

APOLLO 12



AC ELECTRONICS

DIVISION OF GENERAL MOTORS CORPORATION
MILWAUKEE, WISCONSIN 53201

	EARTH	MOON
SATELLITE ORBIT	100 x 100 n mi	60 x 60 n mi
SATELLITE ORBIT DURATION	1 hr 28 min	2 hr
SATELLITE ORBIT RATE	4.1 deg/min	3.0 deg/min
V_C (SURFACE)	7,905.4 m/sec	1,679.5 m/sec
I.E. $V_C = \sqrt{\frac{\mu}{R}}$	25,936.0 ft/sec	5,510.2 ft/sec
	15,356.7 n mi/hr	3,262.6 n mi/hr
ESCAPE VELOCITY (SURFACE)	11,027 m/sec	2,380 m/sec
	36,178 ft/sec	7,750 ft/sec
	21,421 n mi/hr	4,572 n mi/hr
VOLUME	1	0.0202
RADIUS	1	0.272
MASS	1	0.0123
DENSITY	1	0.606
SURFACE GRAVITY	1	0.16
ONE DEGREE ON SURFACE μ	60 n mi $0.3986032 \times 10^{15} \text{ m}^3/\text{sec}^2$	16.4 n mi $0.4902778 \times 10^{13} \text{ m}^3/\text{sec}^2$
RADIUS	6,378,165 m 20,925,738 ft 3,444 n mi	1,738,090 m 5,702,395 ft 938.5 n mi
ORBIT CHARACTERISTICS	EARTH ABOUT SUN	MOON ABOUT EARTH
SEMI MAJOR AXIS	$1.496 \times 10^{11} \text{ m}$ $4.908 \times 10^{11} \text{ ft}$ $8.073 \times 10^7 \text{ n mi}$	384,400,000 m 1,261,139,500 ft 207,430 n mi
ECCENTRICITY	0.0167	0.055
MEAN VELOCITY	29,770 m/sec 97,702 ft/sec 57,888 n mi/hr	1,022 m/sec 3,353 ft/sec 1,980 n mi/hr
PERIOD	365.24 days	27.32 days
INCLINATION	23.44 deg	5.15 deg

MOON SURFACE TEMPERATURE -72°F to +214°F (sun side), -238°F (dark side)

$$\mu_{\text{SUN}} = 0.132715445 \times 10^{21} \text{ m}^3/\text{sec}^2$$

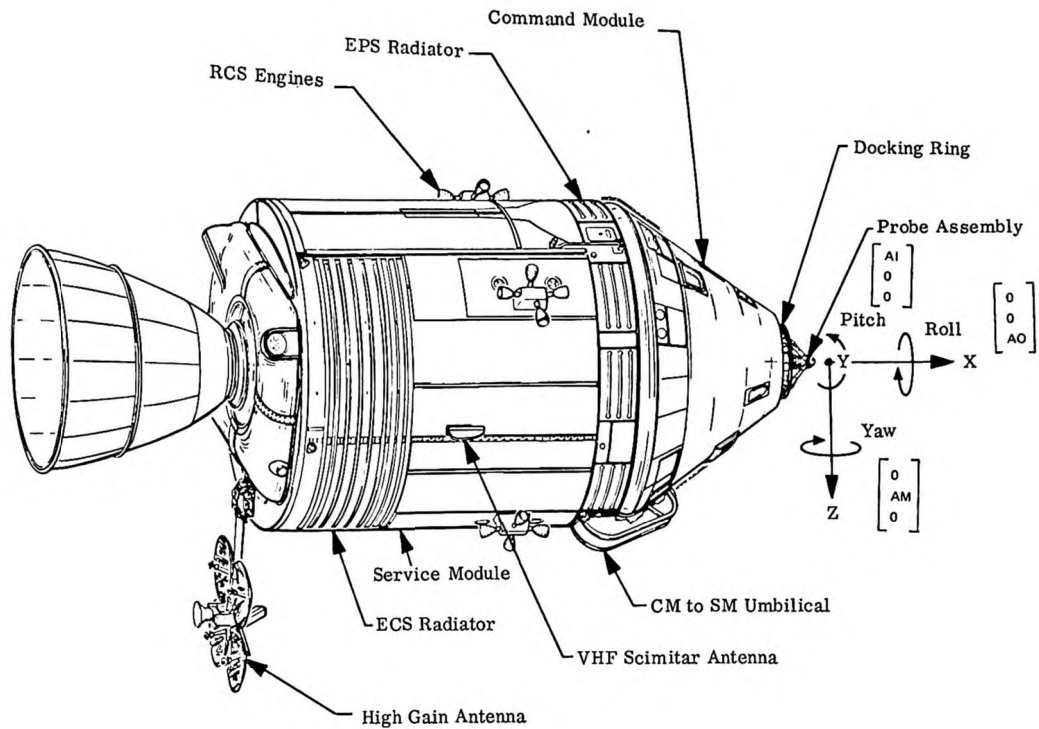
$$\begin{aligned}
 1 \text{ meter} &= 3.2808 \text{ ft} \\
 &= 5.3961 \times 10^{-4} \text{ n mi} \\
 &= 6.2137 \times 10^{-4} \text{ s mi} \\
 1 \text{ arc-second} &= 4.8481 \times 10^{-6} \text{ rad} \\
 &= 2.7778 \times 10^{-4} \text{ deg}
 \end{aligned}$$

$$\begin{aligned}
 1 \text{ meru} &= 7.292115 \times 10^{-8} \text{ rad/sec} \\
 &= 4.178 \times 10^{-6} \text{ deg/sec} \\
 &= 2.507 \times 10^{-4} \text{ arc-min/sec} \\
 &= 0.01504 \text{ arc-sec/sec} \\
 1 \text{ cm/sec}^2 &= 3.281 \times 10^{-2} \text{ ft/sec}^2 \\
 &= 1.0197 \times 10^{-3} \text{ g}
 \end{aligned}$$

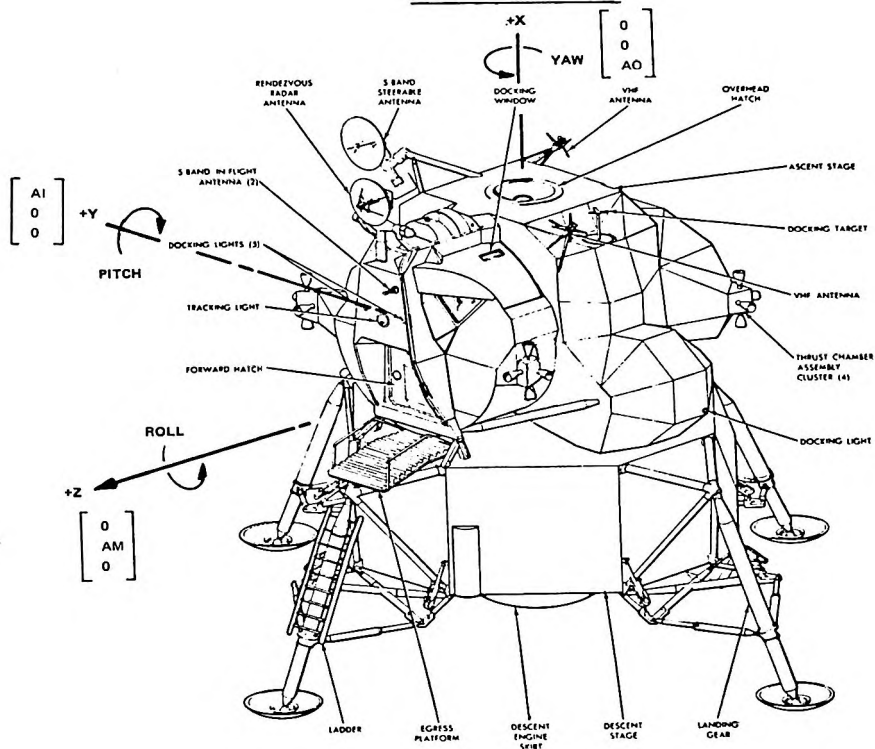
GUIDANCE AND NAVIGATION SUMMARY

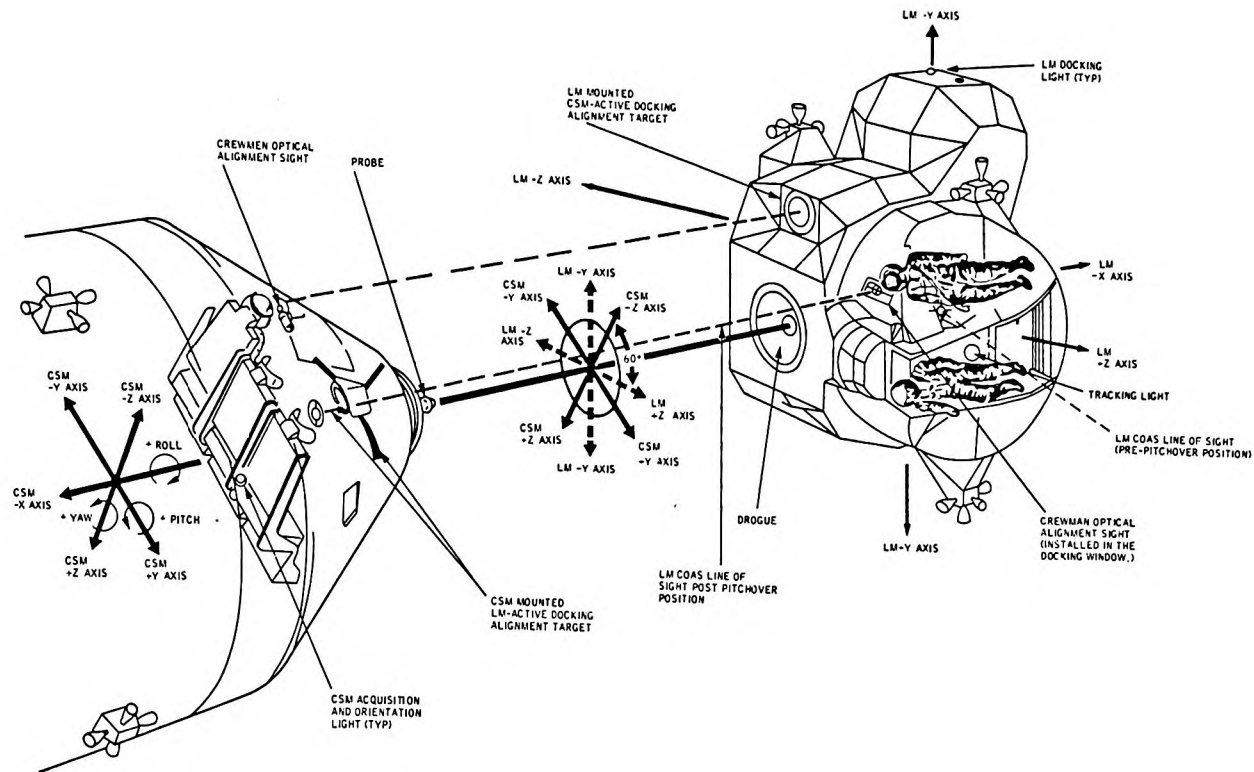
**CM SOFTWARE
LM SOFTWARE
ASPO 45 CRT DISPLAYS
LAUNCH AND BURN SCHEDULE
BURN PERTURBATIONS
HARDWARE**

CM/SM CONFIGURATION



LM CONFIGURATION





CM SOFTWARE

**COLOSSUS 2C
(REV 067 OF COMANCHE)
CM DSKY
COMPUTER PROGRAMS
COMPUTER ROUTINES
VERB CODES
NOUN CODES
ALARM CODES
OPTION CODES
CHECKLIST CODES
FLAGWORD BIT ASSIGNMENTS
IMODES30 AND IMODES33
OPTMODES
RCSFLAGS
DAPDATR1 AND DAPDATR2
CHANNEL BIT ASSIGNMENTS
COMPUTER PROGRAM DESCRIPTION**

CM DSKY

UPLINK ACTY Light

1. Is energized by the first character of a digital UPLINK message received by the AGC.
2. Is energized during the Rendezvous Navigation program (P20) when the Tracking Attitude routine (R61) detects that a gimbal angle change of greater than 10 degrees is required to align the CSM to the desired attitude and that the astronaut has disabled automatic tracking of the LM by taking the rotational hand controller out of detent while the SC control switch is at CMC and the thrust controller is not fully clockwise.

NO ATT Light — is energized when the AGC is in the Operate mode and there is no inertial reference; that is, the ISS is off, caged, or in the Coarse Align mode.

STBY Light — is energized when the AGC is in the Standby mode and deenergized when the AGC is in the Operate mode.

KEY REL Light

1. Energized when:
 - a. An internal display comes up while astronaut has the DSKY.
 - b. An astronaut keystroke is made when an internal flashing display is currently on the DSKY.
 - c. The astronaut makes a keystroke on top of (his own) Monitor Verb Display.
2. Deenergized when:
 - a. Astronaut relinquishes DSKY by hitting KEY REL button.
 - b. Astronaut terminates his current sequence normally, for example,
 - (1) With final ENTR of a load sequence.
 - (2) The ENTR of a response to a flashing display.
 - (3) The ENTR of an extended verb request.

OPR ERR Light — is energized when the DSKY operator performs an improper sequence of key depressions. The light is deenergized by pressing the RSET button.

TEMP Light — The AGC receives a signal from the IMU when the stable member temperature is in the range 126.3° F to 134.3° F. In the absence of this signal, the TEMP light on the DSKY is actuated.

GIMBAL LOCK Light — is energized when the middle gimbal angle exceeds ± 70 degrees from its zero position. When the middle gimbal angle exceeds ± 85 degrees from its zero position, the AGC automatically commands the Coarse Align mode in the ISS to prevent gimbal oscillation. The NO ATT light will then be energized.

PROG Light — The program alarm actuates the PROG light on the DSKY. A program alarm is generated under a variety of situations.

RESTART Light — In the event of a RESTART during operation of a program, a latch is set in the AGC which maintains the RESTART light on the DSKY until the latch is manually reset by pressing RSET.

TRACKER Light

1. The presence of an Optics CDU Fail signal will cause the TRACKER light to be energized.
2. In addition, the TRACKER light is energized during the Rendezvous Navigation program (P20) when the Rendezvous Data Processing routine (R22) reads VHF range data via the VHF DATA link but the DATA GOOD discrete is missing, or the UPDATE flag becomes reset.
3. It is deenergized if the DATA GOOD discrete is present after reading VHF range data and by keying in V88E (shuts off the VHF range data processing section of R22).

COMP ACTY Light — is energized when the AGC is occupied with an internal sequence.

Display Panel — consists of 24 electroluminescent sections. Each section is capable of displaying any decimal character or remaining blank, except the three sign sections. These display a plus sign, a minus sign, or a blank. The numerical sections are grouped to form three data display registers, each of five numerical characters; and three control display registers, each of two numerical characters. The data display registers are referred to as R1, R2, R3. The control display registers are known as VERB, NOUN, and PROGRAM.

CM DSKY (CONTINUED)

Keyboard —contains the following buttons:

1. VERB — pushing this button indicates that the next two numerical characters keyed in are to be interpreted as the Verb Code.
2. NOUN — pushing this button indicates that the next two numerical characters keyed in are to be interpreted as the Noun Code.
3. + and — are sign keys used for sign convention and to identify decimal data.
4. 0 - 9 —are numerical keys.
5. CLR — Used during a data loading sequence to clear or blank the data display register (R1, R2, R3) being used. It allows the operator to reload the data word.
6. PRO —This pushbutton performs two functions:
 - a. When the AGC is in a Standby mode, pressing this button will put the AGC in the Operate mode, turn off the STBY light, and automatically select Routine 00 in the AGC.
 - b1. When the AGC is in the Operate mode but Program 06 is not selected, pressing the button will provide the "Proceed" function. If the proceed button is pressed when VERB lights contain 21, 22, or 23, the action is rejected and the OPR ERR light is energized.
 - b2. When the AGC is in the Operate mode and Program 06 is selected, pressing the button will put the AGC in the Standby mode and turn on the STBY light.
7. ENTR —is used in three ways:
 - a. To direct the AGC to execute the Verb/Noun code now appearing on the Verb/Noun lights.
 - b. To direct the AGC to accept a data word just loaded.
 - c. In response to a "please perform" request.
8. RSET —turns off alarm conditions on the DSKY providing the alarm condition has been corrected.



LIST OF PROGRAMS FOR PROGRAM COLOSSUS 2C

PHASE	PROGRAM	PROGRAM TITLE
Pre-launch and Service	00	AGC Idling
	01	Prelaunch or Service-Initialization
	02	Prelaunch or Service-Gyrocompassing
	03	Prelaunch or Service-Optical Verification of Gyrocompassing
	06	AGC Power Down
	07	System Test
Boost	11	Earth Orbit Insertion Monitor
	17	TPI Search
Coast	20	Rendezvous Navigation
	21	Ground Track Determination
	22	Orbital Navigation
	23	Cislunar Midcourse Navigation
	27	AGC Update
Pre-thrusting	30	External Delta V
	31	Lambert Aim Point Guidance
	32	CSM Coelliptic Sequence Initiation (CSI)
	33	CSM Constant Delta Altitude (CDH)
	34	CSM Transfer Phase Initiation (TPI) Targeting
	35	CSM Transfer Phase Midcourse (TPM) Targeting
	37	Return to Earth
	38	CSM Stable Orbit Rendezvous (SOR) Targeting
	39	CSM Stable Orbit Midcourse (SOM) Targeting
	Thrusting	40	SPS
41		RCS
47		Thrust Monitor
Alignment	51	IMU Orientation Determination
	52	IMU Realign
	53	Backup IMU Orientation Determination
	54	Backup IMU Realign
Entry	61	Entry—Preparation
	62	Entry—CM/SM Separation and Preentry Maneuver
	63	Entry—Initialization
	64	Entry—Post 0.05G
	65	Entry—Upcontrol
	66	Entry—Ballistic
	67	Entry—Final Phase
Pre-thrusting Other Vehicle	72	LM Coelliptic Sequence Initiation (CSI)
	73	LM Constant Delta Altitude (CDH)
	74	LM Transfer Phase Initiation (TPI) Targeting
	75	LM Transfer Phase (Midcourse) Targeting
	76	Target Delta V
	77	LM TPI Search
	78	LM Stable Orbit Rendezvous (SOR) Targeting
	79	LM Stable Orbit Midcourse (SOM) Targeting

LIST OF ROUTINES FOR PROGRAM COLOSSUS 2C

ROUTINE	ROUTINE TITLE
00	Final Automatic Request Terminate
02	IMU Status Check
03	Digital Autopilot Data Load
05	S-Band Antenna
21	Rendezvous Tracking Sighting Mark
22	Rendezvous Tracking Data Processing
23	Backup Rendezvous Tracking Sighting Mark
30	Orbit Parameter Display
31	Rendezvous Parameter Display Routine No. 1
33	AGC/LGC Clock Synchronization
34	Rendezvous Parameter Display Routine No. 2
36	Rendezvous Out-of-Plane Display Routine
40	SPS Thrust Fail
41	State Vector Integration (MID to AVE)
50	Coarse Align
52	Automatic Optics Positioning
53	Sighting Mark
54	Sighting Mark Display
55	Gyro Torquing
56	Alternate LOS Sighting Mark
57	Optics Calibration
60	Attitude Maneuver
61	Tracking Attitude
62	Crew-Defined Maneuver
63	Rendezvous Final Attitude
64	Barbecue Mode Routine

LIST OF VERBS USED IN PROGRAM COLOSSUS 2C

REGULAR VERBS

- 00 Not in use
- 01 Display Octal Component 1 in R1
- 02 Display Octal Component 2 in R1
- 03 Display Octal Component 3 in R1
- 04 Display Octal Components 1, 2 in R1, R2
- 05 Display Octal Components 1, 2, 3 in R1, R2, R3
- 06 Display decimal in R1 or R1, R2 or R1, R2, R3
- 07 Display DP decimal in R1, R2 (test only)
- 08 Spare
- 09 Spare
- 10 Spare
- 11 Monitor Octal Component 1 in R1
- 12 Monitor Octal Component 2 in R1
- 13 Monitor Octal Component 3 in R1
- 14 Monitor Octal Components 1, 2 in R1, R2
- 15 Monitor Octal Components 1, 2, 3 in R1, R2, R3
- 16 Monitor decimal in R1 or R1, R2 or R1, R2, R3
- 17 Monitor DP decimal in R1, R2 (test only)
- 18 Spare
- 19 Spare
- 20 Spare
- 21 Load Component 1 into R1
- 22 Load Component 2 into R2
- 23 Load Component 3 into R3
- 24 Load Components 1, 2 into R1, R2
- 25 Load Components 1, 2, 3 into R1, R2, R3
- 26 Spare
- 27 Display Fixed Memory
- 28 Spare
- 29 Spare
- 30 Request EXECUTIVE
- 31 Request WAITLIST
- 32 Recycle program
- 33 Proceed without DSKY inputs
- 34 Terminate function
- 35 Test lights
- 36 Request FRESH START
- 37 Change program (major mode)
- 38 Spare
- 39 Spare

EXTENDED VERBS

- 40 Zero CDU's (N20 only)
- 41 Coarse align CDU's (specify N20 or N91)
- 42 Fine align IMU
- 43 Load IMU attitude error needles
- 44 Set Surface flag
- 45 Reset Surface flag
- 46 Establish G & N autopilot control
- 47 Move LM state vector into CM state vector
- 48 Request DAP Data Load routine (R03)
- 49 Start automatic attitude maneuver

LIST OF VERBS USED IN PROGRAM COLOSSUS 2C

- 50 Please perform
- 51 Please mark
- 52 Mark on offset landing site
- 53 Please perform COAS mark
- 54 Request Rendezvous Backup Sighting Mark routine (R23)
- 55 Increment AGC time (decimal)
- 56 Terminate tracking (P20 and P25)
- 57 Request Rendezvous Sighting Mark routine (R21)
- 58 Reset Stick flag and set V50 N18 flag
- 59 Please calibrate
- 60 Set astronaut total attitude (N17) to present attitude
- 61 Display DAP following attitude errors (Mode 1)
- 62 Display total attitude errors with respect to Noun 22 (Mode 2)
- 63 Display total astronaut attitude error with respect to Noun 17 (Mode 3)
- 64 Request S-Band Antenna routine (R05)
- 65 Optical verification of prelaunch alignment
- 66 Vehicles are attached. Move this vehicle state vector to other vehicle.
- 67 Start W-matrix RMS error display
- 68 CSM stroke test on
- 69 Cause RESTART
- 70 Update liftoff time (P27)
- 71 Start AGC update; block address (P27)
- 72 Start AGC update; single address (P27)
- 73 Start AGC update; AGC time (P27)
- 74 Initialize erasable dump via DOWNLINK
- 75 Backup liftoff
- 76 Set Preferred Attitude flag
- 77 Reset Preferred Attitude flag
- 78 Update prelaunch azimuth
- 79 Initiate Orbrate or PTC mode (R64)
- 80 Enable LM state vector update
- 81 Enable CSM state vector update
- 82 Request Orbit Parameter display (R30)
- 83 Request Rendezvous Parameter display No. 1 (R31)
- 84 Spare
- 85 Request Rendezvous Parameter display No. 2 (R34)
- 86 Reject Rendezvous Backup Sighting Mark
- 87 Set VHF Range flag
- 88 Reset VHF Range flag
- 89 Request Rendezvous Final Attitude maneuver (R63)
- 90 Request Out of Plane Rendezvous display (R36)
- 91 Display BANKSUM
- 92 Start IMU performance tests (ground use)
- 93 Enable W matrix initialization
- 94 Perform Cislunar Attitude maneuver (R64)
- 95 Spare
- 96 Terminate integration and go to P00
- 97 Please perform engine-fail (R41)
- 98 Spare
- 99 Please Enable Engine Ignition

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2C

00	Not in use	
01	Specify address (fractional)	.XXXXX fractional .XXXXX fractional .XXXXX fractional
02	Specify address (whole)	XXXXX. integer XXXXX. integer XXXXX. integer
03	Specify address (degree)	XXX.XX deg XXX.XX deg XXX.XX deg
04	Spare	
05	Angular error/difference	XXX.XX deg
06	Option code ID Option code	Octal Octal
07	FLAGWORD operator ECADR BIT ID Action	 Octal Octal Octal
08	Alarm data ADRES BBANK ERCOUNT	 Octal Octal Octal
09	Alarm codes First Second Last	 Octal Octal Octal
10	Channel to be specified	Octal
11	TIG of CSI	00XXX. h 000XX. min 0XX.XX s
12	Option code (extended verbs only)	Octal Octal
13	TIG of CDH	00XXX. h 000XX. min 0XX.XX s
14	Spare	
15	Increment address	Octal
16	Time of event (used by extended verbs only)	00XXX. h 000XX. min 0XX.XX s
17	Astronaut total attitude	R XXX.XX deg P XXX.XX deg Y XXX.XX deg

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2C

18	Desired automaneuver FDAI ball angles	R P Y	XXX.XX deg XXX.XX deg XXX.XX deg
19	Bypass Attitude Trim maneuver	R P Y	XXX.XX deg XXX.XX deg XXX.XX deg
20	Present ICDU angles	OG IG MG	XXX.XX deg XXX.XX deg XXX.XX deg
21	PIPA's	X Y Z	XXXXXX. pulses XXXXXX. pulses XXXXXX. pulses
22	Desired ICDU angles	OG IG MG	XXX.XX deg XXX.XX deg XXX.XX deg
23	Spare		
24	Delta time for AGC clock		00XXX. h 000XX. min 0XX.XX s
25	CHECKLIST (used with V50)		XXXXX.
26	PRI0/DELAY, ADRES, BBCON	Octal Octal Octal	
27	Self-test on/off switch		XXXXX.
28	Spare		
29	XSM launch azimuth		XXX.XX deg
30	Target codes	XXXXX. XXXXX. XXXXX.	
31	Time of landing site	00XXX. h 000XX. min 0XX.XX s	
32	Time from perigee	00XXX. h 000XX. min 0XX.XX s	
33	Time of ignition	00XXX. h 000XX. min 0XX.XX s	
34	Time of event	00XXX. h 000XX. min 0XX.XX s	
35	Time from event	00XXX. h 000XX. min 0XX.XX s	
36	Time of AGC clock	00XXX. h 000XX. min 0XX.XX s	

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2C

37	Time of ignition (TPI)	00XXX. h 000XX. min 0XX.XX s
38	Time of state being integrated	00XXX. h 000XX. min 0XX.XX s
39	Delta time for transfer	00XXX. h 000XX. min 0XX.XX s
40 *	Time from ignition/cutoff VG Delta V (accumulated)	XX b XX min/s XXXXX. ft/s XXXXX. ft/s
41	Target	
	Azimuth	XXX.XX deg
	Elevation	XX.XXX deg
42 *	Apocenter altitude Pericenter altitude Delta V (required)	XXXXX. nmi XXXXX. nmi XXXXX. ft/s
43	Latitude Longitude Altitude	XXX.XX deg (+ north) XXX.XX deg (+ east) XXXXX. nmi
44	Apocenter altitude Pericenter altitude TFF	XXXXX. nmi XXXXX. nmi XX b XX min/s
45 *	Marks (VHF/optics) Time from ignition of next burn Middle gimbal angle	XX b XX marks XX b XX min/s XXX.XX deg
46	DAP configuration	Octal Octal
47	CSM weight LM weight	XXXXXX. lbs XXXXXX. lbs
48	Gimbal pitch trim Gimbal roll trim	XXX.XX deg XXX.XX deg
49	Delta R Delta V VHF or optics code	XXXXX. nmi XXXXX. ft/s XXXXXX.
50 *	Splash error Perigee TFF	XXXXX. nmi XXXXX. nmi XX b XX min/s
51	S-band antenna angles	
	Pitch (Alpha)	XXX.XX deg
	Yaw (Beta)	XXX.XX deg
52	Central angle of active vehicle	XXX.XX deg
53	Range Range rate Phi	XXXXX. nmi XXXXX. ft/s XXX.XX deg

*Display cannot be changed via data load (that is, V25 NXXE, and so forth)

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2C

54	Range Range rate Theta	XXX.XX nmi XXXX.X ft/s XXX.XX deg
55	Perigee code Elevation angle Central angle of passive vehicle	0000X. XXX.XX deg XXX.XX deg
56	Reentry angle Delta V	XXX.XX deg XXXXX. ft/s
57	Delta R (SOR)	XXXX.X (+ passive vehicle leads)
58	Pericenter altitude (post TPI or SOR) Delta V (TPI or SOR) Delta V (TPF or SOR final)	XXXX.X nmi XXXXX. ft/s XXXXX. ft/s
59	Delta V LOS 1 Delta V LOS 2 Delta V LOS 3	XXXX.X ft/s XXXXX. ft/s XXXXX. ft/s
60	GMAX VPRED GAMMA EI	XXX.XX g XXXXX. ft/s XXX.XX deg (+ above)
61	Impact Latitude Longitude Heads up/down	 XXX.XX deg (+ north) XXX.XX deg (+ east) +/- 00001
62	Inertial velocity magnitude Altitude rate Altitude above pad radius	XXXXX. ft/s XXXXX. ft/s XXXXX. nmi
63	• Range from EMS altitude to splash Predicted inertial velocity Time from EMS altitude	XXXXX. nmi XXXXX. ft/s XX b XX min/s
64	Drag acceleration Inertial velocity Range to splash	XXX.XX g XXXXX. ft/s XXXXX. nmi (+ is overshoot)
65	Sampled AGC time (fetched in interrupt)	00XXXX. h 000XX. min 0XX.XX s
66	Commanded bank angle Crossrange error Downrange error	XXX.XX deg XXXXX. nmi (+ south) XXXXX. nmi (+ overshoot)
67	Range to target Present latitude Present longitude	XXXXX. nmi (+ overshoot) XXX.XX deg (+ north) XXX.XX deg (+ east)
68	Commanded bank angle Inertial velocity Altitude rate	XXX.XX deg XXXXX. ft/s XXXXX. ft/s
69	Commanded bank angle Drag level Exit velocity	XXX.XX deg XXX.XX g XXXXX. ft/s

*Display cannot be changed via data load (that is, V25NXXE, and so forth)

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2C

70	Star code (before mark) Landmark data Horizon data	Octal Octal Octal
71	Star code (after mark) Landmark data Horizon data	Octal Octal Octal
72	Delta angle (TPI) Delta altitude (TPI) Search option	XXX.XX deg (+ active vehicle ahead) XXXX.X nmi (+ passive vehicle above) 0000X
73	Altitude Velocity Flight path angle	XXXXXb. nmi XXXXX. ft/s XXX.XX deg
74	Commanded bank angle Inertial velocity Drag acceleration	XXX.XX deg XXXXX. ft/s XXX.XX g
75	• Delta altitude (CDH) Delta time (CDH-CSI or TPI-CDH) Delta time (TPI-CDH or TPI-NOMTPI)	XXXX.X nmi XX b XX min/s XX b XX min/s
76	Spare	
77	Spare	
78	Spare	
79	Orbrate or PTC rate Orbrate or PTC deadband Orbrate or PTC axis option	X.XXXX deg/s XXX.XX deg XXXXX.
80	• Time from ignition/cutoff Velocity to be gained Delta V (accumulated)	XX b XX min/s XXXXX. ft/s XXXXX. ft/s
81	Delta VX (LV) Delta VY (LV) Delta VZ (LV)	XXXXX.X ft/s XXXXX.X ft/s XXXXX.X ft/s
82	Delta VX (LV) Delta VY (LV) Delta VZ (LV)	XXXXX.X ft/s XXXXX.X ft/s XXXXX.X ft/s
83	Delta VX (body) Delta VY (body) Delta VZ (body)	XXXXX.X ft/s XXXXX.X ft/s XXXXX.X ft/s
84	Delta VX (LV of other vehicle) Delta VY (LV of other vehicle) Delta VZ (LV of other vehicle)	XXXXX.X ft/s XXXXX.X ft/s XXXXX.X ft/s
85	VGX (body) VGY (body) VGZ (body)	XXXXX.X ft/s XXXXX.X ft/s XXXXX.X ft/s
86	Delta VX (LV) Delta VY (LV) Delta VZ (LV)	XXXXX. ft/s XXXXX. ft/s XXXXX. ft/s
87	Mark data Shaft angle Trunnion angle	XXX.XX deg XX.XXX deg
88	Celestial body 1/2 unit vector	X .XXXXX Y .XXXXX Z .XXXXX

*Display cannot be changed via data load (that is, V25NXXE, and so forth)

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2C

89	Landmark latitude		XX.XXX deg (+ north)
	Landmark longitude/2		XX.XXX deg (+ east)
	Landmark altitude		XXX.XX nmi
90	Rendezvous out of plane parameters		
	Y		XXX.XX nmi
	Y dot		XXX.X ft/s
	PSI		XXX.XX deg
91	Optics angles		
	Shaft		XXX.XX deg
	Trunnion		XX.XXX deg
92	New optics angles		
	Shaft		XXX.XX deg
	Trunnion		XX.XXX deg
93	Delta gyro angles	X	XX.XXX deg
		Y	XX.XXX deg
		Z	XX.XXX deg
94	Alternate LOS		
	Shaft angle		XXX.XX deg
	Trunnion angle		XX.XXX deg
95	Preferred attitude FDAI angles	R	XXX.XX deg
		P	XXX.XX deg
		Y	XXX.XX deg
96	+X axis attitude FDAI angles	R	XXX.XX deg
		P	XXX.XX deg
		Y	XXX.XX deg
97	System test inputs		XXXXX. XXXXX. XXXXX.
98	System test results and input		XXXXX. .XXXXX XXXXX.
99	RMS in position		XXXXX. ft
	RMS in velocity		XXXXX.X ft/s
	RMS option code		XXXXX.

LIST OF ALARM CODES USED WITH V05 N09
FOR PROGRAM COLOSSUS 2C

CODE	PURPOSE	SET BY
00110	No mark since last mark reject	SXTMARK
00112	Mark not being accepted	SXTMARK
00113	No inbits	SXTMARK
00114	Mark made but not desired	SXTMARK
00115	Optics torque request with switch not at CMC	Extended verb optics CDU
00116	Optics switch altered before 15-second ZERO time elapsed	T4RUPT
00117	Optics torque request with optics not available	Extended verb optics CDU
00120	Optics torque request with optics not ZEROED	T4RUPT
00121	Optics CDU's no good at time of mark	SXTMARK
00122	Marking not called for	SXTMARK
00124	• P17 TPI search--no safe pericenter here	TPI search
00205	Bad PIPA reading	SERVICER
00206	Zero encode not allowed with coarse align + gimbal lock	IMU mode switch
00207	ISS turn-on request not present for 90 seconds	T4RUPT
00210	IMU not operating	IMU mode switch, IMU-2 R02, P51
00211	Coarse align error-drive > 2 degrees	IMU mode switch
00212	PIPA fail but PIPA is not being used	IMU mode switch, T4RUPT
00213	IMU not operating with turn-on request	T4RUPT
00214	Program using IMU when turned off	T4RUPT
00215	Preferred orientation selected but not specified	P52, P54
00217	Bad return from Stall routines	CURTAINS
00220	IMU not aligned (no REFSMMAT)	R02, P51
00401	Desired gimbal angles yield Gimbal Lock	Fine Align, IMU-2
00404	• Target out of view (trunnion angle > 90 degrees)	R52
00405	• Two stars not available	P52, P54
00406	Rendezvous navigation not operating	R21, R23
00407	Auto optics request (trunnion angle > 50 degrees)	R52
00421	W-Matrix overflow	INTEGRV
00600	Imaginary roots on first iteration	P32, P72
00601	Perigee altitude after CSI < 85 nmi earth orbit, 35,000 feet moon orbit	P32, P72
00602	Perigee altitude after CDH < 85 nmi earth orbit, 35,000 feet moon orbit	P32, P72
00603	CSI to CDH time < 10 minutes	P32, P33, P72, P73
00604	CDH to TPI time < 10 minutes	P32, P72
00605	Number of iterations exceeds loop maximum	P32, P72, P37
00606	DV exceeds maximum	P32, P72
00611	• No TIG for given elevation angle	P34, P74
00612	State vector in wrong sphere of influence	P37
00613	Reentry angle out of limits	P37
00777	PIPA fail caused ISS warning	T4RUPT
01102	AGC self-test error	SELF-CHECK
01105	Downlink too fast	T4RUPT
01106	Uplink too fast	T4RUPT
01107	Phase table failure; assume erasable memory is destroyed	RESTART
01301	ARCSIN-ARCCOS argument too large	INTERPRETER
01407	VG increasing	S40.8
01426	** IMU unsatisfactory	P61, P62
01427	** IMU reversed	P61, P62
01520	V37 request not permitted at this time	V37
01600	Overflow in Drift Test	Optical Prealignment Calibration
01601	Bad IMU torque	Optical Prealignment Calibration
01602	Bad optics during verification	Optical Alignment Calibration (CSM)
01703	Insufficient time for integration, TIG was slipped	R41

LIST OF ALARM CODES USED WITH V05 N09
FOR PROGRAM COLOSSUS 2C

CODE	PURPOSE	SET BY
03777	ICDU fail caused the ISS warning	T4RUPT
04777	ICDU, PIPA fails caused the ISS warning	T4RUPT
07777	IMU fail caused the ISS warning	T4RUPT
10777	IMU, PIPA fails caused the ISS warning	T4RUPT
13777	IMU, ICDU fails caused the ISS warning	T4RUPT
14777	IMU, ICDU, PIPA fails caused the ISS warning	T4RUPT
20430	Integration abort due to subsurface state vector	All calls to Integration
20607	No solution from Time-Theta or Time-Radius	TIMETHET, TIMERAD
20610	Lambda less than unity	P37
21103	Unused CCS branch executed	ABORT
21204	Negative or zero WAITLIST call	WAITLIST
21206	Second job attempts to go to sleep via Keyboard and Display program	PINBALL
21210	Two programs using device at same time	IMU Mode Switch
21302	SQRT called with negative argument	INTERPRETER
21501	Keyboard and Display alarm during internal use (NVSUB)	PINBALL
21502	Illegal flashing display	GOPLAY
21521	P01, P07 illegally selected	P01, P07
31104	Delay routine busy	EXECUTIVE
31201	Executive overflow—no VAC areas available	EXECUTIVE
31202	Executive overflow—no core sets available	EXECUTIVE
31203	WAITLIST overflow—too many tasks	WAITLIST
31207	No VAC area for marks	SXTMARK
31211	Illegal interrupt of Extended Verb	SXTMARK

2XXXX—Indicates a go-to-Program 00 type abort.

3XXXX—Indicates a bailout type abort.

Note: For V05 N09 Displays:

R1—XXXXX (first alarm to occur after last reset).

R2—XXXXX (second alarm to occur after last reset).

R3—XXXXX (most recent alarm).

Error Reset will set R1 and R2 to zero, but not affect R3.

*This alarm is displayed without having to key in V05 N09E. An astronaut response is required by this alarm.

**This alarm is displayed without having to key in V05 N09E.

LIST OF OPTION CODES USED WITH V04 N06/N12
FOR PROGRAM COLOSSUS 2C

(The specified option codes will be displayed in R1 in conjunction with Flashing V04 N06/N12 to request the astronaut to load into R2 the option he desires.)

CODE	PURPOSE	INPUT FOR R2	PROGRAMS
00001	Specify IMU orientation	1 = preferred, 2 = nominal, 3 = REFSMMAT, 4 = landing site	P50's
00002	Specify vehicle	1 = this vehicle, 2 = other vehicle	P21, R30
00003	Specify tracking attitude	1 = preferred, 2 = +X-axis	R63
00005	Specify SOR phase	1 = first, 2 = second	P38
00007	Specify propulsion system	1 = SPS, 2 = RCS	P37

LIST OF CHECKLIST REFERENCE CODES USED WITH V50 N25
FOR PROGRAM COLOSSUS 2C

CODE	ACTION TO BE EFFECTED
00013	Perform coarse alignment
00014	Key in fine alignment option
00015	Perform celestial body acquisition
00016	Key in Terminate Mark sequence
00041	Switch CM/SM separation to UP
00062	Switch AGC power down
00202	Perform GNCS automatic maneuver
00204	Perform SPS gimbal trim

Notes: Switch—denotes change position of a console switch
Perform—denotes start or end of a task
Key In—denotes key-in of data through the DSKY

**FLAGWORD BIT ASSIGNMENTS (ALPHABETICAL)
FOR COLOSSUS 2C**

ADVTRK	FW8	810	MIDAVFLG	FW9	82
AMOONFLG	FW0	82	MIDFLAG	FW0	813
APSESW	FW8	85	MKOVFLAG*	FW4	83
ASTENFLAG*	FW7	812	MOONFLAG	FW0	812
ATTCHFLG*	FW7	82	MRKIDFLG*	FW4	815
AVEGBIT	FW1	81	MRKNVFLG	FW4	89
AVEGFLAG	FW1	81	MRUPTFLG*	FW4	85
AVEMIDSW	FW9	81	MWAITFLG*	FW4	811
AVFLAG	FW2	85	NEEDLFLG	FW0	89
CALCMAN2	FW2	82	NEWIFLG	FW8	813
CMDAPARM*	FW6	812	NJETSFLG	FW1	815
CMOONFLG	FW8	812	NODOBIT	FW2	81
CM/DSTBY	FW6	82	NODOFLAG	FW2	81
COGAFLAG	FW8	84	NODOP01	FW1	812
COMPUTER	FW5	88	NOP01BIT	FW1	812
CPHIFLAG	FW0	815	NORFHOR	FW0	811
CULTFLAG	FW3	87	NORMSW	FW7	810
D6OR9FLG	FW3	82	NOSWITCH	FW6	87
DAPBIT1	FW6	815	NRMIDFLG*	FW4	813
DAPBIT2	FW6	814	NRMNVFLG	FW4	88
DIMOFFLAG	FW3	81	NRUPTFLG*	FW4	84
DMENFLG	FW5	89	NWAITFLG*	FW4	810
DRIFTFLG	FW2	815	N22ORN17	FW9	86
DSKYFLAG*	FW5	815	OPTNSW	FW2	87
EGSW	FW6	88	ORBWFLAG	FW3	86
ENG2FLAG	FW1	811	ORDERSW	FW8	86
ENGONBIT	FW5	87	PDSPFBIT	FW4	812
ENTRYDSP	FW6	813	PDSPFLAG	FW4	812
ERADFLAG	FW1	813	PFRATFLG	FW2	84
ETPIFLAG	FW2	87	PINBRFLG	FW4	86
FINALFLG	FW2	86	PRECIFLG	FW3	88
FIRSTFLG	FW2	87	PRFTRKAT	FW5	810
FREEFLAG	FW0	83	PRIODFLG*	FW4	814
F2RTE	FW0	85	PRONVFLG	FW4	87
GAMDIFSW*	FW6	811	P21FLAG	FW2	812
GLOKFAIL	FW3	814	P22MKFLG	FW3	811
GLOKFBIT	FW3	814	P39/79SW	FW8	89
GONEBY	FW7	88	QUITFLAG	FW9	85
GONEPAST	FW6	810	REFSMFLG	FW3	813
GRRBKBIT	FW5	85	REINTBIT	FW10	87
GRRBKFLG	FW5	85	REINTFLG	FW10	87
GUESSW	FW1	82	RELVELSW	FW6	89
GYMDIFSW*	FW6	81	RENDWFLG	FW5	81
HIND	FW6	86	RETROFLG	FW5	814
IDLEFAIL	FW1	86	RNDVZBIT	FW0	87
IGNFLAG*	FW7	813	RNDVZFLG	FW0	87
IMPULSW	FW2	89	RNGSCFLG	FW5	810
IMUSE	FW0	88	RPQFLAG	FW8	815
MUSEFLG	FW0	88	RVSW	FW7	89
INCORFLG	FW5	811	R21MARK	FW2	814
INFINFLG	FW8	87	R22CAFLG*	FW9	87
INRLSW	FW6	85	R23BIT	FW1	89
INTFLBIT	FW10	814	R23FLG	FW1	89
INTYPFLG	FW3	84	R31FLAG	FW9	84
ITSWICH	FW7	814	R31FLBIT	FW9	84
JSWICH	FW0	814	R53FLAG	FW0	86
KFLAG	FW0	81	R57FLAG	FW6	88
KNOWNFLG	FW6	88	R60FLAG*	FW5	84
LATSW	FW6	84	SAVECFLG	FW9	810
LMOONFLG	FW8	811	SKIPBIT	FW2	810
LUNAFLAG	FW3	812	SKIPVHF	FW2	810
MAXDBBIT	FW9	812	SLOPESW	FW1	83
MAXDBFLG	FW9	812	SLOWFLG	FW5	813
MGLVFLAG	FW5	82	SOLNSW	FW5	83
MID1FLAG	FW9	83	SOURCBIT	FW9	88

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS (ALPHABETICAL)
FOR COLOSSUS 2C

SOURCEFLG	FW9	B8	VEHUPFLG	FW1	B8
STATEFLG	FW3	B5	VERIFLAG*	FW7	B3
STEERSW	FW2	B11	VFLAG	FW3	B10
STIKBIT	FW1	B14	VHFRFLAG	FW9	B9
STIKFLAG	FW1	B14	VINTFLAG	FW3	B3
STRULLSW	FW6	B13	V37FLAG	FW7	B6
SURFFLAG	FW8	B8	V37FLBIT	FW7	B6
SWTOVER*	FW9	B15	V50N188T	FW3	B15
S32.1F1	FW11	B15	V50N18FL	FW3	B15
S32.1F2	FW11	B14	V59FLAG	FW5	B12
S32.1F3A	FW11	B13	V67FLBIT*	FW9	B14
S32.1F3B	FW11	B12	V82EMFLG	FW9	B13
TARG1FLG	FW1	B10	V94FLAG	FW9	B11
TARG2FLG	FW1	B9	V94FLBIT	FW9	B11
TERMIFLG	FW7	B15	V96ONFLG	FW8	B3
TFFSW	FW7	B1	XDELVFLG	FW2	B8
TIMRFLAG	FW7	B11	XDSPFLAG*	FW4	B1
TRACKBIT	FW1	B5	ZMEASURE	FW0	B10
TRACKFLG	FW1	B5	.05GSW	FW6	B3
TRM03BIT	FW1	B4	22DSPFLG	FW2	B13
TRM03FLG	FW1	B4	360SW	FW8	B1
TRUNFLAG	FW0	B4	3AXISFLG	FW5	B6
UPDATBIT	FW1	B7			
UPDATFLG	FW1	B7			
UPLOCKFL*	FW7	B4			

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 0)

Bit	Name	1	0
1	KFLAG	Search sector < 180 degrees.	Search sector > 180 degrees.
2	AMOONFLG	State vector in lunar sphere at MIDTOAVE.	State vector in earth sphere at MIDTOAVE.
3	FREEFLAG	(Temporary flag used in many routines.)	
4	TRUNFLAG	Driving of trunnion allowed.	Driving of trunnion not allowed.
5	F2RTE	In time critical mode.	Not in time critical mode.
6	R53FLAG	V51 initiated.	V51 not initiated.
7	RNDVZBIT RNDVZFLG	P20 running.	P20 not running.
8	IMUSE IMUSEFLG	IMU in use.	IMU not in use.
9	NEEDFLG	Total attitude error displayed.	A/P following error displayed.
10	ZMEASURE	Measurement planet and primary planet different.	Measurement planet and primary planet same.
11	NORFHOR	Far horizon.	Near horizon.
12	MOONFLAG	Moon is sphere of influence.	Earth is sphere of influence.
13	MIDFLAG	Integration with solar perturbations.	Integration without solar perturbations.
14	JSWITCH	Integration of W matrix.	Integration of state vector.
15	CPHIFLAG	Output of CALCGA is CPHIX.	Output of CALCGA is THETAD.

(FLAGWORD 1)

Bit	Name	1	0
1	AVEGBIT AVEGFLAG	AVERAGEG (SERVICER) to continue.	AVERAGEG (SERVICER) to cease.
2	GUESSW	No starting value for iteration exists	Starting value for iteration exists.
3	SLOPESW	Iterate with bias method in iterator.	Iterate with Regula Falsi method in iterator.
4	TRM03BIT TRM03FLG	Request to terminate P03 has been entered.	No request to terminate P03 has been entered.
5	TRACKBIT TRACKFLG	Tracking allowed.	Tracking not allowed.
6	IDLEFAIL	Inhibit R40.	Enable R40 (engine fail).
7	UPDATBIT UPDATFLG	Updating by marks allowed.	Updating by marks not allowed.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 1)

Bit	Name	1	0
8	VEHUPFLG	CSM state vector being updated.	LM state vector being updated.
9	R23BIT R23FLG	R23 marking.	R21 marking.
	TARG2FLG	Sighting landmark.	Sighting star.
10	TARG1FLG	Sighting LM.	Not sighting LM.
11	ENG2FLAG	RCS burn.	SPS burn.
12	NODOP01 NOP01BIT	P01 not allowed.	P01 allowed.
13	ERADFLAG	EARTH—compute Fischer ellipsoid radius. MOON—use fixed radius	EARTH—use fixed radius. MOON—use RLS for lunar radius.
14	STIKBIT STIKFLAG	RHC control.	AGC control.
15	NJETSFLG	Two-jet RCS burn.	Four-jet RCS burn.

(FLAGWORD 2)

Bit	Name	1	0
1	NODOBIT NODOFLAG	V37 not permitted.	V37 permitted.
2	CALCMAN2	Perform maneuver starting procedure.	Bypass starting procedure.
3	Not Assigned		
4	PFRATFLG	Preferred attitude computed.	Preferred attitude not computed.
5	AVFLAG	LM is active vehicle.	CSM is active vehicle.
6	FINALFLG	Last pass through rendezvous program computations.	Interim pass through rendezvous program computations.
7	OPTNSW	SOI phase of P38/P78.	SOR phase of P38/P78.
	FIRSTFLG	First pass through S40.9.	Succeeding pass through S40.9.
	ETPIFLAG	Elevation angle supplied for P34/P74.	TPI time supplied for P34/P74.
8	XDELVFLG	External Delta V VG computation.	Lambert (AIMPOINT) VG computation.
9	IMPULSW	Minimum impulse burn (cutoff time specified).	Steering burn (no cutoff time yet available).
10	SKIPVBIT SKIPVHF	Disregard radar read because of software or hardware RESTART.	Radar read to proceed normally.
11	STEERSW	Steering to be done.	Steering omitted.
12	P21FLAG	Succeeding pass through P21, use base vector for calculation.	First pass through P21, calculate base vector.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 2)

Bit	Name	1	0
13	22DPSFLG	Display DR, DV.	Do not display DR, DV.
14	R21MARK	Option 1 for MARKRUPT.	Option 2 for MARKRUPT.
15	DRIFTFLG	T3RUPT calls gyro compensation.	T3RUPT does no gyro compensation.

(FLAGWORD 3)

Bit	Name	1	0
1	DIM0FLAG	W matrix is to be used.	W matrix is not to be used.
2	D6OR9FLG	Dimension of W is 9 for integration.	Dimension of W is 6 for integration.
3	VINTFLAG	CSM state vector being integrated.	LM state vector being integrated.
4	INTYPFLG	Conic integration.	Encke integration.
5	STATEFLG	Permanent state vector being updated.	Permanent state vector not being updated.
6	ORBWFLAG	W matrix valid for orbital navigation.	W matrix invalid for orbital integration.
7	CULTFLAG	Star occulted.	Start not occulted.
8	PRECIFLG	CSMPREC, LEMPREC, or INTEGRVS called.	INTGRV called.
9	Not Assigned		
10	VFLAG	Less than two stars in the field of view.	Two stars in the field of view.
11	P22MKFLG	P22 downlinked mark data was just taken.	P22 downlinked mark data not just taken.
12	LUNAFLG	Lunar latitude-longitude.	Earth latitude-longitude.
13	REFSMFLG	REFSMMAT good.	REFSMMAT no good.
14	GLOKFAIL GLOKFBIT	GIMBAL LOCK has occurred.	Not in GIMBAL LOCK.
15	V50N18BT V50N18FL	Enable R60 attitude maneuver.	Inhibit R60 attitude maneuver.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 4)

Bit	Name	1	0
1	XDSPFLAG*	Mark display not to be interrupted.	No special mark information.
2	Not Assigned		
3	MKOVFLAG*	Mark display over normal display.	No mark display over normal display.
4	NRUPTFLG*	Normal display interrupted by priority or mark display.	Normal display not interrupted by priority or mark display.
5	MRUPTFLG*	Mark display interrupted by priority display.	Mark display not interrupted by priority display.
6	PINBRFLG	Astronaut has interfered with existing display.	Astronaut has not interfered with existing display.
7	PRONVFLG	Astronaut using keyboard when priority display initiated.	Astronaut not using keyboard when priority display initiated.
8	NRMNVFLG	Astronaut using keyboard when normal display initiated.	Astronaut not using keyboard when normal display initiated.
9	MRKNVFLG	Astronaut using keyboard when mark display initiated.	Astronaut not using keyboard when mark display initiated.
10	NWAITFLG*	Higher priority display operating when normal display initiated.	No higher priority display operating when normal display initiated.
11	MWAITFLG*	Higher priority display operating when mark display initiated.	No higher priority display operating when mark display initiated.
12	PDSPFBIT PDSPLFLAG	Cannot interrupt priority display.	
13	NRMIDFLG*	Normal display in ENDIDLE.	No normal display in ENDIDLE.
14	PRIODFLG*	Priority display in ENDIDLE.	No priority display in ENDIDLE.
15	MRKIDFLG*	Mark display in ENDIDLE.	No mark display in ENDIDLE.

(FLAGWORD 5)

Bit	Name	1	0
1	RENDWFLG	W matrix valid for rendezvous navigation.	W matrix invalid for rendezvous navigation.
2	MGLVFLAG	Local vertical coordinates computed.	Middle gimbal angle computed.
3	SOLNSW	Lambert does not converge, or time-radius nearly circular.	Lambert converges or time-radius noncircular.
4	R60FLAG*	R61 must use R60.	Normal R61.
5	GRRBKBIT GRRBKFLG	Backup GRR received.	Backup GRR not received.

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 5)

Bit	Name	1	0
6	3AXISFLG	Maneuver specified by three axes.	Maneuver specified by one axis.
7	ENGONBIT	Engine turned on.	Engine turned off.
8	COMPUTER	Computer is AGC.	Computer is LGC.
9	DMENFLG	Dimension of W is 9 for incorporation.	Dimension of W is 6 for incorporation.
10	PRFTRKAT RNGSCFLG	Preferred tracking attitude.	+X axis tracking attitude.
11	INCORFLG	First incorporation.	Second incorporation.
12	V59FLAG	Calibrating for P23.	Normal marking for P23.
13	SLOWFLG	P37 transearth coast slowdown is desired.	Slowdown is not desired.
14	RETROFLG	P37 premaneuver orbit is retrograde.	Orbit is not retrograde.
15	DSKYFLAG*	Displays sent to DSKY.	No displays to DSKY.

