when the OMS engines begin to fire.

The Reaction Control System Digital Autopilot

The RCS DAP works to hold attitude or to accomplish an attitude maneuver through an error correction method. Figure 2-6 shows how it accomplishes its task of generating appropriate signals to send to the effectors.

The state estimator takes IMU data from the ATT PROC, filters it, and sends it to a module called RCS Errors.

In the RCS Errors module, attitude commands coming from the RHC or from the Universal Pointing software (which runs the display by the same name) are compared with the actual attitude as computed by the state estimator. The result is an attitude error and a rate error which are passed to the phase plane module.



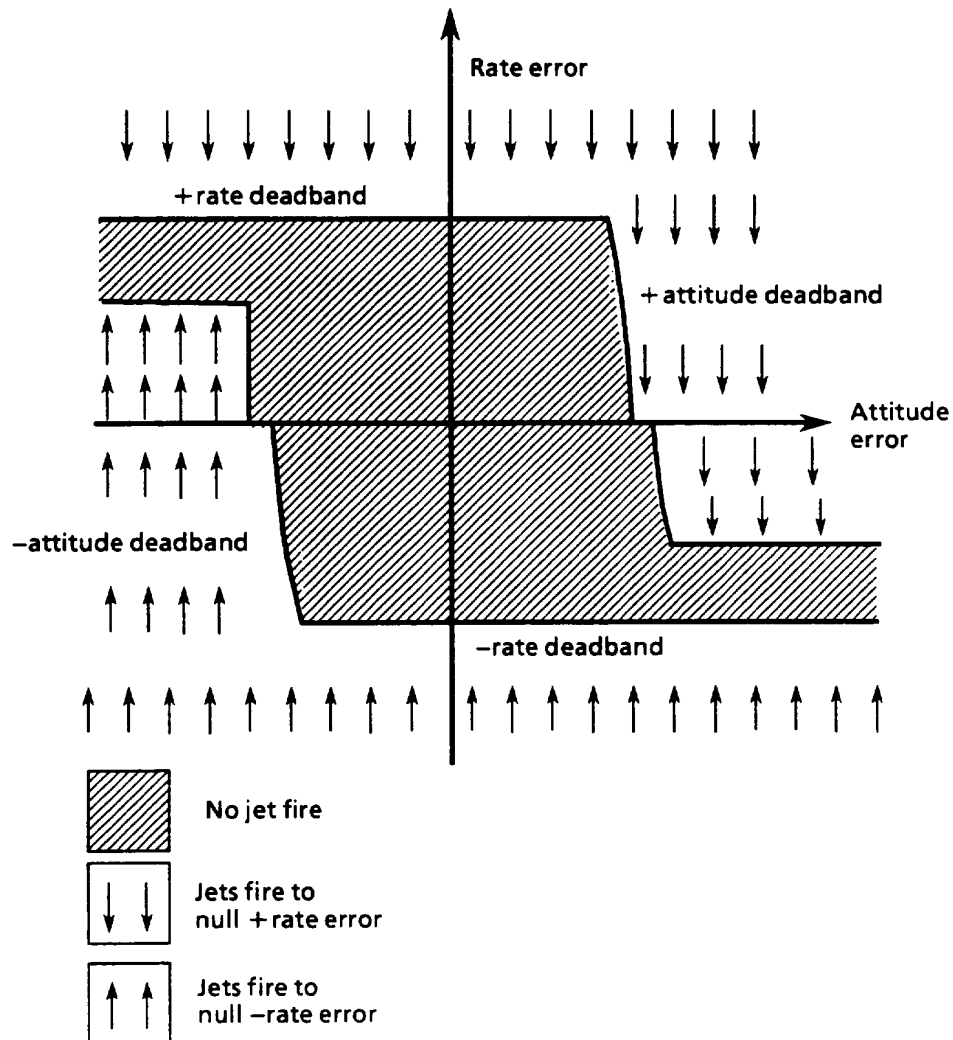
TD315*011:2;a

Figure 2-6. – RCS orbit DAP.

