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Revision 1

LM/AGS OPERATING MANUAL
FLIGHT PROGRAM 6

April 1969

Revised July 1969

TRW
SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

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FOREWORD

These operating procedures apply to Flight Program 6 (FP6). As written they are applicable to an earth or lunar manned mission. Some of the procedures were written for the lunar mission only, however, they can be extended to earth missions where necessary.

The following is a list of significant changes between FP5 and FP6:

- Radar range rate data is entered in a slightly modified way.
- Horizontal orbit injection velocity is computed as a function of the central angle between the LM and CSM, LM altitude at time of injection, and semi-major axis of the predicted orbit.
- CDH maneuver occurs one-half or three-halves LM orbital periods after CSI.
- Only the time to next maneuver (t_{ig}) is now available. However, the nomenclature of t_{igA}, t_{igB} and t_{igC} (time of CSI, time of CDH and time of TPI, respectively) has been retained for clarity.
- The radar filter has been improved and is effective for ranges up to 400 n.mi.
- The CSI solution is now found within 2 seconds and is no longer an iterative process.
- Certain DEDA locations have been changed due to reassembling the program.
- Accelerometer bias compensations are now decimal DEDA quantities rather than octal.
- The ullage counter, 1K9, is now a decimal, DEDA accessible quantity.
- On LM-5 and subsequent, a hardware change has been installed which enables the ABORT STAGE pushbutton signal to bypass the Engine Stop pushbutton switch. This change affects the RCS translation procedures and the APS engine operation procedures.

[Note: The following symbol is used to denote changes between FP5 and FP6 – ◆]

FOREWORD (Cont)

Revision 1 to this document incorporates the following major changes:

- New recommended radar updating schedule
- Added discussion on abort in very early powered descent

[Note: The following symbol is used to denote changes between FP6 and FP6, Revision 1 -]

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

The LM Abort Guidance Section (AGS) is a strapped-down inertial navigation and guidance system used primarily to effect rendezvous of the LM with the CSM in the event of a Primary Guidance and Navigation Control System (PGNCS) failure. The AGS consists of the following three assemblies:

a) Abort Electronics Assembly (AEA)

b) Data Entry and Display Assembly (DEDA)

c) Abort Sensor Assembly (ASA)

The AEA is a general purpose digital computer located in the LM aft equipment compartment used for the data processing function of the AGS. It is a fixed point, 18-bit machine with 17 value bits and a sign bit using 2's complement arithmetic. The AEA memory is of conventional ferrite core construction with a 4096 word capacity.

The DEDA is a general purpose astronaut input-output device for the AGS located on the right-hand side of the LM cockpit. It consists of a keyboard, electroluminescent address and digital data displays. Operation of the DEDA is described in Section 3.1 of this report.

The ASA consists of three strapped-down pendulous accelerometers, three strapped-down gyros and associated electronic circuitry. It is located on the LM navigation base above the flight crew. The ASA provides the AEA with incremental angular rotation information about the vehicle X, Y, and Z axes and incremental velocity changes along the vehicle X, Y, and Z axes. These incremental data are in the form of pulses and are utilized in the AEA to maintain knowledge of the LM vehicle attitude, position, and velocity.

The equations programmed in the AEA for FP6 are defined in the LM/AGS FP6 Programmed Equations Document (Reference 1). A narrative description and derivation of most of the equations are presented in Reference (2).

The purpose of this document is to present the functional capabilities of the system along with a description of how the system is to be utilized. Where applicable, limitations of the system are presented and cautions issued about operating the system in other than the specified manner.

This document is separated into four parts. Part I discusses the system in general along with external interfaces. Part II contains more specific details about AGS utilization and functional capabilities. The actual operating procedures are contained in Parts III and IV. Part III contains the procedures to perform various functions, whereas Part IV contains the procedures to perform the various maneuvers.

The operating procedures discussed herein apply to both lunar missions and earth missions unless otherwise noted. Of course, the lunar surface procedures discussed are not relevant to the earth missions. The actual programmed equations for these two missions are identical except for the rescaling of many quantities. The DEDA input and output quantities required during a mission are presented in Section 6.0 and the complete list of DEDA accessible quantities is found in Appendix A. The Appendix A list does not contain time shared quantities nor does it contain quantities that have been judged of no value in monitoring AGS operation. Section 11 contains a discussion of the conversion of the lunar program to the earth program via the DEDA. This procedure is desirable if a lunar mission is modified to an earth mission after the lunar program has been stored in the AGS computer.

PART I - AGS EQUIPMENT DESCRIPTION & GENERAL OPERATION

2.0 GENERAL OPERATION OF THE AGS

2.1 Control of LM by AGS

Control of the LM by the AGS depends on the settings of certain guidance selectors on the LM instrument panel and the DEDA function selections*. The Guidance Control Switch (PGNS, AGS) must be in the AGS position, the AGS Mode Control Switch** (Off, Attitude Hold, Auto) must be in either the Attitude Hold or Auto position (if in OFF, RCS thrusting is inhibited). The AGS continuously computes steering and engine control quantities regardless of the position of the Guidance Control Switch. For the AGS to exert guidance steering (not merely attitude hold) and engine control, the AGS Mode Control Switch must be in the Auto position. In addition, RCS attitude control must be under Mode Control direction. This is accomplished by setting the Roll, Pitch and Yaw Attitude Control switches (MODE CONT, PULSE, DIR) to the MODE CONT position.

A tabulation of LM attitude control and main engine commands for combinations of switch settings is presented in Table 2.1. The OFF position of the Mode Control switch is not listed since no attitude control is possible for this condition. Settings of $S_{00} \geq +30000$ (address 400) are not listed since they result in zero attitude error signals and issuance of the E/OFF command regardless of the setting of the Guidance Control and Mode Control switches. Table 2.1 assumes that the lunar surface flag in the AEA is not set, i.e., address 604 is a positive number, and that the three Attitude Control switches are in the MODE CONT position. Placement of these three switches in the PULSE or DIR positions results in inhibiting the AGS from LM attitude control. The functioning of the ABORT and ABORT STAGE with respect to the AGS is also shown in Table 2.1.

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*Refer to Sections 4.0 and 6.0 for complete description of these switches.

**Throughout this document reference is made to the "Mode Control Switch." It is understood that LM 4 and subsequent will contain two Mode Control Switches, one for AGS and one for PGNCS. Thus, it is necessary to understand that reference to the "Mode Control Switch" in this document implies the AGS Mode Control Switch.

Table 2. 1. AGS Control of LM

Guid Cont	Mode Cont	Address 400 (See Tables 2. 2 and 2. 3)	AGS Attitude Error Signals	Engine Command
PGNS	ATT HOLD	< +30000	Zero	Issue according to existing status of APS or DPS.
		+00000	AGS issues zero attitude error signals.	
PGNS	AUTO	+10000	AGS issues guidance steering error signals, but they are inhibited from RCS by the CES.	Issue according to existing status of APS or DPS.
		+20000	AGS issues Z body axis steering error signals, but they are inhibited from RCS by the CES.	
AGS	ATT HOLD	< +30000	AGS issues attitude hold error signals which control LM attitude.	Issue according to existing status of APS or DPS.
		+00000	AGS issues attitude hold error signals which control LM attitude.	If Abort or Abort Stage is not ON, issue engine commands according to existing status of APS or DPS. If Abort or Abort Stage is ON, issue E/OFF when address 400 is +00000 or +20000, and issue E/ON when address 400 is +10000 and ullage and velocity to be gained are in an E/ON condition per Section 20.
AGS	AUTO	+10000	AGS issues guidance steering error signals which control LM attitude.	
		+20000	AGS issues Z body axis steering error signals which control LM attitude.	

Placement of only one of the Attitude Control switches in the PULSE or DIR position during AGS attitude control causes loss of AGS attitude control in that channel. A detailed discussion of the limitations of this procedure is contained in Section 10.6.

When the PGNCS controls the LM (Guidance Control Switch in the PGNS position), the AGS is in the Follow-up Mode. Manual control of the LM by the flight crew (Mode Control Switch in Attitude Hold, Hand Control out of detent) also causes the follow-up signal to be transmitted to the AGS. In follow-up, the AGS "follows" the PGNCS by transmitting Engine On or Off commands in accordance with the existing DPS or APS engine operation and the attitude control error signals are inhibited from controlling LM attitude.

The AGS outputs attitude error signals corresponding to the setting of address 400 for FDAI display when the PGNCS is in control and the Mode Control Switch is in AUTO. A setting of address 400 to +00000 results in a display of zero attitude error signals on the FDAI, a setting of 400 +10000 results in guidance steering error signals, and a setting of 400 +20000 results in Z body axis steering error signals. A setting of address 400 to $\geq$ +30000 results in zero error signals displayed.

AGS operations are selected mainly through two DEDA selectors: S_{00} and S_{10} (denoted here by equation symbols). S_{00} (DEDA address 400) is the AGS Submode Selector and S_{10} (DEDA Address 410) is the Guidance Routine Selector.

Eight states are possible for the AGS Submode Selector, S_{00}. These eight states can be grouped into two distinct modes with various submodes as follows:

Inertial Reference Mode - Table 2.2 contains the submodes of the inertial reference mode. The attitude error commands are computed and issued every 40 msec.

Align and Calibrate Mode - AGS outputs zero attitude error and E/OFF engine commands every 40 msec. If the AGS is in control of the LM, the vehicle attitude rate is damped only by the autopilot rate gyro feedback signals. Various submodes of the align and calibrate mode are presented in Table 2.3.

Table 2.2 Submode of Inertial Reference Mode

S_{00}	Submode	Function
0	Attitude Hold	AGS attitude error commands cause the LM to maintain the same inertial attitude that existed when the submode was entered if the follow-up signal is absent or when the follow-up signal is removed (if the submode was previously entered)
1	Guidance Steering	AGS attitude error commands cause the thrust axis (X-body axis) of the LM to orient to the desired direction as computed by the selected guidance routine. Yaw steering (rotation about the X body axis) is as follows: If $S_{623}\begin{cases} 0 & \text{Z body axis is oriented parallel to the CSM orbit plane} \\ 1 & \text{Z body axis is oriented parallel to the plane defined by the unit vector } \underline{W}_b\text{. See Section 10.2} \end{cases}$
2	Z Body Axis Steering	AGS attitude error commands cause the LM X-body axis to be parallel to the CSM orbit plane and the LM Z body axis to be oriented as follows: If $S_{507}\begin{cases} 0 & \text{The LM Z body axis is directed toward the AGS indicated position of the CSM} \\ 1 & \text{The LM Z body axis is oriented to the desired thrust direction} \end{cases}$

S_{10} always selects one of the six possible guidance routines presented in Table 2.4. Guidance calculations associated with the selected routine are completed every two seconds regardless of the S_{00} selection.

Before commencing guidance operations, it is imperative that the AGS be aligned, time initialized, and LM and CSM ephemeris data initialized. The necessity for alignment is obvious. The entry of LM and CSM ephemeris data is required because every guidance selection (every S_{10} selection) uses both the LM and CSM ephemerides in the guidance and steering computations. Performing navigation updates throughout the mission (by either PGNCS downlink, DEDA entry, or rendezvous radar) is also recommended. Navigation updates prior to the CSI and TPI phases are highly desirable because total propellant expenditure to rendezvous is highly dependent upon the accuracy of these maneuvers.

Table 2.3. Submodes of Align and Calibrate Mode

S_{00}	Submode	Function
3	AGS to PGNCS Align	AGS is aligned to the IMU stable member. This submode should only be entered when the PGNCS is operative and properly aligned.
4	Lunar Align	AGS is aligned to the desired inertial coordinate system (depends upon the nominal launch site). This submode is to be used only on the lunar surface.
5	Body Axis Align	AGS inertial reference frame is caused to be coincident with the LM body axes.
6	Gyro and Accelerometer Calibration	In coasting flight, gyro and accelerometer bias calibration is accomplished. Accelerometer calibration is completed in 32 seconds; gyro calibration is completed in 302 seconds. The gyros are calibrated against the PGNCS IMU. Thus this mode should not be entered if the PGNCS is inoperative. On the lunar surface, only gyro calibration is accomplished when this mode is entered provided S_{13} has been entered (lunar surface flag set). PGNCS need not be operative.
7	Accelerometer Only Calibration	In this mode only accelerometer calibration is accomplished. This mode should be entered only when in free flight and never on the lunar surface.

When the LM is under full AGS control (i. e., having engine control as well as attitude control), the Engine ON signal cannot be generated unless the AGS Submode selector is in the guidance steering selection ($S_{00} = 1$). Engine ON is automatically generated after ullage has been sensed for a specified number of consecutive computer cycles (2 sec per cycle). The AGS recognizes ullage to have occurred when the average acceleration in the + X body direction exceeds 0.1 fps^2.

Table 2.4. AGS Guidance Routines

S_{10}	Mode	Function
0	Orbit Insertion	Guidance solutions are generated to drive the LM to specified orbit injection conditions.
1	CSI	Guidance solutions are computed to establish appropriate LM/CSM phasing at TPI time. Thrusting is not performed with this selection.
2	CDH	Guidance solutions are computed to place the LM into an orbit that is coelliptic with the CSM orbit. Thrusting is not performed with this selection.
3	TPI Search	AGS evaluates various direct transfer rendezvous solutions. Flight crew selects desired solution. Thrusting is not performed with this selection.
4	TPI Execute	Guidance solutions are computed to cause the LM to be on a CSM intercept trajectory or for the LM to intersect the CSM orbit plane at a specified time prior to nominal rendezvous time. Thrusting is not performed with this selection.
5	External ΔV	Guidance solutions are generated to perform a specified thrust maneuver. All thrusting, except orbit insertion, is done in this mode.

When the LM is not under full AGS control, i.e.,

a) When neither the "ABORT" nor "ABORT STAGE" button is depressed, or

b) When the Mode Control switch is not in the AUTO position and $S_{00} < 3$, or

c) When the Guidance Control switch is not in the AGS position,

the AGS will issue engine commands (ON or OFF) that correspond to actual engine operation as determined by the state of the Descent Engine ON and Ascent Engine ON discretes.

Under full AGS control, the LM engine (APS or DPS) is automatically commanded OFF when the velocity to be gained in the +X-body direction is less than the nominal ascent engine thrust decay velocity and if the total velocity to be gained is less than a prescribed threshold (a DEDA accessible constant currently set at 100 fps). This dual check serves the purpose of maintaining the engine ON if an Abort occurs during powered flight with the LM poorly oriented for the abort maneuver and the velocity to be gained is large (greater than the 100 fps threshold).

When the velocity to be gained (LM under full AGS control) is less than 15 fps and the sensed thrust acceleration level in the +X-body axis direction is greater than 0.1 fps^2, the desired thrust direction is fixed in inertial space (a form of attitude hold). If this were not done, the LM desired attitude might go through an undesirably wide excursion in an attempt to achieve perfect velocity cutoff conditions. Large attitude variations near the end of a maneuver are undesirable. The velocity cutoff errors incurred by fixing the desired attitude prior to engine cutoff are small. After the maneuver is completed, small cutoff errors can be removed (if desired) by the axis by axis velocity trim capability of the AGS (see Section 28).

Staging of the LM descent section is executed by depressing the "ABORT STAGE" button on the instrument panel. The staging sequence begins only when Engine ON commands are issued. During a thrusting maneuver, the staging sequence will begin immediately upon depression of the "ABORT STAGE" button (assuming all panel controls which transfer control of the LM to the AGS have been set properly). The AGS must sense sufficient average thrust acceleration throughout the staging maneuver so that ullage is maintained (unless the ullage counter threshold, 1K9, has been set to 0). When the AGS receives verification from the CES that the Ascent Engine is ON, the system automatically enters the Attitude Hold submode. After a prescribed time interval between 0 and 10 seconds (presently set at 1 second), the AGS automatically enters the normal guidance steering submode.

A functional flow chart (Figure 2.1) of the AGS control logic is presented below. This logic shows how the external discrete signals

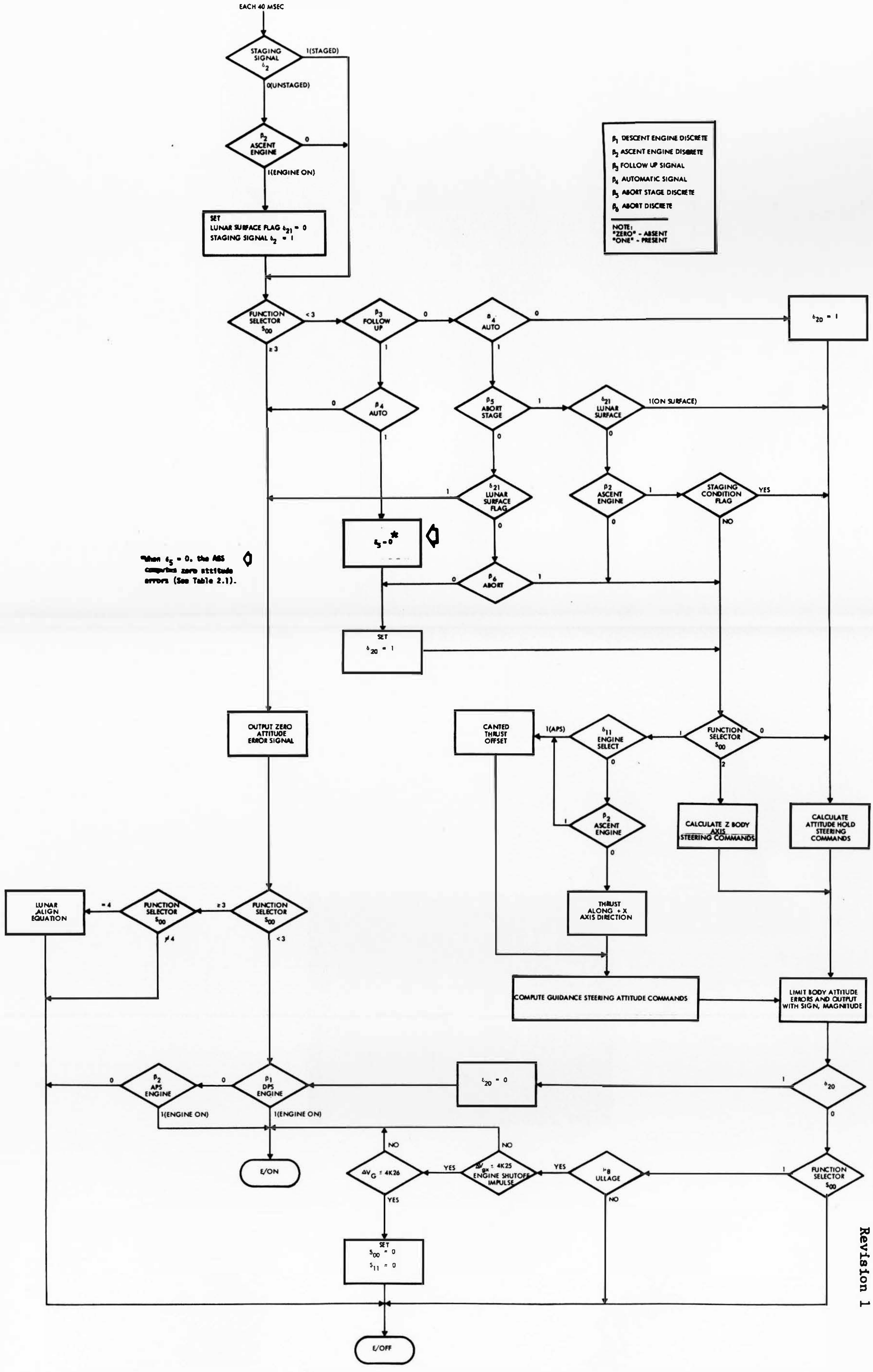

Figure 2-1. AGS Logic Flow Diagram

(β_1 thru β_6), the AGS submode selector (S_{00}), and the DEDA engine select (S_{11}) command AGS attitude error and Engine ON/OFF signals. The lunar surface flag δ_{21} (indicated on the flow chart) is set to 1 (lunar surface) when any value is entered into the store landing azimuth DEDA selector (S_{13}). δ_{21} is set to 0 at the first APS engine ignition. The δ_{21} lunar surface flag MUST be set to 1 after the LM lands on the moon in order that the LM position and velocity can be properly reinitialized and updated on the lunar surface.

2.2 AEA Automatic Function Switching

In this section a discussion is given of the automatic function switching that is performed by the AGS.

1) AGS Guidance Engine OFF

At the time the AGS completes a maneuver by issuing Engine OFF three things occur:

a) S_{00} is set to zero thus putting the AGS in the attitude hold submode.

b) S_{11} is set to zero. This selection is set to 1 when the ascent engine is employed. This enables the AGS to recognize that the LM thrust direction is not along the + X - body axis but rather displaced by the cant of the APS engine.

c) The ullage counter will be reset to zero within 2 sec when the average sensed acceleration drops below 0.1 fps^2 for a 2-sec period.

2) AGS to PGNCS Align

AGS to PGNCS align is selected by setting the submode selector $S_{00} = 3$. Two seconds later, AGS to PGNCS align is completed and S_{00} is set to 0 (attitude hold) automatically.

3) Calibration

Calibration is selected by setting the submode selector to $S_{00} = 6$. If in orbit, an AGS to PGNCS alignment is done automatically and the ASA gyros are then calibrated against the PGNCS IMU and the ASA accelerometers are calibrated in the "zero sensed acceleration" condition of free fall. The accelerometer calibration is completed in 32 seconds, and the gyro calibration is completed in 302 seconds. If on the lunar surface, only the gyros are calibrated. The AGS submode selector switches to $S_{00} = 0$ automatically to end the calibration.

Accelerometer calibration only (during free fall) is commanded by setting S_{00} = 7. Calibration is complete in 32 sec. The AEA automatically resets S_{00} to 0 after 302 sec; it may be manually reset after 35 sec.

4) Ephemeris Data

Ephemeris data are entered into the AEA by setting S_{14}.

S_{14}	Function
1	Initialize LM and CSM state vectors via PGNCS downlink
2	Initialize LM ephemeris with manual entry (DEDA) of externally supplied data
3	Initialize CSM ephemeris with manual entry (DEDA) of externally supplied data

When initialization is completed, S_{14} is automatically set equal to zero.

5) Lunar Surface Stored Azimuth

The LM azimuth orientation is stored by any DEDA entry into S_{13}. S_{13} does not reset. However, a new entry into S_{13} will cause the AEA to store a new azimuth orientation. The entry for S_{13} also causes the lunar surface flag (δ_{21}) to be set to 1.

6) Radar Directed +Z-Body Axis Direction Cosines

The radar directed +Z-body axis direction cosines (corrected for boresight misalignment) are saved in the AEA within 0.5 seconds after setting S_{15} = 1. Two seconds later, S_{15} is automatically reset to 0.

7) External ΔV Reference

The External ΔV Mode (S_{10} = 5) requires that the external ΔV vector be frozen in inertial space at the beginning of the burn. When in the external ΔV mode the ΔV vector may be frozen manually be setting S_{07} to 1. S_{07} is automatically set to 1 by thrusting in the plus X direction, activating the ullage counter. S_{07} is reset to 0 by switching out of the external ΔV guidance mode into CSI, CDH or TPI. It can also be manually reset to zero.

2.3 System Limitations and Constraints

Constraints imposed on system operation are indicated where appropriate throughout this report. In this section several items are discussed that do not readily fit in other sections but are important to system operation.

2.3.1 Sensor Capability

The maximum capability of the AGS gyro/electronics subsystem is 25 deg/sec around each axis. Maximum capability of each AGS accelerometer is 96 ft/sec^2.

2.3.2 DEDA Processing in Octal

Those regions of AEA memory which are not selected for DEDA processing in decimal format are processed in octal. Since the DEDA readout or entry consists of a sign plus five digits, only 16 bits (sign plus 5 octal digits) can be transferred as an octal value. Thus, when outputting from an octal processed memory address, the two least significant bits of the internal computer word are ignored. When an entry is made into an octal processed memory address, the two least significant bits are automatically set to zero. The result is that any value input in octal is quantized at four times its internal computer quantization.

2.3.3 DEDA Entries and Readouts

The following two rules should be observed to preclude any DEDA operation problem due to computer timing.

> A) DO NOT DEPRESS ANY TWO DEDA CONTROL PUSHBUTTONS (CLEAR, ENTER, READOUT OR HOLD) WITHIN .6 SECONDS OF EACH OTHER EXCEPT WHEN DEPRESSING CLEAR TO ERASE THE PREVIOUS OPERATION.
>
> B) AFTER A DEDA ENTRY, DO NOT COMPLETE ANOTHER ENTER OR READOUT SEQUENCE (DEPRESS ENTER OR READOUT) WITHIN 1.5 SECONDS OF THE TIME THE DEDA DISPLAY HAS GONE BLANK FOLLOWING THE DEPRESSION OF ENTER.

2.3.4 Readout of Perifocus Altitude, Apofocus Altitude, and Time to Perifocus

Perifocus altitude, apofocus altitude and time to perifocus can be read out via DEDA address 403, 315, and 313, respectively. For orbits whose eccentricity exceeds 0.125 the perifocus altitude and apofocus altitude quantities are meaningless. Perifocus altitude will read out as the negative value (2K3 minus 5J) in this situation. If the LM orbit is nearly circular the concept of time to perifocus loses its significance and in this situation the quantity read out of DEDA address 313 will be very noisy.

2.3.5 Overflow of Accumulated Velocity Counter

V_{dX} is the accumulated thrust velocity in the X body axis direction. This term also contains the effect of uncompensated accelerometer bias. If this quantity overflows during coasting flight no deleterious effects will result. However, it is undesirable to have an overflow during powered flight. For this reason, if more than 4 hours are spent in orbit with the AGS operating and no thrust along the + X axis occurs, one of the following entries should be made via DEDA:

If vehicle is unstaged enter	404 -12356
If vehicle is staged enter	404 +00000

2.3.6 Detection of Computer Restart

Power transients, under certain conditions, have been known to cause the computer to restart. It is important that a computer restart be recognized when it occurs. When a computer startup or restart takes place, the computer sequences through the power turn-on routine given in Section 7.0.

Briefly, this routine resets some flags and discretes, commands attitude hold submode (S_{00} is set to 0), switches S_{10} to S_{17} are set to 0, V_{DX} and V_{dX} are set to 4K27, and the test mode fail discrete is momentarily sent. An Engine off signal is a result of the power turn-on sequence.

When start-up or restart occurs, the AGS caution and warning lamp is lit and the master alarm is activated. This is the only immediate indication that a computer restart has taken place.

When a computer restart has occured, the AGS should be reinitialized as soon as possible, per Section 13.

3.0 DEDA OPERATION, CONTROLS, AND DISPLAYS

3.1 DEDA Operation

As shown on Figure 3.1, the face of the DEDA contains the following:

a) Ten pushbuttons marked zero through nine

b) A pushbutton marked plus (+)

c) A pushbutton marked minus (-)

d) A pushbutton marked "CLR"

e) A pushbutton marked "ENTR"

f) A pushbutton marked "READOUT"

g) A pushbutton marked "HOLD"

h) Two electro-luminescent display windows; the top one for the "address" and the bottom one for the value for the desired word

i) An operator error light

3.1.1 Data Insertion

The sequence of operations necessary to insert data into the AEA via the DEDA is as follows:

a) DEPRESS the "CLR" pushbutton - this operation initializes (clears) the DEDA system and blanks all lighted characters. The "CLR" button must always be depressed prior to any DEDA entry.

b) DEPRESS three consecutive digits - this operation identifies the address of the AEA memory core location into which the data is to be inserted. The address is in octal form and the number must be 704 or smaller. This is because the Flight Program will not process data with an octal address larger than 7 0 4. Also, octal addresses less than 26 will not be processed.

c) DEPRESS the pushbutton corresponding to the sign (plus (+) or minus (-)) of the data to be inserted.

WHEN KEYING THE DEDA, EACH PUSHBUTTON SHOULD BE DEPRESSED TO THE LIMIT OF TRAVEL TO INSURE MAKING SWITCH CONTACTS.

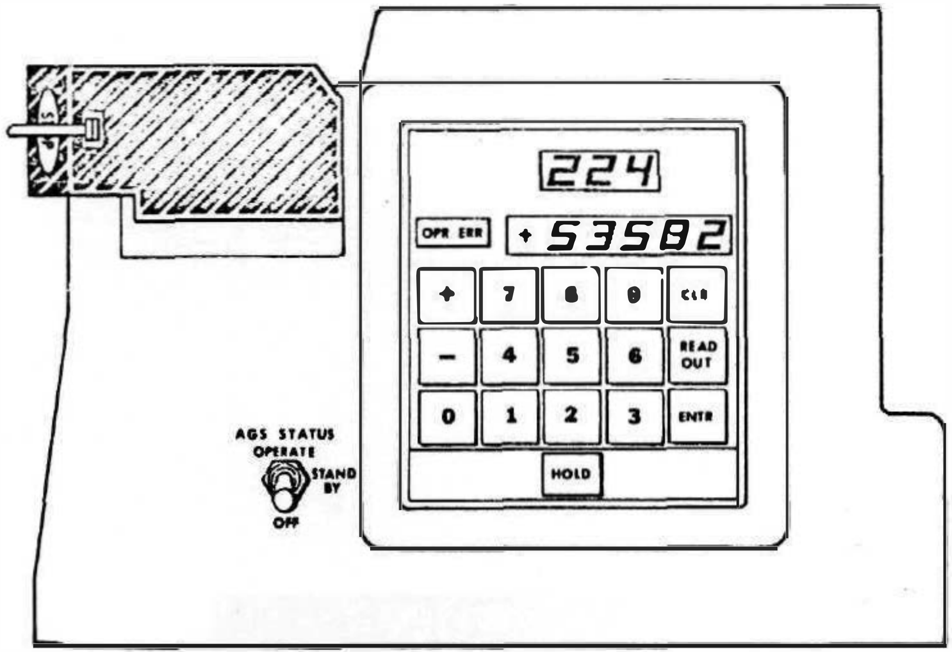

Figure 3.1. DEDA and Bottom Side Panel (Panel 6)

d) DEPRESS five consecutive digits corresponding to the numerical value of the data to be inserted (decimal or octal, as appropriate for the entry).

e) Verify the entry by comparing the illuminated display with the desired address and desired numerical value

f) DEPRESS the "ENTR" pushbutton - at this time the word is entered into the AEA and the address and data displays are extinguished.

3.1.2 Data Readout

The sequence of operations necessary to read the contents of a memory cell within the AEA is as follows:

a) DEPRESS the "CLR" pushbutton - this operation initializes (clears) the DEDA system and blanks all lighted characters. The "CLR" button must always be depressed prior to any readout.

b) DEPRESS three consecutive digits - this operation identifies the address of the AEA memory core location from which data is to be extracted. The address is in octal form and must be no larger than the number 7 0 4. If a number larger than 7 0 4 is entered into the address, the address display will be extinguished when the "READ-OUT" pushbutton is depressed. Octal addresses less than 26 are treated in the same way as addresses greater than 704.

c) Verify the entry by comparing the illuminated address with the desired address.

d) DEPRESS the "READOUT" pushbutton - after the "READOUT" pushbutton has been depressed, the value of the displayed quantity and its address will be updated twice per second. The operator can maintain (or hold) a value on the display by depressing the "HOLD" button. This value is maintained on the display until either the "READOUT" button is depressed (at which time the displayed quantity is updated twice per second) or until the "CLR" pushbutton is depressed (at which time the DEDA system is initialized for the next command and the displays are blanked).

3.1.3 Decimal Point Location

There is no decimal point indication on the DEDA. To use the AGS correctly the flight crew must have knowledge of the quantization of the decimal quantity being entered or read out. This information is contained in Section 6.0 of this report. If a position variable has a quantization of 100 ft, then 42,300 ft is entered or displayed as +00423.

Interpretation of octal quantities on the DEDA is considerably more complex than decimal. Conversion from scaled 2's complement binary form to decimal form for readout or the reverse for entry is required. Examples are given in Section 6.0 of this document.

3.2 Operator Error

The DEDA is capable of detecting certain operator errors and indicating this by illuminating the "operator error" indicator on the face of the DEDA. The operator error indicator remains illuminated until the "CLR" pushbutton is depressed. The DEDA is then ready for a new instruction. The following errors will cause the illumination of the operator error signal:

a) The "ENTR" pushbutton is depressed before nine keys have been depressed following the last depression of the "CLR" pushbutton.

b) More than nine keys have been depressed since the last depression of the "CLR" button.

c) If a plus or minus is entered in other than the fourth position.

d) If a plus or minus is not entered in the fourth position.

e) If the "READOUT" button is depressed before three digits have been entered since the last depression of the "CLR" pushbutton.

f) If the "READOUT" button is depressed after more than three digits have been entered since the last depression of the "CLR" pushbutton.

g) If an 8 or 9 is entered as one of the first three digits.

h) If a quantity is being read out and the "ENTR" button depressed.

Several operator errors can occur that do not cause the illumination of the operator error signal.

a) If any number greater than 7 0 4 or less than 26 is entered into the address portion of the display along with other numbers to be entered, the DEDA will exhibit an odd display when the "ENTR" button is depressed. The numbers will shift and several entry slots will be blanked.

b) If any number greater than 7 0 4 or less than 26 is entered into the address portion of the DEDA and the "READOUT" button depressed the DEDA will be blanked.

Address values greater than 7 0 4 or less than 26 are used for program instructions and are protected from DEDA entry. If such entries are attempted, the symptoms described above will occur. Normal operation will be restored by simply depressing the "CLR" pushbutton.

IF AN OCTAL QUANTITY IS ENTERED WITH A DIGIT GREATER THAN 7 OR IF A NUMBER GREATER THAN ITS ALLOWABLE RANGE IS ENTERED VIA THE DEDA, A COMPUTER PROCESSING ERROR WILL RESULT. IF THE ADDRESS IS READ OUT, THE DISPLAY WILL BE DIFFERENT THAN WHAT WAS ENTERED.

3.3 Controls and Displays

This section contains a description of the controls and displays utilized in AGS operations. Reference is made to Figures 3.1 through 3.7 which were obtained from Reference 6.