(FLAGWORD 6)

Bit	Name	1	0
1	GYMDIFSW*	CDU differences and body rates computed.	CDU differences and body rates not computed.
2	CM/DSTBY	ENTRY DAP activated.	ENTRY DAP not activated.
3	.05GSW	Drag over 0.05 g	Drag less than 0.05 g.
4	LATSW	Downlift not inhibited.	Downlift inhibited.
5	INRLSW	Initial roll V(LV) attitude not held.	Initial roll V(LV) attitude held.
6	HIND	Iterating of HUNTEST calculation to be done after range prediction.	Iterating of HUNTEST calculations to be omitted after range prediction.
7	NOSWITCH	Lateral roll maneuver inhibited in ENTRY.	Lateral roll maneuver permitted in ENTRY.
8	R57FLAG	Do not do R57, trunnion bias has been obtained.	Do R57, trunnion bias needed.
	KNOWNFLG	Landmark known.	Landmark unknown.
	EGSW	In final phase.	Not in final phase.
9	RELVELSW	Targeting uses earth-relative velocity.	Targeting uses inertial velocity.

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 6)

Bit	Name	1	0															
10	GONEPAST	Lateral control calculations to be omitted.	Lateral control calculations to be done.															
11	GAMDIFSW*	Calculate GAMDOT.	GAMDOT not to be calculated.															
12	CMDAPARM*	Allow ENTRY firings and calculations.	Inhibit ENTRY firings and control functions.															
13	ENTRYDSP	Do ENTRY display via ENTRYVN.	Omit ENTRY display.															
	STRULLSW	Do STEERULL.	Do ULAGEOFF only.															
14	DAPBIT2	<table><tr><td>B14</td><td>0</td><td>1</td><td>1</td><td>1</td></tr><tr><td>B15</td><td>0</td><td>0</td><td>0</td><td>1</td></tr><tr><td>A/P</td><td>None</td><td>RCS</td><td>TVC</td><td>Saturn</td></tr></table>	B14	0	1	1	1	B15	0	0	0	1	A/P	None	RCS	TVC	Saturn	DAP selection indicator.
B14	0	1	1	1														
B15	0	0	0	1														
A/P	None	RCS	TVC	Saturn														
15	DAPBIT1																	

(FLAGWORD 7)

Bit	Name	1	0
1	TFFSW	Calculate TPERIGEE.	Calculate TFF.
2	ATTCHFLG*	LM, CM attached.	LM, CM not attached.
3	VERIFLAG*	Changed when V33E occurs at end of P27.	
4	UPLOCKFL*	K-K-K fail.	No K-K-K fail.
5	Not Assigned		
6	V37FLAG V37FLBIT	AVERAGEG (SERVICER) running.	AVERAGEG (SERVICER) off.
7	Not Assigned		
8	GONEBY	Passed target.	Approaching target.
9	RVSWS	Do not compute final state vector in time-theta.	Compute final state vector in time-theta.
10	NORMSW	Unit normal input to Lambert.	Lambert computes its own unit normal.
11	TIMRFLAG	CLOKTASK operating.	CLOKTASK inoperative.
12	ASTNFLAG*	Astronaut has OKed ignition.	Astronaut has not OKed ignition.
13	IGNFLAG*	TIG has arrived.	TIG has not arrived.
14	ITSWICH	Accept next Lambert TPI search solution.	Test Lambert answer against limits.
15	TERMIFLG	Terminate R52.	Do not terminate R52.

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 8)

Bit	Name	1	0
1	360SW	Transfer angle near 360 degrees.	Transfer angle not near 360 degrees.
2	Not Assigned		
3	V96ONFLG	P00 integration has been inhibited by V96	P00 integration is proceeding regularly.
4	COGAFLAG	No conic solution, too close to rectilinear (COGA overflows).	Conic solution exists, (COGA does not overflow.)
5	APSESW	RDESIRED outside of PERICENTER-APOCENTER range in time-radius.	RDESIRED inside of PERICENTER-APOCENTER range in time-radius.
6	ORDERSW	Iterator uses second order minimum mode.	Iterator uses first order standard mode.
7	INFINFLG	No conic solution (closure through infinity required).	Conic solution exists.
8	SURFFLAG	LM on lunar surface.	LM not on lunar surface.
9	P39/79SW	P39/P79 operating.	P38/P78 operating.
10	ADVTRK	Advance ground track sighting wanted.	No advanced ground track.
11	LMOONFLG	Permanent LM state vector in lunar sphere.	Permanent LM state vector in earth sphere.
12	CMOONFLG	Permanent CSM state vector in lunar sphere.	Permanent CSM state vector in earth sphere.
13	NEWIFLG	First pass through integration.	Succeeding iteration of integration.
14	Not Assigned		
15	RPQFLAG	RPQ not computed. (RPQ = vector between secondary body and primary body.)	RPQ computed.

(FLAGWORD 9)

Bit	Name	1	0
1	AVEMIDSW	AVETOMID calling for W matrix integration. Do not overwrite RN, VN, PIPTIME.	No AVETOMID W matrix integration. Allow setup of RN, VN, PIPTIME.
2	MIDAVFLG	Integration entered from one of MIDTOAV portals.	Integration was not entered via MIDTOAV.
3	MID1FLAG	Integrate to TDEC.	Integrate to the then-present time.
4	R31FLAG R31FLBIT	R31 selected (V83).	R34 selected (V85).
5	QUITFLAG	Terminate and exit from integration.	Continue integration.
6	N22ORN17	Compute total attitude errors with respect to N22 (V62).	Compute total attitude errors with respect to N17 (V63).

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

(FLAGWORD 9)

Bit	Name	1	0
7	R22CAFLG*	R22 calculations are going on.	R22 calculations are not going on.
8	SOURCBIT SOURCFLG	Source of input data is from VHF radar.	Source of input data is from optics mark.
9	VHFRFLAG	Allow R22 to accept range data.	Stop acceptance of range data.
10	SAVECFLG	P23 display and data storage after mark is done.	P23 display and data storage before mark is done.
11	V94FLAG V94FLBIT	V94 allowed during P23.	V94 not allowed.
12	MAXDDBIT MAXDBFLG	Maximum A/P deadband selected.	Minimum A/P deadband selected.
13	V82EMFLG	Moon vicinity.	Earth vicinity.
14	V67FLBIT*	Not Assigned.	
15	SWTOVER	Switchover has occurred.	No switchover yet.

*These switches are never called by name.

(FLAGWORD 10, RASFLAG)

Bit	Name	1	0
1-6	Not Assigned		
7	REINTBIT REINTFLG	Integration routine to be RESTARTED.	Integration routine not to be RESTARTED.
8-13	Not Assigned		
14	INTFLBIT	Integration in progress.	Integration not in progress.
15	Not Assigned		

(FLAGWORD 11)

Bit	Name	1	0
1-11	Not Assigned		
12	S32.1F3B	(Bits 12 and 13 function as an ordered pair (13, 12) indicating the possible occurrence of two Newton iterations for S32.1: (0, 0) – First pass of second Newton iteration, (0, 1) – First Newton iteration being done, (1, 0) – Remainder of second Newton iteration, (1, 1) – 50 ft/s stage of second Newton iteration.)	
13	S32.1F3A		
14	S32.1F2	First pass of Newton iteration.	Reiteration of Newton.
15	S32.1F1	Delta V at CSI Time 1 exceeds maximum.	Delta V at CSI Time 1 less than maximum.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

IMODES30, a flag whose individual bits are used to control the monitoring of IMU functions associated with Channel 30 (and in a few cases Channel 33).

Bit	Meaning
15	Last sampled value of Channel 30, Bit 15 (0 if IMU temperature within limits).
14	Last sampled value of Channel 30, Bit 14 (0 if ISS has been turned on or commanded to be turned on).
13	Last sampled value of Channel 30, Bit 13 (0 if an IMU fail indication has been produced).
12	Last sampled value of Channel 30, Bit 12 (0 if an IMU CDU fail indication has been produced).
11	Last sampled value of Channel 30, Bit 11 (0 if an IMU cage command has been produced by crew).
10	Last sampled value of Channel 33, Bit 10 (0 if a PIPA fail indication has been produced), having the same value as Bit 13 of IMODES33.
9	Last sampled value of Channel 30, Bit 9 (0 if IMU has been turned on and operating with no malfunctions).
8	Bit used to control the IMU turn-on sequencing.
7	Bit used to control the IMU turn-on sequencing.
6	Bit is set to 1 to indicate that IMU initialization is being carried out.
5	Bit is set to 1 to inhibit the generation of program alarm 0212g if a PIPA fail signal (Bit 13 of Channel 33) is produced.
4	Bit is set to 1 to inhibit generation of an ISS warning based on receipt of an IMU fail signal.
3	Bit is set to 1 to inhibit generation of an ISS warning based on receipt of an IMU CDU fail signal.
2	Bit is set to 1 to indicate failure of the turn-on delay sequence for IMU turn-on (alarm 0207g is also generated).
1	Bit is set to 1 to inhibit generation of an ISS warning based on receipt of a PIPA fail signal (Bit 13 of Channel 33).

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

IMODES33, a flag whose individual bits are used to control the monitoring of functions associated with Channel 33 (and other items).

Bit	Meaning
15	Not assigned.
14	Last sampled value of Channel 32, Bit 14 (0 if a Proceed command is given using the old "standby" button).
13	Last sampled value of Channel 33, Bit 13 (0 if a PIPA fail has been produced).
12	Last sampled value of Channel 33, Bit 12 (0 if a telemetry end pulse has been rejected because the downlink rate is too fast).
11	Last sampled value of Channel 33, Bit 11 (0 if an uplink bit has been rejected because the uplink rate is too fast).
10-7	Not assigned.
6	Bit is set to 1 to indicate that IMU use for vehicle attitude information should not be attempted.
5	Bit is set to 1 in IMU Zeroing routine external to T4RUPT while zeroing is taking place (for an interval of about 10.56 seconds).
4-2	Not assigned.
1	Bit is set to 1 when a Verb 35 ("lamp test") is received, and reset to 0 about 5 seconds later.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

OPTMODES, a flag whose individual bits are used to control the performance of optics functions within the T4RUPT package.

Bit	Meaning
15-11	Not Assigned
10	Bit is set to 1 to indicate that zeroing of optics has been completed since the last FRESH START or RESTART (both of which set the bit to 0). If an attempt is made to drive the optics and this bit is found to be zero, alarm 0120g is generated (but computation proceeds).
9	Bit is set to 1 if optics has been switched from the Computer Control mode (while being driven; that is, "coarse aligned") to another mode. Value is used when switch-back to the Computer Control mode is effected to reenable driving. Bit is set to 0 as part of FRESH START and when optics system released (at end of marking); a RESTART preserves the bit (see, however, Bit 10).
8	Not assigned.
7	Last sampled value of Channel 30, Bit 7 (0 if an optics CDU fail indication has been generated by the optics CDU hardware). If Bit 2 of this word is 0, a Tracker alarm (Bit 8 of DSPTAB + 11) is generated if this bit has a 1 to 0 transition. Bit is set to 1 by a FRESH START or RESTART.
6	Not assigned.
5	Last sampled value of Channel 33, Bit 5 (0 if Optics Mode switch is set to CMC).
4	Last sampled value of Channel 33, Bit 4 (0 if Optics Zero switch set to Zero). If Bits 5-4 = 11 ₂ , the Optics Mode switch has been set to Manual.
3	Bit is set to 1 when the Optics Zero switch is changed to Zero to indicate that zeroing of the optics is in progress. If bit is 1 and Bit 1 of this word is 0, then a switch out of Zero Optics mode will cause alarm 0116g to be generated (if switched to Manual, a "grace period" of about 5.3 seconds is provided before the optics-zeroing time counter is reset, during which time a switchback to optics zeroing can be made). Bit remains 1 for about 16.2 seconds, and is then reset to 0 (at the same time that Bit 10 of this word is set to 1, and Bits 2-1 of this word are set to 0).
2	Bit is set to 1 to inhibit generation of Tracker alarm (Bit 8 of DSPTAB + 11) if Bit 7 of this word goes from 1 to 0. Bit is set and reset at the same time as Bit 3.
1	Bit is set to 1 to indicate that end of optics zeroing delay will occur in 0.4 second (remains 1 for that length of time, and then is reset to 0 at the same time as Bits 3-2). If bit is 1, generation of alarm 0116g (see Bit 3) is inhibited.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

RCSFLAGS, a flag whose individual bits are used in monitoring the RCS DAP.

Bit	Meaning
15	Bit is set to 1 to indicate that a high rate (2 deg/s) automanuever is in progress. Bit is reset to 0 to indicate that a high rate automanuever is not in progress.
14	Bit is set to 1 if rate estimates are not good and a repeat of the rate filter initialization is required. Bit is reset to 0 if the G & N is in control and the IMU data is usable. Approximately 1 second after the bit is reset to 0 the rate filter initialization is complete.
13	Bit is set to 1 if the rate damping has not been completed on the roll axis. Bit is reset to 0 if the rate damping on the roll axis has been completed.
12	Bit is set to 1 if the rate damping has not been completed on the pitch axis. Bit is reset to 0 if the rate damping has been completed on the pitch axis.
11	Bit is set to 1 if the rate damping has not been completed on the yaw axis. Bit is reset to 0 if the rate damping has been completed on the yaw axis.
*10,9	If either or both bits have been set to 1, there has been a change in the RHC roll command since the last DAP cycle. If both bits are reset to 0, it implies that no change in the RHC roll command has occurred since the last DAP cycle.
8,7	If either or both bits have been set to 1, there has been a change in RHC yaw command since the last DAP cycle. If both bits are reset to 0, it implies that no change in the RHC yaw command has occurred since the last DAP cycle.
**6,5	If either or both bits have been set to 1, there has been a change in the RHC pitch command since the last DAP cycle. If both bits are reset to 0, it implies that no change in the RHC pitch command has occurred since the last DAP cycle.
4	Bit is set to 1 to indicate that the AK values should be updated. Bit is reset to 0 to indicate that the Needle Drive routine should be processed with the AK values which have been previously acquired.
3,2	If (Bit 3, Bit 2) = (1,1) or (1,0), it is necessary to follow the initialization path of the Needle Drive routine. If (Bit 3, Bit 2) = (0, 1), it is necessary to follow Pass 2 of the Needle Drive routine. If (Bit 3, Bit 2) = (0, 0), it is necessary to follow Pass 3 and greater paths of the Needle Drive routine.
1	Bit is set to 1 to indicate that the initial pass path in the T6 program should not be followed. Bit is reset to 0 if the T6 program should be initialized.
	*Bit 9 will also be set to 1 as a result of executing V79 with the PTC option
	**Bit 5 will also be set to 1 as a result of executing V79 with the Orbrate option.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2C

DAPDATR1, a flagword for RCS-CSM DAP interface.

Bit	15-13	12-10	9-7	6-4	3-1
	CONFIG	XTAC	XTBD	DB	RATE
15-13	CONFIG:	Configuration			
		0	No DAP or ENTRY DAP		
		1	CSM		
		2	CSM/LM		
		3	CSM/SIVB		
		6	CSM/LM Ascent Stage Only		
12-10	XTAC:	X-translation using Quads AC			
		0	No AC		
		1	Use AC		
9-7	XTBD:	X-translation using Quads BD			
		0	No BD		
		1	Use BD		
6-4	DB:	Deadband			
		0	± 0.5 degree		
		1	± 5.0 degrees		
3-1	RATE:	Response to RHC, automatic maneuvers			
		0	0.05 degree/second		
		1	0.2 degree/second		
		2	0.5 degree/second		
		3	2.0 degrees/second		

DAPDATR2, a flagword for RCS-CSM DAP interface.

Bit	15-13	12-10	9-7	6-4	3-1
	AC-Roll	Quad A	Quad B	Quad C	Quad D
15-13	AC-Roll:	Roll jet selection			
		0	Use BD Roll		
		1	Use AC Roll		
12-10, 9-7, 6-4, 3-1	A, B, C, D Quad fails				
		0	Quad Failed		
		1	Quad OK		

CHANNEL BIT ASSIGNMENTS (CM)

OUTPUT CHANNEL 11

BIT

1	ISS Warning
2	Light Computer Activity Lamp
3	Light Uplink Activity Lamp
4	Light Temp Caution Lamp
5	Light Keyboard Release Lamp
6	Flash Verb and Noun Lamps
7	Light Operator Error Lamp
8	Spare
9	Test Connector Outbit
10	Caution Reset
11	Spare
12	Spare
13	Engine On/Off (1—On, 0—Off)
14	Spare
15	Spare

OUTPUT CHANNEL 12

1	Zero Optics CDU's
2	Enable Optics CDU Error Counter
3	Not Used
4	Coarse Align Enable
5	Zero IMU CDU's
6	Enable IMU CDU Error Counter
7	Spare
8	TVC Enable
9	Enable SIVB Takeover
10	Zero Optics
11	Disengage Optics DAC
12	Spare
13	SIVB Injection Sequence Start
14	SIVB Cutoff
15	ISS Turn-on Delay Complete

OUTPUT CHANNEL 13

1	Range Unit Select c
2	Range Unit Select b
3	Range Unit Select a
4	Range Unit Activity
5	Not Used
6	Block Inlink
7	Downlink Word Order
8	Not Used
9	Spare
10	Test Alarms
11	Enable Standby
12	Reset Trap 31-A
13	Reset Trap 31-B
14	Reset Trap 32
15	Enable T6RUP

NOTE:

Channel 13 Range Unit Selection: Bits 1 through 4 are assigned control functions for sampling of the VHF range link. These bits must contain 1001₈ in order to obtain control.

CHANNEL BIT ASSIGNMENTS (CM)

OUTPUT CHANNEL 14

BIT

1	Not Used
2	Spare
3	Spare
4	Spare
5	Spare
6	Gyro Enable
7	Gyro Select b
8	Gyro Select a
9	Gyro Sign Minus
10	Gyro Activity
11	Drive CDU S
12	Drive CDU T
13	Drive CDU Z
14	Drive CDU Y
15	Drive CDU X

Channel 14-Gyro Selection

a	b	Gyro
0	0	—
0	1	X
1	0	Y
1	1	Z

OUTPUT CHANNEL 15

BIT

1	Key codes from Main DSKY
2	Key codes from Main DSKY
3	Key codes from Main DSKY
4	Key codes from Main DSKY
5	Key codes from Main DSKY
6	Spare
7	Spare
8	Spare
9	Spare
10	Spare
11	Spare
12	Spare
13	Spare
14	Spare
15	Spare

OUTPUT CHANNEL 16

BIT

1	Key codes from Navigation DSKY
2	Key codes from Navigation DSKY
3	Key codes from Navigation DSKY
4	Key codes from Navigation DSKY
5	Key codes from Navigation DSKY
6	Mark button
7	Mark reject button
8	Spare
9	Spare
10	Spare
11	Spare
12	Spare
13	Spare
14	Spare
15	Spare

CHANNEL BIT ASSIGNMENTS (CM)

INPUT CHANNEL 30

BIT

1	Ullage Thrust Present
2	SM Separate
3	SPS Ready
4	SIVB Separate, Abort
5	Liftoff
6	Guidance Reference Release
7	Optics CDU Fail
8	Spare
9	IMU Operate
10	S/C Control of Saturn
11	IMU Cage
12	IMU CDU Fail
13	IMU Fail
14	ISS Turn-On Request
15	Temperature in Limits

NOTE:

All of the input signals in Channel 30 are inverted; that is, a ZERO bit indicates that the discrete is ON.

INPUT CHANNEL 31

BIT

1	+Pitch Manual Rotation
2	-Pitch Manual Rotation
3	+Yaw Manual Rotation
4	-Yaw Manual Rotation
5	+Roll Manual Rotation
6	-Roll Manual Rotation
7	+X Translation
8	-X Translation
9	+Y Translation
10	-Y Translation
11	+Z Translation
12	-Z Translation
13	Hold Function
14	Free Function
15	G & N Autopilot Control

NOTE:

All of the input signals in Channel 31 are inverted; that is, a ZERO bit indicates that the discrete is ON.

INPUT CHANNEL 32

BIT

1	+Pitch Minimum Impulse
2	-Pitch Minimum Impulse
3	+Yaw Minimum Impulse
4	-Yaw Minimum Impulse
5	+Roll Minimum Impulse
6	-Roll Minimum Impulse
7	Spare
8	Spare
9	Spare
10	Spare
11	LM Attached
12	Spare
13	Spare
14	Proceed
15	Spare

NOTE:

All of the input signals in Channel 32 are inverted; that is, a ZERO bit indicates that the discrete is ON.

CHANNEL BIT ASSIGNMENTS (CM)

INPUT CHANNEL 33

BIT

1	Spare
2	Range Unit Data Good
3	Spare
4	Zero Optics
5	CMC Control
6	Not Used
7	Not Used
8	Spare
9	Spare
10	Block Uplink Input*
11	Uplink Too Fast
12	Downlink Too Fast
13	PIPA Fail
14	AGC Warning
15	AGC Oscillator Alarm

*This bit reads ONE when accept uplink signal is present at interface.

NOTE:

All of the input signals in Channel 33 are inverted; that is, a ZERO bit indicates that the discrete is ON.

P00—CMC IDLING PROGRAM

Purpose:

1. To provide a program to fulfill the following requirements:
 - a. Provide an indication to the crew that the AGC is engaged in no control or computational operations which might require consideration for coordination with other crew tasks in progress.
 - b. To maintain the GNCS in a condition where manual attitude maneuvers can be made by the crew with minimal concern for the GNCS.
 - c. Maintain the AGC in a condition of readiness for entry into other programs.
2. To update the CSM and LM state vectors every four-time steps.

Assumptions:

1. The IMU may or may not be on. If on, the IMU is inertially stabilized but not necessarily aligned to an orientation which is known to the AGC.
2. If non-GNCS controlled attitude maneuvers are made by the crew, care must be taken to avoid IMU gimbal lock. The IMU gimbal angles may be monitored by observing the ICDU's (V16 N20) or by monitoring the FDAI ball.
3. The program is manually selected by the astronaut by DSKY entry.
4. This program is automatically selected by V96E, which may be done during any program. State vector integration is permanently inhibited following V96E. Normal integration functions will resume after selection of any program or extended verb. P00 integration will resume when P00 is reselected. Usage of V96 can cause incorrect W-matrix and state vector synchronization.

Selected Displays:

1. V06 N38

Time of state vector being integrated	00XXX. h
	000XX. min
	0XX.XX s

P01—PRELAUNCH OR SERVICE—INITIALIZATION PROGRAM

Purpose:

1. To initialize the platform for the prelaunch programs.
2. To provide an initial stable member orientation for Gyrocompassing (P02).

Assumptions:

1. The program is manually selected by DSKY entry.
2. Erasable locations have been properly initialized. (Azimuth, +1; Latitude, +1; LAUNCHAZ, +1; IMU compensation parameters).

P02—PRELAUNCH OR SERVICE—GYROCOMPASSING PROGRAM

Purpose:

1. To provide the proper stable member orientation for launch.

Assumptions:

1. This program may be interrupted to perform the Prelaunch or Service—Optical Verification of Gyrocompassing program (P03).
2. V75 will be keyed in and displayed during this program to permit crew backup of the liftoff discrete.
3. The program is automatically selected by the Initialization program (P01).
4. This program has the capability (via V78E) to change the launch azimuth of the stable member while gyrocompassing.

Selected Displays:

1. V06 N29

XSM launch azimuth	XXX.XX deg
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P03—PRELAUNCH OR SERVICE—OPTICAL VERIFICATION OF GYROCOMPASSING

Purpose:

1. To provide an optical check for verification of alignment of the stable member during gyrocompassing prior to launch.

Assumptions:

1. The program is manually selected by the DSKY entry.
2. The astronaut has zeroed the optics just prior to program (P03) selection.
3. A minimum of 45 minutes between V78E and P03 (V65E) assures proper damping of transients.
4. In order to prematurely terminate this program and return to P02 the astronaut may key in V34E on any flashing display.

Selected Displays:

1. V06 N41

Target azimuth	XXX.XX deg
Target elevation	XX.XXX deg
Target identification	0000X
2. V51 (please mark)
3. V50 N25 (terminate mark sequence)

Checklist code	00016
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4. V06 N93

Gyro torque angles	X XX.XXX deg
	Y XX.XXX deg
	Z XX.XXX deg

P06—AGC POWER DOWN PROGRAM

Purpose:

1. To transfer the AGC from the operate to the standby condition.

Assumptions:

1. When this program is turned on the astronaut must power down the AGC to standby. However, the program is not RESTART protected.
2. The normal condition of readiness of the GNCS when not in use is standby. All the G/N circuit breakers (Panel 5) are closed, the IMU and optics G/N power switches (LEB Panel 100) are off and the AGC standby light (DSKY) is on. In this condition the IMU is in standby with only heater power on, optics power is off, and the AGC is in standby.
3. A possible condition of readiness of the GNCS when not completely on is the same as standby (2) above, except the AGC standby light on the main and LEB DSKY's is off. In this configuration the AGC is running for computational purposes that do not require the IMU or optics.
4. If the computer power is switched off it will be necessary to perform a computer FRESH START (V36E) to initialize the erasable storage. The AGC Update program (P27) would have to be done to update the state vector and computer clock time.
5. The AGC is capable of maintaining an accurate value of ground elapsed time (GET) for only 23 hours when in standby. If the AGC is not brought out of the standby condition to the running condition (see Assumption 3 above) at least once within 23 hours the AGC value of GET must be updated.
6. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V50 N25 (AGC power down)

Checklist code	00062
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P11—EARTH ORBIT INSERTION MONITOR PROGRAM

Purpose:

1. To indicate to the astronaut that the AGC has received the liftoff discrete.
2. To generate an attitude error indication on the FDAI error needles, scaled for the 50/15 setting; from liftoff to the beginning of pitchover/rollout the attitude error is equal to the difference between the current vehicle attitude and the attitude stored at liftoff. During pitchover/rollout the attitude error is equal to the difference between the current vehicle attitude and the AGC nominal computation of vehicle attitude based on the stored polynomials in pitch and roll.
3. To display AGC computed trajectory parameters.
4. AGC takeover of Saturn during Boost
 - a. Automatic Control—All Stages: should the Saturn platform fail (during any stage of earth orbit insertion) the astronaut may set the S/C Control of Saturn switch to the ON position. This stores the current attitude errors as a bias. The Attitude Error routine for each cycle thereafter will compute the attitude error, subtract the bias, and transmit the difference information to the Saturn Instrumentation Unit (IU) for steering.
 - b. Manual Control—SII and SIVB Stages only: The astronaut may select the Saturn stick function via V46E (DAP configuration = 3). This will terminate the Attitude Error routine.

Assumptions:

1. The program is normally automatically selected by the Gyrocompassing program (P02) when the AGC receives the liftoff discrete from the SIVB. In the backup case it would have been selected by keying in V75 ENTER.
2. The orbit parameter display routine is available by keying in V82E.

Selected Displays:

1. V06 N62

Inertial velocity magnitude	XXXXX. ft/s
Altitude rate	XXXXX. ft/s
Altitude	XXXX.X nmi
2. V04 N12 (results from V82E)

Option code ID	00002
Option code	0000X (1—this vehicle, 2—other vehicle)
3. V06 N16 (results from V82E)

Time to which state vector will be integrated	00XXX. h
	000XX. min
	0XX.XX s
4. V16 N44 (results from V82E)

Apocenter altitude	XXXX.X nmi
Pericenter altitude	XXXX.X nmi
TFF	XX b XX min/s

P17—CSM TRANSFER PHASE INITIALIZATION SEARCH (TPI)

Purpose:

1. To accept a desired time of Transfer Phase Initiation (TIG(TPI)) as a DSKY input from the astronaut, and to compute therefrom the parameters associated with a minimum energy, safe periapsis transfer maneuver at TIG(TPI) and the resultant rendezvous intercept.
2. To provide the astronaut with the option of defining to the AGC the initial transfer trajectory search sector for central angles either greater or less than 180 degrees from the position of the active vehicle (CSM) at TIG(TPI).
3. To display to the astronaut the parameters associated with the transfer (TPI and intercept).

Assumptions:

1. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks and/or he may allow VHF ranging marks to accumulate.
2. To execute the TPI maneuver select the Transfer Phase Initiation (TPI) program (P34).
3. This program is selected by DSKY entry.

Selected Displays:

1. V06 N37

Time of TPI burn	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N72

Delta angle (TPI)	XXX.XX deg (+ active vehicle ahead)
Delta altitude (TPI)	XXXX.X nmi(+ passive vehicle above)
Search option	0000X (1—intercept at a central angle <180 degrees; 2—intercept at a central angle > 180 degrees)
3. V06 N58

Pericenter altitude (post TPI)	XXXX.X nmi
ΔV (TPI)	XXXX.X ft/s
ΔV (TPF)	XXXX.X ft/s
4. V06 N55

R1: Perigee code	0000X (1—perigee between TPI and TPF 2—perigee after intercept)
R3: Central angle of passive vehicle	XXX.XX deg

P20—RENDEZVOUS NAVIGATION PROGRAM

Purpose:

1. Control CSM attitude and optics to acquire the LM in the SXT field of view and to point the CSM transponder at the LM or to control the CSM attitude to acquire the LM along the +X axis (depends on option code).
2. Update either LM or CSM state vector via optical tracking data and/or VHF range data.

P20 (continued)

Assumptions:

1. IMU on and aligned.
2. The GNCS is in control of the vehicle in the auto mode in the nominal case. If the astronaut takes over control of the vehicle with RHC the CSM will remain at the attitude it is driven to. Regardless of mode selection the GNCS will calculate the preferred tracking attitude and the +X-axis tracking attitude.
3. Routine R03 performed prior to selection of this program. In order for the GNCS to perform the automatic attitude maneuvers, the astronaut should key in V46E at some time prior to the first maneuver.
4. LM maintaining preferred tracking attitude to correctly orient the optical beacon.
5. Program selected by DSKY entry.
6. Terminated by selection of P00, P06, P22, P23 or by V56E.

Selected Displays:

1. V50 N18

Desired gimbal angles	R XXX.XX deg
	P XXX.XX deg
	Y XXX.XX deg

2. V06 N18

Final gimbal angles	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg

3. V51 (please perform SXT mark)

4. V06 N49

ΔR	XXXX.X nmi
ΔV	XXXX.X ft/s
Source Code	0000X (1—optics, 2—VHF)

5. V06 N94 (backup optical device)

Alternate LOS shaft angle	XXX.XX deg
Alternate LOS trunnion angle	XX.XXX deg

6. V53 (please perform COAS mark)

P21—GROUND TRACK DETERMINATION PROGRAM

Purpose:

1. Provide astronaut with details of his ground track.

Assumptions:

1. Program selected by DSKY entry.
2. Can be used while CSM is in either earth or lunar orbit to determine ground track of either LM or CSM.
3. Vehicle whose ground track parameters are calculated to remain in freefall from the present time until T Lat Long.

Selected Displays:

1. V04 N06

Option code ID	00002
Option code ID	0000X (1—this vehicle 2—other vehicle)

P21 (continued)

- | | |
|----------------------------------|------------------------------------|
| 2. V06 N34 | |
| Time of LAT/LONG | 00XXX. h
000XX. min
0XX.XX s |
| 3. V06 N43 | |
| Latitude | XXX.XX deg (+ north) |
| Longitude | XXX.XX deg (+ east) |
| Altitude | XXXX.X nmi |
| 4. V06 N73 (astronaut initiated) | |
| Altitude | XXXXXXb. nmi |
| Velocity | XXXXX. ft/s |
| Flight path angle | XXX.XX deg |

P22—ORBITAL NAVIGATION PROGRAM

Purpose:

1. Locate and track landmark suitable for navigation purposes.
2. Obtain sighting marks on chosen landmark.
3. Calculate the orbital parameter changes generated by landmark sightings.
4. Update state vector as result of sightings (if sightings ok).
5. Update coordinates of known landmarks.
6. Provide coordinates of unknown landmarks.
7. Track preloaded landing site.
8. Provide coordinates of new landing site.
9. Provide coordinates of an offset landing site.
10. Align optics along an advanced orbit ground track for purpose of tracking and mapping a new landing site.

Assumptions:

1. There are two types of landmark tracking methods:
 - a. "Known" Landmark Tracking—The tracking of an earth landmark made known to the AGC by latitude, longitude/2, and altitude, and the tracking of a lunar landmark made known to the AGC by its latitude, longitude/2, and altitude.
 - b. "Unknown" Landmark Tracking—The tracking of a landmark or surface feature identified to the AGC as an unknown landmark, one whose coordinates are not known.
2. There are two types of landing site mapping methods:
 - a. Landing Site Designation—Track and mark on an unknown landmark. Store the resulting coordinates in Landmark Code 01. If mapping only is desired (that is, no state vector calculation or corrections), the astronaut need take only one mark.
 - b. Landing Site Offset—While tracking and marking on a primary landmark (known or unknown), point the optics SLOS at the chosen landing site and mark it once, (at least one mark on the primary landmark must have been made prior to this), then continue marking on the primary landmark. Store the resulting coordinates of the offset landing site in Landmark Code 01.
3. Acquisition of a landmark may be aided by the AGC by use of the Automatic Optics Positioning routine (R52).
4. Acquisition of a preloaded landing site may be aided by keying Landmark Code 01 into the V05 N70 display for use by the Automatic Optics Positioning routine (R52).

P22 (continued)

5. The Ground Track Determination program (P21) is available to aid the crew in choosing appropriate landmarks prior to selection of this program.
6. The Ground Track Determination program (P21) is available to the crew following this program to provide updated ground track information.
7. Possible attitude control methods might be as follows (in all cases care must be taken to monitor possible impending IMU gimbal lock).
 - a. Manual control by the pilot or navigator with the rotational hand controller.
 - b. Manual rate control by the navigator with the minimum impulse control in the GNC free mode.
8. The program may be performed with SIVB attached if the Launch Vehicle Guidance switch is placed in the CMC position thereby permitting SIVB attitude control with the rotational hand controller. GNC A/P control is required in this case.
9. The IMU must be on and aligned in order to complete this program.
10. Selection of this program will terminate the Rendezvous Navigation program (P20).
11. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N45

R3: Maximum middle gimbal angle	XXX.XX deg
---------------------------------	------------
2. V05 N70

R2: ABCDE (before mark)	
A – 1 if known landmark	
2 if unknown landmark	
B – index of offset designator	
C – not used	
DE – Landmark ID	
3. V06 N89 (landmark coordinates)

Latitude	XX.XXX deg (+ north)
Longitude/2	XX.XXX deg (+ east)
Altitude	XXX.XX nmi
4. V06 N92

Shaft angle	XXX.XX deg
Trunnion angle	XX.XXX deg
5. V51 (please mark)
6. V50 N25 (terminate mark sequence)

Checklist code	00016
----------------	-------
7. V05 N71

R2: ABCDE (after mark)	
Display same as Item 2 above	
8. V06 N49

ΔR	XXXX.X nmi
ΔV	XXXX.X ft/s

P23—CISLUNAR MIDCOURSE NAVIGATION PROGRAM

Purpose:

1. To do midcourse navigation by incorporation of star/earth and star/moon optical measurements.

Assumptions:

1. This program does not require that the IMU be on.
2. If the IMU is not aligned the astronaut must acquire the star/LMK or star/HOR manually.
3. If the IMU is:
 - a. Aligned, the astronaut may acquire the LMK/HOR automatically.
 - b. Aligned, the astronaut may acquire the star automatically.
 - c. On, the astronaut must take appropriate precautions to prevent possible IMU gimbal lock.
4. Prior to each mark the program will call for an optics calibration which may be done or bypassed dependent upon the stability history of the calibration.
5. To perform the mark the astronaut should finally select minimum impulse control (either GNCS or SCS) and the optics should be in manual in order to maintain the fix.
6. The optics should be on for 15 minutes prior to marking.
7. The AGC does not check for moon/earth occultation or sun brightness in this program.
8. This program is designed for one man operation within the constraints of mode switching while in the LEB.
9. Nouns 70 and 71 are checked to assure that the codes fall within certain permissible limits. (Check to assure that R2 and R3 do not both equal zero or do not both not equal zero, R1 = 0 to 37 (octal), R2 = ABCDE, C = 1 or 2, R3 = ABCDE, C and D = 1 or 2). Noun 89 is also checked to assure that the values for R1 and R2 fall within certain defined limits (-90 degrees to +90 degrees).
10. Noun 88 allows that any proportional set of components may be loaded for planet direction. However, a unit vector is recommended.
11. The program is selected by the astronaut by DSKY entry.

Selected Displays (Optics Calibration):

1. V05 N70 (before mark)

R1: 000DE

DE—star identification code

R2: ABCDE

AB— not used

C— 1 = earth landmark

2 = moon landmark

DE— not used

R3: 00CD0

C— 1 = earth horizon

2 = moon horizon

D— 1 = near horizon

2 = far horizon

2. V05 N25 (perform GNCS auto maneuver)

Checklist code

00202

3. V59 (perform calibration mark)

4. V06 N87

R2: Trunnion bias angle

XX.XXX deg

5. V51 (please mark)

P23 (continued)

Selected Displays (Navigation Measurement):

1. V05 N70 (before mark)
 - R1: 000DE
 - DE—star indication code
 - R2: ABCDE
 - AB — not used
 - C — 1 = earth landmark
 - 2 = moon landmark
 - DE — not used
 - R3: 00CD0
 - C — 1 = earth horizon
 - 2 = moon horizon
 - D — 1 = near horizon
 - 2 = far horizon
2. V06 N89 (landmark coordinates)
 - Latitude XX. XXX deg (+ north)
 - Longitude/2 XX.XXX deg (+ east)
 - Altitude XXX.XX nmi
3. V06 N88
 - Components of celestial body $\frac{1}{2}$ unit vector .XXXXXX
4. V50 N25 (perform GNCS auto maneuver)
 - Checklist code 00202
5. V50 N18
 - Desired gimbal angles
 - OG XXX.XX deg
 - IG XXX.XX deg
 - MG XXX.XX deg
6. V06 N18
 - Final gimbal angles
 - OG XXX.XX deg
 - IG XXX.XX deg
 - MG XXX.XX deg
7. V06 N92
 - Shaft angle XXX.XX deg
 - Trunnion angle XX.XXX deg
8. V51 (please mark)
9. V50 N25 (terminate mark sequence)
 - Checklist code 00016
10. V05 N71 (after mark)
 - Display same as Item 1 above.
11. V06 N49
 - ΔR XXXX.X nmi
 - ΔV XXXX.X ft/s

P27—AGC UPDATE PROGRAM

Purpose:

1. To insert information into the AGC via the digital uplink by transmission from the ground or via the DSKY keyboard by crew manual input.

Assumptions:

1. The AGC must be in the operate condition. The IMU may be in standby or operate condition.
2. AGC updates are of four categories:
 - a. Provide an update for AGC liftoff time (V70).
 - b. Provide an octal increment for the AGC clock only (V73).
 - c. Provide load capability for a block of sequential erasable locations (1-18 inclusive locations whose address is specified) (V71).
 - d. Provide load capability for 1-9 inclusive individually specified erasable locations (V72).
3. Update is allowed in the CSM when the AGC is in P00 or P02, and if the DSKY is available.
4. The UPTTEL Accept/Block switch must be in Accept for telemetry update.
5. The program is manually selected by the astronaut by DSKY entry or by the ground by uplink transmission.
6. The automatic mode of update is program selection and update via the ground by uplink transmission. The only difference between this and manual selection by the astronaut is that the DSKY responses are keyed in by the astronaut rather than transmitted.

P30—EXTERNAL DELTA V PROGRAM

Purpose:

1. To accept targeting parameters obtained from a source(s) external to the AGC and compute therefrom the required velocity and other initial conditions required by the AGC for execution of the desired maneuver. The targeting parameters inserted into the AGC are the time of ignition (TIG) and the impulsive ΔV along CSM local vertical axes at TIG.
2. To display to the astronaut and the ground certain specific dependent variables associated with the desired maneuver for approval by the astronaut/ground.

Assumptions:

1. Target parameters (TIG and ΔV (LV)) may have been loaded from the ground during a prior execution of P27.
2. External Delta V flag is set during the program to designate to the thrusting program that external Delta V steering is to be used.
3. ISS need not be on to complete this program.
4. Program is selected by DSKY entry.

Selected Displays:

1. V06 N33
 Time of ignition for external ΔV burn
 00XXX. h
 000XX. min
 0XX.XX s
2. V06 N81
 Components of ΔV (LV)
 XXXX.X ft/s

P30 (continued)

- | | |
|--|---------------|
| 3. V06 N42 | |
| Apocenter altitude | XXXX.X nmi |
| Pericenter altitude | XXXX.X nmi |
| ΔV (required) | XXXX.X ft/s |
| 4. V16 N45 | |
| Marks (VHF/optics) | XX b XX marks |
| Time from external ΔV ignition | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |

P31—LAMBERT AIM POINT GUIDANCE PROGRAM

Purpose:

1. To accept targeting parameters obtained from a source(s) external to the AGC and compute therefrom the required velocity and other initial conditions required by the AGC for execution of the desired maneuver. The targeting parameters inserted into the AGC are the time of ignition (TIG), ECSTEER, the target vector, and the time from TIG until the target is to be reached (Delta T Trans).
2. To display to the astronaut and the ground certain specific dependent variables associated with the desired maneuver for approval by the astronaut/ground.

Assumptions:

1. The target parameters (TIG, Target Vector, ECSTEER, and Delta T Trans) have been loaded from the ground during a prior execution of P27.
2. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.
3. ISS need not be on to complete this program.
4. This program is selected by DSKY entry.

Selected Displays:

- | | |
|---|---------------|
| 1. V06 N33 | |
| Time of ignition for Lambert aim point burn | 00XXX. h |
| | 000XX. min |
| | 0XX.XX s |
| 2. V06 N81 | |
| Components of ΔV (LV) | XXXX.X ft/s |
| 3. V06 N42 | |
| Apocenter altitude | XXXX.X nmi |
| Pericenter altitude | XXXX.X nmi |
| ΔV (required) | XXXX.X ft/s |
| 4. V16 N45 | |
| Mark (VHF/optics) | XX b XX marks |
| Time from Lambert aim point ignition | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |

P32—CSM COELLIPTIC SEQUENCE INITIATION (CSI) PROGRAM

Purpose:

1. To calculate parameters associated with the following concentric flight plan maneuvers: the Coelliptic Sequence Initiation (CSI) and the Constant Delta Altitude maneuver (CDH), for Delta V burns.
2. To calculate these parameters based upon maneuver data approved and keyed into the AGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.
4. To store the CSI target parameters for use by the desired thrusting program.

Assumptions:

1. At a selected TPI time the line of sight between the LM and the CSM is selected to be a prescribed angle (E) from the horizontal plane defined at the active position.
2. The time between CSI ignition and CDH ignition must be computed to be greater than 10 minutes for successful completion of the program.
3. The time between CDH ignition and TPI ignition must be computed to be greater than 10 minutes for successful completion of the program.
4. CDH Delta V is selected to minimize the variation of the altitude difference between the orbits.
5. CSI burn is defined such that the impulsive Delta V is in the horizontal plane defined by the active vehicle position at CSI ignition.
6. The pericenter altitude of the orbit following CSI and CDH must be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit) for successful completion of this program.
7. The CSI and CDH maneuvers are originally assumed to be parallel to the plane of the LM orbit. However, crew modification of Delta V (LV) components may result in an out-of-plane CSI maneuver.
8. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
9. This program is selected by the astronaut by DSKY entry.
10. The external Delta V flag is set during this program to designate to the thrusting program that external Delta V steering is to be used.
11. If P20 is in operation while the program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.

Selected Displays:

1. V06 N11

Time of CSI ignition	00XXX. h
	000XX. min
	0XX.XX s

2. V06 N55

Number of apsidal crossings	0000X
Elevation angle	XXX.XX deg
Central angle of passive vehicle	XXX.XX deg

3. V06 N37

Time of TPI ignition	00XXX. h
	000XX. min
	0XX.XX s

P32 (continued)

4. V16 N45	
Marks (VHF/optics)	XX b XX marks
Time from CSI ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
5. V06 N75	
Delta altitude (CDH)	XXXX.X nmi
ΔT (CDH-CSI)	XX b XX min/s
ΔT (TPI-CDH)	XX b XX min/s
6. V06 N81	
Components of ΔV (LV) for CSI	XXXX.X ft/s
7. V06 N82	
Components of ΔV (LV) for CDH	XXXX.X ft/s
8. V06 N13 (astronaut initiated)	
Time of CDH ignition	00XXX. h 000XX. min 0XX.XX s
9. V04 N12 (results from V90E)	
Option code ID	00002
Option code	0000X (1—this vehicle 2—other vehicle)
10. V06 N16 (results from V90E)	
Time of event	00XXX. h 000XX. min 0XX.XX s
11. V06 N90 (results from V90E)	
Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

P33—CSM CONSTANT DELTA ALTITUDE (CDH) PROGRAM

Purpose:

1. To calculate parameters associated with the Constant Delta Altitude maneuver (CDH), for Delta V burns.
2. To calculate these parameters based upon maneuver data approved and keyed into the DSKY by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the CDH maneuver for approval by the astronaut/ground.
4. To store the CDH target parameters for use by the desired thrusting program.

P33 (continued)

Assumptions:

1. This program is based upon previous completion of the Coelliptic Sequence Initiation (CSI) program (P32). Therefore:
 - a. At a selected TPI time (now in storage) the line of sight between the LM and the CSM was selected to be a prescribed angle (E) (now in storage) from the horizontal plane defined at the active vehicle position.
 - b. The time between CSI ignition and CDH ignition was computed to be greater than 10 minutes.
 - c. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - d. The variation of the altitude difference between the orbits was minimized.
 - e. CSI burn is defined such that the impulsive Delta V is in the horizontal plane defined by the active vehicle position at CSI ignition.
 - f. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit).
 - g. The CSI and CDH maneuvers were assumed to be parallel to the plane of the LM orbit. However, crew modification of Delta V (LV) components may have resulted in an out-of-plane CSI maneuver.
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
3. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
4. This program is selected by the astronaut by DSKY entry.
5. The external Delta V flag is set during this program to designate to the thrusting program that external Delta V steering is to be used.

Selected Displays:

1. V06 N13

Time of CDH ignition	00XXX h
	000XX min
	0XX.XX s
2. V16 N45

Marks (VHF/optics)	XX b XX mark
Time from CDH ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
3. V06 N75

Delta altitude (CDH)	XXXX.X nmi
ΔT (TPI-CDH)	XX b XX min/s
ΔT (TPI-NOMTPI)	XX b XX min/s
4. V06 N81

Components of ΔV (LV) for CDH	XXXX.X ft/s
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5. V06 N12 (results from V90E)

Option code ID	00002
Option code	0000X (1—this vehicle, 2—other vehicle)

P33 (continued)

6. V06 N16 (results from V90E)

Time of event

 00XXX. h
 000XX. min
 0XX.XX s

7. V06 N90 (results from V90E)

Y

XXX.XX nmi

YDOT

XXXX.X ft/s

PSI

XXX.XX deg

 P34—CSM TRANSFER PHASE INITIATION (TPI)
 TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the AGC for execution of the Transfer Phase Initiation maneuver. Given:
 - a. TIG (TPI) or the Elevation angle (E) of the CSM/LM LOS at TIG (TPI).
 - b. Central angle of transfer (CENTANG) from TIG (TPI) to intercept time (TIG(TPF)).
2. To calculate TIG (TPI) given E or E given TIG (TPI).
3. To display to the astronaut and the ground certain dependent variables associated with the maneuver for approval by the astronaut/ground.
4. To store the TPI target parameters for use by the desired thrusting program.

Assumptions:

1. The program must be done over a tracking station for real-time ground participation in AGC data input and output.
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
3. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.
 The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.
4. When determining the initial position and velocity of the target at intercept time, either conic or precision integration may be used. The time difference for computation is approximately 10:1 (that is, conic integration is 10 times faster than precision integration).
5. ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
6. This program is selected by DSKY entry.
7. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.

Selected Displays:

1. V06 N37

Time of TPI ignition

 00XXX. h
 000XX. min
 0XX.XX s

P34 (continued)

2. V06 N55		
Integration code	0000X (0—conic, # 0—precision)	
Elevation angle	XXX.XX deg	
Central angle of passive vehicle	XXX.XX deg	
3. V16 N45		
Mark (VHF/optics)	XX b XX marks	
Time from TPI ignition	XX b XX min/s	
Middle gimbal angle	XXX.XX deg	
4. V06 N58		
Pericenter altitude (post TPI)	XXXX.X nmi	
ΔV (TPI)	XXXX.X ft/s	
ΔV (TPF)	XXXX.X ft/s	
5. V06 N81		
Components of ΔV (LV) for TPI	XXXX.X ft/s	
6. V06 N59		
Components of ΔV (LOS) for TPI	XXXX.X ft/s	
7. V06 N52 (astronaut initiated)		
Central angle of active vehicle	XXX.XX deg	
8. V04 N12 (results from V90E)		
Option code ID	00002	
Option code	0000X (1—this vehicle, 2—other vehicle)	
9. V06 N16 (results from V90E)		
Time of event	00XXX. h	
	000XX. min	
	0XX.XX s	
10. V06 N90 (results from V90E)		
Y	XXX.XX nmi	
YDOT	XXXX.X ft/s	
PSI	XXX.XX deg	

P35—CSM TRANSFER PHASE MIDCOURSE (TPM)
TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the AGC for CSM execution of the next midcourse correction of the transfer phase of an active CSM rendezvous.

Assumptions:

1. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.

P35 (continued)

2. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and the expected maneuver time.

3. The time of intercept (T(INT)) was defined by previous completion of the Transfer Phase Initiation (TPI) program (P34) and is presently available in AGC storage.
4. ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
5. The program is selected by DSKY entry.
6. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.

Selected Displays:

1. V16 N45

Mark (VHF/optics)	XX b XX marks
Time from TPM ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
2. V06 N81

Components of ΔV (LV) for TPM	XXXX.X ft/s
---------------------------------------	-------------
3. V06 N59

Components of ΔV (LOS) for TPM	XXXX.X ft/s
--	-------------
4. V06 N52 (astronaut initiated)

Central angle of active vehicle	XXX.XX deg
---------------------------------	------------
5. V04 N12 (results from V90E)

Option code ID	00002
Option code	0000X (1—this vehicle, 2—other vehicle)
6. V06 N16 (results from V90E)

Time of event	00XXX. h 000XX. min 0XX.XX s
---------------	------------------------------------
7. V06 N90 (results from V90E)

Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

P37-RETURN TO EARTH

Purpose:

1. This program will compute a return-to-earth trajectory providing the CSM is outside the lunar sphere of influence at the time of ignition.
2. This program computes and displays a preliminary series of parameters based on a conic trajectory and:
 - a. Astronaut specified time of ignition.
 - b. Astronaut specified maximum change in velocity.
 - c. Astronaut specified reentry angle.
 These parameters are:
 - a. Time from ignition to reentry.
 - b. Reentry inertial velocity.
 - c. Reentry flight path angle.
 - d. Latitude of splash.
 - e. Longitude of splash.
 - f. Delta V (LV).
3. When the initial display is satisfactory to the astronaut, the program recomputes the same data, using applicable perturbations to the conic trajectory, and displays the new values.
4. Upon final acceptance by the astronaut, the program computes and stores the target parameters for return to earth for use by the SPS program (P40) or RCS program (P41).
5. Based upon the specified propulsion system the following are displayed:
 - a. Middle gimbal angle at ignition.
 - b. Time of ignition (TIG).
 - c. Time from ignition (TFI).

Assumptions:

1. This program assumes that contact with the ground is unavailable, and is completely self-contained.
2. The ISS need not be on to complete this program.
3. If value of VPRED entered in Noun 60 is less than the minimum required to return to earth, the Delta V required vector will be computed based on a minimum value. If the value entered is greater than the minimum required to return to earth, then the astronaut desired value will be used to compute the Delta V required vector. The computed Delta V required vector will be displayed in Noun 81.
4. The DAP Data Load routine (R03) should be performed prior to completion of this program.
5. This program is selected by DSKY entry.
6. The reentry range calculation provided by the AUGER KUGEL routine may be overwritten by a pad loaded single precision erasable.
7. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.

Selected Displays:

1. V06 N33

Time of return to earth ignition

00XXX. h

000XX. min

0XX.XX s

P37 (continued)

- | | |
|---|---------------------------------------|
| 2. V06 N60 | |
| R2: Predicted velocity at 400 k ft | XXXXXX. ft/s |
| R3: Predicted flight path angle at 400 k ft | XXX.XX deg |
| 3. V06 N61 | |
| Impact latitude | XXX.XX deg (+ north) |
| Impact longitude | XXX.XX deg (+ east) |
| 4. V06 N39 | |
| ΔT for transfer | 00XXX. h |
| | 000XX. min |
| | 0XX.XX s |
| 5. V06 N81 | |
| Components of ΔV (LV) for transfer | XXXX.X ft/s |
| 6. V04 N06 (thrust program option) | |
| Option code ID | 00007 |
| Option code | 0000X (1-SPS (P-40),
2-RCS (P-41)) |
| 7. V16 N45 | |
| Marks (VHF/optics) | XX b XX marks |
| Time from ignition | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |

P38—CSM STABLE ORBIT RENDEZVOUS (SOR)
TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the AGC for CSM execution of the first phase of the Stable Orbit Rendezvous maneuver.
Given:
 - a. Time of ignition (TIG).
 - b. Central angle of transfer (CENTANG) from TIG to intercept time.
 - c. The offset of the stable orbit point specified as a distance along the passive vehicle orbit.
2. To calculate the required Delta V and other initial conditions required by the AGC for CSM execution of the second phase of the Stable Orbit Rendezvous maneuver.
Given:
 - a. A respecification of 1(a) above.
 - b. An optional respecification of 1(b) above.
3. To calculate these parameters based upon maneuver data approved and keyed into the AGC by the astronaut.
4. To display to the astronaut and the ground certain dependent variables associated with the maneuver for approval by the astronaut/ground.
5. To store the SOR Phase 1 and Phase 2 target parameters for use by the desired thrusting program.

Assumptions:

1. The stable orbit point is defined as the final position (at completion of the second phase) of the active vehicle relative to the passive vehicle.

P38 (continued)

2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
3. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone, the astronaut should reassess the input targeting parameters based upon Delta V and the expected maneuver time.

4. The second phase of this program requires the TIG input be biased as a function of TPF and any midcourse corrections performed in the Stable Orbit Midcourse (SOM) program (P39).
5. ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
6. This program is selected by DSKY entry.
7. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.

Selected Displays:

1. V06 N33

Time of SOR ignition	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N55

R3: Central angle of passive vehicle	XXX.XX deg
--------------------------------------	------------
3. V04 N06 (specify phase)

Option code ID	00005
Option code	0000X (1-first pass, 2-second pass)
4. V06 N57

Offset of the stable orbit point	XXXX.X nmi (+ passive vehicle ahead)
----------------------------------	---
5. V06 N34

Time of arrival at stable orbit	00XXX. h
	000XX. min
	0XX.XX s
6. V16 N45

Marks (VHF/optics)	XX b XX marks
Time of SOR ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
7. V06 N58

Pericenter altitude (SOR)	XXXX.X nmi
ΔV (SOR)	XXXX.X ft/s
ΔV (SOR - final)	XXXX.X ft/s
8. V06 N81

Components of ΔV (LV) for SOR	XXXX.X ft/s
---------------------------------------	-------------
9. V06 N52 (astronaut initiated)

Central angle of active vehicle	XXX.XX deg
---------------------------------	------------

P39—CSM STABLE ORBIT MIDCOURSE (SOM) TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the AGC for CSM execution of the next possible midcourse correction of the stable orbit transfer phase of an active CSM rendezvous.
2. To compute and display suitable information to enable the crew to enter the final rendezvous phase at the correct time to complete the required thrusting maneuver.