A phase plane may be visualized as a graph plotting shuttle rate errors against attitude errors for one axis, with a "box" drawn around the center (figure 2-7). There is a separate phase plane for each of the vehicle rotation axes (roll, pitch, and yaw). The box (actually the sides are parabolic), whose limits are defined by the crew with attitude and rate deadbands, is used to determine when, if, and in what direction rates must be generated to null the errors. If the shuttle is within the specified deadband limits, the rate and attitude errors are represented by a point plotted inside the box. If the point travels outside the box, jets fire to drive it back inside the box, thereby reducing the errors and achieving the maneuver request or maintaining the attitude hold. In an attitude hold situation, the error plot actually cycles around the zero error point with jets turning off and on again each time the limits of the box are exceeded. This is known as "limit cycling." The rate of limit cycling is dependent on the deadband size and the jet selection specified by the crew.

The manual acceleration and PULSE DAP modes, the so-called "free drift" modes, as well as the translation submodes, bypass RCS errors and phase plane and go to the jet select module. The bypass results because the free drift modes are not closed loop and cannot be used for attitude holds. With one of these modes selected, jets are fired only when directly commanded by a crew hand controller input (THC or RHC).

The next part of the DAP is the jet select module. The phase plane generates positive or negative rate commands on an axis by axis basis and jet select determines which jet(s) to fire (figure 2-7). The rate commands also are generated from crew hand controller inputs (THC or RHC). Jet select then commands the selected jet(s) to fire and informs the state estimator of the jet fire commands so that the RCS errors may be generated again.



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Figure 2-7.- The phase plane.

TVC and RCS DAP Control Modes

Both RCS and TVC DAPs can be operated in several different control modes. Which mode is active depends on the configuration of the DAP pushbutton indicators (pbi's), the position of the hand controllers, and in the case of TVC, how many engines are being used. There are so many variables involved that this subject is covered in a separate section of this manual.

BFS – DAP

Since BFS does not have an OPS 2, there is no orbit DAP. As a result, VERN jets are not available. BFS is completely manual, so AUTO maneuvers and the LVLH and FREE modes are not supported (this topic is covered in the section on DAP pbi's). By selecting INRTL with all three rotational axes in DISC RATE, BFS can maintain an inertial attitude hold. There are also several differences in the way that jet RM works in the BFS (the RCS training manual contains more on this subject).

Section 2-B: Questions

1. Briefly describe the differences between PEG 4 and PEG 7 burns.
2. When is the TRANS DAP active?
3. Under what circumstances is the TVC DAP mode active?
4. What is the purpose of the phase plane?

Section 2–B: Answers

1. The differences between PEG 4 and PEG 7 burns are as follows.

PEG 4 – Closed loop guidance scheme which targets for achieving a specified relationship between the horizontal and vertical velocity components of the vehicle at a certain position in the orbit. PEG 4 is not available in OPS 2.

PEG 7 – Open loop guidance scheme which aims to achieve a desired ΔV_x , ΔV_y , and ΔV_z in the LVLH reference frame.

Page 2-12 (PEG 4 Vs. PEG 7 Guidance)

2. The TRANS DAP is active after the "MECO CONFIRM" flag is set in MM 103 through MM 106 and in MM 301 through MM 303.

Page 2-14 (Flight Control)

3. The TVC DAP is active whenever the following two conditions are met:
 - a. An ON command is being sent to one or both of the OMS engines.
 - b. The IMU DATA GOOD flag is set to ON (good) in orbit DAP only. That is, there is at least one good IMU from which attitude data can be derived.

For an engine ON command to be generated:

- (1) The engines (L, R, or both) must be selected on the MNVR EXEC display in OPS 104, 105, 202, or 302.
- (2) The EXEC key must be pressed after the word EXEC flashes on the MNVR display.
- (3) The designated TIG must have been reached.

Page 2-18 (The Thrust Vector Control Digital Autopilot)

4. The purpose of the phase plane is to determine when, if, and in what direction rates must be generated to null any attitude or rate errors that exceed the limitations imposed by the deadbands.