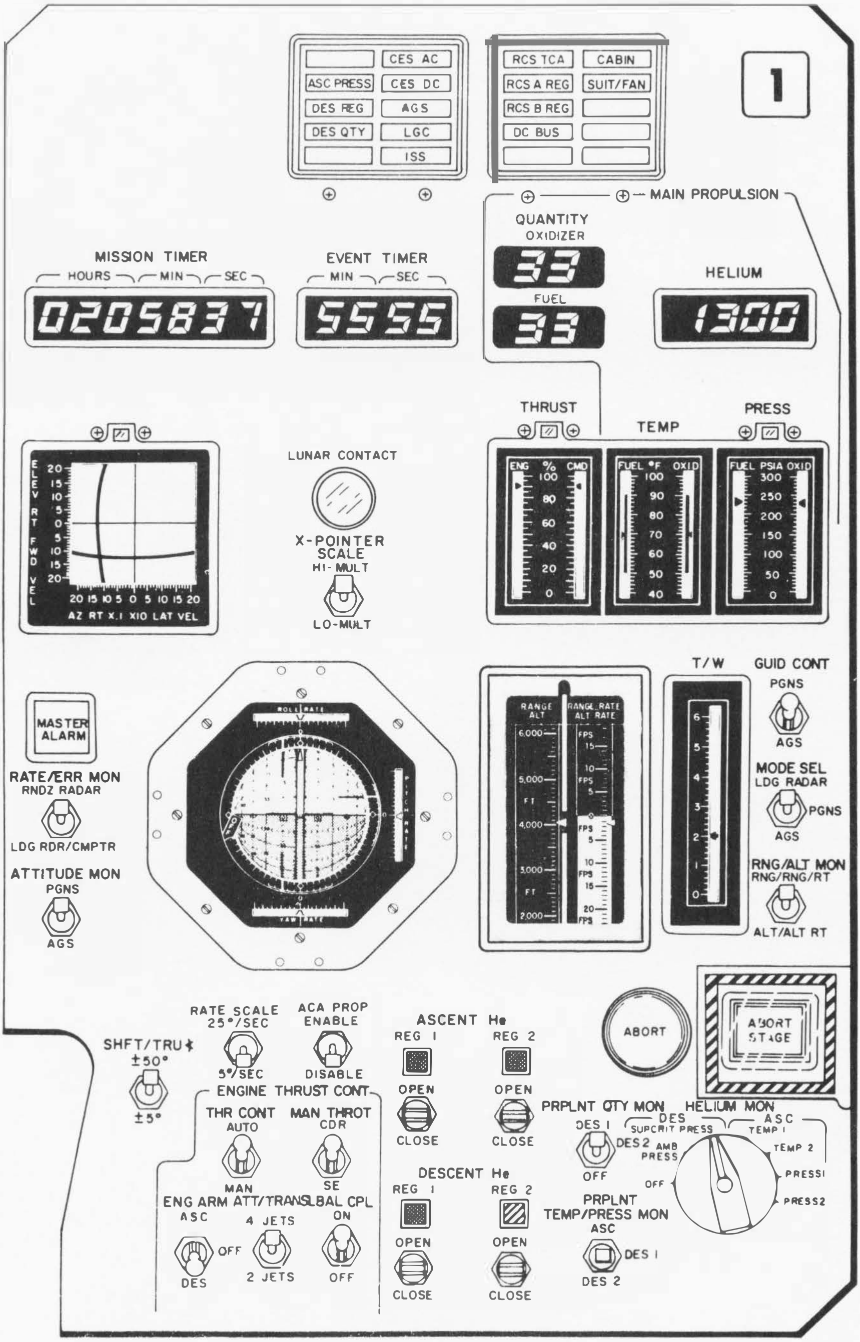

Figure 3.2. Center Console, Commander (Panel 1)

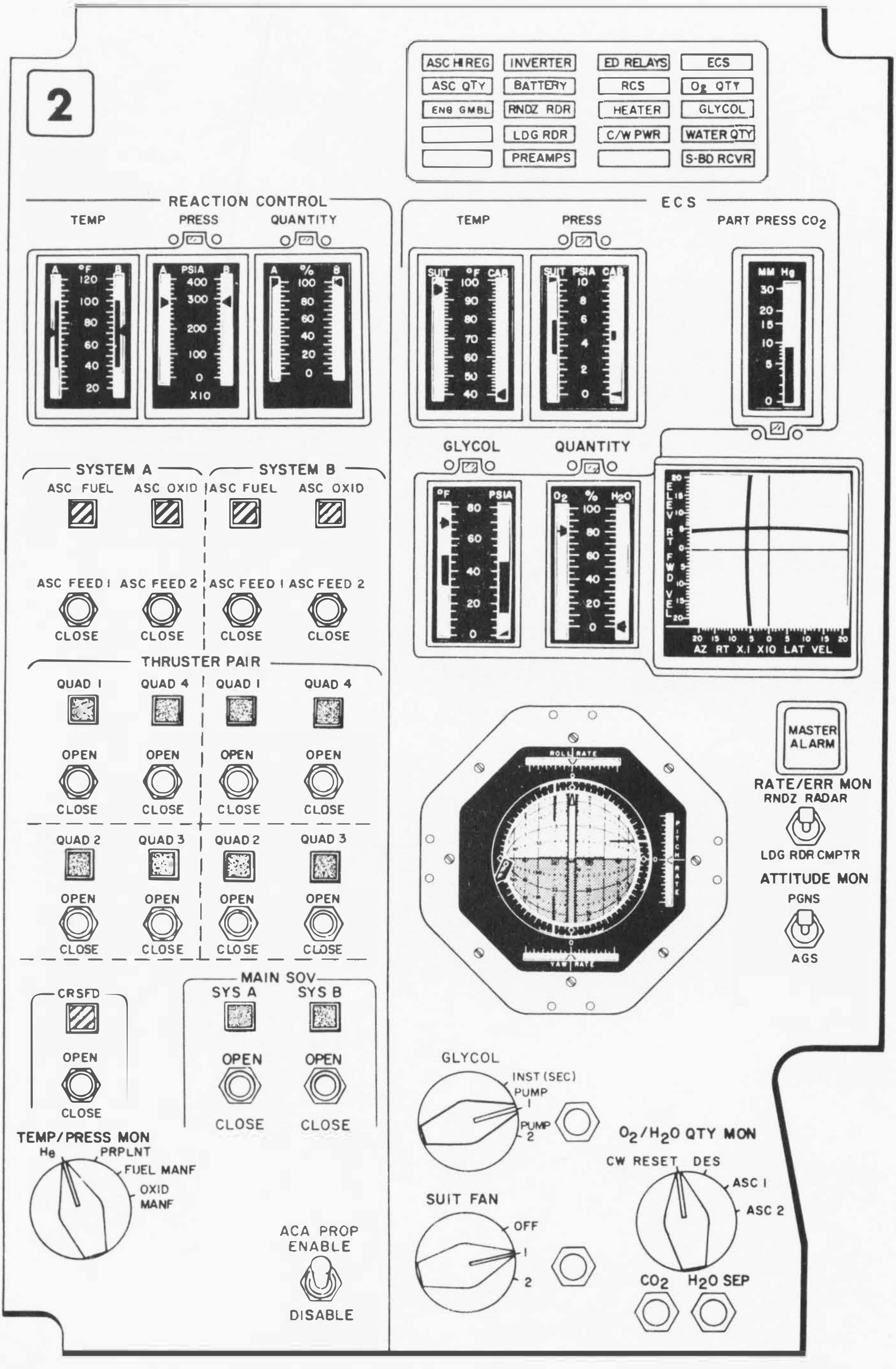

Figure 3. 3. Center Console, Systems Engineer (Panel 2)

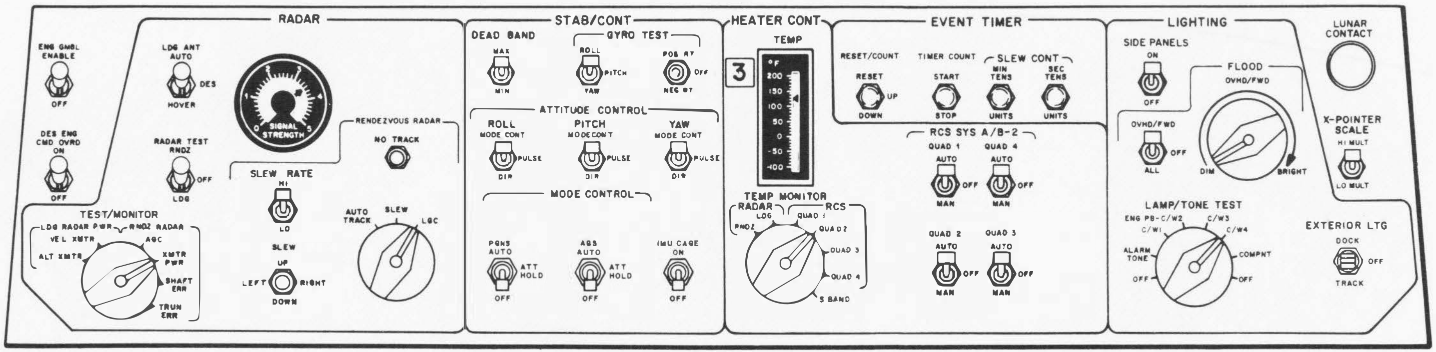

Figure 3.4. Lower Center Panel
(Panel 3)

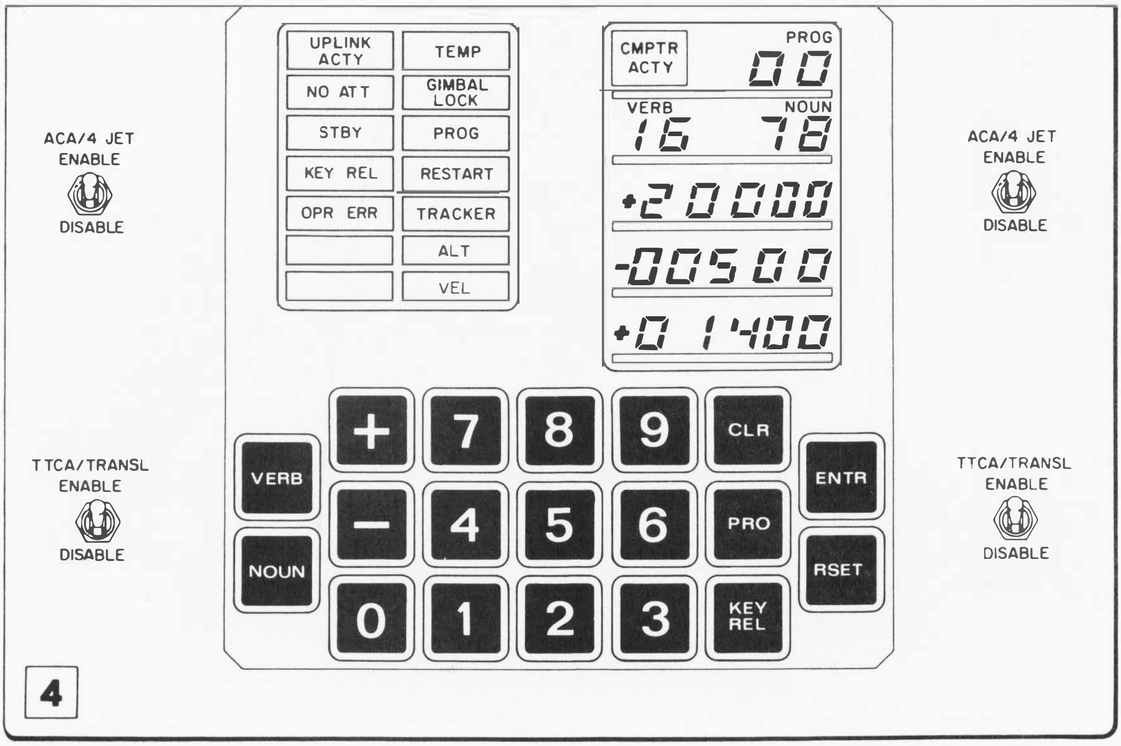

Figure 3.6. Bottom Center Panel (DSKY)
(Panel 4)

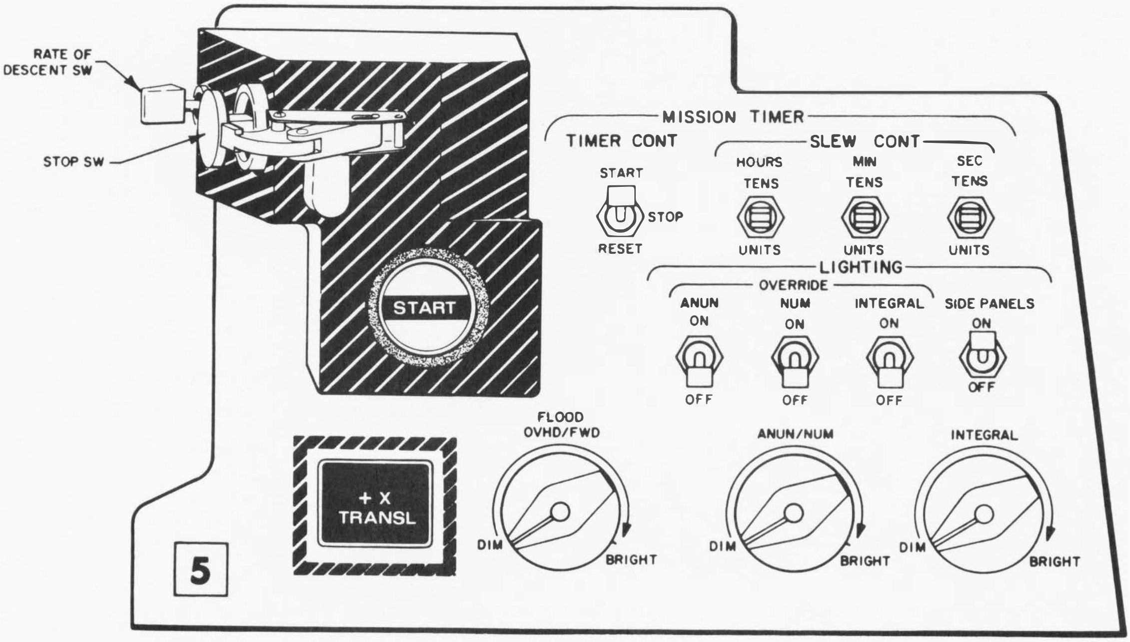

Figure 3.5. Bottom Panel
(Panel 5)

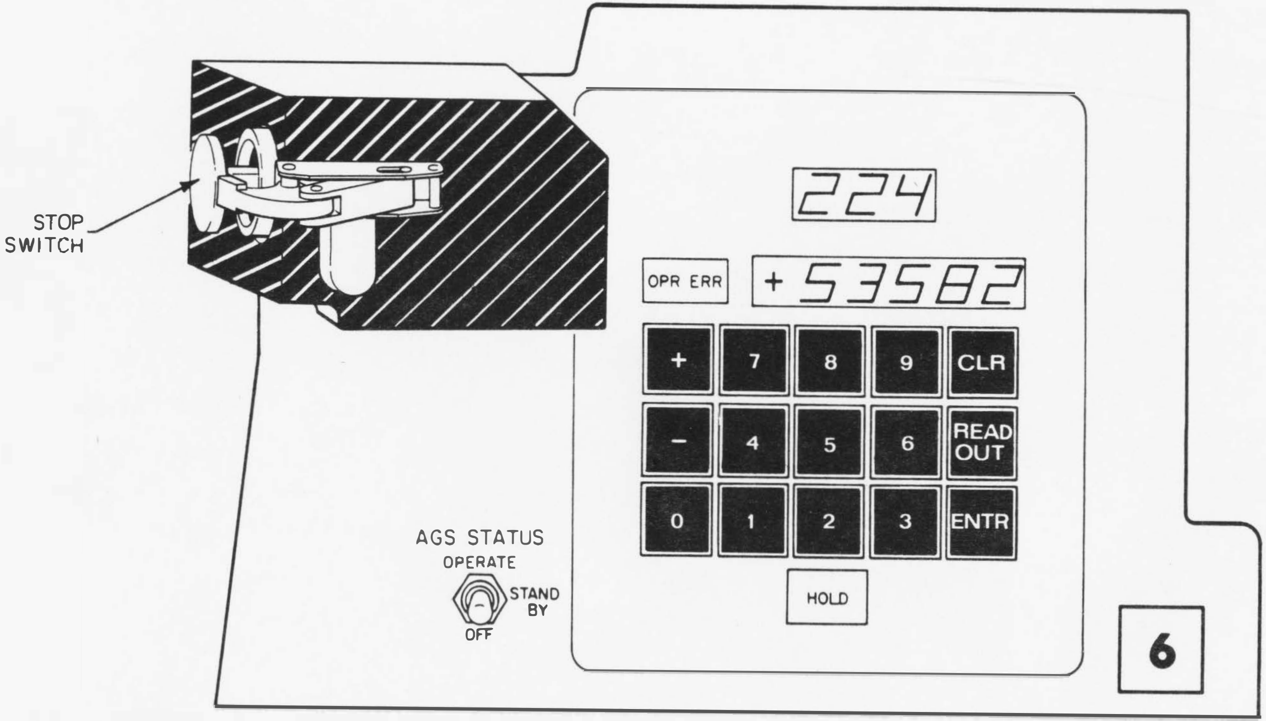

Figure 3.7. Bottom Right Panel, DEDA
(Panel 6)

3.3.1 Instrument Panel Guidance and Control Select Switches

Switch	Position	Function
AGS Status Switch	OFF	Applies inhibit standby signal to ASA and applies standby signal to AEA
	STANDBY	Removes inhibit standby signal to ASA and applies standby signal to AEA
	OPERATE	Removes standby signal to AEA, AEA enters flight program
Guidance Control Switch	PGNS	Applies follow-up signal to AEA, engine commands and attitude error signals issued by AGS are not used to control LM
	AGS	Removes follow-up signal
AGS Mode Control Switch	AUTO	Applies automatic signal to AEA and inhibits follow-up discrete when Guidance Control Switch is in "AGS" position
	ATT HOLD	Removes automatic signal: AGS in Attitude Hold. The AGS goes into follow-up if the attitude controller (hand controller) is out of its detent even if AGS is selected on Guidance Control Switch
	OFF	Inhibits AGS RCS firing. Automatic signal removed from AGS, as in A/H
Attitude Control Switches (Roll, Pitch, and Yaw)	MODE CONT	Controlled by Mode Control Switch
	PULSE	Manual pulse control on per axis basis
	DIR	Manual direct control on per axis basis

3.3.2 Radar Controls and Displays

Instrument	Function
RANGE DISPLAY	Tape meter used to display radar range (scaled in ft when <60, 500 ft, n.mi. when >60, 500 ft)
RANGE RATE DISPLAY	Tape meter used to display radar range rate (scaled to ±700 fps)
SLEW SWITCHES	Used for manual driving of rendezvous radar antenna
SIGNAL STRENGTH METER	Used for indicating and locking on to the strongest radar lobe
RENDEZVOUS RADAR MODE SELECT SWITCH	Selects either automatic or manual drive of the antenna
SHFT/TRUN ANGLE	Selects $\pm 5^{\circ}$ or $\pm 50^{\circ}$ scaling for rendezvous radar gimbal display

3.3.3 Additional Astronaut Controls and Displays for AGS Operation

Instrument	Function
Abort Button	Applies abort signal to AEA and arms the descent engine. A second depression of the button removes the abort signal.
Abort Stage Button	Applies the abort stage signal to AEA and arms the ascent engine. Initiates staging sequence if vehicle is unstaged and E/ON is commanded. A second depression of the button removes the abort stage signal.
Engine Stop Button	Used to shut off descent engine and to inhibit "Engine ON" command. A second depression of this button releases it. (Note: The engine stop button will not shut off ascent engine if the Abort Stage button is set).
Attitude Controller	The hand controller used for manually orienting the LM
DSKY	Used here for AGS state vector initialization via PGNCS downlink and for AGS computer time initialization.
Event Timer	Used here for countdown to AGS burns
Flight Director Attitude Indicator (FDAI)	Instrument used to display vehicle attitude, attitude rates, attitude errors, or rendezvous radar shaft and trunnion angles
Altitude Tape Meter	Tape meter used to display altitude (same display as used for radar range) Not valid above 76840 ft.
Altitude Rate Tape Meter	Tape Meter used to display altitude rate (same display as used for radar range rate)
X-Pointer	Instrument used to display component of inertial velocity normal to CSM plane, V_{y0} (±200 fps)
RNG/ALT MON	Used for selecting radar range and radar range rate or altitude and altitude rate on the tape meters.

Instrument	Function
Mode Sel	Used for selecting source of input to tape meters and cross pointer.
Rate Error Monitor Switch	Used for selecting rendezvous radar gimbal angles, or attitude errors to be displayed on the FDAI and information to cross pointer.
Attitude Monitor Select Switches	Select PGNCS or AGS inputs to FDAI
AEA Circuit Breaker	Closing circuit breaker causes power to be applied to AEA and sends the clock signal to the ASA.
ASA Circuit Breaker	Applies 28V DC and heater power to ASA
AGS Circuit Breaker	Applies 115V, 400 cps for Digital to Analog converters in AEA
AGS Caution and Warning Lamp	Indicates AGS status (See Section 5.1.8)
Thrust/Translation Controller	Used for throttling of descent engine, plus Y and Z translation with RCS or provide all axis RCS translation.
Attitude/Translation Switch	Used for selecting 2 or 4 jet operation for X translation or pitch and roll attitude maneuver
+ X Translation Button	Can be used for creating ullage
Manual Throttle Selection Switch	Selects translation controller from which throttle signals are accepted
Deadband Switch	Selects narrow or wide deadband if guidance control switch is set to AGS and changes the error needle scaling. During main engine firing the system automatically goes to the narrow deadband regardless of the switch setting.
Balanced Couple Switch	Used for selecting "unbalanced couple" during AGS ascent engine (main) burn. This inhibits firing of RCS jets opposite to main engine thrust when in the "OFF" position

Instrument	Function
Thrust Control Switch	Provides capability of switching from automatic control and display to manual throttle control and display (PGNCS control)
Throttle/Jet Control Select Lever	Used to select the throttle capability of the related thrust/translation controller, or X axis RCS translation. Note the RCS Y and Z axis translation capability remains with either switch setting
DES QTY Warning Light	Indicates a low quantity of propellant remaining for the descent engine
ASC QTY Caution Light	Indicates a low quantity of propellant remaining in ascent engine (approximately 10 seconds of propellant)
Main Propulsion Quantity	Indicates quantities of oxidizer and fuel in the selected propulsion system

4.0 AGS INPUTS

This section contains a description of all inputs to the AEA.

4.1 Hardwired Inputs

4.1.1 Accelerometer Inputs (ΔV_{xi}, ΔV_{yi}, ΔV_{zi})

The accelerometer data input to the AEA is in the form of pulses. For each accelerometer, an accumulation of 640 pulses per 20 mseconds (an intentional bias) indicates no acceleration. The equations subtract 640 pulses (K_7^1) from the number of pulses accumulated in 20 mseconds. The difference is the net number of sensed pulses with respect to zero acceleration. The net number of pulses is then multiplied by the appropriate scale factor (K_{18}^1, K_{20}^1, K_{22}^1) to convert pulses to feet per second per 20 mseconds. The values of the three constants just discussed (K_{18}^1, K_{20}^1, K_{22}^1) are obtained from bench test calibrations on the ASA prior to launch. If necessary, these constants can be modified via the DEDA as explained in Section 6.1 below. Accelerometer biases are compensated by the constants (K_{19}^1, K_{21}^1, K_{23}^1) and are also DEDA accessible (see Section 6.0).

The accelerometers on the AGS are always in use when the system is operating. Every two seconds the accumulated sensed velocity is used to update the estimated position and velocity of the LM. Because of the accelerometer biases, the accelerometers can indicate non-zero outputs when the vehicle is not thrusting. If these non-zero outputs were used, the estimated LM position and velocity would gradually increase in error. To avoid this situation, a threshold of 0.25 ft per 2 sec (K_{35}^1) is placed on the total sensed velocity. If total sensed velocity is less than this threshold, the thrust acceleration used in the navigation equations is set to zero.

4.1.2 Gyro Inputs ($\Delta\alpha_{xi}$, $\Delta\alpha_{yi}$, $\Delta\alpha_{zi}$)

The gyro data inputs to the AEA are in the form of pulses. An accumulation of 640 pulses per 20 msec indicates no change in vehicle attitude. The equations subtract 640 pulses (K_7^1) from the number of pulses accumulated and the difference is the net number of sensed pulses of attitude change. The net number of pulses is multiplied by the nominal scale factor (K_2^1) to convert the pulse count to radians. A fine correction to the scale factor is afforded by the constants K_3^1, K_8^1, K_{13}^1. The correction constants are DEDA accessible. Gyro biases are compensated by constants K_1^1, K_6^1, K_{11}^1) which are DEDA accessible. In addition, an X axis gyro correction term is available for the gyro spin axis mass unbalance error. This correction is available by the DEDA accessible constant K_{14}^1.

4.1.3 IMU Gimbal Angles ($\Delta\theta$, $\Delta\psi$, $\Delta\phi$)

Gimbal angle increments are obtained by the AEA in the form of pulses continuously. The pulses are accumulated and used during AGS-to-PGNCS align and during inflight gyro calibration.

4.1.4 CDU Zero

The CDU zero signal is a short duration signal (300 mseconds) from the PGNCS that is used to clear the AEA gimbal angle registers. The AEA gimbal angle registers then count up pulses to obtain the gimbal angles. AGS to PGNCS align should not be performed any sooner than 20 seconds after the CDU zero is issued in order to allow time for the gimbal angles to achieve the correct value.

4.1.5 PGNCS Downlink Data

State vectors of the LM and CSM are transmitted to the AEA on the PGNCS digital downlink upon DSKY command. Epoch times associated with the state vectors are also received. These times are received in AGS computer time (see Section 9.1).

4.1.6 Telemetry Control Signals

The AEA receives several signals from the Instrumentation Subsystem to control the telemetry output data. The AGS downlink "STOP" pulse indicates that the previous telemetry word has been transmitted and the AGS downlink bit sync pulses are the clocking signals to shift the bits out of the register.

4.1.7 Downlink Control Signals

The AEA receives signals from the Instrumentation Subsystem to control the reception of downlink data from the PGNCS. The PGNCS downlink "STOP" pulse indicates to the AEA that a complete word has been entered into the register. The PGNCS Downlink Bit Sync Pulses are the clocking signals used to shift the bits into the register.

4.1.8 DEDA Discretes

Four discretes are received by the AEA from the DEDA. These discretes control the DEDA operation and are:

a) DEDA "CLR" DISCRETE

b) DEDA "HOLD" DISCRETE

c) DEDA "ENTR" DISCRETE

d) DEDA "READOUT" DISCRETE

The effect of these discretes are discussed in Section 3.1.

4.1.9 GSE Discretes 1 and 2

Two input discretes are received from the Ground Service Equipment (GSE) when the AEA is receiving the program. GSE 1 is set by the test equipment to notify the computer that a word has been transmitted. GSE 2 is used in conjunction with GSE 1 to denote the end of the block of words transmitted.

4.1.10 Control Electronic Section (CES) Inputs

Six discretes are received from the Control Electronic Section. These discretes, designated with the symbol β and explained below, are automatically received by the AGS when the appropriate circumstances exist.

4.1.10.1 Engine Discretes (β_1, β_2). The following two discretes are received from the CES:

a) DESCENT ENGINE DISCRETE (β_1) - this discrete has the logic value of 0 if the descent engine is off and the logic value 1 if the descent engine is on.

b) ASCENT ENGINE DISCRETE (β_2) - this discrete has the logic value 0 if the ascent engine is off and the logic value of 1 if the ascent engine is on.

4.1.10.2 Follow Up Discrete (β_3). - The follow-up discrete is transmitted to the AGS under either of the following conditions:

a) Guidance Control Switch in the "PGNS" position.

b) Mode Control Switch in "ATT HOLD" and Attitude Controller out of the detent position.

When the follow-up discrete is present ($\beta_3 = 1$), all engine commands and attitude error signals issued by the AGS to the CES are inhibited from controlling the main engines or RCS thrusters. With the Guidance Control Switch in the "AGS" position, the follow up discrete is removed from the AEA ($\beta_3 = 0$) unless ATT HOLD is selected on the Mode Control Switch and the Attitude Controller is out of its detent position.

4.1.10.3 Automatic Discrete (β_4). - The presence of the automatic discrete in the AEA is completely controlled by the Mode Control Switch.

Mode Control Switch Positions	Automatic Discrete
OFF	Absent ($\beta_4 = 0$)
ATT HOLD	Absent ($\beta_4 = 0$)
AUTO	Present ($\beta_4 = 1$)

The presence of the automatic discrete is one of the necessary conditions for the AGS to exert guidance steering (not merely attitude hold) and engine control.

4.1.10.4 Abort Discrete (β_6). - Depression of the Abort button on the instrument panel applies the "Abort" signal ($\beta_6 = 1$) to the AEA. A second depression of the Abort button removes the "Abort" signal ($\beta_6 = 0$).

4.1.10.5 Abort Stage Discrete (β_5). - Depression of the Abort Stage button on instrument panel applies the "Abort Stage" signal ($\beta_5 = 1$) to the AEA. A second depression of the Abort Stage button removes the "Abort Stage" signal ($\beta_5 = 0$).

4.2 DEDA Inputs

Many quantities can be input via the DEDA. The quantities most likely to be used during a mission are presented in Section 6.0 for both the lunar and earth missions. Appendix A contains a more complete list of DEDA accessible quantities.

5.0 AGS OUTPUTS

5.1 Hardwired Outputs

5.1.1 Attitude Error Commands

Sign and magnitude of the limited angular errors (E_X, E_Y, E_Z) about the three vehicle body axes are updated every 40 msec and output to the CES and to the displays. These error signals drive the vehicle attitude to the desired attitude as discussed in Section 10.0.

5.1.2 Engine ON Command

Each 40 msec, the Engine ON command is updated and sent to the CES if the conditions given in Tables 5.1-A or 5.1-B are satisfied.

Table 5.1-A. Conditions for Engine-On Command

Status	Comment
a) $S_{00} < 3$	Any time $S_{00} \geq 3$, the AGS issues the Engine OFF command
and	
b) Either Guidance Control Switch is in PGNS position or Guidance Control Switch is in AGS position and Mode Control Switch is in A/H	If Mode Control Switch is in AUTO, then the condition in Table 5.1-B below must be satisfied for the Engine ON discrete to be commanded
and	
c) Either Descent or Ascent Engine ON discrete present	If neither the Descent nor the Ascent Engine ON discrete is present, the Engine OFF discrete will be commanded

Table 5.1-B. Conditions for Engine-On Command

Status	Comment
a) Guidance Control Switch is in AGS position and	If Guidance Control Switch is in PGNCS position, then the situation in Table 5.1-A above exists
b) S_{00} = 1 (guidance steering mode selected and	With all other conditions in Table 5.1-B satisfied, any other setting of S_{00} will cause the Engine OFF command to be sent
c) Mode Control Switch in AUTO and	If Mode Control Switch is not in AUTO, then the situation in Table 5.1-A above exists
d) Either ABORT or ABORT STAGE button depressed and	Depressing the ABORT and ABORT STAGE button arms the descent and ascent engines, respectively, in addition to allowing the Engine ON command to be sent
e) Ullage condition is satisfied (average thrust acceleration exceeds 0.1 fps^2 for 1K9 consecutive 2-sec compute cycles) and	
f) Either velocity-to-be-gained in the +X body axis exceeds the nominal ascent engine tailoff velocity impulse (constant 4K25), or the total velocity-to-be-gained magnitude exceeds a threshold (constant 4K26)	

(See Section 20.2 for further explanation of Engine-On logic.)

5.1.3 Engine OFF Command

In all situations other than those listed in Section 5.1.2 the Engine OFF command is sent to the CES every 40 msec.

5.1.4 Sin α, Cos α, Sin β, Cos β, Sin γ, Cos γ

Every 40 msec, these quantities are updated. They are output continuously to the FDAI to drive the attitude ball.

5.1.5 Altitude (h)

Every 200 msec the altitude above the launch site is output to the altitude display. This output is not valid in earth orbit or above 76840 ft in lunar orbit due to the display tape meter limitations (see page 3-10).

5.1.6 Altitude Rate ($\dot{h}$)

Every 200 msec altitude rate is output to the altitude rate display.

5.1.7 Velocity Normal to the CSM Plane (V_{y0})

Every 200 msec the inertial velocity component normal to the CSM plane is output to the X-pointer on the Lateral Velocity display.

5.1.8 AGS Caution and Warning Lamp

This lamp is lit when:

a) Inflight self test indicates an AEA malfunction

b) The AEA fails to complete a minor cycle within 20 msec

c) ASA voltages (+12vdc, +28vdc, +29v 400 cps) are not within tolerances

d) The thermal switch in series with the 12vdc line is activated. This switch is activated at a temperature of 150 ±5°F.

e) Going from OFF-to-STANDBY and from STANDBY-to-OPERATE.

5.1.9 GSE Discrete 5

After a word has been input to the computer via the GSE the computer responds with GSE discrete 5 which is used by the test equipment to initiate transfer of the next word.

5.2 AGS Telemetry Data

The data provided on the AGS downlink (telemetry) comprises a 50 word block of computer memory. All 50 words are repeated every second. The telemetry list is in Table 5.1. The scaling associated with each quantity appears in the FP6 Programmed Equation Docunent. Some quantities telemetered depend on the guidance routine selected, e.g., see words 37, and 46 in Table 5.2.

5.3 AGS Output Telemetry Data Format

The 24-bit telemetry output word assembled in the Output Telemetry Register consists of a 6-bit ID code and 18 bits of information from a particular AEA memory cell. The ID codes range sequentiall from octal 01 to octal 62 with the ID code octal 01 being used to designate the first word of the 50-word block. The ID codes occupy the first 6 most significant bits of the register. The remaining 18 bits, the computer word, represent either codes or numerical data. For numerical data, the 18 bits shall consist of one sign bit followed by 17 value bits, the most significant bit first. The sign bit is 0 for positive data and 1 for negative data. The value bits are in two's complement binary format.

5.4 DEDA Outputs

Many quantities can be output via the DEDA. These quantities are presented in Section 6.0 and Appendix A for both lunar and earth missions.

5.5 DEDA Word Format

A complete DEDA word contains 36 bits consisting of nine 4-bit groups. Each 4-bit group is associated with one of the DEDA display devices. There are three 4-bit groups for the address, one 4-bit group for the data sign, and five 4-bit groups for the data.

DEDA Word Format

Total Bits = 36

0XXX	0XXX	0XXX	000X	*XXX	*XXX	*XXX	*XXX	*XXX
12 bits Address			4 bits Sign	20 bits Data				

Code

0 - Zero

X - Either One or Zero

* { Either One or Zero for binary-coded-decimal data
Zero for octal data

In the 4-bit sign group, the three most significant bits are zeros. A zero in the least significant bit will indicate a positive sign, while a one in that location will indicate a negative sign.

Table 5.2. Telemetry List

Word No.	ID Code (Octal)	Equation Symbol	Units	Description
1	01	δ_{41}	--	DEDA readout mode flag; a 1 in the sign bit indicates DEDA processing is in the readout mode
2	02	DD	--	Most recent DEDA data word in computer units
3	03	δ_{38}	--	DEDA clear mode flag; a 1 in the sign bit indicates DEDA processing is in the clear mode
4	04	a_{11}	--	Row 1 of direction cosine matrix; cosine of angles between LM X-body axis and each of the AGS inertial coordinate axes.
5	05	a_{12}		
6	06	a_{13}		
7	07	ADST	--	Octal address associate with most recent DEDA communication
8	10	a_{31}	--	Row 3 direction cosine matrix; cosine of angles between LM Z-body axis and each of the AGS inertial coordinate axes.
9	11	a_{32}		
10	12	a_{33}		
11	13	h	ft	LM altitude above the nominal lunar (landing site radius) (J^5); valid at words 23 and 43 time.
12	14	$\underline{r}$	ft	Components (x, y, z) of LM inertial position, AGS coordinates; valid at words 23 and 43 time.
13	15			
14	16			
15	17	E/ON, S_{10}	--	Combination of the engine command indicator and the guidance mode indicator. A 1 in the sign bit indicates that the AGS is issuing an E/on command and bits 1-3 indicate the state of S_{10} (see Table 5.3)
16	20	$\underline{r}_c$	ft	Components (x, y, z) of CSM inertial position, AGS coordinates; valid at words 23 and 43 time.
17	21			
18	22			
19	23	r_f	ft	In OI, predicted value of LM radius at the completion of OI maneuver. In CSI, CDH, and TPI, predicted value of LM radius at t_{ig} (word 39). In XDV, r_f has no meaning.
20	24	ΔV_x	fps	Compensated incremental velocity changes along the body axes, sensed by the accelerometers in the 20 msec cycle prior to their output.
21	25	ΔV_y		
22	26	ΔV_z		
23	27	t_2	sec	Least significant half of the double precision AGS absolute time.
24	30	$\Delta\alpha_X$	rad	Compensated incremental components of vehicle rotation about the body axes sensed by the gyros in the 20 msec cycle prior to their output. (Raw gyro counts in PGNCS/AGS or body axis align submodes.)
25	31	$\Delta\alpha_Y$		
26	32	$\Delta\alpha_Z$		
27	33	T_B	sec	Time to LM Engine Burnout during OI. Valid only when engine is thrusting and thrust acceleration exceeds 1 ft/sec^2. Has no meaning in all other guidance modes.

Table 5.2. Telemetry List (Continued)

Word No.	ID Code (Octal)	Equation Symbol	Units	Description
28 29 30	34 35 36	$\underline{V}$	fps	Components (x, y, z) of present LM inertial velocity vector. AGS coordinates: valid at words 23 and 43 time
31	37	μ_{8T}/S_{12T}	--	Stored value of the computer self-test status word S_{12} (bits 1-3) and the ullage counter μ_8 (bits 4-17). See table 5.4 for S_{12} bit configuration. μ_8 is the number of consecutive 2-sec cycles that the sensed X-body axis acceleration has exceeded the threshold value.
32 33 34	40 41 42	$\underline{V}_c$	fps	Components (x, y, z) of CSM inertial velocity vector. AGS coordinates: valid at words 23 and 43 time
35	43	$\dot{h}$	fps	LM altitude rate; valid at words 23 and 43 time
36	44	V_G	fps	Magnitude of the velocity-to-be-gained for the existing guidance mode. Not valid in CDH mode.
37	45	V_{p0}/V_T	fps	Predicted velocity-to-be-gained in CDH burn when in the CSI guidance mode; and total predicted ΔV required to rendezvous when in the TPI guidance mode
38	46	T_{AO}	sec	Predicted time from nominal CSI burn to CDH burn in CSI. Has no meaning in any other guidance modes.
39	47	t_{ig}	sec	Absolute time of next maneuver in CSI, CDH, or TPI. Has no meaning in OI or XDV.
40 41 42	50 51 52	$\underline{X}_{bD}$	--	Components along the x, y, and z inertial axes of unit vector commanding the guidance desired pointing direction for LM thrust axis
43	53	t	sec	Most significant half of the double precision AGS absolute time
44	54	S_{00}	--	AGS Function Selector by which submode logic is selected via DEDA: bits 1-3 indicate the status of S_{00} (see Table 5.5)
45	55	DISC1C	--	Discretes which make up "Discrete Word One", bits 1-8 indicate status (see Table 5-6)
46	56	$\Delta r/q_{1d}$	ft	Predicted differential altitude between the LM and CSM orbits after CDH burn output during CSI and CDH guidance modes; and the perifocus altitude of the computed transfer orbit during TPI guidance mode
47	57	q_{LT}	ft	Perifocus altitude of LM orbit; valid at words 23 and 43 time
48 49 50	60 61 62	V_{dX} V_{dY} V_{dZ}	fps	Sums of the sensed velocity increments along the X, Y and Z body axes; obtained from the compensated accelerometer outputs

Table 5.3. Bit Pattern, Guidance Selector S_{10} (Word 15)

Mode	AEA Bit Pattern				
	0	1	2	3	4-17
Orbit Insertion (OI)	0	0	0	0	0
Coelliptic Sequence Initiate (CSI)	0	0	0	1	0
Constant Differential Altitude (CDH)	0	0	1	0	0
Direct Transfer Search (TPI Search)	0	0	1	1	0
Direct Transfer Execute (TPI Execute)	0	1	0	0	0
External ΔV (XDV)	0	1	0	1	0

Table 5.4. Bit Pattern, Self Test Indicator S_{12} (Word 31)

Mode	AEA Bit Pattern				
	0	1	2	3	4-17
Test Not Complete	0	0	0	0	0
Test Successfully Completed	0	0	0	1	0
Logic Test Failure	0	0	1	1	0
Memory Test Failure	0	1	0	0	0
Logic and Memory Test Failure	0	1	1	1	0

Table 5.5. Bit Pattern, Mode Word S_{00} (Word 44)

Mode	AEA Bit Pattern				
	0	1	2	3	4-17
Attitude Hold	0	0	0	0	0
Guidance Steering	0	0	0	1	0
Z Body Axis Steering	0	0	1	0	0
PGNCS to AGS Align	0	0	1	1	0
Lunar Align	0	1	0	0	0
Body Axis Align	0	1	0	1	0
Calibrate	0	1	1	0	0
Accelerometer Calibrate	0	1	1	1	0

Table 5. 6. Bit Pattern, Discrete Input Word Number One (Word 45)

Bit No.*	Discrete
1	Downlink Telemetry Stop
2	Output Telemetry Stop
3	Follow-up (β_3)
4	Automatic (β_4)
5	Descent Engine ON (β_1)
6	Ascent Engine ON (β_2)
7	Abort (β_6)
8	Abort Stage (β_5)

*A zero in designated bit indicates ON condition.

6.0 DEDA INPUTS AND OUTPUTS

This section contains a list of DEDA inputs and outputs for the AEA that would most likely be utilized on a flight. Other DEDA inputs and outputs are contained in Appendix A. To make the lists as useful as possible, the symbol of the quantity as used in the guidance equations is presented along with the memory address, the quantization and the allowable range of the word. Also presented are the units of the word as well as a definition or description of the entry. The entries for the selection logic are presented in Table 6.1. Table 6.2 contains the inputs for lunar missions, and Table 6.3 contains the outputs for lunar missions. Table 6.4 contains the input list for earth missions and Table 6.5 the output list for earth missions.

6.1 DEDA Display or Entry Data Conversion

When entering or displaying data through the DEDA, the numbers and their placement in the five-digit data word determine the decimal or binary point, since the point is not displayed. For the data which is in decimal form, the quantization is given in the accompanying tables. As an example consider the readout of inertial velocity for the lunar mission. The DEDA address 433 would be inserted into the DEDA by the flight crew after depressing the "CLR" button. Depressing the "READOUT" button would cause a number to appear such as +53210. Since inertial velocity is quantized at 0.1 fps, the inertial velocity should be interpreted as 5321 fps.