Assumptions:

1. ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
3. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and the expected maneuver time.

4. The time of intercept (T(INT)) was defined by previous completion of the Stable Orbit Rendezvous (SOR) program (P38) and is presently available in AGC storage.
5. This program is selected by DSKY entry.
6. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.

Selected Displays:

1. V16 N45

Marks (VHF/optics)	XX b XX marks
Time from SOM ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
2. V06 N81

Components of ΔV (LV) for SOM	XXXX.X ft/s
---------------------------------------	-------------
3. V06 N52 (astronaut initiated)

Central angle of active vehicle	XXX.XX deg
---------------------------------	------------

P40—SPS PROGRAM

Purpose:

1. To compute a preferred IMU orientation and a preferred vehicle attitude for an SPS thrusting maneuver.
2. To calculate and display the gimbal angles which would result from the present IMU orientation if the vehicle were maneuvered to the preferred vehicle attitude for an SPS thrusting maneuver. The crew is thereby given an opportunity to perform the maneuver with:
 - a. The present IMU orientation, if the middle gimbal angle is not greater than 45 degrees, and the IMU has been aligned within the last 3 hours.
 - b. A new orientation achieved by selection of P52.
3. To maneuver the vehicle to the thrusting attitude.
4. To control the GNCS during countdown, ignition, thrusting, and thrust termination of a GNCS controlled SPS maneuver.

P40 (continued)

Assumptions:

1. The target parameters have been calculated and stored in the AGC by prior execution of a prethrusting program.
2. The required steering equations are identified by the prior prethrust program, which either set or reset the external Delta V steering flag. For external Delta V steering, VG is calculated once for the specified time of ignition. Thereafter, both during thrusting and until the crew notifies the AGC trim thrusting has been completed, the AGC updates VG only as a result of compensated accelerometer inputs.
For Lambert steering, VG is calculated and updated similarly; however, it is also updated periodically by Lambert solutions to correct for changes in the CSM state vector.
3. It is normally required that the ISS be on for 15 minutes prior to a thrusting maneuver.
4. The TTE clock is set to count to zero at TIG.
5. Engine ignition may be slipped beyond the established TIG if desired by the crew or if integration can not be completed on time.
6. The SPS thrusting program does not monitor the SC control discrete (Channel 31, Bit 15) during thrusting. This means that the AGC will continue to generate engine actuator commands, SPS Engine On discrete, and FDAI attitude error needle commands until the AGC solution indicates Engine Off at which time these commands and the Engine On discrete are terminated. However, this program is not written to take into account the situation where control may be taken away from the GNCS and then given back, and it is not recommended. In event control is taken away from the GNCS, the AGC will only be responsible for computation of position and velocity.
7. Routine R03 has been performed prior to selection of this program. In order for the GNCS to perform the attitude maneuver and control the thrusting maneuver the astronaut must key in V46E at some time prior to the attitude maneuver.
8. The value of Delta V required will be stored in the local vertical coordinate system and is available during this program until average g turn-on by keying in V06 N81E.
9. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
10. This program is selected by DSKY entry.
11. The AGC issues an SIVB cutoff command (Channel 12, Bit 14) for possible backup use. This signal is recognized by Saturn only if the Launch Vehicle Guidance switch is set to CMC.

Selected Displays:

1. V50 N18

Desired gimbal angle	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
2. V06 N18

Final gimbal angles	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
3. V50 N25 (gimbal drive test)

Checklist code	00204
----------------	-------
4. V06 N40

Time from SPS ignition/cutoff	XX b XX min/s
Velocity to be gained	XXXX.X ft/s
ΔV (accumulated)	XXXX.X ft/s

P40 (continued)

5. V99 N40 (request engine on enable)
Display same as Item 4 above.
6. V97 N40 (perform engine fail procedure)
Display same as Item 4 above.
7. V16 N40
Display same as Item 4 above.
8. V16 N85
Components of velocity to be gained (body) XXXX.X ft/s
9. V06 N81 (astronaut initiated)
Components of initial velocity to be gained (LV) XXXX.X ft/s
10. V04 N12 (results from V82E)
Option code ID 00002
Option code 0000X (1—this vehicle
2—other vehicle)
11. V06 N16 (results from V82E)
Time to which state vector will be integrated 00XXX. h
000XX. min
0XX.XX s
12. V16 N44 (results from V82E)
Apocenter altitude XXXX.X nmi
Pericenter altitude XXXX.X nmi
TFF XX b XX min/s

P41—RCS PROGRAM

Purpose:

1. Compute a preferred IMU orientation and preferred vehicle attitude for an RCS thrusting maneuver.
2. Calculate the gimbal angles which would result from the present IMU orientation if the vehicle +X axis were aligned to the thrust vector. The crew is thereby given an opportunity to perform the maneuver with:
 - a. The present IMU orientation (not recommended if middle gimbal angle is greater than 45 degrees). If the IMU has not been aligned within the last 3 hours, realignment is desirable.
 - b. A new orientation achieved by selection of P52.
3. Do the vehicle maneuver to the thrusting attitude.
4. Provide suitable displays for manual execution of the thrusting maneuver.

Assumptions:

1. The target parameters have been calculated and stored in the AGC by prior execution of a prethrusting program.
2. The required steering equations are identified by the prior prethrust program, which either set or reset the external Delta V steering flag. For external Delta V steering, VG is calculated once for the specified time of ignition. Thereafter, both during thrusting and until the crew notifies the AGC trim thrusting has been completed, the AGC updates VG only as a result of compensated accelerometer inputs.

For Lambert steering, VG is calculated and updated similarly. However, it is also updated periodically by Lambert solutions to correct for changes in the CSM state vector.

P41 (continued)

3. It is normally required that the ISS be on for 15 minutes prior to a thrusting maneuver.
4. The TTE clock is set to count to zero at TIG.
5. Translation initiation may be slipped beyond the established TIG if desired by the crew or if integration cannot be completed on time.
6. This program is selected by DSKY entry.
7. Routine R03 has been performed prior to selection of this program.
8. The value of Delta V required will be stored in the local vertical coordinate system and is available during this program until Average G turn-on by keying in V06 N81E.
9. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.

Selected Displays:

1. V50 N18

Desired gimbal angles	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
2. V06 N18

Final gimbal angles	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
3. V06 N85

Components of velocity to be gained (body)	XXXX.X ft/s
--	-------------
4. V16 N85

Display same as Item 3 above.	
-------------------------------	--
5. V06 N81 (astronaut initiated)

Components of initial velocity to be gained (LV)	XXXX.X ft/s
--	-------------
6. V04 N12 (results from V82E)

Option code ID	00002
Option code	0000X (1—this vehicle 2—other vehicle)
7. V06 N16 (results from V82E)

Time to which state vector will be integrated	00XXX. h
	000XX. min
	0XX.XX s
8. V16 N44 (results from V82E)

Apocenter altitude	XXXX.X nmi
Pericenter altitude	XXXX.X nmi
TFF	XX b XX min/s

P47—THRUST MONITOR PROGRAM

Purpose:

1. To monitor vehicle acceleration during a non-GNCS-controlled thrusting maneuver.
2. To display the Delta V applied to the vehicle by this thrusting maneuver.

P47 (continued)

Assumptions:

1. It is normally required that the IMU be on for 15 minutes prior to a thrusting maneuver.
2. The responsibility of avoiding gimbal lock during execution of this program is upon the astronaut.
3. This program is normally used during rendezvous final phase. If the crew desires to do any final phase thrusting maneuvers automatically under GNCS control, they must be accomplished via selection of the Transfer Phase Initiation (TPI) program (P34) and then the SPS Thrusting program (P40) or the RCS Thrusting program (P41).
4. Range, Range Rate, and Theta may be displayed during this program by calling the Rendezvous Parameter Display routine No. 1 (R31) with V83E.
5. Range, Range Rate, and Phi may be displayed during this program by calling the Rendezvous Parameter Display routine No. 2 (R34) with V85E.
6. VI, H, and H-dot may be called by keying in V16 N62E.
7. The Orbit Parameter Display routine may be called during this program by keying in V82E.
8. This program should be turned on just prior to the planned thrusting maneuver and terminated as soon as possible following the maneuver in order to keep errors of bias and AVERAGE G at a minimum.
9. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V16 N83
Components of ΔV (body) XXXX.X ft/s
2. V16 N54 (results from V83E)
Range XXX.XX nmi
Range rate XXXX.X ft/s
Theta XXX.XX deg
3. V16 N53 (results from V85E)
Range XXX.XX nmi
Range rate XXXX.X ft/s
Phi XXX.XX deg
4. V16 N62 (astronaut initiated)
Magnitude of inertial velocity XXXXX. ft/s
Altitude rate XXXXX. ft/s
Altitude (invalid in moon orbit) XXXX.X nmi
5. V04 N12 (results from V82E)
Option code ID 00002
Option code 0000X (1—this vehicle,
2—other vehicle)
6. V06 N16 (results from V82E)
Time to which state vector will be integrated 00XXX. h
000XX. min
0XX.XX s
7. V16 N44 (results from V82E)
Apocenter altitude XXXX.X nmi
Pericenter altitude XXXX.X nmi
TFF XX b XX min/s

P51-IMU ORIENTATION DETERMINATION PROGRAM

Purpose:

1. To determine the inertial orientation of the IMU using sightings on two celestial bodies using the scanning telescope or the sextant.

Assumptions:

1. The IMU may be:
 - a. Off (standby).
 - b. On, and aligned or not aligned since turn-on.
 If (a) is true, the IMU must be turned on before this program can be performed.
 If (b) is true, this program can be completed.
2. There are no restraints upon the CSM attitude control modes in this program.
3. Time and RCS fuel may be saved, and subsequent IMU alignment decisions greatly simplified if this program is performed in such a way as to leave the IMU inertially stabilized at an orientation as close as possible to the optimum orientation required by future AGC programs.
4. The program is selected by DSKY entry.

Selected Displays:

1. V50 N25 (acquire celestial body)

Checklist code	00015
----------------	-------
2. V41 N22

Gimbal angles to be coarse aligned to	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
3. V51 (please mark)
4. V50 N25 (terminate mark sequence)

Checklist code	00016
----------------	-------
5. V01 N71

Celestial body code (after mark)	000XX
----------------------------------	-------
6. V06 N88

Components of celestial body $\frac{1}{2}$ unit vector	.XXXXX
--	--------
7. V06 N05

Sighting angle difference	XXX.XX deg
---------------------------	------------

P52-IMU REALIGN PROGRAM

Purpose:

1. To align the IMU from a "known" orientation to one of four orientations selected by the astronaut using sightings on two celestial bodies with the scanning telescope or the sextant:
 - a. Preferred Orientation (00001)

An optimum orientation for a previously calculated maneuver. This orientation must be calculated and stored by a previously selected program.

P52 (continued)

b. Landing Site Orientation (00004)

$$X_{SM} = \text{Unit}(R_{LS})$$

$$Y_{SM} = \text{Unit}(Z_{SM} \times X_{SM})$$

$$Z_{SM} = \text{Unit}(H_{CSM} \times X_{SM})$$

where

The origin is the center of the moon.

R_{LS} = The position of the most recently defined landing site at time T (align) selected by the astronaut.

H_{CSM} = The angular momentum vector of the CSM ($R_{CSM} \times V_{CSM}$) at time T (align) selected by the astronaut.

c. Nominal Orientation (00002)

$$X_{SM} = \text{Unit}(Y_{SM} \times Z_{SM})$$

$$Y_{SM} = \text{Unit}(V \times R)$$

$$Z_{SM} = \text{Unit}(-R)$$

where

R = The geocentric (earth orbit) or selenocentric (lunar orbit) radius vector at time T (align) selected by the astronaut.

V = the inertial velocity vector at time T (align) selected by the astronaut.

d. REFSMMAT (00003)

Assumptions:

1. The docked configuration may be SIVB/CSM, LM/CSM, or CSM. The present configuration should have been entered into the AGC by completion of the DAP Data Load routine R03.
2. If the mode switch is in Attitude Hold during the Gyro Torquing routine (R55), the DAP will maneuver the vehicle to follow the platform.
3. This program makes no provision for an attitude maneuver to return the vehicle to a specific attitude. Such a maneuver, if desired, must be done manually. An option is provided however to point the sextant at astronaut or AGC selected stars either manually by crew input or automatically under AGC control.
4. The ISS is on and has been aligned to a known orientation which is stored in the AGC (REFSMMAT). The present IMU orientation differs from that to which it was last aligned only due to gyro drift (that is, neither gimbal lock nor IMU power interruption has occurred since the last alignment).
5. The landing site orientation is used for:
 - a. Aligning the CSM stable member to the same orientation as the LM stable member prior to LM/CSM separation.
 - b. Aligning the CSM stable member to the same orientation as the LM stable member prior to LM ascent from the lunar surface.
6. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V04 N06

Option code ID

00001

Option code

0000X (1—preferred, 2—nominal,
3—REFSMMAT, 4—landing site)

2. V06 N34

Time of alignment

00XXX. h

000XX. min

0XX.XX s

P52 (continued)

- | | |
|---|---|
| 3. V06 N89 (landing site) | |
| Latitude | XX.XXX deg (+ north) |
| Longitude/2 | XX.XXX deg (+ east) |
| Altitude | XXX.XX nmi |
| 4. V06 N22 | |
| Gimbal angles which will result from selected IMU orientation | OG XXX.XX deg
IG XXX.XX deg
MG XXX.XX deg |
| 5. V50 N25 (coarse align) | |
| Checklist code | 00013 |
| 6. V16 N20 | |
| Actual gimbal angles | OG XXX.XX deg
IG XXX.XX deg
MG XXX.XX deg |
| 7. V50 N25 (acquire celestial body) | |
| Checklist code | 00015 |
| 8. V01 N70 | |
| Celestial body code (before mark) | 000XX |
| 9. V06 N88 | |
| Components of celestial body 1/2 unit vector | .XXXXXX |
| 10. V06 N92 | |
| Desired shaft angle | XXX.XX deg |
| Desired trunnion angle | XX.XXX deg |
| 11. V51 (please mark) | |
| 12. V50 N25 (terminate mark sequence) | |
| Checklist code | 00016 |
| 13. V01 N71 | |
| Celestial body code (after mark) | 000XX |
| 14. V06 N05 | |
| Sighting angle difference | XXX.XX deg |
| 15. V06 N93 | |
| Gyro torque angles | X XX.XXX deg
Y XX.XXX deg
Z XX.XXX deg |
| 16. V50 N25 (fine align) | |
| Checklist code | 00014 |

P53—BACKUP IMU ORIENTATION DETERMINATION PROGRAM

Purpose:

1. To determine the inertial orientation of the IMU using a backup optical device.

Assumptions:

1. The IMU may be:
 - a. Off (standby).
 - b. On, and aligned or not aligned since turn-on.
 If (a) is true, the IMU must be turned on before this program can be performed.
 If (b) is true, this program can be completed.
2. This program is identical to P51 except that R56 is called in place of R53.
3. The CSM attitude control mode selected is at the option of the crew.
4. Time and RCS fuel may be saved and subsequent IMU alignment decisions greatly simplified if this program is performed in such a way as to leave the IMU inertially stabilized at an orientation as close as possible to the optimum orientation required by future AGC programs.
5. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V50 N25 (acquire celestial body)

Checklist code	00015
----------------	-------
2. V41 N22

Gimbal angles resulting from coarse align	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
3. V06 N94

Alternate LOS shaft angle	XXX.XX deg
Alternate LOS trunnion angle	XX.XXX deg
4. V53 (perform alternate LOS mark)
5. V50 N25 (terminate mark sequence)

Checklist code	00016
----------------	-------
6. V01 N71

Celestial body code (after mark)	000XX
----------------------------------	-------
7. V06 N88

Components of celestial body ½ unit vector	.XXXXX
--	--------
8. V06 N05

Sighting angle difference	XXX.XX deg
---------------------------	------------

P54-BACKUP IMU REALIGN PROGRAM

Purpose:

1. To align the IMU from a "known" orientation to one of four orientations selected by the astronaut using sightings on two celestial bodies with a backup optical device:

- a. Preferred Orientation (00001)

An optimum orientation for a previously calculated maneuver. This orientation must be calculated and stored by a previously selected program.

- b. Landing Site Orientation (00004)

$$X_{SM} = \text{Unit}(R_{LS})$$

$$Y_{SM} = \text{Unit}(Z_{SM} \times X_{SM})$$

$$Z_{SM} = \text{Unit}(H_{CSM} \times X_{SM})$$

where

The origin is the center of the moon.

R_{LS} = The position of the most recently defined landing site at time T (align) selected by the astronaut.

H_{CSM} = The angular momentum vector of the CSM ($R_{CSM} \times V_{CSM}$) at time T (align) selected by the astronaut.

- c. Nominal Orientation (00002)

$$X_{SM} = \text{Unit}(Y_{SM} \times Z_{SM})$$

$$Y_{SM} = \text{Unit}(V \times R)$$

$$Z_{SM} = \text{Unit}(-R)$$

where

R = The geocentric (earth orbit) or selenocentric (lunar orbit) radius vector at time T (align) selected by the astronaut.

V = The inertial velocity vector at time T (align) selected by the astronaut.

- d. REFSMMAT (00003)

Assumptions:

1. The docked configuration may be SIVB/CSM, LM/CSM, or CSM. The present configuration should have been entered into the AGC by completion of the DAP Data Load routine (R03).
2. If the mode switch is in Attitude Hold during the Gyro Torquing routine (R55) the DAP will maneuver the vehicle to follow the platform.
3. This program makes no provision for an attitude maneuver to return the vehicle to a specific attitude. Such a maneuver, if desired, must be done manually. An option is provided however to point the backup optical device at astronaut or AGC selected stars either manually by crew input or automatically under AGC control.
4. The ISS is on and has been aligned to a known orientation which is stored in the AGC (REFSMMAT). The present IMU orientation differs from that to which it was last aligned only due to gyro drift (that is, neither gimbal lock nor IMU power interruption has occurred since the last alignment).
5. The landing site orientation is used for:
 - a. Aligning the CSM stable member to the same orientation as the LM stable member prior to LM/CSM separation.
 - b. Aligning the CSM stable member to the same orientation as the LM stable member prior to LM ascent from the lunar surface.
6. This program is identical to P52 except that R56 is called in place of R52 and R53.
7. The program is selected by DSKY entry.

P54 (continued)

Selected Displays:

1. V04 N06

Option code ID	00001
Option code	0000X (1—preferred, 2—nominal, 3—REFSMMAT, 4—landing site)
2. V06 N34

Timing of alignment	00XXX h 000XX min 0XX.XX s
---------------------	----------------------------------
3. V06 N89 (landing site)

Latitude	XX.XXX deg (+ north)
Longitude/2	XX.XXX deg (+ east)
Altitude	XXX.XX nmi
4. V06 N22

Gimbal angles which will result from selected IMU orientation	OG XXX.XX deg IG XXX.XX deg MG XXX.XX deg
--	---
5. V50 N25 (coarse align)

Checklist code	00013
----------------	-------
6. V16 N20

Actual gimbal angles	OG XXX.XX deg IG XXX.XX deg MG XXX.XX deg
----------------------	---
7. V50 N25 (acquire celestial body)

Checklist code	00015
----------------	-------
8. V01 N70

Celestial body code (before mark)	000XX
-----------------------------------	-------
9. V06 N88

Components of celestial body $\frac{1}{2}$ unit vector	.XXXXXX
--	---------
10. V06 N94

Alternate LOS shaft angle	XXX.XX deg
Alternate LOS trunnion angle	XX.XXX deg
11. V53 (perform alternate LOS mark)
12. V50 N25 (terminate mark sequence)

Checklist code	00016
----------------	-------
13. V01 N71

Celestial body code (after mark)	000XX
----------------------------------	-------
14. V06 N05

Sighting angle difference	XXX.XX deg
---------------------------	------------
15. V06 N93

Gyro torquing angles	X XX.XXX deg Y XX.XXX deg Z XX.XXX deg
----------------------	--
16. V50 N25 (fine align)

Checklist code	00014
----------------	-------

P61—ENTRY—PREPARATION PROGRAM

Purpose:

1. To start navigation, check IMU alignment, and provide entry monitor system initialization data.

Assumptions:

1. The program is entered with adequate freefall time to complete the maneuvers from a worst case starting attitude.
2. The ISS is on and precisely aligned to a satisfactory orientation.
3. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N61

Impact latitude	XXX.XX deg (+ north)
Impact longitude	XXX.XX deg (+ east)
Heads up/down	00001 (+ heads up/ lift down)
2. V06 N60

Maximum predicted acceleration	XXX.XX g
Predicted velocity at 400 k ft	XXXXX. ft/s
Predicted flight path angle at 400 k ft	XXX.XX deg (+ above)
3. V06 N63

Range to go from EMS altitude	XXXX.X nmi
Predicted inertial velocity	XXXXX. ft/s
Time to EMS altitude	XX b XX min/s

P62—ENTRY—CM/SM SEPARATION AND PREENTRY MANEUVER PROGRAM

Purpose:

1. To notify crew when the GNCS is prepared for CM/SM separation.
2. To orient the CM to the correct attitude for atmospheric entry.

Assumptions:

1. The program is entered with adequate freefall time to accomplish CM/SM separation and complete the maneuver from a worst case starting attitude.
2. The IMU is satisfactorily aligned for entry.
3. The program is automatically selected by the Entry—Preparation program (P61) or it may be selected manually.
4. The astronaut may monitor N63 (RTOGO, VIO, TFE) by keying in V16 N63 E.

Selected Displays:

1. V50 N25 (CM/SM separation)

Checklist code	00041
----------------	-------
2. V06 N61

Impact latitude	XXX.XX deg (+ north)
Impact longitude	XXX.XX deg (+ east)
Heads up/down	00001 (+ heads up/ lift down)

P62 (continued)

3. V06 N22
- | | |
|---------------------------|---------------|
| Final gimbal angles at EI | OG XXX.XX deg |
| | IG XXX.XX deg |
| | MG XXX.XX deg |
4. V16 N63 (astronaut initiated)
- | | |
|-----------------------------------|---------------|
| Range from EMS altitude to splash | XXXX.X nmi |
| Predicted inertial velocity | XXXXX. ft/s |
| Time from EMS altitude | XX b XX min/s |

P63—ENTRY—INITIALIZATION PROGRAM

Purpose:

1. To initialize the entry equations.
2. To continue to hold the CM to the correct attitude with respect to the atmosphere for the onset of entry deceleration.
3. To establish entry DSKY displays.
4. To sense 0.05 g and display this event to the crew by selecting the Entry—Post 0.05 g program (P64).

Assumptions:

1. The program is automatically selected by the Entry—CM/SM Separation and Preentry Maneuver program (P62).
2. The astronaut may monitor N64 (G, VI, RTOTARG) during this program by keying in V16 N64E. He also may monitor N68 (BETA, VI, HDOT) by keying in V16 N68E, N63 (RTOGO, VIO, TFE) by keying in V16 N63E, and N74 (BETA, VI, G) by keying in V16 N74E.

Selected Displays:

1. V06 N64

Drag acceleration	XXX.XX g
Inertial velocity	XXXXX. ft/s
Range to splash	XXXX.X nmi (+ is overshoot)
2. V16 N63 (astronaut initiated)

Range from EMS altitude to splash	XXXX.X nmi
Predicted inertial velocity	XXXXX. ft/s
Time from EMS altitude	XX b XX min/s
3. V16 N68 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Altitude rate	XXXXX. ft/s
4. V16 N74 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Drag acceleration	XXX.XX g

P64-ENTRY—POST 0.05 G PROGRAM

Purpose:

1. To start entry guidance at 0.05 g selecting roll attitude, constant drag level, and drag threshold, KA, which are keyed to the 0.05 g point.
2. Select final phase (P67) when 0.2 g occurs if $V < 27,000$ ft/s at 0.05 g.
3. Iterate for upcontrol solution (P65) if $V > 27,000$ ft/s and if altitude rate and drag level conditions are satisfied.
4. Select final phase (P67) if no upcontrol solution exists with $VL > 18,000$ ft/s.
5. To establish the 0.05 g mode in SCS.
6. To continue entry DSKY displays.

Assumptions:

1. The program is automatically selected by the Entry—Initialization program (P63).
2. The astronaut may monitor N64 (G, VI, RTOTARG) during this program by keying in V16 N64E. He also may monitor N68 (BETA, VI, HDOT) by keying in V16 N68E.

Selected Displays:

1. V06 N74

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Drag acceleration	XXX.XX g
2. V16 N64 (astronaut initiated)

Drag acceleration	XXX.XX g
Inertial velocity	XXXXX. ft/s
Range to splash	XXXXX.X nmi (+ is overshoot)
3. V16 N68 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Altitude rate	XXXXX. ft/s

P65—ENTRY—UPCONTROL PROGRAM

Purpose:

1. To execute Entry—Upcontrol guidance which steers the CM to a controlled exit (skip out) condition.
2. To establish Entry—Upcontrol displays which are used in conjunction with the EMS to determine for the astronaut if the backup procedures should be implemented.
3. To sense exit (drag acceleration less than $Q7$ ft/s²) and thereupon to select the Entry—Ballistic Phase program (P66).
4. Where RDOT is negative and the V is sufficiently low (V-VL-C18 neg), the program will exit directly to P67 (Final Phase).

Assumptions:

1. This program is automatically selected by the Entry—Post 0.05 g program (P64) when constant drag control has brought range prediction to within 25 nmi of the desired range. It is skipped in earth orbit missions.
2. The astronaut may monitor N64 (G, VI, RTOTARG) during this program by keying in V16 N64E. He may also monitor N68 (BETA, VI, HDOT) by keying in V16 N68E.
3. Manual response to N69 is not necessary to terminate P65. Selection of either P66 or P67 by entry guidance provides automatic termination.

P65 (continued)

Selected Displays:

1. V16 N69

Commanded bank angle	XXX.XX deg
Drag level	XXX.XX g
Skip out velocity	XXXXX. ft/s
2. V06 N74

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Drag acceleration	XXX.XX g
3. V16 N64 (astronaut initiated)

Drag acceleration	XXX.XX g
Inertial velocity	XXXXX. ft/s
Range to splash	XXXXX.X nmi (+ is overshoot)
4. V16 N68 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Altitude rate	XXXXX. ft/s

P66-ENTRY—BALLISTIC PROGRAM

Purpose:

1. To maintain CM attitude during ballistic (skip out) phase for atmospheric reentry.
2. To sense reentry (drag acceleration builds up to $Q7 + 0.5 \text{ ft/s}^2$ or approximately 0.2 g) and thereupon to select the Entry-Final Phase program (P67).

Assumptions:

1. This program is automatically selected by the Entry—Upcontrol program (P65) when drag acceleration becomes less than $Q7 \text{ ft/s}^2$.
2. The astronaut may monitor N64 (G, VI, RTOTARG) during this program by keying in V16 N64E. He may also monitor N68 (BETA, VI, HDOT) by keying in V16 N68E, and N74 (BETA, VI, G) by keying in V16 N74E.

Selected Displays:

1. V06 N22

Desired gimbal angles	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
2. V16 N64 (astronaut initiated)

Drag acceleration	XXX.XX g
Inertial velocity	XXXXX. ft/s
Range to splash	XXXXX.X nmi (+ is overshoot)
3. V16 N68 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Altitude rate	XXXXX. ft/s

P66 (continued)

4. V16 N74 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Drag acceleration	XXX.XX g

P67—ENTRY—FINAL PHASE PROGRAM

Purpose:

1. To continue entry guidance after Q7F + 0.5 ft/s² (or approximately 0.2 g) until termination of steering when the CM velocity WRT earth = 1,000 ft/s (altitude is approximately 65,000 ft).
2. To continue entry DSKY displays.

Assumptions:

1. The program is automatically selected by:
 - a. P65 when RDOT is negative and the V is sufficiently low (V-VI-C18 neg).
 - b. P66 when drag acceleration builds up to Q7F + 0.5 ft/s² (or approximately 0.2 g).
 - c. P64 if no upcontrol solution exists with VL > 18,000 ft/s.
2. The astronaut may monitor N64 (G, VI, RTOTARG) during this program by keying in V16 N64E. He also may monitor N68 (BETA, VI, HDOT) by keying in V16 N68E, and N74 (BETA, VI, G) by keying in V16 N74E.

Selected Displays:

1. V06 N66

Commanded bank angle	XXX.XX deg
Crossrange error	XXXX.X nmi (+ south)
Downrange error	XXXX.X nmi (+ overshoot)

2. V16 N67

Range to target	XXXX.X nmi (+ overshoot)
Present latitude	XXX.XX (+ north)
Present longitude	XXX.XX (+ east)

3. V16 N64 (astronaut initiated)

Drag acceleration	XXX.XX g
Inertial velocity	XXXXX. ft/s
Range to splash	XXXX.X nmi (+ overshoot)

4. V16 N68 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Altitude rate	XXXXX. ft/s

5. V16 N74 (astronaut initiated)

Commanded bank angle	XXX.XX deg
Inertial velocity	XXXXX. ft/s
Drag acceleration	XXX.XX g

P72-LM COELLIPTIC SEQUENCE INITIATION (CSI) PROGRAM

Purpose:

1. To calculate parameters associated with the following concentric flight plan maneuvers for LM execution of the maneuvers under the control of the LGC; the Coelliptic Sequence Initiation (CSI) and the Constant Delta Altitude maneuver (CDH).
2. To calculate these parameters based upon maneuver data approved and keyed into the AGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.

Assumptions:

1. At a selected TPI time the line of sight between the CSM and the LM is selected to be a prescribed angle (E) from the horizontal plane defined at the LM position.
2. The time between CSI ignition and CDH ignition must be computed to be greater than 10 minutes for successful completion of the program.
3. The time between CDH ignition and TPI ignition must be computed to be greater than 10 minutes for successful completion of the program.
4. CDH Delta V is selected to minimize the variation of the altitude difference between the orbits.
5. CSI burn is defined such that the impulsive Delta V is in the horizontal plane defined by the active vehicle position at CSI ignition.
6. The pericenter altitude of the orbit following CSI and CDH must be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit) for successful completion of this program.
7. The CSI and CDH maneuvers are assumed to be parallel to the plane of the CSM orbit. However, crew modification of Delta V(LV) components may result in an out-of-plane CSI maneuver.
8. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
9. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
10. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N11

Time of CSI ignition	00XXX. h
	000XX. min
	0XX.XX s

2. V06 N55

Number of apsidal crossings	0000X
Elevation angle	XXX.XX deg
Central angle of passive vehicle	XXX.XX deg

3. V06 N37

Time of TPI ignition	00XXX. h
	000XX. min
	0XX.XX s

P72 (continued)

4. V16 N45	
Marks (VHF/optics)	XX b XX marks
Time from CSI ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
5. V06 N75	
Delta altitude (CDH)	XXXX.X nmi
ΔT (CDH-CSI)	XX b XX min/s
ΔT (TPI-CDH)	XX b XX min/s
6. V06 N13 (astronaut initiated)	
Time of CDH ignition	00XXX. h
	000XX. min
	0XX.XX s
7. V06 N81	
Components of ΔV (LV) for CSI	XXXX.X ft/s
8. V06 N82	
Components of ΔV (LV) for CDH	XXXX.X ft/s
9. V04 N12 (results from V90E)	
Option code ID	00002
Option code	0000X (1—this vehicle, 2—other vehicle)
10. V06 N16 (results from V90E)	
Time of event	00XXX. h
	000XX. min
	0XX.XX s
11. V06 N90 (results from V90E)	
Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

P73—LM CONSTANT DELTA ALTITUDE (CDH)
TARGETING PROGRAM

Purpose:

1. To calculate parameters associated with the concentric flight plan maneuvers with the exception of Coelliptic Sequence Initiation (CSI) for LM execution of the maneuvers under control of the LGC. The concentric flight plan maneuvers are the Coelliptic Sequence Initiation (CSI), the Constant Delta Altitude maneuver (CDH), the Transfer Phase Initiation (TPI), and the Transfer Phase Final (TPF) or braking maneuver.
2. To calculate these parameters based upon maneuver data approved and keyed into the AGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.

P73 (continued)

Assumptions:

1. This program is based upon previous completion of the Coelliptic Sequence Initiation (CSI) program (P72). Therefore:
 - a. At a selected TPI time the line of sight between the CSM and the LM was selected to be a prescribed angle (E) from the horizontal plane defined at the active vehicle position.
 - b. The time between CSI ignition and CDH ignition was computed to be greater than 10 minutes.
 - c. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - d. The variation of the altitude difference between the orbits was minimized.
 - e. The CSI burn was defined such that the impulsive Delta V was in the horizontal plane defined by the active vehicle position at CSI ignition.
 - f. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit).
 - g. The CSI and CDH maneuvers were assumed to be parallel to the plane of the CSM orbit, however, crew modification of Delta V(LV) components may have resulted in an out-of-plane CSI maneuver.
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
3. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
4. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N13

Time of CDH ignition	00XXX h
	000XX min
	0XX.XX s
2. V16 N45

Marks (VHF/optics)	XX b XX marks
Time from CDH ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
3. V06 N75

Delta altitude (CDH)	XXXX.X nmi
ΔT (TPI-CDH)	XX b XX min/s
ΔT (TPI-NOMTPI)	XX b XX min/s
4. V06 N81

Components of ΔV (LV) for CDH	XXXX.X ft/s
---------------------------------------	-------------
5. V04 N12 (results from V90E)

Option code ID	00002
Option code	0000X (1—this vehicle, 2—other vehicle)
6. V06 N16 (results from V90E)

Time of event	00XXX. h
	000XX. min
	0XX.XX s

P73 (continued)

7. V06 N90 (results from V90E)

Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

P74—LM TRANSFER PHASE INITIATION (TPI)
TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the Transfer Phase Initiation maneuver, given:
 - a. Time of ignition (TIG(TPI)) or the elevation angle (E) of the LM/CSM LOS at TIG(TPI).
 - b. Central angle of transfer (CENTANG) from TIG(TPI) to intercept time TIG(TPF).
2. To calculate TIG(TPI) given E or E given TIG(TPI).
3. To display to the astronaut and the ground certain dependent variables associated with the maneuver for approval by the astronaut/ground.

Assumptions:

1. The program must be done over a tracking station for real-time ground participation in AGC data input and output.
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
3. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone, the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

4. When determining the initial position and velocity of the target at intercept time, either conic or precision integration may be used. The time difference for computation is approximately 10:1 (that is, conic integration is 10 times faster than precision integration).
5. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
6. This program is selected by DSKY entry.

Selected Displays:

1. V06 N37

Time of TPI ignition	00XXX. h
	000XX. min
	0XX.XX s

2. V06 N55

Integration code	0000X (0—conic # 0—precision)
Elevation angle	XXX.XX deg
Central angle of passive vehicle	XXX.XX deg

P74 (continued)

3. V16 N45		
Marks (VHF/optics)		XX b XX marks
Time until TPI burn		XX b XX min/s
Middle gimbal angle		XXX.XX deg
4. V06 N58 (post TPI)		
Pericenter altitude		XXXX.X nmi
ΔV (TPI)		XXXX.X ft/s
ΔV (TPF)		XXXX.X ft/s
5. V06 N81		
Components of ΔV (LV) for TPI		XXXX.X ft/s
6. V06 N59		
Components of ΔV (LOS) for TPI		XXXX.X ft/s
7. V05 N52 (astronaut initiated)		
Central angle of active vehicle		XXX.XX deg
8. V04 N12 (results from V90E)		
Option code ID		00002
Option code		0000X (1—this vehicle, 2—other vehicle)
9. V06 N16 (results from V90E)		
Time of event		00XXX. h 000XX. min 0XX.XX s
10. V06 N90 (results from V90E)		
Y		XXX.XX nmi
YDOT		XXXX.X ft/s
PSI		XXX.XX deg

P75—LM TRANSFER PHASE MIDCOURSE (TPM)
TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the next midcourse correction of the transfer phase of an active LM rendezvous.

Assumptions:

1. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
2. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

P75 (continued)

3. The time of intercept (T(INT)) was defined by previous completion of the LM Transfer Phase Initiation (TPI) program (P74) and is presently available in AGC storage.
4. There is no requirement for ISS operation during this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
5. The program is selected by the astronaut by DSKY entry.

Selected Displays:

- | | |
|--|--|
| 1. V16 N45 | |
| Marks (VHF/optics) | XX b XX marks |
| Time until TPM ignition | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |
| 2. V06 N81 | |
| Components of ΔV (LV) for TPM | XXXX.X ft/s |
| 3. V06 N59 | |
| Components of ΔV (LOS) for TPM | XXXX.X ft/s |
| 4. V06 N52 (astronaut initiated) | |
| Central angle of active vehicle | XXX.XX deg |
| 5. V04 N12 (results from V90E) | |
| Option code ID | 00002 |
| Option code | 0000X (1—this vehicle,
2—other vehicle) |
| 6. V06 N16 (results from V90E) | |
| Time of event | 00XXX. h
000XX. min
0XX.XX s |
| 7. V06 N90 (results from V90E) | |
| Y | XXX.XX nmi |
| YDOT | XXXX.X ft/s |
| PSI | XXX.XX deg |

P76—TARGET DELTA V PROGRAM

Purpose:

1. To provide a means of notifying the AGC that the LM has changed its orbital parameters by the execution of a thrusting maneuver.
2. To provide to the AGC the Delta V applied to the LM to enable an updating of the LM state vector.

Assumptions:

1. The CSM crew has the Delta V to be applied by the LM in local vertical axes at a specified TIG. These values are displayed prior to TIG by the Prethrust Targeting program in the LM. No provision is made in these thrusting programs to display the results of the maneuver in a form usable by this routine. If the burn is not nominal and this Delta V is not as specified or if TIG is not as originally specified, consult backup procedures.

P76 (continued)

2. Care should be exercised to incorporate state vector changes via this program in logical order with state vector changes resulting from the Rendezvous Navigation program (P20). A suggested procedure would be to stop optics marking, verify data incorporation by reviewing Noun 45 mark counters, incorporate state vector changes via this program, but do not take optics marks or enable VHF range link until the LM maneuver has taken place.
3. In the event of an uplink failure, the astronaut can create a reasonable LM state vector for LM insertion into orbit from the lunar surface by keying in the expected LM thrusting maneuver from the lunar surface while the surface flag is set. This will cause the computer to take the position vector of the landing site and add the inputted Delta V and store the results in the LM state vector. The landing site will not be altered.
4. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N84
Components of ΔV (OV) XXXX.X ft/s
2. V06 N33
Time of ignition 00XXX. h
000XX. min
0XX.XX s

P77—LM TRANSFER PHASE INITIATION (TPI)
SEARCH PROGRAM

Purpose:

1. To accept a desired time of Transfer Phase Initiation (TIG(TPI)) as a DSKY input from the astronaut, and to compute therefrom the parameters associated with a minimum energy, safe periapsis transfer maneuver at TIG (TPI) and the resultant rendezvous intercept for an active LM.
2. To provide the astronaut with the option of defining to the AGC the initial transfer trajectory search sector for central angles either greater than or less than 180 degrees from the position of the active vehicle (LM) at TIG(TPI).
3. To display to the astronaut the parameters associated with the transfer (TPI and intercept).

Assumptions:

1. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
2. To execute the TPI maneuver, select the LM Transfer Phase Initiation Targeting (TPI) program (P74) and transmit maneuver data to the LM.
3. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N37
Time of TPI ignition 00XXX. h
000XX. min
0XX.XX s

P77 (continued)

2. V06 N72

Delta angle (TPI)	XXX.XX deg (+active vehicle ahead)
Delta altitude (TPI)	XXXX.X nmi (+ passive vehicle above)
Search option	0000X (1-central angle < 180 degrees; 2-central angle > 180 degrees)

3. V06 N58

Pericenter altitude	XXXX.X nmi
ΔV (TPI)	XXXX.X ft/s
ΔV (TPF)	XXXX.X ft/s

4. V06 N55

R1: Perigee code	0000X (1—perigee between TPI and TPF, 2—perigee after intercept)
R3: Central angle of passive vehicle	XXX.XX deg

P78—LM STABLE ORBIT RENDEZVOUS (SOR)
TARGETING PROGRAM

Purpose:

- To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the first phase of the Stable Orbit Rendezvous maneuver.
Given:
 - Time of ignition (TIG).
 - Central angle of transfer (CENTANG) from TIG to intercept time.
 - The offset of the stable orbit point specified as a distance along the passive vehicle orbit.
- To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the second phase of the Stable Orbit Rendezvous maneuver.
Given:
 - A respecification of 1.a above.
 - An optional respecification of 1.b above.
- To calculate these parameters based upon maneuver data approved and keyed into the AGC by the astronaut.
- To display to the astronaut and the ground certain dependent variables associated with the maneuver for approval by the astronaut/ground.

Assumptions:

- The stable orbit point is defined as the final position (at completion of second phase) of the active vehicle relative to the passive vehicle.
- If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.
- Once the parameters required for computation of the maneuver have been completely specified, the value of the active central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

- The second phase of this program requires the TIG input be biased as a function of TPF and any midcourse corrections performed in the LM Stable Orbit Midcourse Targeting program (P79).

P78 (continued)

5. There is no requirement for ISS operation during this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
6. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N33

Time of SOR ignition	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N55

R3: Central angle of passive vehicle	XXX.XX deg
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3. V04 N06 (specify phase)

Option code ID	00005
Option code	0000X (1-first pass, 2-second pass)
4. V06 N57

Stable orbit offset	XXXX.X nmi (+ passive vehicle ahead)
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5. V06 N34

Time of arrival at stable orbit	00XXX. h
	000XX. min
	0XX.XX s
6. V16 N45

Marks (VHF/optics)	XX b XX marks
Time of SOR ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
7. V06 N58

Pericenter altitude (SOR)	XXXX.X nmi
ΔV (SOR)	XXXX.X ft/s
ΔV (SOR-final)	XXXX.X ft/s
8. V06 N81

Components of ΔV (LV) for SOR	XXXX.X ft/s
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9. V06 N52 (astronaut initiated)

Central angle of active vehicle	XXX.XX deg
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P79—LM STABLE ORBIT MIDCOURSE (SOM)
TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the next possible midcourse correction of the Stable Orbit Transfer Phase of an active LM rendezvous.
2. To compute and display suitable information to enable the crew to enter the Final Rendezvous Phase at the correct time to complete the required thrusting maneuver.

Assumptions:

1. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20).
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and turn on the Rendezvous Sighting Mark routine (R21 or R23) and take optics marks, and/or he may allow VHF ranging marks to accumulate.

P79 (continued)

3. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

4. The time of intercept (T(INT)) was defined by previous completion of the LM Stable Orbit Rendezvous Targeting (SOR) program (P78) and is presently available in AGC storage.
5. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V16 N45

Marks (VHF/optics)	XX b XX marks
Time from SOM ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
2. V06 N81

Components of ΔV (LV) for SOM	XXXX.X ft/s
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3. V06 N52 (astronaut initiated)

Central angle of active vehicle	XXX.XX deg
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LM SOFTWARE

**LUMINARY 1B
(REV 116 OF LUMINARY)
LM DSKY
COMPUTER PROGRAMS
COMPUTER ROUTINES
VERB CODES
NOUN CODES
ALARM CODES
OPTION CODES
CHECKLIST CODES
FLAGWORD BIT ASSIGNMENTS
IMODES30 AND IMODES33
CHANNEL BIT ASSIGNMENTS
COMPUTER PROGRAM DESCRIPTION**

LM DSKY

UPLINK ACTY light — is energized by the first character of a digital UPLINK message received by the LGC.

NO ATT Light — is energized when the LGC is in the Operate mode and there is no inertial reference; that is, the ISS is off, caged, or in the Coarse Align mode.

STBY Light — is energized when the LGC is in the Standby mode and deenergized when the LGC is in the Operate mode.

KEY REL Light

1. Energized when:
 - a. An internal display comes while the astronaut has the DSKY.
 - b. An astronaut keystroke is made while an internal flashing display is currently on the DSKY.
 - c. The astronaut makes a keystroke on top of (his own) Monitor Verb display.
2. Deenergized when:
 - a. Astronaut relinquishes the DSKY by operating the KEY REL button.
 - b. Astronaut terminates his current sequence normally, for example:
 - (1) with final ENTR of a load sequence.
 - (2) the ENTR of a response to a flashing display.
 - (3) the ENTR of an extended verb request.

OPR ERR Light — is energized when the DSKY operator performs an improper sequence of key depressions.

TEMP Light — The LGC receives a signal from the IMU when the stable member temperature is in the range 126.3° F to 134.3° F. In the absence of this signal, the TEMP lamp on the DSKY is actuated.

GIMBAL LOCK Light — is energized when the middle gimbal angle exceeds ± 70 degrees from its zero position. When the middle gimbal angles exceeds ± 85 degrees from its zero position the LGC automatically commands the Coarse Align mode in the ISS to prevent gimbal oscillation. The NO ATT light will then be energized.

PROG Light — Under a variety of situations a program alarm is generated. The program alarm actuates the PROG lamp on the DSKY.

RESTART Light — In the event of a RESTART during operation of a program, a latch is set in the LGC which illuminates the RESTART lamp on the DSKY until the latch is manually reset by pressing RSET.

TRACKER Light — When the Rendezvous Radar is on, the light is energized when:

1. a RR CDU failed with the RR in the Auto mode and RR CDU's not being zeroed.
2. when the RR Data Good bar discrete occurs during an LGC data read sequence.

ALT Light — When the Landing Radar is on, the light is energized (on steady or flashing) when:

1. LR Range Data Good discrete was not present before and after LR altitude sampling (STEADY).
2. LR Low Scale discrete missing after LR indicated slant range was less than 2,481 feet (STEADY).
3. LR Altitude Reasonability test was failed (FLASHING).

VEL Light — When the Landing Radar is on, the light is energized (on STEADY or FLASHING) when:

1. LR Velocity Data Good discrete was not present before and after LR velocity sampling (STEADY).
2. LR Velocity Reasonability test was failed (FLASHING).

COMP ACTY Light — is energized when the LGC is occupied with an internal sequence.

Display Panel — consists of 24 electroluminescent sections. Each section is capable of displaying a decimal character or remaining blank, except the three sign sections. These

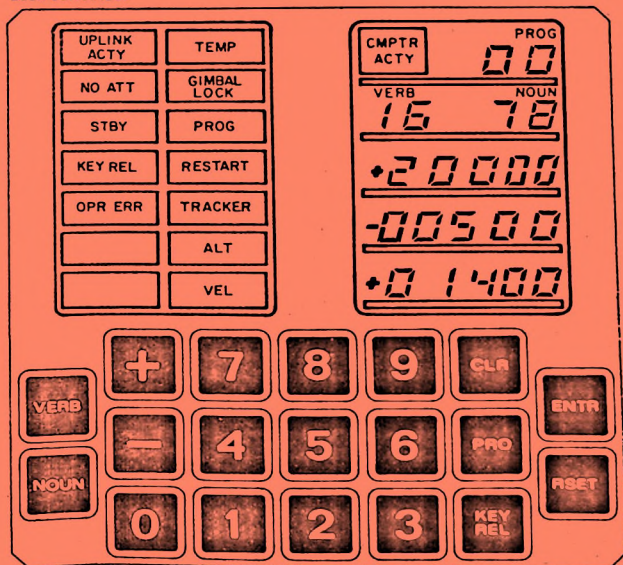
LM DSKY (continued)

display a plus sign, a minus sign, or a blank. The numerical sections are grouped to form three data display registers, each of five numerical characters; and three control display registers, each of two numerical characters. The data display registers are referred to as R1, R2, R3. The control display registers are known as VERB, NOUN, and PROGRAM.

At maximum activity, the complete display panel may be updated in 0.50 second.

Keyboard—contains the following buttons:

1. VERB — Pushing this button indicates that the next two numerical characters keyed are to be interpreted as the Verb Code.
2. NOUN — Pushing this button indicates that the next two numerical characters keyed are to be interpreted as the Noun Code.
3. + and - are sign keys used for sign convention and to identify decimal data.
4. 0-9—are numerical keys.
5. CLR — is used during a data loading sequence to blank the data display register (R1, R2, R3) being used. It allows the operator to reload the data word.
6. PRO — This pushbutton performs two functions:
 - a. When the LGC is in the Standby mode, pressing this button will put the LGC in the Operate mode, turn off the STBY light, and automatically select Routine 00 in the LGC, after restoring the clock.
 - b1. When the LGC is in the Operate mode but Program 06 is not selected, pressing the button will provide the "Proceed" function.
 - b2. When the LGC is in the Operate mode and Program 06 is selected, pressing the button will put the LGC in the Standby mode and turn on the STBY light.
7. ENTR — is used in three ways:
 - a. To direct the LGC to execute the Verb/Noun now appearing on the Verb/Noun lights.
 - b. To direct the LGC to accept a data word just loaded.
 - c. To respond to a "Please Perform" request.
8. RSET — turns off alarm indicator on the DSKY providing the alarm condition has been corrected.