Page 2-19 (The Reaction Control System Digital Autopilot)

Section 3–A: Displays and Controls

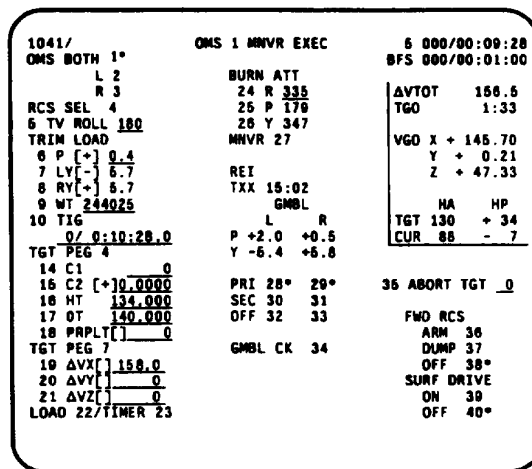
Objectives

After completing this section, you should be able to

- Identify PEG 4 target parameters
- Identify items computed by guidance
- Identify burn attitude and maneuver parameters
- Identify burn data

Maneuver Execute Display

This section identifies the uses of the Maneuver Execute (MNVR EXEC) display (figure 3-1).



TD315A*0536

Figure 3-1.– MNVR EXEC display.

Availability: Guidance, navigation, and control (GNC) MMs 104, 105, 106, 202, 301, 302, and 303

Purpose: To provide a means by which OMS and RCS translation and (sometimes) attitude maneuvers can be set up, executed, and monitored

Uses: OMS 1, OMS 2, on-orbit, and deorbit burns

The title of the display changes depending on which MM it is being used for:

<u>MM</u>	<u>Title</u>
104	OMS 1 MNVR EXEC
105	OMS 2 MNVR EXEC
106	OMS 2 MNVR COAST
202	ORBIT MNVR EXEC
301	DEORB MNVR COAST
302	DEORB MNVR EXEC
303	DEORB MNVR COAST

If an abort to orbit (ATO) or an abort once around (AOA) has been declared via either the abort select rotary switch and pushbutton or through an abort target item entry, the following display titles appear:

<u>MM</u>	<u>Title</u>
104	ATO 1 MNVR EXEC
104	AOA 1 MNVR EXEC
105	ATO 2 MNVR EXEC
105	AOA MNVR TRANS
106	ATO 2 MNVR COAST

Notice that the display titles end in either EXEC, COAST, or TRANS. While any of these displays can be used to set up a burn, only the EXEC displays can be used to perform one.

Aside from the titles, all these displays look exactly the same. There are some subtle differences, however, in the way they behave.

Engine Configuration (Items 1–4)

The four mutually exclusive engine configurations to choose from are both OMS, left only, right only, and RCS SEL. Burns using any one of the three OMS engine configurations must be targeted and enabled using this display. RCS burns, on the other hand, can be performed without automatic guidance if the crew so desires. Once an OMS burn is targeted and enabled, the crew has the option to fly it manually using the RHC or let automatic flight control fly it. On the other hand, RCS burns have no automatic flight control and thus happen only when a crewmember begins commanding with a THC deflection (except for the special case of the auto ET SEP – Z translation maneuver). Such an RCS burn fires four aft-firing jets if done while in TRANS DAP or only two jets while in orbit DAP.

If an OMS engine fails, a down arrow appears in the display field next to the failed engine. This arrow is driven by a low engine chamber pressure ($P_c < 80$ percent) and a decrease in vehicle acceleration in the PASS. With BFS engaged, the down arrow is driven ONLY by the P_c check. When a commfault is present, an "M" (for missing data) appears in the display field. Malfunctions are considered in greater depth later in this manual. One more thing to note. If one or both engines should fail during the burn, and downmoding to a single engine or RCS is necessary, do not select a different engine, because you will have to reload the targets and reexecute the burn. By turning off the appropriate OMS ENG switches, you inform guidance about the engine status and it corrects the problem.