The data which must be entered or displayed in octal form requires considerably more manual conversion to interpret in decimal form. These variables are identified in the tables by listing their binary scaling as opposed to the quantization for decimal variables. Octal data which is displayed may be converted to the decimal system by first converting to the DEDA binary word form, next taking the 2's complement if the data has a negative sign, then entering the binary point as specified by the scaling, and finally converting the data from binary to decimal. This procedure is reversed to convert data from decimal to DEDA octal form for entry via the DEDA.

The binary scaling which determines the placement of the binary point specifies the range of a variable. For example, a variable whose maximum value is 0.01 which is less than $0.015625 = 2^{-6}$ may be scaled at binary -6 which is designated B-6. The most significant bit of the variable is then equal to $2^{-7} = 0.0078125$ and the range is actually $\pm(2^{-6} - 1\ \text{LSB})$, where LSB indicates "least significant bit." This scaling definition is applied to the DEDA conversions in the following examples.

Example 1. Decimal-to-DEDA octal conversion

Given $\sin \delta_L = -0.5625$

Conversion to binary gives

$$-0.5625|_{10} \rightarrow -0.100100|_2 \text{ exactly}$$

Shift the binary point one place to the left, since $\sin \delta_L$ is scaled at B1, to get the scaled binary number

$$-0.0100100|_2$$

If the number to be input is negative, the scaled binary number must be converted to the 2's complement number. This may be done by inverting all bits to the left of the least significant bit which is a one resulting in

$$-0.1011100|_2$$

The 2's complement number is now converted to octal form.

$$-0.1011100|_2 \rightarrow -0.56000|_8 \text{ exactly}$$

The number -56000 is then the DEDA octal equivalent of $-0.5625|_{10}$ for $\sin \delta_L$.

Example 2. Decimal-to-DEDA Octal Conversion

Given that $1K22 = 0.00354|_{10}$

Conversion to binary gives

$$0.00354|_{10} \rightarrow .00000000111001111111111010|_2$$

Next shift the binary point 8 places to the right since 1K22 is scaled at B-8.

$$.111001111111111010|_2$$

The binary number is truncated at 15 bits since the DEDA only displays 5 octal digits.

$.111001111111111$

Converting to octal for DEDA

$+.111001111111111|_2 - +71777|_8$

The number +71777 is then the DEDA octal of $+.00354|_{10}$ for 1K22.

Example 3. DEDA Octal-to-Decimal Conversion

When converting an octal DEDA readout, the procedure is the reverse of what it is for converting to a DEDA input. Given the DEDA readout of

$1K13 = +00200|_8$

Converting to binary

$+00200|_8 \rightarrow +.000000010000000|_2$

Since 1K13 is scaled at binary -7, shift the point 7 bits to the left to get

$+.0000000000000001000000|_2 \rightarrow 2^{-15}|_{10}$

Hence, a DEDA readout of +00200 for 1K13 is equivalent to

$+.00003052|_{10}$.

6.2 DEDA Accessible Quantities

In this section the DEDA accessible variables most likely to be utilized on a mission are presented.

Table 6-1. AGS Selector Logic

Equation Symbol	Address	Value	Description
S_{00}	400	+00000	AGS Submode Selector is in Attitude Hold. If the AGS is in control, the LM maintains the inertial attitude it had when this mode was entered. The program automatically enters this mode upon AGS engine cutoff, PGNCS to AGS align completion and calibration completion.
S_{00}	400	+10000	AGS Submode Selector is in Guidance Steering Mode. If the AGS is in control, the attitude error signals will orient the LM to the desired thrust direction.
S_{00}	400	+20000	AGS Submode Selector is in Z-body Axis Steering Mode. If the AGS is in control, the attitude errors signals will drive the +Z-body axis in the estimated direction of the CSM if S_{507} is zero or in the desired thrust direction if S_{507} is one.
S_{00}	400	+30000	AGS Submode Selector is in PGNCS to AGS Align. The system is in this mode for 2 seconds during which time the AGS stable member coordinate frame is aligned to the PGNCS stable member frame. Upon completion of this operation, the AGS Submode Selector is automatically returned to the "attitude hold" mode.
S_{00}	400	+40000	AGS Submode Selector is in the Lunar Align mode. See Section 16.2.
S_{00}	400	+50000	AGS Submode Selector is in the Body Axis Align mode. See Section 16.2
S_{00}	400	+60000	AGS Submode Selector is in the Gyro and Accelerometer Calibrate mode. See Section 17. Gyro calibration time is 302 sec and accelerometer calibration time is 32 sec. Upon completion of the calibrations, the AGS Submode Selector returns to the Attitude Hold mode (S_{00} = +00000).
S_{00}	400	+70000	AGS Submode Selector is in the inflight Accelerometer Calibrate mode. The Submode Selector should <u>NEVER</u> be in this mode on the lunar surface. Completion of the calibration requires 32 sec; the AGS Submode Selector returns to the Attitude Hold mode after 302 sec.
S_{07}	407	+00000	This is the normal value prior to freezing the external ΔV velocity-to-be-gained in inertial space.
S_{07}	407	+10000	If in the external ΔV mode of guidance, and the initiation of thrust is not to be along the positive X-body direction, then this entry must be made prior to the time of thrust initiation. If thrusting is initially along the positive X-body axis direction, this selection will automatically be set upon the detection of ullage. The purpose of this entry is to freeze the external ΔV velocity-to-be-gained vector in inertial space. The time to set S_{07} is specified by Mission Control so as to be consistent with the targeted ΔV values, also supplied by Mission Control.
S_{10}	410	+00000	AGS Guidance Routine Selector is in the "Orbit Insertion" mode. See Section 22.0. The purpose of this mode is to guide the LM vehicle to a prescribed orbital trajectory. Targeting constants for this trajectory are altitude, altitude rate and semi-major axis limits.
S_{10}	410	+10000	AGS Guidance Routine Selector is in the "Coelliptic Sequence Initiate" (CSI) mode. See Section 23.0. Three targeting constants are required for this mode: the time of the CSI maneuver, the nominal time of the TPI maneuver (DEDA entry 1J), and the desired cotangent of the line-of-sight angle between the LM and CSM at the time of the TPI maneuver (DEDA entry 2J).
S_{10}	410	+20000	AGS Guidance Routine Selector is in the "Constant Delta h" (CDH) mode. Targeting required is CDH time. See Section 24.0. The purpose of the maneuver is to make the LM orbit "coelliptic" with the CSM orbit.
S_{10}	410	+30000	AGS Guidance Routine Selector is in a TPI Search Mode. See Section 25.0. This mode is used prior to the TPI maneuver to determine when the direct transfer (TPI) maneuver is to be performed. Targeting inputs necessary for this mode are a time increment (T_{Δ}) necessary for the search and the desired time increment from TPI to rendezvous (DEDA entry 6J).
S_{10}	410	+40000	AGS Guidance Routine Selector is in the TPI Execute mode. See Section 25.0. This mode is used to actually perform any direct transfer maneuvers. Targeting for this mode is the AGS time of the maneuver and the time from the beginning of the maneuver to rendezvous (6J). An additional DEDA entry can be made to force the node to occur 4J minutes prior to normal rendezvous time.
S_{10}	410	+50000	AGS Guidance Routine Selector is in the "External ΔV" mode. See Section 27.0. This mode is used to perform maneuvers based upon externally supplied velocity-to-be-gained components. Targeting inputs necessary for this mode are three components of velocity-to-be-gained in local vertical coordinates. The time when the burn commences must be known but is not an entry into the AEA. If other than +X thrusting is planned as the first burn maneuver, the time when the external ΔV input is "frozen" must also be known (i.e., time when S_{07} is set to +10000).

Table 6-1. AGS Selector Logic (Continued)

Equation Symbol	Address	Value	Description
S_{11}	411	+10000	The actual thruat direction of the LM depends upon the engine being used. The DPS and RCS engines are assumed to thrust along the X-body axis and the APS engine is assumed canted through nominal angles. If the APS engine is being used, this address and value should be entered. If an abort stage occurs during a burn, it is not necessary to enter S_{11} = +10000 because the appropriate action is taken in the computer.
S_{12}	412	+00000	This entry resets the equation self-test error indicator and re-initiates testing. In general, this is the only entry that ever need be made in this address. The remainder of the valid states (+10000-test successfully completed, +30000-logic test failure, +40000 memory test failure, +70000-logic and memory test failure) are for readout purposes only.
S_{13}	413	+10000	Any entry in this cell (+10000 is suggested) causes the lunar surface flag to be set and the lunar azimuth stored. The value of +00000 for S_{13} is reset only by the computer power turn-on sequence. However, lunar azimuth is stored each time S_{13} is set to + 10000, whether or not S_{13} was previously + 00000.
S_{14}	414	+00000	Following completion of any navigation initialization, the program automatically establishes this value in the cell. It is used only to indicate completion of initialization. Do not enter +00000 since it will be treated as a +10000 entry. See Section 15.1.
S_{14}	414	+10000	This entry commands a LM and CSM navigation initialization via the PGNCS downlink.
S_{14}	414	+20000	This entry commands a LM navigation initialization via the DEDA. The ephemeris data are first entered and then this entry made.
S_{14}	414	+30000	This entry commands a CSM navigation initialization via the DEDA. The ephemeris data are first entered and then this entry made.
S_{15}	415		Any entry in this cell causes the Z-body axis direction cosines, the time since the last range input, and the last computed range and range rate to be stored in the appropriate cells for use in the radar filter. The entry +10000 is suggested.
S_{16}	416	+10000	This entry causes the CSI calculations to compute the CSI maneuver with the CDH maneuver occurring at one-half orbital period following CSI.
S_{16}	416	+30000	This entry causes the CSI calculations to compute the CSI maneuver with the CDH maneuver occurring at three-halves orbital periods following CSI.
S_{17}	417	+00000	This is the normal value of the "radar filter initialization" command. This entry need never be made by the astronaut since the program resets the value automatically to +00000 after the command to initialize the radar filter.
S_{17}	417	+10000	This entry causes the radar filter to be initialized. The entry +10000 is required. The entry in this address is then set back to the nominal value (+00000).
S_{507}	507	+00000	Orient Z-body to direction of CSM when Z-body steering is commanded (400 + 20000).
S_{507}	507	+10000	Orient Z-body to desired thrust direction when Z-body steering is commanded (400 + 20000).
S_{623}	623	+00000	Orient Z-body axis parallel to CSM orbit plane when guidance steering is commanded (400 + 10000).
S_{623}	623	+10000	Orient Z-body axis parallel to plane defined by $\underline{W}_b$ when guidance steering is commanded (400 + 10000).

Table 6.2. DEDA Inputs - Lunar Mission

Equation Symbol	Address	Units	Value	Range	Quantization	Description
W_{bx}	514	octal		B1	-	Unit vector in AGS inertial coordinates, normal to the plane in which the Z body axis is commanded during guidance steering when $S_{623} = 1$
W_{by}	515	octal		B1	-	
W_{bz}	516	octal		B1	-	
1J1	240	ft		±8,388,600	10^2	X component of LM position used in LM initialization via the DEDA
1J2	241	ft		±8,388,600	10^2	Y component of LM position used in LM initialization via the DEDA
1J3	242	ft		±8,388,600	10^2	Z component of LM position used in LM initialization via the DEDA
1J4	260	ft/sec		±8191	0.1	X component of LM velocity used in LM initialization via the DEDA
1J5	261	ft/sec		±8191	0.1	Y component of LM velocity used in LM initialization via the DEDA
1J6	262	ft/sec		±8191	0.1	Z component of LM velocity used in LM initialization via the DEDA
1J7	254	min		0 to 4369	0.1	Epoch time of LM ephemeris data used in LM navigation initialization via the DEDA. This time must be expressed in AGS computer time (see Section 9.1)
2J1	244	ft		±8,388,600	10^2	X component of CSM position used in CSM initialization via the DEDA
2J2	245	ft		±8,388,600	10^2	Y component of CSM position used in CSM initialization via the DEDA
2J3	246	ft		±8,388,600	10^2	Z component of CSM position used in CSM initialization via the DEDA
2J4	264	ft/sec		±8191	0.1	X component of CSM velocity used in CSM initialization via the DEDA
2J5	265	ft/sec		±8191	0.1	Y component of CSM velocity used in CSM initialization via the DEDA
2J6	266	ft/sec		±8191	0.1	Z component of CSM velocity used in CSM initialization via the DEDA
2J7	272	min		0 to 4369	0.1	Epoch time of CSM ephemeris data used in CSM navigation initialization via the DEDA. This time must be expressed in AGS computer time (see Section 9.1)
t	377	min		0 to 4369	0.1	AGS computer time (see Section 9.1)
28J1	450	ft/sec		±8191	0.1	Component of External ΔV input in the direction parallel to the CSM orbit plane. A positive value indicates a velocity-to-be-added in the posigrade direction.
28J2	451	ft/sec		±8191	0.1	Component of External ΔV input in the direction perpendicular to the CSM orbit plane. A positive value indicates a velocity-to-be-added opposite to the LM angular momentum vector.
28J3	452	ft/sec		±8191	0.1	Component of External ΔV input in the radial direction. A positive value indicates a velocity-to-be-added toward the Moon

Table 6. 2. DEDA Inputs - Lunar Mission (Continued)

Equation Symbol	Address	Units	Value	Range	Quantization	Description
$\Delta\delta$	547	octal rad		B0		Lunar Align Azimuth Correction (see Section 16. 2)
1J	275	min		0 to 4369	0. 1	Desired time of TPI maneuver as utilized in the CSI calculations. This time must be input in AGS computer time
2J	605	octal		B7		Desired cotangent of line-of-sight angle between LM and CSM at desired TPI time as used in the CSI computations
3J	312	min		±136	0. 01	This entry is a TPI rendezvous offset time as used in the stable orbit rendezvous technique
4J	306	min		±136	0. 01	Time increment of node prior to nominal rendezvous
5J	231	ft			10^2	Radial distance of landing site from the center of the attracting body
6J	307	min		0 to 136	0. 01	Transfer time from beginning of direct transfer maneuver to rendezvous
7J	224	ft		±8,388,600	10^2	Term in semi-major axis computation, α_L (OI)
8J	225	ft		±8,388,600	10^2	α_L lower limit (OI)
9J	226	ft		±8,388,600	10^2	α_L upper limit (OI)
16J	232	ft		0 to 10^5	10^2	Targeted injection altitude at orbit insertion
17J	503	ft/sec		±8191	0. 1	Radar range rate
18J	316	nmi		0 to 1379.6	0. 1	Radar range
21J	233	feet		0 to 10^5	10^2	Vertical pitch steering altitude threshold
22J	464	ft/sec		±1000	0. 1	Vertical pitch steering altitude rate threshold
23J	465	ft/sec		±1000	0. 1	Target radial rate at orbit insertion
25J	223	ft			10^2	DEDA altitude update during descent phase
29J	274	min		-4369 to 0		Initial radar filter value for t_1
T_Δ	310	min		0 to 136	0. 01	Time increment until TPI used in guidance TPI search routine
t_{igA}	373	min		0 to 4369	0. 1	Absolute time of CSI maneuver in AGS computer time
t_{igB}	373	min		0 to 4369	0. 1	AGS absolute time of CDH maneuver
t_{igC}	373	min		0 to 4369	0. 1	Absolute time of TPI or midcourse maneuver in AGS computer time
$\sin\delta_L$	047			B1		Sine of the Landing Azimuth Angle (see Section 16. 2)
$\cos\delta_L$	053			B1		Cosine of the Landing Azimuth Angle (see Section 16. 2)

Table 6-2. DEDA Inputs — Lunar Mission (Continued)

Equation Symbol	Address	Units	Value	Range	Quantization	Description
V_{dX}	404	ft/sec-		B13*		Accumulated ΔV in X-body direction minus descent engine capability (updated every 40 mseconds).
1K1	544	deg/hr		±10	0.01	X-gyro drift compensation constant
1K6	545	deg/hr		±10	0.01	Y-gyro drift compensation constant
1K11	546	deg/hr		±10	0.01	Z-gyro drift compensation constant
1K19	540	ft/sec^2		±0.064	0.001	Compensation for X-axis accelerometer bias
1K21	541	ft/sec^2		±0.064	0.001	Compensation for Y-axis accelerometer bias
1K23	542	ft/sec^2		±0.064	0.001	Compensation for Z-axis accelerometer bias
1K18	534	ft/sec/ pulse		B-8		X-Accelerometer Scale Factor
1K20	535	ft/sec/ pulse		B-8		Y-Accelerometer Scale Factor
1K22	536	ft/sec/ pulse		B-8		Z-Accelerometer Scale Factor
3K4	613			B1		Sine of TPI interdict region
K55	607			B0		$\dot{h}$ display scale factor

*Because V_{dX} was not intended for DEDA processing but is on the downlink, it is in a region of memory for which a non-applicable DEDA processing scale factor is selected. The only access to this cell via DEDA should be as described in Section 2.3.5.

Table 6.3. DEDA Outputs - Lunar Mission

Equation Symbol	Address	Units	Range	Quantization	Description
r_x	340	ft	±8,388,600	10^2	X component of LM position
r_y	341	ft	±8,388,600	10^2	Y component of LM position
r_z	342	ft	±8,388,600	10^2	Z component of LM position
V_x	360	ft/sec	±8191	0.1	X component of LM velocity
V_y	361	ft/sec	±8191	0.1	Y component of LM velocity
V_z	362	ft/sec	±8191	0.1	Z component of LM velocity
V	433	ft/sec	+8191	0.1	LM velocity magnitude
r_{cx}	344	ft	±8,388,600	10^2	X component of CSM position
r_{cy}	345	ft	±8,388,600	10^2	Y component of CSM position
r_{cz}	346	ft	±8,388,600	10^2	Z component of CSM position
V_{cx}	364	ft/sec	±8191	0.1	X component of CSM velocity
V_{cy}	365	ft/sec	±8191	0.1	Y component of CSM velocity
V_{cz}	366	ft/sec	±8191	0.1	Z component of CSM velocity
t	377	min	0 to 4369	0.1	AGS computer time
q_{LT}	403	nmi	±1379.6	0.1	Perifocus altitude of LM trajectory
q_{1D}	402	nmi	±1379.6	0.1	Perifocus altitude of predicted LM trajectory (TPI only)
q_a	315	nmi	±1379.6	0.1	Apofocus altitude of LM trajectory
ΔV_{gX}	500	ft/sec	±8191	0.1	Velocity-to-be-gained in X-body direction

Table 6. 3. DEDA Outputs - Lunar Mission (Continued)

Equation Symbol	Address	Units	Range	Quantization	Description
ΔV_{gY}	501	ft/sec	±8191	0. 1	Velocity-to-be-gained in Y-body direction
ΔV_{gZ}	502	ft/sec	±8191	0. 1	Velocity-to-be-gained in Z-body direction
V_{DX}	470	ft/sec	±8191	0. 1	ΔV expended in X-body direction minus descent capability (updated every 2 seconds)
V_{DY}	471	ft/sec	±8191	0. 1	ΔV expended in Y-body direction (updated every 2 seconds)
V_{DZ}	472	ft/sec	±8191	0. 1	ΔV expended in Z-body direction (updated every 2 seconds)
$\dot{r}_A$	477	ft/sec	±8191	0. 1	Predicted altitude rate of LM at CSI, CDH, or TPI time.
V_{p0}	371	ft/sec	±8191	0. 1	ΔV for CDH maneuver (valid when in CSI guidance mode)
Δr	402	nmi	±1379. 6	0. 1	Differential altitude in coelliptic orbit (valid in CSI or CDH only)
ξ	277	deg	0 to 360	0. 01	In plane angle between Z body axis and local horizontal
T_{A0}	372	min	0 to 4369	0. 1	Time from CSI to CDH (valid in CSI only)
δr	314	nmi	±1379. 6	0. 1	Differential orbital altitude along LM radial at CSI time

Table 6.3. DEDA Outputs - Lunar Mission (Continued)

Equation Symbol	Address	Units	Range	Quantization	Description
R	317	nmi	0 to 1379.6	0.1	Range from LM to CSM
$\dot{R}$	440	ft/sec	±8191	0.1	Range rate between LM and CSM (negative sign indicates LM closing on CSM)
$\dot{r}$	367	ft/sec	±8191	0.1	LM altitude rate
h	337	nmi	0 to 1379.6	0.1	LM altitude
θ_f	303	deg	0 to 360	0.01	LM to CSM Phase Angle (in OI at present; CSI or CDH modes at t_{ig}).
ΔV_G	267	ft/sec	0 to 8191	0.1	Magnitude of LM velocity to-be gained (Not valid in CDH mode)
θ_{LOS}	303	deg	0 to 360	0.01	Predicted line-of-sight angle at TPI time (TPI mode only)
V_T	371	ft/sec	0 to 8191	0.1	Total velocity to rendezvous (TPI Mode Only)
V_{py}	263	ft/sec	±8191	0.1	Predicted LM out-of-plane velocity at t_{ig} in CSI, CDH, or TPI; present LM out-of-plane velocity in OI. Has no meaning in XDV.
V_{y0}	270	ft/sec	±8191	0.1	Present LM out-of-plane velocity
y	211	ft	±8,388,600	10^2	Present LM out-of-plane distance

Table 6-3. DEDA Outputs — Lunar Mission (Continued)

Equation Symbol	Address	Units	Range	Quantization	Description
t_{ig}	373	min	0 to 4369	0.1	AGS absolute time of next maneuver
T_{Δ}	310	min	0 to 136	0.01	Time to go until CSI maneuver when in CSI mode, CDH maneuver when in CDH, and TPI maneuver when in TPI
T_{perg}	313	min	0 to 136	0.01	Time to go until perifocus of LM orbit
1J	275	min	0 to 4369	0.1	Nominal time of TPI maneuver
3J	312	min	0 to 136	0.1	TPI Rendezvous offset time
4J	306	min	0 to 136	0.1	Time of node prior to nominal rendezvous time
6J	307	min	0 to 136	0.01	Time from TPI to rendezvous
T_r	311	min	0 to 136	0.01	Time to go until rendezvous in TPI mode
$*\delta_2$	574				Descent section staging flag
$*\delta_{21}$	604				Lunar surface flag

*These are internal computer flags. Only the sign of the quantity has significance.

Table 6-3. DEDA Outputs — Lunar Mission (Continued)

Equation Symbol	Address	Units	Range	Quantization	Description
μ_6	612	40 msec counts	B17		Staging sequence counter
μ_8	614	2-sec increments	0 to 131,072	1.0	Ullage counter (Decimal)
$\dot{r}_f$	423	ft/sec	±8191	0.1	Desired final value of altitude rate
1K19	540	ft/sec^2	0.064	0.001	X-accelerometer bias compensation (Decimal)
1K21	541	ft/sec^2	0.064	0.001	Y-accelerometer bias compensation (Decimal)
1K23	542	ft/sec^2	0.064	0.001	Z-accelerometer bias compensation (Decimal)
1K18	534	ft/sec/pulse	B-8		X-accelerometer scale factor
1K20	535	ft/sec/pulse	B-8		Y-accelerometer scale factor
1K22	536	ft/sec/pulse	B-8		Z-accelerometer scale factor
1K1	544	deg/hr	10.0	0.01	X-gyro drift compensation
1K6	545	deg/hr	10.0	0.01	Y-gyro drift compensation
1K11	546	deg/hr	10.0	0.01	Z-gyro drift compensation
1K9	616	2-sec increment	0 to 131,072	1.0	Ullage counter value for ullage completion

Table 6-4. DEDA Inputs — Earth Mission

Equation Symbol	Address	Units	Value	Range	Quantization	Description
W_{bx}	514	Octal		B1	-	Unit vector in AGS inertial coordinates, normal to the plane in which the Z-body axis is commanded during guidance steering when $S_{623} = 1$
W_{by}	515	Octal		B1	-	
W_{bz}	516	Octal		B1	-	
1J1	240	ft		±33,554,000	10^3	X component of LM position used in LM initialization via the DEDA
1J2	241	ft		±33,554,000	10^3	Y component of LM position used in LM initialization via the DEDA
1J3	242	ft		±33,554,000	10^3	Z component of LM position used in LM initialization via the DEDA
1J4	260	ft/sec		±32767	1	X component of LM velocity used in LM initialization via the DEDA
1J5	261	ft/sec		±32767	1	Y component of LM velocity used in LM initialization via the DEDA
1J6	262	ft/sec		±32767	1	Z component of LM velocity used in LM initialization via the DEDA
1J7	254	min		0 to 4369	0.1	Epoch time of LM ephemeris data used in LM navigation initialization via the DEDA. This time must be expressed in AGS computer time (see Section 9.1)
2J1	244	ft		±33,554,000	10^3	X component of CSM position used in CSM initialization via the DEDA
2J2	245	ft		±33,554,000	10^3	Y component of CSM position used in CSM initialization via the DEDA
2J3	246	ft		±33,554,000	10^3	Z component of CSM position used in CSM initialization via the DEDA
2J4	264	ft/sec		±32767	1	X component of CSM velocity used in CSM initialization via the DEDA
2J5	265	ft/sec		±32767	1	Y component of CSM velocity used in CSM initialization via the DEDA
2J6	266	ft/sec		±32767	1	Z component of CSM velocity used in CSM initialization via the DEDA
2J7	272	min		0 to 4369	0.1	Epoch time of CSM ephemeris data used in CSM navigation initialization via the DEDA. This time must be expressed in AGS computer time (see Section 9.1)
t	377	min		0 to 4369	0.1	AGS computer time (see Section 9.1)
28J1	450	ft/sec		±32767	1	Component of External ΔV input in the direction parallel to the CSM orbit plane. A positive value indicates a velocity-to-be-added in the posigrade direction
28J2	451	ft/sec		±32767	1	Component of External ΔV input in the direction perpendicular to the CSM orbit plane. A positive value indicates a velocity-to-be-added opposite to the LM angular momentum vector
28J3	452	ft/sec		±37767	1	Component of External ΔV input in the radial direction. A positive value indicates a velocity-to-be-added toward the Earth

Table 6-4. DEDA Inputs — Earth Mission (Continued)

Equation Symbol	Address	Units	Value	Range	Quantization	Description
$\Delta\delta$	547	octal rad		B0		Lunar Align Azimuth Correction (see Section 16.2)
1J	275	min		0 to 4369	0.1	Desired time of TPI maneuver as utilized in the CSI calculations. This time must be input in AGS computer time
2J	605	octal		B7		Desired cotangent of line-of-sight angle between LM and CSM at desired TPI time as used in the CSI computations
3J	312	min		±136	0.01	This entry is a TPI rendezvous offset time as used in the stable orbit rendezvous technique
4J	306	min		±136	0.01	Time increment of node prior to nominal rendezvous
5J	231	ft			10^3	Radial distance of launch site from the center of the attracting body (Earth)
6J	307	min		0 to 136	0.01	Transfer time from beginning of direct transfer maneuver to rendezvous
7J	224	ft		±33,554,000	10^3	Term in semi-major axis computation, σ_L (OI)
8J	225	ft		±33,554,000	10^3	σ_L lower limit (OI)
9J	226	ft		±33,554,000	10^3	σ_L lower limit (OI)
16J	232	ft		0 to 33,554,000	10^3	Targeted injection altitude at orbit insertion
17J	503	ft/sec		±32767	1	Radar range rate
18J	316	nmi		0 to 5518.4	0.1	Radar range
21J	233	ft		0 to 33,554,000	10^3	Vertical pitch steering altitude threshold
22J	464	ft/sec		±32767	1	Vertical pitch steering altitude rate threshold
23J	465	ft/sec		±32767	1	Target radial rate of orbit insertion
25J	223	ft			10^3	DEDA attitude update during descent phase
29J	274	min		-4369 to 0		Initial radar filter value for t_I
T_Δ	310	min		0 to 136	0.01	Time increment until TPI used in TPI search guidance routine
t_{igA}	373	min		0 to 4369	0.1	Absolute time of CSI maneuver in AGS computer time
t_{igB}	373	min		0 to 4369	0.1	Absolute time of CDH maneuver
t_{igC}	373	min		0 to 4369	0.1	Absolute time of TPI or midcourse maneuver in AGS computer time
$\sin \delta_L$	047			B1		Sine of the Landing Azimuth Angle (see Section 16.2)
$\cos \delta_L$	053			B1		Cosine of the Landing Azimuth Angle (see Section 16.2)
V_{dX}	404	ft/sec		B15*		Accumulated ΔV in X-body direction minus descent engine capability (updated every 40 mseconds)
1K1	544	deg/hr		±10	0.01	X-gyro drift compensation constant
1K6	545	deg/hr		±10	0.01	Y-gyro drift compensation constant
1K11	546	deg/hr		±10	0.01	Z-gyro drift compensation constant
1K19	540	ft/sec^2		±.06	0.01	Compensation for X-axis accelerometer bias
1K21	541	ft/sec^2		±.06	0.01	Compensation for Y-axis accelerometer bias
1K23	542	ft/sec^2		±.06	0.01	Compensation for Z-axis accelerometer bias

*See footnote on next page

Table 6-4. DEDA Inputs — Earth Mission (Continued)

Equation Symbol	Address	Units	Value	Range	Quantization	Description
1K18	534	ft/sec/pulse		B-6		X-accelerometer scale factor
1K20	535	ft/sec/pulse		B-6		Y-accelerometer scale factor
1K22	536	ft/sec/pulse		B-6		Z-accelerometer scale factor
3K4	613	-		±1.0 B1		Sine of TPI interdict region
K55	607	-		B0		$\dot{h}$ display scale factor

*Because V_{dx} was not intended for DEDA processing, but is on the AGS downlink, it is in a region of memory for which a nonapplicable DEDA processing scale factor is selected. The only access to this cell via DEDA should be as described in Section 2.3.5.

Table 6-5. DEDA Outputs — Earth Mission

Equation Symbol	Address	Units	Range	Quantization	Description
r_x	340	ft	±33,554,000	10^3	X-component of LM position
r_y	341	ft	±33,554,000	10^3	Y-component of LM position
r_z	342	ft	±33,554,000	10^3	Z-component of LM position
V_x	360	ft/sec	±32767	1	X-component of LM velocity
V_y	361	ft/sec	±32767	1	Y-component of LM velocity
V_z	362	ft/sec	±32767	1	Z-component of LM velocity
V	433	ft/sec	+ 32767	1	LM velocity magnitude
r_{cx}	344	ft	±33,554,000	10^3	X-component of CSM position
r_{cy}	345	ft	±33,554,000	10^3	Y-component of CSM position
r_{cz}	346	ft	±33,554,000	10^3	Z-component of CSM position
V_{cx}	364	ft/sec	±32767	1	X-component of CSM velocity
V_{cy}	365	ft/sec	±32767	1	Y-component of CSM velocity
V_{cz}	366	ft/sec	±32767	1	Z-component of CSM velocity
t	377	min	0 to 4369	0.1	AGS computer time
q_{LT}	403	nmi	±5518.4	0.1	Perigee altitude of LM trajectory
q_{id}	402	nmi	±5518.4	0.1	Perigee altitude of predicted LM trajectory (Direct Intercept Only)
q_a	315	nmi	±5518.4	0.1	Apofocus Altitude of LM trajectory
ΔV_{gX}	500	ft/sec	±32767	1	Velocity-to-be-gained in X-direction
ΔV_{gY}	501	ft/sec	±32767	1	Velocity-to-be-gained in Y-direction
ΔV_{gZ}	502	ft/sec	±32767	1	Velocity-to-be-gained in Z-direction
V_{DX}	470	ft/sec	±32767	1	ΔV expended in X-body direction minus descent capability (updated every 2 seconds)
V_{DY}	471	ft/sec	±32767	1	ΔV expended in Y-body direction (updated every 2 seconds)
V_{DZ}	472	ft/sec	±32767	1	ΔV expended in Z-body direction (updated every 2 seconds)
$\dot{r}_A$	477	ft/sec	±32767	1	Predicted, altitude rate of LM at CSI, CDH or TPI time.
V_{p0}	371	ft/sec	±32767	1	ΔV for CDH maneuver (valid when in CSI guidance mode)
Δr	402	nmi	5518.4	0.1	Differential altitude in coelliptic orbit (CSI/CDH only)
ξ	277	deg	0 to 360	0.01	In plane angle between Z-body axis and local horizontal
T_{A0}	312	min	0 to 4369	0.1	Time from CSI to CDH
R	317	nmi	0 to 5518.4	0.1	Range from LM to CSM
$\dot{R}$	440	ft/sec	±32767	1	Range rate between LM and CSM (negative sign indicates LM closing on CSM)
$\dot{r}$	367	ft/sec	±32767	1	LM altitude rate
h	337	nmi	0 to 5518.4	0.1	LM altitude
θ_f	303	deg	0 to 360	0.01	LM to CSM phase angle (in [illegible] at present; CSI or CDH modes at t_{ig}).
ΔV_C	267	ft/sec	0 to 32767	1	Magnitude of LM velocity-to-be-gained (Not valid in CDH mode)
θ_{LOS}	303	deg	0 to 360	0.01	Predicted line-of-sight angle at TPI time (TPI only)
V_T	371	ft/sec	0 to 32767	1	Total velocity to rendezvous (TPI Mode Only)
Δr	314	nmi	±5518.4	0.1	Differential orbital altitude along LM radial at CSI time.

Table 6-5. DEDA Outputs — Earth Mission (Continued)

Equation Symbol	Address	Units	Range	Quantization	Description
V_{py}	263	ft/sec	±32767	1	Predicted LM out-of-plane velocity at t_{ig} in CSI, CDH, or TPI; present LM out-of-plane velocity in OI. Has no meaning in XDV.
V_{y0}	270	ft/sec	±32767	1	Present LM out-of-plane velocity
y	211	ft	±33,554,000	10^3	Present LM out-of-plane distance
t_{ig}	373	min	0 to 4369	0.1	AGS absolute time of next maneuver
T_{Δ}	310	min	0 to 136	0.01	Time to go until CSI maneuver when in CSI mode, CDH maneuver when in the CDH mode, and TPI maneuver when in direct transfer
T_{perg}	313	min	0 to 136	0.01	Time to go until perifocus of LM orbit
1J	275	min	0 to 4369	0.1	Normal time of TPI maneuver
3J	312	min	0 to 136	0.1	TPI Rendezvous offset time
4J	306	min	0 to 136	0.1	Time of node prior to nominal rendezvous time
6J	307	min	0 to 136	0.01	Time from TPI to rendezvous in TPI mode
T_r	311	min	0 to 136	0.01	Time to go until rendezvous in TPI mode
$*\delta_2$	574				Descent section staging flag
$*\delta_{21}$	604				Lunar surface flag
μ_6	612	40 msec counts	B17		Staging sequence counter
μ_8	614	2-sec increments	0to 131,072	1.0	Ullage counter (decimal)
$\dot{r}_f$	423	ft/sec	±32767	1	Desired final value of altitude rate
1K1	544	deg/hr	±10.0	0.01	X-gyro drift compensation
1K6	545	deg/hr	±10.0	0.01	Y-gyro drift compensation
1K11	546	deg/hr	±10.0	0.01	Z-gyro drift compensation
1K9	616	2 sec	0 to 131,072	1.0	Ullage counter value for ullage completion
1K19	540	ft/sec^2	±0.06	0.01	X-accelerometer bias compensation (decimal)
1K21	541	ft/sec^2	±0.06	0.01	Y-accelerometer bias compensation (decimal)
1K23	542	ft/sec^2	±0.06	0.01	Z-accelerometer bias compensation (decimal)
1K18	534	ft/sec/pulse	B-6		X-accelerometer scale factor
1K20	535	ft/sec/pulse	B-6		Y-accelerometer scale factor
1K22	536	ft/sec/pulse	B-6		Z-accelerometer scale factor

*These are internal computer flags. Only the sign of the quantity has significance.

PART II - AGS UTILIZATION AND FUNCTIONAL CAPABILITIES

7.0 POWER TURN ON

The AGS is in an unpowered mode when the ASA, AEA, and AGS circuit breakers are open. Closing the ASA circuit breaker causes the ASA to be in a temperature controlled condition. Closing the AEA and AGS circuit breakers cause power to be applied to the AEA. With the circuit breakers closed the AGS status switch controls the condition of the ASA and AEA as follows:

AGS Status Switch	ASA Condition	AEA Condition
OFF	Warm up, temperature controlled condition	STANDBY
STANDBY	OPERATE (temperature controlled condition and gyro motors operating)	STANDBY
OPERATE	OPERATE (temperature controlled condition and gyro motors operating)	OPERATE

To use the AGS the AGS status switch must be in the operate position. The ASA should have been in a temperature controlled condition (OFF, STANDBY, OPERATE) for 40 minutes and in a condition with the gyro motors operating (STANDBY, OPERATE) for 25 minutes. This situation can be achieved by closing the circuit breakers and setting the AGS status switch to OPERATE. After 40 minutes the system would be ready for use. This procedure is not recommended, however, since it is better to have the ASA in its temperature controlled state only, prior to operating the gyro motors. Thus the recommended procedure is to close the ASA circuit breaker and keep the AGS Status Switch in OFF for 15 minutes. Then place the AGS Status Switch in the STANDBY position, close the AEA circuit breaker and allow 25 additional minutes prior to system utilization (OPERATE). Degraded system performance is available 10 minutes after closing the circuit breakers, if at least the last 5 minutes of this period were spent in the STANDBY or Operate Mode.

When the AGS STATUS SWITCH is in the OFF position the AEA has no functional capability, except it can accept the CDU zero signal and accumulate the PGNCS Euler Angle Increments if the AEA circuit breaker is closed. Full AEA capability is afforded when the system is switched to OPERATE and all circuit breakers are closed.

When the AGS circuit breaker is closed and the AGS status switch is turned to the OPERATE position, the AEA enters a core priming routine that insures that the computer memory is magnetized properly. Moreover, various "computer operation" discretes are initialized so that correct sequencing of the "computation subcycles" results. The state of the computer when the system is turned to OPERATE is the same as the previous turn off state except that the following quantities are reinitialized:

1)	Engine ON	signal is set to OFF.
2)	S_{00} is set to 0	this places the AGS in the attitude hold submode.
3)	S_{10} is set to 0	this places the AGS in the "orbit insertion" guidance routine.
4)	S_{11} is set to 0	cant angle correction to guidance steering attitude errors are not computed.
5)	S_{12} is set to 0	this resets the self test error indicator and re-initilizes computer self-test.
6)	S_{13} is set to 0	performs no function.
7)	S_{14} is set to 0	this setting means that no navigation initialization is to be performed this computer cycle.