PROGRAMS FOR PROGRAM LUMINARY 1B

PHASE	PROGRAM NUMBER	PROGRAM TITLE
Service	00	LGC Idling
	06	LGC Power Down
Ascent	12	Powered Ascent
Coast	20	Rendezvous Navigation
	21	Ground Track Determination
	22	Lunar Surface Navigation
	25	Preferred Tracking Attitude
	27	LGC Update
Pre-thrusting	30	External Delta V
	32	Coelliptic Sequence Initiation (CSI)
	33	Constant Delta Altitude (CDH)
	34	Transfer Phase Initiation (TPI)
	35	Transfer Phase Midcourse (TPM)
Thrusting	40	DPS
	41	RCS
	42	APS
	47	Thrust Monitor
Alignments	51	IMU Orientation Determination
	52	IMU Realign
	57	Lunar Surface Align
Descent	63	Braking Phase
	64	Approach Phase
	65	Landing Phase (Auto)
	66	Landing Phase (ROD)
	67	Landing Phase (Manual)
	68	Landing Confirmation
Aborts and Backups	70	DPS Abort
	71	APS Abort
	72	CSM Coelliptic Sequence Initiation (CSI) Targeting
	73	CSM Constant Delta Altitude (CDH) Targeting
	74	CSM Transfer Phase Initiation (TPI) Targeting
	75	CSM Transfer Phase Midcourse (TPM) Targeting
	76	Target Delta V

ROUTINES FOR PROGRAM LUMINARY 1B

ROUTINE	ROUTINE TITLE
00	Final Automatic Request Terminate
01	Erasable Modification
02	IMU Status Check
03	DAP Data Load
04	Rendezvous Radar/Landing Radar Self-Test
05	S-Band Antenna
09	R10/R11/R12 Service
10	Landing Analog Displays
11	Abort Discretes Monitor
12	Descent State Vector Update
13	Landing Auto Modes Monitor
14	Landing Radar Position Command
20	Landing Radar/Rendezvous Radar Read
21	Rendezvous Radar Designate
22	Rendezvous Radar Data Read
23	Rendezvous Radar Manual Acquisition
24	Rendezvous Radar Search
25	Rendezvous Radar Monitor
26	Lunar Surface RR Designate
29	Powered Flight Rendezvous Radar Designate
30	Orbit Parameter Display
31	Rendezvous Parameter Display
33	LGC/AGC Clock Synchronization
36	Out-of-Plane Rendezvous Display
40	DPS/APS Thrust Fail
41	State Vector Integration (MIDTOAVE)
47	AGS Initialization
50	Coarse Align
51	In-Flight Fine Align
52	Auto Optics Positioning
53	AOT Mark
54	Sighting Data Display
55	Gyrotorquing
56	Terminate Tracking
57	MARKRUPT
58	Celestial Body Definition
59	Lunar Surface Sighting Mark
60	Attitude Maneuver
61	Preferred Tracking Attitude
62	Crew-Defined Maneuver
63	Rendezvous Final Attitude
65	Fine Preferred Tracking Attitude
76	Extended Verb Interlock
77	LR Spurious Test

LIST OF VERBS USED IN PROGRAM LUMINARY 1B

REGULAR VERBS

00	Not in use
01	Display Octal Component 1 in R1
02	Display Octal Component 2 in R1
03	Display Octal Component 3 in R1
04	Display Octal Components 1, 2 in R1, R2
05	Display Octal Components 1, 2, 3 in R1, R2, R3
06	Display decimal in R1 or R1, R2 or R1, R2, R3
07	Display DP decimal in R1, R2 (test only)
08	Spare
09	Spare
10	Spare
11	Monitor Octal Component 1 in R1
12	Monitor Octal Component 2 in R1
13	Monitor Octal Component 3 in R1
14	Monitor Octal Components 1, 2 in R1, R2
15	Monitor Octal Components 1, 2, 3 in R1, R2, R3
16	Monitor decimal in R1 or R1, R2 or R1, R2, R3
17	Monitor DP decimal in R1, R2 (test only)
18	Spare
19	Spare
20	Spare
21	Load Component 1 into R1
22	Load Component 2 into R2
23	Load Component 3 into R3
24	Load Components 1, 2 into R1, R2
25	Load Components 1, 2, 3 into R1, R2, R3
26	Spare
27	Display Fixed Memory
28	Spare
29	Spare
30	Request EXECUTIVE
31	Request WAITLIST
32	Recycle program
33	Proceed without DSKY inputs
34	Terminate function
35	Test lights
36	Request FRESH START
37	Change program (major mode)
38	Spare
39	Spare

EXTENDED VERBS

40	Zero CDU's (specify N20 or N72)
41	Coarse align CDU's (specify N20 or N72)
42	Fine align IMU
43	Load IMU attitude error needles
44	Terminate RR continuous designate (V41N72 Option 2)
45	Spare
46	Spare
47	Initialize AGS (R47)
48	Request DAP Data Load routine (R03)
49	Request Crew Defined Maneuver routine (R62)
50	Please perform
51	Spare
52	Mark X reticle
53	Mark Y reticle
54	Mark X or Y reticle
55	Increment LGC time (decimal)
56	Terminate tracking (P20 and P25)
57	Permit Landing Radar updates
58	Inhibit Landing Radar updates
59	Command LR to Position 2
60	Display vehicle attitude rates on FDAI error needles

LIST OF VERBS USED IN PROGRAM LUMINARY 1B

61 Display DAP following attitude errors
 62 Display total attitude errors with respect to N22
 63 Sample radar once per second (R04)
 64 Request S-Band Antenna routine (R05)
 65 Disable U and V jet firings during DPS burns
 66 Vehicles are attached. Move this vehicle state vector to other vehicle
 67 Display W matrix
 68 Spare
 69 Cause RESTART
 70 Start LGC update, liftoff time (P27)
 71 Start LGC update, block address (P27)
 72 Start LGC update, single address (P27)
 73 Start LGC update, LGC time (P27)
 74 initialize erasable dump via DOWNLINK
 75 Enable U and V jet firings during DPS burns
 76 Minimum Impulse Command mode
 77 Rate Command and Attitude Hold mode
 78 Start LR spurious test (R77)
 79 Stop LR spurious test
 80 Enable LM state vector update
 81 Enable CSM state vector update
 82 Request Orbit Parameter display (R30)
 83 Request Rendezvous Parameter display (R31)
 84 Spare
 85 Display Rendezvous Radar LOS azimuth and elevation
 86 Spare
 87 Spare
 88 Spare
 89 Request Rendezvous Final Attitude maneuver (R63)
 90 Request Out of Plane Rendezvous display (R36)
 91 Display BANKSUM
 92 Start IMU performance tests (ground use)
 93 Enable W matrix initialization
 94 Spare
 95 No update of either state vector allowed (P20 or P22)
 96 Interrupt integration and go to P00
 97 Perform Engine Fail procedure (R40)
 98 Spare
 99 Please Enable Engine Ignition

LIST OF NOUNS USED IN PROGRAM LUMINARY 1B

00	Not in use	
01	Specify address (fractional)	.XXXXX fractional .XXXXX fractional .XXXXX fractional
02	Specify address (whole)	XXXXX. integer XXXXX. integer XXXXX. integer
03	Specify address (degree)	XXX.XX deg XXX.XX deg XXX.XX deg
04	Angular error/difference	XXX.XX deg
05	Angular error/difference	XXX.XX deg
06	Option code ID Option code Dat code	Octal Octal Octal
07	FLAGWORD operator ECADR BIT ID Action	 Octal Octal Octal
08	Alarm data ADRES BBANK ERCOUNT	 Octal Octal Octal
09	Alarm codes First Second Last	 Octal Octal Octal
10	Channel to be specified	Octal
11	TIG of CSI	00XXX. h 000XX. min 0XX.XX s
12	Option code (extended verbs only)	Octal Octal
13	TIG of CDH	00XXX. h 000XX. min 0XX.XX s
14	CHECKLIST (used internally by extended verbs only; N25 is pasted after display)	XXXXX.
15	Increment address	Octal
16	Time of event (used by extended verbs only)	00XXX. h 000XX. min 0XX.XX s
17	Spare	.
18	Desired automaneuver FDAI ball angles	R XXX.XX deg P XXX.XX deg Y XXX.XX deg

LIST OF NOUNS USED IN PROGRAM LUMINARY 1B

19	Spare		
20	Present ICDU angles	OG IG MG	XXX.XX deg XXX.XX deg XXX.XX deg
21	PIPA's	X Y Z	XXXXX. pulses XXXXX. pulses XXXXX. pulses
22	Desired ICDU angles	OG IG MG	XXX.XX deg XXX.XX deg XXX.XX deg
23	Spare		
24	Delta time for LGC clock		00XXX. h 000XX. min 0XX.XX s
25	CHECKLIST (used with V50)		XXXXX.
26	PRIO/DELAY, ADRES, BBCON	Octal Octal Octal	
27	Self-test on/off switch		XXXXX.
28	Spare		
29	Spare		
30	Spare		
31	Spare		
32	Time from perigee		00XXX. h 000XX. min 0XX.XX s
33	Time of ignition		00XXX. h 000XX. min 0XX.XX s
34	Time of event		00XXX. h 000XX. min 0XX.XX s
35	Time from event		00XXX. h 000XX. min 0XX.XX s
36	Time of LGC clock		00XXX. h 000XX. min 0XX.XX s
37	Time of ignition (TPI)		00XXX. h 000XX. min 0XX.XX s
38	Time of state being integrated		00XXX. h 000XX. min 0XX.XX s
39	Spare		

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LIST OF NOUNS USED IN PROGRAM LUMINARY 1B

40	• Time from ignition/cutoff VG Delta V (accumulated)	XX b XX min/s XXXX.X ft/s XXXX.X ft/s
41	Target Azimuth Elevation	 XXX.XX deg XX.XXX deg
42	Apocenter altitude Pericenter altitude Delta V (required)	XXXX.X nmi XXXX.X nmi XXXX.X ft/s
43	Latitude Longitude Altitude	XXX.XX deg (+ north) XXX.XX deg (+ east) XXXX.X nmi
44	• Apocenter altitude Pericenter altitude TFF	XXXX.X nmi XXXX.X nmi XX b XX min/s
45	• Marks Time from ignition of next burn Middle gimbal angle	XXXXXX. XX b XX min/s XXX.XX deg
46	DAP configuration	Octal
47	LM weight CSM weight	XXXXX. lb XXXXX. lb
48	Gimbal pitch trim Gimbal roll trim	XXX.XX deg XXX.XX deg
49	Delta R Delta V Radar data source code	XXXX.X nmi XXXXX.X ft/s 0000X
50	Spare	
51	S-band antenna angles Pitch (Alpha) Yaw (Beta)	 XXX.XX deg XXX.XX deg
52	Central angle of active vehicle	XXX.XX deg
53	Spare	
54	Range Range rate Theta	XXX.XX nmi XXXXX.X ft/s XXX.XX deg
55	Number of apsidal crossings Elevation angle Central angle of passive vehicle	XXXXXX. XXX.XX deg XXX.XX deg
56	RR LOS Azimuth Elevation	 XXX.XX deg XXX.XX deg
57	Spare	
58	Pericenter altitude (post TPI) Delta V (TPI) Delta V (TPF)	XXXX.X nmi XXXXX.X ft/s XXXXX.X ft/s

*Display cannot be changed via a data load (that is, V25 NXXE, and so forth)

LIST OF NOUNS USED IN PROGRAM LUMINARY 1B

59	Delta V LOS 1 Delta V LOS 2 Delta V LOS 3	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
60	Horizontal velocity Altitude rate Computed altitude	XXXX.X ft/s XXXX.X ft/s XXXXX. ft
61	• Time to go in braking phase Time from ignition Crossrange distance	XX b XX min/s XX b XX min/s XXXXX. nmi
62	• Absolute value of velocity Time from ignition Delta V (accumulated)	XXXX.X ft/s XX b XX min/s XXXXX. ft/s
63	Absolute value of velocity Altitude rate Computed altitude	XXXX.X ft/s XXXX.X ft/s XXXXX. ft
64	• Time left for redesignations (TR)/LPD Altitude rate Computed altitude	XX b XX seconds/deg XXXXX. ft/s XXXXX. ft
65	Sampled LGC time (fetched in interrupt)	00XXXX. h 000XX. min 0XX.XX s
66	• LR slant range LR position	XXXXXX. ft +0000X.
67	LR VX LR VY LR VZ	XXXXX. ft/s XXXXX. ft/s XXXXX. ft/s
68	• Slant range to landing site Time to go in braking phase LR altitude-computed altitude	XXXXX. nmi XX b XX min/s XXXXX. ft
69	Landing site correction Landing site correction Landing site correction	Z XXXXX. ft Y XXXXX. ft X XXXXX. ft
70	AOT detent code/star code (before mark)	Octal Octal Octal
71	AOT detent code/star code (after mark)	Octal Octal Octal
72	RR trunnion angle (360 degrees — CDU trunnion angle) RR shaft angle	XXX.XX deg XXX.XX deg
73	Desired RR trunnion angle (360 degrees — CDU trunnion angle) Desired RR shaft angle	XXX.XX deg XXX.XX deg
74	• Time from ignition Yaw after vehicle rise Pitch after vehicle rise	XX b XX min/s XXX.XX deg XXX.XX deg
75	• Delta altitude (CDH) Delta time (CDH-CSI or TPI-CDH) Delta time (TPI-CDH or TPI-NOMTPI)	XXXXX. nmi XX b XX min/s XX b XX min/s

*Display cannot be changed via a data load (that is, V25 NXXE, and so forth)

LIST OF NOUNS USED IN PROGRAM LUMINARY 1B

76	Desired downrange velocity Desired radial velocity Crossrange distance	XXXX.X ft/s XXXX.X ft/s XXXX.X nmi
77 *	Time to engine cutoff Velocity normal to CSM plane	XX b XX min/s XXXX.X ft/s
78 *	RR range RR range rate Time from ignition	XXX.XX nmi XXXXX. ft/s XX b XX min/s
79	Cursor angle Spiral angle Position code	XXX.XX deg XXX.XX deg +0000X
80	Data indicator Omega	XXXXX. XXX.XX deg
81	Delta VX (LV) Delta VY (LV) Delta VZ (LV)	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
82	Delta VX (LV) Delta VY (LV) Delta VZ (LV)	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
83	Delta VX (body) Delta VY (body) Delta VZ (body)	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
84	Delta VX (LV of other vehicle) Delta VY (LV of other vehicle) Delta VZ (LV of other vehicle)	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
85	VGX (body) VGY (body) VGZ (body)	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
86	VGX (LV) VGY (LV) VGZ (LV)	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
87	Backup optics LOS Azimuth Elevation	 XXX.XX deg XXX.XX deg
88	Components of celestial body 1/2 unit vector	X .XXXXX Y .XXXXX Z .XXXXX
89	Landmark latitude Landmark longitude/2 Landmark altitude	XX.XXX deg XX.XXX deg XXX.XX nmi
90	Rendezvous out of plane parameters Y Y dot PSI	 XXX.XX nmi XXXX.X ft/s XXX.XX deg
91	Altitude Velocity Flight path angle	XXXXXXb. nmi XXXXX. ft/s XXX.XX deg
92	Spare	

*Display cannot be changed via a data load (that is, V25 NXXE, and so forth)

LIST OF NOUNS USED IN PROGRAM LUMINARY 1B

93	Delta gyro angles	X XX.XXX deg Y XX.XXX deg Z XX.XXX deg
94	Spare	
95	Spare	
96	Spare	
97	System test inputs	XXXXX. XXXXX. XXXXX.
98	System test results and input	XXXXX. .XXXXX XXXXX.
99	RMS in position RMS in velocity RMS in bias	XXXXX. ft XXXXX.X ft/s XXXXX. milliradians

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LIST OF ALARM CODES USED WITH VERB 05
NOUN 09 FOR PROGRAM LUMINARY 1B

CODE	PURPOSE	SET BY
00107	More than five mark pairs in flight, five marks on lunar surface	R57
00111	Mark missing	R53
00112	Mark or mark reject not being accepted	R57
00113	No inbits	R57
00114	Mark made but not desired	R57
00115	No marks in last pair of reject	R57
00206	Zero Encode not allowed with Coarse Align plus Gimbal Lock	IMU mode switching V40 N20
00207	ISS turn-on request not present for 90 seconds	T4RUPT
00210	IMU not operating	IMU mode switching, R02
00211	Coarse Align error	IMU mode switching, P51, P57, R50
00212	PIPA fail but PIPA is not being used	IMU mode switching, T4RUPT
00213	IMU not operating with turn-on request	T4RUPT
00214	Program using IMU when turned off	T4RUPT
00217	Bad return from IMUSTALL	P51, P57, R50
00220	Bad REFSMMAT	R02, R47
00401	Desired gimbal angles yields Gimbal Lock	In-flight alignment, IMU-2, FINDCDUW
00402	FINDCDUW routine not controlling attitude because of inadequate pointing vectors	FINDCDUW
00404	• Two stars not available in any detent	R59
00405	• Two stars not available	R51
00421	W-matrix overflow	INTEGRV
00501	• Radar antenna out of limits	R23
00502	Bad radar gimbal angle input	V41N72
00503	• Radar antenna designate fail	R21, non-* in V41 N72
00510	Radar auto discrete not present	R25, V40 N72
00511	LR not in Position 2 or repositioning	R12
00514	• RR goes out of Auto mode while in use	P20, P22
00515	RR CDU Fail discrete present	R25
00520	RADARUPT not expected at this time	Radar read, P20, P22, R12
00521	Could not read radar	R12, R22
00522	LR position change	R12
00523	• LR antenna did not achieve Position 2	R12, V60 (non-* in V60)
00525	• Delta Theta greater than 3 degrees	R22
00526	Range greater than 400 nmi	P20, P22
00527	LOS not in Mode 2 coverage in P22	R24
	Or vehicle maneuver required in P20	R24
00530	• LOS not in Mode 2 coverage while on lunar surface after 600 seconds	R21
00600	• Imaginary roots on first iteration	P32, P72
00601	• Perigee altitude after CSI < 85 nmi earth orbit, < 35,000 feet moon orbit	P32, P72
00602	• Perigee altitude after CDH < 85 nmi earth orbit, < 35,000 feet moon orbit	P32, P72
00603	• CSI to CDH time less than 10 minutes	P32, P33, P72, P73
00604	• CDH to TPI time less than 10 minutes	P32, P72
00605	• Number of iterations exceeds P32/P72 loop maximum	P32, P72
00606	• DV exceeds maximum	P32, P72
00611	• No TIG for given E angle	P33, P34, P73, P74
00701	• Illegal option code selected	P57
00777	PIPA Fail caused ISS warning	T4RUPT
01102	LGC self-test error	SELFCHK
01105	DOWNLINK too fast	T4RUPT
01106	UPLINK too fast	T4RUPT
01107	Phase table failure. Assume erasable memory is suspect.	RESTART

LIST OF ALARM CODES USED WITH VERB 05
NOUN 09 FOR PROGRAM LUMINARY 1B

CODE	PURPOSE	SET BY
01301	ARCSIN-ARCCOS input angle too large	INTERPRETER
01406	Bad return from ROOTSPRS during descent guidance	P63, P64
01407	VG increasing (Delta V accumulated at 90 degrees from desired thrust vector)	P40, P42
01410	Unintentional overflow in guidance	P63, P64, P65, P66
01412	Descent ignition algorithm not converging	P63
01520	V37 request not permitted at this time	R00
01600	Overflow in drift test	Ground Test
01601	Bad IMU torque	Ground Test
01703	Too close to ignition; slip time of Ignition	R41
01706	Incorrect program selected for vehicle configuration	P40, P42
02001	Jet failures have disabled Y-Z translation	DAP
02002	Jet failures have disabled X translation	DAP
02003	Jet failures have disabled P rotations	DAP
02004	Jet failures have disabled U-V rotations	DAP
03777	ICDU fail caused the ISS warning	T4RUPT
04777	ICDU, PIPA fails caused the ISS warning	T4RUPT
07777	IMU fail caused the ISS warning	T4RUPT
10777	IMU, PIPA fails caused the ISS warning	T4RUPT
13777	IMU, ICDU fails caused the ISS warning	T4RUPT
14777	IMU, ICDU, PIPA fails caused the ISS warning	T4RUPT
20105	AOT mark system in use	R53
20430	Acceleration overflow in integration	Orbital integration
20607	No solution from TIME-THETA or TIME-RADIUS	TIMETHET, TIMERAD
21103	Unused CCS branch executed	ABORT
21204	WAITLIST, VARDELAY, FIXDELAY, DELAYJOB, or LONGCALL called with zero or negative delta time	WAITLIST
21302	SORT called with negative argument	INTERPRETER
21406	Bad return from ROOTSPRS during descent preignition	Ignition algorithm
21501	Keyboard and Display alarm during internal use (NVSUB)	PINBALL
31104	Delay routine busy	EXECUTIVE
31201	Executive overflow—no VAC areas	EXECUTIVE
31202	Executive overflow—no core sets	EXECUTIVE
31203	WAITLIST overflow—too many tasks	WAITLIST
31206	Second job attempts to go to sleep via Keyboard and Display program	PINBALL
31207	No VAC area for marks	R53
31210	Two programs using device at same time	IMU mode switching
31211	Illegal interrupt of extended verb	R53
31502	Two priority displays waiting	GOPLAY
32000	DAP still in progress at next T5RUPT	DAP

NOTE:

For V05 N09 displays:
R1—XXXXX (first alarm to occur after last RSET)
R2—XXXXX (second alarm to occur after last RSET)
R3—XXXXX (alarm which occurred last)

R3 will be of the form 4XXXX if more than three alarms occurred since the last RSET or FRESH START.

3XXXX indicates an Abort code that results in a software RESTART
2XXXX indicates a more serious Abort code that results in the program going to R00

*This alarm displayed without having to key in V05 N09E.
An astronaut response is required by this alarm.

LIST OF CHECKLIST REFERENCE CODES USED WITH
VERB 50 NOUN 25 PROGRAM LUMINARY 1B

R1 CODE	ACTION TO BE EFFECTED	PROGRAM
00013	Key in normal or gyro torque coarse align	P52
00014	Proceed: Do fine alignment option	R51, P63, P57
	Enter: Do landing site determination (N89)	P57 Option 2
00015	Perform celestial body acquisition	R51, P51
00062	Switch LGC power down	P06
00201	Switch RR mode to automatic	P20, P22, R04
00203	Switch guidance control to PGNS, mode to Auto, thrust control to Auto	P12, P42, P71, P40, P63, P70
00205	Perform manual acquisition of CSM with RR	R23
00500	Switch LR antenna to Position 1	P63

NOTES: Switch: denotes change position of a console switch
Perform: denotes start or end of a task
Key In: denotes key-in of data through the DSKY

LIST OF OPTION CODES DISPLAYED IN R1 IN
CONJUNCTION WITH VERB 04 NOUN 06 TO REQUEST THE
ASTRONAUT TO LOAD INTO R2 THE OPTION HE DESIRES
FOR PROGRAM LUMINARY 1B

CODE	PURPOSE	INPUT FOR R2	PROGRAM
00001	Specify IMU Orientation	1 = preferred, 2 = nominal 3 = REFSMMAT, 4 = landing site	P52, P57
00002	Specify vehicle	1 = this, 2 = other	P21, R30
00003	Specify tracking attitude	1 = preferred, 2 = other	R63
00004	Specify radar	1 = RR, 2 = LR	R04
00006	Specify RR coarse align option	1 = lockon, 2 = continuous designate	V41N72
00010	Specify alignment mode	0 = anytime, 1 = REFSMMAT + g 2 = two bodies, 3 = one body + g	P57
00012	Specify CSM orbit option	1 = no orbit change, 2 = change orbit to pass over LM	P22

**FLAGWORD BIT ASSIGNMENTS (ALPHABETICAL)
FOR LUMINARY 1B**

ACCSOKAY	FW13	B3	GMBDRVSW	FW6	B10
ACC4-2FL	FW13	B11	GUESSW	FW1	B2
ACC4OR2X	FW13	B11	HFLSHBIT	FW11	B1
ACMODFLG	FW2	B13	HFLSHFLG	FW11	B1
ALTSCBIT	FW12	B9	IDLEFBIT	FW7	B7
ANTENBIT	FW12	B12	IDLEFLAG	FW7	B7
AORBSYST	FW5	B5	IGNFLAG	FW7	B13
AORBTFLG	FW13	B10	IGNFLBIT	FW7	B13
AORBTTRAN	FW13	B10	IMPULBIT	FW2	B9
APSESW	FW8	B5	IMPULSW	FW2	B9
APSFFLAG	FW10	B13	IMUSE	FW0	B8
APSFBLBIT	FW10	B13	IMUSEBIT	FW0	B8
ASTNBIT	FW7	B12	INFINFLG	FW8	B7
ASTNFLAG	FW7	B12	INITABIT	FW8	B2
ATTFLAG	FW6	B1	INITALGN	FW8	B2
ATTFBLBIT	FW6	B1	INTFLBIT	FW10	B14
AUTOMBIT	FW12	B2	INTYPFLG	FW3	B4
AUTR1FLG*	FW13	B1	ITSWICH	FW7	B1
AUTR2FLG*	FW13	B2	JSWITCH	FW0	B1
AUXFLBIT	FW6	B2	LETABBIT	FW9	B9
AVEGFBIT	FW7	B5	LETABORT	FW9	B9
AVEGFFLAG	FW7	B5	LMOONBIT	FW8	B11
AVEMIDSW	FW9	B1	LMOONFLG	FW8	B11
AVFLAG	FW2	B5	LOKONBIT	FW0	B5
CALCMAN2	FW2	B2	LOKONSW	FW0	B5
CALCMAN3	FW2	B3	LOSCMBIT	FW2	B12
CDESBIT	FW12	B15	LOSCMFLG	FW2	B12
CDESFLAG	FW12	B15	LPOS2BIT	FW11	B6
CMOONBIT	FW8	B12	LPOS2FLG	FW11	B6
CMOONFLG	FW8	B12	LRALTBIT	FW12	B5
COGAFLAG	FW8	B4	LRBYBIT	FW11	B15
CSDMOCKD	FW13	B13	LRBYPASS	FW11	B15
CULTFLAG	FW3	B7	LRINH	FW11	B8
DBSELECT	FW13	B4	LRINHBIT	FW11	B8
DBSELECT2	FW13	B5	LRPOSBIT	FW12	B6
DESIGBIT	FW12	B10	LRVELFLG*	FW12	B8
DESIGFLG	FW12	B10	LUNAFLAG	FW3	B12
DIDFLBIT	FW1	B14	MANUFLGG*	FW7	B14
DIMOFLAG	FW3	B1	MGLVFLAG	FW5	B2
DMENFLG	FW5	B9	MIDAVFLAG	FW9	B2
DRFTBIT	FW2	B15	MIDFLAG	FW0	B13
DRIFTBIT	FW13	B8	MIDIFLAG	FW9	B3
DRIFTDFL	FW13	B8	MKOVBIT	FW4	B3
DRIFTFLG	FW2	B15	MOONFLAG	FW0	B12
DSKYBIT	FW5	B15	MRKIDFLG*	FW4	B15
D6OR9FLG	FW3	B2	MRKNVBIT	FW4	B9
ENGONBIT	FW5	B7	MRKNVFLG	FW4	B9
EDRADFLAG	FW1	B13	MRUPTFLG*	FW4	B5
ETPIFLAG	FW2	B7	MUNFLAG	FW6	B8
FINALFLG	FW2	B6	MUNFLBIT	FW6	B8
FLAP	FW9	B8	MWAITFLG*	FW4	B11
FLPC	FW9	B12	NEEDLBIT	FW0	B4
FLPI	FW9	B11	NEEDLFLG	FW0	B4
FLRCS	FW9	B10	NEED2BIT	FW0	B15
FLRCSBIT	FW9	B10	NEED2FLG	FW0	B15
FLUNDBIT	FW8	B10	NEWIFLG	FW8	B13
FLUNDISP	FW8	B10	NJETSFLG	FW1	B15
FLVR	FW9	B14	NODOBIT	FW2	B1
FREEFBIT	FW0	B3	NODOFLAG	FW2	B1
FREEFLAG	FW0	B3	NOLRRBIT	FW11	B10
FSPASFLG	FW0	B10	NOLRRREAD	FW11	B10
GLOKFAIL	FW3	B14	NORMSW	FW7	B10
GMBDRBIT	FW6	B10	NORRMBIT	FW5	B4

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS (ALPHABETICAL)
FOR LUMINARY 1B

NORRMON	FW5	B4	RVSW	FW7	B9
NOR29FLG	FW3	B11	R04FLAG	FW3	B9
NOTHRBIT	FW5	B12	R04FLBIT	FW3	B9
NOUPFBIT	FW1	B6	R10FLG	FW0	B2
NOUPFLAG	FW1	B6	R10FLBIT	FW0	B2
NO511BIT	FW11	B3	R61FLAG	FW1	B10
NO511FLG	FW11	B3	R61FLBIT	FW1	B10
NRMNVFLAG	FW4	B8	R77FLAG	FW5	B11
NRMIDFLG*	FW4	B13	R77FLBIT	FW5	B11
NRUPTFLG*	FW4	B4	SLOPESW	FW1	B3
NR29FBIT	FW3	B11	SNUFFBIT	FW5	B13
NTARGFLG	FW6	B3	SNUFFER	FW5	B13
NWAITFLG*	FW4	B10	SOLNSW	FW5	B3
OLDESBIT	FW0	B1	SRCHOBIT	FW2	B14
ORBWFLAG	FW3	B6	SRCHOPTN	FW2	B14
ORDERSW	FW8	B6	STATEBIT	FW3	B5
OURRCBIT	FW13	B12	STATEFLG	FW3	B5
PDSPFBIT	FW4	B12	STEERBIT	FW2	B11
PDSPFLAG	FW4	B12	STEERSW	FW2	B11
PFRATBIT	FW2	B4	SURFFBIT	FW8	B8
PFRATFLG	FW2	B4	SURFFLAG	FW8	B8
PINBRFLG	FW4	B6	SWANDBIT	FW7	B11
POOHFLAG	FW3	B15	SWANDISP	FW7	B11
PRECIFLG	FW3	B8	S32.1F1	FW6	B15
PRIODBIT	FW4	B14	S32.1F2	FW6	B14
PRONVFLG	FW4	B7	S32.1F3A	FW6	B13
PSTHIBIT	FW11	B11	S32.1F3B	FW6	B12
PULSEFLG	FW13	B15	TFFSW	FW7	B1
PULSES	FW13	B15	TRACKBIT	FW1	B5
P21FLAG	FW0	B11	TRACKFLG	FW1	B5
P21FLBIT	FW0	B11	TURNONBT	FW12	B1
P25FLAG	FW0	B9	ULLAGER	FW13	B6
P25FLBIT	FW0	B9	ULLAGFLG	FW13	B6
P7071BIT	FW9	B13	UPDATBIT	FW1	B7
P7071FLG	FW9	B13	UPDATFLG	FW1	B7
QUITFLAG	FW9	B5	UPLOCBIT	FW7	B4
RCDUFBIT	FW12	B7	USEQRJTS	FW13	B14
RCDU0BIT	FW12	B13	VEHUPFLG	FW1	B8
READRBIT	FW3	B9	VELDABIT	FW11	B7
READRFLG	FW3	B9	VERIFBIT	FW7	B3
READVBIT	FW11	B5	VFLAG	FW3	B10
READVEL	FW11	B5	VFLSHBIT	FW11	B2
REDFLAG	FW6	B6	VFLSHFLG	FW11	B2
REDFLBIT	FW6	B6	VINTFLAG	FW3	B3
REFSMBIT	FW3	B13	VXINH	FW11	B12
REFSMFLG	FW3	B13	VXINHBIT	FW11	B12
REINTBIT	FW10	B7	V37FLAG	FW7	B6
REINTFLG	FW10	B7	V37FLBIT	FW7	B6
REMODBIT	FW12	B14	V67FLAG	FW7	B8
RENDWBIT	FW5	B1	V82EMFLG	FW7	B2
RENDWFLG	FW5	B1	XDELVFLG	FW2	B8
REPOSBIT	FW12	B11	XDSPBIT	FW4	B1
RHCSCALE	FW13	B7	XDSPFLAG	FW4	B1
RNDVZBIT	FW0	B7	XORFLBIT	FW11	B9
RNDVZFLG	FW0	B7	XORFLG	FW11	B9
RNGEDBIT	FW11	B4	XOVINFLG	FW13	B9
RNGSCBIT	FW5	B10	XOVINHIB	FW13	B9
RNGSCFLG	FW5	B10	ZOOMBIT	FW5	B8
RODFLAG	FW1	B12	ZOOMFLAG	FW5	B8
RODFLBIT	FW1	B12	3AXISBIT	FW5	B6
ROTFLAG	FW9	B6	3AXISFLG	FW5	B6
RPQFLAG	FW8	B15	360SW	FW8	B1
RRDATABIT	FW12	B4			
RRNBSW	FW0	B6			
RRRSBIT	FW12	B3			

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 0)

Bit	Name	1	0
1	OLDESBIT	R29 gyro command loop requested.	R29 gyro command loop not requested.
2	R10FLAG R10FLBIT	R10 outputs data to altitude and altitude rate meters only.	Besides outputs to altitude and altitude rates, when set, R10 also outputs data to forward and lateral velocity crosspointer
3	FREEFBIT FREEFLAG	Used by P51-53 in many different routines and by lunar and solar ephemerides.	
4	NEEDLBIT NEEDLFLG	Total attitude error displayed.	A/P following error displayed.
5	LOKONBIT LOKONSW	Radar lock-on desired.	Radar lock-on not desired.
6	RRNBSW	Radar target in NB coordinates.	Radar target in SM coordinates.
7	RNDVZBIT RNDVZFLG	P20 running (radar in use).	P20 not running.
8	IMUSE IMUSEBIT	IMU in use.	IMU not in use.
9	P25FLAG P25FLBIT	P25 operating.	P25 not operating
10	FSPASFLG	First pass through reposition routine.	Not first pass through reposition routine.
11	P21FLAG P21FLBIT	Succeeding pass through P21; use base vectors already calculated.	First pass through P21; calculate base vectors.
12	MOONFLAG	Moon is sphere of influence.	Earth is sphere of influence.
13	MIDFLAG	Integration with secondary body and solar perturbations.	Integration without solar perturbations.
14	JSWITCH	Integration of W matrix.	Integration of state vector.
15	NEED2BIT NEED2FLG	Display DAP rates on FDAI needles.	Check Bit 4 of this FLAGWORD for display modes (1 or 2).

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 1)

Bit	Name	1	0
1	Not Assigned		
2	GUESSW	No starting value for iteration.	Starting value for iteration exists.
3	SLOPESW	Iterate with bias method in iterator.	Iterate with Regula Falsi method in iterator.
4	Not Assigned		
5	TRACKBIT TRACKFLG	Tracking allowed.	Tracking not allowed.
6	NOUPFBIT NOUPFLAG	Neither CSM nor LM state vector may be updated.	Either state vector may be updated.
7	UPDATBIT UPDATFLG	Updating by marks allowed.	Updating by marks not allowed.
8	VEHUPFLG	CSM state vector being updated.	LM state vector being updated.
9	Not Assigned		
10	R61FLAG R61FLBIT	Run R61 LM.	Run R65 LM.
11	Not Assigned		
12	RODFLAG RODFLBIT	If in P66, normal operation continues. Restart clears flag.	If in P66, reinitialization is performed.
13	ERADFLAG	Compute REARTH Fischer ellipsoid.	Use constant REARTH pad radius.
14	DIDFLBIT	Inertial data is available.	Perform data display initialization functions.
15	NJETSFLG	Two-jet RCS burn.	Four-jet RCS burn.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 2)

Bit	Name	1	0
1	NODOBIT NODOFLAG	V37 not permitted.	V37 permitted.
2	CALCMAN2	Perform maneuver starting procedure.	Bypass starting procedure.
3	CALCMAN3	No final roll.	Final roll is necessary.
4	PFRATBIT PFRATFLG	Preferred attitude computed.	Preferred attitude not computed.
5	AVFLAG	LM is active vehicle.	CSM is active vehicle.
6	FINALFLG	Last pass through rendezvous program computations.	Interim pass through rendezvous program computations.
7	ETPIFLAG	Elevation angle supplied for P34, P74.	TP1 time supplied for P34, P74 to compute elevation.
8	XDELVFLG	External Delta V VG computation.	Lambert (aimpoint) VG computation.
9	IMPULBIT IMPULSW	Minimum impulse burn (cutoff time specified).	Steering burn (no cutoff time yet available).
10	Not Assigned		
11	STEERBIT STEERSW	Sufficient thrust is present.	Insufficient thrust is present.
12	LOSCMBIT LOSCMFLG	Line of sight being computed (R21). In R29, RR gyro command loop running.	Line of sight not being computed (R21). In R29, RR gyro command loop off.
13	ACMODFLG	Manual acquisition by Rendezvous Radar.	Auto acquisition by Rendezvous Radar.
14	SRCHOBIT SRCHOPTN	Radar in automatic search option (R24).	Radar not in automatic search option.
15	DRFTBIT DRIFTFLG	T3RUPT calls gyro compensation.	T3RUPT does no gyro compensation.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 3)

Bit	Name	1	0
1	DIMOFLAG	W matrix is to be used.	W matrix is not to be used.
2	D60R9FLG	Dimension of W is 9 for integration.	Dimension of W is 6 for integration.
3	VINTFLAG	CSM state vector being integrated.	LM state vector being integrated.
4	INTYPFLG	Conic integration.	Encke integration.
5	STATEBIT STATEFLG	Permanent state vector being updated.	Permanent state vector not being updated.
6	ORBWFLAG	W matrix valid for orbital navigation.	W matrix invalid for orbital navigation.
7	CULTFLAG	Star occulted.	Star not occulted.
8	PRECIFLG	Normal integration in P00.	Engages four-time step (P00) logic in integration.
9	READRBIT READRFLG	Reading RR data pursuant to R29.	Not reading RR data pursuant to R29.
	R04FLAG R04FLBIT	Alarm 521 suppressed.	Alarm 521 allowed.
10	VFLAG	Less than two stars in the field of view.	Two stars in the field of view.
11	NOR29FLG NR29FBIT	R29 not allowed.	R29 allowed (RR designate, powered flight).
12	LUNAFLAG	Lunar latitude-longitude.	Earth latitude-longitude.
13	REFSMBIT REFSMFLG	REFSMMAT good (protected from FRESH START).	REFSMMAT no good (protected from FRESH START).
14	GLOKFAIL	GIMBAL LOCK has occurred.	Not in GIMBAL LOCK.
15	POOHFLAG	Inhibit backwards integration.	Allow backwards integration.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 4)

Bit	Name	1	0
1	XDSPBIT XDSPFLAG	Mark display not to be interrupted.	No special mark information.
2	Not Assigned		
3	MKOVBIT	Mark display over normal.	No mark display over normal.
4	NRUPTFLG*	Normal display interrupted by priority or mark display.	Normal display not interrupted by priority or mark display.
5	MRUPTFLG*	Mark display interrupted by priority display.	Mark display not interrupted by priority display.
6	PINBRFLG	Astronaut has interfered with existing display.	Astronaut has not interfered with existing display.
7	PRONVFLG	Astronaut using keyboard when priority display initiated.	Astronaut not using keyboard when priority display initiated.
8	NRMNVFLG	Astronaut using keyboard when normal display initiated.	Astronaut not using keyboard when normal display initiated.
9	MRKNVBIT MRKNVFLG	Astronaut using keyboard when mark display initiated.	Astronaut not using keyboard when mark display initiated.
10	NWAITFLG*	Higher priority display operating when normal display initiated.	No higher priority display operating when normal display initiated.
11	MWAITFLG*	Higher priority display operating when mark display initiated.	No higher priority display operating when mark display initiated.
12	PDSPFBIT PDSPFLAG	P20 sets so as to turn a normal display into a priority display in R60.	Leave as normal display.
13	NRMIDFLG*	Normal display in ENDIDLE.	No normal display in ENDIDLE.
14	PRIODBIT	Priority display in ENDIDLE.	No priority display in ENDIDLE.
15	MRKIDFLG*	Mark display in ENDIDLE.	No mark display in ENDIDLE.

*Theses switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 5)

Bit	Name	1	0
1	RENDWBIT RENDWFLG	W matrix valid for rendezvous navigation.	W matrix invalid for rendezvous navigation.
2	MGLVFLAG	Local vertical coordinates computed.	Middle gimbal angle computed.
3	SOLNSW	Lambert does not converge, or time-radius nearly circular.	Lambert converges or time-radius noncircular.
4	NORRMBIT NORRMON	Bypass RR gimbal monitor.	Perform RR gimbal monitor.
5	AORBSYST	Prefer P-axis jet pairs 7, 15 and 8, 16.	Prefer P-axis jet pairs 4, 12 and 3, 11.
6	3AXISBIT 3AXISFLG	Maneuver specified by three axes.	Maneuver specified by one axis; R60 call VECPOINT.
7	ENGONBIT	Engine turned on.	Engine turned off.
8	ZOOMBIT ZOOMFLAG	Throttleup has occurred in P63.	Throttleup has not occurred in P63.
9	DMENFLG	Dimension of W is 9 for incorporation.	Dimension of W is 6 for incorporation.
10	RNGSCBIT RNGSCFLG	Scale change has occurred during RR reading.	No scale change has occurred during RR reading.
11	R77FLAG R77FLBIT	R77 is on; suppress all radar alarms and tracker fails.	R77 is not on.
12	NOTHRBIT NOTHROTL	Inhibit full throttle.	Permit full throttle.
13	SNUFFER SNUFFBIT	U, V jets disabled during DPS burns (V65).	U, V jets enabled during DPS burns (V75).
14	Not Assigned		
15	DSKYFBIT	Displays sent to DSKY.	No displays to DSKY.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 6)

Bit	Name	1	0
1	ATTFLAG ATTFLBIT	LM attitude exists in moon-fixed coordinates.	No LM attitude available in moon-fixed coordinates.
2	AUXFLBIT	Providing IDLEFLAG is not set, SERVICER will exercise DVMON on its next pass.	SERVICER will skip DVMON on its next pass even if the IDLEFLAG is not set. It will then set AUXFLBIT.
3	NTARGFLG	Astronaut did overwrite Delta V at TPI or TPM (P34, P35).	Astronaut did not overwrite Delta V.
4	Not Assigned		
5	Not Assigned		
6	REDFLAG REDFLBIT	Landing site redesignation permitted.	Landing site redesignation not permitted.
7	Not Assigned		
8	MUNFLAG MUNFLBIT	SERVICER calls MUNRVG.	SERVICER calls CALCRVG.
9	Not Assigned		
10	GMBDRBIT GMBDRVSW	TRIMGIMB over.	TRIMGIMB not over.
11	Not Assigned		
12	S32.1F3B	(Bits 12 and 13 function as an ordered pair (13, 12) indicating the possible occurrence of two Newton iterations for S32.1: (0, 0) - First pass of second Newton iteration, (0, 1) - First Newton iteration being done, (1, 0) - Remainder of second Newton iteration, (1, 1) - 50 ft/s stage of second Newton iteration.)	
13	S32.1F3A		
14	S32.1F2	First pass of Newton iteration.	Reiteration of Newton.
15	S32.1F1	Delta V at CSI Time 1 exceeds maximum.	Delta V at CSI Time 1 less than maximum.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 7)

Bit	Name	1	0
1	TFFSW	Calculate TPERIGEE.	Calculate TFF.
2	V82EMFLG	Moon vicinity.	Earth vicinity.
3	VERIFBIT	(Changed when V33E occurs at end of P27).	
4	UPLOCBIT	K-K-K fail.	No K-K-K fail.
5	AVEGFBIT AVEGFLAG	AVERAGEG (SERVICER) desired.	AVERAGEG (SERVICER) not desired.
6	V37FLAG V37FLBIT	AVERAGEG (SERVICER) running.	AVERAGEG (SERVICER) off.
7	IDLEFBIT IDLEFLAG	No Delta V monitor.	Connect Delta V monitor.
8	V67FLAG	Astronaut overwrites W-matrix initial values.	Astronaut does not overwrite W-matrix initial values.
9	RVSF	Do not compute final state vector in time-theta.	Compute final state vector in time-theta.
10	NORMSW	Unit normal input to Lambert.	Lambert computes its own normal.
11	SWANDBIT SWANDISP	Landing analog displays enabled.	Landing analog displays suppressed.
12	ASTNBIT ASTNFLAG	Astronaut has OKed ignition.	Astronaut has not OKed ignition.
13	IGNFLAG IGNFLBIT	TIG has arrived.	TIG has not arrived.
14	MANUFLAG*	Attitude maneuver going on during RR search.	No attitude maneuver during RR search.
15	ITSWICH	P34; TPI time to be computed.	TPI has been computed.

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 8)

Bit	Name	1	0
1	360SW	Transfer angle near 360 degrees.	Transfer angle not near 360 degrees.
2	INITABIT INITALGN	Initial pass through P57.	Second pass through P57.
3	Not Assigned		
4	COGAFLAG	No conic solution, too close to rectilinear (COGA overflows).	Conic solution exists (COGA does not overflow).
5	APSESW	RDESIRED outside of PERICENTER-APOCENTER range in time-radius.	RDESIRED inside of PERICENTER-APOCENTER range in time-radius.
6	ORDERSW	Iterator uses second order minimum mode.	Iterator uses first order standard mode.
7	INFINFLG	No conic solution (closure through infinity required).	Conic solution exists.
8	SURFFBIT SURFFLAG	LM on lunar surface (protected from FRESH START).	LM not on lunar surface (protected from FRESH START).
9	Not Assigned.		
10	FLUNDBIT FLUNDISP	Current guidance displays inhibited.	Current guidance displays permitted.
11	LMOONBIT LMOONFLG	Permanent LM state vector in lunar sphere (protected from FRESH START).	Permanent LM state vector in earth sphere (protected from FRESH START).
12	CMOONBIT CMOONFLG	Permanent CSM state vector in lunar sphere (protected from FRESH START).	Permanent CSM state vector in earth sphere (protected from FRESH START).
13	NEWIFLG	First pass through integration.	Succeeding iteration of integration.
14	Not Assigned		
15	RPQFLAG	RPQ not computed. (RPQ = vector between secondary body and primary body.)	RPQ computed.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 9)

Bit	Name	1	0
1	AVEMIDSW	AVETOMID calling for W-matrix integration. Do not overwrite RN, VN, PIPTIME.	No AVETOMID W-matrix integration. Allow setup of RN, VN, PIPTIME.
2	MIDAVFLAG	Integration entered from one of MIDTOAV portals.	Integration was not entered via MIDTOAV.
3	MID1FLAG	Integrate to TDEC.	Integrate to the then-present time.
4	Not Assigned		
5	QUITFLAG	Discontinue integration.	Continue integration.
6	ROTFLAG	P70 and P71 will force vehicle rotation in the preferred direction.	P70 and P71 will not force vehicle rotation in the preferred direction.
7	Not Assigned		
8	FLAP	APS continued abort after DPS staging (ascent guidance).	APS abort is not a continuation.
9	LETABBIT LETABORT	Abort programs are enabled.	Abort programs are not enabled.
10	FLRCS FLRCSBIT	RCS injection mode (ascent guidance).	Main engine mode.
11	FLPI	Preignition phase (ascent guidance).	Regular guidance.
12	FLPC	No position control (ascent guidance).	Position control.
13	P7071BIT P7071FLG	P70 or P71 is using ascent guidance equations.	P12 is using ascent guidance equations.
14	FLVR	Vertical rise (ascent guidance).	Nonvertical rise.
15	Not Assigned		

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 10, RASFLAG)

Bit	Name	1	0
1	Not Assigned		
2	Not Assigned		
3	Not Assigned		
4	Not Assigned		
5	Not Assigned		
6	Not Assigned		
7	REINTBIT REINTFLG	Integration routine to be RESTARTED.	Integration routine not to be RESTARTED.
8	Not Assigned		
9	Not Assigned		
10	Not Assigned		
11	Not Assigned		
12	Not Assigned		
13	APSFLAG APSFLBIT	Ascent stage (protected from FRESH START).	Descent stage (protected from FRESH START).
14	INTFLBIT	Integration in progress.	Integration not in progress.
15	Not Assigned		

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 11)

Bit	Name	1	0
1	HFLSHBIT HFLSHFLG	LR altitude fail lamp should be flashing.	LR altitude fail lamp should not be flashing.
2	VFLSHBIT VFLSHFLG	LR velocity fail lamp should be flashing.	LR velocity fail lamp should not be flashing.
3	NO511BIT NO511FLG	Do not test LR antenna position in R12.	Test LR antenna position in R12.
4	RNGEDBIT	LR altitude measurement made.	LR altitude measurement not made.
5	READVBIT READVEL	OK to read LR velocity data.	Do not read LR velocity data.
6	LPOS2BIT LPOS2FLG	Use LR Position 2 transformation.	Use LR Position 1 transformation.
7	VELDABIT	LR velocity measurement made.	LR velocity measurement not made.
8	LRINH LRINHBIT	LR updates permitted by astronaut.	LR updates inhibited by astronaut.
9	XORFLBIT XORFLG	Below limit; inhibit X-axis override.	Above limit; do not inhibit.
10	NOLRRBIT NOLRREAD	LR repositioning; bypass update.	LR not repositioning.
11	PSTHIBIT	Posthigate.	Prehigate.
12	VXINH VXINHBIT	If Z velocity data unreasonable, bypass X-axis velocity update on next pass.	Update X-axis velocity.
13	Not Assigned		
14	Not Assigned		
15	LRBYBIT LRBYPASS	Bypass all LR updates.	Do not bypass LR updates.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 12, RADMODES)

Bit	Name	1	0
1	TURNONBT	RR turn-on sequence in progress (zero RR CDU's; fix antenna position).	No RR turn-on sequence in progress.
2	AUTOMBIT	RR not in Auto mode. Auto mode discrete is not present.	RR in Auto mode.
3	RRRSBIT	RR range reading on the high scale.	RR range reading on the low scale.
4	RRDATABT	RR data fail. Data could not be read successfully.	No RR data fail.
5	LRALTBIT	LR altitude data fail. Data could not be read successfully.	No LR altitude data fail.
6	LRPOSBIT	LR in Position 2.	LR in Position 1.
7	RCDUFBIT	RR CDU fail has not occurred.	RR CDU fail has occurred.
8	LRVELFLG*	LR velocity data fail.	No LR velocity data fail.
9	ALTSCBIT	LR altitude reading is on high scale.	LR altitude reading is on low scale.
10	DESIGBIT DESIGFLG	RR designate requested or in progress.	RR designate not requested or in progress.
11	REPOSBIT	Reposition monitor, RR reposition is taking place.	No RR reposition taking place.
12	ANTENBIT	RR antenna is in Mode 2.	RR antenna is in Mode 1.
13	RCDU0BIT	RR CDU's being zeroed.	RR CDU's not being zeroed.
14	REMODBIT	Change in antenna mode has been requested.	No remode requested or occurring.
15	CDESBIT CDESFLAG	Continuous designate. LGC commands RR regardless of lock-on.	LGC checks for lock-on when antenna being designated.

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

(FLAGWORD 13, DAPBOOLS)

Bit	Name	1	0
1	AUTR1FLG*	These bits (2, 1) are used together to indicate astronaut-chosen KALCMANU maneuver rates: (0, 0) = 0.2 deg/second (Bit 2, Bit 1), (0, 1) = 0.5 deg/second, (1, 0) = 2.0 deg/second, (1, 1) = 10.0 deg/second.	
2	AUTR2FLG*		
3	ACCSOKAY	Control authority values from 1/ACCS usable.	RESTART or FRESH START since last 1/ACCS; outputs suspect.
4	DBSELECT	1-degree deadband selected by crew.	Minimum deadband selected by crew (0.3 degree).
5	DBSLECT2	5-degree deadband selected by crew (maximum deadband).	1- or 0.3-degree deadband selected by crew (See Bit 4).
6	ULLAGER ULLAGFLG	Ullage request by mission program.	No internal ullage request.
7	RHCSCALE	Normal RHC scaling requested.	Fine RHC scaling requested.
8	DRIFTBIT DRIFTDFL	Assume zero offset drifting flight.	Use offset acceleration estimate.
9	XOVINFLG XOVINHIB	X-axis override locked out.	X-axis override OK.
10	AORBTFLG AORBTRAN	B system for X-translation preferred.	A system for X-translation preferred.
11	ACC4-2FL ACC4OR2X	Four-jet X-axis translation requested.	Two-jet X-axis translation requested.
12	OURRCBIT	Current DAP pass is rate command.	Current DAP pass is not rate command.
13	CSMDOCKD	CSM docked; use backup DAP.	CSM not docked to LM.
14	USEQRJTS	Gimbal unusable; use jets only.	Trim gimbal may be used.
15	PULSEFLG PULSES	Minimum impulse command mode in "attitude hold" (V76).	Not in minimum impulse command mode (V77).

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

IMODES33, a flag whose individual bits are used to control the monitoring of functions associated with Channel 33 (and other items).

Bit	Meaning
15	Not assigned.
14	Last sampled value of Channel 32, Bit 14 (0 if a Proceed command is given using the old "standby" button).
13	Last sampled value of Channel 33, Bit 13 (0 if an accelerometer fail signal, or PIPA fail, has been produced by hardware).
12	Last sampled value of Channel 33, Bit 12 (0 if a telemetry end pulse has been rejected because the downlink rate is too fast).
11	Last sampled value of Channel 33, Bit 11 (0 if an uplink bit has been rejected because the uplink rate is too fast).
10,9	Not assigned.
8	Bit is set to 1 when R10 routine is initialized during the powered descent trajectory.
7	A switch employed in R10 for alternate computations of altitude rate and altitude.
6	Bit is set to 1 to indicate that IMU use for vehicle attitude information should not be attempted.
5	Bit is set to 1 in IMU Zeroing routine external to T4RUPT while zeroing is taking place (for an interval of about 10.56 seconds).
4-2	Not assigned.
1	Bit is set to 1 when a Verb 35 ("lamp test") is received, and reset to 0 about 5 seconds later.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1B

IMODES30, a flag whose Individual bits are used to control the monitoring of IMU functions associated with Channel 30 (and in a few cases Channel 33).

Bit	Meaning
15	Last sampled value of Channel 30, Bit 15 (0 if IMU temperature within limits).
14	Last sampled value of Channel 30, Bit 14 (0 if ISS has been turned on or commanded to be turned on).
13	Last sampled value of Channel 30, Bit 13 (0 if an IMU fail indication has been produced).
12	Last sampled value of Channel 30, Bit 12 (0 if an IMU CDU fail indication has been produced).
11	Last sampled value of Channel 30, Bit 11 (0 if an IMU cage command has been produced by crew).
10	Last sampled value of Channel 33, Bit 10 (0 if a PIPA fail indication has been produced), having the same value as Bit 13 of IMODES33.
9	Last sampled value of Channel 30, Bit 9 (0 if IMU has been turned on and operating with no malfunctions).
8	Bit used to control the IMU turn-on sequencing.
7	Bit used to control the IMU turn-on sequencing.
6	Bit is set to 1 to indicate that IMU initialization is being carried out.
5	Bit is set to 1 to inhibit the generation of program alarm 0212g if a PIPA fail signal (Bit 13 of Channel 33) is produced.
4	Bit is set to 1 to inhibit generation of an ISS warning based on receipt of an IMU fail signal.
3	Bit is set to 1 to inhibit generation of an ISS warning based on receipt of an IMU CDU fail signal.
2	Bit is set to 1 to indicate failure of the turn-on delay sequence for IMU turn-on (alarm 0207g is also generated).
1	Bit is set to 1 to inhibit generation of an ISS warning based on receipt of a PIPA fail signal (Bit 13 of Channel 33).

CHANNEL BIT ASSIGNMENTS (LM)

OUTPUT CHANNEL 11

BIT

1	ISS Warning
2	Light Computer Activity Lamp
3	Light Uplink Activity Lamp
4	Light Temperature Caution Lamp
5	Light Keyboard Release Lamp
6	Flash Verb and Noun Lamps
7	Light Operator Error Lamp
8	Spare
9	Test Connector Outbit
10	Caution Reset
11	Spare
12	Spare
13	Engine On
14	Engine Off
15	Spare

OUTPUT CHANNEL 12

BIT

1	Zero Rendezvous Radar CDU's
2	Enable Rendezvous Radar Error Counters
3	Not Used
4	Coarse Align Enable
5	Zero IMU CDU's
6	Enable IMU Error Counters
7	Spare
8	Display Inertial Data
9	+Pitch Vehicle Motion (-Pitch Gimbal Trim, Bell motion)
10	-Pitch Vehicle Motion (+Pitch Gimbal Trim, Bell motion)
11	+Roll Vehicle Motion (-Roll Gimbal Trim, Bell motion)
12	-Roll Vehicle Motion (+Roll Gimbal Trim, Bell motion)
13	Landing Radar Position 2 Command
14	Rendezvous Radar Enable Auto Track
15	ISS Turn-on Delay Complete

CHANNEL BIT ASSIGNMENTS (LM)

OUTPUT CHANNEL 13

BIT	
1	Radar Select c
2	Radar Select b
3	Radar Select a
4	Radar Activity
5	Inhibit Uplink, Enable Crosslink (should not be set to 1)
6	Block Inlink
7	Downlink Word Order
8	RHC Counter Enable
9	Start RHC Read
10	Test Alarms
11	Enable Standby
12	Reset Trap 31-A
13	Reset Trap 31-B
14	Reset Trap 32
15	Enable T6RUPT

Channel 13 Radar Selections

a	b	c	Function
0	0	0	—
0	0	1	Rendezvous Radar range
0	1	0	Rendezvous Radar range rate
0	1	1	—
1	0	0	Landing Radar X velocity
1	0	1	Landing Radar Y velocity
1	1	0	Landing Radar Z velocity
1	1	1	Landing Radar range

OUTPUT CHANNEL 14

BIT	
1	Outlink Activity (should not be set to 1)
2	Altitude Rate Select
3	Altitude Meter Activity
4	Thrust Drive
5	Spare
6	Gyro Enable
7	Gyro Select b
8	Gyro Select a
9	Gyro Sign Minus
10	Gyro Activity
11	Drive CDU S
12	Drive CDU T
13	Drive CDU Z
14	Drive CDU Y
15	Drive CDU X

Channel 14-Gyro Selection

a	b	Gyro
0	0	—
0	1	X
1	0	Y
1	1	Z

INPUT CHANNEL 15

BIT	
1-5	Key codes from Main DSKY
6-15	Spare

CHANNEL BIT ASSIGNMENTS (LM)

INPUT CHANNEL 16

BIT

1	Spare
2	Spare
3	Mark X
4	Mark Y
5	Mark reject
6	Descent +
7	Descent -
8	Spare
9	Spare
10	Spare
11	Spare
12	Spare
13	Spare
14	Spare
15	Spare

INPUT CHANNEL 30

BIT

1	Abort with Descent Stage
2	Descent Stage Attached
3	Engine Armed
4	Abort with Ascent Stage
5	Auto Throttle
6	Display Inertial Data
7	Rendezvous Radar CDU Fail
8	Spare
9	IMU Operate
10	G/N Control of S/C
11	IMU Cage
12	IMU CDU Fail
13	IMU Fail
14	ISS Turn-On Request
15	Temp in Limits

NOTE:

All of the input signals in Channel 30 are inverted; that is, a ZERO bit indicates that the discrete is ON.

INPUT CHANNEL 31

BIT

1	+EL (LPD), + PMI
2	-EL (LPD), - PMI
3	+ YMI
4	-YMI
5	+AZ (LPD), +RMI
6	-AZ (LPD), -RMI
7	+X Translation
8	-X Translation
9	+Y Translation
10	-Y Translation
11	+Z Translation
12	-Z Translation
13	Attitude Hold
14	Auto Stabilization
15	Attitude Control Out of Detent

NOTE:

All of the input signals in Channel 31 are inverted; that is, a ZERO bit indicates that the discrete is ON.

CHANNEL BIT ASSIGNMENTS (LM)

INPUT CHANNEL 32

BIT

1	Thruster 2 — 4 Disabled by Crew
2	Thruster 5 — 8 Disabled by Crew
3	Thruster 1 — 3 Disabled by Crew
4	Thruster 6 — 7 Disabled by Crew
5	Thruster 14 — 16 Disabled by Crew
6	Thruster 13 — 15 Disabled by Crew
7	Thruster 9 — 12 Disabled by Crew
8	Thruster 10 — 11 Disabled by Crew
9	Descent Engine Gimbals Disabled by Crew
10	Apparent Descent Engine Gimbal Fail
11	Spare
12	Spare
13	Spare
14	Proceed
15	Spare

NOTE:

All of the input signals in Channel 32 are inverted; that is, a ZERO bit indicates that the discrete is ON.

INPUT CHANNEL 33

BIT

1	Spare
2	Rendezvous Radar Auto-Power On
3	Rendezvous Radar Range Low Scale
4	Rendezvous Radar Data Good
5	Landing Radar Range Data Good
6	Landing Radar Position 1
7	Landing Radar Position 2
8	Landing Radar Velocity Data Good
9	Landing Radar Range Low Scale
10	Block Uplink Input*
11	Uplink Too Fast
12	Downlink Too Fast
13	PIPA Fail
14	LGC Warning (repeated hardware or software alarms)
15	Oscillator Alarm

*This bit reads ONE when accept uplink signal is present at interface.