TV Roll (Item 5)

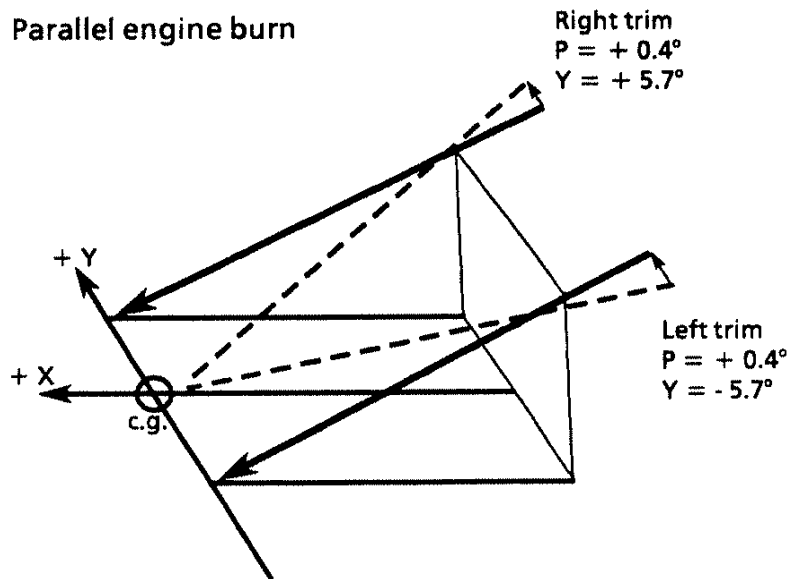
The only two numbers that are needed to specify the relative orientation of the thrust vector are pitch and yaw. Viewed another way, the vehicle could roll about the body thrust direction (not the body roll axis) without affecting the burn. When an initial calculation of the burn attitude is made prior to an OMS burn, a roll orientation must be specified. This is the purpose of item 5 (TV ROLL). Once this has been done, the pitch and yaw of the initial burn attitude can be determined. TV ROLL is defined such that a value of 0° means heads up (or away from the Earth). Both insertion and deorbit burns are performed using a value of 180° . Changes to item 5 are legal only in OPS 2; therefore, it must be set up as desired for deorbit before leaving OPS 2, since the last value is carried across the OPS transition.

Limits: 0° to 359°

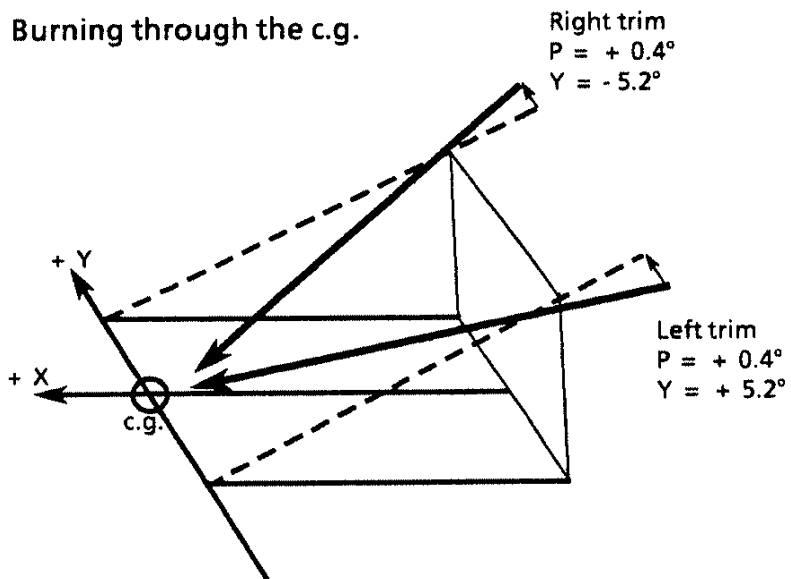
Trim Load (Items 6–8)

The trim load tells the DAP and guidance what the initial position of the OMS gimbals should be at TIG. Guidance uses trim data to calculate the burn attitude. The item entries are broken up into pitch (P) for both engines, right engine yaw (RY) and left yaw (LY). The two commonly used two-engine burn configurations are "parallel" or "through the c.g." (figure 3-2). To burn with the engine thrust vectors parallel to each other, the trim values to enter are: $P = +0.4^\circ$, $RY = +5.7^\circ$, and $LY = -5.7^\circ$. To burn through the c.g., the values to enter are approximately: $P = +0.4^\circ$, $RY = -5.2^\circ$, $LY = +5.2^\circ$ (note the sign reversal). For a right engine only burn, the values are $P = +0.4^\circ$ and $RY = -5.2^\circ$. Since the left engine is not being used, its trim value does not matter.