8)	S_{15} is set to 0	performs no function.
9)	S_{16} is set to 0	this is not the normal state; it must be set to one or three during CSI targeting.
10)	S_{17} is set to 0	this is the normal value of the "radar filter initialization" command. Setting this quantity to one initializes the radar filter covariance matrix.
11)	δ_5 is set to 0	this is an internal computer routine flag that requires an initial value of zero
12)	μ_{10} is set to 0	this is a computer subcycle counter that controls logic flow in the AEA
13)	V_{dX}, V_{DX} are set to constant 4K27	this entry places a bias on the thrust velocity gained in the X-body direction. Thus, if it is desired to determine the accumulated thrust velocity in the X-body direction the constant 4K27 must be subtracted from the DEDA readout of V_{DX}. When on the lunar surface V_{dX} is set equal to zero so that after this time no bias need be subtracted. Note that these quantities contain the effect of uncompensated accelerometer bias.

After the system is turned on and prior to guidance operations a check should be made of the computer readiness. This is accomplished by DEDA readout of the following quantities.

DEDA Address	Description of Variable
574	Internal AEA staging recognition signal (δ_2)
604	Internal AEA lunar surface recognition flag (δ_{21})
612	Internal AEA staging sequence counter (μ_6)
412	Self test indicator

Procedures for performing the readiness checks are contained in Section 14. 1.

7. 1 Power Interrupt

Certain power transients can cause the AEA to shutdown (the AEA will function as if the AGS' Status Switch has been turned off). Upon return of normal power, the AGS will return to the operate state. When the AEA returns to the operate state, various quantities are reinitialized as described in the preceding paragraphs.

7. 2 Power Turn-Off

The recommended procedure for turning off the AGS is to open the AEA circuit breaker, turn the AGS Status Switch to OFF, and open the AGS circuit breaker. The ASA circuit breaker should be left closed (ASA in temperature controlled condition) until the AGS will no longer be used on a mission.

8.0 SELF-TEST ROUTINE

The inflight self-test routine checks on a continuous basis that the computer logic and memory are functioning properly. DEDA address 412 is used in conjunction with the test to indicate test results to the astronaut and to allow resetting of error indicators. If a readout of address 412 on the DEDA is performed the following outputs are possible.

+ 00000 test not completed
+ 10000 test successfully completed
+ 30000 logic test failure
+ 40000 memory test failure
+ 70000 logic and memory test failure

An input of +00000 is used to allow the astronaut to reinitiate testing and reset the AGS Caution and Warning Lamp after any error is detected. Whenever an error is encountered during a pass through the test, the value in memory location 412 and the AGS Caution and Warning Lamp are set accordingly and future tests are inhibited until astronaut reinitiation. Reinitiation is accomplished by entering +00000 in address 412. There is no need for the astronaut to monitor DEDA address 412 periodically since a visual indication of an error is available on the AGS Caution and Warning Lamp. However, as part of the AGS turn on procedure the DEDA check should be made as a partial check on the operation of the AGS Caution and Warning Lamp and the computer.

9.0 AGS COMPUTER TIME, TIME TO EVENTS AND TIMING ERRORS

9.1 AGS Computer Time

Ground elapsed time is defined as the time difference between current Greenwich Mean Time and Greenwich Mean Time of Apollo liftoff from the Earth. Because of the AGS computer word size, Ground Elapsed Time cannot be used for AGS time. Instead, a time bias (K-factor) is subtracted from Ground Elapsed Time and the resulting time used as AGS time. The bias used equals the Ground Elapsed Time when the AGS computer time is initialized at AGS time zero.

9.2 Time to Events

In general it is assumed that the astronaut will utilize the "events timer" on the instrument panel to know when to perform the next maneuver. However, in all AGS guidance routines except "orbit insertion" and "external ΔV" the capability exists of either setting the events timer with a DEDA output quantity or comparing the time to go as depicted on the events timer with that in the guidance computer. This section contains a discussion of these DEDA output quantities.

9.2.1 CSI

One of the targeting parameters for the CSI maneuver is the AGS time of the CSI maneuver (t_{igA})*. This entry is made via DEDA address 373. Time to go until the CSI maneuver can be obtained by reading out address 310 on the DEDA. This is called T_Δ in the guidance equations.

After the CSI solution is obtained, the time from the CSI maneuver to the CDH maneuver can be read out. This is accomplished by reading out address 372 on the DEDA which corresponds to the symbol T_{A0} of the guidance equations.

Several other times of interest are also available. These are presented in Table 9.1 below.

*Only the time to next maneuver (t_{ig}) is available for DEDA input and read out. However, the nomenclature of t_{igA}, t_{igB} and t_{igC} (time to CSI, time to CDH and time to TPI, respectively) has been retained for clarity.

Table 9.1. Time Quantities Available in CSI Mode

Address	Quantization	Units	Equation Symbol	Description
373	0.1	min	t_{igA}	Targeted AGS time of CSI maneuver
310	0.01	min	T_{Δ}	Time to go until CSI maneuver
372	0.1	min	T_{A0}	Time from CSI to CDH maneuver
275	0.1	min	J^1	Nominal AGS time of TPI maneuver (targeting quantity)
313	0.01	min	T_{perg}	Time to perifocus of present LM orbit
377	0.1	min	t	AGS computer time

9.2.2 CDH

In a nominal mission the CDH maneuver is assumed to occur after the CSI maneuver. If this is the situation in flight, targeting is accomplished automatically for the CDH maneuver by the CSI computations. Moreover, the "events timer" can be set by utilizing the quantity T_{Δ} (after the CDH routine is entered) which is the time to go until the CDH maneuver, if T_{Δ} is no greater than 136 minutes.

If the CDH maneuver does not follow the CSI maneuver, then the AGS absolute time of the CDH maneuver t_{igB} must be input as a targeting constant. This is done with DEDA address 373. In Table 9.2 the times of interest during the CDH phase are presented.

Table 9.2. Time Quantities Available in CDH Mode

Address	Quantization	Units	Equation Symbol	Description
310	0.01	min	T_Δ	Time to go until CDH maneuver
373	0.1	min	t_{igB}	AGS predicted absolute time of CDH
313	0.01	min	T_{perg}	Time to perifocus of present LM orbit
377	0.1	min	t	AGS computer time

9.2.3 TPI

There are two modes that can be used for the TPI maneuver and are discussed in Section 25.0. Tables 9.3 and 9.4 define the time quantities of interest in each mode.

Table 9.3. Times of Interest with Guidance Selector in the TPI Search Routine (S_{10} = 3)

Address	Quantization	Unit	Equation Symbol	Description
310	0.01	min	T_Δ	Input quantity. TPI search assumes TPI to occur in T_Δ minutes.
373	0.1	min	t_{igC}	AGS computer time of TPI maneuver; output quantity.
307	0.01	min	J^6	Input quantity. Time from TPI to intercept (assuming no burns after TPI).

Table 9.3. Times of Interest with Guidance Selector in the TPI Search Routine (S_{10} = 3) (Continued)

Address	Quantization	Unit	Equation Symbol	Description
311	0.01	min	T_r	Time to go until intercept; output quantity
313	0.01	min	T_{perg}	Time to perifocus of present LM orbit
377	0.1	min	t	AGS computer time
306	0.01	min	J^4	Time increment prior to rendezvous at which node is created
312	0.01	min	J^3	Stable orbit offset

Table 9.4. Times of Interest with Guidance Selector in the TPI Execute Routine (S_{10} = 4)

Address	Quantization	Unit	Equation Symbol	Description
373	0.1	min	t_{igC}	Either input quantity or quantity obtained from TPI search mode (S_{10} = 3). This is AGS computer time of the TPI maneuver.
310	0.01	min	T_{Δ}	Time to go until TPI maneuver; output quantity.
307	0.01	min	J^6	Input quantity. Time from TPI to intercept (assuming no burns after TPI).
311	0.01	min	T_r	Time to go until intercept; output quantity.
313	0.01	min	T_{perg}	Time to perifocus of present LM orbit

Table 9.4. Time of Interest with Guidance Selector in the TPI Execute Routine (S_{10} = 4)(Continued)

Address	Quantization	Unit	Equation Symbol	Description
377	0.1	min	t	AGS computer time
306	0.01	min	J^4	Time increment prior to rendezvous at which node is created
312	0.01	min	J^3	Stable orbit offset

9.3 Timing Errors

Two types of timing errors are considered; DEDA time entry errors and maneuver initiation time errors. The DEDA time entry errors consist of absolute time and epoch errors introduced at entry into the AEA via the DEDA.

9.3.1 DEDA Time Entry Errors

AGS absolute time is initialized at 0 or a multiple of 6 sec (0.1 min) by entering the value into address 377 via DEDA. The DEDA Enter button is depressed at the initial AGS absolute time. Since the DEDA routine is exercised only every 0.48 or 0.56 sec, there is a maximum possible error in absolute time of 0.56 sec. A bias of 0.25 sec. (approximately half the interval between DEDA branches) is subtracted from computed time to reduce the maximum error to ±0.31 sec

Mission Control can determine this error in AGS absolute time by monitoring t_1 and t_2 on the AGS telemetry. Since this time error results in LM and CSM state errors in the AGS during state initialization, it may be used to improve initialization accuracy. For example, the PGNCS time downlink word used for Downlink Initialization (Section 15.1) can be modified by altering the PGNCS to AGS absolute time bias. For DEDA Initialization of LM and CSM states, the states themselves may be biased to correct for the AGS absolute time error.

Epoch times downlinked from the PGNCS are quantized at less than a millisecond.

9.3.2 Maneuver Initiation Time Errors

In this section consideration is given to the effect of performing maneuvers either earlier or later than the targeted times. The various maneuvers are considered in turn.

Orbit Insertion. Orbit insertion times are not targeted in the AEA. However, the effect of initiating the orbit insertion maneuver at different times (either early or late) is to change the phasing of the LM with respect to the CSM.

CSI, CDH, TPI. The philosophy used for the CSI, CDH and TPI guidance routines is to compute the predicted maneuvers prior to the nominal maneuver time and then perform thrusting in the external ΔV mode based upon the computed nominal maneuver time. Because these maneuvers are performed in the external ΔV mode, refer to the next paragraph for a discussion of timing errors.

External ΔV. The effect of initiating the external ΔV maneuver either early or late is simply one of not achieving the desired orbit at cutoff. Large timing errors would result in large differences between the actual orbit obtained and the orbit desired.

9.4 DEDA Time Display Quantization

This AGS computer time (DEDA Address 377) is updated every 0.1 min (6 sec) for display. Internal to the computer, the AGS time is updated every 2 seconds. Because of computer round-off, the displayed AGS computer time is updated by 0.1 min at the 4 sec (0.1 min), 10 sec (0.2 min), 16 sec (0.3 min), etc. time intervals. (Therefore, the AGS displayed time is updated 2 seconds prior to reaching the corresponding AGS absolute time).

10.0 AGS STEERING MODES

This section contains a discussion of the various steering modes mechanized in the AGS. All "active" steering modes output attitude errors about the LM body axes to the autopilot (CES). The magnitudes of the angular errors are limited to ±15 deg. It is currently understood that the autopilot attitude turning rates are limited to ±10 deg/sec about the Y-body axis and ±5 deg/sec about the X and Z-body axes except after staging with the DEADBAND switch in "MAX" at which time no rate limiting exists. AGS steering in no way protects the PGNCS platform against gimbal lock. The following discussions assume Guidance Control in AGS, the LM in orbit (lunar surface flag not set) and the Attitude Control Switches in the "MODE" position.

10.1 Attitude Hold

The object of the "attitude hold" mode is to generate steering commands such that the vehicle maintains the inertial attitude existing when the attitude hold mode is first entered. Attitude hold can be entered by either setting the Mode Control switch on the lower center instrument panel to the A/H position or by utilizing address 400 on the DEDA and entering the value +00000. Once the attitude hold mode is established it can be released by either causing the followup signal to be issued (Guidance Control Switch to PGNS) or with the Mode Control Switch in A/H, moving the "stick" out of detent. The preferred method for reorientation of the LM is to put the Mode Control Switch to A/H and orient the vehicle to the desired attitude utilizing the attitude controller. Reentering the "attitude hold" mode (returning "stick" to detent) will cause the vehicle to maintain the attitude that exists when the mode is reentered.

If the AGS is in the "guidance steering" mode, i.e., DEDA Address 400 is +10000 and the Mode Control Switch is set to A/H, the AGS will issue E/ON or E/OFF commands that agree with the existing status of the main engine. If the AGS is issuing E/ON commands and the Mode Control Switch is in AUTO then entering "attitude hold" by setting DEDA Address 400 to +00000 will cause E/OFF commands to be sent.

10.2 Guidance Steering

The address for ordering Guidance Steering is 400; the entry is +10000. The object of the Guidance Steering selection of attitude control is to orient the LM so that the LM thrust vector points in the desired direction for achieving the objective of the selected guidance routine. The LM X-body axis orientation also depends upon which engine is used. The RCS engines are assumed to thrust along the body axes. If the DPS engine is used, the thrust vector is assumed to be along the positive X-body axis. If the APS engine is used, the thrust vector is assumed to be displaced from the LM positive X-body axis by an amount equal to the nominal cant of the APS engine.

Because of thrust alignment errors, the actual thrust vector will not lie exactly along the nominal direction. Small velocity errors at engine cutoff may result. The cutoff errors are sensed by the AGS, however. If desired, sensed velocity errors at cutoff can be removed through axis-by-axis thrusting (ΔV residual removal, see Section 28.0).

When the ascent engine is used, the equations that compensate for the canted engine should also be used. This is accomplished via the DEDA. The address 411 should be entered with a value of +10000. This should be done prior to active AGS guidance steering in order to achive desired orientation of the thrust axis before thrusting starts. When the APS is ignited, the canted thrust direction is selected by the AEA, regardless of the value of the address 411 entry (see Section 20.1).

The AEA correction for the canted engine is adjusted by two octal constants, one for pitch and one for roll. The constants are preprogrammed into the computer but are DEDA accessible so that they can be changed during the mission. The pitch constant is entered with the address 566. The value of the constant is entered in octal in units of radians and should be positive if the canted engine causes a thrust acceleration component along the +Z-body axis. Similarly the roll component is entered in octal in units of radians via DEDA address 602. The sign of the value entered should be positive if the cant of the engine causes a thrust acceleration component along the +Y axis direction.

As mentioned, the AGS aligns the LM thrust vector along the desired thrust vector. The LM Z-body axis can be controlled in any of the following ways.

a) DEDA Address 623 +00000

The LM Z-body axis is driven parallel to the CSM orbit plane. If the positive X-body axis points ahead of the local vertical (posigrade) the Z axis lies below the local horizontal. If the positive X-body axis is behind the local vertical the Z axis lies above the local horizontal. If the X-body axis is vertically upward, the Z-body axis will be pointed horizontally forward whereas if the X-body axis is pointed vertically downward the Z-body axis will be directed horizontally opposite to the direction of motion.

b) DEDA Address 623 +10000

The LM Z-body axis is driven parallel to a plane determined by its normal unit vector $\underline{W}_b$ (DEDA entries 514, 515, 516). This mode is normally employed to maintain S-band communication during lunar orbit insertion. The unit vector $\underline{W}_b$ is entered in octal and is nominally defined prior to the mission.

c) X Axis Override

The Z-body axis can be oriented to any desired position about the thrust axis by setting the Yaw Attitude Control Switch to either "PULSE" or "DIRECT" position and by means of the hand controller orienting the axis to the desired attitude.

In either situation (a) or (b) above the desired +Z-body axis orientation is a continuous function of the X-body axis orientation. The gain in the E_x channel decreases toward zero as the +X-body axis approaches a perpendicular orientation with respect to the specified plane. Thus, if DEDA Address 623 is +00000 and the X-body axis is perpendicular to the CSM orbit plane, then the gain in the yaw steering channel is zero for any orientation of the Z axis. By specifying a unit vector $\underline{W}_b$ not normal to the CSM orbit plane and by setting DEDA Address 623 to +10000, yaw steering control can be maintained.

10.3 Z-Body Axis Steering

This mode is entered via the DEDA by using the address 400 and entering the value +20000. No DPS or APS thrust can be accomplished in this mode with AGS in control. An option exists for specifying the desired direction of the Z-body axis:

a) DEDA Address 507 +00000, Orient Z-body axis toward estimated direction of CSM

b) DEDA Address 507 +10000, Orient Z-body Axis in the desired thrust direction.

Option (a) is normally used during rendezvous radar acquistion whereas option (b) is used to perform small thrusting maneuvers along the Z-body axis. In either option with the Z axis pointed in the desired direction, the X-body axis is oriented parallel to the CSM orbit plane. If the +Z-body axis is pointed ahead of the LM, the +X-body axis will be above the local LM horizontal plane. If the Z axis is behind the LM, the +X-body axis will be below the local horizontal plane. The gain in the roll channel (Z axis) decreases toward zero as the +Z axis approaches a perpendicular orientation with respect to the CSM orbit plane. When perpendicular, the gain in the roll steering channel is zero for any orientation of the +X axis.

In this mode, manual control of the X-body axis can be achieved by setting the roll attitude control switch to either the "Pulse" or "Direct" position and manually controlling the roll channel with the hand controller.

10.4 Pre-Thrust Steering

Pre-thrust steering is defined as that guidance steering (address 400 = + 10000) done prior to ullage for the purpose of orienting the LM for the burn. AGS guidance steering is obtained by setting Guidance Control to AGS, Mode Control to AUTO, the three Attitude Controls to MODE CONT, and entering address 400 + 10000. The AGS will then orient the LM to the particular guidance mode selected (address 410). Note that it is not necessary to depress the Abort or Abort Stage buttons to obtain guidance steering. All pre-thrust steering is done in the External ΔV guidance mode (DEDA entry 410 + 50000).

10.5 Orbital Rate Pitch Steering

The AGS has the capability of maintaining the LM vehicle at any attitude in a local coordinate frame during free flight. In particular, the vehicle can be pitched at the orbital rate in order to maintain the X-body axis along the local horizontal. To accomplish this, use is made of the "external ΔV" guidance routine along with the "Guidance Steering" mode of operation (See Section 27.0 for procedures).

10.6 Open Steering Channels

When the AGS is in control of the vehicle, the attitude control switches (PITCH, YAW, ROLL) are usually in the "MOD CONT" position. Manual override on any particular channel can be accomplished by changing the switch position for that channel to either "PULSE" or "DIR." In some instances manually orienting one LM axis more than 90° from the desired (AGS computed) direction can cause the LM to rotate through large angles about the two AGS controlled axes. For this reason the following general rule should be observed.

IN ATTITUDE HOLD AND GUIDANCE STEERING, X AXIS OVERRIDE CAN BE ACCOMPLISHEDTHRUANY DESIRED ANGLE. IN Z-BODY AXIS STEERING Z AXIS OVERRIDE CAN BE ACCOMPLISHED THRU ANY DESIRED ANGLE. IF MANUAL OVERRIDE OF ANY OTHER STEERING CHANNEL IS DESIRED, THE ATTITUDE EXCURSION ABOUT THAT AXIS SHOULD BE LIMITED TO LESS THAN 90° FROM THE DESIRED ORIENTATION AS COMPUTED BY THE AGS

11.0 RESCALING FROM LUNAR TO EARTH MISSION

In order to make an inflight conversion of a lunar scaled program to an earth scaled program, various constants must be input via DEDA. In addition to all targeting J constants the following DEDA entries should be made. All constants are based on Flight Program No. 6 and are not mission constants.

Parameter	DEDA Address	DEDA Entry	Definition
*B23SF	677	**+20305	DEDA scale factor
*B13VSF	701	**+20000	DEDA scale factor
*B23RSF	703	**+32756	DEDA scale factor
1K35	634	**+00020	Acc. bias threshold
4K2	654	(Note 6)	T_B factor
4K3	655	(Note 6)	T_B factor
4K25	657	**+00002	Eng. cutoff comp.
4K26	454	+00100	ΔV_G threshold
4K27	473	-07332	Descent stage bias
4K34	660	**+00100	a_T lower limit
4K35	661	**+00007	Ullage threshold
2K1	636	**+62026	Gravity constant
2K2	637	**+50732	1/2K1
2K4	674	**-15752	-2(2K1)
3K4	613	**+12744	Sine of TPI central angle limit
4K4	565	(Note 6)	$\dot{r}_f$ constant (O.I.)
4K5	662	(Note 6)	$\dot{r}_f$ constant (O.I.)
4K6	527	(Note 6)	$\dot{r}_f$ upper limit (O.I.)
4K10	227	(Note 6)	Constant in α_L (O.I.)
4K12	506	(Note 6)	Accel. check for $\ddot{r}_d$ lower limit (O.I.)

Parameter	DEDA Address	DEDA Entry	Definition
5K16	561	(Note 6)	Upper limit of $\dot{\dot{y}}_d$ (O. I.)
5K17	601	(Note 6)	Lower limit of $\dot{\dot{y}}_d$ (O.I.)
5K18	564	(Note 6)	Lower limit of $\dot{\dot{r}}_d$ (O. I.)
5K26	466	+00015	V_G threshold
K55	607	**+20000	Altitude rate scaling
2K11	526	**+13560	V_T limit
1K18	534	(Note 3)	Accelerometer scale factors including compensation
1K20	535	(Note 3)	
1K22	536	(Note 3)	
1K19	540	(Note 5)	Accelerometer bias compensation constants
1K21	541	(Note 5)	
1K23	542	(Note 5)	
BACCSF	446	+10000	DEDA scale factor
1K14	537	(Note 4)	X gyro SAMU compensation constant
6K2	457	(Note 6)	Radar filter constants
6K4	456	(Note 6)	
6K5	656	(Note 6)	
6K6	522	(Note 6)	
6K8	304	(Note 6)	
6K9	611	(Note 6)	
6K10	517	(Note 6)	

*Note 1: The three DEDA scale factors must be entered first and in the above order as they are used for input processing of other DEDA entries.

***Note 2: These entries are octal values.*

Note 3: These values must be read out via DEDA and rescaled prior to DEDA entry as earth orbit constants. The steps are:

A. Read out the constant
B. Convert the octal readout to binary
C. Round the constant by adding 1 to the 2nd least significant bit
D. Drop the two least significant bits and add two bits at the most significant end of the word. The two bits added are zeros if the readout was plus and ones if the readout was minus. Regroup as five digits.

E. Enter into the original address with the original sign:

Example Correct 1K18

A. Read out 534 +63147

B. 110 011 001 100 111

C. 110 011 001 101 001

D. 001 100 110 011 010

E. Enter 534 +14632

Note 4: This value must be readout and rescaled prior to entry as follows:

A. Read out 1K14

B. Convert the octal readout to binary

C. Drop the two most significant bits and add two zeros at the least significant end of the word. Regroup as five octal digits.

D. Enter the new value into the original location with the original sign.

Example:

A. Read out 537 +00120

B. 000 000 001 010 000

C. 000 000 101 000 000

D. Enter 537 +00500

Note 5: Before changing BACCSF, read out and record the constant in units of ft/sec^2, quantized at 0.001 ft/sec^2. After changing BACCSF (the accelerometer bias compensation DEDA scale factor), round the constant by adding 0.005 to its magnitude, and re-enter the constant quantized at 0.01 ft/sec^2.

Example Change 1K21

Read out 541 -00036. This equals -0.036 ft/sec^2. Adding 0.005 to 0.036 gives -0.041 ft/sec^2. After BACCSF is changed, enter 541 -00004.

Note 6: These parameters do not apply for an earth mission.

DUE TO PROGRAM SCALING, RENDEZVOUS RADAR NAVIGATION STATE VECTOR UPDATING CAPABILITY DOES NOT EXIST WHEN THE AGS FP6 IS USED IN EARTH ORBIT.

12. GROUND CHECKOUT PROCEDURES PRIOR TO EARTH LAUNCH

This section lists those functions which are performed to assure that the AGS is in a flight readiness configuration prior to Earth launch. The intent of this section is to provide general information. Detail information can be found in Reference 4.

1) Pre-Installation Calibration—Determination of all AGS hardware parameters (scale factors, biases, drifts, misalignments, etc.) before 35 days to launch. A subset of these parameters constituting significant mission error sources will be used to prepare the Mission Constants Tape.

2) Flight Simulation—End to end spacecraft systems check. Interface between AGS and all related subsystems as CES, ASCENT/DESCENT engines, FDAI, etc., tested in a programmed flight simulation.

3) Earth Prelaunch Calibration—Measurement of the Y and Z gyro constant drift parameters and also the lumped X gyro constant drift and MUSRA (Mass Unbalance about the Spin Reference Axis) term. The data is used for evaluation and parameter update. In the normal flow, a final EPC will be performed prior to cabin closeout during countdown.

4) Flight Program Load—Flight program is loaded into the AEA by ACE. The load operation will then be verified by means of a Memory Dump and Compare routine. The program contains nominal values of all octal and decimal constants including the nominal values of the compensation constants (scale factors, biases, etc.) and mission dependent constants (targeting, etc.)

5) Updating Compensation Constants—Subsequent to the Flight Program Load and prior to earth launch the following constants can be updated in the AEA by means of ACE C Start:

1K1, 1K6, 1K11	-	Gyro drift compensation coefficients
1K3, 1K8, 1K13	-	Gyro scale factor error compensation coefficients
1K14	-	Compensation constant for X gyro spin axis mass unbalance drift

1K19, 1K21, 1K23	-	Compensation constants for accelerometer bias
1K18, 1K20, 1K22	-	Accelerometer scale factors

6) <u>Memory Check</u>—Subsequent to Step 5 a memory dump should be executed via ACE for final memory verification.

PART III - PROCEDURES FOR AGS FUNCTIONS

13.0 SYSTEM TURN ON

The following procedure should be followed to turn on the AGS.

1) Verify the positions of the following switches:

   a) Guidance Control Switch in PGNCS Position - follow-up signal is sent to the AEA and the AEA outputs are not utilized.

   b) AGS Status Switch in OFF position - applies inhibit standby signal to ASA and AEA.

   c) ASA Circuit Breaker is closed. This breaker remains closed to keep the sensors in the ASA up to temperature.

2) After 15 minutes, set AGS status switch to STANDBY - this removes inhibit standby signal to ASA.

3) Close AEA Circuit Breaker - this applies power to AEA.

4) After 25 minutes in standby, close the AGS circuit breaker and set the AGS status switch to "OPERATE". AGS flight program is initialized in an attitude hold, orbit insertion mode. AGS is also in followup and outputs Engine OFF commands.

WHEN THE AGS IS SWITCHED TO OPERATE FROM STANDBY OR FROM OFF TO STANDBY, THE AGS CAUTION AND WARNING LAMP ON THE CAUTION WARNING PANEL WILL COME ON. SIMULTANEOUSLY, THE AUDIO WARNING ALARM IN THE ASTRONAUT EARPHONES WILL SOUND. THE LAMP MUST BE RESET BY SWITCHING THE "O_2/H_2O QTY MON" TO "CW RESET." THE ALARM SIGNALED THROUGH THE EARPHONES MUST BE MANUALLY RESET TO STOP THE SOUND. THE ACTIVATION OF THE TEST MODE FAILURE AND ALARM SIGNALS IS NORMAL WITH THE ABOVE SWITCHINGS AND DOES NOT IMPLY EQUIPMENT FAILURE.

5) The system is now in operating condition.

6) Checks of Computer Readiness

A check of computer readiness should be made according to the procedures of Section 14. 1.

7) AGS Computer Time Initialization

AGS computer time should be initialized using the procedure of Section 14. 2

8) Perform CSM, LM Navigation Initialization

The LM and CSM state vectors should be initialized with the appropriate procedures of Section 15. 0.

9) Align

An AGS align should be performed according to the procedure of Section 16. 0

10) Calibration

The AGS should be calibrated according to the procedures of Section 17. 0.

11) During step 10) enter targeting parameters for orbit insertion per Section 22. 0.

13. 1 System Turn-Off

The following procedure should be used to turn off the AGS.

1) Open the AEA circuit breaker - AGS warning lamp will come on due to ASA low voltage (because of absence of AEA clock).

2) Set AGS Status Switch to OFF - AGS warning lamp will go out.

3) Open the AGS circuit breaker.

4) Leave the ASA Circuit Breaker closed. This breaker remains closed to keep the sensors in the ASA up to temperature.

14.0 COMPUTER READINESS AND AGS TIME INITIALIZATION

These procedures are the first to be performed during AGS turn on once the AGS is in an operate condition. The computer readiness procedures may be performed when an AGS failure has been detected or an AGS failure is suspected.

14.1 Computer Readiness

In order to check the readiness of the AGS, the following procedures should be followed:

1) Readout the self test selector (S_{12}) on the DEDA (address 412).

2) If the output is +10000, proceed to step 5. If not +10000, then an AEA error has occurred. The error indications are:*

+00000	Test not complete, if this state exists for more than 15 sec, test is not being executed
+30000	Logic test failure
+40000	Memory test failure
+70000	Logic and Memory test failure

If the indication is +00000 some failure has occurred which is preventing execution of the self test. If the readout is one of the other indications determine if normal AEA operation has resumed by performing step 3.

3) Enter via DEDA 412 + 00000.

4) At least 12 seconds after step 3 read out the self test via the DEDA (address 412).

> FOR THE SYSTEM TO BE OPERATING CORRECTLY THE SELF TEST OUTPUT SHOULD BE 412 + 10000.

If the readout is not +10000, then self test indicates an AEA error is still occurring. Further operations with the AGS are not recommended.

*Note: BTME tapes do an automatic tape load checksum immediately after loading memory which sets S_{12} = +50000 if a failure is detected. This is not a valid inflight state.

5) Readout DEDA address 574, the state of the AEA staging recognition signal.

Output of DEDA address 574	Indication
Any negative number	Staging has occurred
Any positive number	Staging has not occurred

If the readout indication is not consistent with the actual vehicle situation, insert via DEDA address 574, an appropriate value (suggested values are +00000, if the vehicle has not staged, -00000 if the vehicle has staged).

6) Readout DEDA address 604, the state of the lunar surface flag (δ_{21}).

Output of DEDA address 604	Indication
Any negative number	Vehicle is on lunar surface
Any positive number	Vehicle is not on lunar surface

7) If the readout indication is not consistent with the actual vehicle situation, insert via DEDA address 604 an appropriate value (suggested values are +00000 if LM is not on the lunar surface, -00000 if LM is on the lunar surface).

8) Readout via DEDA address 612, the value of the staging sequence counter.

9) If vehicle is not staged, value should read +00000. Enter this value if necessary.

If vehicle is staged, value should read +00006. If +00000 is read out, enter +00007.

10) Readout DEDA address 507, the indication of desired Z-body axis pointing direction during Z-body axis steering.

Output of DEDA address 507	Indication
+00000	In Z-body axis steering mode the Z-body axis will orient in the estimated direction of the CSM.
+10000	In Z-body axis steering mode the Z-body axis will orient in the desired thrust direction.

11) If the readout indication is not as desired insert via DEDA address 507 the desired value.

12) Readout DEDA address 623, the indication of desired Z-body axis direction during guidance steering.

Output of DEDA address 623	Indication
+00000	In guidance steering mode the Z-body axis will orient parallel to the CSM orbit plane.
+10000	In guidance steering mode the Z-body axis will orient parallel to the plane defined by the unit vector $\underline{W}_b$.

13) If the readout indication is not as desired insert via DEDA address 623 the desired value.

When these readiness procedures are used following a suspected AGS failure and normal operation has resumed, a check should then be made that the AEA computed LM and CSM state vectors and the AGS attitude alignment are still valid. This can be accomplished by Mission Control using the AGS telemetry data.

14.2 AGS Computer Time Initialization

14.2.1 AGS Time Initialization when PGNCS is Operative

If the PGNCS is operating: The following PGNCS and AGS operating procedures must be performed in the order presented*.

PROCEDURES	REMARKS
1. Select AGS Initialization Routine (R47): Key V47E Poss PROG lt - on Key V05 N09E - call alarm R1 00220 REFSMFLAG not set R2 XXXXX R3 XXXXX exit R47 Key KEY REL & RSET, exit R47 Perform IMU Orientation Determination (P51) Return to beginning of step 1.	
2. FL V06 N16 R1 00XXX hr R2 000XX min R3 0XX.XX sec	Before first AEA clock initialization, V06 N16 contains meaningless value. After AEA clock initialization, V06 N16 contains stored GET of AEA clock zero (K). (GET of AEA clock zero is MIT/IL expression for AGS time bias.) AGS time bias is required because AGS time is limited to approximately 72 hours. GET - AGS time bias (K) = AGS time.
3. Initialization of AGS time: Selection of specific AGS time bias (K)	To simplify computation of AGS time, value for GET of AEA clock zero (K) can be determined that: 1. Can be readily subtracted from GET to obtain AGS time 2. Has occurred in recent past 3. Is easy to remember
Key DEDA C 377+XXXX.X (0.1 min)	Positive value of XXXX.X (and GET of AEA ENTR must be determined so that GET of AEA ENTR less XXXX.X equals predetermined AGS time bias (K).
Key DEDA ENTR	Entry to be made at GET of AEA ENTR.

*These operating procedures were obtained from the Apollo Operations Handbook, Lunar Module 4, dated 3 February 1969.

PROCEDURES	REMARKS
4. Verify AGS time is incrementing from XXXXX value entered in step 3: Key DEDA C 377R	
5. Press DSKY Key Release Key V25E	V25 is used to load in desired value of AGS time bias (K).
6. Check V06 N16 If value is not satisfactory, Return to Step 5 Record K, Key PRO	If navigation initialization is to be done next, Key DEDA C 414 + 10000E before Keying PRO, and proceed to Step 6 of Section 15.1
7. FLV50 N16 R1 00XXX hr R2 000XX min R3 0XX.XX sec	
8. To continue interrupted PGNCS program; Key PRO, exit R47	

14.2.2 AGS Time Initialization if PGNCS is Inoperative

If the PGNCS is inoperative:

1) Enter into the DEDA 377 + 00000.
2) Mission Control Center then determines the AGS time bias which is recorded for possible future use. Mission Control Center also determines LM and CSM state vectors for Navigation Initialization.

> AFTER THE AGS SYSTEM HAS BEEN SWITCHED TO "OPERATE" AGS COMPUTER TIME MUST BE INITIALIZED PRIOR TO ENTERING CSM OR LM EPHEMERIS DATA.

This procedure is necessary for the following two reasons:

a) A computer overflow may occur if the epoch time is inconsistent with AGS computer time.
b) The computer obtains the current LM state vector by propagating the ephemeris data to the present time. For this propagation to be valid the present time must be known.

15.0 NAVIGATION INITIALIZATION PROCEDURES

In this section procedures are presented to initialize AGS navigation for the LM and CSM from external sources.

15.1 Procedures for LM, CSM Navigation Update via PGNCS Downlink

The following PGNCS and AGS procedures must be followed in the order presented.

> **PGNCS DOWNLINK UPDATES SHOULD NOT BE PERFORMED IF THE LM PGNCS COMPUTER (LGC) IS INOPERATIVE OR THE TELEMETRY IS IN THE LOW BIT RATE MODE.**

PROCEDURES	REMARKS
1. Select AGS Initialization Routine(R47): Key V47E Poss PROG lt - on Key V05 N09E - Call alarm R1 00220 REFSMFLAG not set R2 XXXXX R3 XXXXX exit R47 Key KEY REL & RSET, exit R47 Perform IMU Orientation Determination (P51) Return to beginning of step 1.	
2. FL V06 N16 R1 00XXX hr R2 000XX min R3 0XX.XX sec	Before first AEA clock initialization, V06 N16 contains meaningless value. After AEA clock initialization, V06 N16 contains stored GET of AEA clock zero (K). (GET of AEA clock zero is MIT/IL expression for AGS time bias.) AGS time bias is required because AGS time is limited to approximately 72 hours. GET - AGS time bias (K) = AGS time.
3. Command LM/CSM state vector update via PGNCS downlink: Key DEDA C 414+10000E	

PROCEDURES	REMARKS
4. Check V06 N16 Record K, Key PRO	
5. V50 N16 R1 00XXX hr R2 000XX min R3 0XX.XX sec	
6. FL V50 N16 R1 00XXX hr R2 000XX min R3 0XX.XX sec	After keying PRO (step 4), display is static until AEA downlink list is transmitted 10 times. If IMU is not in use CDU, LGC and and AEA gimbal-angle counters are zeroed, DAP is disabled during this time (≈12 seconds).
7. Verify AGS initialization complete: Key DEDA C 414R+00000 To continue interrupted PGNCS program: Key PRO, exit R47 To terminate: Key V34E, exit R47	Occurs within 2 seconds.
8. If update accuracy verification is desired: Display LGC rendezvous parameters (R31) - Key V83E FL V06 N54 R1 Range XXX.XX nm R2 Range rate XXXX.X fps R3 θ XXX.XX	Range rate comparison is usable up to 8,388,000 feet (1380 nm) in lunar orbit or up to 33,554,000 feet (5,518 nm) in earth orbit.
9. Read out AGS range rate: Key DEDA C 440R XXXXX (0.1/1 fps) Compare PGNCS & AGS values of range rate Values should be within 10 fps To terminate R31: Key PRO	If IMU orientation has changed since last AGS alignment, perform AGS/PGNCS Align. Wait at least 30 seconds after CDU zero.

15.2 Procedures for LM Initialization Via DEDA*

1) Enter the LM data via the DEDA and verify according to the following table: (all data must be entered)

Equation Symbol	Address	Description
1J1	240	x component of LM position, AGS coordinates
1J2	241	y component of LM position, AGS coordinates
1J3	242	z component of LM position, AGS coordinates
1J4	260	x component of LM velocity, AGS coordinates
1J5	261	y component of LM velocity, AGS coordinates
1J6	262	z component of LM velocity, AGS coordinates
1J7	254	Epoch time of LM ephemeris data, AGS time

2) Enter into the DEDA 414 +20000.

3) Verify "completion of initialization" by reading out DEDA address 414. The value is automatically set to +00000 after the update is complete (within 2 sec of step 2).

*Position components are quantized at 100 feet and velocity components at 0.1 fps for lunar missions and 1000 ft and 1 fps respectively for earth missions. Epoch times are quantized at 0.1 minute.

Epoch times input to the AEA via the DEDA are in units of minutes with a quantization level of 1/10 minutes or 6 seconds.

EPOCH DATA USED IN THE AGS FOR NAVIGATION UPDATES VIA THE DEDA MUST BE VALID AT A MULTIPLE OF 1/10 MINUTE

If this is not so, position errors on the order of 12 miles for Earth missions and three miles for lunar missions could result just due to roundoff of epoch time through the DEDA.