NOTE:

All of the input signals in Channel 33 are inverted; that is, a ZERO bit indicates that the discrete is ON.

P00—LGC IDLING PROGRAM

Purpose:

1. To provide a program to fulfill the following requirements:
 - a. Provide an indication to the crew that the LGC is engaged in no control or computational operations which might require consideration for coordination with other crew tasks in progress.
 - b. Maintain the LGC in a condition of readiness for entry into any other program.

Assumptions:

1. The IMU may or may not be on. If on, the IMU is inertially stabilized but not necessarily aligned to an orientation which is known to the LGC.
2. If the IMU is on, the DAP is available for manually controlled attitude maneuvers. If attitude maneuvers are made by the crew, care must be taken to avoid IMU gimbal lock by observing the ICPU's (V16 N20) or by monitoring the FDAI ball.
3. During this program the Coasting Integration routine will periodically update the LM and CSM state vectors to approximately the current time. The capability to select an LGC program (V37 XXE) is inhibited by the LGC during this integration. V37 use at this time will result in a program alarm (1520).
4. This program is automatically selected by V96E, which may be done during any program. State vector integration is permanently inhibited following V96E. Normal integration functions will resume after selection of any program. Use of V96 can cause incorrect W-matrix extrapolation since state vector synchronization is not maintained.
5. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N38 (astronaut selected when desired)

Time of state vector being integrated	00XXX. h
	000XX. min
	0XX.XX s

P06—LGC POWER-DOWN PROGRAM

Purpose:

1. To transfer the LGC from the operate to the standby condition.

Assumptions:

1. The normal condition of readiness of the PGNCs when not in use is standby. In this condition the IMU standby circuit breaker is on, the IMU operate circuit breaker is off, the LGC/DSKY circuit breaker is on, and the standby light on the DSKY is on. In this configuration both the IMU and LGC are off, with power applied only to the IMU heat control circuitry and the LGC timing circuitry.
2. A possible condition of readiness of the PGNCs when not completely on is the same as standby (Assumption 1) except that the standby light on the DSKY is off. In this configuration the LGC is running for computational purposes that do not require the IMU.
3. If the computer power is switched off it will be necessary to perform a Computer FRESH START (V36E) to initialize the erasable storage. The LGC Update program (P27) would have to be done to update the LM and CSM state vectors and computer clock time.
4. The LGC is capable of maintaining an accurate value of ground elapsed time (GET) for only 23 hours when in the Standby mode. If the LGC is not brought out of the standby condition to the running condition at least once within 23 hours the LGC value of GET must be updated.

P06 (continued)

5. Once the program has been selected the LGC must be shut down. After P06 selection the LGC will not honor a new program request (V37EXXE), a terminate (V34E), or an enter in response to the LGC request for LGC standby.
6. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V50 N25 (LGC power down)

Checklist code

00062

P12—POWERED ASCENT PROGRAM

Purpose:

1. To display to the crew, prior to ascent engine ignition, certain LGC-stored parameters associated with the powered ascent, for possible modification by the crew.
2. To display to the crew, prior to ascent engine ignition, certain FDAI ball readings associated with the early phases of the ascent maneuver.
3. To control the PGNCs during countdown, ignition, thrusting, and thrust termination of a PGNCs-controlled APS powered ascent maneuver from the lunar surface.

Assumptions:

1. The LGC has stored injection values which define an ascent trajectory. These values are altitude of injection, the distance at injection between the LM and the CSM orbital plane, and the LM vertical (V(R)) and horizontal (V(Y)) and (V(Z)) velocities at injection. This trajectory is designed to be coplanar with that of the CSM and to result in an apolune of 45 nmi. All altitudes are measured with respect to the magnitude of the landing site position vector which is an LGC initialization parameter.

This predefined ascent trajectory may be partially modified during this program by astronaut input.

2. The PGNCs will control the LM ascent maneuver such that the LM velocity at injection is parallel to the CSM orbital plane, either in that plane, or at a specified distance from that plane as controlled by astronaut definition of crossrange. The astronaut can also change the required injection conditions by modifying the nominal initial downrange and radial velocity display values. Crossrange should not be specified such as to cause the ascent trajectory to cross through the CSM orbital plane.
3. The initial period of the ascent trajectory will consist of two phases:
 - a. Vertical Rise Phase, from TIG until the radial velocity (V(R)) of the LM exceeds 40 ft/s. During this phase the LM will be held by the PGNCs to an attitude such that the LM +X axis is parallel to the LM position vector at TIG. At TIG the PGNCs will command the LM around its X axis (yaw) until the LM +Z axis points downrange.
 - b. Pitchover Phase, when V(R) exceeds 40 ft/s and the LM yaw attitude is within 5 degrees of the desired attitude. During this phase the PGNCs will command the LM to pitch down (about the LM Y axis) an amount defined by the guidance equations.

The LM attitude will subsequently be controlled by the guidance equations.

4. The X-axis override option provides the crew with the ability to exercise manual control about the LM X axis with the attitude controller even though the PGNCs Attitude Control mode is Auto. When the controller is returned to detent, the PGNCs damps the yaw rate, stores the yaw attitude when the yaw rate is damped, and then maintains that attitude.

The X-axis override option is always available to the crew except when the LGC is specifying a desired yaw attitude. Thus the option is inhibited by this program from TIG(AS) until 10 seconds after V(R) equals 40 ft/s and the LM yaw attitude is within 5 degrees of the desired attitude for pitchover initiation.

P12 (contineud)

5. The IMU is on and must be at a known orientation before this program may be completed. Normally, the Lunar Surface Align program (P57) has been completed before selection of this program. It is normally required that the ISS be on for a minimum of 15 minutes prior to a thrusting maneuver.
6. Engine ignition may be slipped beyond TIG(AS) if desired by the crew or if state vector integration cannot be completed in time. Variation of the time of ascent ignition (TIG(AS)) either by design or inadvertent slippage will change the relative phasing with respect to the CSM of the ascent trajectory and the resultant LM orbit.
7. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Auto, the PGNCs will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors for display on the FDI. The crew may exercise control around the yaw axis only with the ACA (X-axis override) if the X-axis override capability is permitted by the program in process. This manual control will be in the Rate Command/Attitude Hold mode.

If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCs will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold mode the PGNCs will not be responsible if register overflows occur within the LGC.

8. Control of the LM RCS and APS is transferred from the PGNCs to the Abort Guidance System (AGS) by placing the Guidance Control switch from PGNS to AGS.

The AGS will be capable of taking over control of the LM during any phase of the lunar ascent, and guiding it to a safe orbit.

The AGS may be initialized by the LGC at any time by manual selection of the AGS Initialization routine (R47), which should have been performed prior to selection of P12.

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors. However, the PGNCs will not be responsible if register overflows occur within the LGC.

9. The PGNCs can generate two types of attitude errors for display on the FDI:

Mode 1 — Selected by Extended Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.

Mode 2 — Selected by Extended Verb 62. Total attitude errors used to assist crew in manually maneuvering the vehicle.

10. The Rendezvous Radar (RR) was energized and checked out prior to selection of this program.
11. The Landing Analog Displays routine (R10) is enabled at TIG. However, R10 use of the RR CDU's is inhibited by this program. The Powered Flight Designate routine (R29) is enabled after pitchover. R10 and R29 are terminated upon termination of Average G.
12. Either the Load DAP Data routine (R03) or the Landing Confirmation program (P68) has been performed prior to selection of this program.
13. For each burn an ignition total allowable time delay will be specified in the mission rules. This delay time is the total time which the thrusting maneuver may be delayed beyond the LGC calculated time of ignition. If engine restarts are involved, the accounting of this total time delay is up to the crew.
14. The DAP will be energized whenever the PGNS Control mode and the Auto Attitude or Attitude Hold Control mode have been selected. If this occurs prior to the PGNS auto check in this program, the attitude errors will be zeroed and the attitude deadband will be set to the value specified by P68 (5 degrees) or R03 (astronaut defined), whichever occurred most recently. Immediately prior to the PGNCs autocheck, this program will set the attitude deadband to 1 degree.
15. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is called at APS ignition by this program.

P12 (continued)

16. This program is selected by the astronaut by DSKY entry at least 5 minutes before the estimated time of ascent ignition TIG(AS).

Selected Displays:

1. V06 N33

Time of ascent ignition	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N76

Desired downrange velocity	XXXX.X ft/s
Desired radial velocity	XXXX.X ft/s
Crossrange distance	XXXX.X nmi
3. V50 N25 (change guidance mode)

Checklist code	00203
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4. V06 N74

Time from ascent ignition	XX b XX min/s
Yaw after vehicle rise	XXX.XX deg
Pitch after vehicle rise	XXX.XX deg
5. V99 N74 (request engine on enable)

Display same as Item 4 above	
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6. V16 N63

Absolute value of velocity	XXXX.X ft/s
Altitude rate	XXXX.X ft/s (+ ascent)
Computed altitude	XXXXX. ft
7. V16 N85

Components of VG (LM body axis)	XXXX.X ft/s
---------------------------------	-------------
8. V16 N77 (astronaut initiated)

Time to engine cutoff	XX b XX min/s
LM velocity normal to CSM plane	XXXX.X ft/s
9. V16 N56 (results from V85E)

RR LOS azimuth	XXX.XX deg
RR LOS elevation	XXX.XX deg

P20—RENDEZVOUS NAVIGATION PROGRAM

Purpose:

1. To control the LM attitude and the Rendezvous Radar (RR) to acquire and track the CSM with the RR while the LM is in flight.
2. To update either the LM or CSM state vector (as specified by the astronaut by DSKY entry) on the basis of RR tracking data or to track the CSM without updating either vehicle state vector.
3. To point the LM optical beacon at the CSM.

Assumptions:

1. The ISS may be in standby or operate. The IMU would normally be on and the IMU Orientation Determination program (P51) completed before the selection of this program. No preferred orientation is specified or required for this program as the Attitude Maneuver routine (R60) can always calculate a vehicle orientation about the LM +Z axis that can avoid gimbal lock for any IMU inertial orientation. The ISS thus may be:
 - a. Off (standby).
 - b. On and not aligned since turn-on.

P20 (continued)

- c. On and at an inertial orientation known only inaccurately by the LGC; that is, having been aligned at least once since turn-on but having drifted from the stored alignment.
 - d. On and at an inertial orientation known accurately by the LGC.
- If a is true a program alarm will be made by this program.
- If b is true a program alarm will be made by this program.
- If c is true the LGC may or may not have a satisfactory inertial reference to accurately complete the program.
- If d is true the LGC has a satisfactory inertial reference to accurately complete the program.
2. The CSM is maintaining a preferred tracking attitude for RR tracking by the LM. This preferred attitude correctly orients the CSM radar transponder.
 3. At the beginning of the program, the state vector update option is automatically set to the LM. This option may be changed at any time later by one of the following manual entries:
 - a. V80E—Update LM state vector,
 - b. V81E—Update CSM state vector,
 - c. V95E—No state vector update.
 4. The Rendezvous Radar is on, and preliminary checkout has been completed.
 5. The initialization of the W matrix is enabled by:
 - a. A manual DSKY entry (V93E),
 - b. Computer Fresh Start (V36E),
 - c. State vector update from the ground (P27) (Except for update of Landing Site vector when the LM is on the lunar surface).
 - d. The powered ascent program (P12) invalidates the W-matrix used by P22 and causes P20 to reinitialize the W-matrix when selected.
 6. The RR tracking mark counter counts the number of RR marks processed by the LGC. This counter is zeroed by:
 - a. Manual selection of P20/22 (V37E20/22E),
 - b. Completion of the Target Delta V program (P76),
 - c. Selection of a new program from a program which had turned on Average G.
 - d. Initialization of the W matrix.
 - e. Completion of RR search routine (R24) in P20.
 7. The crew may manually adjust the LGC-stored values of RR shaft and trunnion bias by a direct load of four registers. However, unless the RR has been jarred, the LGC bias estimate should be more accurate than that from another source.
 8. The selection and termination of P20, P22, and P25 are subject to special operating procedures different from all other programs:
 - a. Selection
 - (1) By selection of P00, V56E, or by V34E.
 - (2) If any other program is running at the time of P20/22/25 selection the new program will replace the old. This includes P20/22/25 selection whenever either P20, 22, or 25 is running.
 - (3) If P20 or P25 is running, selection of any program other than P00 or P22 will result in P20 or P25 continuing and the new program also operating with its number in the DSKY program lights.
 - (4) If P20 or P25 is running, selection of P00 or P22 will result in the termination of the old program and operation of the new.
 - b. Termination
 - (1) By selection of P00, V56E, or by V34E.
 - (2) P00 selection will terminate P20, 22, and 25 and any other program in process, and establish P00.

P20 (continued)

- (3) V56E selection will select the Terminate Tracking routine (R56) which will terminate only P20 or P25 if either of these programs is running in conjunction with another program. In all other cases R56 will select R00. V56E may be performed any time during P20, 22, or 25 operation.
- (4) The LGC will act upon V34E only in response to a flashing verb-noun. If this display was originated by P20, 22, or 25, V34E will result in an identical LGC response to that of V56E; that is, selection of R56. If this display was not originated by P20, 22, or 25 (such as P32, while running with P20), the LGC will go to R00, however, the program in the background will continue. The new program selected follows the selection rules above.
9. The RR Manual Acquisition routine (R23) may only be selected if P20 is not running in conjunction with another program.
10. When P20 is selected anytime prior to the landing phase in the lunar mission, this program must be operated in the No Update mode.
11. The RMS position and velocity errors computed from the W matrix are available by Extended Verb (V67E). Based upon values in this display and the details of the mission, the astronaut can elect to stop or continue the current navigation procedure or to reinitialize the W matrix and continue navigating. The capability to reinitialize the W matrix is also provided via V67E.
12. State vector integration may be permanently inhibited by V96E. This entry will terminate all present programs and select the LGC Idling program (P00) with the P00 automatic state vector integration permanently inhibited until selection of another program. Use of V96 can cause incorrect W-matrix extrapolation since state vector synchronization is not maintained.

Selected Displays:

1. V50 N25 (change RR mode)

Checklist code	00201
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2. V06 N05

Difference angle between RR LOS and state vector	XXX.XX deg
--	------------
3. V06 N49

ΔR due to RR mark data incorporation	XXXX.X nmi
ΔV due to RR mark data incorporation	XXXX.X ft/s
Source code	0000X (1—RR range, 2—RR range rate, 3—RR shaft angle, 4—RR trunnion angle)
4. V50 N25 (manual RR acquisition of CSM)

Checklist code	00205
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5. V16 N80

Data indicator (displays 11111 when search is successful, otherwise blank)	XXXXX
Angle between RR LOS and +Z axis	XXX.XX deg
6. V50 N18

Desired automanuever FDAI ball angles	R	XXX.XX deg	
	P	XXX.XX deg	
	Y	XXX.XX deg	
7. V06 N18

Final FDAI ball angles	R	XXX.XX deg	
	P	XXX.XX deg	
	Y	XXX.XX deg	

LM-45

P20 (continued)

- | | |
|--|---------------|
| 8. V50 N72 | |
| RR Trunnion angle (360 degrees — CDU trunnion angle) | XXX.XX deg |
| RR shaft angle | XXX.XX deg |
| 9. V16 N45 (astronaut initiated) | |
| Marks | XXXXX. marks |
| Time from ignition of next burn | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |
| 10. V06 N38 (astronaut initiated) | |
| Time of state being integrated | 00XXX. h |
| | 000XX. min |
| | 0XX.XX s |
| 11. V06 N99 (results from V67E) | |
| RMS in position | XXXXX. ft |
| RMS in velocity | XXXXX.X ft/s |
| RMS in bias | XXXXX. mrad |

P21—GROUND TRACK DETERMINATION

Purpose:

1. To provide astronaut with details of his ground track.

Assumptions:

1. Program is selected by the astronaut by DSKY entry.
2. Vehicle whose ground track parameters are calculated remains in freefall from start of program until T LAT/LONG.
3. Program may be selected while LM is either in earth or lunar orbit to define ground track of either LM or CSM.

Selected Displays:

- | | |
|----------------------------------|--|
| 1. V04 N06 | |
| Option code ID | 00002 |
| Option code | 0000X (1—this vehicle,
2—other vehicle) |
| 2. V06 N34 | |
| Time of LAT/LONG | 00XXX. h |
| | 000XX. min |
| | 0XX.XX s |
| 3. V06 N43 | |
| Ground track latitude | XXX.XX deg (+ north) |
| Ground track longitude | XXX.XX deg (+ east) |
| Altitude above ground | XXXXX.X nmi |
| 4. V06 N91 (astronaut initiated) | |
| Altitude | XXXXXXb. nmi |
| Velocity | XXXXX. ft/s |
| Flight path angle | XXX.XX deg |

P22—LUNAR SURFACE NAVIGATION PROGRAM

Purpose:

1. To control the Rendezvous Radar (RR) to acquire and track the CSM while the LM is on the lunar surface.

P22 (continued)

2. To update the CSM state vector on the basis of RR tracking data.
3. To track the CSM without updating either vehicle state vector.

Assumptions:

1. The ISS may be in standby or operate. The IMU would normally be on and the Lunar Surface Align program (P57) completed before the selection of this program. The ISS thus may be:
 - a. Off (standby).
 - b. On and not aligned since turn-on.
 - c. On and at an inertial orientation known only inaccurately by the LGC; that is, having been aligned at least once since turn-on but either having been inaccurately aligned or having drifted from the stored alignment.
 - d. On and at an inertial orientation known accurately by the LGC.

If a is true a program alarm will be made by this program.

If b is true a program alarm will be made by this program.

If c is true the LGC may not have a satisfactory inertial reference to accurately complete the program.

If d is true the LGC has a satisfactory inertial reference to accurately complete the program.

2. The CSM may or may not be below the lunar horizon. Although above the horizon, it may still be outside of the available RR coverage sector. Although within the available RR coverage sector, it may be outside the allowable RR coverage sector. This program will always track the CSM with the radar in Mode 2. In Mode 2 the available coverage is always less than horizon to horizon.
3. The CSM is maintaining a preferred tracking attitude for RR tracking by the LM. This preferred attitude correctly orients the CSM radar transponder.
4. At the beginning of the program the state vector update option is automatically set to the CSM. This option may be inhibited at any time and later restored by the following manual entries:
 - a. V81E—Update CSM state vector.
 - b. V95E—No state vector update.
5. The Rendezvous Radar is on; preliminary checkout has been completed.
6. The initialization of the W matrix is enabled by:
 - a. A manual DSKY entry (V98E).
 - b. Computer FRESH START (V36E).
 - c. State vector update from the ground (P27).
7. The RR tracking mark counter counts the number of RR marks processed by the LGC. This counter is zeroed:
 - a. By manual selection of P20/P22 (V37E20/22E)
 - b. Completion of the Target Delta V program (P76).
 - c. Selection of a new program from a program which had turned on Average G.
 - d. Initialization of the W matrix (Assumption 6).
8. The RMS position and velocity errors computed from the W matrix are available by Extended Verb (V67E). Based upon values in this display and the details of the mission, the astronaut can elect to stop or continue the current navigation procedure or to reinitialize the W matrix and continue navigating. The capability to reinitialize the W matrix is also provided via V67E.
9. The selection and termination of P20, P22, and P25 are subject to special operating procedures different from all other programs:
 - a. Selection
 - (1) Always by V37E XXE.

P22 (continued)

- (2) If any other program is running at the time of P20/22/25 selection the new program will replace the old. This includes P20/22/25 selection whenever either P20, 22, or 25 is running.
- (3) If P20 or P25 is running, selection of any program other than P00 or P22 will result in P20 or P25 continuing and the new program also operating with its number in the DSKY program lights.
- (4) If P20 or P25 is running, selection of P00 or P22 will result in the termination of the old program and operation of the new.

b. Termination

- (1) By selection of P00, V56E, or by V34E.
 - (2) P00 selection will terminate P20, P22, and P25 and any other program in process and establish P00.
 - (3) V56E selection will select the Terminate Tracking routine (R56) which will terminate only P20 or P25 if either of these programs is running in conjunction with another program. In all other cases R56 will select R00. V56E may be performed any time during P20, 22, or 25 operation.
 - (4) The LGC will act upon V34E only in response to a flashing verb-noun. If this display was originated by P20, 22, or 25, V34E will result in an identical LGC response to that of V56E; that is, selection of R56.
If this display was not originated by P20, 22, or 25 (such as P32, while running with P20) the LGC will go to R00; however, the program in the background will continue. The new program selected follows the selection rules shown above.
10. State vector integration may be permanently inhibited by V96E. This entry will terminate all present programs and select the LGC Idling program (P00) with the P00 automatic state vector integration permanently inhibited until selection of another program. Use of V96 can cause incorrect W-matrix extrapolation since state vector synchronization is not maintained.

Selected Displays:

1. V04 N06

Option code ID
Option code

00012

0000X (1—no orbit change,
2—change orbit to pass over LM)

2. V06 N33

Time of ascent ignition

00XXX. h

000XX. min

0XX.XX s

3. V50 N25 (change RR mode)

Checklist code

00201

4. V06 N05

Difference angle between RR LOS and state vector

XXX.XX deg

5. V06 N49

 ΔR due to RR mark data incorporation

XXXX.X nmi

 ΔV due to RR mark data incorporation

XXXX.X ft/s

6. V16 N80

Data indicator (displays 11111 when search is successful otherwise blank)

XXXXXX

Angle between RR LOS and +Z axis

XXX.XX deg

7. V50 N25 (manual RR acquisition of CSM)

Checklist code

00205

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P22 (continued)

- | | |
|---------------------------------------|---------------|
| 8. V16 N56 (results from V85E) | |
| RR LOS azimuth | XXX.XX deg |
| RR LOS elevation | XXX.XX deg |
| 9. V06 N38 (astronaut initiated) | |
| Time of state vector being integrated | 00XXX. h |
| | 000XX. min |
| | 0XX.XX s |
| 10. V16 N45 (astronaut initiated) | |
| Marks | XXXXX. marks |
| Time from ignition of next burn | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |
| 11. V06 N99 (results from V67E) | |
| RMS in position | XXXXX. ft |
| RMS in velocity | XXXXX. ft/s |
| RMS in bias | XXXXX. mrad |

P25—PREFERRED TRACKING ATTITUDE PROGRAM

Purpose:

1. To compute the preferred tracking attitude of the LM which enables CSM tracking of the beacon.
2. To perform the maneuver to the preferred tracking attitude.

Assumptions:

1. During the Rendezvous Navigation program (P20) the LM attitude control is intimately associated with the Rendezvous Radar (RR). Should RR malfunction preclude correct operation of P20, this program (P25) should be selected to provide a LM preferred tracking attitude.
2. The preferred tracking attitude is defined as follows:
 - a. The LM +Z axis is aligned along the LOS to the CSM.
 - b. The roll attitude (about LM +Z axis) is unconstrained and is defined as necessary to avoid gimbal lock.
3. The ISS may be in standby or operate. The IMU would normally be on and the IMU Orientation Determination program (P51) completed before the selection of this program. No preferred orientation is specified or required for this program as the Fine Preferred Tracking Attitude routine (R65) can always calculate a vehicle orientation about a specified LM +Z vector that can avoid gimbal lock for any inertial IMU orientation. The ISS thus may be:
 - a. Off (standby).
 - b. On and not aligned since turn-on.
 - c. On and at an inertial orientation known only inaccurately by the LGC; that is, having been aligned at least once since turn-on but not within the last 3 hours.
 - d. On and at an inertial orientation known accurately by the LGC; that is, having been aligned within the last 3 hours.

If a is true a program alarm will be made by this program.

If b is true a program alarm will be made by this program.

If c is true the LGC may or may not have a satisfactory inertial reference to accurately complete the program.

If d is true the LGC has a satisfactory inertial reference to accurately complete the program.

4. The LM tracking beacon field of view is a 30-degree half-angle cone with the cone axis parallel to the LM +Z axis.
5. The selection and termination of P20, P22, and P25 are subject to special operating procedures different from all other programs.
 - a. Selection

(1) Always by V37EXXE.

P25 (continued)

- (2) If any other program is running at the time of P20/22/25 selection the new program will replace the old. This includes P20/22/25 selection whenever either P20, 22, or 25 is running.
- (3) If P20 or P25 is running, selection of any program other than P00 or P22 will result in P20 or P25 continuing and the new program also operating with its number in the DSKY program lights.
- (4) If P20 or P25 is running, selection of P00 or P22 will result in the termination of the old program and operation of the new.

b. Termination

- (1) By selection of P00, V56E, or by V34E.
- (2) P00 selection will terminate P20, 22, and 25 and any other program in process and establish P00.
- (3) V56E selection will select the Terminate Tracking routine (R56) which will terminate only P20 or P25 if either of these programs is running in conjunction with another program. In all other cases R56 will select P00. V56E may be performed any time during P20, 22, or 25 operation.
- (4) The LGC will act upon V34E only in response to a flashing verb-noun. If this display was originated by P20, 22, or 25, V34E will result in an identical LGC response to that of V56E; that is, selection of R56. If this display was not originated by P20, 22, or 25 (such as P32, while running with P20) the LGC will go to R00. However, the program in the background will continue. The new program selected follows the selection rules above.

Selected Displays:

1. V50 N18

Desired automaneuver FDAI ball angles	R XXX.XX deg
	P XXX.XX deg
	Y XXX.XX deg

2. V06 N18

Final FDAI ball angles	R XXX.XX deg
	P XXX.XX deg
	Y XXX.XX deg

P27—LGC UPDATE

Purpose:

1. To enter data into the LGC via the digital uplink or by crew input via the DSKY.

Assumptions:

1. LGC must be in operate condition; IMU may be in the standby or operate condition.
2. LGC updates are of four categories:
 - a. Provide a decrement for the LGC clock and the orbital integration state vector time tags, and an increment for TEPHEM (V70).
 - b. Provide load capability for a block of sequential erasable locations (1 through 18 whose addresses are specified) (V71).
 - c. Provide load capability for individually specified erasable locations (1 through 9) (V72).
 - d. Provide an octal increment for the LGC clock only (V73).
3. The uplink may be blocked by placing the Voice/Off/Voice BU switch to Voice BU.
4. Update is allowed in the LM only when the LGC is in the LGC Idling program (P00). P27 exit is always to P00.
5. The program is manually selected by the astronaut by DSKY entry or by the ground by uplink transmission.

P30-EXTERNAL DELTA V PROGRAM

Purpose:

1. To accept targeting parameters obtained from a source(s) external to the LGC and compute therefrom the required velocity and other initial conditions required by the LGC for execution of the desired maneuver. The targeting parameters inserted into the LGC are the time of ignition (TIG) and the impulsive Delta V along LM local vertical axes at TIG.
2. To display to the astronaut and the ground certain specific dependent variables associated with the desired maneuver for approval by the astronaut/ground.

Assumptions:

1. The target parameters (TIG and Delta V(LV)) may have been loaded from the ground during a prior execution of P27.
2. The External Delta V flag is set during this program to designate to the thrusting program that External Delta V steering is to be used.
3. The ISS need not be on to complete this program unless the Rendezvous Radar is to be used for automatic state vector updating by the Rendezvous Navigation program (P20).
4. The Rendezvous Radar may or may not be used to update the LM or CSM state vectors for this program. If radar use is desired, the ISS should be in operation and the radar should have been turned on and locked on the CSM by previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled by the Track and Update flags.
5. This program is applicable in either earth or lunar orbit.
6. This program is selected by the astronaut by DSKY entry.

Selected Displays:

- | | |
|-------------------------------|------------------------------------|
| 1. V06 N33 | |
| Time of ignition | 00XXX. h
000XX. min
0XX.XX s |
| 2. V06 N81 | |
| Components of ΔV (LV) | XXXX.X ft/s |
| 3. V06 N42 | |
| Apocenter altitude | XXXX.X nmi |
| Pericenter altitude | XXXX.X nmi |
| ΔV (required) | XXXX.X ft/s |
| 4. V16 N45 | |
| Marks | XXXXX. marks |
| Time until next burn | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |

P32-LM COELLIPTIC SEQUENCE INITIATION (CSI) PROGRAM

Purpose:

1. To calculate parameters associated with the following concentric flight plan maneuvers: the Coelliptic Sequence Initiation (CSI) and the Constant Delta Altitude maneuver (CDH), for Delta V burns.
2. To calculate these parameters based upon maneuver data approved and keyed into the LGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.
4. To store the CSI target parameters for use by the desired thrusting program.

Assumptions:

1. At a selected TPI time the line of sight between the LM and the CSM is selected to be a prescribed angle (E) from the horizontal plane defined at the active position.
2. The time between CSI ignition and CDH ignition must be computed to be greater than 10 minutes for successful completion of the program.
3. The time between CDH ignition and TPI ignition must be computed to be greater than 10 minutes for successful completion of the program.
4. CDH Delta V is selected to minimize the variation of the altitude difference between the orbits.
5. CSI burn is defined such that the impulsive Delta V is in the LM horizontal plane at CSI ignition.
6. The pericenter altitude of the orbit following CSI and CDH must be greater than 35,000 ft (lunar orbit) or 85 nmi (earth orbit) for successful completion of this program.
7. The CSI and CDH maneuvers are originally assumed to be parallel to the plane of the CSM orbit. However crew modification of Delta V (LV) components may result in an out-of-plane CSI maneuver.
8. The Rendezvous Radar may or may not be used to update the LM or CSM state vectors for this program. If radar use is desired the radar was turned on and locked on the CSM by previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
9. The ISS need not be on to complete this program unless the Rendezvous Radar is to be used for automatic state vector updating by the Rendezvous Navigation program (P20). P20 will define the status of the ISS.
10. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N11

Time of CSI ignition	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N55

Number of apsidal crossings	0000X. crossings
Elevation angle	XXX.XX deg
Central angle of passive vehicle	XXX.XX deg
3. V06 N37

Time of TPI ignition	00XXX. h
	000XX. min
	0XX.XX s
4. V06 N75

Delta altitude (CDH)	XXXX.X nmi
ΔT (CSI-CDH)	XX b XX min/s
ΔT (CDH-TPI)	XX b XX min/s
5. V06 N81

Components of ΔV (LV) for CSI	XXXX.X ft/s
---------------------------------------	-------------
6. V06 N82

Components of ΔV (LV) for CDH	XXXX.X ft/s
---------------------------------------	-------------
7. V16 N45

Marks	XXXXX. marks
Time from CSI ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg

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P32 (continued)

8. V06 N16 (results from V90E)

Time of event	00XXX. h
	000XX. min
	0XX.XX s

9. V06 N90 (results from V90E)

Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

P33—LM CONSTANT DELTA ALTITUDE (CDH) PROGRAM

Purpose:

1. To calculate parameters associated with the Constant Delta Altitude maneuver (CDH), for Delta V burns.
2. To calculate these parameters based upon maneuver data approved and keyed into the LGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the CDH maneuver for approval by the astronaut/ground.
4. To store the CDH target parameters for use by the desired thrusting program.

Assumptions:

1. This program is based upon previous completion of the Coelliptic Sequence Initiation (CSI) program (P32). Therefore:
 - a. At a selected TPI time (now in storage) the line of sight between the LM and the CSM was selected to be a prescribed angle (E) (now in storage) from the horizontal plane defined at the active position.
 - b. The time between CSI ignition and CDH ignition was computed to be greater than 10 minutes.
 - c. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - d. The variation of the altitude difference between the orbits was minimized.
 - e. CSI burn was defined such that the impulsive Delta V was in the LM horizontal plane at CSI ignition.
 - f. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 ft (lunar orbit) or 85 nmi for earth orbit.
 - g. The CSI and CDH maneuvers were assumed to be parallel to the plane of the CSM orbit. However, crew modification of Delta V (LV) components may have resulted in an out-of-plane CSI maneuver.
2. The Rendezvous Radar may or may not be used to update the LM or CSM state vectors for this program. If radar use was desired the radar was turned on and locked on the CSM by previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
3. This ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20). If selected, P20 will define the status of the ISS.
4. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N13

Time of CDH ignition	00XXX. h
	000XX. min
	0XX.XX s

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P33 (continued)

- | | |
|---------------------------------------|---------------|
| 2. V06 N75 | |
| Delta altitude (CDH) | XXXX.X nmi |
| ΔT (CDH-TPI) | XX b XX min/s |
| ΔT (TPI-NOMTPI) | XX b XX min/s |
| 3. V06 N81 | |
| Components of ΔV (LV) for CDH | XXXX.X ft/s |
| 4. V16 N45 | |
| Marks | XXXXX. |
| Time from CDH ignition | XX b XX min/s |
| Middle gimbal angle | XXX.XX deg |
| 5. V06 N16 (results from V90E) | |
| Time of Event | 00XXX. h |
| | 000XX. min |
| | 0XX.XX s |
| 6. V06 N90 (results from V90E) | |
| Y | XXX.XX nmi |
| YDOT | XXXX.X ft/s |
| PSI | XXX.XX deg |

P34—LM TRANSFER PHASE INITIATION (TPI) PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the transfer phase initiation (TPI) maneuver. Given:
 - a. Time of ignition (TIG(TPI)) or the elevation angle (E) of the LM/CSM LOS at TIG(TPI).
 - b. Central angle of transfer (CENTANG) from TIG(TPI) to intercept time (TIG(TPF)).
2. To calculate TIG(TPI) given E or E given TIG(TPI)
3. To calculate these parameters based upon maneuver data approved and keyed into the LGC by the astronaut.
4. To display to the astronaut and the ground certain dependent variables associated with the maneuver for approval by the astronaut/ground.
5. To store the TPI target parameters for use by the desired thrusting program.

Assumptions:

1. This program is based upon previous completion of the Constant Delta Altitude (CDH) program (P33). Therefore:
 - a. At a selected TPI time (now in storage) the line of sight between the LM and the CSM was selected to be a prescribed angle (E) (now in storage) from the horizontal plane defined at the LM position.
 - b. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - c. The variation of the altitude difference between the orbits was minimized.
 - d. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 ft (lunar orbit) or 85 nmi (earth orbit).
 - e. The CSI and CDH maneuvers were assumed to be parallel to the plane of the CSM orbit. However, crew modification of Delta V (LV) components may have resulted in an out-of-plane CDH maneuver.

P34 (continued)

2. The Rendezvous Radar may or may not be used to update the LM or CSM state vectors for this program. If radar use is desired the radar was turned on and locked on the CSM by previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
3. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20). If selected, P20 will define the status of the ISS.
4. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

5. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N37
Time of TPI ignition
00XXX. h
000XX. min
0XX.XX s
2. V06 N55
Integration constant N
0000X (00000—Kepler conic integration with no target offset, 00001—Precision integration with one target offset, 00002—Precision integration with two target offsets.)
Elevation angle
XXX.XX deg
Central angle of passive vehicle
XXX.XX deg
3. V06 N58
Pericenter altitude
XXXX.X nmi
 ΔV (TPI)
XXXX.X ft/s
 ΔV (TPF)
XXXX.X ft/s
4. V06 N81
Components of ΔV (LV) for TPI
XXXX.X ft/s
5. V06 N59
Components of ΔV (LOS)
XXXX.X ft/s
6. V16 N45
Marks (RR)
XXXXX. marks
Time from TPI ignition
XX b XX min/s
Middle gimbal angle
XXX.XX deg
7. V06 N52 (astronaut initiated)
Central angle of active vehicle
XXX.XX deg
8. V06 N16 (results from V90E)
Time of event
00XXX. h
000XX. min
0XX.XX s

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P34 (continued)

9. V06 N90 (results from V90E)

Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

P35—LM TRANSFER PHASE MIDCOURSE (TPM) PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the next midcourse correction of the transfer phase of an active LM rendezvous.

Assumptions:

1. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20). If selected, P20 will define the status of the ISS.
2. The Rendezvous Radar is on and is locked on the CSM. This was done during previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
3. The time of intercept (T(INT)) was defined by previous completion of the Transfer Phase Initiation (TPI) program (P34) and is presently available in LGC storage.
4. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

5. The program is selected by the astronaut by DSKY entry prior to any anticipated rendezvous midcourse correction.

Selected Displays:

1. V06 N81
Components of ΔV (LV) XXXX.X ft/s
2. V06 N59
Components of ΔV (LOS) XXXX.X ft/s
3. V16 N45
Marks XXXXX. marks
Time from TPM ignition XX b XX min/s
Middle gimbal angle XXX.XX deg
4. V06 N52 (astronaut initiated)
Central angle of active vehicle XXX.XX deg
5. V06 N16 (results from V90E)
Time of event 00XXX. h
000XX. min
0XX.XX s
6. V06 N90 (results from V90E)
Y XXX.XX nmi
YDOT XXXX.X ft/s
PSI XXX.XX deg

P40-DPS PROGRAM

Purpose:

1. To compute a preferred IMU orientation and a vehicle attitude for an LM DPS thrusting maneuver.
2. To maneuver the vehicle to the thrusting attitude.
3. To control the PGNCs during countdown, ignition, thrusting, and thrust termination of a PGNCs controlled DPS maneuver.

Assumptions:

1. The target parameters have been calculated and stored in the LGC by prior execution of a prethrusting program.
2. The required steering equations are identified by the prior prethrust program, which either reset ("ASTEER") or set (External Delta V) the External Delta V flag. For External Delta V steering, VG is calculated once for the specified time of ignition. Thereafter both during DPS thrusting and until the crew notifies the LGC that RCS trim thrusting has been completed, the LGC updates VG only as a result of accelerometer inputs.

For steering control when using "ASTEER", the velocity required is calculated from the most recent intercept trajectory semimajor axis. The Lambert routine periodically recomputes the intercept trajectory semimajor axis for the "ASTEER" calculations. The interval between Lambert solutions is controlled by an erasable load value (UT).

3. The IMU is on and must be at a known orientation before this program may be completed. It is normally required that the ISS be on for a minimum of 15 minutes prior to a thrusting maneuver.
4. The event timer is set to count to zero at TIG.
5. Engine ignition may be slipped beyond the established TIG if desired by the crew, or if state vector integration cannot be completed in time.
6. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Auto, the PGNCs will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control around the yaw axis only with the ACA (X-axis override), if the X-axis override capability is permitted by the program in process. This manual control will be in the Rate Command/Attitude Hold mode.

If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold the PGNCs will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold mode the PGNCs will not be responsible if register overflows occur within the LGC. In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors; however, the PGNCs will not be responsible if register overflows occur within the LGC.

7. The PGNCs can generate two types of attitude errors for display on the FDAI:
 - a. Mode 1—Selected by Extended Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
 - b. Mode 2—Selected by Extended Verb 62. Total attitude errors used to assist crew in manually maneuvering the vehicle.

P40 (continued)

8. The X-axis override option provides the crew with the ability to exercise manual control about the LM X axis with the attitude controller even though the PGNCS Attitude Control mode is Auto. When the controller is returned to detent the PGNCS damps the yaw rate, stores the yaw attitude when the yaw rate is damped, and then maintains that attitude.

The X-axis override option is always available to the crew. However, it should not be exercised when the LGC is specifying a desired yaw attitude; that is, during the attitude maneuver to the thrusting attitude.

9. When the thrust/translation controller is set to minimum thrust position and the LGC throttle command is zero, the DPS will start at 10 percent thrust.
10. The Load DAP Data routine (R03) has been performed prior to selection of this program and the DPS engine gimbal has been previously driven to the correct trim position. If this burn is of sufficient duration that vehicle transients at ignition due to CG/thrust do not affect accomplishment of maneuver aim conditions, then the gimbal need not be driven to the trim position before TIG. Driving the gimbal to the trim position in worst case conditions could required 2 minutes.
11. During DPS burns only, the pitch-roll RCS jet autopilot (U and V jets) may be disabled by (V65) or enabled by (V75). This capability is intended to be used to prevent LM and descent stage thermal constraint violations during CSM-docked DPS burns (P40). The capability exists during P63 and P70 also. Performance of FRESH START (V36E) will always enable the capability in the autopilot.
12. For each burn an ignition total allowable time delay will be specified in the mission rules. This delay time is the total time which the thrusting maneuver may be delayed beyond the LGC calculated time of ignition. If engine restarts are involved, the accounting of this total time delay is up to the crew.
13. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is called at DPS ignition by this program.
14. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
15. This program should be selected by the astronaut by DSKY entry at least 5 minutes before the estimated time of ignition.
16. This program is selected manually by DSKY entry.
17. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
18. The value of Delta V required will be stored in the local vertical coordinate system and is available during this program by keying V06 N81E.

Selected Displays:

- | | | | |
|---|---|------------|-------|
| 1. V50 N25 (change guidance control mode) | | | |
| Checklist code | | | 00203 |
| 2. V50 N18 | | | |
| Desired automaneuver FDAI ball angles | R | XXX.XX deg | |
| | P | XXX.XX deg | |
| | Y | XXX.XX deg | |
| 3. V06 N18 | | | |
| Final FDAI ball angles | R | XXX.XX deg | |
| | P | XXX.XX deg | |
| | Y | XXX.XX deg | |

P41 (continued)

7. V16 N44 (results from V82E)

Apocenter altitude	XXXX.X nmi
Pericenter altitude	XXXX.X nmi
TFF	XX b XX min/s

P42—APS PROGRAM

Purpose:

1. To compute a preferred IMU orientation and a vehicle attitude for an LM APS thrusting maneuver.
2. To maneuver the vehicle to the thrusting attitude.
3. To control the PGNCs during countdown, ignition, thrusting, and thrust termination of a PGNCs-controlled APS maneuver.

Assumptions:

1. The target parameters have been calculated and stored in the LGC by prior execution of a prethrusting program.
2. The required steering equations are identified by the prior prethrust program, which either reset ("ASTEER") or set (External Delta V) the External Delta V flag. For external Delta V steering, VG is calculated once for the specified time of ignition. Thereafter both during APS thrusting and until the crew notifies the LGC that RCS trim thrusting has been completed, the LGC updates VG only as a result of accelerometer inputs.

For steering control when using "ASTEER", the velocity required is calculated from the most recent intercept trajectory semimajor axis. The Lambert routine periodically recomputes the intercept trajectory semimajor axis for the "ASTEER" calculations. The interval between Lambert solutions is controlled by an erasable load value (UT).

3. The IMU is on and must be at a known orientation before this program may be completed. It is normally required that the ISS be on for a minimum of 15 minutes prior to a thrusting maneuver.
4. The event timer is set to count to zero at TIG.
5. Engine ignition may be slipped beyond the established TIG if desired by the crew or if state vector integration cannot be completed in time.
6. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Auto, the PGNCs will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control around the yaw axis only with the ACA (X-axis override) if the X-axis override capability is permitted by the program in process. This manual control will be in the Rate Command/Attitude Hold mode.

If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold the PGNCs will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display in the FDAI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNCs/Attitude Hold mode the PGNCs will not be responsible if register overflows occur within the LGC.

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors; however, the PGNCs will not be responsible if register overflows occur within the LGC.

7. The PGNCs can generate two types of attitude errors for display on the FDAI:
 - a. Mode 1—Selected by Extended Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
 - b. Mode 2—Selected by Extended Verb 62. Total attitude errors used to assist crew in manually maneuvering the vehicle.

P42 (continued)

8. The X-axis override option provides the crew with the ability to exercise manual control about the LM X axis with the attitude controller even though the PGNCS Attitude Control mode is Auto. When the controller is returned to detent the PGNCS damps the yaw rate, stores the yaw attitude when the yaw rate is damped, and then maintains that attitude.

The X-axis override option is always available to the crew. However, it should not be exercised when the LGC is specifying a desired yaw attitude; that is, during the attitude maneuver to the thrusting attitude.

9. For each burn an ignition total allowable time delay will be specified in the mission rules. This delay time is the total time which the thrusting maneuver may be delayed beyond the LGC calculated time of ignition. If engine restarts are involved, the accounting of this total time delay is up to the crew.
10. The Load DAP Data routine (R03) may have been performed prior to selection of this program.
11. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is called at APS ignition by this program.
12. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
13. This program should be selected by the astronaut by DSKY entry at least 5 minutes before the estimated time of ignition.
14. This program is selected manually by DSKY entry.
15. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
16. The value of Delta V required will be stored in the local vertical system and is available in this program until Average G turns on by keying V06 N38E.

Selected Displays:

- | | | |
|--|---|---------------|
| 1. V50 N25 (change guidance control mode) | | |
| Checklist code | | 00203 |
| 2. V50 N18 | | |
| Desired automaneuver FDAI ball angles | R | XXX.XX deg |
| | P | XXX.XX deg |
| | Y | XXX.XX deg |
| 3. V06 N18 | | |
| Final FDAI ball angles | R | XXX.XX deg |
| | P | XXX.XX deg |
| | Y | XXX.XX deg |
| 4. V06 N40 | | |
| Time from APS ignition/cutoff | | XX b XX min/s |
| Magnitude of velocity to be gained | | XXXX.X ft/s |
| ΔV (accumulated) | | XXXX.X ft/s |
| 5. V99 N40 (request engine on enable) | | |
| Display same as Item 4 above | | |
| 6. V16 N85 | | |
| Components of VG (LM body axes) | | XXXX.X ft/s |
| 7. V06 N81 (astronaut initiated) | | |
| Components of VG (LV) for thrusting maneuver | | XXXX.X ft/s |

LM-62

P42 (continued)

- | | |
|---------------------------------------|--|
| 8. V06 N38 (astronaut initiated) | |
| Time of state vector being integrated | 00XXX.h
000XX. min
0XX.XX s |
| 9. V04 N12 (results from V82E) | |
| Option code ID | 00002 |
| Option code | 0000X (1—this vehicle,
2—other vehicle) |
| 10. V16 N44 (results from V82E) | |
| Apocenter altitude | XXXX.X nmi |
| Pericenter altitude | XXXX.X nmi |
| TFF | XX b XX min/s |

P47-THRUST MONITOR PROGRAM

Purpose:

1. To monitor vehicle acceleration during a non PGNCS controlled thrusting maneuver.
2. To display Delta V applied to the vehicle by this thrusting maneuver.

Assumptions:

1. The IMU would normally be on and the IMU Orientation Determination program (P51) completed before selection of this program.
2. The responsibility of avoiding gimbal lock during execution of this program is upon the astronaut.
3. This program is normally used during the final phase of the rendezvous. If the crew desires to do any final phase thrusting maneuvers automatically under PGNC control they must be accomplished via selection of the Transfer Phase Initiation (TPI) program (P34) and then the DPS Thrusting program (P40).
4. Range, range rate, and theta may be displayed during this program by calling the Rendezvous Parameter Display routine (R31).
5. This program should be turned on just prior to the planned thrusting maneuver and terminated as soon as possible after the maneuver in order to keep errors associated with Average G integration at a minimum.
6. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.

Selected Displays:

- | | |
|---|--|
| 1. V16 N83 | |
| Components of ΔV (LM body axes) | XXXX.X ft/s |
| 2. V16 N54 (results from V83E) | |
| Range | XXX.XX nmi |
| Range rate | XXXX.X ft/s |
| Angle between LM +Z axis and local horizontal | XXX.XX deg |
| 3. V04 N12 (results from V82E) | |
| Option code ID | 00002 |
| Option code | 0000X (1—this vehicle,
2—other vehicle) |
| 4. V16 N44 (results from V82E) | |
| Apocenter attitude | XXXX.X nmi |
| Pericenter attitude | XXXX.X nmi |
| TFF | XX b XX min/s |

P51—IMU ORIENTATION DETERMINATION PROGRAM

Purpose:

1. To determine the inertial orientation of the IMU using sightings on two celestial bodies with the AOT or a backup optical system.

Assumptions:

1. This program may only be performed while the LM is in flight.
2. The ISS may be:
 - a. Off (standby).
 - b. On and aligned or not aligned since turn-on.

If (a) is true, the IMU must be turned on before this program can be performed.

If (b) is true, this program can be completed.
3. There are no restraints upon the LM attitude control modes until a PGNCIS controlled maneuver is called by a program or the crew wishes to manually maneuver the vehicle.
4. Time and RCS fuel may be saved, and subsequent IMU alignment decisions greatly simplified, if this program is performed in such a way as to leave the IMU inertially stabilized at an orientation as close as possible to the optimum orientation sequence followed by future LGC programs.
5. Extended Verbs should not be exercised during this program because of possible interference with R53.
6. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V50 N25 (star acquisition)

Checklist code	00015
----------------	-------
2. V41 N22

CDU gimbal angles	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
3. V01 N71 (after mark)

R1: ABCDE
 AB—Blank
 C—AOT Detent
 0—COAS calibration (not allowed), 1—Front left,
 2—Front center, 3—Front right, 4—Right rear,
 5—Rear center, 6—Rear left, 7—Backup optical system
 DE—Celestial body code
 00—Planet, 01/45—Star from star code list
 46—Sun, 47—Earth, 50—Moon
4. V06 N87

Backup optics LOS azimuth	XXX.XX deg
Backup optics LOS elevation	XXX.XX deg
5. V54 N71 (mark X or Y reticle)
 Display same as Item 3 above
6. V52 N71 (mark X reticle)
 Display same as Item 3 above
7. V53 N71 (Mark Y reticle)
 Display same as Item 3 above

LM-64

P51 (continued)

- | | |
|--|------------|
| 8. V06 N05 | |
| Star angle difference | XXX.XX deg |
| 9. V06 N88 | |
| Components of celestial body 1/2 unit vector | .XXXXX |

P52—IMU REALIGN PROGRAM

Purpose:

1. To align the IMU from a "known" orientation to one of four orientations selected by the astronaut using sightings on two celestial bodies with the AOT or a backup optical system.
 - a. Preferred Orientation (Option 0001). An optimum orientation for a previously calculated maneuver. This orientation must be calculated and stored by a previously selected program.

- b. Landing Site Orientation (Option 0004)

$$X_{SM} = \text{Unit}(R_{LS})$$

$$Y_{SM} = \text{Unit}(Z_{SM} \times X_{SM})$$

$$Z_{SM} = \text{Unit}(H_{CSM} \times X_{SM})$$

where:

The origin is the center of the moon.

R_{LS} = The position vector of the LM on the lunar surface at a landing site and a time $T(\text{align})$ selected by the crew.

H_{CSM} = The angular momentum vector of the CSM ($R_{CSM} \times V_{CSM}$).

A special case of the landing site orientation occurs when $T(\text{align})$ is defined as the time of lunar landing $T(\text{land})$. This case occurs only if $T(\text{land})$ has been defined by the MSFN, transmitted to the crew, and the crew has then defined $T(\text{align})$ to be $T(\text{land})$ in this program.

- c. Nominal Orientation (Option 00002)

$$X_{SM} = \text{Unit}(R)$$

$$Y_{SM} = \text{Unit}(V \times R)$$

$$Z_{SM} = \text{Unit}(X_{SM} \times Y_{SM})$$

where:

R = The geocentric (earth orbit) or selenocentric (lunar orbit) radius vector at time $T(\text{align})$ selected by the astronaut.

V = The inertial velocity vector at time $T(\text{align})$ selected by the astronaut.

- d. REFSMMAT (Option 00003)

Assumptions:

1. This program may only be performed while the LM is in flight.
2. The configuration may be docked (LM/CSM) or undocked (LM alone). The present configuration should have been entered into the LGC by completion of the DAP Data Load routine (R03).
3. There are no restraints upon the LM attitude control modes until a PGNCs controlled maneuver is called by a program or the crew wishes to manually maneuver the vehicle. The Guidance Control switch may be at PGNS or AGS and, if at PGNS, the mode may be Auto or Attitude Hold. Prior to PGNCs controlled maneuvers the LGC will request the correct mode if it is not in effect. For manually controlled maneuvers the crew must select the correct modes.

P52 (continued)

4. This program makes no provision for an attitude maneuver to return the vehicle to a specific attitude. Such a maneuver, if desired, must be done manually. An option is provided however to allow pointing of the AOT at astronaut or LGC selected stars either manually by the crew or automatically by an LGC controlled attitude maneuver.
5. The ISS is on and has been aligned to a "known" orientation which is stored in the LGC (REFSMMAT). The present IMU orientation differs from that to which it was last aligned only due to gyro drift; that is, neither gimbal lock nor IMU power interruption has occurred since the last alignment).
6. An option is provided to realign the IMU to the preferred, nominal, or landing site orientations without making celestial body sightings.
7. Extended Verbs should not be exercised during this program because of possible interference with R53.
8. The program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V04 N06

Option code ID	00001
Option code	0000X (1—preferred, 2—nominal, 3—REFSMMAT, 4—landing site)
2. V06 N34

Time of alignment	00XXX. h
	000XX. min
	0XX.XX s
3. V06 N89

Designated landing site latitude	XX.XXX (+ north)
Designated landing site longitude/2	XX.XXX (+ east)
Designated landing site altitude	XXX.XX nmi
4. V06 N22

IMU gimbal angles at desired orientation	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
5. V50 N25 (coarse align)

Checklist code	00013
----------------	-------
6. V16 N20

IMU gimbal angles	OG XXX.XX deg
	IG XXX.XX deg
	MG XXX.XX deg
7. V50 N25 (fine alignment)

Checklist code	00014
----------------	-------
8. V50 N25 (star acquisition)

Checklist code	00015
----------------	-------

P52 (continued)

9. V01 N70 (before mark)
 R1: ABCDE
 AB—Blank
 C—AOT Detent
 0—COAS calibration, 1—Front left, 2—Front center,
 3—Front right, 4—Right rear, 5—Rear center,
 6—Left rear, 7—Backup optical system
 DE—Celestial body code
 00—Planet, 01/45—Star from star code list
 46—Sun, 47—Earth, 50—Moon
10. V06 N87
 Backup optics LOS azimuth XXX.XX deg
 Backup optics LOS elevation XXX.XX deg
11. V01 N71 (after mark)
 Display same as Item 9 above
12. V54 N71 (Mark X or Y-reticle)
 Display same as Item 9 above
13. V52 N71 (Mark X-reticle)
 Display same as Item 9 above
14. V53 N71 (Mark Y-reticle)
 Display same as Item 9 above
15. V06 N05
 Sighting angle difference XXX.XX deg
16. V06 N93
 Gyro torque angles
 X XX.XXX deg
 Y XX.XXX deg
 Z XX.XXX deg
17. V06 N88
 Components of celestial body ½ unit vector .XXXXX
18. V50 N18
 Desired automaneuver FDAI ball angles
 R XXX.XX deg
 P XXX.XX deg
 Y XXX.XX deg
19. V06 N18
 Final FDAI ball angles
 R XXX.XX deg
 P XXX.XX deg
 Y XXX.XX deg

P57—LUNAR SURFACE ALIGN PROGRAM

Purpose:

1. While on the surface of the moon to align or realign the IMU to one of three types of orientations:
 - a. Landing Site Orientation

$$X_{SM} = \text{Unit}(R_{LS})$$

$$Y_{SM} = \text{Unit}(Z_{SM} \times X_{SM})$$

$$Z_{SM} = \text{Unit}(H_{CSM} \times X_{SM})$$

P57 (continued)

where:

The origin is the center of the moon.

R_{LS} = The position vector of the LM on the lunar surface at the most recently designated landing site and a time $T(\text{align})$ selected by the crew.