Parallel engine burn



Burning through the c.g.



TD315A*019.3

Figure 3-2.— Parallel engine burn and burning through the c.g.

The MCC or the crew's onboard Hewlett Packard program supplies the exact trim values to use. If trim values for a PEG 4 burn are off a little, the burn is only less efficient. This is because PEG 4 burns correct for transients caused by initial gimbal mistrim (the DAP commands the gimbals as necessary to put the net thrust vector through the vehicle c.g.). For PEG 7 burns, however, mistrim can result in a target miss since the DAP only burns out the ΔV 's. In general, for both PEG 4 and PEG 7 burns, the shorter the burn, the more critical it is that the trim values be correct.

When this display is first called up, the values of trim read whatever the gimbal position was at the end of the last burn. After a new value is entered, the gimbals do not move to the new position until guidance becomes active, which is 15 seconds before the burn begins. If the difference between the gimbal trim values and actual position is less than 0.4° , the gimbals are not repositioned at TIG - 15 seconds.

Limits: -9.9° to $+9.9^\circ$

Weight (Item 9)

This item entry tells the DAP what the vehicle weight is at the beginning of the burn. As the burn progresses, guidance computes how much propellant is being used and updates the display accordingly. Each time the display is called up, weight reads the value computed at the end of the previous burn.

Limits: 100,000 to 999,999 pounds

TIG (Items 10–13)

The TIG is displayed in days/hours:minutes:seconds mission elapsed time (MET) with item 10 referring to the days, 11 to the hours, 12 to the minutes, and 13 to the seconds. The TIG entered for the burn is constrained to be within 5 minutes in the past or 12 hours in the future.

Limits: 0 to 365 days, 0 to 23 hr
0 to 59 min, 0 to 59.9 sec

PEG 4 Targets (Items 14–18)

As previously mentioned, PEG 4 is a closed loop guidance scheme which targets for a specified set of horizontal and vertical velocity components at a certain point in the vehicle's orbit. This scheme is the one nominally used for both the insertion and

deorbit burns but is not available for use in OPS 2. A breakdown of the individual target parameters follows.

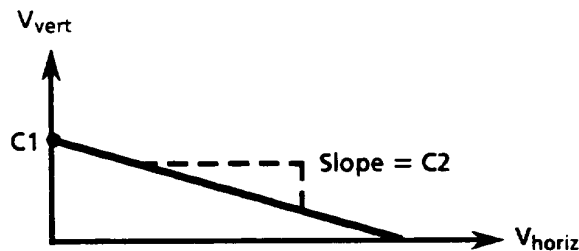
C1 and C2

These two parameters establish the relationship between the horizontal and vertical velocities by acting as coefficients in the equation:

$$V_{\text{vert}} = C2 \cdot V_{\text{horiz}} + C1$$

(Note the $Y = mX + b$ format, which is the equation of a straight line.)

This is a straight line relating horizontal and vertical velocities. In this case, C2 is the slope of the line, while C1 is the Y-intercept as shown in figure 3-3.