15.3 Procedures for CSM Initialization via DEDA*

1) Enter the CSM data via the DEDA and verify according to the following table: (all data must be entered)

Equation Symbol	Address	Description
2J1	244	x component of CSM position, AGS coordinates
2J2	245	y component of CSM position, AGS coordinates
2J3	246	z component of CSM position, AGS coordinates
2J4	264	x component of CSM velocity, AGS coordinates
2J5	265	y component of CSM velocity, AGS coordinates
2J6	266	z component of CSM velocity, AGS coordinates
2J7	272	Epoch time of CSM ephemeris data, AGS time

*Position components are quantized at 100 feet and velocity components at 0.1 fps for lunar missions and 1000 ft and 1 fps respectively for earth missions. Epoch times are quantized at 0.1 minute.

2) Enter into the DEDA 414 +30000.

3) Verify "completion of initialization" by reading out DEDA address 414. The value is automatically set to +00000 after the update is complete (within 2 sec of step 2).

15.4 Discussion of AGS Navigation for Information Purposes

This section contains a discussion of the navigation employed by the AGS along with the limitations imposed.

15.4.1 CSM Navigation

The CSM position and velocity at any time is determined by utilization of a subroutine called the "Ellipse Predictor". This subroutine has the capability of accepting position and velocity of a vehicle, say at time t_E, and determining the position and velocity of a vehicle at another time say $t_E + T_i$. T_i can be either positive or negative but because of computer scaling it is limited in magnitude. The prediction of position and velocity is based upon the assumption that the gravity model of the attracting body is spherical. Because the actual gravity is not truly "spherical" the proportionality constant used in the gravity model is "tuned" to the range of trajectories under consideration.

For CSM navigation, position and velocity, valid at an epoch time t_E, are stored in the computer. If, for example, it is desired to know the position and velocity of the CSM at the present time t then the time (t_b) since epoch time is computed and used in the ellipse predictor along with the epoch position and velocity. The output of the ellipse predictor is the present position and velocity of the CSM. The epoch point is maintained as the original point unless "bootstrapped" by the AEA (Section 15.4.2).

SINCE THE ELLIPSE PREDICTOR ASSUMES THE VEHICLE TO BE IN FREE FLIGHT, THE AGS MUST RECEIVE NEW CSM EPOCH DATA AFTER EVERY CSM MANEUVER.

15.4.2 Epoch Time Bootstrap

As indicated in Section 15.4.1, the prediction time T_i can be either positive or negative but it is limited in magnitude because of computer scaling. The limit is ±8191 seconds which is somewhat greater than the time of 1 CSM orbit. In order not to exceed the computer scaling the quantity t_b (time from CSM epoch to present time) is compared to the orbital period of the CSM (T_{CSM}). When t_b exceeds T_{CSM} the CSM epoch time (t_E) is advanced by one orbital period. Thus, no computer overflow occurs during CSM navigation because of the manner in which the update operation is performed in the computer:

> NO FUTURE EPOCH POINT SHOULD BE ENTERED FOR THE CSM NAVIGATION UPDATE.

15.4.3 LM Navigation

15.4.3.1 Inflight Navigation. The "ellipse predictor" subroutine as discussed in Section 15.1 does not take into account any acceleration of the vehicle other than that due to "spherical" gravity. Thus, the technique used for CSM navigation is not used for LM navigation since the LM vehicle goes through various thrusting phases. LM navigation is done by integrating the equations of motion of the vehicle. In this way all accelerations (including thrust) can be used where appropriate. The only time the ellipse predictor subroutine is used for LM navigation is during coasting flight when new LM ephemeris data is obtained and this data is updated to the present time (for use as initial conditions in the integration equations). Of course, for the updating to be valid two conditions are required.

> 1. NO LM THRUST ACCELERATION CAN OCCUR BETWEEN THE TIME THE EPHEMERIS IS DETERMINED (FROM EXTERNAL SOURCES) AND THE UPDATE TIME.
> 2. THE TIME FROM THE EPHEMERIS POINT TO THE UPDATE TIME CANNOT EXCEED 8191 SEC.

15.4.3.2 Surface Navigation. On the lunar surface a simplified form of LM navigation is performed. For this reason:

> THE EPOCH TIME FOR LM NAVIGATION UPDATES ON THE LUNAR SURFACE SHOULD BE WITHIN 0.5 HOUR OF NOMINAL LIFT-OFF TIME.

15.4.4 DEDA Entry Errors

A DEDA entry of +00000 in address 414 is treated as a +10000 entry by the flight program. If the PGNCS downlink contains the correct identification word, the PGNCS downlink will be used to initialize the LM and CSM states in the AGS. If the identification word is not present, initialization will not take place.

> NEVER ENTER +00000 INTO ADDRESS 414 VIA DEDA. IF THIS IS DONE, THE FLIGHT PROGRAM WILL SEARCH THE PGNCS DOWNLINK FOR THE IDENTIFICATION WORD. SHOULD THE IDENTIFICATION WORD BE LOCATED THE LM AND CSM STATE VECTORS COULD BE DESTROYED.

> SHOULD +00000 OR +10000 BE INADVERTENTLY ENTERED INTO ADDRESS 414, THE PGNCS SEARCH CAN BE ELIMINATED BY ENTERING 563+00000.

Position, velocity and time DEDA entry errors prior to entry of +20000 or +30000 in address 414 (LM or CSM DEDA initialization) may be corrected by reentering the correct quantities prior to the address 414 entry.

16.0 ALIGNMENT

Alignment of the strapdown system consists of the computation of the direction cosines which relate vehicle body axes to the desired inertial coordinate system. In the AGS system the alignment techniques can be classified according to whether or not the PGNCS is operative.

16.1 AGS Alignment with PGNCS Operative (AGS Align to PGNCS)

16.1.1 In Flight Procedure

1) Verify that the PGNCS inertial platform is operating.*

2) Verify that after the AGS system is put in the "OPERATE" status, a PGNCS downlink navigation update has been performed. This procedure can cause a CDU zero signal to be sent to the AEA which in turn would cause the AEA Euler angle registers to be set to zero and to count up to the correct value.**

3) At least 30 seconds after completing the PGNCS downlink navigation update, enter via the DEDA the code 400 + 30000. This causes the AGS to PGNCS align to be accomplished within 2 sec. The system is then automatically placed in the attitude hold submode ($S_{00} = 0$).

4) Verify that AGS to PGNCS align has been completed by reading out DEDA address 400. The output should be 400 + 00000. Further verification of alignment is obtained by observing that the attitude ball on an FDAI gives the same reading (within system tolerances) when the Attitude Monitor switch is in either the PGNCS or AGS position.

16.1.2 Lunar Surface Procedure

1) Verify that the PGNCS inertial platform is operating.

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*To avoid CDU "coarse" switching transients, ensure that no IMU gimbal angle is within ±5 degrees of integer multiples of 45 degrees (including 0 degrees). CDU "fine" switching transients are avoided as long as all gimbal angles are more than 11.25 degrees away from 0 degrees and a CDU zero has been executed. If this procedure is followed, it is highly unlikely that fine switching transients will occur during alignment.

**Setting the CDU's to zero is required once each time the AEA Circuit Breaker is closed.

2) Verify that after the AGS system is put in the "OPERATE" status, a PGNCS downlink navigation update has been performed. This procedure can cause a CDU zero signal to be sent to the AEA which in turn would cause the AEA Euler angle registers to be set to zero and to count up to the correct value.

3) At least 30 seconds after completing the PGNCS downlink navigation update, enter via DEDA the code 400 + 30000. This causes the AGS to PGNCS align to be accomplished within 2 seconds. The system is automatically placed in the attitude hold submode ($S_{00} = 0$).

4) Verify that AGS to PGNCS align has been completed by reading out DEDA address 400. The output should be 400 + 00000. Verification that CDU coarse transients have not occurred during alignment is made as follows:

   a) After completion of alignment (DEDA Address 400 + 00000), read out DEDA Address 132 (octal).

   b) Repeat AGS to PGNCS align by entering via DEDA the code 400 + 30000. Verify completion of alignment by reading out DEDA address 400. (The output should again be 400 + 00000).

   c) Upon completion of second alignment, again read out DEDA Address 132. If a change of more than 2 octal counts is indicated in the fourth place of Address 132 (±XXX?X), reperform the AGS-to-PGNCS alignment.*

16.1.3 Discussion

In the AGS to PGNCS align mode, the AGS direction cosines are set equal to the PGNCS direction cosines as computed from the PGNCS Euler Angles θ_p, ϕ_p, ψ_p. Thus the AGS inertial reference frame is the same as the PGNCS stable member coordinate frame.

THE X-Z PLANE OF THE AGS INERTIAL REFERENCE FRAME MUST LIE WITHIN 10 DEG OF THE CSM ORBIT PLANE DURING RENDEZVOUS RADAR UPDATING TO OBTAIN CORRECT OPERATION OF THE RADAR FILTER

*A change of three counts in the next-to-least-significant octal digit would indicate a change in the pitch plane Euler angle of from 0.056 deg to 0.084 deg.

16.2 AGS Alignment with PGNCS Inoperative

In the event the PGNCS is inoperative several alignment techniques exist for the AGS. On the lunar surface the submode called Lunar Align (S_{00} = 4) can be utilized as well as the Body Axis Align techniques discussed below. When inflight, only the Body Axis Align techniques are applicable. These various methods are now considered.

16.2.1 Lunar Align

Lunar Align orients the AGS x-inertial axis to the vertical. The y and z-inertial axes with respect to the z-body axis are determined from azimuth reference data input to the DEDA before the Lunar Align.

One method of providing the azimuth reference is to use the stored AGS indicated LM attitude existing in the AEA shortly after touchdown. Storing is accomplished immediately by DEDA entry 413 = any number (+ 10000 is suggested). The basic assumption inherent in storing attitude data is that the landing shock will not disrupt the inertial attitude reference nor will the LM change its azimuth angular orientation (by settling or shifting) after the attitude is stored.

Near the end of the lunar stay, the earth will determine if an update is necessary to correct the stored attitude data for the moon's rotation and the CSM orbit plane change. If so, azimuth correction $\Delta\delta$ (octal) is communicated to the LM where it is entered via DEDA entry 547 into the AEA prior to the Lunar Align.

A second, more general method of obtaining the azimuth reference is provided by the AOT. The general procedure is as follows:

a) Perform Lunar Align (orients x-inertial axis to be vertical).

b) Take AOT star shot, one known star.

c) Communicate the two angles to earth.

d) Earth records star data and telemetered AGS attitude cosines and computes azimuth reference correction.

e) Earth communicates and flight crew enters either

   (i) Δ (if correction $\leq$ 5 degrees) DEDA address 547

   (ii) cos δL, sin δ_L (if correction > 5 degrees) DEDA address 053 and 047 respectively. Also enter 547 + 00000 which sets $\Delta\delta = 0$.

f) Perform Lunar align at designated time just before launch for final alignment.

The AOT procedure is not affected by landing shock or LM settling before the AOT star shot.

Lunar Align is started by entering via DEDA address 400 + 40000. A minimum of three minutes is required to perform lunar align. The system does not automatically switch out of lunar align after 3 minutes. In fact, final lunar alignment should only be terminated within ±4 minutes of the nominal liftoff time.* This is accomplished by entering a value of + 00000 or + 10000 into address 400.

THE AGS MUST REMAIN IN THE LUNAR ALIGN SUBMODE (ADDRESS 400 + 40000) UNTIL JUST PRIOR TO NOMINAL LIFT OFF TIME. EARLY EXIT FROM LUNAR ALIGN RESULTS IN ALIGNMENT ERROR ACCUMULATION AT THE RATE OF APPROXIMATELY 0.5 DEG/HR (LUNAR RATE).

*When the lunar align is terminated, the reference frame goes inertial. Nominal lunar liftoff time is the time when the reference frame achieves its designated orientation.

16.2.2 AGS In-Orbit Align

Proposed in-orbit Align techniques are outlined below. MSC has not decided on the procedure to be used. Two classifications,

a) Use existing reference frame

b) Establish desired reference frame

are apparent and are discussed below. For either type alignment, the following two steps are necessary:

1) Two star sightings are taken with the selected optical device, either the AOT and/or the COAS. Mission Control Center must record the AGS direction cosines existing simultaneously with each star sighting.

2) The Mission Control Center computes the orientation of the AGS inertial reference frame existing at the time of the two star sightings. This is to say, Mission Control can compute unit vectors pointing in the respective directions of the AGS x, y, and z inertial axes, expressed in the ground computer's computation inertial reference frame.

AGS Alignment is then performed as follows:

a) Existing Reference Frame Orientation

In this mode, the DEDA entry for Body Axis Align is not necessary. The ground computer, knowing the orientation of the AGS reference frame and knowing also the position and velocity of the LM and CSM, computes the LM and CSM state vectors with coordinates expressed in AGS reference frame. The state vectors are communicated to the LM where they are inserted into the AEA. If only the IMU has failed (assuming PGNCS failure) but not the LGC, the AGS state vectors can be up-linked to the LGC and then downlinked by the crew to the AEA. The alignment is now complete.

The alignment errors resulting from the above procedure depend on the accuracy of the star sightings and the capability of Mission Control to record the telemetered AGS cosines existing at the instant each star sighting is made. Because of the possibility of timing errors, it is highly advisable that LM rotation rates, at the time of marking a star sighting, be held to a minimum. In addition, the existing AEA reference frame must be such that the y inertial axis is greater than 10 degrees from the LM orbit plane.

b) <u>Preferred Reference Frame Orientation</u>

If a preferred orientation of the AGS reference frame is desired, the reference frame existing at the time of the star measurements may not suffice. In this case, Mission Control can direct the flight crew to orient the LM, in inertial space, to a desired attitude as indicated by the attitude angles on the FDAI. "Body Axis Align" is then executed via two DEDA commands.

1) Enter via the DEDA 400 + 50000. This slaves the reference computational frame to the body axes (instantaneously).

2) At the time when the align is to be performed, enter via the DEDA 400 + 00000. This releases the reference frame from the body axes allowing it to remain fixed in inertial space.

Unless the preferred reference frame corresponds to the one in which the LM and CSM state vectors already existing in the AEA are valid, the LM and CSM state vectors must be updated. The error in achieving the desired LM attitude via the FDAI results directly in an alignment error. Other error sources using this technique are noted in a) above. Because of the restrictions on the AEA computations, the preferred attitude used in this align technique must be such that the y inertial axis is greater than 10 deg from the CSM orbit plane.

The procedure described above does not require the simultaneous sightings of the two stars nor that the vehicle attitude be held between sightings. If it is possible that the AOT can be employed in such a way that the two star sightings may be taken simultaneously, and if Body Axis Align can be entered simultaneously with the star sighting, then it is not necessary for Mission Control to monitor the telemetered AGS direction cosines closely in time. At the time of the "mark," the cosines obviously take on the values of the unity matrix. The resulting AGS reference frame orientation, however, will correspond to the orientation of the LM at the time of the align. In general, LM and CSM state vectors must be reinitialized.

17.0 CALIBRATION

Calibration of the gyros and accelerometers as performed in the AGS can be placed in three separate categories; Lunar Surface Gyro Calibration, Inflight Gyro and Accelerometer Calibration, Inflight Accelerometer Calibration only. Procedures for performing these calibrations are considered in turn.

17.1 Lunar Surface Gyro Calibration

Shortly after lunar touchdown the DEDA entry 413 + 10000 should have been made. This entry does three things:

a) Stores AGS attitude for possible future lunar align

b) Sets the AEA lunar surface signal flag

c) Inhibits accelerometer calibration

PROCEDURE

1) If the PGNCS is operative, perform a PGNCS to AGS align. If PGNCS is not operative, perform a lunar align.

THE AGS ALIGNMENT MUST RESULT IN A Y-INERTIAL AXIS THAT IS WITHIN 10 DEG (HALF CONE ANGLE) OF THE MOON'S NORTH POLAR AXIS.

2) At the completion of align, enter via the DEDA 400 + 60000.

3) Completion of calibration (302 seconds required) can be verified by reading out DEDA address 400. At completion, the readout automatically returns to + 00000.

17.2 Inflight Gyro and Accelerometer Calibration (DEDA entry 400 + 60000)

IF THE PGNCS IS INOPERATIVE, DO NOT ENTER THIS MODE WHILE IN FLIGHT. TO DO AN INFLIGHT ACCELEROMETER CALIBRATION, PROCEED TO SECTION 17.3.

PROCEDURE

1) Vehicle in PGNCS ATT HOLD.

2) Maneuver vehicle via ACA until DSKY display of ICDU angles read approximately 22.5 degrees away from 0°, 45°, 90°, 135°, etc., in all three channels.

3) Perform IMU CDU zero. Wait at least 20 seconds before proceeding to step 4. As long as all gimbal angles are more than 11.25 degrees away from 0°, the CDU zero and subsequent "count-up" (requires a maximum of 20 seconds) exercises all of the CDU "fine" switches and it is highly unlikely that fine switching transients will occur during calibration.

4) Inhibit the RCS.

5) Enter the calibrate mode via DEDA entry 400 + 60000. Wait at least 35 seconds before proceeding to step 6.

6) Return the vehicle to PGNCS ATT HOLD. Wait two minutes before proceeding to step 7.

7) Inhibit the RCS. Remain in this state until calibration is complete.

8) If during the last minute of calibration it would be necessary to manually command an RCS jet firing to prevent a "coarse" CDU transient in any channel (ICDU angles crossing 0°, 45°, 90°, 135°, etc.) then manually exit the calibration via DEDA entry 400 + 00000.

INFLIGHT GYRO AND/OR ACCELEROMETER CALIBRATION MUST ONLY BE PERFORMED DURING FREE FLIGHT. ATTITUDE ROTATION RATE SHOULD BE LESS THAN 0.1 DEGREE PER SECOND.*

*With the AGS in control, there is no automatic attitude control during inflight calibration since the attitude error commands are set to zero. When the PGNCS is in control, attitude hold can be achieved with the Mode Control Switch.

17.3 Inflight Accelerometer Calibration Only

PROCEDURE

1) Vehicle in ATT HOLD.

2) Inhibit the RCS.*

3) Enter the calibrate mode via DEDA entry 400 + 70000.

Calibration is completed in 32 seconds. After 302 seconds, the readout of DEDA address 400 returns to + 00000 (attitude hold). Inflight Accelerometer Calibration Only does not affect AGS alignment. Vehicle attitude maneuvers may be resumed after 35 seconds. (Inflight Accelerometer Calibration may be terminated any time after 35 seconds via DEDA entry 400 + 00000.)

17.4 Discussion

The gyro and accelerometer bias compensation values should be on record prior to the inflight calibration. These can be obtained via DEDA readout.

Equation Symbol	Address	Description
1K1	544	x gyro drift compensation coefficient
1K6	545	y gyro drift compensation coefficient
1K11	546	z gyro drift compensation coefficient
1K19	540	x accelerometer bias compensation coefficient
1K21	541	y accelerometer bias compensation coefficient
1K23	542	z accelerometer bias compensation coefficient

*It is acceptable to do an inflight accelerometer only calibration with the RCS not inhibited, but calibration accuracy may be degraded.

After calibration, the new compensation values can be read out. The gyro compensations are DEDA available as decimal quantities, degrees/hour, quantized to 0.01 degree/hour. The accelerometer compensations are read out as decimal quantities, quantized to 0.001 fps^2 ($\approx$ 31 μg). The acceptable bounds on gyro drift and accelerometer bias shifts, which can occur between two successive calibrations, are given in Table 17.1. Three limits are given for each instrument. The first is for the time interval between prelaunch and the first inflight calibration. The second is for the difference between two successive inflight calibrations. The third limit indicates suspected instrument failure. (The first and second limits define normal behavior). Should an inflight calibration result in a compensation shift which exceeded the acceptable limit, but not the failure limit, it is recommended that another IFC be conducted. If the limit is still exceeded, it is recommended that the new values be discussed with Mission Control. If the IFC results in a compensation value which exceeds the failure limit, a system problem is evident and Mission Control should again be contacted.

Table 17.1 Bounds on Inflight Instrument Compensation Shift (Lunar Mission)

Instrument	Launch to IFC	IFC to IFC	Failure Limit
Gyro Drift	$\pm 0.90^\circ/hr$ (1)	$\pm 0.70^\circ/hr$ (3)	will be specified prior to launch
Accelerometer Bias	± 0.008 fps^2 (2)	± 0.008 fps^2 (3)	will be specified prior to launch

(1) Based on 18 days from EPC to IFC

(2) Based on 60 days from PIC to IFC

(3) Based on less than 24 hours between IFC's.

Thirty two (32) sec after entering the calibrate mode, the accelerometer calibration is completed. The accelerometer bias compensation constants are modified in the AEA only at the completion of the calibration process. If the AGS is removed from the calibrate mode prior to 32 seconds, the initial values of the calibration constants will be maintained. The gyro calibration updating is performed differently. Once each two-second compute cycle during calibration, the gyro calibration constants are reestimated and updated in the AEA. If the AGS is removed from the calibrate mode before the allotted 302 seconds has elapsed, the updated constants will be utilized by the AGS. If the calibration mode is exited before 180 seconds have elapsed, reload the initial values of the gyro calibration constants. The constants obtained after 180 seconds will be more accurate than those existing prior to entering the calibrate mode but less accurate than those that would have resulted had the gyro calibration been completed.

18.0 RENDEZVOUS RADAR NAVIGATION UPDATING

This section contains the procedure to be used to obtain a LM navigation update using the Rendezvous Radar.

The digital radar filter used in the AEA accepts both range and range rate information. The value of radar range entered into the DEDA must be the value read from the tape meter at the time the radar gimbal angles are zero (time at which DEDA entry 415+10000 is made). The value of radar range rate entered into the DEDA must be the value read from the tape meter at the time DEDA entry 415+10000 is made. However, the radar gimbal angles need not be zero when the radar range rate is read.

It is recommended that the radar data entry schedule consist of a sequence of at least six range entries. One (1) range rate entry should be made in the interval between each pair of range entries. (Any more than one range rate entry between range entries neither improves nor degrades performance.) At long ranges (pre-CSI), a radar data entry schedule should consist of a sequence of at least nine range entries.

The time between range updates should be maintained relatively constant in any particular updating sequence, and should be between two and six minutes. It is desirable that the total time interval between the first and last range entry in a given sequence be large, in order to take advantage of the changing geometry.

> ANY EXTERNAL NAVIGATION UPDATE INFORMATION (PGNCS DOWNLINK, MSFN) OBTAINED DURING THE RADAR DATA GATHERING PROCESS COMPLETELY SUPERSEDES THE PREVIOUS RADAR NAVIGATION UPDATING; I.E., THERE IS NO COMBINING OF UPDATE INFORMATION WITH THE NAVIGATION ESTIMATES ALREADY IN THE COMPUTER.

The radar filter is initialized by setting DEDA address 417 to +10000.

> PRIOR TO THE START OF TAKING EACH SEQUENCE OF RADAR DATA (I.E., PRIOR TO CSI, CDH, TPI AND MIDCOURSE), DEDA ADDRESS 417 MUST BE SET TO +10000 TO INITIALIZE THE RADAR FILTER.

18.1 Procedure for Rendezvous Radar Updating

1) General

As an aid to rendezvous radar acquisition, enter the Z-body axis steering mode (DEDA entry 400 + 20000) and orient the Z-body axis toward the estimated direction of the CSM (DEDA entry 507 + 00000). When the MODE CONT is placed in AUTO, the LM will orient the Z-body axis to the desired direction. After the desired pointing direction is achieved, set the MODE CONT to A/H.

During rendezvous radar updating, the X-Z plane of the AGS inertial reference frame must lie within 10 deg of the CSM orbit plane to obtain correct operation of the radar filter.

2) Procedure

The following steps, required for radar data entry, are to be performed when the rendezvous radar is locked on to the CSM.

A. RADAR RANGE DATA

1) Insert on the DEDA (but do not enter) 415 + 10000. This is the command to "store Z-axis direction cosines and assign a time tag to the radar data."

2) Set Deadband Switch to "MIN" position.

3) Using the Attitude Controller, rotate the vehicle manually in order to null the rendezvous radar gimbal angles (as observed on the rendezvous radar gimbal display). When the stick is moved out of the detent position, the AGS enters the followup submode and zero attitude errors are output. When the stick returns to detent, attitude hold is reentered.

4) At gimbal angle null depress the "ENTR" button on the DEDA and note radar range on the Rendezvous Radar Range Display.

5) If it is felt that the radar gimbal angles were not zeroed when the DEDA "ENTR" button was depressed (step 4), the process should be repeated beginning with step 1. At this time in the filtering process no external data has been irrevocably placed in the AEA. The above steps can be repeated any number of times (at any frequency) until the radar gimbal angles are zeroed when the DEDA "ENTR" is depressed (with the entry 415 + 10000).

6) Attitude controller can be returned to detent at which time AGS goes into "attitude hold."

7) Via DEDA address 316 (quantized at 0.1 n. mi.*) enter the recorded value of radar range. This should be accomplished within 30 seconds of step 4. At this time the radar data is irrevocably entered into the AEA.

8) Set Deadband Switch to "MAX" position.

BECAUSE OF TECHNIQUES USED TO CODE THE RADAR FILTER IN THE AEA, ENTRIES SHOULD NOT BE MADE IN DEDA ADDRESS 415 FOR AT LEAST 16 SECONDS AFTER A RANGE OR RANGE RATE ENTRY HAS BEEN MADE.

B. RADAR RANGE RATE DATA

The following steps are required for radar range rate entries into the AEA:

1) Deadband switch is in "MAX" position.

2) Insert on DEDA (but do not enter) 415 + 100000. This is the command to "store Z-axis direction cosines." However, no special orientation of the spacecraft is necessary; all that is required is that the rendezvous radar be locked-on to the CSM beacon.

3) At any convenient time, depress the "ENTR" button on the DEDA and note radar range rate on the Rendezvous Radar Range Rate Display.

*Address 316 (radar range entry) is quantized at 0.1 n. mi. for both earth and lunar scaling. At short ranges the radar range display is in units of feet, so that range must be converted to n. mi. by dividing by 6000 prior to entering via DEDA.

4) Via DEDA address 503 (quantized at 0.1 fps) enter the noted value of radar range rate. This should be accomplished as soon as possible and within 30 seconds of step 3. At this time, the range rate is irrevocably entered into the AEA. (Range rate must be entered with the correct sign, i.e., negative for closing.)

5) If it is decided not to use the range rate reading after the 415 entry is made, begin the procedure over with a new 415 entry when the new range rate is desired.

IT IS NOT NECESSARY THAT THE RADAR GIMBAL ANGLES BE ZERO FOR THE RADAR RANGE RATE ENTRY.

19.0 LUNAR SURFACE OPERATIONS

This section presents the procedures to be utilized on the lunar surface.

19.1 Operations Prior to AEA Shutdown

1) Immediately after touchdown, enter DEDA address 413 + 10000 (any other entry in address 413 is just as valid). This command sets the lunar surface flag and stores the lunar azimuth of the LM. Setting the lunar surface flag is mandatory for LM navigation initialization on the lunar surface.

2) If the PGNCS is operating, perform the following steps:

   a) Enter DEDA address 400 + 30000 to obtain an AGS-to PGNCS align.

   b) After the PGNCS is fine aligned (approximately 20 minutes after touchdown) reinitialize LM and CSM state vectors via downlink (see Section 15.1). This may send the CDU zero signal to the AEA.

   c) Verify completion of initialization via DEDA readout of + 00000 on DEDA address 414.

3) If the CDU zero signal was not sent to the AEA (Step 2b) go to Step 4. If the CDU zero signal was sent, perform the following steps:

   a) At least 30 seconds after step 2b) enter DEDA address 400 + 30000. This entry is for an AGS-to-PGNCS align.

   b) Enter DEDA address 413 + 10000 to store the lunar azimuth of the LM. This step stores the improved azimuth available as a result of the AGS-to-PGNCS align.

4) Pull out AEA circuit breaker. This removes 28 VDC power from the AEA.

5) Set AGS status switch to OFF.

6) Pull out the AGS circuit breaker. This removes 115 V, 400 CPS power from the AEA.

DO NOT PULL OUT THE ASA CIRCUIT BREAKER. THE BREAKER SUPPLIES HEATER POWER TO THE ASA SENSORS WHOSE TEMPERATURE MUST BE MAINTAINED DURING LUNAR STAY.

In this status, all information in the computer is saved for use when the system is again turned on.

19.2 Operations Prior to Lunar Liftoff

In sufficient time (greater than 30 minutes) prior to lunar liftoff, the following steps should be performed:

1) Set AGS status switch to STANDBY.

2) Close AEA circuit breaker. This applies 28 VDC power to the AEA.

3) After 25 minutes in standby, close the AGS circuit breaker.

4) Set AGS status switch to "OPERATE". AGS flight program is entered with the pre-shutdown parameters retained. When first entering the OPERATE status, address 400 and 410 are automatically set to + 00000 (See Section 7.0). The address 410 entry of + 00000 selects the orbit insertion routine. Because the lunar surface signal is set, the AGS outputs zero attitude control signals when Guidance Control is in AGS and Mode Control in AUTO. If Guidance Control is in PGNS and Mode Control in ATT HOLD, the AGS will also output zero attitude control signals. If Guidance Control is in PGNS and Mode Control in AUTO, the AGS will issue zero attitude error signals since address 400 is + 00000. If Guidance Control is in AGS and Mode Control in ATT HOLD, the AGS will attempt to reestablish the LM attitude with continued, fruitless RCS thrusting. AGS is in follow-up if the Guidance Control switch is in the PGNS position and outputs Engine OFF commands.

The system is now in operating condition. A series of checks should be made to verify the readiness of the AGS.

5) Checks of Computer Readiness

   A check of computer readiness should be made according to the procedures of Section 14.1.

6) AGS Computer Time Initialization

   AGS computer time should be initialized according to the procedures of Section 14.2.

7) Obtain nominal liftoff time from MSFN and set events timer appropriately.

8) If the PGNCS is operative, go to step 9. If not, proceed to step 12.

9) CSM, LM Navigation Initialization

Perform CSM, LM navigation update via PGNCS downlink (Section 15.1). This procedure should occur within 0.5 hour of nominal liftoff time.

10) AGS to PGNCS Align

At least 30 seconds after the completion of step 9, perform a AGS to PGNCS align according to the procedures of Section 16.1.

11) Proceed to step 14.

12) Align

Perform either Lunar Align or Body Axis align according to the procedures of Section 16.2.

13) LM, CSM Navigation Update

During Lunar Align or after Body Axis Align, perform LM and CSM navigation update via DEDA according to the procedures of Section 15.0.

14) Lunar Surface Gyro Calibration

Perform Lunar surface gyro calibration according to the procedures of Section 17.0.

15) During step 14, enter targeting parameters for Orbit Insertion per Section 22.0. If so desired, CSI targeting parameters can also be entered at this time.

16) If PGNCS is operative, proceed to step 18. If not, perform step 17.

17) After gyro calibration is completed enter DEDA address 400 + 40000 to return to lunar align mode.

18) Enter appropriate octal values into DEDA addresses 514, 515 and 516 if during orbit insertion the vehicle is to yaw to maintain S-band communication. These values must be obtained from Mission Control. Also enter 623 + 10000. If no yaw maneuver is required, i.e., if the Z-body axis is to be parallel to the CSM orbit plane, then DEDA address 623 should be set or verified at the value +00000.

19) Verify DEDA address 410 + 00000 for orbit insertion mode.

20) If AGS is to be used for "orbit insertion," verify that the Guidance Control Switch is in AGS position and the AGS Mode Control Switch is in AUTO.

21) Enter address 400 + 10000 within ±4 minutes of the nominal lift off time. If lunar align was used, it is completed at this time.

22) At liftoff time depress the "Abort Stage" button. This automatically initializes the staging sequence and fires the ascent engine.

20.0 ENGINE IGNITION

This section describes the AGS procedures to follow for turning on the engine(s) in coasting flight or on the lunar surface, when the AGS actively controls the LM. AGS control during the abort staging sequence is also described.

20.1 DPS, RCS or APS Engine Selection

The AEA assumes that translational thrust is applied in certain nominal directions.

Engine	Direction of Thrust Assumed by AEA
DPS	+ X -body axis direction
APS	Canted. Cant angle data is used by AEA to account for the canted thrust direction.
RCS	The ±X, ±Y, ±Z RCS translation engines are assumed to thrust along the ±X, ±Y, ±Z body axes, respectively.

The nominal cant angle assumed by the AGS is controlled by two constants in the AEA program (DEDA accessible in octal).

K_7^4 Cant angle (radians) of thrust vector in pitch plane. DEDA address 566. Positive sign indicates thrust vector is canted from the +X -body axis toward the direction of the +Z -body axis.

K_8^4 Cant angle (radians) of thrust vector in the roll plane. DEDA address 602. Positive sign indicates thrust vector is canted from the +X -body axis toward the direction of the +Y -body axis.

DPS or APS misalignments less than 2 degrees with respect to the assumed thrust directions result in lateral cut-off velocity errors less than 3 fps. This type of error is sensed by the navigation guidance loop and consequently can be removed by performing a ΔV trim maneuver using axis-by-axis RCS thrusting (see Section 28.0).

Prior to in-orbit maneuvers, the flight crew chooses which translation engine(s) will be employed. The AGS must be instructed via the

DEDA of the decision to ignite the APS so that steering transients will not occur at the start of the burn. Prior to each AGS controlled orientation to the desired thrust attitude, the following DEDA selection should be set or verified:

DEDA Address 411	Entry +00000	DPS or RCS Selection
	Entry +10000	APS Selection

As indicated by Figure 20.1, regardless of the above selection, the AEA assumes the canted thrust direction whenever the APS ON discrete is received. Hence, at staging or lift-off from the lunar surface, an entry via DEDA address 411 is not required. Note, however, that if 411 + 10000 is selected, and the DPS or RCS is used, the AEA will assume canted thrust.

At AGS sensed engine cut-off conditions, address 411 is set automatically to +00000 (see Section 2.2).

If only the RCS engines are to be used for all in-orbit maneuvers, address 411 need be verified +00000 only prior to the first RCS maneuver. Address 411 never switches automatically to +10000.

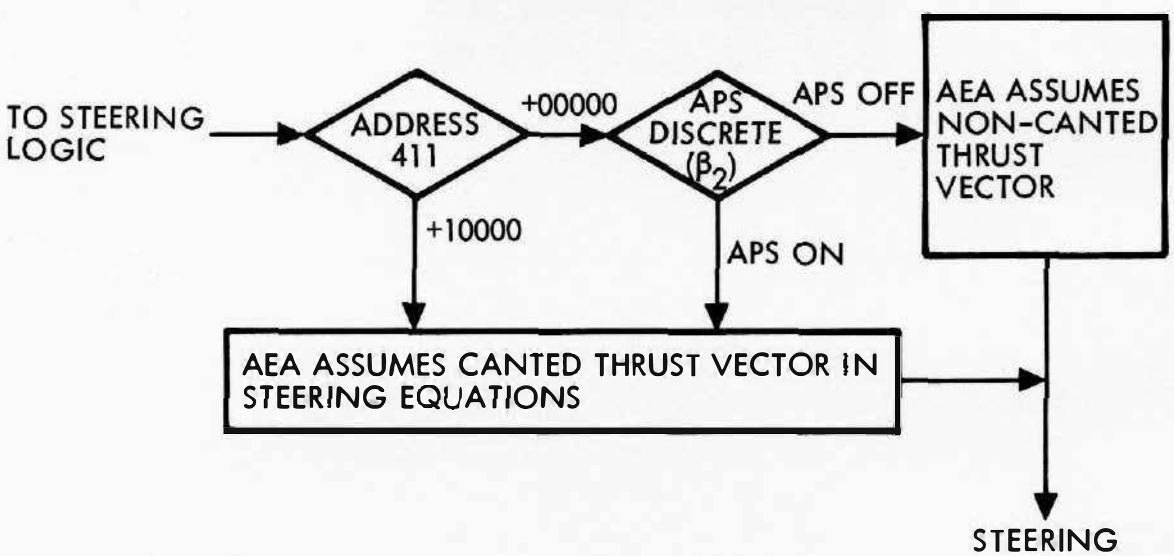

Figure 20.1. Canted Thrust Selection Logic

20.2 Required Control Panel and DEDA Selections for Engine Ignition (AGS Control)

Necessary Conditions for the AEA to Generate an Engine ON Signal			
Condition	Control	Position	Remarks
1.	Guidance Control	AGS	Removes follow-up signal to AGS.
2.	Mode Control	Auto	Transmits Auto discrete to AGS. Removes AGS from A/H.
3.	a. Abort b. Abort Stage	Depressed	Enables Engine ON. a. Abort arms the DPS b. Abort Stage arms the APS
4.	DEDA Entry	Enter 400 + 10000	Enables Engine ON and Guidance Steering

The above conditions are sufficient

1) for the AGS to assume control and orient the LM in accord with the selected guidance routine.

2) to arm the appropriate engine.

In order to effect DPS or APS engine ON, however, additional conditions must be met.

20.3 Velocity-to-be-Gained Checks

For the Engine ON discrete signal to be issued to the CES by the guidance equations, at least one of the two following conditions must be satisfied.

Condition 5. ΔV Magnitude	The magnitude of the velocity-to-be-gained vector, as computed in the AEA, must exceed 100 fps. (constant 4K26)
Condition 6. X-Body Axis Component of ΔV.	The component (sign and magnitude) of the velocity-to-be-gained vector (positive measure in the direction of the + X-body axis) must exceed the engine tail-off ΔV value (currently + 2.125 fps in the program). This component of velocity-to-be-gained is the projection of the velocity-to-be-gained vector on the X-body axis.

The velocity-to-be-gained vector is computed by the selected guidance routine. Any guidance routine (address 410) other than TPI search (DEDA entry 410 + 30000) may be selected. The TPI search routine should be restricted to planning the TPI maneuver (per Section 25.0) because the computed rendezvous point is not fixed in inertial space. However, engine ignition should only be commanded when in the orbit insertion guidance routine (DEDA entry 410 + 00000) or the external ΔV guidance routine (DEDA entry 410 + 50000).

20.4 Ullage for DPS or APS Ignition

Before main engine ignition, the AGS must sense ullage. Ullage must be supplied manually with the Thrust/Translation Controller Assembly or by depressing the +X Translation button until main engine ignition. The precise condition governing the AEA recognition of successful ullage is given as follows:

Condition 7. Ullage Recognition	The AEA recognizes ullage if and only if the sensed velocity change per two second compute cycle equals or exceeds 0.2 fps in the + X-body axis direction for 1K9 consecutive compute cycles.