H_{CSM} = The angular momentum vector of the CSM ($R_{CSM} \times V_{CSM}$).

b. Preferred Orientation

An IMU orientation specified by the ground and loaded into the LGC by the LGC Update program (P27). When such an orientation is loaded by the ground the preferred orientation flag will be also set during P27.

c. REFSMMAT (Option 3).

Assumptions:

1. There are several methods available to the crew for completing an IMU alignment. The resultant accuracy of the IMU to the specified desired orientation (that is, that orientation defined by the final REFSMMAT) is dependent upon the mode of alignment which the crew selects. This selection will be dictated by the circumstances at the time of alignment.
2. The LM has landed on the lunar surface. The LM yaw angle with respect to the inertial orientation of the IMU at landing was not constrained during landing.
3. All possible efforts have been made by the crew to assure that the LM will not shift its position with respect to the lunar surface. No provision has been made to incorporate in the LGC any measurement of LM settling on the lunar surface. However, a shifting of the LM will result in a misaligned IMU only in the case where an alignment is made from a stored LM attitude with respect to the lunar surface (Option Codes 00000 and 00001) and the IMU is not subsequently aligned by reference to celestial bodies and/or lunar gravity.
4. The ISS is on and may be:
 - a. At an inertial orientation "unknown" to the LGC; that is, having been shut down and restarted since landing without subsequent orientation determination.
 - b. At an inertial orientation "known" by the LGC; that is, neither gimbal lock nor IMU power interruption has occurred since the last IMU alignment or orientation determination. Therefore the present orientation differs from that stored in REFSMMAT only due to gyro drift and/or the initial misalignment of the IMU to the stored REFSMMAT.
5. Extended Verbs should not be exercised during the R59 portion of this program because of possible interference with R53.
6. No monitor or control of the Rendezvous Radar (RR) will be exercised by the LGC during this program except as defined by the RR Monitor routine (R25).
7. The LM attitude with respect to the lunar surface is available in LGC storage; that is, it will have been stored by the Landing Conformation program (P68). Once this attitude has been stored it will be preserved by the LGC until it is replaced by a more recent value.
8. This program is selected by the astronaut by DSKY entry. It will normally be selected to perform an alignment of the IMU immediately after landing on the lunar surface, prior to selection of the RR Lunar Surface Navigation program (P22), prior to AGS initialization, and approximately 15 minutes prior to ascent. This program may also be used to provide an IMU alignment in time-critical emergencies prior to ascent.
9. The DAP should be off during gyro torquing by this program to preclude RCS jet firings due to realignment of the IMU causing attitude errors exceeding the maximum deadband.
10. A determination of the LM position vector while on the lunar surface (R_{LS}) can be accomplished only in conjunction with IMU alignment mode option 2 (using AOT sightings on two celestial bodies). It is valid only if the lunar gravity vector has been previously defined during P57, using IMU alignment mode option 1 (using REFSMMAT or stored LM attitude and determination of lunar gravity vector) or option 3 (using single celestial body sighting and determination of lunar gravity vector).

P57 (continued)

Selected Displays:

1. V06 N34
GET(ALIGN)
00XXX. h
000XX. min
0XX.XX s
2. V04 N06
Assumed IMU option
LGC assumed IMU orientation
00010
0000X (1—preferred,
2—nominal (not valid),
3—REFSMMAT, 4—landing site)
3. V05 N06
Option code assumed alignment
technique
R1: 00010
R2: 0000X (0—prestored attitude,
1—prestored attitude + g,
2—two celestial bodies,
3—one celestial body + g)
R3: 00CD0 (C = 1—REFSMMAT
defined, C = 0—REFSMMAT not
defined, D = 1—stored LM
attitude available,
D = 0—stored LM attitude not
available)
4. V06 N04 (angle between present and stored gravity vector)
R1: Angle
XXX.XX deg
5. V01 N70 (before mark)
R1: ABCDE
AB—Blank
C—AOT Detent
0—COAS calibration (not allowed)
1—Front left
2—Front center
3—Front right
4—Right rear
5—Center rear
6—Left rear
7—Backup optical system
DE—Celestial body code
00—Planet
01/45—Star list
46—Sun
47—Earth
50—Moon
6. V06 N79
Cursor angle
Spiral angle
Position code
XXX.XX deg
XXX.XX deg
0000X
7. V01 N71
R1: ABCDE (see Item 5 above)
8. V06 N87 (LOS definition)
Azimuth
Elevation
XXX.XX deg
XXX.XX deg
9. V52 (Mark X)

P57 (continued)

- | | | | |
|-----|--|----|------------|
| 10. | V06 N88 | | |
| | Components of celestial body 1/2 unit vector | | .XXXXX |
| 11. | V50 N25 (celestial body acquisition) | | |
| | Checklist code | | 00015 |
| 12. | V06 N05 | | |
| | R1: Sighting angle difference | | XXX.XX deg |
| 13. | V06 N93 | | |
| | Gyro torque angles | X | XX.XXX deg |
| | | Y | XX.XXX deg |
| | | Z | XX.XXX deg |
| 14. | V50 N25 (fine align) | | |
| | Checklist code | | 00014 |
| 15. | V06 N22 | | |
| | Desired ICDU angles | OG | XXX.XX deg |
| | | IG | XXX.XX deg |
| | | MG | XXX.XX deg |
| 16. | V06 N89 | | |
| | Landing site latitude | | XX.XXX deg |
| | Landing site longitude/2 | | XX.XXX deg |
| | Landing site altitude | | XXX.XX nmi |

P63—BRAKING PHASE PROGRAM

Purpose:

1. To calculate the required time of DPS ignition (TIG) and other initial conditions required by the LGC for a PGNCs-controlled, DPS-executed, braking phase of the powered landing maneuver.
2. To provide option to fine align the IMU to an existing REFMMAT.
3. To align the LM to the thrusting ignition attitude.
4. To control the PGNCs during countdown, ignition, and thrusting of the powered landing maneuver until HI gate.
5. To indicate to the crew that HI gate has been reached by automatic selection of the Approach Phase program (P64).

Assumptions:

1. The LM is on a descent coast orbit (Hohmann transfer) approaching the braking ignition point which is nominally 50,000 feet above the lunar radius at the designated landing site. The descent coast orbit is approximately coplanar with the CSM orbital plane. If the designated landing site is not in the descent coast plane at the nominal time of landing the plane change will be accomplished by the powered landing maneuver (Braking program, P63, and Approach program, P64).
2. The CSM is in a near-circular orbit around the moon at a nominal altitude of 60 nautical miles. The CSM is maintaining a preferred tracking attitude for optical tracking of the LM.
3. The IMU is on and aligned to a landing site orientation defined for the designated landing site and the nominal time of landing (T(land)), but should be fine aligned to this orientation as closely as possible prior to DPS ignition. The LM has not yet been aligned to the correct attitude for ignition for the powered landing maneuver.

P63 (continued)

4. The Landing Radar (LR) was energized, checked out, and made ready at LR Position No. 1 prior to selection of this program. Radar data will not be incorporated into the LM state vector until the astronaut sets the LR permit flag via V57E indicating he is satisfied with the quality of the data. V58E will reset the LR permit flag.
5. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
6. The Landing Analog Displays routine (R10) is enabled at DPS ignition and is terminated upon termination of Average G. The Powered Flight Designate routine (R29) is not enabled during the lunar descent.
7. The entire powered landing maneuver (braking, approach, and landing) will be accomplished using the DPS engine.
8. The aim conditions for braking phase are stored in the LGC.
9. The following parameters required by this program have been stored by the LGC since LGC initialization by erasable load.
 - a. The LM and CSM state vectors. The LGC has updated these as required. No further state vector updates from any external source other than the LR will be accepted by this program.
 - b. The nominal landing time at the designated landing site T(land) and the position RLS.
10. The DPS is not throttlable over the whole range (0 to maximum). It must be operated either at maximum throttle or over a specific throttle range of lower settings. These throttle settings are total throttle settings; that is, the sum of the manual setting (whose minimum is about 10 percent) and the PGNCs commanded setting.

This program assumes the Throttle Control switch to be in Auto (the DPS receives the sum of the manual and PGNCs commanded settings) and the manual throttle to be set at minimum for ZOOMTIME seconds of thrusting, and thereafter at a level less than that required by the LGC. The value ZOOMTIME is in erasable storage, having been loaded prior to launch or by P27.

Due to the region of forbidden throttling, thrust command logic in conjunction with the interim terminal conditions assures that the commanded throttle remains at maximum until the guidance equations first require it to be within the allowable throttle range. Thereafter it should remain within the allowable throttle range.

Furthermore, the DPS must be started in the following sequence: (1) +X axis 2-jet ullage for 7.5 seconds, (2) ignition at minimum throttle, (3) ullage off 0.5 seconds after ignition, (4) ZOOMTIME seconds at minimum thrust, and (5) maximum throttle. The throttle setting then becomes controlled by the guidance equations.

11. During the powered landing maneuver, the LGC will monitor the presence or absence of the Auto Stabilization discrete. This discrete is issued to the LGC when the Mode Control switch is in the Auto position.

The LGC will also monitor the presence or absence of the Auto Throttle discrete. This discrete is issued to the LGC when the Thrust Control switch is in the Auto position.

Should either of these discretes be interrupted during the powered landing maneuver, the LGC assumes that it no longer has complete automatic control of the maneuver.

The monitor and the associated LGC logic is included in the Landing Auto Modes Monitor routine (R13) which will be called by this program.

P63 (continued)

12. The X-axis override option provides the crew with the ability to exercise manual control about the LM X axis with the attitude controller even though the PGNCS Mode Control switch is in Auto. When the controller is returned to detent the PGNCS damps the yaw rate, stores the yaw attitude when the yaw is damped, and then maintains that attitude.

The X-axis override option is available to the crew (until the estimated altitude is below 30,000 feet); however, it should not be exercised when the LGC is specifying a desired yaw attitude; that is, during the attitude maneuver to the thrusting attitude. The option is inhibited by this program from midway in the program to the end.

13. The LGC specifies LM attitude during the powered landing maneuver based upon the requirements of thrust vector control, landing site visibility, and LR orientation. After DPS ignition, thrust vector control is required through the remainder of this program. The landing site becomes visible at the beginning of the approach phase.

Thrust vector control does not constrain the LM orientation about the thrust axis (yaw attitude). Rotation about the LM Y and LM Z axes is used to point the measured thrust vector along the desired thrust vector.

The first restraint upon the LM yaw attitude to occur is that of LR orientation. The LGC will not attempt to use LR data until the LGC estimation of altitude is 50,000 feet. Automatic X-axis override lockout and yaw attitude specification by the LGC will not occur until the LGC estimated altitude is 30,000 feet. Before this time, the astronaut must maneuver to a roughly-window-up yaw orientation to prevent subsequent loss of S-band lock-on. The LGC will then command the vehicle to the LGC-specified yaw attitude.

Subsequent to X-axis override lockout, control of the vehicle about the LM X axis is governed by LR orientation requirements during this program. The landing site becomes visible to the command pilot if the "look" angle (the angle between the LM -X axis and the LOS to the landing site) is greater than 25 degrees and the LOS is in or near the LM X/Z plane.

At any time during P63, P64, or P65, the magnitude of the look angle and the orientation of the look angle plane (that plane containing the LOS and the LM X axis) are defined by the inertial orientation of the LM X axis and the position of the LM with respect to the landing site.

14. The crew has the capability to display LGC calculated values of forward velocity, lateral velocity, altitude, and altitude rate on certain LM meters during this program. The calculations of these parameters is under the control of the Landing Analog Displays routine.

P63 (continued)

15. The Rate of Descent (ROD) mode is not enabled during this program.

16. An abort from the lunar descent may be required at any time during the descent orbit injection, the descent coast, or the powered descent (P63), (P64), (P65), (P66), or (P67).

For aborts after DPS ignition for the powered landing maneuver, time is critical. During this period an abort is nominally commanded by pushing one of two buttons in the LM. The abort may be commanded to use the descent stage (Abort button) or the ascent stage (Abort Stage button). If the descent stage is selected, and the DPS propellant approaches exhaustion, control must be switched to the ascent stage by the crew by ascent stage selection (Abort Stage button).

During the powered landing maneuver, the LGC will continuously monitor the Abort and Abort Stage discretes, and upon receipt of either will terminate the program in process and call the appropriate abort program (DPS Abort program (P70) or APS Abort program (P71)). Both abort programs will guide the LM to an acceptable orbit.

The monitor of the Abort and Abort Stage buttons is controlled by the Abort Discretes Monitor routine (R11) which will be enabled by this program.

17. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Auto, the PGNS will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control around the yaw axis only with the ACA (X-axis override) and only if the X-axis override capability is permitted by the program in process. This manual control will be in the Rate Command/Attitude Hold mode.

If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNS will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. It is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold mode the astronaut is responsible for maintaining small enough attitude errors to achieve guidance objectives.

18. Control of LM DPS, RCS, and APS is transferred from PGNS to the Abort Guidance System (AGS) by changing the Guidance Control switch from PGNS to AGS.

The AGS will be capable of taking over control of the LM during any portion of the lunar descent or ascent or during either of the abort programs (P70 or P71). The AGS will guide the LM to a safe orbit.

The AGS may be initialized by the LGC at any time by manual selection of the AGS Initialization routine (R47).

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors. However, the PGNS will not be responsible if register overflows occur within the LGC.

19. The PGNS can generate two types of attitude errors for display on the FDAI:
- Mode 1—Selected by Extended Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.

P63 (continued)

- b. Mode 2—Selected by Extended Verb 62. Total attitude errors used to assist crew in manually maneuvering the vehicle.

Display selection is always based upon the last entry made in the DSKY.

20. The event timer was set prior to selection of this program to count to zero at T BRAK based on a time from ignition provided by the ground.
21. The Load DAP Data routine (R03) has been performed prior to selection of this program. At that time the DPS engine gimbal should have been driven to the correct trim position.
22. During DPS burn only, the pitch-roll RCS jet autopilot (U and V jets) may be disabled (V65E) or enabled (V75) by Extended Verb as shown. This capability is intended to be used to prevent LM and descent stage thermal constraint violations during CSM-docked DPS burns (P40). The capability exists during P70 also. Performance of FRESH START (V36E) will always enable the pitch-roll jets.
23. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is enabled at DPS ignition by this program.
24. This program is selected by the astronaut by DSKY entry. It should be selected at least 20 minutes before the nominal time of ignition for the powered landing maneuver (T BRAK).
25. It is normally required that the ISS be on for a minimum of 15 minutes prior to a thrusting maneuver.
26. Engine ignition may be slipped beyond the established TIG if desired by the crew or if state vector integration cannot be completed in time.
27. Two alarm conditions may be originated by the PGNCS powered landing equations:
 - a. If subroutine ROOTSPRS in the RG/VG calculation fails to converge in 8 passes the LGC will turn on the Program Alarm light, store Alarm Code 1406, and go immediately to the final Automatic Request routine (R00). This alarm can occur only in P63 or P64.
 - b. If an overflow occurs anywhere in the landing equations the LGC will turn on the Program Alarm light, store Alarm Code 1410, stop all vehicle attitude rates, and continue. This alarm can occur only in P63, P64, P65, or P66.
28. This program allows manual control of LM attitude and the selection of P66.

During P63 (P64 and P65) the astronaut can display the PGNCS total guidance error on the FDAI error needles (Attitude Monitor switch in PGNCS) by having keyed in V62E through the DSKY. He can then steer out the PGNCS P63 attitude errors with the PGNCS manually (Guidance Control switch in PGNCS and the PGNCS Mode Control switch in Attitude Hold); or automatically (PGNCS Mode Control switch in Auto); or with the AGS manually (Guidance Control switch in AGS and the AGS Mode Control switch in Attitude Hold).

NOTE: If the astronaut hits the ROD (Rate of Descent) switch while the PGNCS Mode Control switch is in Attitude Hold, the LGC will irrevocably transfer him out of the automatic guidance program modes (P63, P64, and P65) into the ROD program (P66).

Selected Displays:

1. V06 N61

TG	XX b XX min/s
TF GETI (DPS ignition)	XX b XX min/s
Crossrange	XXXX.X nmi
2. V06 N33 (astronaut initiated)

Time of PDI ignition	00XXX. h
	000XX. min
	0XX.XX s

P63 (continued)

3. V50 N25 (fine align)

Checklist code	00014
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4. V50 N18

Desired automaneuver FDAI ball angles	R XXX.XX deg P XXX.XX deg Y XXX.XX deg
---------------------------------------	--
5. V06 N18

Final FDAI ball angles	R XXX.XX deg P XXX.XX deg Y XXX.XX deg
------------------------	--
6. V06 N62

Absolute value of velocity	XXXX.X ft/s
Time from ignition	XX b XX min/s
V (measured)	XXXX.X ft/s
7. V99 N62 (request engine on enable)

Same display as Item 15 above
8. V06 N63

Absolute value of velocity	XXXX.X ft/s
Altitude rate	XXXX.X ft/s (+ ascent)
Computed altitude	XXXXX. ft
9. V50 N25 (reposition LR antenna)

Checklist code	00500
----------------	-------
10. V50 N25 (change guidance mode)

Checklist code	00203
----------------	-------
11. V06 N68 (astronaut initiated)

Slant range to landing site	XXXX.X nmi
Time to go in braking phase	XX b XX min/s
LR altitude (computed altitude)	XXXXX. ft
12. V16 N68 (astronaut initiated)

Display same as Item 11 above.

P64—APPROACH PHASE PROGRAM

Purpose:

1. To control the PGNCs during the thrusting of the powered landing maneuver between HI gate and LO gate.
2. To control the DPS thrust and attitude between HI gate and LO gate.
3. To provide the crew with the capability of redesignating the landing site to which the PGNCs is guiding the LM.
4. To select P65 automatically when TG is less than TENDAPPR (time to end of approach phase).

Assumptions:

1. The LM is on the powered landing descent between HI gate and LO gate.
2. The CSM is in a near circular orbit around the moon at a nominal altitude of 60 nautical miles. The CSM is maintaining a preferred tracking attitude for optical tracking of the LM.
3. The IMU is on and accurately aligned to a landing site orientation defined for the designated landing site and the nominal time of landing (T(land)).

P64 (continued)

4. The Landing Radar (LR) is on, checked out, and should have been providing to the LGC velocity and range information with respect to the moon. This information should have been incorporated into the LM state vector. The LGC/LR operation is under the control of the Descent State Vector Update routine (R12) which is already in process.
5. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
6. The entire powered landing maneuver (braking, approach, and landing) will be accomplished using the DPS engine.
7. The aim conditions (LO gate) for the approach phase are stored in the LGC.
8. The LM state vector has been stored in the LGC since initialization by ERASABLE register load. The LGC has updated this as required during thrusting. No further state vector updates from any source other than the LR will be accepted by this program.
9. The DPS is not throttleable over the whole range from 0 to maximum. It must be operated either at maximum throttle or over a specific throttle range of lower settings. These throttle settings are total throttle settings; that is, the sum of the manual setting (whose minimum is about 10 percent) and the PGNCs commanded setting.

This program assumes the Throttle Control switch to be in Auto (the DPS receives the sum of the manual and PGNCs commanded settings) and the manual throttle to be set at a level less than that required by the LGC.

Nominally, if the Approach Phase program is completed without any redesignation of the landing site (see Assumption 11), the throttle will remain within the allowable throttle range throughout the phase. Excessive target redesignations during this program, however, may result in required throttle excursions outside the allowable range. In such cases the LGC will command maximum throttle for at least 2 seconds, and until the required throttle setting returns to the permitted throttle region.

10. During the powered landing maneuver, the LGC will monitor the presence or absence of the Auto Stabilization discrete. This discrete is issued to the LGC when the Mode Control switch is in the Auto position.

The LGC will also monitor the presence or absence of the Auto Throttle discrete. This discrete is issued to the LGC when the Thrust Control switch is in the Auto position.

Should either of these discretes be interrupted during the powered landing maneuver, the LGC assumes that it no longer has complete automatic control of the maneuver.

The monitor and the associated LGC logic is included in the Landing Auto Modes Monitor routine (R13) which is already in process.

11. The X-axis override option is not provided to the crew whenever the LGC estimated altitude is below 30,000 feet.
12. During most of the approach phase, the LGC provides the crew with the option to redesignate the landing site to which the PGNCs is guiding the LM. This option is called the Landing Point Designator (LPD) mode. The PGNCs Mode Control switch must be in Auto for the ACA to function as a landing site redesignator.

The landing point redesignation, if exercised, is based upon visual assessment of the lunar terrain with respect to the presently designated landing site. During the LPD mode the present landing site is displayed on the DSKY in terms of coordinates on the LPD sighting grid on the left hand LM window (LPD angle). Landing site redesignations are manually put into the computer via the attitude controller on an incremental basis; that is, a limit switch actuation in the attitude controller causes the LGC to redesignate the landing site as a fixed angular increment (1/2 degree in elevation, 2 degrees in azimuth) from the present LM/landing site LOS. The applicable attitude controller polarities are:

- a. -Pitch Rotation gives -LPD Elevation (new site beyond present site).
- b. +Pitch Rotation gives +LPD Elevation (new site short of present site).
- c. +Roll Rotation gives +LPD Azimuth (new site to right of present site).
- d. -Roll Rotation gives -LPD Azimuth (new site to left of present site).

P64 (continued)

13. The initial maneuver of the approach phase is the LM attitude transition from the LM attitude at the start of P64 to a satisfactory attitude for landing site visibility. After the completion of this maneuver the LM attitude is constrained by thrust pointing requirements and is controlled about the thrust axis so as to maintain the current landing site in the LM X-Z plane. The conditions achieved at the start of P64 should be such that the thrust pointing requirements of the approach phase will yield satisfactory visibility and radar orientations.

The landing site becomes visible to the command pilot if the "look" angle (the angle between the -X LM axis and the LOS to the landing site) is greater than 25 degrees and the LOS is in or near the LM X-Z plane.

At any time during P63, P64, or P65, the magnitude of the look angle and the orientation of the look angle plane (that plane containing the LOS and the LM X axis) are defined by the inertial orientation of the LM X axis and the position of the LM with respect to the landing site.

The inertial orientation of the LM X axis is controlled by requirements of thrust vector control. The orientation of the LM windows with respect to the look angle plane is controlled by rotation of the vehicle about the LM X axis.

14. The crew has the capability to display LGC calculated values of forward velocity, lateral velocity, altitude, and altitude rate on certain LM meters during this program. The calculation of these parameters is under control of the Landing Analog Display routine which is already in process.
15. The Rate of Descent (ROD) mode is not enabled during this program.
16. An abort from the lunar descent may be required at any time during the descent orbit injection, the descent coast, or the powered descent (P63), (P64), (P65), (P66), or (P67).

For aborts after DPS ignition for the powered landing maneuver, time is critical. During this period an abort is nominally commanded by pushing one of two buttons in the LM. The abort may be commanded to use the descent stage (Abort button) or the ascent stage (Abort Stage button). If the descent stage is selected, and the DPS propellant approaches exhaustion, control must be switched to the ascent stage by the crew by ascent stage selection (Abort Stage button).

During the powered landing maneuver the LGC will continuously monitor the Abort and the Abort Stage discretes, and upon receipt of either will terminate the program in process and call the appropriate abort program (DPS Abort program (P70) or APS Abort program (P71)). Both abort programs will guide the LM to an acceptable orbit.

Monitoring the Abort and Abort Stage buttons is controlled by the Abort Discretes Monitor routine (R11) which is already in process.

17. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Auto, the PGNS will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors for display on the FDI.

If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold the PGNS will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. It is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold mode the PGNS will not be responsible if register overflows occur within the LGC.

18. Control of the LM DPS, RCS, and APS is transferred from the PGNS to the Abort Guidance System (AGS) by placing the Guidance Control switch from PGNS to AGS.

The AGS will be capable of taking over control of the LM during any portion of the lunar descent or ascent or during either of the abort programs (P70 or P71). The AGS will guide the LM to a safe orbit.

P64 (continued)

The AGS may be initialized by the LGC at any time during this program by manual selection of the AGS Initialization routine (R47).

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors. However, the PGNS will not be responsible if register overflows occur within the LGC.

19. The PGNS can generate two types of attitude errors for display on the FDAI:
 - a. Mode 1—Selected by Extended Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
 - b. Mode 2—Selected by Extended Verb 62. Total attitude errors used to assist crew in manually maneuvering the vehicle.
20. The Load DAP Data routine (R03) has been performed prior to the start of the powered landing maneuver and should not be required during this program.
21. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is in effect during this program, having been enabled by P63.
22. This program is automatically selected by the Braking Phase program (P63) at the completion of the P63 aim conditions.
23. Two alarm conditions may be originated by the PGNS powered landing equations:
 - a. If Subroutine ROOTSPRS in the RG/VG calculation fails to converge in 7 passes the LGC will turn on the Program Alarm light, store Alarm Code 1406, and go immediately to the Final Automatic Request routine (R00). This alarm can occur only in P63 or P64.
 - b. If an overflow occurs anywhere in the landing equations the LGC will turn on the Program Alarm light, store Alarm Code 1410, stop all vehicle attitude rates, and continue. This alarm can occur only in P63, P64, P65, or P66.
24. This program allows manual control of the LM attitude. If manual control is desired, put the PGNS Mode Control switch in Attitude Hold and use the ACA to control the LM attitude.

If P66 is desired, click the ROD switch while the PGNS Mode Control switch is in Attitude Hold. The ACA does not redesignate the landing site while the Mode Control switch is in Attitude Hold. To use the ACA to redesignate the landing site, put the Mode Control in Auto and rotate the ACA in the desired direction.

P67 can be entered by placing the Throttle Control switch to Manual.

NOTE: Landing Site Redesignation must be completed before either P66 or P67 are selected, since P64 cannot be reentered once it has been exited.

Selected Displays:

1. V06 N64

Time left for redesignations (TG)/LPD	XX b XX s/deg
Altitude rate	XXXX.X ft/s
Computed altitude	XXXXX. ft

P65—LANDING PHASE (AUTO) PROGRAM

Purpose:

1. To control the PGNS during the thrusting of the powered landing maneuver from the period immediately after completion of the approach phase aim conditions (LO gate) until touchdown on the lunar surface.

P65 (continued)

Assumptions:

1. The LM is on the powered landing descent having just arrived at the LO gate conditions.
2. The CSM is in a near circular orbit around the moon at a nominal altitude of 60 nautical miles. The CSM's position with respect to the LM is approximately 0 degrees central angle above the LM. The CSM is maintaining a preferred tracking attitude for optical tracking of and RR tracking by the LM.
3. The IMU is on and accurately aligned to a landing site orientation defined for the designated landing site and the nominal time of landing (T(land)).
4. The Landing Radar (LR) is on, checked out, and providing to the LGC velocity and range information with respect to the moon. This information has been incorporated into the LM state vector. The LGC/LR operation is under the control of the Descent State Vector Update routine (R12) which is already in process.
5. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
6. The entire powered landing maneuver (braking, approach, and landing) will be accomplished using the DPS engine.
7. The LM state vector has been stored in the LGC since initialization by ERASABLE register load. The LGC has updated this as required during thrusting. No further state vector updates from any source other than the LR will be accepted by this program.
8. The DPS is not throttleable over the whole range from 0 percent to maximum. It must be operated either at maximum throttle or over a specific throttle range of lower settings. These throttle settings are total throttle settings; that is, the sum of the manual setting (whose minimum is about 10 percent) and the PGNCs commanded setting.
 This program assumes the Throttle Control switch to be in Auto (the DPS receives the sum of the manual and PGNCs commanded settings) and the manual throttle to be set at a level less than that required by the LGC.
 Nominally the throttle will remain within the allowable throttle range throughout this program.
9. During the powered landing maneuver, the LGC will monitor the presence or absence of the Auto Stabilization discrete. This discrete is issued to the LGC when the Mode Control switch is in the Auto position.
 The LGC will also monitor the presence or absence of the Auto Throttle discrete. This discrete is issued to the LGC when the Thrust Control switch is in the Auto position.
 Should either of these discretes be interrupted during the powered landing maneuver, the LGC assumes that it no longer has complete automatic control of the maneuver.
 The monitor and the associated LGC logic is included in the Landing Auto Modes Monitor routine (R13) which is already in process.
10. The X-axis override option provides the crew with the ability to exercise manual control about the LM X axis with the Attitude Controller even though the PGNCs Attitude Control mode is auto. When the controller is returned to detent, the PGNCs damps the yaw rate, stores the Y attitude when the rate is damped, and then maintains that attitude. The X-axis override option is always available to the crew except when the LGC is specifying a desired yaw attitude. Thus the option is not inhibited by the program.

11. The LPD option is not provided to the crew during this program.
12. The initial maneuver of the auto landing phase is the LM attitude transition from the LM attitude at LO gate to the hover attitude (LM X axis along the local vertical). The final designated landing site remains in the LM X-Z plane during this transition. The LM attitude rate is maintained at -3 ft/s until touchdown.
13. The crew can display LGC calculated values of forward velocity, lateral velocity, altitude, and altitude rate on certain LM meters during this program. The calculation of these parameters is under the control of the Landing Analog Displays routine (R10) which is already in process.
14. The Rate of Descent (ROD) mode is not enabled during this program.
15. An abort from the lunar descent may be required at any time during descent orbit injection, descent coast, or powered descent (P63), (P64), (P65), (P66), or (P67).

For aborts after DPS ignition for the powered landing maneuver, time is critical. During this period an abort is commanded by pushing one of two buttons in the LM. The abort may be commanded to use the descent stage (Abort button) or the ascent stage (Abort Stage button). If the descent stage is selected, and the DPS propellant approaches exhaustion, control must be switched to the ascent stage by the crew by ascent stage selection (Abort Stage button).

During the powered landing maneuver, the LGC will continuously monitor the Abort and Abort Stage discretes, and upon receipt of either will terminate the program in process and call the appropriate abort program (DPS Abort program (P70) or APS Abort program (P71)). Both abort programs will guide the LM to an acceptable orbit.

Monitoring the Abort and Abort Stage buttons is controlled by the Abort Discretes Monitor routine (R11) which is already in process.

16. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in auto, the PGNS will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control around the yaw axis only with the ACA (X-axis override) if the X-axis override capability is permitted by the program in process. This manual control will be in the Rate Command/Attitude Hold mode.

If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNS will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. It is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold mode the PGNS will not be responsible if register overflows occur within the LGC.

17. Control of the LM DPS, RCS, and APS is transferred from the PGNS to the Abort Guidance System (AGS) by placing the Guidance Control switch from PGNS to AGS.

The AGS will be capable of taking over control of the LM during any portion of the lunar descent or ascent or during either of the abort programs (P70 or P71) and guiding the LM to a safe orbit.

The AGS may be initialized by the LGC at any time by manual selection of the AGS Initialization routine (R47).

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors. However, the PGNS will not be responsible if register overflows occur within the LGC.

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P65 (continued)

18. The Load DAP Data routine (R03) has been performed prior to the start of the powered landing maneuver and should not be required during this program.
19. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is in effect during this program until selection of the Landing Conformation program (P68), having been called by P63.
20. This program is automatically selected by the Approach Phase program (P64) at the completion of the LO gate aim conditions.
21. This program allows for manual control of LM attitude and the selection of P66.

During P65 the astronaut can display the PGNCs total guidance error on the FDAI error needles (Attitude Monitor switch in PGNCs) by having keyed in V62E through the DSKY. He can then steer out the PGNCs P65 attitude errors with the PGNCs manually (Guidance Control switch in PGNCs and the PGNCs Mode Control switch in Attitude Hold); or automatically (PGNCs Mode Control switch in Auto), or with the AGS manually (Guidance Control switch in AGS and the AGS Mode Control switch in Attitude Hold).

NOTE: If the astronaut hits the ROD (Rate of Descent) switch while the PGNCs Mode Control switch is in Attitude Hold, the LGC will irrevocably transfer him out of P65 and into the ROD program (P66).

Selected Displays:

- | | |
|---------------------|-------------|
| 1. V06 N60 | |
| Horizontal velocity | XXXX.X ft/s |
| Altitude rate | XXXX.X ft/s |
| Computed altitude | XXXXX. |

P66—LANDING PHASE (ROD) PROGRAM

Purpose:

1. To modify the rate of descent of the LM (with respect to the lunar surface) in response to astronaut originated inputs via the LM Rate of Descent switch to the LGC.
2. To modify the inertial attitude of the LM in response to astronaut originated inputs via the attitude controller only if the Mode Control switch is in Attitude Hold.
3. In the absence of manual control inputs, to maintain a constant rate of descent and LM inertial attitude.
4. To update the LM state vector with vehicle acceleration and Landing Radar (LR) data.

Assumptions:

1. The LM is in the late stages of landing, with a relatively low inertial velocity.
2. The IMU is on and accurately aligned to a landing site orientation defined for the designated landing site and the nominal time of landing (T(land)). IMU alignment took place during the Braking Phase program (P63) prior to DPS ignition.
3. The Landing Radar (LR) is on, checked out, and providing to the LGC velocity and range information with respect to the moon. This information has been incorporated into the LM state vector. The LGC/LR operation is under the control of the Descent State Vector Update routine (R12) which is already in process.
4. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
5. The entire powered landing maneuver (braking, approach, and landing) will be accomplished using the DPS engine.

P66 (continued)

6. The LM state vector has been stored in the LGC since initialization by ERASABLE register load. The LGC has updated this as required during thrusting. No further state vector updates from any source other than the LR will be accepted by this program.
7. The DPS is not throttleable over the whole range from 0 percent to maximum. It must be operated either at maximum throttle or over a specific throttle range of lower settings. These throttle settings are total throttle settings; that is, the sum of the manual setting (whose minimum is 10 percent) and the PGNS commanded setting.

This program assumes the Throttle Control switch to be in Auto (the DPS receives the sum of the manual and PGNS commanded settings) and the manual throttle to be set at a level less than that required by the LGC.

Nominally the throttle will remain within the allowable throttle range through this program.

8. During the powered landing maneuver, the LGC will monitor the presence or absence of the Auto Stabilization discrete. This discrete is issued to the LGC when the Mode Control switch is in the Auto position.

The LGC will also monitor the presence or absence of the Auto Throttle discrete. This discrete is issued to the LGC when the Thrust Control switch is in the Auto position.

Should either of these discretes be interrupted during the powered landing maneuver, the LGC assumes that it no longer has complete automatic control of the maneuver.

The monitor and the associated LGC logic is included in the Landing Auto Modes Monitor routine (R13) which is already in process.

9. The LPD option is not provided to the crew during this program.
10. The LGC assumes all attitude changes to be manual throughout this program. The Mode Control switch may be in Auto or Attitude Hold. The LGC will hold inertial attitude in either mode. However, in the Attitude Hold mode the attitude may be changed by manual control via the attitude controller.
11. The crew has the capability to display LGC calculated values of forward velocity, lateral velocity, altitude and altitude rate on certain LM meters during this program. The calculation of these parameters is under the control of the Landing Analog Displays routine (R10) which is already in process.
12. During this program the LGC monitors the output of the Rate of Descent (ROD) switch in the LM. This switch is operated by the astronaut in response to his assessment of the present LM rate of descent based on out-the-window references and LM/DSKY displays.
Switch operation is on an incremental bias: either -(increase ROD) or +(decrease ROD). Each command results in an LGC-commanded change of "RODSCALE" in the LM rate of descent. ("RODSCALE" is a value loaded into erasable storage prior to flight).
13. An abort from the lunar descent may be required at any time during descent orbit injection, descent coast, or powered descent (P63), (P64), (P65), (P66), or (P67).

For aborts after DPS ignition for the powered landing maneuver, time is critical. During this period an abort is commanded by pushing one of two buttons in the LM. The abort may be commanded to use the descent stage (Abort button) or the ascent stage (Abort Stage button). If the descent stage is selected, and the DPS propellant approaches exhaustion, control must be switched to the ascent stage by the crew by ascent stage selection (Abort Stage button).

During the powered landing maneuver, the LGC will continuously monitor the Abort and Abort Stage discretes, and upon receipt of either will terminate the

P66 (continued)

program in process and call the appropriate abort program (DPS Abort program (P70) or APS Abort program (P71)). Both abort programs will guide the LM to an acceptable orbit.

Monitoring the Abort and Abort Stage buttons is controlled by the Abort Discretes Monitor routine (R11) which is already in process.

14. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold the PGNS will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. It is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold mode the PGNS will not be responsible if register overflows occur within the LGC.

15. Control of the LM DPS, RCS, and APS is transferred from the PGNS to the Abort Guidance System (AGS) by placing the Guidance Control switch from PGNS to AGS.

The AGS will be capable of taking over control of the LM during any portion of the lunar descent or ascent or during either of the abort programs (P70 or P71). The AGS will guide the LM to a safe orbit.

The AGS may be initialized by the LGC at any time by manual selection of the AGS Initialization routine (R47).

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors; however, the PGNS will not be responsible if register overflows occur within the LGC.

16. The Load DAP Data routine (R03) has been performed prior to the start of the powered landing maneuver and should not be required during this program.
17. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is in effect during this program until selection of the Landing Conformation program (P68), having been enabled by P63.
18. This program is automatically selected by the Landing Auto Modes Monitor routine (R13) during the powered landing maneuver when:
 - a. Attitude control is first transferred to manual (Attitude Control switch to Attitude Hold). If the throttle control remains in auto (Throttle switch at Auto) and the astronaut commands a net change in the rate of descent by means of the ROD switch.
 - b. Auto Throttle Control is selected during the Landing Phase (Manual) program (P67).

Once this program has been selected it is no longer possible to return to the completely automatic powered landing programs (P63, P64, or P65).

Selected Displays:

1. V06 N60

Horizontal velocity	XXXX.X ft/s
Altitude rate	XXXX.X ft/s
Computed altitude	XXXXX. ft

P67—LANDING PHASE (MANUAL) PROGRAM

Purpose:

1. To update the LM state vector with vehicle acceleration and Landing Radar (LR) data during a non-PGNCS controlled landing maneuver.
2. To display horizontal velocity, altitude rate, and computed altitude during a non-PGNCS controlled landing maneuver.

Assumptions:

1. The LM could be anywhere on the powered landing descent but nominally it has just completed the second transition.
2. The CSM is in a near circular orbit around the moon at a nominal altitude of 60 nautical miles. The CSM's position with respect to the LM is approximately 0-degrees central angle above the LM. The CSM is maintaining a preferred tracking attitude for optical tracking of and RR tracking by the LM.
3. The IMU is on and accurately aligned to a landing site orientation defined for the designated landing site and the nominal time of landing (T(land)). The most recent IMU alignment took place during the Braking Phase program (P63) prior to DPS ignition.
4. The Landing Radar (LR) is on, checked out, and providing to the LGC velocity and range information with respect to the moon. This information has been incorporated into the LM state vector. The LGC/LR operation is under the control of the Descent State Vector Update routine (R12) which is already in process.
5. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
6. The entire powered landing maneuver (braking, approach, and landing) will be accomplished using the DPS engine.
7. The LM state vector has been stored in the LGC since initialization by ERASABLE register load. The LGC has updated this as required during thrusting. No further state vector updates from any source other than the LR will be accepted by this program.
8. This program assumes all throttle control to be manual throughout the program.
9. During the powered landing maneuver, the LGC will monitor the presence or absence of the Auto Stabilization discrete. This discrete is issued to the LGC when the Mode Control switch is in the Auto position.
The LGC will also monitor the presence or absence of the Auto Throttle discrete. This discrete is issued to the LGC when the Thrust Control switch is in the Auto position.
Should either of these discrettes be interrupted during the powered landing maneuver, the LGC assumes that it no longer has complete automatic control of the maneuver.
The monitor and the associated LGC logic is included in the Landing Auto Modes Monitor routine (R13) which is already in process.
10. The LPD option is not provided the crew during this program.
11. The LGC assumes all attitude changes to be manual throughout this program. The Mode Control switch may be in Auto or Attitude Hold. The LGC will hold inertial attitude in either mode, however, only in the Attitude Hold mode may the attitude be changed by manual control via the attitude controller.
12. The crew has the capability to display LGC calculated values of forward velocity, lateral velocity, altitude, and altitude rate on certain LM meters during this program. The calculation of these parameters is under the control of the Landing Analog Displays routine (R10) which is already in process.
13. The Rate of Descent (ROD) mode is not enabled during this program.

P67 (continued)

14. An abort from the lunar descent may be required at any time during descent orbit injection, descent coast, or powered descent (P63), (P64), (P65), (P66), or (P67).

For aborts after DPS ignition for the powered landing maneuver, time is critical. During this period an abort is commanded by pushing one of two buttons in the LM. The abort may be commanded to use the descent stage (Abort button) or the ascent stage (Abort Stage button). If the descent stage is selected, and the DPS propellant approaches exhaustion, control must be switched to the ascent stage by the crew by ascent stage selection (Abort Stage button).

During the powered landing maneuver, the LGC will continuously monitor the Abort and Abort Stage discretes, and upon receipt of either will terminate the program in process and call the appropriate abort program (DPS Abort program (P70) or APS Abort program (P71)). Both abort programs will guide the LM to an acceptable orbit.

Monitoring the Abort and Abort Stage buttons is controlled by the Abort Discretes Monitor routine (R11) which is already in process.

15. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNS will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. It is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold Mode, the PGNS will not be responsible if register overflows occur within the LGC.

16. Control of the LM DPS, RCS, and APS is transferred from the PGNS to the Abort Guidance System (AGS) by placing the Guidance Control switch from PGNS to AGS.

The AGS will be capable of taking over control of the LM during any portion of the lunar descent or ascent or during either of the abort programs (P70 or P71). The AGS will guide the LM to a safe orbit.

The AGS may be initialized by the LGC at any time by manual selection of the AGS Initialization routine (R47).

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors; however, the PGNS will not be responsible if register overflows occur within the LGC.

17. The Load DAP Data routine (R03) has been performed prior to the start of the powered landing maneuver and should not be required during this program.
18. LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40). This routine is in effect during this program until selection of the Landing Conformation program (P68), having been enabled by P63.
19. This program is automatically selected by the Landing Auto Modes Monitor routine (R13) at any time during the powered landing maneuver when the throttle is manual (Thrust Control switch to Manual).

Once this program has been selected it is no longer possible to return to the completely automatic powered landing programs (P63, P64, or P65).

Selected Displays:

1. V06 N60

Horizontal velocity	XXXX.X ft/s
Altitude rate	XXXX.X ft/s (+ ascent)
Computed altitude	XXXXX. ft

P68—LANDING CONFIRMATION PROGRAM

Purpose:

1. To terminate landing program and DAP functions.
2. To initialize the LGC for lunar surface operation.
3. To permit the astronaut to prevent RCS jet firings on the lunar surface.

Assumptions:

1. This program is selected by the astronaut by DSKY entry. It is to be selected only after the LM has landed on the lunar surface (Programs P65, P66, or P67).
2. V37E68E selection of P68 will terminate Average G and command the engine off (see R00).
3. The selection of this program places the DAP in the Minimum Impulse mode. As long as the astronaut keeps the mode control in Attitude Hold, RCS jet firings will not occur, even while the platform is being torqued (in P57).
4. This program will not shut off the DAP. However, the attitude errors are zeroed and the maximum deadband is set. No jet firings should result until one of the following occurs in sufficient magnitude to cause the attitude errors to exceed the deadband:
 - a. The moon rotates,
 - b. The LM shifts on the lunar surface,
 - c. The IMU gyros are torqued for alignment by P57,
 - d. The IMU drifts.

The DAP may be shut off by setting the Mode-Control-PGNS switch to Off.

Selected Displays:

1. V06 N43

Latitude	XXX.XX deg (+ north)
Longitude	XXX.XX deg (+ east)
Altitude	XXXX.X nmi
2. V16 N56 (results from V85E)

RR LOS Azimuth	XXX.XX deg
RR LOS Elevation	XXX.XX deg

P70—DPS ABORT PROGRAM

Purpose:

1. To control a PGNS controlled DPS abort from the powered landing maneuver (P63, P64, P65, P66, or P67) when required.

Assumptions:

1. This program will control a DPS abort in one of two ways:
 - a. If the altitude is greater than 25,000 feet, this program will command maximum DPS throttle, continue DPS thrusting, perform an attitude maneuver (using the RCS) to the correct attitude to continue the abort ascent, and complete the abort ascent to insert the LM on an abort orbit.
 - b. If the altitude is less than 25,000 feet, this program will command maximum DPS throttle and enter a vertical rise phase which will terminate either when the LM altitude exceeds 25,000 feet or when both of the following conditions are met: the LM Y axis is within 5 degrees of the desired pitchover axis and the LM vertical velocity is greater than 40 ft/s.

During the vertical rise phase, the vehicle is maneuvered to align the LM +X axis with the local vertical (using the RCS), and the LM +Y axis normal to the anticipated pitch maneuvers plane. The program will then pitch the LM to the correct attitude for ascent and complete the abort ascent to insert the LM on an abort orbit.

P70 (continued)

2. The LM is on the powered landing descent somewhere between DPS ignition for the maneuver (P63) and DPS shutdown on the lunar surface (P65, P66, or P67).
3. The CSM is in a near circular orbit around the moon at a nominal altitude of 60 nautical miles. The CSM is maintaining a preferred tracking attitude for optical tracking of and RR tracking by the LM.
4. The IMU is on and accurately aligned to the landing orientation.
5. The Landing Radar (LR) is on and was checked out when in Position No. 1. The LGC/LR operation is under the control of the Descent State Vector Update routine (R12).
6. The Rendezvous Radar (RR) was energized and checked out prior to selection of this program.
7. The Landing Analog Displays routine (R10) is enabled upon entry to this program, having been enabled by P63. R10 use of RR CDU's is inhibited by this program. R29 is enabled after completion of the vertical rise phase (if any). R10 and R29 are terminated upon termination of Average G.
8. The DPS is not throttlable over the whole range from zero to maximum. It must be operated either at maximum throttle or over a specific throttle range of lower settings. These throttle settings are total throttle settings; that is, the sum of the manual setting (whose minimum is 10 percent) and the PGNCs commanded setting. This program assumes the Throttle Control switch to be in Auto (the DPS receives the sum of the manual and PGNCs commanded settings) and the manual throttle to be set at a level less than that required by the LGC. The LGC will command maximum throttle for all DPS thrusting controlled by this program.
9. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Auto, the PGNCs will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors (see Assumption 11) for display on the FDAI.
 If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold the PGNCs will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. It is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in PGNS/Attitude Hold mode the PGNCs will not be responsible if register overflows occur within the LGC.
10. Control of the LM DPS, RCS, and APS is transferred from the PGNCs to the Abort Guidance System (AGS) by placing the Guidance Control switch from PGNS to AGS.
 The AGS will be capable of taking over control of the LM during any portion of the lunar descent or ascent or during either of the abort programs (P70 or P71). The AGS will guide the LM to a safe orbit.
 The AGS may be initialized by the LGC at any time by manual selection of the AGS Initialization routine (R47).
- In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors. However, the PGNCs will not be responsible if register overflows occur within the LGC.
11. The PGNCs can generate two types of attitude errors for display on the FDAI:
 - a. Mode 1—Selected by Extended Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
 - b. Mode 2—Selected by Extended Verb 62. Total attitude errors used to assist crew in manually maneuvering the vehicle.

P70 (continued)

12. The Load DAP Data routine (R03) was completed prior to DPS ignition for the powered landing maneuver and should not be selected during this program.
13. During DPS burns only, the Pitch-Roll RCS jet autopilot (U and V jets) may be disabled (V65) or enabled (V75) by Extended Verb as shown. This capability is intended to be used to prevent LM and descent stage thermal constraint violations during CSM-docked DPS burns (P40). The capability exists during P63 also. Performance of FRESH START (V36E) will always enable the capability of the autopilot.
14. This program may be called in two ways:
 - a. Abort button—If the Abort button is used during the powered descent it will be detected by the Abort Discretes Monitor routine (R11). R11 will then call this program.
 - b. V37E 70E—This program may be called by the same procedure as other programs are manually called.
15. The LGC will not automatically select the APS Abort program (P71) if DPS fuel exhaustion occurs during execution of P70. The crew must anticipate DPS fuel exhaustion and select P71 by the Abort Stage button or by V37E 71E.

Selected Displays:

1. V16 N77 (astronaut initiated)

Time to engine cutoff	XX b XX min/s
LM velocity normal to CSM plane	XXXX.X ft/s
2. V16 N85 (astronaut initiated)

Components of velocity to be gained (body axis)	XXXX.X ft/s
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3. V50 N25 (change guidance control mode)

Checklist code	00203
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4. V06 N63

Absolute value of velocity	XXXX.X ft/s
Altitude rate	XXXX.X ft/s (+ ascent)
Computed altitude	XXXXX. ft
5. V06 N76 (astronaut initiated)

Downrange velocity	XXXX.X ft/s
Radial velocity	XXXX.X ft/s
Crossrange	XXXX.X nmi
6. V16 N44 (results from V82E)

Apocenter altitude	XXXX.X nmi
Pericenter altitude	XXXX.X nmi
TFF	XX b XX min/s

P71-APS ABORT PROGRAM

Purpose:

1. To control a PGNCs controlled APS abort from the powered landing maneuver (P63, P64, P65, P66, or P67) or a DPS Abort (P70) when required.

Assumptions:

1. The program will control an APS abort in one of two ways:
 - a. If the altitude is greater than 25,000 feet this program will ignite the APS, continue APS thrusting, perform an attitude maneuver (using the RCS) to the correct attitude to continue the abort ascent, and complete the abort ascent to insert the LM into an abort orbit.
 - b. If the altitude is less than 25,000 feet this program will ignite the APS, continue APS thrusting, enter a vertical rise phase which will terminate either when the LM altitude exceeds 25,000 feet or when both of the following conditions are met: the LM Y axis is within 5 degrees of the desired pitchover axis and the LM vertical velocity is greater than 40 ft/s.

During the vertical rise phase the vehicle is maneuvered to align the LM +X axis with the local vertical (using the RCS) and the LM +Y axis normal to the anticipated pitch maneuver plane. The program will then pitch the LM to the correct attitude for ascent, and then complete the abort ascent to insert the LM on an abort orbit.

2. This program does not check to see if the DPS has been staged. Thus if P71 is selected via V37 and the descent stage has not been manually staged this program may command engine on (Assumption 1.a or 1.b above). In such cases the command will go to the DPS.
3. The CSM is in a near circular orbit around the moon at a nominal altitude of 60 nautical miles. The CSM is maintaining a preferred tracking attitude for optical tracking of and RR tracking by the LM.
4. The IMU is on and accurately aligned to the landing site orientation.
5. The Landing Radar (LR) is on and was checked out when in Position No. 1. The LGC/LR operation is under the control of the Descent State Vector Update routine (R12).
6. The Rendezvous Radar (RR) was energized and checked out prior to selection of this program.
7. The Landing Analog Displays routine (R10) is enabled upon entry to this program, having been enabled by P63. R10 use of the RR CDU's is inhibited by this program. R29 is enabled after completion of the vertical rise phase (if any). R10 and R29 are terminated upon termination of Average G.
8. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Auto, the PGNCs will control the total vehicle attitude and generate either Mode 1 or Mode 2 attitude errors for display on the FDI.

If a thrusting maneuver is performed with the Guidance Control switch set at PGNS and the Mode Control switch in Attitude Hold, the PGNCs will hold the vehicle attitude and will generate either Mode 1 or Mode 2 attitude errors for display on the FDI. The crew may exercise manual attitude control about all vehicle axes with the ACA in either the Rate Command or Minimum Impulse mode. It is strongly recommended that powered flight not be attempted in the Minimum Impulse mode. During a thrusting maneuver in the PGNS/Attitude Hold mode, the PGNCs will not be responsible if register overflows occur within the LGC.

P71 (continued)

9. Control of the LM DPS, RCS, and APS is transferred from the PGNCs to the Abort Guidance System (AGS) by placing the Guidance Control switch from PGNS to AGS.

The AGS will be capable of taking over control of the LM during any portion of the lunar descent or ascent or during either of the abort programs (P70 or P71). The AGS will guide the LM to a safe orbit.

The AGS may be initialized by the LGC at any time by manual selection of the AGS Initialization routine (R47).

In the event that the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC will continue computation of position and velocity, the desired thrust vector, and the desired attitude errors. However, the PGNCs will not be responsible if register overflows occur within the LGC.

10. The PGNCs can generate two types of attitude errors for display on the FDAI:
- Mode 1—Selected by Extended Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
 - Mode 2—Selected by Extended Verb 62. Total attitude errors used to assist crew in manually maneuvering the vehicle.
11. The Load DAP Data routine (R03) was completed prior to DPS ignition for the powered landing maneuver and should not be selected during this program.
12. This program may be called in two ways:
- Abort Stage button—If the Abort Stage button is used during the powered descent or the DPS Abort program (P70), it will be detected by the Abort Discretes Monitor routine (R11). R11 will then call this program.
 - V37E71E—This program may be called by the same procedure as other programs are manually called.

Selected Displays:

- V16 N77 (astronaut initiated)

Time to engine cutoff	XX b XX min/s
LM velocity normal to CSM plane	XXXX.X ft/s
- V16 N85 (astronaut initiated)

Components of velocity to be gained (body axis)	XXXX.X ft/s
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- V50 N25 (change guidance control mode)

Checklist code	00203
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- V06 N63

Absolute value of velocity	XXXX.X ft/s
Altitude rate	XXXX.X ft/s (+ ascent)
Computed altitude	XXXX.X ft
- V06 N76 (astronaut initiated)

Downrange velocity	XXXX.X ft/s
Radial velocity	XXXX.X ft/s
Crossrange	XXXX.X nmi
- V16 N44 (results from V82E)

Apocenter altitude	XXXX.X nmi
Pericenter altitude	XXXX.X nmi
TFF	XX b XX min/s

P72—CSM COELLIPTIC SEQUENCE INITIATION (CSI) TARGETING PROGRAM

Purpose:

1. To calculate parameters associated with the following concentric flight plan maneuvers for CSM execution of the maneuvers under the control of the CMC: the Coelliptic Sequence Initiation (CSI) and the Constant Delta Altitude maneuver (CDH).
2. To calculate these parameters based upon maneuver data approved and keyed into the LGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.

Assumptions:

1. At a selected TPI time the line of sight between the CSM and the LM is selected to be a prescribed angle (E) from the horizontal plane defined at the CSM position.
2. The time between CSI ignition and CDH ignition must be computed to be greater than 10 minutes for successful completion of the program.
3. The time between CDH ignition and TPI ignition must be computed to be greater than 10 minutes for successful completion of the program.
4. CDH Delta V is selected to minimize the variation of the altitude difference between the orbits.
5. CSI burn is defined such that the impulsive Delta V is in the CSM horizontal plane at CSI ignition.
6. The pericenter altitude of the orbit following CSI and CDH must be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit) for successful completion of this program.
7. The CSI and CDH maneuvers are assumed to be parallel to the plane of the LM orbit, however crew modification of Delta V(LV) components may result in an out-of-plane CSI maneuver.
8. The Rendezvous Radar may or may not be used to update the LM or CSM vectors for this program. If radar use is desired the radar was turned on and locked on the CSM by previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
9. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20). If selected, P20 will define the status of the ISS.
10. This program is selected by the astronaut by the DSKY entry.