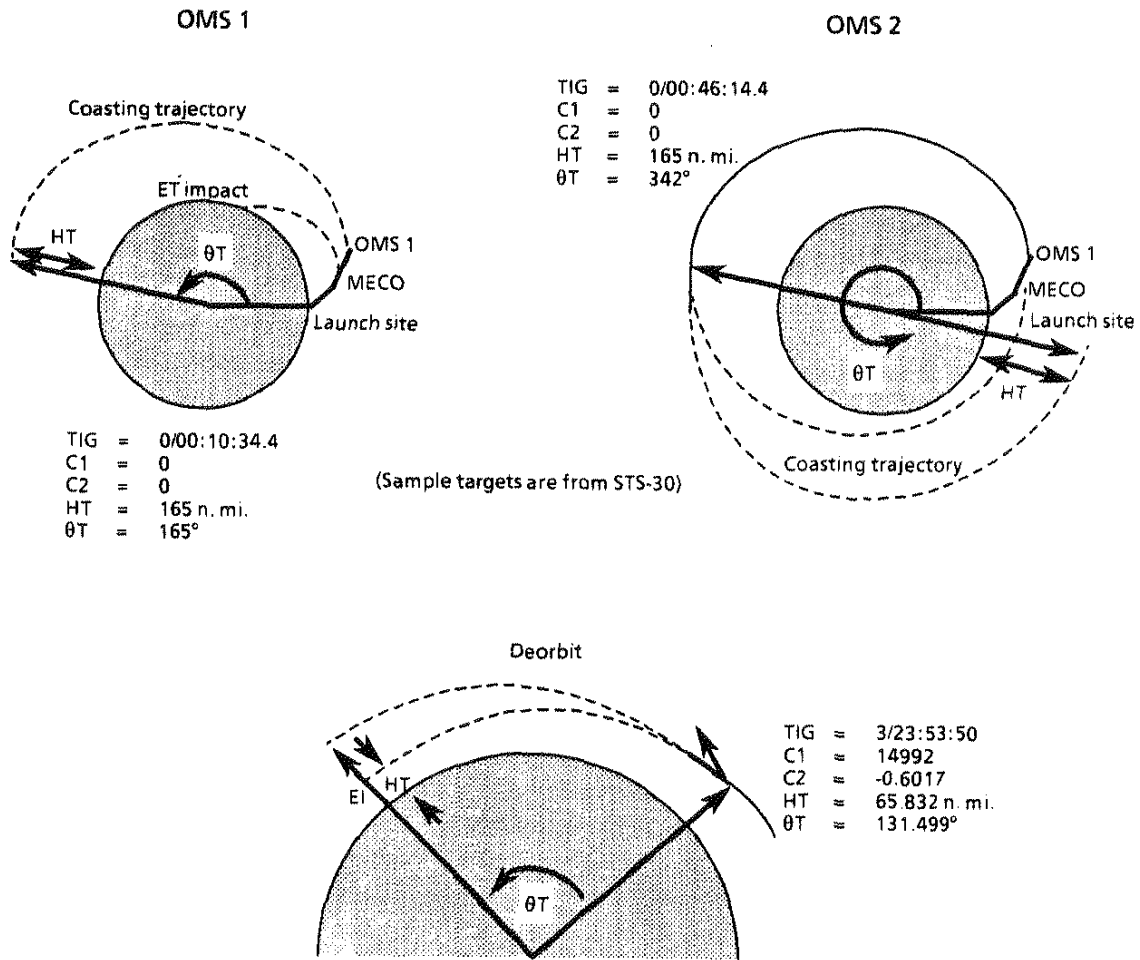
TD315A*020-3

Figure 3-3.—Relationship of C1, C2, V_{vert} and V_{horiz}.

For the OMS 1 or OMS 2 burn, the target point is always an apogee or perigee point which implies that the vertical velocity is zero. So C1 and C2 should be set equal to zero. For a deorbit burn, the vertical velocity must be a negative number at EI, which is the target point. As it turns out, for deorbit maneuvers, C1 would be a large positive number, and C2 would be a dimensionless number between 0 and -1. For example, a typical deorbit from a 150 n. mi. orbit might have $C1 = 15,434$ and $C2 = -0.6200$.

Limits: $C1 = 0$ to 99999 ft/s
 $C2 = -9.9999$ to +9.9999

Figure 3-4 illustrates sample targets from STS-30.



TD315A*021-3

Figure 3-4.—PEG 4 target parameters.