If the sensed velocity increment drops below 0.2 fps in a two second compute cycle, the engine OFF command will be issued. Before the engine can be reignited, the ullage recognition condition must again be established and address 400 must be reset to + 10000.

During the powered flight abort staging sequence, the sensed velocity accumulated over any two second period will be well above 0.2 fps; hence ullage is maintained and the AEA generates the engine ON signal without interruption.

In order to prevent 1) a premature engine shutdown (during a critical phase) due to a momentary loss of ullage or 2) a delay in APS ignition during abort, NASA/MSC has recommended (Reference 8) that the ullage counter limit (1K9) be set to 0 (DEDA Entry 616 + 00000) after the start of powered descent. The ullage counter should be reset to 616 + 00003 (equivalent to 3 - 2 sec cycles) after orbit insertion has been completed.

It can be seen that the time duration required to generate AEA ullage recognition, when 1K9 is set equal to 3 compute cycles, can vary between slightly over 4 seconds up to slightly over 6 seconds. The exact time duration depends upon when in the compute cycle ullage is initiated and to a lesser extent upon the thrust acceleration level.

20.5 Sufficient Conditions for DPS or APS Ignition

The logical product of the seven conditions described above is sufficient to generate the AGS engine ON signal. Note that the chosen engine must be armed. Explicitly:

> To ignite the DPS, combined conditions 1, 2, 3a, 4, 5 and/or 6, 7 are sufficient.
>
> To ignite the APS, combined conditions 1, 2, 3b, 4, 5 and/or 6, 7 are sufficient.

20.6 DPS Variable Thrust

The AGS will perform guidance properly for any DPS thrust level selection with the exception that in the Orbit Insertion routine

1) sufficient thrust is required to overcome the net effect of gravity and centrifugal accelerations
2) thrust level changes should be avoided, if possible, particularly when near guidance engine cut-off (see Section 22).

20.7 RCS Translation; AGS Steering Control

RCS translation can be employed with full AGS steering control.

a) Establish conditions 1, 2 and 4 in sufficient time for the LM to orient to the desired thrust attitude.

Condition	Control	Position
1	Guidance Control	AGS
2	Mode Control	Auto
4	DEDA address 400	Entry +10000

b) Select DEDA quantity ΔV_{gX} for read-out. (DEDA Address 500).

c) Set the ATT/Translation switch to the desired number of jets (2 or 4).

d) At the maneuver time utilize the Thrust/Translation Controller to perform the maneuver. Null out the DEDA reading by moving the Thrust/Translation Controller up.

e) When the ΔV_{gX} becomes less than 15 fps, set the MODE CONT TO A/H.

f) When $\Delta V_{gX} = 0$, immediately reduce the thrust to zero.

20.8 Lunar Surface Liftoff

Ullage is automatically generated on the lunar surface. Switch settings are

Guidance Control to "AGS"

Mode Control in "Auto"

AGS Submode Selector must be

Address 400	Entry +10000 (Guidance)

AEA Guidance Routine must be

Address 410	Entry +00000 (Orbit Insertion)

On the lunar surface, the orbit insertion guidance routine generates a large value of velocity-to-be-gained.

Depress the Abort Stage button. The AGS issues the E/ON command igniting the APS engine and ascent to orbit insertion follows.

20.9 Manual Engine Operation

In the event that a main engine is ignited manually by depression of the Engine Start button, then it can only be extinguished by depressing the Engine Stop button unless fuel depletion or staging occurs first. Activation of either of these two pushbuttons, as indicated by a red light in the button, will result in the AGS engine commands being inhibited from main engine control.

> THE AGS WILL NOT TERMINATE A MAIN ENGINE BURN IF THE ENGINE WAS IGNITED BY DEPRESSION OF THE ENGINE START BUTTON.

In the event that a main engine was ignited manually, the flight crew can monitor ΔV_{gX} via DEDA (address 500) quanitized at 0.1 fps lunar mission or 1 fps for earth missions and depress the Engine Stop button when ΔV_{gX} is near zero. (The Engine -Stop button will function if the Abort Stage button is not set.)

20.10 Satisfaction of Ullage Condition Due to Angular Accelerations

The maximum distance between the ASA and the LM center of gravity is approximately 10 ft in the +X-body axis direction and 5 ft in the +Z-body axis direction. There is effectively no displacement in the Y direction. Because the ASA is offset in the Z direction the possibility of angular accelerations about the pitch axis causing the ullage condition to be satisfield exists. (If ullage is sensed in the CSI mode, CDH mode, TPI modes or External ΔV mode, S_{07} will be set to 1.) The required angular acceleration is slightly greater than 1 deg/sec^2 and must exist for a minimum of 1K9 consecutive 2-sec compute cycles.

> IF ALL CONDITIONS FOR ENGINE IGNITION EXCEPT THE ULLAGE CONDITION ARE SATISFIED (SEE SECTION 20.5) AND THE LM IS TO BE REORIENTED THROUGH A LARGE ANGLE UNDER AGS CONTROL, THEN THE ABORT OR ABORT STAGE BUTTON MUST NOT BE DEPRESSED UNTIL LM REORIENTATION HAS OCCURRED IN ORDER TO AVOID SENDING THE E/ON COMMAND.

21.0 THRUST TERMINATION

In this section procedures for terminating thrusting maneuvers are presented and discussed. It should be noted for all thrusting maneuvers that the desired thrust direction becomes fixed in inertial space when the velocity-to-be-gained is less than 15 fps (DEDA accessible constant 5K26) and ullage has been detected during the current 2 sec computing cycle. The desired thrust direction is fixed in order to avoid large attitude variations by the LM to achieve small velocity cutoff errors (as velocity-to-be-gained goes to zero).

21.1 APS or DPS Engines

Termination of main engine thrust by the AGS is a wholly automatic process that occurs when the Engine OFF command is sent to the CES, provided the engine was not turned on manually (by depression of the Engine Start button). With the AGS in control the Engine OFF command will be generated under any of the following conditions:

1) Velocity-to-be-gained magnitude < 4K26 fps and the component of the velocity-to-be-gained vector resolved along the +X-body axis ≤ 4K25 fps (APS tail-off ΔV value).

2) Loss of ullage recognition (less than 0.2 fps sensed velocity in a two second computer cycle).

3) Address 400 does not contain the value +10000.

An AGS guidance (engine) cut-off is initiated by 1) above; at the same time address 400 is automatically set to +00000, attitude hold, and address 411 is set to +00000. If Engine OFF command is due to condition 2), address 400 and 411 remain unchanged.

21.2 Follow-up and Attitude Hold

If the Guidance Control Switch is in "PGNS," the AGS will continue to follow up the engine operation commands.

If the Mode Control is switched to "A/H" during AGS controlled powered flight, the AGS will hold LM attitude. Engine ON will continue because the AEA is in an engine follow-up mode. The flight crew can assume manual attitude control, with continued engine operation, by moving the Attitude Controller (hand control) out of the detent (AGS will transmit zero steering signals at this time). Thrust will not terminate unless accomplished manually. Upon returning the Attitude

Controller to the detent position and switching the Mode Control back to "Auto", the AGS will resume guidance control and terminate thrust when the velocity-to-be-gained conditions for engine cut-off are met.

21.3 RCS Engines

The following procedure applies to each axis individually if axis by axis translation is being performed (LM in attitude hold - see Section 28) or to the X-body axis if AGS steering is being employed (Section 20.7).

1) Monitor via the DEDA the velocity-to-be-gained in the appropriate thrust direction, i.e.,

Quantity	DEDA Address	Units	DEDA Least Significant Digit	
			Lunar Mission	Earth Mission
ΔV_{gX}	500	fps	0.1	1.0
ΔV_{gY}	501	fps	0.1	1.0
ΔV_{gZ}	502	fps	0.1	1.0

These quantities are computed every 40 msec and updated on the DEDA display every 1/2 sec.

2) Terminate thrust manually with the thrust/translation controller when velocity-to-be-gained (along the appropriate axis) equals zero.

3) Cautionary Note on RCS Thrusting with AGS Steering

At AGS controlled main engine cut-off, the LM is placed in Attitude hold at the time the Engine ON command is changed to an Engine OFF command. With RCS X axis thrusting, the same logic will switch the AGS to attitude hold (address 400 is switched to +00000) when $\Delta V_{gX} \leq$ 4K25 fps only if the RCS burn has continued long enough (greater than 1K9 2-sec intervals) for the ullage recognition signal to be generated in the AEA. Otherwise address 400 will remain +10000 (guidance steering).

If the burn is too short for ullage recognition, or if thrusting along the Z body axis with $S_{507} = 1$, then after the termination of thrust the AGS will orient the LM along the direction of the residual ΔV vector. Since this could be any direction, the LM would probably begin an attitude maneuver at the maximum allowable rate (up to 10 deg/sec pitch rotation, 5 deg/sec yaw and roll axes rotation) to align the +X-body along the residual ΔV vector.

Before presenting a procedure for preventing post-burnout rotations subsequent to short RCS X-axis burns, another aspect of the guidance steering will be reviewed. As mentioned in Section 2.1, when the velocity-to-be-gained is less than 15 fps and the sensed thrust acceleration level in the + X-body axis direction is greater than 0.1 fps^2, the AEA will cease updating the computation of the desired thrust direction. Hence if the velocity-to-be-gained during the RCS burn is to be less than 15 fps, it can be seen that once the burn commences the AEA would normally adhere to a fixed desired thrust direction.

The above discussion leads to the following procedure for performing RCS burns of less than 15 fps magnitude when AGS steering is employed prior to the maneuver to orient the LM X-body axis in the desired thrust direction.

1) Orient to the desired thrust direction
   a) Guidance Control "AGS"
   b) Mode Control "Auto"
   c) Verify DEDA entry 400 + 10000 (Guidance Steering Submode)
2) Monitor ΔV_{gX} via DEDA
   Read address 500
3) Immediately preceding the maneuver (within 10 seconds)
   Set Mode Control to A/H
4) Perform the maneuver with Thrust/Translation Controller Assembly (not necessary to depress Engine Stop button)
5) Terminate RCS thrusting when $\Delta V_{gX} = 0$.

If the option to perform a Z-body axis RCS burn with the Z body oriented in the desired thrust direction is chosen (DEDA Address 400 +20000, DEDA Address 507 +10000) it is necessary to set the Mode Control Switch to A/H when the velocity-to-be-gained along the Z-body axis (DEDA Address 502) is less than 15 ft/sec. This procedure will eliminate undesired vehicle rotation after thrust termination.

PART IV - PROCEDURES FOR MANEUVERS

22.0 ORBIT INSERTION

22.1 Procedures for Using Orbit Insertion Routine

1) Initial Guidance and Control Configuration

PGNCS in Control

a) Guidance Control in "PGNS"

b) DEDA: Enter Guidance Steering

Address: 400
Entry: +10000

c) Other PGNCS control as required

AGS in Control

a) Guidance Control in "AGS"

b) Mode Control in "A/H"

c) DEDA: Enter Guidance Steering

Address: 400
Entry: +10000

2) AGS: Select Orbit Insertion Routine

DEDA Address 410 Entry +00000

3) AGS Targeting

Parameter	Address	Entry	Remarks
Injection Altitude (16J)	232		DEDA least significant digit 100 ft, lunar mission 1000 ft, earth mission
Injection Altitude Rate, Lower Limit (23J)	465		DEDA least significant digit 0.1 fps, lunar mission 1.0 fps, earth mission
Semi-Major Axis Targeting Term (7J)	224		DEDA least significant digit 100 ft, lunar mission 1000 ft, earth mission
Semi-Major Axis Lower Limit (8J)	225		DEDA least significant digit 100 ft, lunar mission 1000 ft, earth mission
Semi-Major Axis Upper Limit (9J)	226		DEDA least significant digit 100 ft, lunar mission 1000 ft, earth mission

4) AGS: Select Engine(s)

DEDA Address 411	Entry +00000 (DPS or RCS)
	Entry +10000 (APS)

5) AGS: Yaw Steering Selection

a) If Z body axis is to be oriented parallel to the CSM orbit plane verify or enter 623 +00000.

b) If Z body axis is to be oriented parallel to a specified plane enter 623 +10000 and verify or select the plane with DEDA entries

Address	Octal Scaling	Description
514	B1	X component of unit vector normal to specified plane
515	B1	Y component of unit vector normal to specified plane
516	B1	Z component of unit vector normal to specified plane

6) Establish Guidance System Control For Maneuver

PGNCS in Control

a) Mode Control to "Auto" Perform normal PGNCS functions

b) To abort, depress Abort or Abort Stage Button

c) To Switch-over to AGS -
   (i) Guidance Control to "AGS".
   (ii) Verify Abort or Abort Stage.

AGS in Control

a) Mode Control to "Auto" (LM now orients to desired thrust attitude)

b) Initiate and Complete Selected Thrust Sequence (See Section 20). Balance Couple Switch as Desired.*

c) TRIM Burnout Residual. At engine cut-off, the system enters attitude hold. If desired, at this time the balance couple switch can be set or verified ON and the residual burn velocities removed (See Section 28.0).

*For liftoff from the lunar surface, it is recommended that the Balance Couple switch be on from liftoff until the pitch over maneuver is completed at approximately 18 seconds.

7) After Maneuver

a) Balance Couple Switch ON

b) Deadband Switch to MAX

c) Establish Desired Guidance and Control Configuration for Coasting Flight

22.2 Altitude Update During Powered Descent

AN ALTITUDE UPDATE SHOULD BE DONE TO INSURE SAFE PERICYNTHION DURING AN AGS CONTROLLED ORBIT INSERTION.

The capability exists for the astronaut to manually update the magnitude of the AGS computed LM inertial radius vector during powered descent. This is accomplished by the astronaut entering valid altitude information from the altitude tape meter or any other available means into DEDA address 223 (DEDA least significant digit, 100 ft lunar missions.) The altitude update (zero is not a valid update) can be done anytime during powered descent. The altitude update is implemented by first entering the desired altitude in the DEDA address 223; when the altitude (as indicated by the altitude tape meter) becomes equal to the desired altitude, the ENTER button is depressed and the LM position vector is normalized to the desired altitude.

22.3 Discussion

The "orbit insertion" guidance mode has been designed to drive the LM vehicle to a prescribed altitude above the moon with a specified value of altitude rate and a computed orbit apocynthion based upon the current LM-CSM Phase angle. In addition, steering in this mode is such that the LM is driven into the CSM orbit plane with an out of CSM orbit plane velocity component of zero.

Each steering channel (Y and Z) is a two degree of freedom loop, steering for desired position and desired velocity at engine cutoff. The equations have been designed to maintain the derivative of acceleration (radial and out-of-plane) constant. By limiting the allowable range of the derivative of acceleration the desired turning rate of the LM is also limited. This has the effect that as the velocity-to-be-gained decreases the system concentrates more and more on attaining the targeted velocity conditions rather than the insertion position conditions. The derivative of radial acceleration is so limited that the AGS will never allow the LM to steer downward to a nominally targeted altitude below the LM altitude (it can steer down to obtain desired velocity cutoff conditions). Whenever the derivatives of acceleration reach their limits the LM may not attain the targeted position at engine cutoff.

As nominally targeted, an out-of-CSM plane error of 0.5° can be removed for an abort from the lunar surface. If the abort occurs later in powered ascent or in the powered descent, less dispersion will be removed. In the event there is more than 0.5° out-of-CSM plane error, the orbit insertion mode will remove 0.5° and the remainder can be removed with the CSI, PCI, CDH and TPI maneuvers. The program is normally set up this way because of the fuel efficiency achieved. The amount of out-of-plane errors removed in orbit insertion can be varied by changing DEDA accessible constants 5K16 (DEDA address 561) and 5K17 (DEDA address 601).

In some off-nominal abort situations it may not be possible to achieve the desired orbital altitude prior to achieving desired velocity cutoff conditions. In these situations a new value of desired radial rate is computed in the AEA based upon the predicted burnout altitude. A plot of the function of this desired radial rate is shown in Figure 22. 1. If desired, the parameters of this function can be changed by DEDA entry of the constants 4K4, 4K5, 4K6 (DEDA addresses 565, 662, 527 respectively). The purpose of computing altitude rate in this manner is to ensure that if cutoff altitude is low the LM will be on a rising trajectory. At a later time when ascending through 60 K feet altitude, an appropriate small ΔV addition can be made to the orbit to insure a safe pericynthion by again using the Orbit Insertion routine.

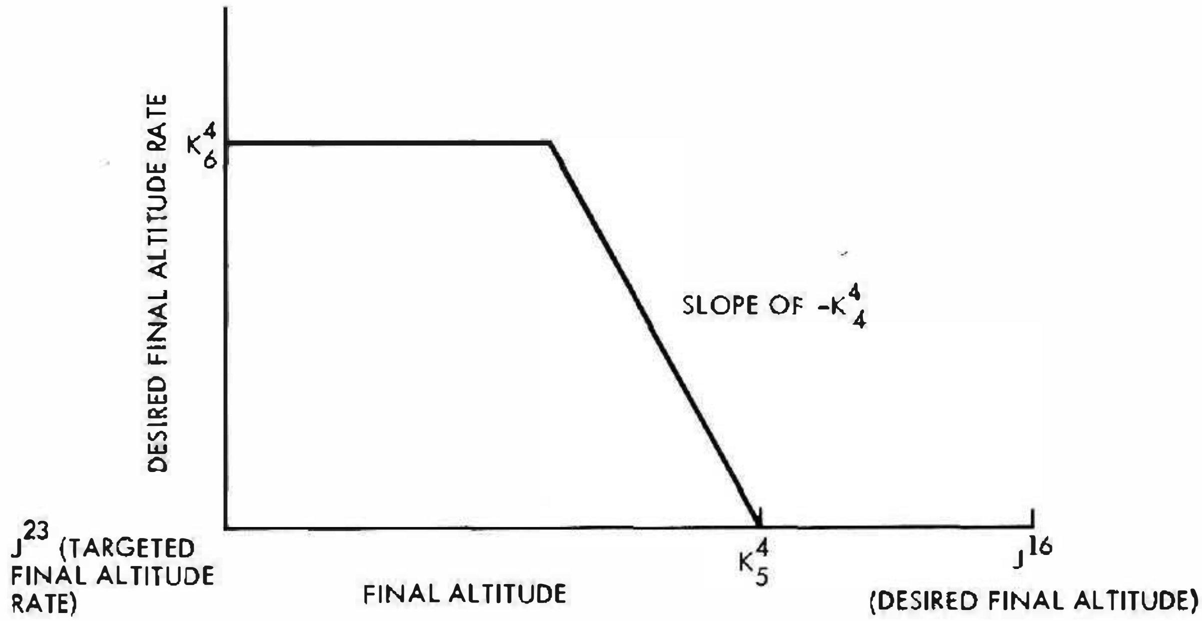

Figure 22. 1. Desired Final Altitude Rate versus Final Altitude

22. 4 Abort in Very Early Powered Descent (Lunar Mission)

Powered descent is initiated under PGNCS control. The LM thrust vector is oriented essentially opposite to the inertial velocity vector. LM velocity is initially lower than the Orbit Insertion targeted velocity, thus the Orbit Insertion velocity-to-be-gained vector points essentially in the minus X-body axis direction (ΔV_{gX} is negative).

With 4K26 set to 70 fps (engine cutoff criteria for ΔV_G when ΔV_{gX} is negative), the probability of an automatic cutoff due to thrust vector misorientation is small. The following options are available for completing the Orbit Insertion portion of the abort:

a) The DPS may be manually shut down. After the vehicle stabilizes in the desired thrust direction, the DPS thrust lever is set for engine ignition and ullage is executed. After DPS ignition, the throttle should be advanced to 50% or greater to complete the Orbit Insertion maneuver.

b) The DPS may be allowed to thrust at low acceleration (10%) while the vehicle is rotating. Once the vehicle thrust vector is oriented approximately in the desired direction the throttle should be advanced to 50% or greater. It will shut down after the Orbit Insertion maneuver is completed.

c) If the DPS has failed, the vehicle should be staged, oriented to the desired thrust direction and the insertion completed on the APS.

For aborts throughout powered descent the basic policy in regard to throttling the descent engine for AGS is as follows:

a) Use maximum thrust until altitude rate is positive. If the vehicle is not oriented in the desired thrust direction at the time of abort allow the vehicle to orient to the desired direction while maintaining the throttle setting that existed at the time of abort. After reorientation increase the throttle setting to obtain maximum thrust. If the possibility of lunar impact exists, maximum thrust should be commanded as soon as the thrust axis orients above the local horizontal.

b) After a positive altitude rate is achieved reduce the throttle setting to obtain 50% thrust. This setting has been chosed to minimize the transient when staging occurs and to assure sufficient thrust to overcome gravity.

22.5 Switch-Over to AGS in Very Late Powered Ascent

Consider that the switch-over from the PGNCS to the AGS is delayed until the targeted velocity magnitude is achieved (5530 fps). Also, consider that the actual trajectory is quite perturbed and that the AGS sensed altitude rate (or cross-plane velocity) is more than ±100 fps with respect to the targeted cut-off conditions. It can be seen that the LM will overshoot the desired cut-off velocity and begin a rotation to reverse its thrust direction without shutting off the engine. It is conceivable that APS propellant could be exhausted before the targeted orbit insertion conditions are achieved.

In essence, if the LM is not "on course", the velocity-to-be-gained vector will swing very rapidly as orbital speed is approached. The flight crew should initiate a switch-over early enough before reaching the speed of 5530 fps so that large attitude rates, prohibited by the CES, are not necessary to acquire the proper powered flight trajectory.

If the very late switch-over cannot be avoided, and the inertial velocity surpasses 5530 fps without engine cut-off, terminate APS thrusting. The AGS will rotate and stabilize the LM attitude in the proper orientation to continue the orbit insertion maneuver. Then, complete the maneuver with RCS thrusting (monitoring ΔV_{gX} which goes to zero) or reset the Abort Stage button, allowing APS ignition, manually commence ullage, receive an AGS On command, and complete the maneuver automatically with the APS.

Notice that the basic situation causing the events noted in 22.4 also causes those discussed immediately above. At switch-over to the AGS, velocity-to-be-gained is small and the LM is pointing grossly in the wrong direction for driving ΔV directly to zero. However, since the LM speed is essentially orbital, the crew can perform the corrective actions discussed above without undue haste, except where vital propellant expenditure is concerned.

22.6 Steering

In the guidance steering selection, the LM orients so that the LM thrust vector lies along the desired thrust vector. For a discussion, see Section 10.2.

22.7 Pitch Profile (Lunar Mission)

The steering equations are so designed that if the LM altitude above the launch site is less than 25,000 feet (constant 21J, DEDA address 233) and altitude rate is less than 50 fps (constant 22J, DEDA address 464) the vehicle will thrust in the vertical direction. After liftoff from the lunar surface, 50 fps altitude rate is exceeded at approximately 12 seconds. At this time, the normal pitch steering profile begins (pitch-over).

In the orbit insertion routine, the LM commanded attitude depends upon the thrust acceleration level. During DPS operations, once the vertical thrusting phase is executed, the thrust control lever should be set and then left alone until cutoff or staging occurs. The Orbit Insertion routine assumes a constant propellant flow rate in the computation of time-to-go-to-maneuver completion. Changing the thrust level setting causes the AGS to change the LM's pitch attitude to account for the newly sensed value of acceleration.

After staging, some change in attitude can be expected. The LM attitude will stabilize above the horizon about 5 to 15 degrees higher, depending on what ΔV remains to be gained and the relative values of the DPS and APS thrust level at staging. Part of the increased pitch angle is due to accounting for the canted APS thrust.

During powered ascent (from the lunar surface or abort from powered descent) the thrust level should exceed by a factor of at least two the net value of the gravitational force minus the centrifugal force. At very slow speeds (near the lunar surface) the centrifugal force is almost zero; the thrust acceleration level should exceed 10 fps^2. At near orbital speeds, the DPS thrust level can be less, but a safe rule of thumb would be to maintain a sensed acceleration of at least 10 fps^2.

It is important to note that the Orbit Insertion routine is targeted for variable velocity conditions at cut-off. Any post-orbit injection ΔV trim maneuver should be performed immediately (unless the targeted values are revised) and with sufficient thrust acceleration to achieve the targeted values. It is recommended that residuals not be nulled unless they exceed 5 fps.

22.8 Plots of the AGS Ascent Trajectory

Figures 22.2 through 22.5 are typical plots of altitude, altitude rate, out-of-plane position and out-of-plane velocity respectively for an AGS controlled launch from the lunar surface. Initial out-of-CSM plane displacement assumed for these plots is -24,000 feet. Targeting conditions for this simulated run were 60,000 ft altitude, 19.5 fps altitude rate and 5510.2 fps horizontal velocity. At 12 seconds into the flight the pitch profile changes from vertical rise to normal pitch steering. This is discussed in Section 22.7.

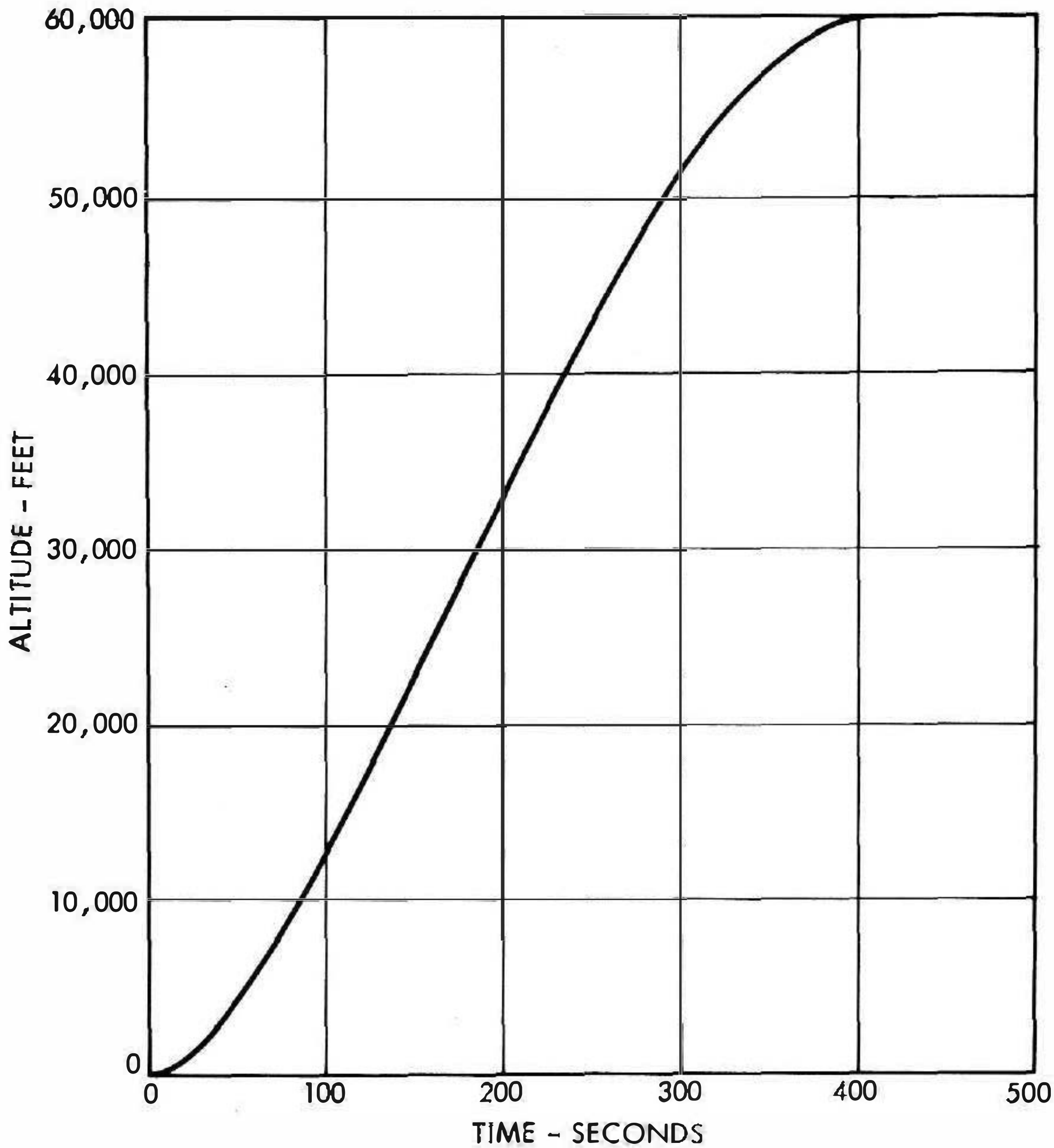

Figure 22. 2. Altitude versus Time for Lunar Surface Abort

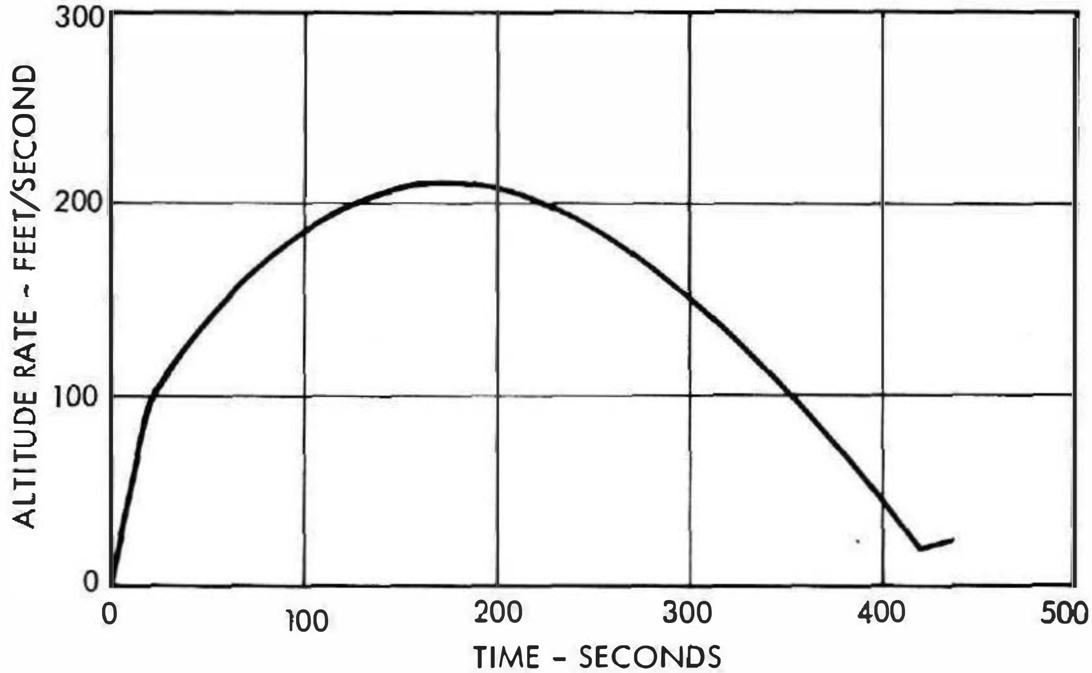

Figure 22. 3. Altitude Rate versus Time for Lunar Surface Abort

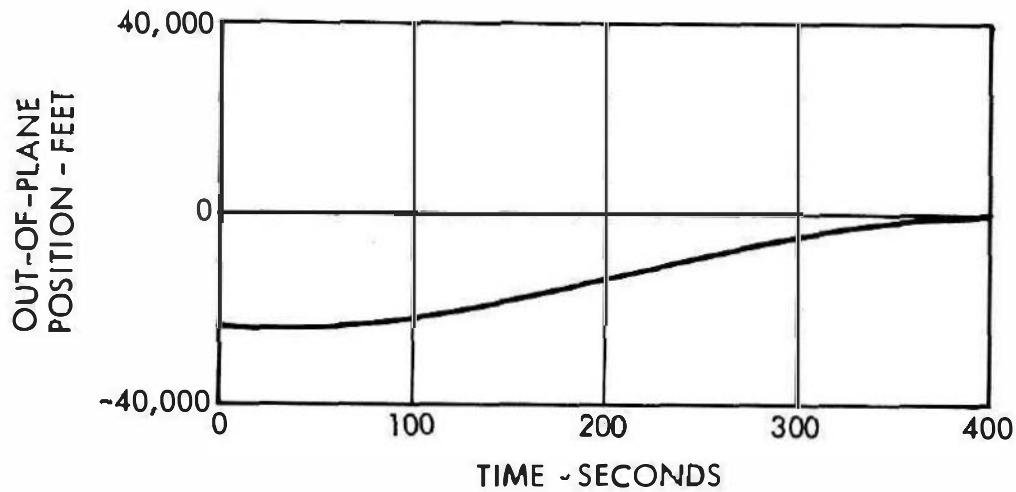

Figure 22. 4. Out-of-Plane Position versus Time for Lunar Surface Abort

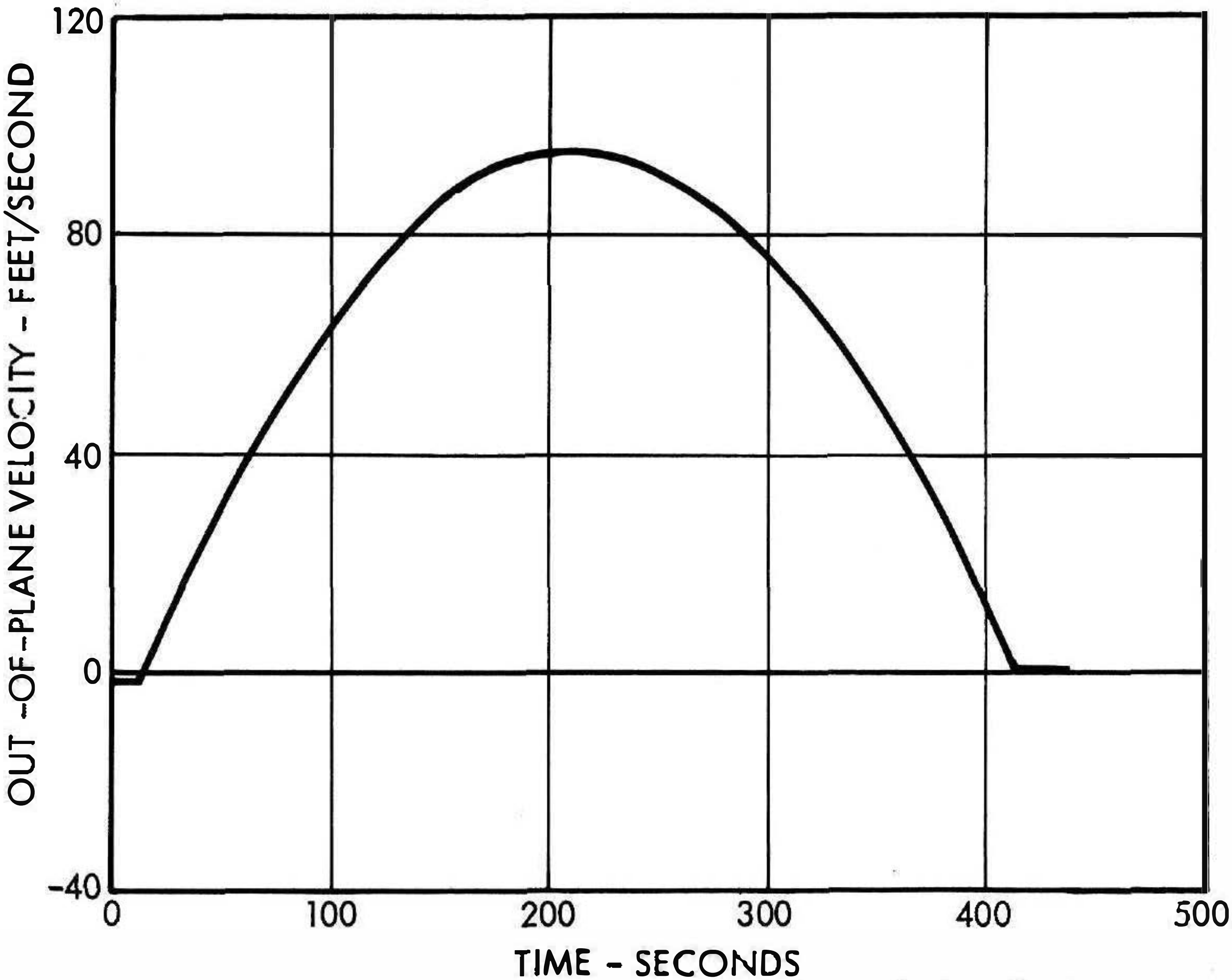

Figure 22.5. Out-of-Plane Velocity versus Time for Lunar Surface Abort

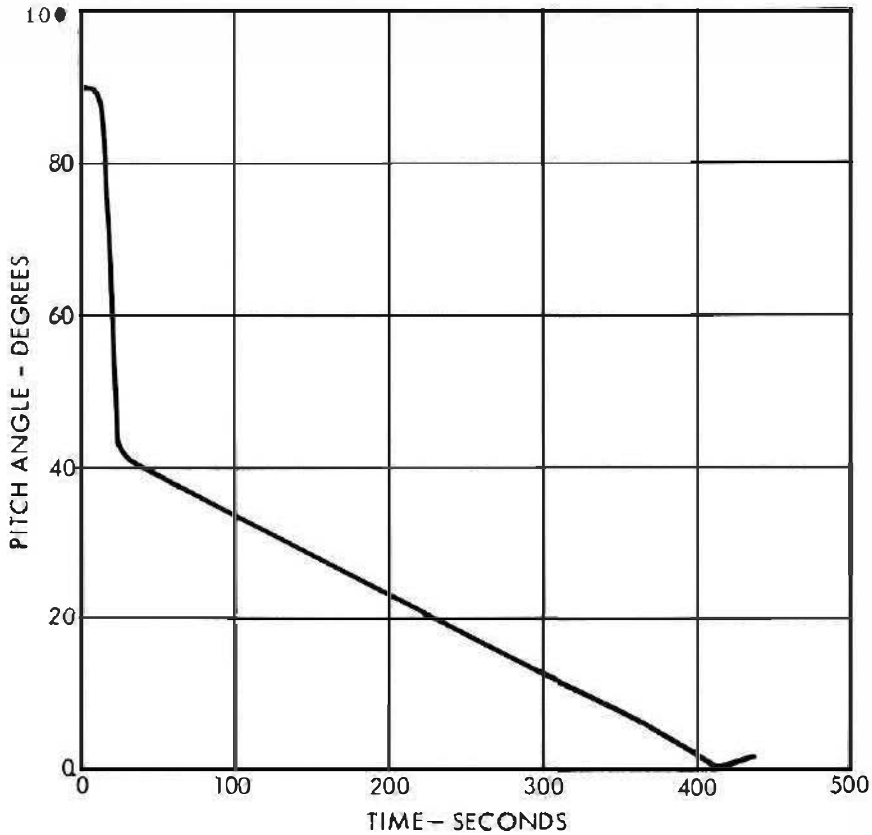

Figure 22. 6. Pitch Angle versus Time for Lunar Surface Abort

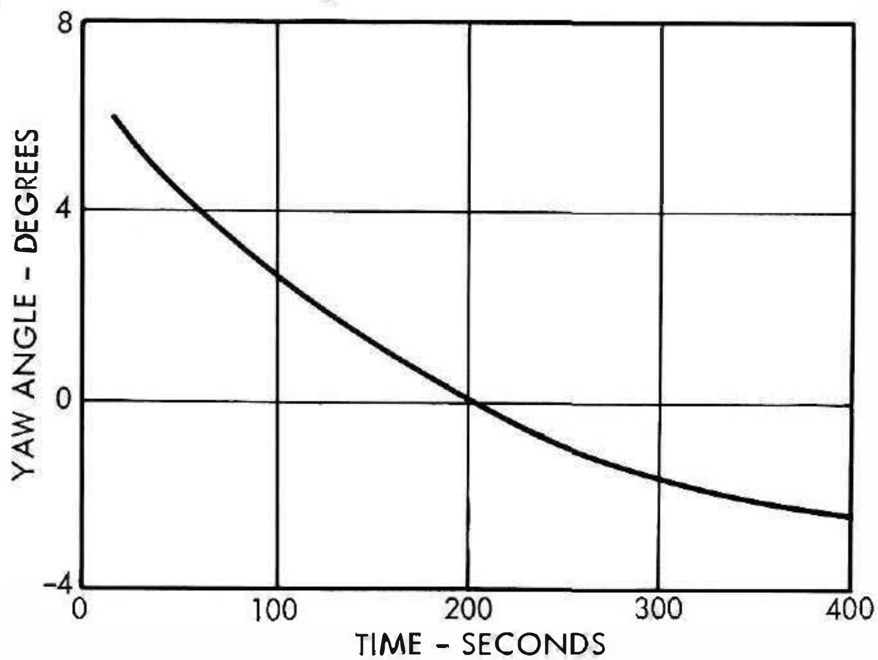

Figure 22. 7. Yaw Angle versus Time for Lunar Surface Abort

23.0 CSI

23.1 Procedures For Using CSI Routine

1) Initial Guidance and Control Configuration

PGNCS in Control

a) Guidance Control in "PGNS"

b) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000

c) Other PGNCS Controls as required.