Selected Displays:

1. V06 N11

Time of ignition for CSI	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N55

Number of apsidal crossings	0000X
Elevation angle at TPI	XXX.XX deg
Central angle of passive vehicle	XXX.XX deg
3. V06 N37

Time of TPI ignition	00XXX h
	000XX min
	0XX.XX s

P72 (continued)

4. V06 N75	
Delta altitude	XXXX.X nmi
ΔT (CDH-CSI)	XX b XX min/s
ΔT (TPI-CDH)	XX b XX min/s
5. V06 N81	
Components of ΔV (LV) for CSI	XXXX.X ft/s
6. V06 N82	
Components of ΔV (LV) for CDH	XXXX.X ft/s
7. V16 N45	
Marks	XXXXX.
Time from CSI ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
8. V06 N16 (results from V90E)	
Time of event	00XXX. h
	000XX. min
	0XX.XX s
9. V06 N90 (results from V90E)	
Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

P73—CSM CONSTANT DELTA ALTITUDE (CDH)
TARGETING PROGRAM

Purpose:

1. To calculate parameters associated with the concentric flight plan maneuvers with the exception of Coelliptic Sequence Initiation (CSI) for CSM execution of the maneuvers under control of the CMC. The concentric flight plan maneuvers are the Coelliptic Sequence Initiation (CSI), the Constant Delta Altitude maneuver (CDH), the Transfer Phase Initiation (TPI), and the Transfer Phase Final (TPF) or braking maneuver.
2. To calculate these parameters based upon maneuver data approved and keyed into the LGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.

P73 (continued)

Assumptions:

1. This program is based upon previous completion of the Coelliptic Sequence Initiation (CSI) Targeting program (P72). Therefore:
 - a. At a selected TPI time the line of sight between the CSM and the LM was selected to be a prescribed angle (E) from the horizontal plane defined at the CSM position.
 - b. The time between CSI ignition and CDH ignition was computed to be greater than 10 minutes.
 - c. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - d. The variation of the altitude difference between the orbits was minimized.
 - e. CSI burn was defined such that the impulsive Delta V was in the CSM horizontal plane at CSI ignition.
 - f. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit).
 - g. The CSI and CDH maneuvers were assumed to be parallel to the plane of the LM orbit. However, crew modification of Delta V(LV) components may have resulted in an out-of-plane CSI maneuver.

Unless the inputs to this program are changed from those values inserted in P72, the calculated parameters for the remaining maneuvers of the concentric flight plan will vary from those originally calculated and displayed only due to the continuous radar updating of the LM or CSM orbit.

2. The Rendezvous Radar may or may not be used to update the LM or CSM state vectors for this program. If radar use is desired the radar should have been turned on and locked on the CSM by previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
3. The ISS need not be on to complete this program unless automatic state vector updating is required by the Rendezvous Navigation program (P20). If selected, P20 will define the status of the ISS.
4. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N13

Time of ignition for CDH	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N75

Delta altitude	XXXX.X nmi
ΔT (TPI-CDH)	XX b XX min/s
ΔT (TPI-NOMTPI)	XX b XX min/s
3. V06 N81

Components of ΔV (LV) for CDH	XXXX.X ft/s
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4. V16 N45

Marks	XXXXX.
Time from CDH ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg

P73 (continued)

5. V06 N16 (results from V90E)

Time of event

00XXX. h

000XX. min

0XX.XX s

6. V06 N90 (results from V90E)

Y

XXX.XX nmi

YDOT

XXXX.X ft/s

PSI

XXX.XX deg

P74—CSM TRANSFER PHASE INITIATION (TPI)
TARGETING PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the CMC for CSM execution of the Transfer Phase Initiation (TPI) maneuver. Given:
 - a. Time of ignition (TIG(TPI)) or the elevation angle (E) of the CSM/LM LOS at TIG(TPI).
 - b. Central angle of transfer (CENTANG) from TIG(TPI) to intercept time.
2. To calculate TIG(TPI) given E or E given TIG(TPI).
3. To calculate these parameters based upon maneuver data approved and keyed into the LGC by the astronaut.
4. To display to the astronaut and the ground certain dependent variables associated with the maneuver for approval by the astronaut/ground.

Assumptions:

1. This program is based upon previous completion of the Constant Delta Altitude (CDH) Targeting program (P73). Therefore:
 - a. At a selected TPI time (now in storage) the line of sight between the CSM and the LM was selected to be a prescribed angle (E) (now in storage) from the horizontal plane defined at the CSM position.
 - b. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - c. The variation of the altitude difference between the orbits was minimized.
 - d. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit).
 - e. The CSI and CDH maneuvers were assumed to be parallel to the plane of the LM orbit. However, crew modification of Delta V(LV) components may have resulted in an out-of-plane CDH maneuver.

Unless the inputs to this program are changed from those inserted in P72 and/or P73, the calculated parameters for the remaining maneuvers of the concentric flight plan will vary from those originally calculated and displayed only due to the continuous radar updating of the LM or CSM orbit.

2. The Rendezvous Radar may or may not be used to update the LM or CSM state vectors for this program. If radar use is desired the radar should be turned on and locked on the CSM by previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
3. There is no requirement for ISS operation during this program unless automatic state vector updating is desired by the Rendezvous Navigation program (P20). If selected, P20 will define the status of the ISS.

P74 (continued)

4. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone, the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

5. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N37

Time of ignition for TPI	00XXX. h
	000XX. min
	0XX.XX s
2. V06 N55

Integration constant	0000X (00000—Kepler conic integration with no target offset) 00001—Precision integration with one target offset. 00002—Precision integration with two target offsets.)
Elevation angle	XXX.XX deg
Central angle of passive vehicle	XXX.XX deg
3. V06 N58

Perigee altitude (post TPI)	XXXX.X nmi
ΔV for TPI	XXXX.X ft/s
ΔV for TPF	XXXX.X ft/s
4. V06 N81

Components of ΔV (LV) for TPI	XXXX.X ft/s
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5. V06 N59

Components of ΔV (LOS) for TPI	XXXX.X ft/s
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6. V16 N45

Marks (RR)	XXXXX.
Time from TPI ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg
7. V06 N52 (astronaut initiated)

Central angle of active vehicle	XXX.XX deg
---------------------------------	------------
8. V06 N16 (results from V90E)

Time of event	00XXX. h
	000XX. min
	0XX.XX s
9. V06 N90 (results from V90E)

Y	XXX.XX nmi
YDOT	XXXX.X ft/s
PSI	XXX.XX deg

**P75—CSM TRANSFER PHASE MIDCOURSE (TPM)
TARGETING PROGRAM**

Purpose:

1. To calculate the required Delta V and other initial conditions required by the CMC for CSM execution of the next midcourse correction of the transfer phase of an active CSM rendezvous.

Assumptions:

1. There is no requirement for ISS operating during this program, unless automatic state vector updating is desired by the Rendezvous Navigation program (P20). If selected, P20 will define the status of the ISS.
2. The Rendezvous Radar is on and is locked on the CSM. This was done during previous selection of P20. Radar sighting marks will be made automatically approximately once a minute when enabled. The rendezvous tracking mark counter is zeroed by the selection of P20 and after each thrusting maneuver.
3. The time of intercept (T(INT)) was defined by previous completion of the Transfer Phase Initiation (TPI) Targeting program (P74) and is presently available in LGC storage.
4. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.

5. The program is selected by the astronaut by DSKY entry prior to any anticipated CMC rendezvous midcourse correction requiring LM parameter computation.

Selected Displays:

1. V06 N81
Components of ΔV (LV) for TPM XXXX.X ft/s
2. V06 N59
Components of ΔV (LOS) for TPM XXXX.X ft/s
3. V16 N45
Marks (RR) XXXXXX.
Time of TPM ignition XX b XX min/s
Middle gimbal angle XXX.XX deg
4. V06 N52 (astronaut initiated)
Central angle of active vehicle XXX.XX deg
5. V06 N16 (results from V90E)
Time of event 00XXX. h
000XX. min
0XX.XX s
6. V06 N90 (results from V90E)
Y XXX.XX nmi
YDOT XXXX.X ft/s
PSI XXX.XX deg

P76—TARGET DELTA V PROGRAM

Purposes:

1. To provide a means of notifying the LGC that the CSM has changed its orbital parameters by the execution of a thrusting maneuver.
2. To provide to the LGC the Delta V applied to the CSM to enable an updating of the CSM state vector.

Assumptions:

1. The LM crew has the Delta V to be applied to the CSM in local vertical axes at the specified TIG. These values are displayed prior to TIG by the thrusting programs (P40 and P41 in the CMC). No provision is made in these thrusting programs to display the results of the maneuver in a form usable by this program.
2. If the Rendezvous Navigation program (P20) or the Lunar Surface Navigation program (P22) is in process this program must be selected prior to the CSM thrusting maneuver. This can be assured by voice communication between the LM and CSM.
3. This program is selected by the astronaut by DSKY entry.

Selected Displays:

1. V06 N33
 Time of ignition of other vehicle
 00XXX. h
 00XX. min
 0XX.XX s
2. V06 N84
 Components of ΔV (other vehicle)
 XXXX.X ft/s

ASPO 45 CRT DISPLAYS

MSK-683 (CM)

MSK-966 (CM)

MSK-1123 (LM)

MSK-1137 (LM)

CSM GNC PRIMARY TAB

0683

GMT			SITE				QUADA		QUADB		QUADC		QUADD	
GETA			WPU	CAL C	LES									
CTE			HE	P/T R	PCT									
CMC			PKG	TEMP	*F									
GETC			HE	TK P	PSIA									
CMC ΔT			HE	TK T	*F									
ISS			HE	MN P	PSIA									
OPT			FU	MN P	PSIA									
CMC			OX	MN P	PSIA									
ID			CM-RCS			SYS A		SYS B			SPS			
VERB			HE	TK P	PSIA					OX TK	PSI			
NOUN			HE	MN P	PSIA					OX IN	PSI			
PRGM										EG CH	PSI			
										FU TK	PSI			
										FU IN	PSI			
										HE TK	PSI			
REG 1			PITCH			YAW			ROLL					
REG 2														
REG 3														
DAP			ISS ATT											
RATE	DB		ACDU											
			FCDU											
VEH ACC			ERR											
VG X			CMC									HE TK T *F		
VG Y			SCS									OX FD LN *F		
VG Z			ENT									FU FD LN *F		
PIPX			RATE									OX LN I *F		
PIPY			G/N									FU LN I *F		
PIPZ			SCS									EG VLV *F		
PIP T												N2 T1 PSI		
TEV			GMB CMD									N2 T2 PSI		
TIG			OCDU DC									OX T1 PCT		
			SPS GMB									OX T2 PCT		
			AT TVC									FU T1 PCT		
			MN TVC									FU T2 PCT		

MSK-683

GMT	- GREENWICH MEAN TIME	D H M S XX:XX:XX:XX	PIPX, PIPY, PIFZ	- X, Y, AND Z PIPA COUNTS	±XXXXX COUNTS
GETA	- GROUND ELAPSED TIME ACTUAL	H M S XXXX:XX:XX	PIP T	- PIPA TEMPERATURE	+XXX.X °F
CIE	- CENTRAL TIMING EQUIPMENT TIME	H M S XXXX:XX:XX	TEV	- TIME OF EVENT	H M S XXXX:XX:XX
CNC	- CM COMPUTER CLOCK	H M S XXXX:XX:XX	TIG	- TIME TO/FROM IGNITION	H M S XXXX:XX:XX
GETC	- GROUND ELAPSED TIME COMPUTED	H M S XXXX:XX:XX	ISS	- ISS RESOLVER INDICATED ATTITUDE	+XXX.X DEG
CNC ΔT	- DIFFERENCE BETWEEN GETC AND CNC	S XXX.XXX	ACDU	- ACTUAL CDU ANGLES	+XXX.X DEG
ISS	- ISS MODE	OFF/TRM OR/CDU ZR/ CO ALN/FN ALN/ INTERTL/CAGE	PCDU	- FINAL DESIRED CDU ANGLES	+XXX.X DEG
OPT	- OPTICS MODE	OFF/ZERO/CNC/HAN	ERR CNC	- COMPUTED ATTITUDE ERRORS TO FDAI	±XX.X DEG
CNC	- RCS CONTROL MODE	AUTO/BOLD/FREE/SCS	ERR SCS	- SCS ATTITUDE ERRORS	±XX.X DEG
ID	- IDENTIFICATION OF DOWNLIST BEING TRANSMITTED		RATE ENT	- RATES COMPUTED IN ENTRY DAP	±XX.X DEG/SEC
*VERB	- DSKY VERB DISPLAY	XX	RATE G/H	- DAP COMPUTED BODY RATES	±XX.X DEG/SEC
*NOUN	- DSKY NOUN DISPLAY	XX	RATE SCS	- SCS DETERMINED BODY RATES	±XX.X DEG/SEC
*PRGM	- DSKY PROGRAM NUMBER DISPLAY	XX	GMB CMD	- COMPUTER COMMANDED SPS ENGINE COMMANDS	±XX.XX DEG
REG1, REG2, REG3	- DSKY ROWS 1, 2, AND 3	±XXXXX	OCDU DC	- OCDU DAC OUTPUT FOR GMB CMD	±XX.XX DEG
RATE	- SELECTED MAXIMUM DAP RATE	X.X DEG/SEC	SPS GMB	- SPS GIMBAL POSITION OUTPUTS FOR GMB CMD	±XX.XX DEG
DB	- SELECTED DAP DEADBAND	X.X DEG	AT TVC	- SCS AUTOMATIC CONTROL SPS	±X.XX DEG
VEH ACC	- VEHICLE ACCELERATION	±XXX.X FPS ²	MM TVC	- SCS MANUAL CONTROL SPS GIMBAL COMMANDS	±X.XX DEG
VG X, VG Y, VG Z	- VELOCITY TO BE GAINED IN SM COORDINATES	±XXXX. FPS	SITE	- SITE FROM WHICH DATA IS BEING RECEIVED	

*SEE CM SOFTWARE SECTION FOR FURTHER DEFINITION

ID		GMT		SITE		X/ROLL	Y/PITCH	Z/YAW
		CIE			PIPA			
FGWD	0	GETA			DELV			
FGWD	1	GETC			VGDMU			
FGWD	2	GETH						
FGWD	3	CMC			FCDU			
FGWD	4	TCMSV			DCDU			
FGWD	5	TIMSV			ACDU			
FGWD	6	TGO						
FGWD	7	TIG			ERROR			
FGWD	8	TEVNT			AK			
FGWD	9				ADOT			
FGWD	10	PG	FL	WARN	OMGAC			
FGWD	11	VB	NN	PRG				
				KKK	BIAS			
CHNL	11	R1		UPEST	MASS			
CHNL	12	R2		UPSW	IM	ACTOFF		
CHNL	13	R3		CMD	CSM	GMBCMD		
CHNL	14							
CHNL	30	REDO	DSTELL	HAPO		TMRK		
CHNL	31		FAIRG	CDRFL	HFER	VHFRNG	NM	
CHNL	32	RSBBQ			LAT	RANGE	NM	
CHNL	33				LONG	RRATE	FPS	
						THE/TAH	DEG	
IMDE	30	HLDFG		CRSTR		ELEVN	DEG	
IMDE	33			CDH Δ ALT NM		OFSTPT	NM	
OPTIMDE		RCSFG	STARID1	VGTIGX		CNTL	DEG	
DPDTR1			STARID2	VGTIGY		TRNF		
DPDTR2		CDU SHFT		VGTIGZ		TTPI		
		CDU TRUN				TTFF		

ID	- IDENTIFICATION OF DOWNLIST BEING TRANSMITTED		ADOT	- DAP COMPUTED BODY RATES	XX.XX DEG/SEC
GMT	- GREENWICH MEAN TIME	D H M S XX:XX:XX	OMGAC	- COMMANDED BODY RATES FROM CROSS PRODUCT STEERING	XX.XX DEG/SEC
CTE	- CENTRAL TIMING EQUIPMENT TIME	H M S XXXX:XX:XX	BIAS	- COMPUTED PIPA BIAS	±X.XXXX FT/SEC
GETA	- GROUND ELAPSED TIME (ACTUAL)	H M S XXXX:XX:XX	*FGWD 0 - FGWD 11	- COMPUTER FLAGWORDS 0 THRU 11	XXXXX ₈
GETC	- GROUND ELAPSED TIME (COMPUTED)	H M S XXXX:XX:XX	*CHAN 11 - CHAN 14	- COMPUTER OUTPUT CHANNELS	XXXXX ₈
GETH	- GROUND ELAPSED TIME (RTCC)	H M S XXXX:XX:XX	*CHAN 30 - CHAN 33	- COMPUTER INPUT CHANNELS	XXXXX ₈
CMC	- CM COMPUTER CLOCK	H M S XX:XX:XX.XX	*IDDE30, IDDE33	- COMPUTER IDU STATUS REGISTERS	XXXXX ₈
TCMSV	- TIME OF CM STATE VECTOR	H M S XX:XX:XX.XX	*OPDME	- COMPUTER OPTICS STATUS REGISTER	XXXXX ₈
TIMSV	- TIME OF IM STATE VECTOR	H M S XX:XX:XX.XX	*DPDTR1, DPDTR2	- DATA FOR DAP SELECTION AND OPERATION	XXXXX ₈
TGO	- TIME TO CUTOFF	H M S XX:XX:XX	*PG	- COMPUTER PROGRAM NUMBER	XX
TIG	- TIME TO/FROM IGNITION	H M S XX:XX:XX.XX	FL	- VERB/NOU FLASHER STATUS	
TEVNT	- TIME OF EVENT	H M S XX:XX:XX.XX	WARN	- CMC WARNING LAMP STATUS	
SITE	- SITE FROM WHICH DATA IS BEING RECEIVED		PRC	- PROGRAM ALARM LAMP STATUS	
PIPA	- PIPA COUNTS	±XXXXX COUNTS	KCK	- UPLINK DATA STATUS	
DELV	- VALUES OF PIPA'S AT LAST READING, CORRECTED FOR SCALE FACTOR ERROR AND BIAS	±XXXXX FPS	UPFST	- BLOCK INLINK DISCRETE STATUS	
VOIDMU	- VELOCITY TO BE GAINED IN SM COORDINATES	±XXXX.X FPS	UPSW	- UPLINK ACCEPT/BLOCK SWITCH STATUS	
FCDU	- FINAL DESIRED CDU ANGLES	°XX.XX DEG	CHD	- UPLINK TOO FAST STATUS	
DCDU	- DESIRED CDU ANGLES	°XX.XX DEG	*VB	- DSKY VERB DISPLAY	XX
ACDU	- ACTUAL CDU ANGLES	°XX.XX DEG	*NN	- DSKY NOU DISPLAY	XX
ERROR	- ATTITUDE ERRORS COMPUTED BY RCS DAP	±XX.XX DEG	R1, R2, & R3	- DSKY ROW 1, ROW 2, AND ROW 3 DISPLAYS	±XXXXX
CDRFL	- RETURN ADDRESS INFORMATION ASSOCIATED WITH DSKY DISPLAYS	XXXXX ₈	REDO	- NUMBER OF RESTARTS	XXXXX ₈
AK	- RCS DAP FOLLOWING ERRORS OR TVC DAP ATTITUDE ERRORS	±XX.XX DEG	RSBQ	- VALUE OF RBAIK AND Q REGISTERS AT THE TIME OF A RESTART	XXXXX ₈
			DSTBL	- DISPLAY TABLE OF DSKY STATUS LIGHTS X0400 ₈ = PROGRAM CAUTION, X0C00 ₈ = TRACKER WARNING, X0020 ₈ = NO ATTITUDE, X0040 ₈ = CIGAL LOCK	XXXXX ₈
			*FALRG	- 1ST, 2ND, AND MOST RECENT ALARM CODES	XXXXX ₈
			*SEE CM SOFTWARE SECTION FOR FURTHER DEFINITION		

MSK-566 (CONTINUED)

*HLDPO	- STATUS OF ATTITUDE HOLD CONTROL MODE OF CSM RCS DAP	XXXXX ₈	VGTIX, VGTIY, VGTICZ	- COMPONENTS OF VELOCITY TO BE GAINED IN ECI COORDINATES	±XXXX.X FPS
*RCSPO	- DATA FOR RCS DAP	XXXXX ₈	DMK	- TIME OF LAST MARK (OPTICS/VHF)	H M S XXX:XX:XX.XX
STARID1	- IDENTIFICATION NUMBER OF STAR 1	XXX ₈	VHFRNG	- RANGE TO OTHER VEHICLE AS DETERMINED BY VHF RANGING SYSTEM	±XXX.XX NM
STARID2	- IDENTIFICATION NUMBER OF STAR 2	XXX ₈	RANGE	- COMPUTED RANGE TO OTHER VEHICLE	±XXX.XX NM
CDU SHFT	- OPTICS SHAFT ANGLE DIVIDED BY TEN	±XX.XXX DEG	RRATE	- COMPUTED RANGE RATE WITH RESPECT TO OTHER VEHICLE	±XXXX.X FPS
CDU TRIM	- OPTICS TURNION ANGLE	±XX.XXX DEG	THETAH	- RANGE BETWEEN PRESENT POSITION AND ESTIMATED LANDING SITE	XXX.X DEG
IM	- PRESENT MASS OF THE IM	XXXXX LBS	ELEVH	- DESIRED LOS ANGLE AT TPI	±XXX.XX DEG
CSM	- PRESENT MASS OF THE CSM	XXXXX LBS	OPSTPT	- DESIRED SEPARATION OF THE TWO VEHICLES AT RENDEZVOUS	±XXX.XX NM
ACTOFF	- SPS GIMBAL TRIMS	±XX.XXX DEG	CNTR ANG	- ORBITAL CENTRAL ANGLE OF THE PASSIVE VEHICLE DURING TRANSFER FROM TPI TO INTERCEPT	±XXX.XX DEG
GRCOMD	- COMPUTER COMMANDED SPS ENGINE COMMANDS	±XX.XXX DEG	TRUF	- DESIRED TRANSFER TIME FOR LAUNCH MANEUVER	H M S XXX:XX:XX.XX
HAPO	- ALTITUDE AT APOGEE	±XXXX.X NM	TTP1	- TIME OF INITIATION OF TPI MANEUVER	H M S XXX:XX:XX.XX
EPER	- ALTITUDE AT PERIGEE	±XXXX.X NM	TTFP	- TIME OF INTERCEPT	H M S XXX:XX:XX.XX
LAT	- LATITUDE OF LANDMARK	±XX.XXX DEG			
LONG	- LONGITUDE OF LANDMARK	±XXX.XX DEG			
CRSTR	- CROSS PRODUCT STEERING CONSTANT	±X.XXXX			
CDH Δ ALT	- DIFFERENCE IN ALTITUDE BETWEEN VEHICLES AT CDH	±XX.XX NM	*SEE CH SOFTWARE SECTION FOR FURTHER DEFINITION		

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LM GUID, CONTROL AND PROP RT

AEA LGC PCM

1123

GET	_____	MET	_____	
AGS	_____	LGC	_____	LGC FMT _____
	TGO	_____	TTF/8	_____
PGNS RATE	_____	_____	_____	_____
RGA RATE	_____	_____	_____	_____
ASA RATE	_____	_____	_____	_____
	ROLL/Z	PITCH/Y	YAW/X	
ATT CMDS	_____	_____	_____	_____
LOC VER/HOR	_____	_____	_____	_____
RSVR GMBL	_____	_____	_____	_____
ICDUD ATT	_____	_____	_____	_____
CDUA ATT	_____	_____	_____	_____
IMU ATT	_____	_____	_____	_____
AGS ATT	_____	_____	_____	_____
PGNS ERR	_____	_____	_____	_____
AGS ERR	_____	_____	_____	_____
MMNT OFFSET	_____	_____	_____	_____
AGS VEL	_____	_____	_____	_____
LGC DEL VEL	_____	_____	_____	_____
AGS DEL VEL	_____	_____	_____	_____
AGS ULL	_____	ACT VEL	_____	_____
	AUTO	_____	FO	_____
R	ATT H	_____	F1	_____
P	_____	_____	F2	_____
Y	AP	_____	DEDA	_____
RR	VD	_____	AD	_____
TRK	RD	_____	RO	_____
R	R	_____	CLR	_____
RDT	VX	_____	M	_____
SH	VY	_____		_____
TR	VZ	_____	REDO	_____

GET	-	GROUND ELAPSED TIME	H M S XX:XX:XX	AGS DEL VEL	-	ABORT GUIDANCE SYSTEM MEASURED VELOCITY	XX.X FT/SEC
MET	-	MISSION ELAPSED TIME	H M S XX:XX:XX	AGS ULL	-	ABORT GUIDANCE ULLAGE MEASUREMENT	XX.X FT/SEC
AGS	-	ABORT GUIDANCE SYSTEM TIME	H M S XX:XX:XX	ACT VEL	-	ACCUMULATED VELOCITY ALONG THRUST	XX.X FT/SEC
LGC	-	LM GUIDANCE COMPUTER TIME	H M S XX:XX:XX	AUTO	-	AUTO STABILIZATION MODE STATUS	XX/BLANK
LGC FMT	-	IDENTIFICATION OF DOWNLIST BEING TRANSMITTED		R P Y	-	ROLL, PITCH AND YAW ACHIEVED FROM PULSES, DIRECT OR AUTO (NORM)	±XX.X DEG
SITE	-	IDENTIFICATION OF SITE FROM WHICH DATA IS BEING RECEIVED		ATT H	-	ATTITUDE HOLD MODE STATUS	XX/BLANK
TGO	-	TIME TO GO UNTIL ENGINE CUTOFF	M S XX:XX	*FO } *F1 } *F2 }	ALARM CODES	- FIRST - SECOND - MOST RECENT	
TTF/8	-	TIME TO GO UNTIL END OF PHASE (DESCENT PROGRAMS)	M S XX:XX	*RR	-	RADAR MODE FLAGWORD (RADMODES)	XXXXX ₃
PGNS RATE	-	ROLL, PITCH, YAW DAP RATES	XX.X DEG/SEC	TRK	-	RADAR TRACK ENABLE	CH 12 B 14
RGA	-	AGS BODY MOUNTED RATE GYRO OUTPUT	XX.X DEG/SEC	RDT	-	RENDEZVOUS RADAR RANGE RATE	XXXX FT/SEC
ASA	-	AGS ABORT SENSING ASSEMBLY BODY RATES	XX.X DEG/SEC	R	-	RENDEZVOUS RADAR RANGE	XX.XX NM
ATT CHDS	-	LGC ATTITUDE COMMANDS	XX.X DEG	SH	-	RENDEZVOUS RADAR SHAFT ANGLE	±XXX DEG
LOC VER/HOR	-	BODY ANGLES FROM THE LOCAL VERTICAL COORDINATE SYSTEM	XX.X DEG	TR	-	RENDEZVOUS RADAR TURNION ANGLE	±XXX DEG
RSVR QMBL	-	1X RESOLVER GIMBAL ANGLES	XXX.X DEG	AP	-	LANDING ANTENNA POSITION	1 OR 2
ICDUD ATT	-	DESIRED CDU ANGLES TO THE DAP	XXX.X DEG	VD	-	LANDING VELOCITY DATA GOOD	GOOD/BAD
CDUA ATT	-	ACTUAL CDU ANGLES	XXX.X DEG	RD	-	LANDING RANGE DATA GOOD	GOOD/BAD
DMU ATT	-	1X RESOLVER GIMBAL ANGLES	XXX.X DEG	R	-	LANDING RADAR RANGE	X NM
AGS ATT	-	ABORT GUIDANCE SYSTEM BODY ANGLES	XXX.X DEG	V _X V _Y V _Z	-	LANDING RADAR VELOCITIES	±XXXXX FT/SEC
PGNS ERR	-	CDU-DAC OUTPUT	XX.X DEG	DEDA AD RD CLR M	-	AGS DSKY - ADDRESS - READOUT - CLEAR - REGISTER 5 DIGIT CONTENTS	
AGC ERR	-	ABORT GUIDANCE SYSTEM ATTITUDE ERRORS	XXX.X DEG	REDO	-	NUMBER OF LGC RESTARTS	
MAGT OFFSET	-	ANGULAR ACCELERATION ABOUT ROLL AND PITCH	XX.X DEG/SEC ²	DSKY *P *V *N 1 2 3	-	PROGRAM - VERB - NOUN - ROW 1, 2, AND 3	
AGS VEL	-	ABORT GUIDANCE SYSTEM INDICATED VELOCITY	XXXX FT/SEC				
LGC DEL VEL	-	PIPA OUTPUT FOR A 2 SECOND INTERVAL	XX.X FT/SEC				

*SEE LM SOFTWARE SECTION FOR FURTHER DEFINITION

GET	- GROUND ELAPSED TIME	H M S XXX:XX:XX	WT	- MASS OF THE LM	XXXXX LBS
LGC	- LM COMPUTER CLOCK	H M S XXX:XX:XX	RTCC	- RTCC COMPUTED MASS OF THE LM OR LM + CSM	XXXXX LBS
GMT	- GREENWICH MEAN TIME	H M S XXX:XX:XX	CSM	- MASS OF THE CSM	XXXXX LBS
SITE	- SITE FROM WHICH DATA IS BEING RECEIVED		PIP-S	- PIPA COUNTS	XXXXX ₁₀
D/L	- DOWNLIST IDENTIFICATION		RATE	- DESIRED RATES FOR AUTOMATIC MANEUVERS	±XX.X DEG/SEC
SELECT	- THROTTLE SELECT SWITCH STATUS	AUTO/BLANK	RHC	- SCALING STATUS ON RHC	NORM/FINE
DECA	- DESCENT THROTTLE COMMAND	±XXX.XX%	X-TRANS	- RCS FUEL SYSTEM SELECTION/NUMBER OF JETS TO BE USED FOR X- TRANSLATION	A OR B/2 OR 4
MAN THR	- MANUAL THROTTLE COMMAND	XXX%	*DAP	- DAP FLAGWORD (DAPBOOLS)	XXXXX ₈
AUTO THR	- AUTO THROTTLE COMMAND	XXX%	*CH 11 - CH 14	- LM COMPUTER OUTPUT CHANNELS	XXXXX ₈
CMD THR	- TOTAL THROTTLE COMMAND (MAN THR + AUTO THR)	XXX%	*CH 30 - CH 33	- LM COMPUTER INPUT CHANNELS	XXXXX ₈
VAR ACT	- VARIABLE ACTUATOR POSITION	XXX%	*RAD	- RADAR FLAGWORD (RADMODES)	XXXXX ₈
GUID CMD	- LGC COMMANDED THRUST	XXX%	LOCAL	- BODY ATTITUDE ABOUT LOCAL HORIZONTAL	±XXX.X DEG
TCP	- THRUST CHAMBER PRESSURE	XXX%	CMD	- GIMBAL COMMANDS/CYRO TORQUE COMMANDED/DESIRED CDU ANGLES IN COARSE ALIGN MODE	±XXX.XX DEG
LGC ERR	- TOTAL OR DAP FOLLOWING ATTITUDE ERRORS	±XX.X DEG	SERVO	- GIMBAL SERVO ERRORS	±XX.X VOLTS
ACS ERR	- ACS POSITIONAL ERROR	±XXX.X DEG	RSVR-S	- GIMBAL RESOLVER INDICATED ANGLES	±XXX.XX DEG
OMEGA-D	- DESIRED BODY RATES FOR AUTOMATIC MANEUVER	±X.XX DEG/SEC	RSVR-F	- GIMBAL RESOLVER INDICATED ANGLES IN FDAI COORDINATES	±XXX.XX DEG
OFFSET	- COMPUTED ANGULAR ACCELERATION ABOUT Y AND Z BODY AXES DUE TO THE ENGINE	±XX.XXX DEG/SEC ²	ACT-F	- LM ATTITUDE TRANSFORMED TO FDAI COORDINATES	±XXX.XX DEG
QMBL DR	- DIRECTION OF ENGINE BELL MOTION	±R & ±P	IDES-F	- INTERMEDIATE DESIRED CDU ANGLES TRANSFORMED TO FDAI COORDINATES	±XXX.XX DEG
A/H	- ATTITUDE HOLD MODE STATUS	XX/BLANK	FDES-F	- FINAL DESIRED CDU ANGLES TRANSFORMED TO FDAI COORDINATES	±XXX.XX DEG
AUTO	- AUTO STABILIZATION MODE STATUS	XX/BLANK	AGS-F	- AGS EULER ANGLES TRANSFORMED TO FDAI COORDINATES	±XXX.XX DEG
+ TORQ-U, TORQ-V, TORQ-P	- CUMULATIVE SUM OF POSITIVE COMMANDED TORQUE ABOUT CONTROL AXES U, V, AND P RESPECTIVELY	XX.XX SECS	ΔERR-S	- DIFFERENCE BETWEEN PGMS EULER ANGLES AND AGS EULER ANGLES	±XX.X DEG
- TORQ-U, TORQ-V, TORQ-P	- CUMULATIVE SUM OF NEGATIVE COMMANDED TORQUE ABOUT CONTROL AXES U, V, AND P RESPECTIVELY	XX.XX SECS			

*SEE LM SOFTWARE SECTION FOR FURTHER DEFINITION

MSK-1137 (CONTINUED)

PGNS-B	- DAP COMPUTED BODY RATES	±XX.XX DEG/SEC	LR RWG	- STATUS OF LANDING RADAR RANGE DATA	GOOD/BAD
RGA-B	- AGE RATE GYRO OUTPUTS IN BODY COORDINATES	±XX.X DEG/SEC	VEL	- STATUS OF LANDING RADAR VELOCITY DATA	GOOD/BAD
AGS-B	- AGE INDICATED LINEAR VELOCITY IN BODY COORDINATES	±XX.X FT/SEC	VXB, VYB, VZB	- VELOCITY DATA IN BODY AXIS COORDINATES	±XXXX FT/SEC
LOC-B	- ACCUMULATED PIPA COUNTS WHILE SERVICES IS RUNNING IN BODY AXIS COORDINATES	±XX.X FT/SEC	RWG	- LANDING RADAR SLANT RANGE ALTITUDE	XXXXX FT
ACT ΔV	- ACTUAL ΔV GAINED (GROUND COMPUTED)	XX.X FT/SEC	ΔH	- PGNS COMPUTED ALTITUDE	XXXXX FT
SM	- ACCUMULATED PIPA COUNTS OVER 2 SECONDS IN STABLE MEMBER COORDINATE	±XX.X FT/SEC	RWG	- AGE COMPUTED ALTITUDE	XX.XX NM
DAP	- LEFT - POSITION OF GUIDANCE AND CONTROL SWITCH	AGS/PGNS	RR	- STATUS OF RENDEZVOUS RADAR	ON/OFF
	RIGHT - STATUS OF THE DAP	ON/OFF	DATA	- MODE STATUS OF RENDEZVOUS RADAR	AUTO/MAN
TIO	- TIME OF IGNITION	H M S XXX:XX:XX	MODE	- STATUS OF RENDEZVOUS RADAR ANTENNA	1/2
TOO	- TIME TO ENGINE CUTOFF	S XXXXX.	LOC	- RENDEZVOUS RADAR ANTENNA POSITION (CDU)	±XX.X DEG
TEVT	- TIME OF LAST/NEXT SIGNIFICANT EVENT	H M S XXX:XX:XX	RR	- RENDEZVOUS RADAR ANTENNA POSITION IN FDIAT COORDINATES	±XX.X DEG
T/P	- TIME TO END OF PHASE (DESCENT ONLY)	S XXXXX.	ENR	- COMPUTER COMMANDED RENDEZVOUS RADAR ANTENNA RATE	±XX.XX DEG/SEC
LOC	- LOC WARNING LAMP STATUS		RANGE	- RENDEZVOUS RADAR RANGE	XXX.XX NM
ISS	- ISS WARNING LAMP STATUS		RNGRT	- RENDEZVOUS RADAR RANGE RATE	±XXXX FT/SEC
PGNS	- PGNS CAUTION LAMP STATUS		800 ~	- 800 ~ VOLTAGE	XX.X VOLTS
PROG	- PROGRAM CAUTION LAMP STATUS		3200 ~	- 3200 ~ VOLTAGE	XX.X VOLTS
*FREGO, FREG1, FREG2	- 1ST, 2ND, AND MOST RECENT ALARM CODE	XXXXX ₉	120V	- 120 VDC PIPA SUPPLY VOLTAGE	XXX VOLTS
*REDO	- NUMBER OF RESTARTS	XXXXX ₉	BIAS	- TM BIAS VOLTAGE	X.XX VOLTS
*PROG	- COMPUTER PROGRAM NUMBER	XX	LR	- LANDING RADAR ANTENNA TEMPERATURE	±XX.X °F
*VERB	- DSKY VERB DISPLAY	XX	RR	- RENDEZVOUS RADAR ANTENNA TEMPERATURE	±XX.X °F
*NOUN	- DSKY NOUN DISPLAY	XX	PIP	- PIPA TEMPERATURE	±XX.X °F
FL	- INDICATES WHETHER OR NOT VERB/NOUN FLASHER IS ON	FLASH/BLANK			
*R1, R2, R3	- DSKY ROW 1, ROW 2, AND ROW 3 DISPLAYS	±XXXXX		*SEE IN SOFTWARE SECTION FOR FURTHER DEFINITION	

LAUNCH AND BURN SCHEDULE

STABLE MEMBER ORIENTATIONS
TRANSLUNAR INJECTION
MIDCOURSE CORRECTIONS
LUNAR ORBIT INSERTION(LOI₁)
LUNAR ORBIT CIRCULARIZATION (LOI₂)
LM DESCENT AND LANDING
LM ASCENT AND RENDEZVOUS
TRANSEARTH INJECTION
MIDCOURSE CORRECTIONS
ENTRY

PRELAUNCH IMU COMPENSATION

CM

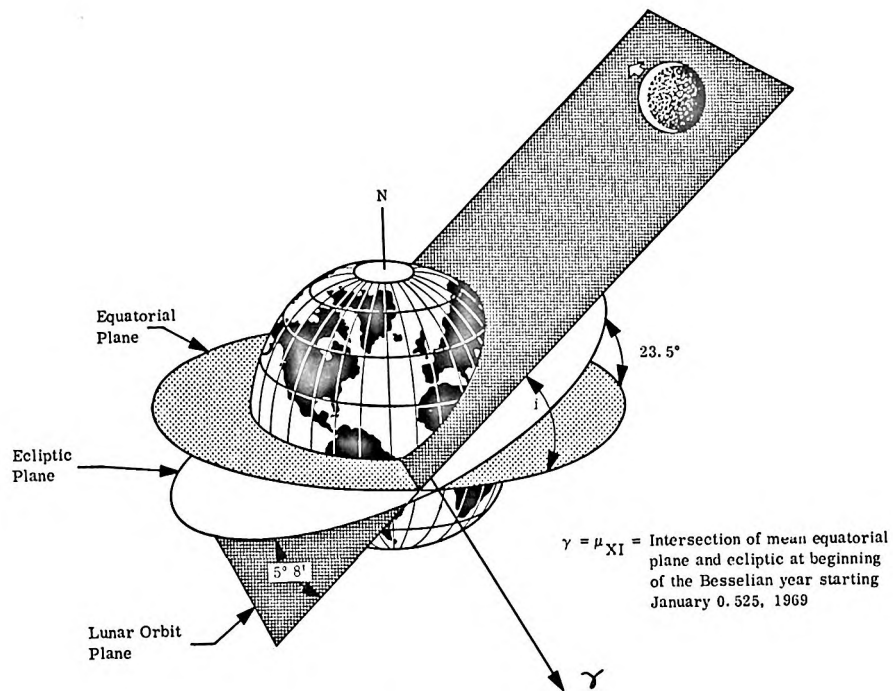
POSITION	GYRO DRIFTS			PIPA	
	NBD (meru)	ADIA (meru/g)	ADSRA (meru/g)	BIAS (cm/s ²)	SCALE FACTOR (ppm)
X					
Y					
Z					

LM

POSITION	GYRO DRIFTS			PIPA	
	NBD (meru)	ADIA (meru/g)	ADSRA (meru/g)	BIAS (cm/s ²)	SCALE FACTOR (ppm)
X					
Y					
Z					

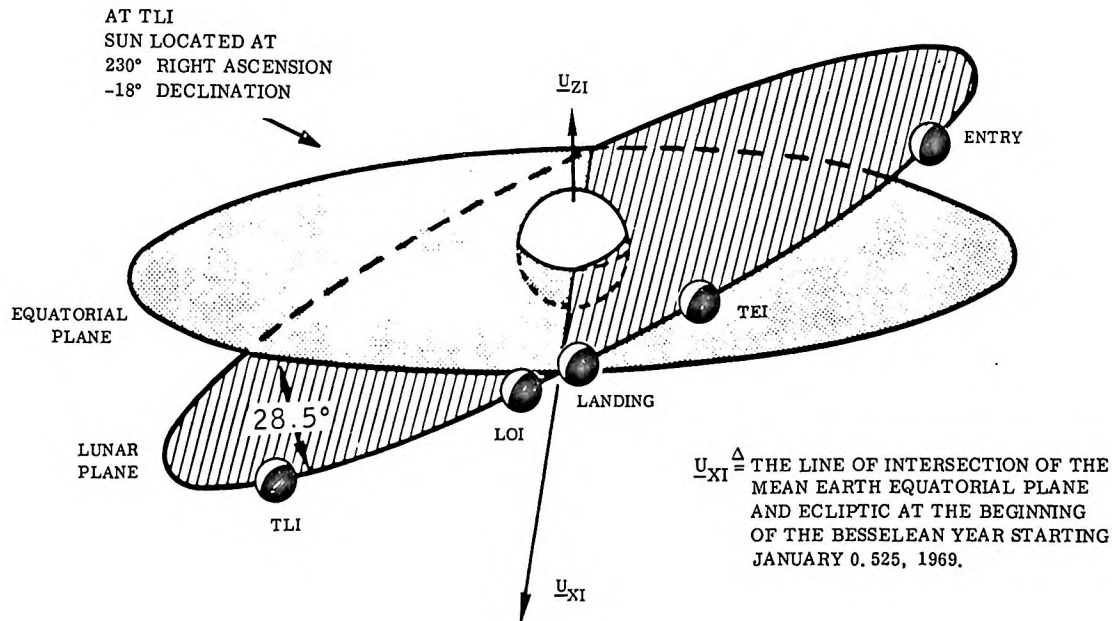
IMU COMPENSATION UPDATES

SPACECRAFT (CM or LM)	POSITION	GYRO NBD (meru)	PIPA BIAS (cm/s ²)	TIME OF UPDATE GET		
				h	min	s
	X					
	Y					
	Z					
	X					
	Y					
	Z					
	X					
	Y					
	Z					
	X					
	Y					
	Z					
	X					
	Y					
	Z					



Lunar Orbit Plane in 1969 (Inclination Angle, i , ~ 28 Degrees)

POSITION OF MOON AT VARIOUS STAGES OF APOLLO 12



APOLLO 12 CSM POWERED MANEUVER SUMMARY

EVENT	TYPICAL G. E. T. (h:min:s)	PROPULSION SYSTEM	BURN DURATION (s)	ULLAGE DURATION (s)	TOTAL ΔV (ft/s)	RESULTANT rp/ra (nmi)	GUIDANCE MODE	REFSMMAT
Orbit Insertion	11:53	-	-	-	-	100/100	-	Launch Pad
TLI	2:47:21.7	S-IVB	322.0	-	10,510	-	S-IVB/IU	Launch Pad
CSM/LM Ejection	4:13:00	SM-RCS	3.0	0	0.4	-	EXT ΔV	Launch Pad
S-IVB APS SEP	4:25:00	S-IVB APS	-	-	10.0	-	S-IVB/IU	-
S-IVB Slingshot	4:57:00	S-IVB	-	-	68.7	Solar Orbit	S-IVB/IU	-
MCC ₁	11:52:43.7	SPS/RCS	Nom. Zero	0	Nom. Zero	-	EXT ΔV	Launch Pad
MCC ₂	30:52:43.7	SPS	10	0	68.8	-	EXT ΔV	PTC
MCC ₃	61:28:47.5	SPS/RCS	Nom. Zero	0	Nom. Zero	-	EXT ΔV	PTC
MCC ₄	78:28:47.5	SPS/RCS	Nom. Zero	0	Nom. Zero	-	EXT ΔV	Landing Site
LOI ₁	83:28:47.5	SPS	360.2	0	2,890.4	59.7/170.1	EXT ΔV	Landing Site
LOI ₂	87:47:36.7	SPS	18.1	19.0	169.3	54.1/65.9	EXT ΔV	Landing Site
Undocking	107:58:00	-	-	-	-	-	-	-
CSM/LM SEP	108:27:49.5	SM-RCS	15.8	-	2.5	55.6/64.1	EXT ΔV	Landing Site
CSM Plane Change No. 1	119:47:02	SPS	19.4	15.0	372.4	56.9/62.7	EXT ΔV	Preferred
LM Jettison and Separation	148:00:00.0	SM-RCS	4.6	-	1.5	59.0/59.4	EXT ΔV	Liftoff
CSM Plane Change No. 2	159:01:46	SPS	18.1	16.0	360.0	57.8/61.2	EXT ΔV	Preferred
TEI	172:24:47.8	SPS	136.2	16.0	3,044.6	-	EXT ΔV	Preferred
MCC ₅	187:24:47.8	SPS/RCS	-	-	Nom. Zero	-	EXT ΔV	PTC
MCC ₆	222:26:36.0	SPS/RCS	-	-	Nom. Zero	-	EXT ΔV	PTC
MCC ₇	241:26:36.0	SPS/RCS	-	-	Nom. Zero	-	EXT ΔV	Entry
Entry	244:26:36	-	-	-	-	-	-	Entry

Lab

APOLLO 12 LM POWERED MANEUVER SUMMARY

EVENT	TYPICAL G. E. T. (h:min:s)	PROPULSION SYSTEM	BURN DURATION (s)	ULLAGE DURATION (s)	TOTAL ΔV (ft/s)	RESULTANT rp/ra (nm)	GUIDANCE MODE	REFSMAT
DOI	109:26:27.0	DPS	28.0	7.5	72.1	55.3/63.5	EXT ΔV	Landing Site
PDI	110:23:26.0	DPS	717.0	7.5	6,779.0	-	PGNCS	Landing Site
Touchdown	110:35:23.0							
Ascent	142:04:37.1	APS	430.6	0	6,049.0	9.0/46.5	PGNCS	Liftoff
CSI	143:01:25.3	RCS	44.7	-	49.9	44.5/46.7	EXT ΔV	Liftoff
LM Plane Change	143:31:29	RCS	-	-	Nom. Zero	44.5/46.7	EXT ΔV	Liftoff
CDH	143:59:49.9	RCS	2.0	-	4.4	44.4/45.3	EXT ΔV	Liftoff
TPI	144:38:56.1	RCS	22.2	-	24.8	43.8/61.9	Lambert	Liftoff
MCC ₁	144:53:52.1	RCS	-	-	Nom. Zero	43.8/61.9	Lambert	Liftoff
MCC ₂	145:08:52.1	RCS	-	-	Nom. Zero	43.8/61.9	Lambert	Liftoff
1st Braking Maneuver	145:17:44.5	RCS	-	-	Nom. Zero	43.8/61.9	Manual	Liftoff
2nd Braking Maneuver	145:20:15	RCS	10.7	-	12.0	49.1/60.9	Manual	Liftoff
3rd Braking Maneuver	145:21:28.3	RCS	8.7	-	9.8	53.9/60.2	Manual	Liftoff
4th Braking Maneuver	145:23:06.7	RCS	4.3	-	4.8	56.5/60.1	Manual	Liftoff
5th Braking Maneuver	145:24:26.3	RCS	4.1	-	4.7	59.2/60.0	Manual	Liftoff
APS Lunar Impact	149:28:00	RCS	100.0	100.0	201.0	-40/60	PGNCS	Liftoff

STABLE MEMBER ORIENTATION

- CSM IMU IS LEFT ON FOR ENTIRE FLIGHT.
- LM IMU IS TURNED OFF FOR 27 HOURS OF 32 HOURS LUNAR STAY.
- ORIENTATION OF PLATFORM.
 1. LAUNCH ORIENTATION THROUGH MCC₁.
 2. PTC THROUGH MCC₃.
 3. LANDING SITE REFSMMAT, FROM MCC₄ THROUGH LM TOUCHDOWN.
 4. PREFERRED THRUSTING ORIENTATION (CSM ONLY) FOR PLANE CHANGE MANEUVER 1.
 5. MOON LAUNCH ORIENTATION (BOTH VEHICLES) FROM LM ASCENT THROUGH LM JETTISON AND SEPARATION.
 6. PREFERRED THRUSTING ORIENTATION FOR PLANE CHANGE MANEUVER 2 AND TEL.
 7. PTC ORIENTATION THROUGH MCC₆.
 8. ENTRY REFSMMAT, FROM MCC₇ THROUGH ENTRY.