HT

This parameter specifies the height of the target point (HT) above the surface of the Earth in nautical miles. The value of HT varies widely from flight to flight depending on mission objectives. To establish a circular 150 n. mi. orbit, for instance, HT would equal 150 for both the OMS 1 and OMS 2 target sets. For deorbit maneuvers, this target point would be EI, which is at an altitude of 400,000 feet or HT = 65.8 n. mi.

Limits: 0 to 999.999 n. mi.

θT

Theta T (θT) has different definitions in OPS 1 and OPS 3. In OPS 1, θT is the angle from the launch site to the target point. See figure 3-4 for clarification. By way of example, for STS-30, the OMS 1 θT was 165° for an HT of 165 n. mi. This becomes the orbit apogee. To raise perigee to circularize the orbit, the OMS 2 burn must be performed about 180° around the Earth from where OMS 1 was done. Since θT is still measured from the launch pad, for OMS 2, one would expect the value to be approximately $165 + 180$, or 345° . The actual OMS 2 θT was 342° for STS-30.

In OPS 3, θT is the angle from TIG to EI. It is roughly correlated to the orbital altitude before the burn such that the higher the orbit, the greater the θT angle. For example, on STS-50, when HA was 156 n. mi., the deorbit θT had a value of 128° .

Limits: 0° to 540°

PRPLT

Item 18 works only in OPS 3. It specifies the total amount of OMS propellant (PRPLT) in pounds mass to be expended on an OMS burn.

When the absolute value of PRPLT is less than or equal to the minimum amount required to complete the burn, the most efficient solution is calculated and the actual value entered for PRPLT is essentially ignored. In some deorbit burns, it is desirable to burn excess propellant for c.g. control and weight reduction. In this case, the orbiter executes the burn in an attitude that directs some of the thrust in an out-of-plane direction. Such an action consumes propellant while having almost no effect on the trajectory. The PRPLT quantity can be entered as a positive or negative number or zero, which determines whether the out-of-plane component is toward the positive (north) or negative (south) angular momentum vector. If a zero is entered, there is no out-of-plane component and thus no propellant wasting. This item is unique in that it can be executed at any time without necessitating a reload (during the burn, only a zero can be entered on the display).

Limits: $-99,999$ to $+99,999$ pounds

PEG 7 Targets

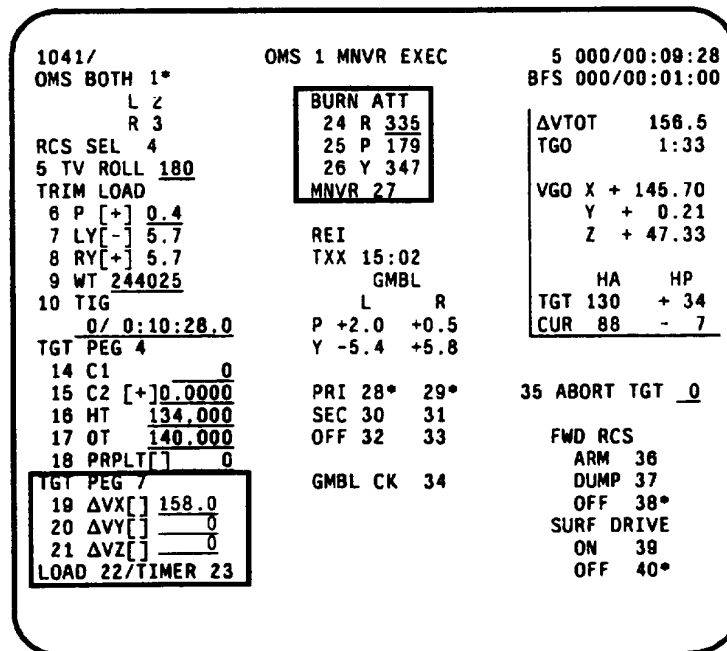
A PEG 7 burn attempts to achieve a specified change in velocity with respect to the LVLH reference frame at TIG. When an item entry to a PEG 7 target is made, any values in PEG 4 are blanked and vice versa (figure 3-5).