AGS in Control

a) Guidance Control in "AGS"

b) Mode Control in "A/H"

c) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000

2) AGS: Select CSI Routine

DEDA Address 410	Entry +10000

Note: A valid CSI solution should not be attempted earlier than 136 minutes prior to t_{igA}.

3) CSI Targeting

Parameter	Address	Entry	Remarks
CSI Time	373		Absolute time of CSI; DEDA least significant digit 0.1 minute
TPI Time	275		Absolute time of nominal TPI; DEDA least significant digit 0.1 minute
Cotangent of Line-of-Sight Angle at TPI	605		Cotangent of Line-of-sight angle to CSM. Limit between cot 20° and cot 70°. Scaled at B7.
28J2	451	+00000	Out-of-plane velocity-to-be-gained in CSI maneuver (not automatically zero)

(continued on next page)

Parameter	Address	Entry	Remarks
Select Half Orbital Period Transfers (One of these two entries must be made)	416	+10000	Select CDH transfer at one-half orbital period following CSI
		+30000	Select CDH transfer at three-halves orbital period following CSI

4) AGS: Select Engine(s)

DEDA Address 411	Entry +00000 (DPS or RCS)
	Entry +10000 (APS)

5) AGS: Yaw Steering Selection

a) If Z body axis is to be oriented parallel to the CSM orbit plane verify or enter 623 +00000.

b) If Z body axis is to be oriented parallel to a specified plane enter 623 +10000 and verify or select the plane with DEDA entries

Address	Octal Scaling	Description
514	B1	X component of unit vector normal to specified plane
515	B1	Y component of unit vector normal to specified plane
516	B1	Z component of unit vector normal to specified plane

6) Events Timer

a) Readout DEDA address 310 (minutes, quantized at 0.01 minute), the time to go till the CSI maneuver (T_{Δ}).

b) Set the events timer to this value. Begin count-down to CSI.

7) CSI Solution Checks

The following quantities can be readout via DEDA to indicate the characteristics of the maneuver.

Equation Symbol	Quantization		Units	Address	Description
	Lunar Mission	Earth Mission			
ΔV_G	0.1	1.0	fps	267	Total velocity-to-be-gained magnitude in CSI maneuver (will not contain out-of-plane velocity component until 28J2 is entered.)
28J1	0.1	1.0	fps	450	Downrange velocity-to-be-gained in CSI maneuver
Δr	0.1	0.1	nmi	402	Differential altitude in coelliptic orbit
T_{A0}	0.1	0.1	min	372	Time from CSI to CDH
θ_f	0.01	0.01	deg	303	LM to CSM Phase Angle at CSI time
V_{p0}	0.1	1.0	fps	371	Velocity-to-be-gained in CDH maneuver
$\dot{r}_A$	0.1	1.0	fps	477	LM altitude rate at CSI time
δr	0.1	0.1	nmi	314	Differential orbital altitude along LM radial at CSI time

If any of these quantities are unsatisfactory (See Section 23.5) proceed to Section 23.2.

8) Establish Guidance System Configuration for CSI Maneuver

a) Enter into address 410 + 50000. The AGS is now in the External ΔV guidance mode. The procedure for executing an External ΔV maneuver can be found in Section 27. If an axis-by-axis ΔV maneuver is desired, refer to the procedures of Section 28.

b) The downrange and radial components are automatically entered by the flight program and may be verified by reading out addresses 450 and 452, respectively. Since this is a horizontal burn, address 452 will be zero.

9) If a CSI out-of-plane maneuver to reduce the wedge angle between LM and CSM orbit planes is desired, proceed with the following steps. If a normal CSI maneuver (parallel to the CSM orbit plane) is desired, set 451 + 00000 and proceed to execute the CSI maneuver.

Establish CSI out-of-plane guidance

a) Read out address 263 via DEDA. This is the value of V_{py} which is quantized at 0.1 fps lunar scaling (1.0 fps earth scaling). V_{py} is the out-of-CSM plane velocity of the LM at the time of the CSI maneuver.

b) This value, or a fraction of it, is then entered via DEDA into address 451 quantized at 0.1 fps lunar scaling (1.0 fps earth scaling). This sets up the crossrange component for an external ΔV maneuver at CSI time. The sign of the quantity entered in 451 should be the same as that readout in address 263.

Note: If V_{py} as obtained in step (a) is zero, this out-of-plane burn will be identical to the normal in-plane burn.

ALL CSI MANEUVERS WILL BE PERFORMED IN THE EXTERNAL ΔV MODE (DEDA ENTRY 410 + 50000). IT IS SUGGESTED THAT THE EXTERNAL ΔV MODE NOT BE ENTERED UNTIL 4 OR 5 MINUTES PRIOR TO t_{igA}. THIS WOULD ALLOW MONITORING OF CSI PARAMETERS. (EARLY SWITCHING WILL NOT INVALIDATE THE CSI SOLUTION)*

10) After CSI Maneuver

a) Balance Couple Switch ON.

b) Deadband Switch to MAX.

c) Enter via DEDA address 410 + 20000 (CDH guidance mode).

d) Monitor the time to go to CDH maneuver via DEDA address 310 (quantized at 0.01 minute for earth or lunar mission).

*If radar data is entered into the AEA after switching to the External ΔV mode or a navigation update is made, the CSI mode (DEDA entry 410 + 10000) should be reentered and a new CSI solution computed.

THIS QUANTITY IS ONLY VALID WHEN TIME TO GO IS LESS THAN 136 MINUTES.

e) Set Events timer based upon DEDA readout for countdown to CDH.

f) Establish Desired Guidance and Control Configuration for coasting flight.

g) This terminates the CSI procedure.

23.2 In the Event of an Unsatisfactory Solution

A.1 Request new targeting from Mission Control and enter per Step (3).

A.2 Proceed to Step (6).

or

B.1 Generate a new TPI time to get a desirable solution and enter per Step (3). If lighting is an important consideration in the rendezvous a good first guess for a new value of TPI time would be the present value of TPI time plus 125 minutes (lunar mission). This means the TPI would occur approximately 1 orbit later than originally programmed.

B.2 Proceed to Step (6).

23.3 Discussion

The CSI maneuver is a burn performed along the local horizontal parallel to the CSM orbit plane for the normal in-plane option. The CSI out-of-plane option results in a burn which may not be parallel to the CSM orbit plane. The purpose of the maneuver is to create the correct phasing between the LM and CSM such that following the coelliptic maneuver (CDH) the desired line of sight angle between LM and CSM will be achieved at nominal TPI time.

This flight program (FP6) has the feature that CDH follows CSI by one-half or three-halves of a LM orbital period.

A valid CSI computation should not be attempted earlier than 136 minutes before t_{igA} due to computer scaling limitations on T_{Δ}.

Targeting for this maneuver is critical. That is, the phasing between the LM and CSM at CSI time should be such that physically realizable solutions can be obtained. For example, if the CSM is above and far ahead of the LM the computed solution could be a retrograde maneuver that would possibly force pericynthion of the transfer orbit to be lower than "safe pericynthion". On the other hand if the LM is far ahead of the CSM the resultant LM trajectory would be one with apocynthion much higher than the CSM. Subsequent maneuvers by the LM to achieve rendezvous would be costly as far as fuel is concerned.

The line of sight angle is measured from the LM local horizontal plane. The targeted (DEDA input) line of sight angle is always input as the cotangent of the angle between 20 degrees and 70 degrees. In the TPI mode(s), the actual line of sight angle can be monitored via the DEDA. For purposes of this readout the line of sight angle has a range of 0 degree to 360 degrees. The angle convention is as follows:

LM/CSM Phasing	Line of Sight Readout (θ_{LOS})
CSM ahead and above LM	0 degree to 90 degrees
CSM behind and above LM	90 degrees to 180 degrees
CSM behind and below LM	180 degrees to 270 degrees
CSM ahead and below LM	270 degrees to 360 degrees

23.4 Reasonableness of Solutions

After the CSI solution has been obtained, several quantities can be examined to determine the reasonableness of the resultant solution. These quantities are:

ΔV_G	(DEDA Address 267 quantized at 0.1 fps for lunar missions, 1.0 fps for earth missions)	total velocity-to-be-gained magnitude in the CSI maneuver. (Will not contain out-of-plane velocity component until 28J2 is entered.) Limits on this magnitude are mission dependent.
$\dot{r}_A$	(DEDA Address 477, quantized at 0.1 fps for lunar missions, 1.0 fps for earth missions)	LM altitude rate at CSI time. Limits on this magnitude are mission dependent.

V_{p0}	(DEDA Address 371, quantized at 0.1 fps for lunar missions, 1.0 fps for earth missions)	Predicted velocity-to-be-gained at CDH time to make LM orbit coelliptic with CSM orbit. Limit on the magnitude of this maneuver is mission dependent.
T_{A0}	(DEDA Address 372 quantized at 0.1 min)	time from CSI to CDH. This quantity should be approximately 60 or 180 minutes.
Δr	(DEDA Address 402, quantized at 0.1 nmi for lunar missions and earth missions)	Predicted differential altitude at CDH in coelliptic orbit (negative quantity indicates LM higher than CSM).
28J1	(DEDA Address 450 quantized at 0.1 fps for lunar missions, 1.0 fps for earth missions)	Downrange velocity-to-be-gained in the CSI maneuver. Limits on this magnitude are mission dependent. If this quantity is of negative sign the maneuver will be performed in a retrograde manner, in general decreasing pericynthion of the orbit.
θ_f	(DEDA Address 303, quantized at 0.01 deg for lunar missions a and earth missions)	LM to CSM phase angles at CSI time. Limits on this magnitude are mission dependent.
δr	(DEDA Address 314, quantized at 0.1 mni for lunar missions and earth missions)	Differential orbital altitude along LM radial at CSI time.

23.5 Plane Change Maneuver (PCI)

The purpose of a plane change maneuver (PCI) is to create a node at any desired time. A node is defined as that point at which a desired orbital plane crosses the actual orbital plane. A node is created by removing the out-of-plane velocity at a point 90° before the desired nodal point. At the nodal point, another out-of-plane thrusting maneuver is done to cause the two orbital planes to become coplanar. It is recommended that the CSI Routine be used to compute the required out-of-plane velocities. In order to do this, it is necessary to specify the absolute time of the out-of-plane maneuver. For PCI targeting consideration, t_{igA} will represent this time. The following procedure can be used to perform the plane change (PCI) maneuver.

1) Initial Guidance and Control Configuration

PGNCS in Control

a) Guidance Control in "PGNS"

b) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000

c) Other PGNCS Controls as required.

AGS in Control

a) Guidance Control in "AGS"

b) Mode Control in "A/H"

c) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000

2) AGS: Select CSI Routine

DEDA Address 410   Entry + 10000

3) PCI Targeting

Parameter	Address	Entry	Remarks
PCI Time	373		Absolute time of PCI; DEDA least significant digit 0.1 minute.

4) Events Timer

a) Readout DEDA address 310 (minutes, quantized at 0.01 minute), the time to go till the PCI maneuver (TΔ).

b) Set the events timer to this value. Begin countdown to PCI.

5) Establish PCI Out-of-Plane Guidance

a) Enter into address 410 + 50000. The AGS is now in the External ΔV guidance mode. The procedure for executing an External ΔV maneuver can be found in Section 27. If an axis-by-axis ΔV maneuver is desired, refer to the procedures of Section 28.

b) Readout address 263 via DEDA (this is the out-of-CSM plane velocity of the LM at the time of the PCI maneuver). The value of V_{py} is enter via DEDA into address 451 (quantized at 0.1 fps lunar scaling 1.0 fps earth scaling). This sets up the crossrange component for an external ΔV maneuver at PCI time. The sign of the quantity entered in 451 should be the same as that read out in address 263. Set the downrange and radial velocity components (DEDA addresses 450 and 452, respectively) to zero.

6) After PCI Maneuver

a) Balance Couple Switch ON.

b) Deadband Switch to MAX.

c) Establish Desired Guidance and Control Configuration for coasting flight.

d) This terminates the PCI procedure.

24.0 CDH

24.1 Procedures For Using CDH Routine

1) Initial Guidance and Control Configuration

PGNCS in Control

a) Guidance Control in "PGNS"

b) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000

c) Other PGNCS controls as required

AGS in Control

a) Guidance Control in "AGS"

b) Mode Control in "A/H"

c) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000

2) AGS: Select CDH Routine

DEDA Address 410	Entry + 20000

3) AGS Targeting

a) CSI computed maneuver performed immediately prior to CDH selection.

No Targeting Required*

b) Otherwise, after selecting CDH routine, enter AGS absolute time of CDH maneuver t_{igB} (information from Mission Control).

DEDA Address 373	Enter CDH time, in Minutes; DEDA least significant digit 0.1 minute

*The out-of-plane velocity-to-be-gained in the CDH maneuver (28J2) should be set to zero (DEDA entry 451 + 00000) after entering the CDH routine.

4) AGS: Select Engines

DEDA Address 411	Entry +00000 (DPS or RCS)
	Entry +10000 (APS)

5) AGS: Yaw Steering Selection

a) If Z-body axis is to be oriented parallel to the CSM orbit plane verify or enter 623 +00000.

b) If Z-body axis is to be oriented parallel to a specified plane enter 623 +10000 and verify or select the plane with DEDA entries.

Address	Octal Scaling	Description
514	B1	X component of unit vector normal to specified plane
515	B1	Y component of unit vector normal to specified plane
516	B1	Z component of unit vector normal to specified plane

6) Events Timer

a) Readout DEDA address 310 (minutes, quantized at 0.01 minute), time-to-go-to CDH maneuver.

b) Set events timer to this value.

7) CDH Solution Checks

The following quantities can be readout via DEDA to indicate the characteristics of the maneuver.

Equation Symbol	DEDA Address	Quantization and Units (lunar mission)	Quantization and Units (earth mission)	Description
T_Δ	310	0.01 min	0.01 min	time to go until CDH maneuver
$\dot{r}_f$	423	0.1 ft/sec	1.0 ft/sec	desired final value of altitude rate at CDH time

Equation Symbol	DEDA Address	Quantization and Units (lunar mission)	(lunar mission)	Description
ΔV_G	267	0.1 ft/sec	1.0 ft/sec	total velocity-to-be-gained magnitude in CDH maneuver (Not valid until the External ΔV mode has been entered. (Will not contain out-of-plane velocity componentuntil 28J2 is entered.)
Δr	402	0.1 nmi	0.1 nmi	differential altitude between coelliptic orbits
$\dot{r}_A$	477	0.1 fps	1.0 fps	altitude rate of LM at time of CDH
28J1	450	0.1 fps	1.0 fps	downrange velocity-to-be-gained in CDH maneuver
28J3	452	0.1 fps	1.0 fps	radial velocity-to-be-gained in CDH maneuver

8) Establish Guidance System Configuration for CDH Maneuver

   a) Enter into address 410 +50000. The AGS is now in the External ΔV guidance mode. The procedure for executing an External ΔV maneuver can be found in Section 27. If an axis by axis maneuver is desired, refer to the procedures of Section 28.

   b) The downrange and radial components are automatically entered by the flight program and may be verified by reading out addresses 450 and 452, respectively.

9) If a CDH out-of-plane maneuver to reduce the wedge angle between LM and CSM orbit planes is desired, procced with the following steps. If a normal in-plane CDH maneuver is desired, set 451 +00000 and proceed to execute the CDH maneuver.

   a) Read out address 263 via DEDA. This is the value of V_{py} which is quantized at 0.1 fps lunar scaling (1 fps earth scaling). V_{py} is the out-of-CSM plane velocity of the LM at nominal CDH time.

b) This value, or a fraction of it, is then entered via DEDA into address 451 quantized at 0.1 fps lunar scaling (1 fps earth scaling). This sets up the crossrange component for an External ΔV maneuver at CDH time. The sign of the quantity entered in 451 should be the same as that readout in address 263.

NOTE: If V_{py} as obtained in step (a) is zero, this out-of-plane burn will be identical to the normal in-plane burn.

> ALL CDH MANEUVERS WILL BE PERFORMED IN THE EXTERNAL ΔV MODE (DEDA ENTRY 410 + 50000). IT IS SUGGESTED THAT THE EXTERNAL ΔV MODE NOT BE ENTERED UNTIL 4 OR 5 MINUTES PRIOR TO t_{igB}. THIS WOULD ALLOW MONITORING OF CDH PARAMETERS. (EARLY SWITCHING WILL NOT INVALIDATE THE CDH SOLUTION).*

10) After Maneuver

a) Balance Couple Switch ON

b) Deadband Switch to MAX

c) Establish Desired Guidance and Control Configuration for coasting flight.

24.2 Discussion

The "CDH" maneuver is used to place the LM in a trajectory such that the differential altitude between the CSM and LM orbits is essentially a constant. If the CDH maneuver follows the CSI maneuver, no targeting inputs are required. Otherwise, the time of the maneuver must be entered. Prior to the targeted time of CDH, the AGS predicts the maneuver. When real time exceeds the targeted time, however, the system computes the guidance solution on a real time basis.

The CDH maneuver is a burn performed parallel to the CSM orbit plane when the normal in-plane option is used.

It is important to note:

a) Following the CSI maneuver, if CDH is selected prior to receiving a CSM or LM navigation update, then no CDH targeting is required.

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*If radar data is entered into the AEA after switching to the External ΔV mode or a navigation update is made, the CDH mode (DEDA entry 410 + 20000) should be reentered and a new CDH solution computed.

b) If the CSI maneuver does not precede the CDH maneuver, then the AGS absolute time of the CDH maneuver must be inserted via DEDA address 373 (quantized at 0.1 minute).

c) If the CDH maneuver time t_{igB} is greater than 136 minutes from the present time, a valid CDH solution will not be obtained due to computer overflow of T_{Δ}. Note that this may occur if the CDH solution is to be performed three-halves orbital periods following CSI. A valid solution will be obtained, however, when absolute time (t) is within 136 minutes of t_{igB}.

25.0 TPI

The terminal phase initiate (TPI) maneuver begins the direct transfer to rendezvous. There are two direct transfer routines; one primarily for mission planning, the other for computing the maneuver. The latter can also be used for mission planning if desired. In general, the routines are used together in sequence to compute the required TPI maneuver.

In the mission planning mode the object is to determine when the direct transfer should occur. This determination is based upon either achieving the desired line-of-sight angle between the LM and CSM or finding the minimum (acceptable) fuel rendezvous. Once the ignition time is determined, the AGS is switched to the TPI Execute mode to freeze the solution and then to External ΔV for the performance of the maneuver.

25.1 Procedures for Using TPI Routines

1) Initial Guidance and Control Configuration

PGNCS in Control	AGS in Control
a) Guidance Control in "PGNS"	a) Guidance Control in "AGS"
b) DEDA: Enter Guidance Steering Address: 400 Entry: +10000	b) Mode Control in "A/H"
c) Other PGNCS controls as required	c) DEDA: Enter Guidance Steering Address: 400 Entry: +10000

2) TPI Search Procedure

a) Select TPI Search Routine

DEDA Address 410	Entry +30000

b) TPI Search Time Increment Input

Parameter	Address	Entry	Remarks
Time to Go to TPI, T_{Δ}	310		Fixed time from "now" to TPI: DEDA least significant digit 0.01 minute

Note: Time-to-go-to-TPI, address 310, must be entered after TPI Search Routine, entry 410 + 30000. Otherwise the entry is lost. A valid TPI solution should not be attempted earlier than 136 minutes prior to targeted rendezvous time. (Targeted rendezvous time equals $6J + T_{\Delta}$.)

3) Targeting for Direct Transfer

Parameter	Address	Entry	Remarks
Time Duration of Transfer, 6J	307		TPI to Rendezvous, transfer time in minutes. DEDA least significant digit 0.01 min.

4) Search Procedure; Line-of-Sight Angle Search

a) Readout line-of-sight angle via DEDA.

Line-of-Sight Angle, θ_{LOS}	Address 303	Read θ_{LOS}, degrees. DEDA least significant digit 0.01 deg

b) Select TPI Execute Routine when θ_{LOS} achieves desired value (known to flight crew). Time of TPI (t_{igC}) is now selected.

TPI Execute Routine

DEDA Address 410	Entry +40000

c) Set Events Timer

DEDA Address 310	Readout Time-to-go to TPI

Set Event Timer to Correspond to Time-to-go.

d) Go to Step 6).

5) TPI Execute Procedure

a) Select TPI Execute Routine

DEDA Address 410	Entry +40000

b) TPI Execute: AGS Time Entry

Parameter	Address	Entry	Remarks
Targeted Time of TPI burn, t_{igC}	373		AGS absolute time of TPI burn, minutes. DEDA least significant digit 0.1 minutes

6) Select Node

Enter or verify via DEDA Address 306 the time increment prior to rendezvous at which the node is to occur. This time, 4J, should be a positive number quantized at 0.01 minutes.

7) Check the TPI Solution

Equation Symbol	DEDA Address	Lunar Mission Quantization	Earth Mission Quantization	Units	Description
T_r	311	0.01	0.01	min	time to rendezvous
θ_{LOS}	303	0.01	0.01	deg	line of sight angle between LM and CSM
ΔV_G	267	0.1	1.0	fps	velocity-to-be-gained in initial maneuver
V_T	371	0.1	1.0	fps	total velocity-to-be-gained magnitude to rendezvous (only valid if 4J = 0, i.e., node occurs at rendezvous)
q_{1d}	402	0.1	0.1	nmi	transfer orbit pericynthion
t_{igC}	373	0.1	0.1	min	AGS time of TPI

Equation Symbol	DEDA Address	Lunar Mission Quantization	Earth Mission Quantization	Units	Description
T_{Δ}	310	0.01	0.01	min	Time-to-go-to-TPI
4J	306	0.01	0.01	min	Time increment prior to nominal rendezvous time at which the nodal crossing is to occur.
3J	312	0.01	0.01	min	TPI rendezvous offset time
6J	307	0.01	0.01	min	Transfer time from TPI to rendezvous.

If DEDA address 371 reads 6000 the p iterator has not converged to a valid solution. In this situation the rendezvous problem should be retargeted. The best way to proceed (assuming no targeting data available from the earth) would be to change the time to rendezvous by entering a new value into DEDA address 307.

8) AGS: Establish Desired Steering

If thrusting is to be performed with the Z body axis in the desired thrust direction perform the following steps. If not go to Step 9.

a)

DEDA ENTRY	REMARKS
507 + 10000	Specifies Z body axis to be aligned a long desired thrust direction
400 + 20000	Specifies Z body axis steering

b) Go to step 10.

9) AGS: Yaw Steering Selection

a) If Z body axis is to be oriented parallel to the CSM orbit plane verify or enter 623 +00000.

b) If Z body axis is to be oriented parallel to a specified plane enter 623 +10000 and verify or select the plane with DEDA entries.

Address	Octal Scaling	Description
514	B1	X component of unit vector normal to specified plane
515	B1	Y component of unit vector normal to specified plane
516	B1	Z component of unit vector normal to specified plane

10) Establish Guidance System Configuration for TPI Maneuver

Enter into address 410 + 50000. The AGS is now in the External ΔV guidance mode. The procedure for executing an External ΔV maneuver can be found in Section 27. If an axis by axis maneuver is desired, refer to the procedures of Section 28.

ALL TPI MANEUVERS WILL BE PERFORMED IN THE EXTERNAL ΔV MODE (DEDA ENTRY 410 + 50000). IT IS SUGGESTED THAT THE EXTERNAL ΔV MODE NOT BE ENTERED UNTIL 4 OR 5 MINUTES PRIOR TO t_{igC}. THIS WILL ALLOW MONITORING OF TPI PARAMETERS. (EARLY SWITCHING WILL NOT INVALIDATE THE TPI SOLUTION).*

11) After Maneuver

a) Balance Couple Switch ON

b) Deadband Switch to MAX

c) TPI Execute Routine (DEDA Entry 410 + 4000) reentered. See Section 26.0.

d) Establish Desired Guidance and Control Configuration for coasting flight.

25.2 Discussion

a) The TPI maneuver begins the final direct transfer phase to rendezvous. The direct transfer mode is used in the coelliptic rendezvous scheme following the CDH maneuver.

*If radar data is entered into the AEA after switching the External ΔV mode or a navigation update is made, the TPI Search Routine (DEDA entry 410 + 30000) should be reentered and a new TPI solution computed.

The two previous maneuvers (CSI and CDH) are performed such that at the nomi al TPI time the proper phasing between the LM and CSM should exist so that the desired line-of-sight angle is achieved.

Because of errors in the system (sensors, navigation, maneuver execution, etc.) the desired line-of-sight is not achieved at exactly the targeted TPI time. In order to determine when the desired line-of-sight will be achieved and thus when to perform the maneuver, a direct transfer search guidance option is available in the AGS ($S_{10} = 3$). In this mode also, the astro aut can determine total velocity required to rendezvous and perform the TPI maneuver based upon achieving a desirable value of this quantity. The alternate direct transfer guidance mode ($S_{10} = 4$) is used to fix the solution for the maneuver.

The two different modes operate as follows:

$\underline{S_{10} = 3}$

The flight crew introduces an increment of time, T_{Δ}, ahead of the present time t at which he wishes to look at the rendezvous solution. The time at which the TPI maneuver is to occur is always moving ahead 2 sec per 2 sec compute interval because the time of initiation of the burn t_{igC} equals $t + T_{\Delta}$. T_{Δ} is a fixed number and t increments two seconds per 2 second. When the solution is satisfactory, based upon DEDA monitoring of the line of sight angle, S_{10} is set equal to 4 by the flight crew via DEDA.

$\underline{S_{10} = 4}$

Whereas the guidance mode $S_{10} = 3$ is used as a form of "mission planning," the mode $S_{10} = 4$ is used for the fixing of the solution. If the desired rendezvous solution is found with $S_{10} = 3$ and the S_{10} is set to 4, no additional entry of t_{igC} need be inserted in the computer since this is done automatically. If guidance mode $S_{10} = 4$ is used, a value of targeted TPI time (t_{igC}) must be inserted. Many different values of t_{igC} could be tried if the crew desired to do some "mission planning" in this mode and did not care to use the alternate mode. After a value of t_{igC} is inserted, a solution is found in one two-second computing increment. Assuming the value of t_{igC} has been selected (and $S_{10} = 4$) then the quantity T_{Δ} is the time to go until the maneuver. This quantity could be used to set the events timer.

In this mode the capability exists for computing a solution so that thrusting in a given manner will achieve a node (intersection of LM and CSM orbit planes) at a specified time increment prior to nominal rendezvous time. The required time increment, 4J, is entered in DEDA address 306 scaled at 0.01 minutes. If 4J is not zero the indication of total velocity required to rendezvous (DEDA address 371) is not valid. It should be noted that entering a value for 4J only controls the direction of the maneuver and thus need only be entered prior to enabling steering. The advantage to this is that DEDA address 371 can be used as an indication of total velocity required to rendezvous prior to making the 4J entry.

Just as the quantity 4J can be used to create a node, the quantity 3J (DEDA address 312 quantized at 0.01 minutes) can be used to establish the desired relationship between the LM and CSM for a "stable orbit" rendezvous. By entering a time increment, 3J, via DEDA the AGS will calculate the two impulse maneuvers to place the LM on the CSM orbit displaced from the CSM by time 3J. A positive value for 3J will place the LM behind the CSM and a negative value of 3J will place the LM ahead of the CSM.

b) If the TPI maneuver is to occur based upon the desired line-of-sight angle between LM and CSM, then DEDA address 303 (quantized at 0.01 degrees) should be readout to obtain this quantity. When the desired value is obtained, the DEDA entry 410 + 40000 should be made to put the AGS in the TPI Execute mode.

c) If the TPI maneuver is to occur when the total fuel to rendezvous is minimum, a continuous readout of DEDA address 371 (quantized at 0.1 fps for lunar missions, 1.0 fps for earth missions) should be made. When the readout attains its minimum value or when other constraints are being approached (such as lighting) the DEDA entry 410 + 40000 should be made to put the AGS in the TPI Execute mode.

d) If the DEDA readout of address 371 indicates a value of + 6000 fps, a valid solution to the direct transfer problem has not been found. In this case the direct transfer problem has not been found. The 6000 indicates computer overflow or that the iteration procedure has not converged (two seconds required).

e) Prior to the TPI maneuver, when the TPI Execute routine is selected, the AGS time of computed rendezvous (two impulse rendezvous solution) can be computed.

$$\text{time of rendezvous} = 6J + t_{igC}$$

Time-to-go-to rendezvous, T_r, can be read out of the DEDA directly, address 311.

Time-to-go-to nodal crossing can be calculated as $T_r - 4J$.

25. 3 Constraints on TPI Transfer Time

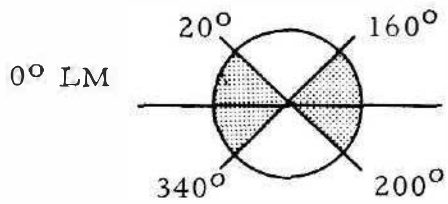
DEDA address 307, (quantized at 0. 01 min) is the desired time from TPI to rendezvous. This time must be so chosen that the rendezvous transfer angle (θ_r)(central angle between LM at TPI initiation and the rendezvous point) lies within the following regions.

For earth missions

$20^\circ \le \theta_r \le 160^\circ$

$200^\circ \le \theta_r \le 340^\circ$

pictorially



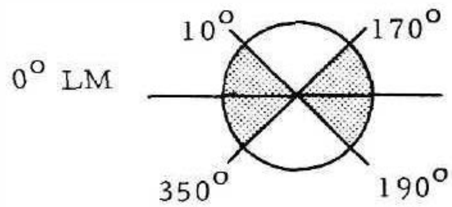
shaded region non-valid

For lunar missions

$10^\circ \le \theta_r \le 170^\circ$

$190^\circ \le \theta_r \le 350^\circ$

pictorially



shaded region non-valid

These conditions are checked internally in the computer, and if found to be violated cause the quantity V_T to be set to 6000. In general, these conditions can be satisfied if DEDA address 307 does not have the following values entered into it.

DEDA Address 307	For earth missions (Based upon 200 nm CSM orbit)	For lunar missions (Based upon 80 nm CSM orbit)
not less than	5 min	3. 5 min
does not lie between	42 min to 53 min 90 min to 100 min	57 min to 65 min
does not exceed	130 min	119 min

The above constraints are imposed to avoid inaccuracy due to indeterminancies existing at the 0°, 180°, and 360° transfer angles.

26.0 MIDCOURSE CORRECTION

To compute the midcourse corrections, use is made of the TPI execute routine ($S_{10} = 4$). There are several ways in which the midcourse maneuver can be targeted.

26.1 Retarget the Entire Rendezvous Problem

a) Determine from the mission plan the required time of initiating the midcourse maneuver, t_{igC}.

b) Determine from the mission plan the required transfer time duration from midcourse to rendezvous, 6J.

c) With the above data, compute a TPI maneuver. Follow the procedures of Section 25.0 for the TPI execute routine ($S_{10} = 4$).

26.2 Maintain the Same Rendezvous Time, Inflight Targeting of New Midcourse Maneuver Time

The flight crew may want to keep the same computed rendezvous point (as used in the TPI maneuver) and perform the midcourse maneuver at a newly specified time, t_{igC}. A procedure that can be used is exactly that of Section 25.0 except for specifying the rendezvous targeting. This can be done in flights as follows:

a) Decide or specify the time t_{igC} that the midcourse maneuver will be performed. This time will be DEDA entered and should be sufficiently later than "present" AGS computer time to permit the desired orientation steering to be performed.

b) From the calculated time of rendezvous (as determined in Section 25.0), calculate 6J, the desired time from midcourse to rendezvous by 6J = time of rendezvous - t_{igC}.

c) Use the new values of 6J and t_{igC} to target the TPI execute routine (Section 25.0).

d) Set or verify that 4J, which specifies time of nodal crossing, is as desired.

26.3 Maintain the Original TPI Rendezvous Problem

If this alternative is used, no new targeting need be done for the midcourse maneuvers.

> THE GUIDANCE MODE SELECTOR (DEDA ADDRESS 410) SHOULD BE RESET TO + 40000 AFTER EXECUTION OF THE TPI MANEUVER IN THE EXTERNAL ΔV GUIDANCE MODE

Since the TPI execute routine operates in real time after the targeted time t_{igC} to achieve rendezvous at the (fixed) rendezvous point, no new targeting entries are required. Perform the direct transfer maneuver at the desired time following the procedure of Section 25.

26.4 Approaching the Node

As indicated above, the capability exists of creating a node 4J minutes prior to nominal rendezvous time. As the node is approached (within 10 degrees for a lunar mission and 20 degrees for the earth missions) the quantity 4J is automatically set to zero and the node is established at the targeted rendezvous time. The purpose of this is to have the midcourse maneuver (at the node) be in such a direction as to cause the LM to be in the CSM plane. When the switchover occurs the LM will be out of the CSM orbit plane by an angle that depends upon the wedge angle between the two trajectories. This is depicted in Figure 26.1. If the midcourse is not performed near the node and the switchover has occured then the maneuver will continue to be computed with the node at the nominal rendezvous point.

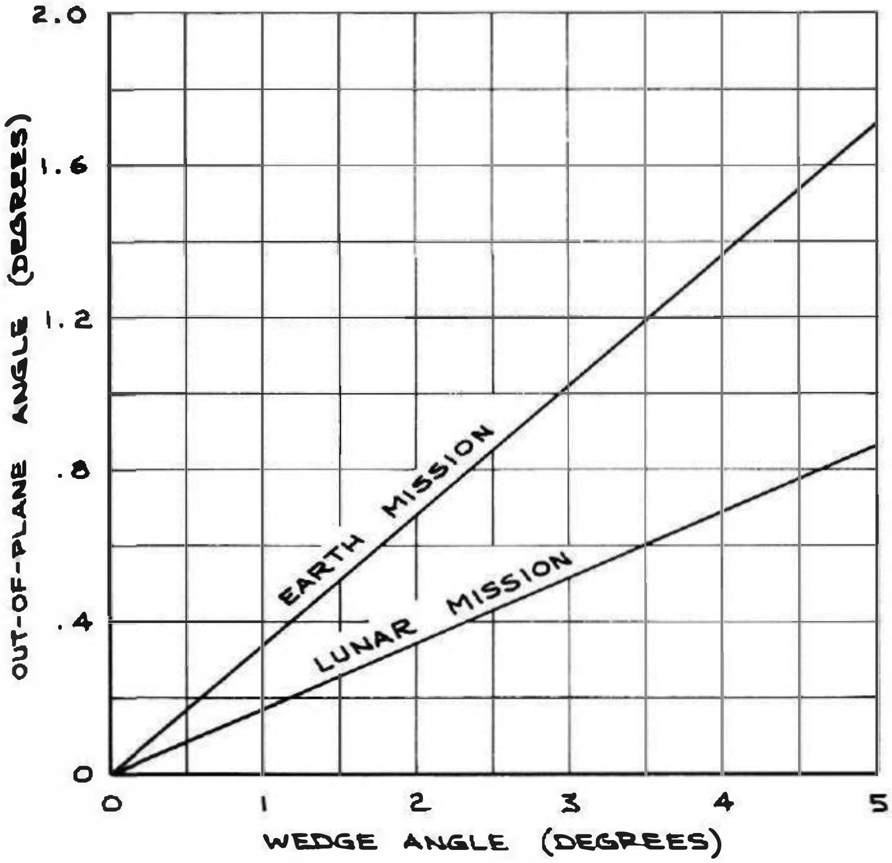


Figure 26.1. Out-of-Plane Angle at Switchover to Node at Rendezvous Versus Wedge Angle for Lunar and Earth Mission

At the time the switchover occurs (4J is set to zero) the desired LM thrust direction will change to cause the node to be created at the rendezvous point. For one two-second compute cycle the guidance solution will be invalid. If the midcourse maneuver is to be performed near the node it is recommended that 4J be examined (DEDA address 306) prior to the maneuver to ascertain that 4J has been set to zero. If not zero either delay the maneuver until switchover has occurred or manually set 4J to zero via DEDA entry 306+00000.

27.0 EXTERNAL ΔV

The external ΔV routine accepts components of a velocity-to-be-gained vector in local vertical coordinates input either via the DEDA or computed in the CSI, CDH or TPI Mode. At the time of maneuver initiation the velocity-to-be-gained vector is "frozen" in inertial space.

27.1 Procedures for Using the External ΔV Routine

1) Initial Guidance and Control Configuration

PGNCS in Control

a) Guidance Control in "PGNS"

b) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000*

c) Other PGNCS controls as required

AGS in Control

a) Guidance Control in "AGS"

b) Mode Control in "A/H"

c) DEDA: Enter Guidance Steering

Address:	400
Entry:	+10000*

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*For Z-Body Axis Steering, set DEDA address 400 to +20000 and DEDA address 507 to +10000.

2) AGS: Select External ΔV Routine

DEDA Address 410	Entry +50000

THE ORDER OF SELECTING THE EXTERNAL ΔV ROUTINE AND TARGETING IS IMPORTANT. AN INVALID EXTERNAL ΔV SOLUTION MAY RESULT IF THE PROPER SEQUENCE IS NOT FOLLOWED

3) AGS Targeting (only done when not coming from CSI, CDH or TPI modes)*

Parameter		Address	Entry	DEDA Least Significant Digit	
				Lunar Mission	Earth Mission
ΔV_x	Component of velocity-to-be-gained vector in the horizontal direction parallel to the CSM orbit plane. A positive value indicates a velocity-to-be-added in the posigrade direction.	450		0.1 fps	1.0 fps
ΔV_y	Component of velocity-to-be-gained vector in the horizontal direction perpendicular to the CSM orbit plane. A positive value indicates a velocity-to-be-added opposite to the LM angular momentum vector.	451		0.1 fps	1.0 fps
ΔV_z	Component of velocity-to-be-gained vector in the radial direction. A positive value indicates a velocity-to-be-added toward the gravitational source.	452		0.1 fps	1.0 fps

*If successive External ΔV maneuvers are to be performed, DEDA address 407 must be set to +00000 as part of the targeting procedure.

4) AGS: Select Engine(s)

DEDA Address 411	Entry +00000 (DPS or RCS) Entry +10000 (APS)

5) Event Timer

Set Event Timer for count-down to External ΔV maneuver initiation.

6) Establish Guidance System Control for Maneuver

PGNS in Control

a) Mode Control to "Auto." Perform normal PGNCS functions.

b) To abort: depress Abort or Abort Stage Button

c) To switch-over to AGS

(i) Guidance Control to AGS

(ii) Verify Abort or Abort Stage

AGS in Control

a) Mode Control to "Auto." (LM now orients to desired thrust attitude).

b) Prior to thrusting verify DEDA address 407 equals +00000 (if +10000, reset to +00000).

c) At Count-Down Time Zero: Initiate and complete selected thrust sequence (see Section 20). Balance Couple Switch as desired.*

d) Trim Burnout Residual. At engine cutoff, the system enters attitude hold. If desired at this time the Balanced Couple Switch can be set or verified ON and the residual burn velocities removed (see Section 28.1).

*If Z-Body Axis Steering has been chosen (DEDA address 400 + 20000), set DEDA address 407 to +10000 just prior to thrusting.

7) After Maneuver

a) Balance Couple Switch ON

b) Deadband Switch to MAX

c) Establish desired Guidance and Control configuration for coasting flight

27.2 Using External ΔV Routine for Orbital Rate Pitch Steering

The AGS has the capability of maintaining the LM vehicle at any attitude in a local vertical coordinate frame during free flight. In particular, the vehicle can be pitched at the orbital rate in order to maintain the X-body axis along the local horizontal. To accomplish this, use is made of the "External ΔV" guidance routine and the procedures of Section 27.1. A fictitious velocity-to-be-gained vector is entered via the DEDA to obtain the desired attitude. Thus, for example, the necessary entries (Step 2, Section 27.1) to maintain the X-body axis along the local horizontal with the z axis downward are the following (earth or lunar mission):

Address	Value
450	+05000
451	+00000
452	+00000

Since thrusting is not to be performed, steps 6c and 6d are unnecessary.

IF ULLAGE IS SENSED WHILE IN THIS CONFIGURATION THE VEHICLE ATTITUDE WILL BECOME FIXED IN INERTIAL SPACE

Orbital rate steering would again be achieved by entering via DEDA address 407 + 00000.

28.0 AXIS BY AXIS TRIM

After any maneuver the residual velocity-to-be-gained can be reduced by placing the vehicle in attitude hold and performing translational thrusting along each axis. This procedure can also be used to perform small ΔV maneuvers if desired. It should be recognized however that thrusting successively along each axis requires more fuel than thrusting with one engine along the desired direction.

FOR AXIS BY AXIS TRIM OR RESIDUAL REMOVAL, THE Y AND Z BODY COMPONENTS OF VELOCITY-TO-BE-GAINED ARE TO BE REMOVED PRIOR TO REMOVING THE X COMPONENT.

28.1 Procedure

1) Verify that the AGS is in Attitude Hold: i. e., Mode Control in "A/H" or DEDA selection 400 + 00000.

2) Set deadband switch to MIN

3) Set balanced couple switch to ON.

4) If necessary, verify via DEDA readout (address 410) that the system is in the External ΔV guidance routine.

5) Set ATT/Translation switch to "2 jet" position.

6) Set throttle/jet control select level of desired crew member to "jet" position.

7) Set DEDA address 407 to + 10000.

8) Readout velocity-to-be-gained in Y direction via DEDA address 501. (ΔV_{gY})

9) Null out DEDA reading by moving related thrust/translation controller to right (or left). Right (left) corresponds to Y translation which nulls positive (negative) values of ΔV_{gY}.

10) Readout velocity-to-be-gained in Z direction via DEDA address 502. (ΔV_{gZ}).

11) Null out DEDA reading by moving related thrust/controller in (or out). In (out) corresponds to Z translation which nulls positive (negative) values of ΔV_{gZ}.

12) Readout velocity-to-be-gained in X direction via DEDA address 500. (ΔV_{gX})

13) Null out the DEDA reading by moving related thrust/translation controller up (or down). Up (down) corresponds to X translation which nulls positive (negative) values of ΔV_{gX}.

14) Set deadband to MAX.

28.2 Notes

1) If this trim procedure is utilized after orbit insertion it should be done immediately. This is because the orbit insertion equations are designed to drive the LM to a particular point on the desired orbit. Thus as time goes by, the computer will indicate an increasing velocity-to-be-gained (even if cutoff were perfect) since the vehicle is departing from the injection point.

2) If the axis by axis procedure is used to perform an external ΔV maneuver and the first burn is not in the +X-body axis direction, then DEDA entry 407 + 10000 must be made to freeze the targeted external ΔV vector in inertial space (see Section 27.0). The time at which the burn is initiated, affects the orbit parameters of the ensuing trajectory. Hence targeting for an axis-by-axis External ΔV maneuver must include the time when DEDA entry 407 + 10000 is to be executed (if required) as well as the time for thrust initiation.

APPENDIX A

DEDA ACCESSIBLE QUANTITIES

The following tables are complete lists of the meaningful quantities available for entry or readout via DEDA. The decimal region quantities are grouped by scaling; i.e., all velocity quantities with a quantization of 0.1 ft/sec are listed together, and etc. Both lunar and earth mission scaling are given in the form lunar/earth. For example, V_{py} which is located at address 263 has a lunar mission binary scaling of B13, a lunar DEDA range of 8191.9 ft/sec and a lunar DEDA quantization of 0.1 ft/sec.

The octal region quantities are presented in numerical order of their addresses. The binary scaling is given for both lunar and earth missions. One number in the scale column indicates the same binary scaling for both lunar and earth missions.

The right hand columns on these lists indicate the guidance modes in which each quantity is meaningful. For example, R5X at address 174 is computed in the OI, CSI, CDH and TPI guidance modes.

Time shared locations are omitted from these lists since DEDA readouts are not easily interpreted when two quantities are alternately displayed.

DEDA AVAILABLE PARAMETERS
DECIMAL REGION
--------FP6------FP6-------
BINARY SCALING LUNAR/EARTH 23/25
DEDA RANGE 8,388,600/33,554,000 FEET
DEDA QUANTIZATION 100/1000 FEET

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
			(0 = NOT AVAILABLE)				
R5X	174	LM PREDICTED POSITION VECTOR AT CSI,CDH,	1	1	1	1	0
R5Y	175	OR TPI BURN TIME, PRESENT R IN O.I.	1	1	1	1	0
R5Z	176		1	1	1	1	0
AL	177	PREDICTED LM SEMI-MAJOR AXIS.	1	1	1	0	0
REX	200	CSM EPOCH POSITION VECTOR.	1	1	1	1	1
REY	201		1	1	1	1	1
REZ	202		1	1	1	1	1
RT	203	PREDICTED CSM POSITION MAGNITUDE.	1	1	1	1	1
ROX	204	POSITION VECTOR INPUT TO ORBIT PARAMETER	1	1	1	1	1
ROY	205	SUBROUTINE.	1	1	1	1	1
ROZ	206		1	1	1	1	1
RO	207	PREDICTION POSITION MAGNITUDE.	1	1	1	1	1
R	210	LM PRESENT INERTIAL POSITION MAGNITUDE.	1	1	1	1	1
Y	211	LM OUT OF PLANE POSITION.	1	1	1	1	1
POUTFS	213	MAX P DISPLAYABLE.	1	1	1	1	1
2K3	216	OL SET ON OVERFLOW.	1	1	1	1	1
2K14	217	INITIAL P PERTURBATION.	1	1	1	1	1
25J	223	DEDA ENTRY FOR ALTITUDE UPDATE.	1	1	1	1	1
7J	224	TERM IN O.I. SEMIMAJOR AXIS.	1	1	1	1	1
8J	225	PRED. O.I. LM SEMI-MAJOR AXIS LOWER LIMIT.	1	1	1	1	1
9J	226	PRED. O.I. LM SEMI-MAJOR AXIS UPPER LIMIT.	1	1	1	1	1
2K19	230	DELTA P LIMITER.	1	1	1	1	1
5J	231	NOMINAL LUNAR LANDING SITE RADIUS.	1	1	1	1	1
16J	232	TARGETED ORBIT INSERTION ALTITUDE.	1	1	1	1	1
21J	233	VERTICAL PITCH STEERING ALT THRESHOLD.	1	1	1	1	1
1J1	240	LM EPHEMERIS POSITION (X COMPONENT).	1	1	1	1	1
1J2	241	LM EPHEMERIS POSITION (Y COMPONENT).	1	1	1	1	1
1J3	242	LM EPHEMERIS POSITION (Z COMPONENT).	1	1	1	1	1
2J1	244	CSM EPHEMERIS POSITION (X COMPONENT).	1	1	1	1	1
2J2	245	CSM EPHEMERIS POSITION (Y COMPONENT).	1	1	1	1	1
2J3	246	CSM EPHEMERIS POSITION (Z COMPONENT).	1	1	1	1	1

DEDA AVAILABLE PARAMETERS
DECIMAL REGION

--------FP6------FP6-------

BINARY SCALING LUNAR/EARTH 23/25
DEDA RANGE 8,388,600/33,554,000 FEET
DEDA QUANTIZATION 100/1000 FEET

SYMBOL	ADD	DEFINITION	(0 = NOT AVAILABLE) DIN	CSI	CDH	TPI	XDV
RX	340	LM POSITION VECTOR.	1	1	1	1	1
RY	341		1	1	1	1	1
RZ	342		1	1	1	1	1
RCX	344	CSM PRESENT POSITION VECTOR.	1	1	1	1	1
RCY	345		1	1	1	1	1
RCZ	346		1	1	1	1	1
RF	347	PRED. LM ALT. AT TIG	0	1	1	1	0
		--------FP6------FP6------- BINARY SCALING LUNAR/EARTH 23/25 (FEET) DEDA RANGE 1379.6/5518.4 NAUTICAL MILES DEDA QUANTIZATION 0.1/0.1 NAUTICAL MILES					
DELRP	314	LM-CSM DIFFERENTIAL ALTITUDE AT TIG.	0	1	1	0	0
QA	315	COMPUTED LM APOFOCUS ALTITUDE.	1	1	1	1	1
18J	316	RADAR RANGE.	1	1	1	1	1
RR	317	COMPUTED RANGE.	1	1	1	1	1
H	337	LM ALTITUDE.	1	1	1	1	1
DELH	402	LM-CSM DIFFERENTIAL ALTITUDE AFTER CDH.	0	1	1	0	0
Q1DEDA	402	LM TRANSFER ORBIT PERICYTHION ALTITUDE.	0	0	0	1	0
QLTELE	403	LM PRESENT PERICYTHION ALTITUDE.	1	1	1	1	1
		--------FP6------FP6------- BINARY SCALING LUNAR/EARTH 13/15 DEDA RANGE 8191.9/32767 FT/SEC DEDA QUANTIZATION 0.1/1 FT/SEC					
1J4	260	LM INITIAL VELOCITY (X COMPONENT).	1	1	1	1	1
1J5	261	LM INITIAL VELOCITY (Y COMPONENT).	1	1	1	1	1
1J6	262	LM INITIAL VELOCITY (Z COMPONENT).	1	1	1	1	1
VPY	263	OUT-OF-PLANE VEL. AT TIG(AT PRES.IN O.I.).	1	1	1	1	0
2J4	264	CSM INITIAL VELOCITY (X COMPONENT).	1	1	1	1	1
2J5	265	CSM INITIAL VELOCITY (Y COMPONENT).	1	1	1	1	1
2J6	266	CSM INITIAL VELOCITY (Z COMPONENT).	1	1	1	1	1
DELVG	267	VELOCITY TO GAIN MAGNITUDE.	1	1	0	1	1
VYO	270	LM PRESENT OUT-OF-PLANE VELOCITY.	1	1	1	1	1

DEDA AVAILABLE PARAMETERS
DECIMAL REGION
-------FP6-----FP6-------
BINARY SCALING LUNAR/EARTH 13/15
DEDA RANGE 8191.9/32767 FT/SEC
DEDA QUANTIZATION 0.1/1 FT/SEC

SYMBOL	ADD	DEFINITION	(0 = NOT AVAILABLE) OIN	CSI	CDH	TPI	XDV
VX	360	PRESENT LM INERTIAL VELOCITY VECTOR.	1	1	1	1	1
VY	361		1	1	1	1	1
VZ	362		1	1	1	1	1
VCX	364	PRESENT CSM INERTIAL VELOCITY VECTOR.	1	1	1	1	1
VCY	365		1	1	1	1	1
VCZ	366		1	1	1	1	1
HDOT	367	LM ALTITUDE RATE.	1	1	1	1	1
VG	370	VELOCITY TO GAIN MAGNITUDE.	1	1	0	1	1
VPO	371	PREDICTED VELOCITY-TO-BE-GAINED IN CDH.	0	1	0	0	0
VT	371	TOTAL VELOCITY REQUIRED FOR RENDEZVOUS.	0	0	0	1	0
VEX	420	CSM EPOCH VELOCITY VECTOR.	1	1	1	1	1
VEY	421		1	1	1	1	1
VEZ	422		1	1	1	1	1
RFDOT	423	DESIRED ALTITUDE RATE.	1	1	1	1	0
VOX	424	VELOCITY VECTOR INPUT TO ORBIT PARAMETER	1	1	1	1	1
VOY	425	SUBROUTINE.	1	1	1	1	1
VOZ	426		1	1	1	1	1
VH	427	PRESENT LM HORIZONTAL VELOCITY.	1	1	1	1	1
V	433	PRESENT LM VELOCITY.	1	1	1	1	1
RRDOT	440	ESTIMATED RANGE RATE BETWEEN CSM AND LM.	1	1	1	1	1
RDOTS	441	RANGE RATE AT TIME OF RADAR UPDATE.	1	1	1	1	1
28J1	450	DELTA V DOWNRANGE. EXTERNAL	0	1	1	0	1
28J2	451	DELTA V CROSSRANGE. DELTA V	0	1	1	0	1
28J3	452	DELTA V RADIAL. INPUTS	0	1	1	0	1
4K26	454	VG THRESHOLD.	1	1	1	1	1
VHA	463	HORIZ. VEL. AT TIG(AT PRESENT IN O.I.).	1	1	1	1	0

DEDA AVAILABLE PARAMETERS
DECIMAL REGION

--------FP6-----FP6-------

BINARY SCALING LUNAR/EARTH 13/15
DEDA RANGE 8191.9/32767 FT/SEC
DEDA QUANTIZATION 0.1/1 FT/SEC

(O = NOT AVAILABLE)

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
22J	464	VERT PITCH STEERING ALT RATE THRESHOLD.	1	1	1	1	1
23J	465	RFDOT LOWER LIMIT.	1	1	1	1	1
5K26	466	THRESHOLD FOR FREEZING THRUST DIRECTION.	1	1	1	1	1
VDX	470	ACCUMULATED TOTAL OF SENSED VELOCITY	1	1	1	1	1
VDY	471	INCREMENTS UPDATED EVERY 2 SEC.	1	1	1	1	1
VDZ	472		1	1	1	1	1
4K27	473	DESCENT STAGE DELTA V CAPABILITY.	1	1	1	1	1
VSMGX	474	COMPONENTS OF TOTAL VELOCITY-TO-BE-	1	1	1	1	1
VSMGY	475	GAINED DURING A BURN.	1	1	1	1	1
VSMGZ	476		1	1	1	1	1
RADOT	477	RADIAL VELOCITY AT TIG(AT PRESENT IN O.I.)	1	1	1	1	0
DELVGX	500	INCREMENTS OF TOTAL VELOCITY-TO-BE-	1	1	1	1	1
DELVGY	501	GAINED DURING BURN.	1	1	1	1	1
DELVGZ	502		1	1	1	1	1
17J	503	RANGE RATE INPUT (RADAR).	1	1	1	1	1

--------FP6-----FP6-------

BINARY SCALING LUNAR/EARTH 13/13
DEDA RANGE 136.5/136.5 MIN
DEDA QUANTIZATION 0.01/0.01 MIN

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
4J	306	TIME OF NODE PRIOR TO RENDEZVOUS.	0	0	0	1	0
6J	307	DESIRED TRANSFER TIME.	1	1	1	1	1
TDEL	310	TIME FROM PRESENT TO CSI, CDH, OR TPI.	0	1	1	1	0
TR	311	TIME FROM PRESENT TO RENDEZVOUS.	0	0	0	1	0
3J	312	TARGET OFFSET TIME.	1	1	1	1	1
TPERG	313	COMPUTED TIME TO LM PERIFOCUS.	1	1	1	1	1

DEDA AVAILABLE PARAMETERS
DECIMAL REGION
--------FP6-----FP6--------
BINARY SCALING LUNAR/EARTH 18/18
DEDA RANGE 4369/4369 MIN
DEDA QUANTIZATION 0.1/0.1 MIN

(0 = NOT AVAILABLE)

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
1J7	254	LM EPOCH.	1	1	1	1	1
2J7	272	CSM EPOCH.	1	1	1	1	1
2[illegible]J	274	INITIAL VALUE OF TI FOR RADAR FILTER.	1	1	1	1	1
1J	275	DESIRED TIME OF TPI MANEUVER FOR CSI.	1	1	1	1	1
DELTAT	276	TIME BETWEEN RADAR RANGE UPDATES.	1	1	1	1	1
TA0	372	TIME FROM CSI TO CDH.	0	1	0	0	0
TIG	373	ABSOLUTE TIME OF NEXT MANEUVER.	1	1	1	1	1
TA1	377	AGS ABSOLUTE TIME.	1	1	1	1	1

--------FP6-----FP6--------
BINARY SCALING LUNAR/EARTH 3/3
DEDA RANGE 360/360 DEG
DEDA QUANTIZATION 0.01/0.01 DEG

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
XT	277	Z AXIS/LOCAL HORIZONTAL ANGLE.	1	1	1	1	1
TLOS	303	COMPUTED LOS.	0	0	0	1	0
THETAF	303	LM-CSM CENTRAL ANGLE AT TIG.	[illegible]	1	1	0	0

--------FP6-----FP6--------
BINARY SCALING LUNAR/EARTH 1/3
DEDA RANGE .064/.064 FT/SEC SQUARED
DEDA QUANTIZATION .001/.01 FT/SEC SQUARED

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
1K19	540	X ACCELEROMETER BIAS COMPENSATION.	1	1	1	1	1
1K21	541	Y ACCELEROMETER BIAS COMPENSATION.	1	1	1	1	1
1K23	542	Z ACCELEROMETER BIAS COMPENSATION.	1	1	1	1	1

DEDA AVAILABLE PARAMETERS
DECIMAL REGION

-------FP6-----FP6-------

BINARY SCALING LUNAR/EARTH -13/-13
DEDA RANGE 10/10 DEG/HR
DEDA QUANTIZATION 0.01/0.01 DEG/HR

(0 = NOT AVAILABLE)

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
1K1	544	X GYRO DRIFT COMPENSATION.	1	1	1	1	1
1K6	545	Y GYRO DRIFT COMPENSATION.	1	1	1	1	1
1K11	546	Z GYRO DRIFT COMPENSATION.	1	1	1	1	1

-------FP6-----FP6-------

BINARY SCALING LUNAR/EARTH 17/17
DEDA RANGE 131072/131072 COUNTS
DEDA QUANTIZATION 1/1 COUNT

SYMBOL	ADD	DEFINITION	OIN	CSI	CDH	TPI	XDV
MU8	614	ULLAGE COUNTER(2SEC COUNT).	1	1	1	1	1
1K9	616	ULLAGE COUNTER THRESHOLD(2SEC COUNT).	1	1	1	1	1
1K30	617	GYRO CALIB. TIME DURATION(2SEC COUNT).	1	1	1	1	1
2K17	620	NUMBER OF P-ITERATIONS-3.	1	1	1	1	1
1K37	621	ACCELEROMETER CALIB. TIME DURATION(2SEC).	1	1	1	1	1
4K23	622	STEERING DELAY AFTER STAGING(40MSEC COUNT).	1	1	1	1	1

DEDA AVAILABLE PARAMETERS
OCTAL REGION
-------FP6-----FP6-------

SYMBOL	ADD	LUN/EARTH SCALE	DEFINITION	OIN	CSI	CDH	TPI	XDV
				(0 = NOT AVAILABLE)				
C2	033	1	RENDEZVOUS ANGLE SINE.	0	0	0	1	0
V1X	034	1	LM IN-PLANE HORIZONTAL UNIT VECTOR	1	1	1	1	1
V1Y	035	1	AT TIG FOR CSI,CDH AND TPI,AT PRESENT	1	1	1	1	1
V1Z	036	1	FOR OI,XDV.	1	1	1	1	1
W1X	040	1	LM OUT-OF-PLANE UNIT VECTOR AT TIG FOR	1	1	1	1	1
W1Y	041	1	TPI, OTHERWISE CURRENT.	1	1	1	1	1
W1Z	042	1		1	1	1	1	1
A31S	044	1	RADAR NULL DIRECTION COSINES.	1	1	1	1	1
A32S	045	1		1	1	1	1	1
A33S	046	1		1	1	1	1	1
SIDELL	047	1	SINE OF AZIMUTH ANGLE.	1	1	1	1	1
CODELL	053	1	COSINE OF AZIMUTH ANGLE.	1	1	1	1	1
WCX	054	1	OUT-OF-CSM ORBIT PLANE UNIT VECTOR	1	1	1	1	1
WCY	055	1		1	1	1	1	1
WCZ	056	1		1	1	1	1	1
U1X	060	1	NORMALIZED LM POSITION VECTOR AT TIG	1	1	1	1	1
U1Y	061	1	FOR CSI,CDH AND TPI, AT PRESENT FOR	1	1	1	1	1
U1Z	062	1	OI AND XDV.	1	1	1	1	1
AT	067	7/9	THRUST ACCELERATION (FT/SEC SQ).	1	1	1	1	1
DRX	104	14/16	LM POSITION REMAINDERS (FEET).	1	1	1	1	1
DRY	105	14/16		1	1	1	1	1
DRZ	106	14/16		1	1	1	1	1

DEDA AVAILABLE PARAMETERS
OCTAL REGION
-------FP6-----FP6-------

SYMBOL	ADD	LUN/EARTH SCALE	DEFINITION	OIN	CSI	CDH	TPI	XDV
				(0 = NOT AVAILABLE)				
THEP	107	15	PGNS THETA (PULSES).	1	1	1	1	1
PSIP	113	15	PGNS PSI (PULSES).	1	1	1	1	1
PHIP	117	15	PGNS PHI (PULSES).	1	1	1	1	1
DIGX	110	7/9	PREDICTED CHANGE IN INTEGRATED	1	1	1	1	1
DIGY	111	7/9	GRAVITY (FPS).	1	1	1	1	1
DIGZ	112	7/9		1	1	1	1	1
GXDT	114	7/9	GRAVITY TIMES MAJOR CYCLE TIME (FPS).	1	1	1	1	1
GYDT	115	7/9		1	1	1	1	1
GZDT	116	7/9		1	1	1	1	1
DVSX	120	7/9	RESOLVED SENSED DELTA VELOCITIES	1	1	1	1	1
DVSY	121	7/9	ALONG INERTIAL AXES (FPS).	1	1	1	1	1
DVSZ	122	7/9		1	1	1	1	1
SIGA	123	1	SINE OF FDAI GAMMA.	1	1	1	1	1
RRX	124	23/25	COMPUTED LM-CSM RANGE (FT).	1	1	1	1	1
RRY	125			1	1	1	1	1
RRZ	126			1	1	1	1	1
COGA	127	1	COSINE OF FDAI GAMMA.	1	1	1	1	1
A11	130	1	XB DIRECTION COSINES.	1	1	1	1	1
A12	131	1		1	1	1	1	1
A13	132	1		1	1	1	1	1
A21	140	1	YB DIRECTION COSINES.	1	1	1	1	1
A22	141	1		1	1	1	1	1
A23	142	1		1	1	1	1	1
A31	134	1	ZB DIRECTION COSINES.	1	1	1	1	1
A32	135	1		1	1	1	1	1
A33	136	1		1	1	1	1	1
T1	147	18	TIME OF LAST RADAR RANGE UPDATE (SEC).	1	1	1	1	1
A11D	160	1	XD DIRECTION COSINES.	1	1	1	1	1
A12D	161	1		1	1	1	1	1
A13D	162	1		1	1	1	1	1
A31D	164	1	ZD DIRECTION COSINES.	1	1	1	1	1
A32D	165	1		1	1	1	1	1
A33D	166	1		1	1	1	1	1
MU17	167	17	FILTER CYCLE COUNTER(2SEC COUNTS).	1	1	1	1	1

DEDA AVAIABLE PARAMETERS

OCTAL REGION

--------FP6-----FP6-------

SYMBOL	ADD	LUN/EARTH SCALE	DEFINITION	DIN	CSI	CDH	TPI	XDV
ALPHA	171	23/25	XFR ORBIT SEMI-MAJOR AXIS(FT).	0	0	0	1	0
S0	400	3	AGS FUNCTION SELECTOR.	1	1	1	1	1
DISC1C	401	8	DISCRETE WORD ONE.	1	1	1	1	1
S7	407	3	REFERENCE FRAME SELECTOR FOR EXT DV.	0	0	0	0	1
S10	410	3	GUIDANCE MODE SELECTOR.	1	1	1	1	1
S11	411	3	CANT ANGLE CORRECTION SELECTOR.	1	1	1	1	1
S12	412	3	IN FLIGHT SELF TEST STATUS INDICATOR.	1	1	1	1	1
S13	413	3	STORE/NO STORE LUNAR AZIMUTH SELECTOR.	1	1	1	1	1
S14	414	3	NAVIGATION INITIALIZE.	1	1	1	1	1
S15	415	3	RADAR GIMBAL NULL.	1	1	1	1	1
S16	416	3	NBR OF LM HALF-ORBITS FROM CSI TO CDH.	1	1	1	1	1
S17	417	3	RADAR FILTER INITIALIZE.	1	1	1	1	1
RD3DOT	504	-2/0	DESIRED RADIAL JERK (FT/SEC CUBED).	1	0	0	0	0
YD3DOT	505	-2/0	DESIRED OUT-OF-PLANE JERK(FT/SEC CUBED)	1	0	0	0	0
4K12	506	7/9	ACCEL CHECK FOR RD3DTL IN O.I.	1	1	1	1	1
S507	507	3	ORIENT Z BODY AXIS TO THRUST AXIS	1	1	1	1	1
C1	513	1	RENDEZVOUS ANGLE COSINE.	0	0	0	1	0
WBX	514	1	UNIT VECTOR INPUT FOR COMMANDING	1	1	1	1	1
WBY	515	1	YAW WHEN S00 = 1.	1	1	1	1	1
WBZ	516	1		1	1	1	1	1
6K10	517	28/32	RADAR FILTER RANGE VARIANCE(FT SQRD).	1	1	1	1	1
TE1	520	18	CSM EPOCH MS (SEC).	1	1	1	1	1
TL1	521	18	LM EPOCH MS (SEC).	1	1	1	1	1
6K6	522	8	RADAR FILTER VY WEIGHT(NO UNITS).	1	1	1	1	1
5K20	523	-2	RD3DOT LOWER LIMIT TERM(1/SEC)	1	1	1	1	1
TE2	524	1	CSM EPOCH LS (SEC).	1	1	1	1	1
TL2	525	1	LM EPOCH LS (SEC).	1	1	1	1	1
2K11	526	13/15	SET VALUE OF VT (FPS).	1	1	1	1	1
4K6	527	13/15	RFDOT UPPER LIMIT (FPS).	1	1	1	1	1
DAXA	530	-6	X-AXIS ALIGNMENT ERROR SIGNALS(RAD).	1	1	1	1	1
DAYA	531	-6	Y-AXIS ALIGNMENT ERROR SIGNALS(RAD).	1	1	1	1	1
DAZA	532	-6	Z-AXIS ALIGNMENT ERROR SIGNALS(RAD).	1	1	1	1	1

(0 = NOT AVAILABLE)

DEDA AVAILABLE PARAMETERS

OCTAL REGION

-------FP6-----FP6-------

SYMBOL	ADD	LUN/EARTH SCALE	DEFINITION
DISC1	533	8	DISCRETE WORD ONE COMPLEMENT.
1K18	534	-8/-6	X-AXIS ACCEL SCALE FACTOR(FPS/PULSE).
1K20	535	-8/-6	Y-AXIS ACCEL SCALE FACTOR(FPS/PULSE).
1K22	536	-8/-6	Z-AXIS ACCEL SCALE FACTOR(FPS/PULSE).
1K14	537	-14/-16	X-AXIS MASS UNBAL COMP (RAD/FPS).
DDEL	547	0	LUNAR ALIGN CORRECTION(RAD).
1K3	550	-7	X-GYRO SCALE FACTOR COMPENSATION.
1K8	551	-7	Y-GYRO SCALE FACTOR COMPENSATION.
1K13	552	-7	Z-GYRO SCALE FACTOR COMPENSATION.
HRF	553	--	HIGH(+)LOW(-)ANGULAR RATE SCALING.
5K14	560	-2/0	RD3DOT UPPER LIMIT(FPS CUBED).
5K16	561	-2/0	YD3DOT UPPER LIMIT(FPS CUBED).
DLWN	562	17	DOWNLINK WORD COUNTER.
DLIF	563	--	DL INITIALIZE FLAG (- IS ENABLE).
5K18	564	-2/0	RD3DOT LOWER LIMIT TERM(FT/SEC CUBED).
4K4	565	-7	FACTOR IN REDOT FOR O.I.(1/SEC).
4K7	566	0	PITCH CANT ANGLE (RAD).
DSPF1	567	--	DISPLAY FLAG (- IS NAV UPDATE CYCLE).
ID1F	570	--	DL ID1 (RECEIVED IF NEG).
IDRF	571	--	DL INPUT (COMPLETE IF NEG).
FLAGT	572	--	MEMORY TEST (TEST IF NEG).
FLAG1	573	--	20 MS BRANCH CONTROL.
DEL2	574	--	STAGED FLAG (- IS STAGED).
DEL5	575	--	ATT HOLD FLAG (- IS HOLD).
DEL6	576	--	FLAG CAUSING PGNCS/AGS ALIGN BEFORE CALIBRATION.
DEL10	577	--	TPI LOGIC FLAG.
RD3DTL	600	-2/0	RD3DOT LOWER LIMIT(FPS CUBED).
5K17	601	-2/0	YD3DOT LOWER LIMIT(FPS CUBED).

THE AVAILABILITY OF PARAMETERS ON THIS PAGE IS INDEPENDENT OF THE GUIDANCE MODE.

DEDA AVAILABLE PARAMETERS
OCTAL REGION
--------FP6------FP6-------

SYMBOL	ADD	LUN/EARTH SCALE	DEFINITION	(0 = NOT AVAILABLE) OIN	CSI	CDH	TPI	XDV
4K8	602	0	YAW CANT ANGLE(RAD).	1	1	1	1	1
DEL20	603	--	LOGIC FLAG FOR ENGINE CONTROL.	1	1	1	1	1
DEL21	604	--	LUNAR SURFACE FLAG (- IS LUN SURF).	1	1	1	1	1
2J	605	2	COTAN OF DESIRED LINE OF SIGHT ANGLE.	1	1	1	1	1
K55	607	0	SCALE FACTOR FOR HDOT DISPLAY	1	1	1	1	1
6K9	611	-10	RADAR FILTER ANGULAR VAR.(RAD SQUARED).	1	1	1	1	1
MU6	612	17	STAGING COUNTER(40MSEC COUNTS).	1	1	1	1	1
3K4	613	1	CENTRAL ANGLE LIMIT IN TPI.	1	1	1	1	1
S623	623	3	CREW SELECTION OF STEERING VECTOR.	1	1	1	1	1
1K4	624	0	ALT, ALT RATE DISPLAY CONSTANT.	1	1	1	1	1
1K24	625	1	SINGULARITY THRESHOLD, FDAI COMP(RAD).	1	1	1	1	1
1K26	626	8	X-AXIS ALIGNMENT GAIN CONSTANT(1/RAD).	1	1	1	1	1
1K27	627	-4/-6	LUNAR ALIGN CONSTANT(RAD/FPS).	1	1	1	1	1
1K28	630	7	LUNAR ALIGN CONSTANT(1/RAD).	1	1	1	1	1
1K29	631	- 4	LUNAR ALIGN STOP CRITERION (RAD).	1	1	1	1	1
1K33	632	- 3	CALIBRATE GAIN CONSTANT.	1	1	1	1	1
1K34	633	-15	CALIBRATE GAIN CONSTANT(1/20 MS).	1	1	1	1	1
1K35	634	7/9	NAVIGATION SENSED ACCEL THRESHOLD(FPS).	1	1	1	1	1
1K36	635	0	ACCEL CALIB GAIN CONSTANT.	1	1	1	1	1
2K1	636	48/54	GRAVITATIONAL CONSTANT(FT CUBED/SEC SQ).	1	1	1	1	1
2K2	637	-47/-53	1/2K1	1	1	1	1	1
P11	640	30	RADAR FILTR X VARIANCE (FT SQUARED).	1	1	1	1	1
P12	641	30	X-Z COVARIANCE (FT SQRD).	1	1	1	1	1
P13	642	20	X-VX COVARIANCE (FT SQ/SEC).	1	1	1	1	1
P14	643	20	X-VZ COVARIANCE (FT SQ/SEC).	1	1	1	1	1
P21	644	30	Z-X COVAR.(FT SQUARED).	1	1	1	1	1
P22	645	30	Z VAR.(FT SQUARED).	1	1	1	1	1
P23	646	20	Z-VX COVAR.(FT SQ/SEC).	1	1	1	1	1
P24	647	20	Z-VZ COVAR.(FT SQ/SEC).	1	1	1	1	1
P33	650	10	VX VAR.(FT SQ/SEC SQ).	1	1	1	1	1
P34	651	10	VX-VZ COVAR.(FT SQ/SEC SQ).	1	1	1	1	1
P43	652	10	VZ-VX COVAR.(FT SQ/SEC SQ).	1	1	1	1	1
P44	653	10	VZ VARIANCE (FT SQ/SEC SQ).	1	1	1	1	1

DEDA AVAILABLE PARAMETERS
OCTAL REGION
--------FP6-----FP6-------

SYMBOL	ADD	LUN/EARTH SCALE	DEFINITION
4K2	654	-12/-14	FACTOR IN TB,TIME TO BURN,COMP.(1/FPS).
4K3	655	-25/-29	FACTOR IN TB,TIME TO BURN,COMP.(1/FPS SQ).
6K5	656	0	FILTER Y WEIGHT(MQ UNITS).
4K25	657	13/15	ENGINE CUTOFF COMPENSATION(FPS).
4K34	660	7/9	THRUST ACCEL(AT) LOWER LIM (FT/SEC SQ).
4K35	661	7/9	ULLAGE THRESHOLD (FT/SEC SQ).
4K5	662	23/25	NOMINAL BURNOUT ALTITUDE IN 0.1.(FT).
VYOFS	665	13/15	MAX VYO DISPLAYABLE (FPS).
4K21	666	2	SCALE FACTOR FOR ATTITUDE ERROR OUTPUT(RAD).
M25B16	667	16	CYCLE COUNTS TO SECONDS FACTOR.
DTB	670	1	1 SEC + DEDA TIME BIAS.
ID1	671	17	DOWNLINK CODE.
1K56	673	-14	GYRO CALIB. LUNAR RATE COMPENSATION(RAD)
2K4	674	49/55	-2(2K1) (FT CUBED/SEC).
KDT	675	1	DELTA T / 2 (SEC).

THE AVAILABILITY OF PARAMETERS ON THIS PAGE IS INDEPENDENT OF THE GUIDANCE MODE.

--------FP6-----FP6-------
OCTAL REGION
DEDA CONVERSION SCALE FACTORS
--------FP6-----FP6-------

BACCSF	446	0	.001/.01 FT/SEC SQ TO FPS/20MSEC SCALED AT 1/3.
BM13SF	676	0	.01 DEG/HR TO RAD/20MS SCALED AT -13.
B23SF	677	0	100/1000 FT TO FT SCALED AT 23/25.
B18SF	700	0	.1 MIN TO SEC SCALED AT 18.
B13VSF	701	0	.1/1 FPS TO FPS SCALED AT 13/15.
B3SF	702	0	.01 DEG TO RAD SCALED AT 3.
B23RSF	703	0	.1 NMI TO FT SCALED AT 23/25.
B13SF	704	0	.01 MIN TO SEC SCALED AT 13.

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