To target for such a burn, enter a delta V in each of the three LVLH axes: X, Y, and Z. Guidance computes an appropriate burn attitude which satisfies the request. In the LVLH reference frame, +X is basically along the velocity vector (in the same

direction the orbiter is traveling), + Y is out of plane toward the negative angular momentum vector (or southern pole of the orbit), and + Z is radially inward toward the Earth. The origin of the LVLH frame is at the vehicle's center of mass.

Whenever Lambert targeting is used for rendezvous burns, the word LAMBERT appears in the normally blank field to the right of the PEG 7 target data. If C&W equations are used for orbit targeting, that same field reads EXT ΔV. EXT ΔV also appears any time the MCC uplinks or the crew enters an external delta V target set into the display.

Limits: X = -9999.9 to +9999.9 ft/s
 Y and Z = -999.9 to +999.9 ft/s



TD315A*053:3

Figure 3-5.- TGT PEG 7 field.

Load

Once items 19-21 have been set up and checked to the satisfaction of the crew, item 22 should be executed to load the data so that guidance may initiate its calculations. When a MNVR display is first called up or an item 1 through 21 is changed (except PRPLT), LOAD begins to flash, indicating that item 22 must be executed to inform guidance of the update. The only exception to this occurs in MM 104, where the LOAD is performed automatically for the crew since the workload is very heavy prior to the OMS 1 burn. (Note: Any time the word LOAD is capitalized in this manual, reference is being made to item 22 EXEC.)

Timer (Item 23)

Item 23 starts the timer which counts down to the burn. Any attempt to start the timer before the targets are loaded results in an ILLEGAL ENTRY message. The timer is started automatically in MM 104.

Burn Attitude and Maneuver (Items 24–27)

Whenever a target set is LOAded, guidance computes and displays a burn attitude in inertial roll, pitch, and yaw coordinates. The crew must maneuver to the attitude either manually or automatically and ensure that the orbiter is pointed the right way at burn ignition. To perform an auto maneuver, execute item 27 (MNVR) with the DAP control mode in AUTO. An asterisk appears and the maneuver begins. When the attitude is reached, the asterisk disappears if you are in orbit DAP but remains if in TRANS DAP; therefore, the attitude should be checked by reading the ADI. The crew also has the option to maneuver to burn attitude manually. In TRANS DAP, the ADI error needles are referenced to the burn attitude as soon as the targets are loaded, regardless of whether or not an item 27 was performed. In orbit DAP, for an OPS 202 burn attitude maneuver, however, an item 27 must be executed to make use of the ADI error needles.

In TRANS DAP, when there is a maneuver to burn attitude in progress or the burn attitude is being held, there is an asterisk next to item 27. If a new target set or different trim values are loaded or if TIG is in the past, the burn attitude changes and the current vehicle attitude is held inertially and the asterisk goes away. The crew must then reexecute item 27 to maneuver to and hold the new burn attitude. If in orbit DAP and manual mode, and item 27 is executed, the error needles register the proper errors for flying manually to the burn attitude. If AUTO is selected subsequent to this, however, the automatic maneuver begins without a reexecution of the item 27, as you would have to do in TRANS DAP.

In either orbit or TRANS DAP, if item 27 is not executed at any time prior to TIG and the control mode is in AUTO, the steering from guidance begins as soon as ignition occurs. Since this happens concurrently with OMS ignition, there is much OMS thrust and RCS propellant wasted until the correct attitude is reached. If an item 27 is executed before guidance computes a solution (in other words, when the burn attitude is blank) the orbiter maneuvers to a default M50 attitude of roll = 0°, pitch = 0°, yaw = 0°.

In OPS 3 only, the guidance-computed burn attitude may be overridden at any time by entering the desired roll, pitch, and yaw for items 24 to 26. To regain the burn attitude, a LOAD must be performed again. Attempting to enter data into the burn attitude items in OPS 1 or 2 results in an ILLEGAL ENTRY message.

Limits: R and P = 0° to 359°
Y = 0° to 90° and 270° to 359°