● REFSMMAT MATRICES

- | | | | |
|-----------|---|-----------------------------|---|
| 1. LAUNCH | $\begin{aligned} \underline{U} \text{ XSM} &= \text{DOWNRANGE} \\ \underline{U} \text{ YSM} &= \underline{U} \text{ ZSM} \times \underline{U} \text{ XSM} \\ \underline{U} \text{ ZSM} &= \text{UNIT } (-\underline{r} \text{ LAUNCH}) \end{aligned}$ | 3. LANDING SITE | $\begin{aligned} \underline{U} \text{ XSM} &= \text{UNIT } (\underline{r} \text{ LANDING}) \\ \underline{U} \text{ YSM} &= \underline{U} \text{ ZSM} \times \underline{U} \text{ XSM} \\ \underline{U} \text{ ZSM} &= \text{UNIT } [(\underline{r} \text{ CSM} \times \underline{v} \text{ CSM}) \times \underline{U} \text{ XSM}] \end{aligned}$ |
| 2. PTC | $\begin{aligned} \underline{U} \text{ XSM} &= \text{IN THE ECLIPTIC PLANE} \\ &\text{AND PERPENDICULAR TO THE} \\ &\text{EARTH-MOON LINE PROJECTION} \\ &\text{IN THE ECLIPTIC PLANE AT} \\ &\text{THE AVERAGE TIME OF TRANS-} \\ &\text{EARTH INJECTION FOR THE} \\ &\text{MONTHLY LAUNCH WINDOW AND} \\ &\text{AZIMUTH RANGE} \\ \underline{U} \text{ YSM} &= \underline{U} \text{ ZSM} \times \underline{U} \text{ XSM} \\ \underline{U} \text{ ZSM} &= \text{PERPENDICULAR TO THE} \\ &\text{ECLIPTIC PLANE AND DIRECTED} \\ &\text{SOUTH} \end{aligned}$ | 4. PREFERRED
(THRUSTING) | $\begin{aligned} \underline{U} \text{ XSM} &= \text{UNIT } (\Delta \underline{v} \text{ COMPENSATED}) \\ \underline{U} \text{ YSM} &= \text{UNIT } (\underline{U} \text{ XSM} \times \underline{r} \text{ TIG}) \\ \underline{U} \text{ ZSM} &= \underline{U} \text{ XSM} \times \underline{U} \text{ YSM} \end{aligned}$ |
| | | 5. MOON LAUNCH | $\begin{aligned} \underline{U} \text{ XSM} &= \text{UNIT } (\underline{r} \text{ LAUNCH}) \\ \underline{U} \text{ YSM} &= \underline{U} \text{ ZSM} \times \underline{U} \text{ XSM} \\ \underline{U} \text{ ZSM} &= \text{UNIT } [(\underline{r} \text{ CSM} \times \underline{v} \text{ CSM}) \times \underline{U} \text{ XSM}] \end{aligned}$ |
| | | 6. ENTRY | $\begin{aligned} \underline{U} \text{ XSM} &= \underline{U} \text{ YSM} \times \underline{U} \text{ ZSM} \\ \underline{U} \text{ YSM} &= \text{UNIT } (\underline{v} \text{ ENTRY} \times \underline{r} \text{ ENTRY}) \\ \underline{U} \text{ ZSM} &= \text{UNIT } (-\underline{r} \text{ ENTRY}) \end{aligned}$ |

BOOST MONITOR ERROR ANALYSIS

The equation for the time history of thrust applied to achieve earth orbital insertion is

$$\bar{A}_T(t) = \bar{A}_V(t) - \bar{G}$$

where

$$\bar{A}_T(t) = \text{measured acceleration}$$

$$\bar{A}_V(t) = \text{vehicle acceleration}$$

$$\bar{G} = \text{gravitational acceleration}$$

Define an earth-centered inertial coordinate system such that the X, Y, Z axes are coincident with the IMU X, Y, Z stable member axes, respectively. The radius vector, \bar{R} , is

$$\bar{R} = \bar{X} + \bar{Y} + \bar{Z}$$

$$|\bar{R}| = R = (\bar{X}^2 + \bar{Y}^2 + \bar{Z}^2)^{1/2}$$

Thus, vehicle acceleration and gravitational acceleration are

$$\bar{A}_V = \ddot{\bar{X}} + \ddot{\bar{Y}} + \ddot{\bar{Z}}$$

$$\bar{G} = -\frac{\mu}{R^3} \bar{R}$$

Propagation of errors to the thrust profile due to initial misalignments and inertial instrument anomalies may be evaluated from the perturbation equation

$$\Delta \bar{G} = \frac{\partial \bar{G}}{\partial \bar{R}} \Delta \bar{R}$$

$$\Delta \bar{G} = -\mu \frac{\partial}{\partial R} \left(\frac{\bar{R}}{R^3} \right) \Delta \bar{R}$$

$$\Delta \bar{G} = -\mu \frac{\Delta \bar{R}}{R^3} - \mu \bar{R} \frac{\partial}{\partial R} (R^{-3}) \cdot \Delta \bar{R}$$

$$\Delta \bar{G} = -\mu \frac{\Delta \bar{R}}{R^3} + 3\mu \frac{\bar{R}}{R^4} \frac{\partial R}{\partial \bar{R}} \cdot \Delta \bar{R}$$

Since $\partial R / \partial \bar{R} = \bar{U}_R$,

$$\Delta \bar{G} = -\mu \frac{\Delta \bar{R}}{R^3} + 3\mu \frac{\bar{R}}{R^4} (\bar{U}_R \cdot \Delta \bar{R})$$

$$\Delta \bar{G} = -\mu \frac{\Delta \bar{R}}{R^3} + 3 \frac{\mu}{R^5} (\bar{R} \cdot \Delta \bar{R}) \bar{R}$$

The perturbation equations for measured acceleration and vehicle acceleration are

$$\Delta \bar{A}_T = \Delta \bar{A}_V - \Delta \bar{G}$$

$$\Delta \bar{A}_V = \Delta \ddot{X} + \Delta \ddot{Y} + \Delta \ddot{Z}$$

Combine the last three equations and form the three component equations.

$$\Delta A_X = \Delta \ddot{X} + \frac{\mu}{R^3} \Delta X - \frac{3\mu}{R^5} (\bar{R} \cdot \Delta \bar{R}) X$$

$$\Delta A_Y = \Delta \ddot{Y} + \frac{\mu}{R^3} \Delta Y - \frac{3\mu}{R^5} (\bar{R} \cdot \Delta \bar{R}) Y$$

$$\Delta A_Z = \Delta \ddot{Z} + \frac{\mu}{R^3} \Delta Z - \frac{3\mu}{R^5} (\bar{R} \cdot \Delta \bar{R}) Z$$

The expression $(\bar{R} \cdot \Delta \bar{R})$ can be written as

$$(\bar{R} \cdot \Delta \bar{R}) = X \Delta X + Y \Delta Y + Z \Delta Z$$

The platform misalignments are represented by α , β , and θ , which are the small angle misalignments about the X, Y, and Z axes, respectively. The acceleration error due to this misalignment is

$$\epsilon_X = \theta A_Y - \beta A_Z$$

$$\epsilon_Y = -\theta A_X + \alpha A_Z$$

$$\epsilon_Z = \beta A_X - \alpha A_Y$$

where

A_X = X-axis sensed acceleration

A_Y = Y-axis sensed acceleration

A_Z = Z-axis sensed acceleration

The gyro drift rate causes the platform to become misaligned with time,

$$\delta X = \alpha$$

$$\delta Y = \beta$$

$$\delta Z = \theta$$

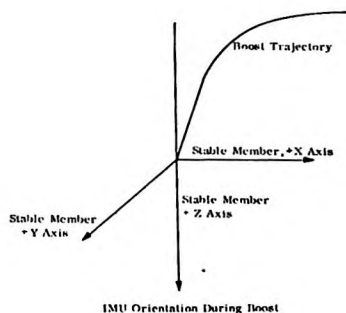
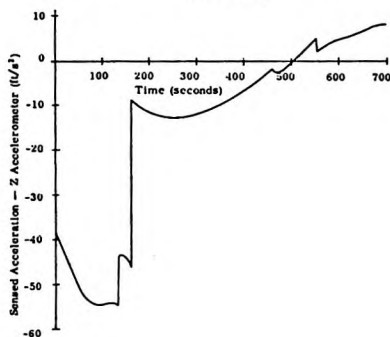
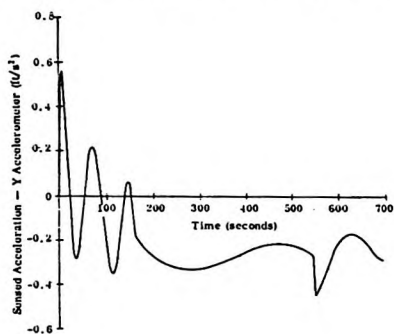
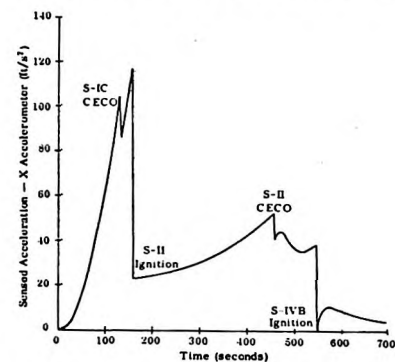
The complete set of error equations are obtained by adding in the misalignment error and gyro drift rate error. These three equations are

$$\Delta A_X = \Delta \ddot{X} + \frac{\mu}{R^3} \Delta X - \frac{3\mu}{R^5} (X^2 \Delta X + XY \Delta Y + XZ \Delta Z) + \theta A_Y - \beta A_Z$$

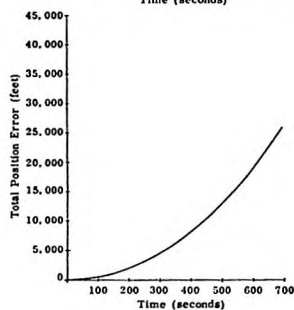
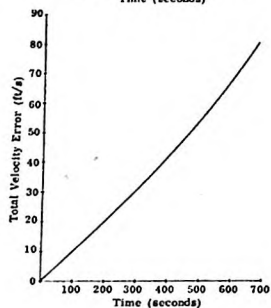
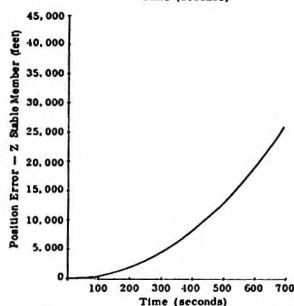
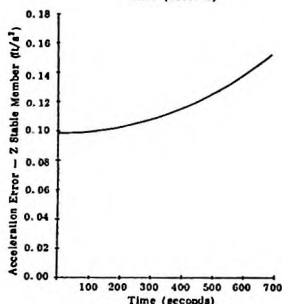
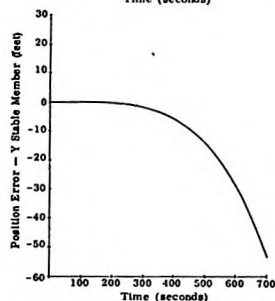
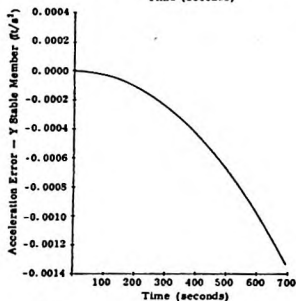
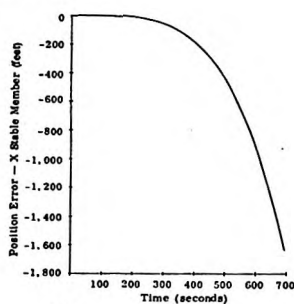
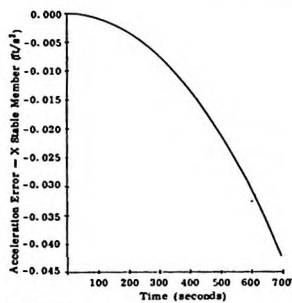
$$\Delta A_Y = \Delta \ddot{Y} + \frac{\mu}{R^3} \Delta Y - \frac{3\mu}{R^5} (XY \Delta X + Y^2 \Delta Y + YZ \Delta Z) - \theta A_X + \alpha A_Z$$

$$\Delta A_Z = \Delta \ddot{Z} + \frac{\mu}{R^3} \Delta Z - \frac{3\mu}{R^5} (XZ \Delta X + YZ \Delta Y + Z^2 \Delta Z) - \alpha A_Y + \beta A_X$$

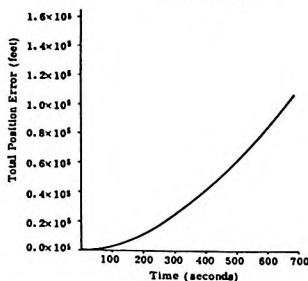
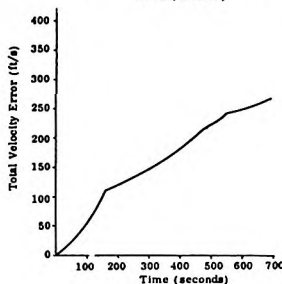
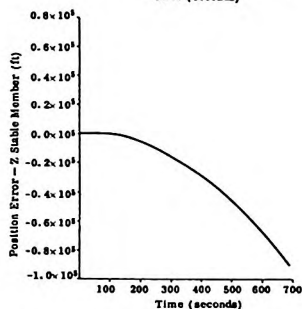
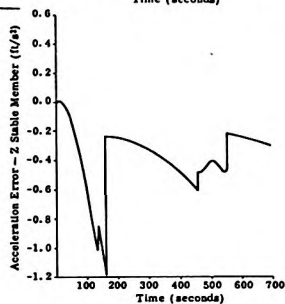
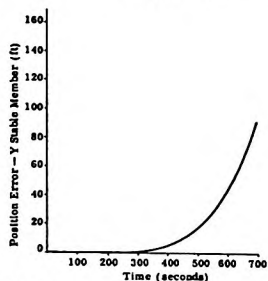
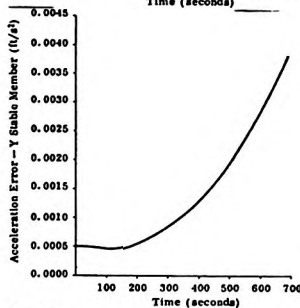
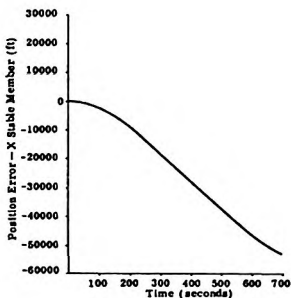
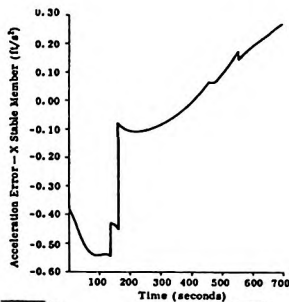
The following graphs illustrate how these errors propagate with time during boost.



BOOST MONITOR ERRORS
Uncompensated Z PIPA Bias (3 cm/s²)



BOOST MONITOR ERRORS Inner Gimbal Misalignment (10 mrad)



P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option		X	0	0	0	0
+	0	0			Hours } Minutes } Seconds }	GET	+	0	0		
+	0	0	0				+	0	0	0	
+	0						+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	
					Star Angle Difference (degrees)	N05					
					X } Y } Z } Gyro Torquing Angles (degrees)	N93					
					X } Y } Z } Calculated Gyro Drift (meru)						

X	0	0	0	0	P52 Option		X	0	0	0	0
+	0	0			Hours } Minutes } Seconds }	GET	+	0	0		
+	0	0	0				+	0	0	0	
+	0						+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	
					Star Angle Difference (degrees)	N05					
					X } Y } Z } Gyro Torquing Angles (degrees)	N93					
					X } Y } Z } Calculated Gyro Drift (meru)						

NOTES:

OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	<p>PREFERRED Thrusting</p> <p>The PREFERRED option refers to one of two possibilities:</p> <ol style="list-style-type: none"> The PREFERRED thrusting orientation which is calculated and stored by P40 and P41. Any orientation uplinked by MSFN via P27. <p>The CMC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40 or P41 and stored, or uplinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the CMC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{PREFERRED REFSMMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} U_{TD} \\ \text{Unit} (U_{TD} \times R_{TIG}) \\ \text{Unit} (U_{TD} \times (U_{TD} \times R_{TIG})) \end{bmatrix}$ <p>where</p> <p>U_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.</p> <p>R_{TIG} is the position vector of the vehicle at ignition expressed in the basic reference system.</p>
00002 (NOMINAL)	<p>Nominal</p> <p>The CMC requests the g. e. l. for which the vehicle R and V are to be selected to define the NOMINAL orientation. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{NOMINAL REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} V_{SM} \times Z_{SM} \\ \text{Unit} (V_{ENTR} \times R_{ENTR}) \\ \text{Unit} (-R_{ENTR}) \end{bmatrix}$ <p>where</p> <p>$\begin{Bmatrix} R_{ENTR} \\ V_{ENTR} \end{Bmatrix}$ are position and velocity vectors of vehicle at the time specified.</p>
00003 (REFSMAT)	<p><u>This option is used for gyro drift determination.</u> This option realigns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.</p>	$\begin{bmatrix} \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{orientation} \end{bmatrix}$
00004 (Landing Site)	<p>Landing Site</p> <p>The latitude, longitude/2, and altitude above the mean lunar radius of the landing site must be entered to determine R_{LS}. The g. e. l. for which the CSM R and V are to be selected must also be entered. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{Landing Site REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit} (R_{LS}) \\ Z_{SM} \times X_{SM} \\ \text{Unit} ((R_{ENTR} \times V_{ENTR}) \times Z_{SM}) \end{bmatrix}$ <p>where</p> <p>R_{LS} is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system.</p> <p>$\begin{Bmatrix} R_{ENTR} \\ V_{ENTR} \end{Bmatrix}$ are the CSM position and velocity vectors at the time specified.</p>

PROCEDURE FOR SPECIFYING OPTIONS

- When P52 is entered, the CMC checks the PREFERRED ATTITUDE flag.
- If the flag is set, the DSKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
- If the flag is not set, the DSKY flashes Verb 04, Noun 06, R3 = 00003, indicating the PREFERRED option may not be selected.
- The desired option is loaded into R2 via Verb 22.

P47-THRUST MONITOR

V37 Enter, 47 Enter

V16 N83 Flashing, ΔV XYZ Body Axes

N62 Enter

V16 N62 Flashing, Inertial Velocity, Altitude Rate, Altitude

X						TB 6p* (h:min:s)	X					
X	X	X				R	Predicted Spacecraft IMU Gimbal Angles at TLI Ignition (degrees)	X	X	X		
X	X	X				P		X	X	X		
X	X	X				Y		X	X	X		
X	X	X				BT	Duration of TLI (min:s)	X	X	X		
						ΔVC^{**} (ft/s)						
+						Vt^{\dagger} (ft/s)	+					
X	X	X				R SEP	Predicted S/C IMU Gimbal Angles at Completion of S-IVB Maneuver to CSM/SIV-B Separation Attitude (degrees)	X	X	X		
X	X	X				P SEP		X	X	X		
X	X	X				Y SEP		X	X	X		
X	X	X				R	Predicted S/C IMU Gimbal Angles at Extraction	X	X	X		
X	X	X				P		X	X	X		
X	X	X				Y		X	X	X		
						X		N83				
						Y	ΔV ft/s					
						Z						
						V	ft/s	N62				
						HDOT	ft/s					
						H	nmi					

*Predicted Time of Beginning of S-IVB Restart Preparation for TLI (TB6 = TLI Ignition - 9 minutes)

**Nominal TLI ΔV Set into EMS ΔV Control † Nominal Inertial Velocity Displayed on DSKY at TLI Cutoff

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GET1

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		(degrees)			0	0	
+	0	0		YTrim					
+	0	0	0	Hours	N33	+	0	0	
+	0	0	0	Minutes GET1		+	0	0	0
+	0			Seconds		+	0		
				ΔV_x	N81				
				ΔV_y LV					
				ΔV_z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				nmi					
+				HPerigee					
				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				(degrees)					
+				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g					
				Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

NOTES:

<i>PRO/GUID</i>		PROPULSION SYSTEM (SPS/RCS)/ GUIDANCE (SCS/G&N)
WT	XXXXX (lbs)	PREMANEUVER VEHICLE WEIGHT
P TRIM	X.XX (DEG)	SPS PITCH GIMBAL OFFSET TO PLACE THRUST
Y TRIM	X.XX (DEG)	SPS YAW GIMBAL OFFSET TO PLACE THRUST
GETI	XX:XX:XX (HRS:MIN:SEC)	TIME OF MNRV IGNITION
ΔV_X	XXXX.X (fps)	P30 VELOCITY TO BE GAINED COMPONENTS IN LOCAL VERTICAL COORDINATES
ΔV_Y	XXXX.X (fps)	
ΔV_Z	XXXX.X (fps)	
R	XXX (DEG)	IMU GIMBAL ANGLES OF MANEUVER ATTITUDE
P	XXX (DEG)	
Y	XXX (DEG)	
H _A	XXXX.X (nm)	PREDICTED APOGEE ALTITUDE AFTER MANEUVER
H _P	XXXX.X (nm)	PREDICTED PERIGEE ALTITUDE AFTER MANEUVER
ΔVT	XXXX.X	TOTAL VELOCITY OF MANEUVER
BT	X:XX (MIN:SEC)	MANEUVER DURATION
ΔVC	XXXX.X (fps)	PREMANEUVER ΔV SETTING IN EMS ΔV COUNTER
SXTS	XX (OCTAL)	SEXTANT STAR FOR MANEUVER ATTITUDE CK
SFT	XXX.X (DEG)	SEXTANT SHAFT SETTING FOR MANEUVER ATTITUDE CK
TRN	XX.X (DEG)	SEXTANT TRUNNION SETTING FOR MANEUVER ATTITUDE CK
BSS	XXX (OCTAL)	BORESIGHT STAR FOR MANEUVER ATTITUDE CK USING THE COAS
SPA	XX.X (DEG)	BSS PITCH ANGLE ON COAS
SXP	X.X (DEG)	BSS X POSITION ON COAS
LAT LONG	XX.XX XXX.XX	LATITUDE AND LONGITUDE OF THE LANDING POINT FOR ENTRY GUIDANCE
RTGO	XXXX.X	RANGE TO GO FOR EMS INITIALIZATION
VIO	XXXXXX (fps)	INERTIAL VELOCITY AT .05G FOR EMS INITIALIZATION
GET(.05G)	XX:XX:XX	TIME OF .05G
SET STARS		STARS FOR TELESCOPE FOR BACKUP GDC ALIGN
R, P, Y (ALIGN)		ATTITUDE TO BE SET IN ATTITUDE SET TW FOR BACKUP GDC ALIGN
ULLAGE		NO. OF SM RCS JETS USED AND LENGTH OF TIME OF USAGE
HORIZON WINDOW		WINDOW MARKING AT WHICH HORIZON IS PLACED AT A SPECIFIED TIG (ATT CK)

P37 - RETURN TO EARTH

V37 Enter, 37 Enter

V06 N33 Flashing

Time of Ignition (h, min, 0.01 s)

V06 N60 Flashing

Blank, ΔV Desired, GAMMA EI Desired (ft/s, 0.01 deg)

V06 N61 Flashing

Impact Latitude and Longitude (0.01 deg, 0.01 deg)

V06 N39 Flashing

 ΔT of Transfer (h, min, 0.01 s)

V06 N60 Flashing

Blank, V Predicted GAMMA EI (ft/s, 0.01 deg)

V06 N81 Flashing

 ΔV_X (LV), ΔV_Y (LV), ΔV_Z (LV) at TIG (0.1 ft/s)

V04 N06 Flashing

R1: 0 0 0 0 7

R2: 0 0 0 0 X (1-SPS, 2-RCS)

V06 N33 Flashing

Time of Ignition (h, min, 0.01 s)

V16 N45 Flashing

Marks, TFI, Middle Gimbal Angle (marks, min/s, 0.01 deg)

				Time of Ignition (h, min)	N33						
				ΔV Required (ft/s)	N60						
				Longitude of Splash Point (deg)							
				Time of Entry Interface (h, min)							

				Time of Ignition (h, min)	N33						
				ΔV Required (ft/s)	N60						
				Longitude of Splash Point (deg)							
				Time of Entry Interface (h, min)							

P47-THRUST MONITOR

V37 Enter, 47 Enter

V16 N83 Flashing, ΔV XYZ Body Axes

N62 Enter

V16 N62 Flashing, Inertial Velocity, Altitude Rate, Altitude

X						TB 6P* (h:min:s)	X					
X	X	X				R Predicted Spacecraft IMU Gimbal Angles at TLI Ignition (degrees)	X	X	X			
X	X	X				P	X	X	X			
X	X	X				Y	X	X	X			
X	X	X				BT Duration of TLI (min s)	X	X	X			
						ΔV^{***} (ft/s)						
+						$V I^{\dagger}$ (ft/s)	+					
X	X	X				R SEP Predicted S/C IMU Gimbal Angles at Completion of S-IVB Maneuver to CSM/SIV-B Separation Attitude (degrees)	X	X	X			
X	X	X				P SEP	X	X	X			
X	X	X				Y SEP	X	X	X			
X	X	X				R Predicted S/C IMU Gimbal Angles at Extraction	X	X	X			
X	X	X				P	X	X	X			
X	X	X				Y	X	X	X			
						X N83						
						Y ΔV ft/s						
						Z						
						V ft/s N62						
						HDOT ft/s						
						H nmi						

*Predicted Time of Beginning of S-IVB Restart Preparation for TLI (TB6 = TLI Ignition - 9 minutes)

****Nominal TLI ΔV Set into EMS ΔV Control**

† Nominal Inertial Velocity Displayed on DSKY at TLI Cutoff

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P37 – RETURN TO EARTH

V37 Enter, 37 Enter

V06 N33 Flashing

Time of Ignition (h, min, 0.01 s)

V06 N60 Flashing

Blank, ΔV Desired, GAMMA EI Desired (ft/s, 0.01 deg)

V06 N61 Flashing

Impact Latitude and Longitude (0.01 deg, 0.01 deg)

V06 N39 Flashing

 ΔT of Transfer (h, min, 0.01 s)

V06 N60 Flashing

Blank, V Predicted GAMMA EI (ft/s, 0.01 deg)

V06 N81 Flashing

 ΔV_X (LV), ΔV_Y (LV), ΔV_Z (LV) at TIG (0.1 ft/s)

V04 N06 Flashing

R1: 00007

R2: 0 0 0 0 X (1-SPS, 2-RCS)

V06 N33 Flashing

Time of Ignition (h, min, 0.01 s)

V16 N45 Flashing

Marks, TFI, Middle Gimbal Angle (marks, min/s, 0.01 deg)

			Time of Ignition (h, min)	N33						
X			ΔV Required (ft/s)	N60	X					
X			Longitude of Splash Point (deg)		X					
			Time of Entry Interface (h, min)							

[illegible]

P23—OPTICS CALIBRATION

V37 Enter, 23 Enter

V06 N70 Flashing

R1: 000DE Star ID

R2: 00000

R3: 00CD0 Hor ID C and D 1 or 2

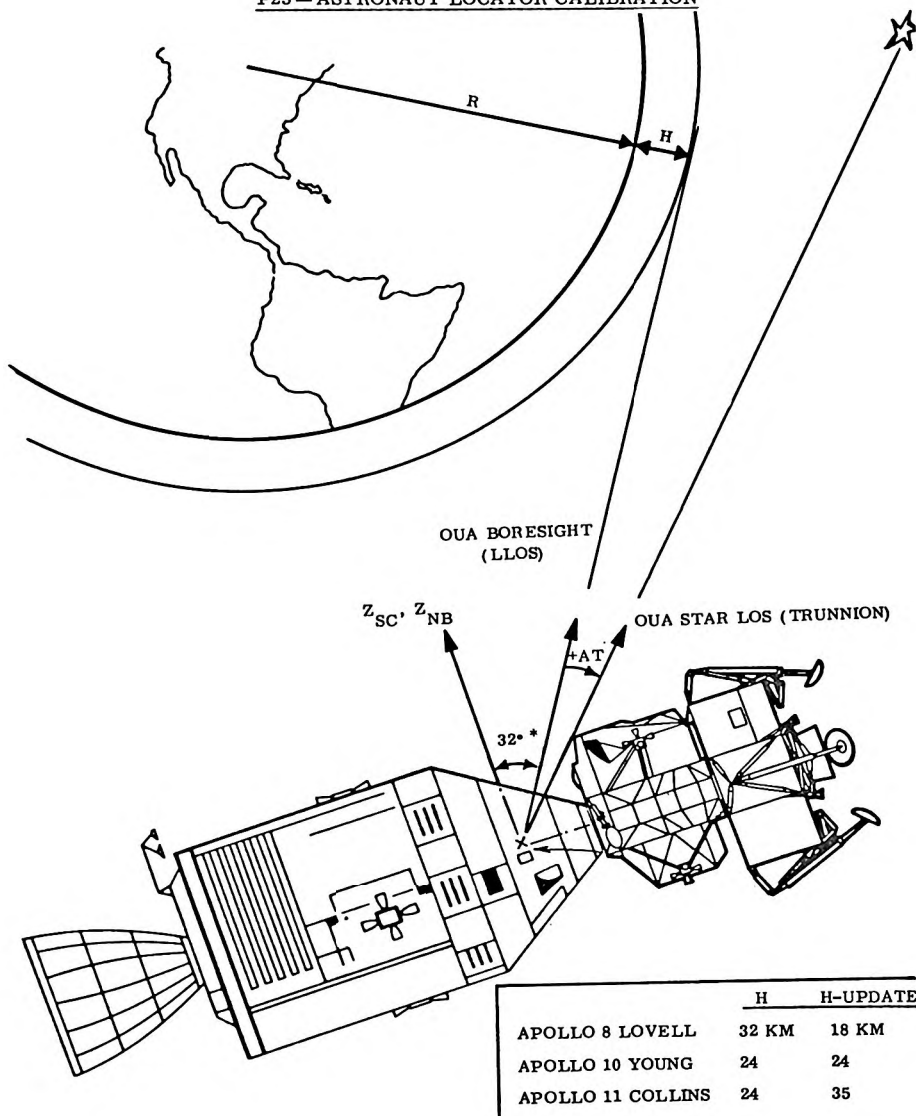
V59 Flashing, Perform Optics Calibration

+	0	0			Hours	+	0	0			
+	0	0	0		Minutes GET	+	0	0	0		
+	0				Seconds	+	0				
X	X				R IMU Gimbal	X	X				
X	X				P Angles (deg)	X	X				
X	X				Y	X	X				
X	0	0	0		Star ID	N70	X	0	0	0	
+					Trun Angle Bias	N87 R2	+				
+					Trun Angle Bias	N87 R2	+				
+					Trun Angle Bias	N87 R2	+				

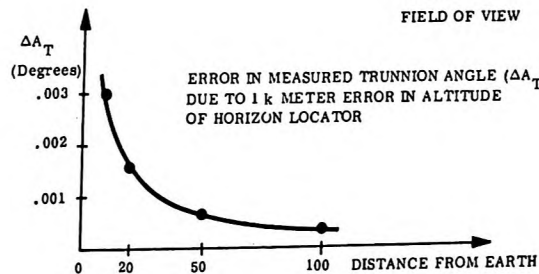
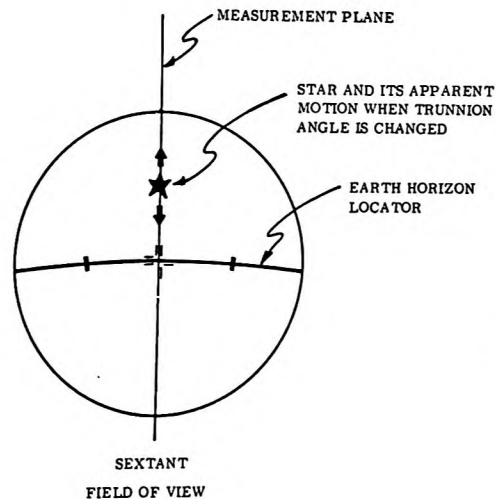
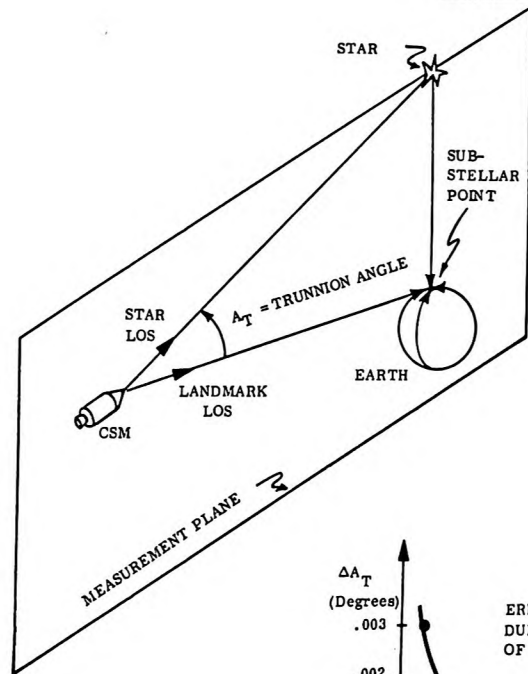
+	0	0			Hours	+	0	0			
+	0	0	0		Minutes GET	+	0	0	0		
+	0				Seconds	+	0				
X	X				R IMU Gimbal	X	X				
X	X				P Angles (deg)	X	X				
X	X				Y	X	X				
X	0	0	0		Star ID	N70	X	0	0	0	
+					Trun Angle Bias	N87 R2	+				
+					Trun Angle Bias	N87 R2	+				
+					Trun Angle Bias	N87 R2	+				

NOTES:

P23 — ASTRONAUT LOCATOR CALIBRATION



STAR/HORIZON GEOMETRY



LB-26

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 000XX Celestial Body Code

R2: 00X00 0 – Horizon
1 – Earth Landmark
2 – Moon Landmark

R3: 00CDO C = 0, D = 0 Landmark
C-1 Earth Horizon
C-2 Moon Horizon
D-1 Near Horizon
D-2 Far Horizon

V51 Flashing – Please Mark

+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	X					R IMU P Gimbal Angles (deg) Y		X	X				
X	X							X	X				
X	X							X	X				
+						Pos Err (ft) W Matrix Vel Error (ft/s)	V67	+					
+								+					
X	0	0	0			Ster ID LMK ID Hor ID	N70	X	0	0	0		
X	0	0		0	0			X	0	0		0	0
X	0	0			0			X	0	0			0
+						Trun Angle Degrees ΔR nmi ΔV ft/s	N92 R2 N49	+					

NOTES:

LB-27

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 000XX Celestial Body Code

R2: 00X00 0 - Horizon
1 - Earth Landmark
2 - Moon Landmark

R3: 00CD0 C = 0, D = 0 Landmark
C-1 Earth Horizon
C-2 Moon Horizon
D-1 Near Horizon
D-2 Far Horizon

V51 Flashing -- Please Mark

+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	X					R IMU P Gimbal Angles (deg) Y		X	X				
X	X							X	X				
X	X							X	X				
+						Pos Err (ft) W Matrix Vel Error (ft/s)	V67	+					
+								+					
X	0	0	0			Star ID LMK ID Hor ID	N70	X	0	0	0		
X	0	0		0	0			X	0	0		0	0
X	0	0			0			X	0	0			0
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
								ΔV ft/s					

NOTES:

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 000XX Celestial Body Code
 0 – Horizon
 1 – Earth Landmark
 2 – Moon Landmark

R2: 00X00
 C = 0, D = 0 Landmark
 C-1 Earth Horizon
 C-2 Moon Horizon
 D-1 Near Horizon
 D-2 Far Horizon

V51 Flashing – Please Mark

+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	X					R IMU P Gimbal Y Angles (deg)		X	X				
X	X							X	X				
X	X							X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix		+					
						Vel Error (ft/s)		+					
X	0	0	0			Star ID	N70	X	0	0	0		
X	0	0		0	0	LMK ID		X	0	0		0	0
X	0	0			0	Hor ID		X	0	0			0
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

LB-29

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 0 0 0 X X Celestial Body Code

R2: 0 0 X 0 0 0 - Horizon
1 - Earth Landmark
2 - Moon Landmark

R3: 0 0 C D 0 C = 0, D = 0 Landmark
C-1 Earth Horizon
C-2 Moon Horizon
D-1 Near Horizon
D-2 Far Horizon

V51 Flashing - Please Mark

+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	X					R IMU p Gimbal Angles (deg) Y		X	X				
X	X							X	X				
X	X							X	X				
+						Pos Err (ft) W Matrix Vel Error (ft/s)	V67	+					
+								+					
X	0	0	0			Star ID LMK ID Hor ID	N70	X	0	0	0		
X	0	0		0	0			X	0	0		0	0
X	0	0			0			X	0	0			0
+						Trun Angle Degrees ΔR nmi ΔV ft/s	N92 R2 N49	+					

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	<p><u>PREFERRED Thrusting</u></p> <p>The PREFERRED option refers to one of two possibilities.</p> <ol style="list-style-type: none"> The PREFERRED thrusting orientation which is calculated and stored by P40 and P41. Any orientation uplinked by MSFN via P27. <p>The CMC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40 or P41 and stored, or uplinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the CMC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \vec{U}_{TD} \\ \text{Unit}(\vec{U}_{TD} \times \vec{R}_{TIG}) \\ \text{Unit}(\vec{U}_{TD} \times (\vec{U}_{TD} \times \vec{R}_{TIG})) \end{bmatrix}$ <p>where</p> <p>\vec{U}_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.</p> <p>\vec{R}_{TIG} is the position vector of the vehicle at ignition expressed in the basic reference system.</p>
00002 (NOMINAL)	<p><u>Nominal</u></p> <p>The CMC requests the g.e.l. for which the vehicle \vec{R} and \vec{V} are to be selected to define the NOMINAL orientation. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{NOMINAL} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \vec{V}_{SM} \times \vec{Z}_{SM} \\ \text{Unit}(\vec{V}_{ENTR} \times \vec{R}_{ENTR}) \\ \text{Unit}(-\vec{R}_{ENTR}) \end{bmatrix}$ <p>where</p> <p>$\left. \begin{matrix} \vec{R}_{ENTR} \\ \vec{V}_{ENTR} \end{matrix} \right\}$ are position and velocity vectors of vehicle at the time specified.</p>
00003 (REFSMAT)	<p><u>This option is used for gyro drift determination.</u> This option re-aligns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.</p>	$\begin{bmatrix} \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{orientation} \end{bmatrix}$
00004 (Landing Site)	<p><u>Landing Site</u></p> <p>The latitude, longitude/2, and altitude above the mean lunar radius of the landing site must be entered to determine \vec{R}_{LS}. The g.e.l. for which the CSM \vec{R} and \vec{V} are to be selected must also be entered. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{Landing Site} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit}(\vec{R}_{LS}) \\ \vec{Z}_{SM} \times \vec{X}_{SM} \\ \text{Unit}((\vec{R}_{ENTR} \times \vec{V}_{ENTR}) \times \vec{X}_{SM}) \end{bmatrix}$ <p>where</p> <p>\vec{R}_{LS} is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system.</p> <p>$\left. \begin{matrix} \vec{R}_{ENTR} \\ \vec{V}_{ENTR} \end{matrix} \right\}$ are the CSM position and velocity vectors at the time specified.</p>

PROCEDURE FOR SPECIFYING OPTIONS

- When P52 is entered, the CMC checks the PREFERRED ATTITUDE flag.
- If the flag is set, the DISKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
- If the flag is not set, the DISKY flashes Verb 04, Noun 06, R3 = 00003, indicating the PREFERRED option may not be selected.
- The desired option is loaded into R2 via Verb 22.

P40 - SPS THRUSTING CSM

V37 Enter, 40 Enter
 V50 N18 Flashing, Request Maneuver to FDAI R, P, Y Angles
 V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
 V50 N25 Flashing, R1 = 0 0 2 0 4, Gimbal Actuator Test Option
 V06 N40, Time from Ignition, Velocity to be Gained, Measured Change in Velocity
 V99 N40 Flashing, Engine On Enable Request
 V06 N40, Time from Cutoff, Velocity to be Gained, Measured Change in Velocity
 V16 N40 Flashing, Final Values at Engine Cutoff
 V16 N85 Flashing, Body Axes Residuals (to be Nullified)
 V37 Flashing, V82 Enter
 V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-40	TFI (min:s)
						VG (ft/s)
						Δ V (ft/s)
					06-40	TFC (min:s)
						VG (ft/s)
						Δ V (ft/s)
					16-40	TFC (min:s)
						VG (ft/s)
						Δ V (ft/s)
					85	X
						Y Residuals (ft/s)
						Z
					85	X
						Y TRIM (ft/s)
						Z
					44	HA (nmi)
						HP (nmi)
						TFF (min:s)

P41 - RCS THRUSTING

V37 Enter, 41 Enter
 V50 N18 Flashing, Request Maneuver to FDAI R, P, Y, Angles
 V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
 V06 N85, X, Y, Z Body Axes Velocity to be Gained
 V16 N85 (Average G on at TIG -30) Velocity to be Gained
 V16 N85 Flashing, Body Axes Residuals (to be Nullified)

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y Residuals (ft/s)
						Z
						X
						Y Trim (ft/s)
						Z

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option	X	0	0	0	0
+	0	0			Hours	GET	+	0	0	
+	0	0	0		Minutes		+	0	0	0
+	0				Seconds		+	0		
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0
					Star Angle Difference (degrees)	N05				
					X	Gyro Torquing Angles (degrees)				
					Y					
					Z					
					X	Calculated Gyro Drift (meru)				
					Y					
					Z					

X	0	0	0	0	P52 Option	X	0	0	0	0
+	0	0			Hours	GET	+	0	0	
+	0	0	0		Minutes		+	0	0	0
+	0				Seconds		+	0		
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0
					Star Angle Difference (degrees)	N05				
					X	Gyro Torquing Angles (degrees)				
					Y					
					Z					
					X	Calculated Gyro Drift (meru)				
					Y					
					Z					

NOTES:

OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	<p>PREFERRED Thrusting</p> <p>The PREFERRED option refers to one of two possibilities:</p> <ol style="list-style-type: none"> The PREFERRED thrusting orientation which is calculated and stored by P40 and P41. Any orientation unlinked by MSFN via P27. <p>The CMC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40 or P41 and stored, or unlinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the CMC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. This option is not used for gyro drift determination.</p>	$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} U_{TD} \\ \text{Unit} (U_{TD} \times R_{TIG}) \\ \text{Unit} (U_{TD} \times (U_{TD} \times R_{TIG})) \end{bmatrix}$ <p>where</p> <p>U_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.</p> <p>R_{TIG} is the position vector of the vehicle at ignition expressed in the basic reference system.</p>
00002 (NOMINAL)	<p>Nominal</p> <p>The CMC requests the g.e.l. for which the vehicle R and V are to be selected to define the NOMINAL orientation. This option is not used for gyro drift determination.</p>	$\begin{bmatrix} \text{NOMINAL} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} V_{ENTR} \times Z_{SM} \\ \text{Unit} (V_{ENTR} \times R_{ENTR}) \\ \text{Unit} (V_{ENTR} \times (V_{ENTR} \times R_{ENTR})) \end{bmatrix}$ <p>where</p> <p>$\begin{Bmatrix} R_{ENTR} \\ V_{ENTR} \end{Bmatrix}$ are position and velocity vectors of vehicle at the time specified.</p>
00003 (REFSMAT)	<p>This option is used for gyro drift determination. This option realigns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.</p>	$\begin{bmatrix} \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{orientation} \end{bmatrix}$
00004 (Landing Site)	<p>Landing Site</p> <p>The latitude, longitude/2, and altitude above the mean lunar radius of the landing site must be entered to determine R_{LS}. The g.e.l. for which the CSM R and V are to be selected must also be entered. This option is not used for gyro drift determination.</p>	$\begin{bmatrix} \text{Landing Site} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit} (R_{LS}) \\ Z_{SM} \times X_{SM} \\ \text{Unit} ((R_{ENTR} \times V_{ENTR}) \times Z_{SM}) \end{bmatrix}$ <p>where</p> <p>R_{LS} is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system.</p> <p>$\begin{Bmatrix} R_{ENTR} \\ V_{ENTR} \end{Bmatrix}$ are the CSM position and velocity vectors at the time specified.</p>

PROCEDURE FOR SPECIFYING OPTIONS

- When P52 is entered, the CMC checks the PREFERRED ATTITUDE flag.
- If the flag is set, the DSKY flashes Verb 04, Noun 04, R2 = 00001, indicating the PREFERRED option may be selected.
- If the flag is not set, the DSKY flashes Verb 04, Noun 06, R2 = 00003, indicating the PREFERRED option may not be selected.
- The desired option is loaded into R2 via Verb 22.

P23—OPTICS CALIBRATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 0 0 0 D E Star ID

R2: 0 0 0 0 0

R3: 0 0 C D 0 Hor ID C and D 1 or 2

V59 Flashing, Perform Optics Calibration

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
X	X					R IMU Gimbal		X	X				
X	X					P Angles (deg)		X	X				
X	X					Y		X	X				
X	0	0	0			Star ID	N70	X	0	0	0		
+						Trun Angle Bias	N87 R2	+					
+						Trun Angle Bias	N87 R2	+					
+						Trun Angle Bias	N87 R2	+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
X	X					R IMU Gimbal		X	X				
X	X					P Angles (deg)		X	X				
X	X					Y		X	X				
X	0	0	0			Star ID	N70	X	0	0	0		
+						Trun Angle Bias	N87 R2	+					
+						Trun Angle Bias	N87 R2	+					
+						Trun Angle Bias	N87 R2	+					

NOTES:

LB-37

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 000XX Celestial Body Code

R2: 00X00 0 - Horizon
1 - Earth Landmark
2 - Moon Landmark

R3: 00CD0 C = 0, D = 0 Landmark
C-1 Earth Horizon
C-2 Moon Horizon
D-1 Near Horizon
D-2 Far Horizon

V51 Flashing - Please Mark

+	0	0				Hours	} GET	+	0	0					
+	0	0	0			Minutes		+	0	0	0				
+	0					Seconds		+	0						
X	X					R	IMU Gimbal Angles (deg)	X	X						
X	X					P		X	X						
X	X					Y		X	X						
+						Pos Err (ft)	V67	+							
+						W Matrix Vel Error (ft/s)		+							
X	0	0	0			Star ID	N70	X	0	0	0				
X	0	0		0	0	LMK ID		X	0	0			0	0	
X	0	0			0	Hor ID		X	0	0				0	
+						Trun Angle Degrees	N92 R2	+							
						ΔR nmi		N40							
						ΔV ft/s									

NOTES:

LB-38

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 0 0 0 X X Celestial Body Code
 R2: 0 0 X 0 0 0 – Horizon
 1 – Earth Landmark
 2 – Moon Landmark
 R3: 0 0 C D 0 C = 0, D = 0 Landmark
 C-1 Earth Horizon
 C-2 Moon Horizon
 D-1 Near Horizon
 D-2 Far Horizon

V51 Flashing – Please Mark

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (deg)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix		+					
						Vel Error (ft/s)		+					
X	0	0	0			Star ID	N70	X	0	0	0		
X	0	0		0	0	LMK ID		X	0	0		0	0
X	0	0			0	Hor ID		X	0	0			0
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 0 0 0 X X Celestial Body Code

R2: 0 0 X 0 0 0 – Horizon
1 – Earth Landmark
2 – Moon Landmark

R3: 0 0 C D 0 C = 0, D = 0 Landmark
C-1 Earth Horizon
C-2 Moon Horizon
D-1 Near Horizon
D-2 Far Horizon

V51 Flashing – Please Mark

+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	X					R IMU p Gimbel Angles (deg) Y		X	X				
X	X							X	X				
X	X							X	X				
+						Pos Err (ft) W Matrix Vel Error (ft/s)	V67	+					
+								+					
X	0	0	0			Star ID LMK ID Hor ID	N70	X	0	0	0		
X	0	0		0	0			X	0	0		0	0
X	0	0			0			X	0	0			0
+						Trun Angle Degrees ΔR nmi ΔV ft/s	N92 R2 N49	+					

NOTES:

LB-40

P23 CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter

V05 N70 Flashing

R1: 000XX Celestial Body Code

R2: 00X00
0 - Horizon
1 - Earth Landmark
2 - Moon Landmark

R3: 00CDO
C = 0, D = 0 Landmark
C-1 Earth Horizon
C-2 Moon Horizon
D-1 Near Horizon
D-2 Far Horizon

V51 Flashing - Please Mark

+	0	0				Hours	} GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (deg)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix Vel Error (ft/s)		+					
X	0	0	0			Star ID	N70	X	0	0	0		
X	0	0		0	0	LMK ID		X	0	0		0	0
X	0	0			0	Hor ID		X	0	0			0
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P30-EXTERNAL ΔV

MCC 2

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y LV					
				ΔV_Z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee nmi	N44	+			
				HPerigee					
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT (degrees)	N51		0		
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

V50 N18 Flashing, Request Maneuver to FDI R, P, Y Angles

V50 N°5 Flashing, R1 = 00204, Gimbal Actuator Test Option

'99 N40 Flashing, Engine On Enable Request

V06 N40. Time from Cutoff. Velocity to be Gained. Measured Change in Velocity

V16 N40 Flashing. Final Values at Engine Cutoff

V16 N85 Flashing, Body Axes Residuals (to be Nulled)

V37 Flashing, V82 Enter

V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

[illegible]

P30-EXTERNAL ΔV

LOI - 5

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y LV					
				ΔV_Z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee nmi	N44	+			
				HPerigee					
+				ΔVT (ft/s)		+			
X	X	X		BT (min s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT (degrees)	N61		0		
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P30-EXTERNAL ΔV

MCC 3

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y LV					
				ΔV_Z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				HPerigee nmi					
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				LONG (degrees)					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

P40 - SPS THRUSTING CSM

V37 Enter, 40 Enter
 V50 N18 Flashing, Request Maneuver to FDAI R, P, Y Angles
 V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
 V50 N25 Flashing, R1 = 0 0 2 0 4, Gimbal Actuator Test Option
 V06 N40, Time from Ignition, Velocity to be Gained, Measured Change in Velocity
 V99 N40 Flashing, Engine On Enable Request
 V06 N40, Time from Cutoff, Velocity to be Gained, Measured Change in Velocity
 V16 N40 Flashing, Final Values at Engine Cutoff
 V16 N85 Flashing, Body Axes Residuals (to be Nullified)
 V37 Flashing, V82 Enter
 V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-40	TFI (min:s)
						VG (ft/s)
						ΔVM (ft/s)
					06-40	TFC (min:s)
						VG (ft/s)
						ΔVM (ft/s)
					16-40	TFC (min:s)
						VG (ft/s)
						ΔVM (ft/s)
					85	X
						Y Residuals (ft/s)
						Z
					85	X
						Y TRIM (ft/s)
						Z
					44	HA (nmi)
						HP (nmi)
						TFF (min:s)

P41 - RCS THRUSTING

V37 Enter, 41 Enter
 V50 N18 Flashing, Request Maneuver to FDAI R, P, Y, Angles
 V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
 V06 N85, X, Y, Z Body Axes Velocity to be Gained
 V16 N85 (Average G on at TIG -30) Velocity to be Gained
 V16 N85 Flashing, Body Axes Residuals (to be Nullified)

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y Residuals (ft/s)
						Z
					X	
					Y	Trim (ft/s)
					Z	

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 — Preferred, 2 — Nominal,

3 — REFSMMAT, 4 — Landing Site

V51 Flashing — Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P30-EXTERNAL ΔV
Pericynthion + 2

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_x	N81				
				ΔV_y LV					
				ΔV_z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				HPerigee nmi					
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				LONG (degrees)					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g					
				Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

LUNAR ORBIT INSERTION MANEUVER

The approach of a spacecraft to the moon follows a hyperbolic trajectory with respect to the moon. To enter into an orbit about the moon, a transfer from a hyperbolic orbit to an elliptical orbit is desired. This transfer can be accomplished by applying a ΔV at pericynthion of the hyperbolic orbit (Figure A).

The velocity change, ΔV , required is

$$\Delta V = V_H - V_E \quad \text{ft/s at pericynthion}$$

where

V_H is the hyperbolic velocity at pericynthion

$$V_H = \left(\frac{2\mu}{r_P} \right)^{1/2} \left(1 + \frac{r_P V_\infty^2}{2\mu} \right)^{1/2} \quad \text{ft/s}$$

and V_E is the desired elliptical velocity at pericynthion

$$V_E = \left(\frac{2\mu}{r_P} \right)^{1/2} \left(\frac{r_A}{r_A + r_P} \right)^{1/2} \quad \text{ft/s}$$

The complete equation for ΔV is

$$\Delta V = \left(\frac{2\mu}{r_P} \right)^{1/2} \left[\left(1 + \frac{r_P V_\infty^2}{2\mu} \right)^{1/2} - \left(\frac{r_A}{r_A + r_P} \right)^{1/2} \right] \quad \text{ft/s}$$

where

$$V_\infty^2 = V^2 - \frac{2\mu}{r}$$

r_A = radius of apocynthion

r_P = radius of pericynthion

In order to obtain the sensitivity of changes in apocynthion and pericynthion to errors in ΔV burned, the following form of the targeting equation is used

$$\Delta V = V_H - \left(\frac{2\mu}{r_P} \right)^{1/2} \left(\frac{r_A}{r_A + r_P} \right)^{1/2} \quad \text{ft/s}$$

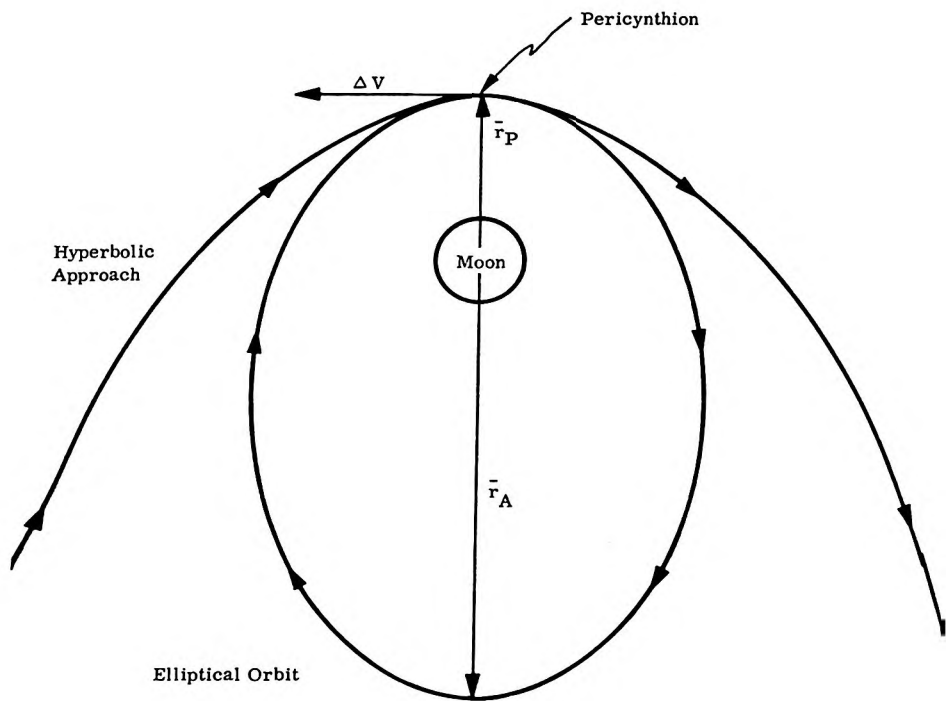


Figure A. Celestial Mechanics of a Transfer From a Hyperbola to an Ellipse

For V_H constant, the targeting equation for execution of an orbital transfer has the following functional form.

$$\Delta V = f(r_A, r_P) \quad \text{ft/s}$$

Errors in r_A and r_P which are caused by anomalies in the ΔV achieved are evaluated from the perturbed targeting equation.

$$\Delta V + \delta = f(r_A + \Delta r_A, r_P + \Delta r_P) \quad \text{ft/s}$$

Expanding the function on the right into a Taylor series and ignoring all higher order terms results in a linearized error relation.

$$\Delta V + \delta = f(r_A, r_P) + (\Delta r_A \frac{\partial}{\partial r_A} + \Delta r_P \frac{\partial}{\partial r_P}) f(r_A, r_P) \quad \text{ft/s}$$

This reduces to

$$\delta = \frac{\partial}{\partial r_A} [f(r_A, r_P)] \Delta r_A + \frac{\partial}{\partial r_P} [f(r_A, r_P)] \Delta r_P \quad \text{ft/s}$$

where

$$\begin{aligned} \frac{\partial}{\partial r_A} [f(r_A, r_P)] &= \left(\frac{\mu r_P}{2r_A (r_A + r_P)^3} \right)^{1/2} \quad \text{ft/s/nmi} \\ \frac{\partial}{\partial r_P} [f(r_A, r_P)] &= \left(\frac{(r_A^2 + 2r_A r_P)}{(r_A^2 + r_A r_P)^2} \right) \left(\frac{\mu r_A r_P + \mu r_P^2}{2r_A} \right)^{1/2} \quad \text{ft/s/nmi} \end{aligned}$$

The total linearized error equation relating errors in ΔV burned to errors in apocynthion and pericynthion is

$$\begin{aligned} \delta = \Delta(\Delta V) &= - \left(\frac{\mu r_P}{2r_A (r_A + r_P)^3} \right)^{1/2} \Delta r_A \\ &+ \left(\frac{(r_A^2 + 2r_A r_P)}{(r_A^2 + r_A r_P)^2} \right) \left(\frac{\mu r_A r_P + \mu r_P^2}{2r_A} \right)^{1/2} \Delta r_P \quad \text{ft/s} \end{aligned}$$

A graph illustrating these relationships is shown on the next page (Figure B).

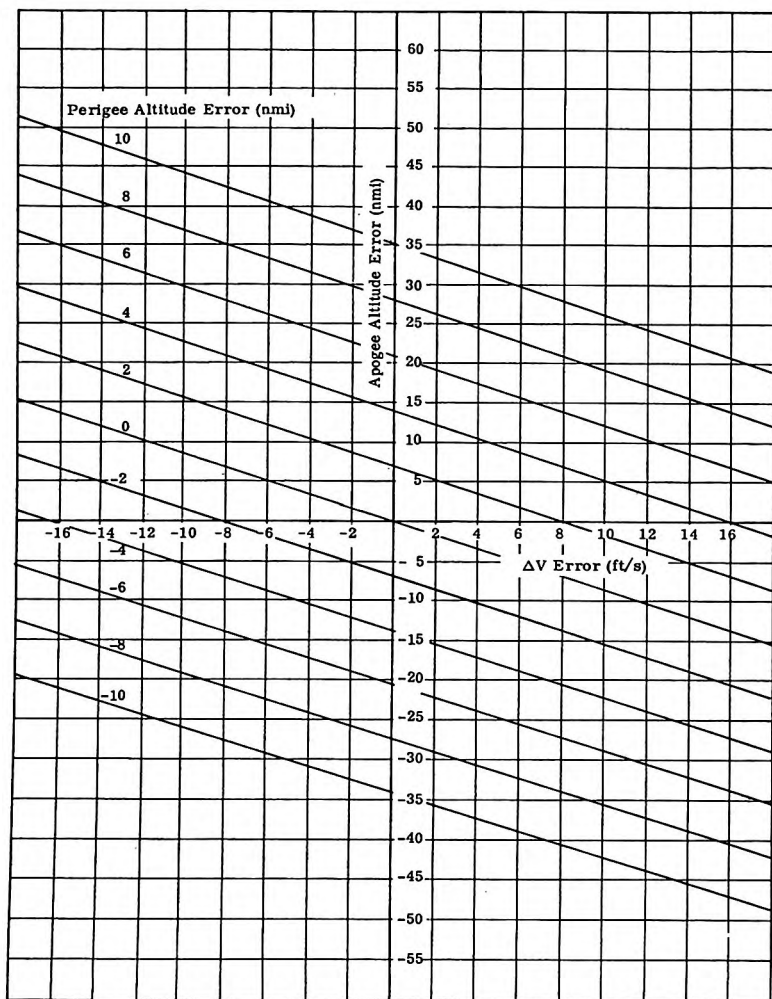
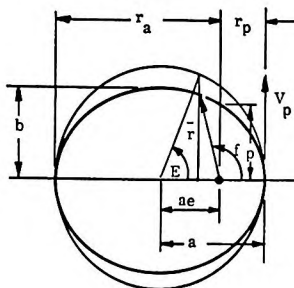


Figure B

ELLIPSE



Semiminor Axis

$$b = \sqrt{r_a r_p}$$

Semimajor Axis

$$a = \frac{r_a + r_p}{2}$$

Eccentricity

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} < 1$$

Position

$$r = \frac{a(1-e^2)}{1+e \cos f} = a(1-e \cos E)$$

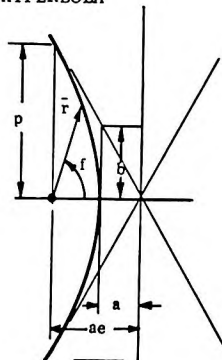
Velocity

$$V = \left[\frac{\mu}{a} \left(\frac{1+2e \cos f + e^2}{1-e^2} \right) \right]^{1/2}$$

Semilatus Rectum

$$p = a(1-e^2)$$

HYPERBOLA



$$r_p \sqrt{1 + \frac{2a}{r_p}}$$

$$\frac{\mu}{V_\infty^2}$$

$$\sqrt{1 + \left(\frac{b}{a}\right)^2} > 1$$

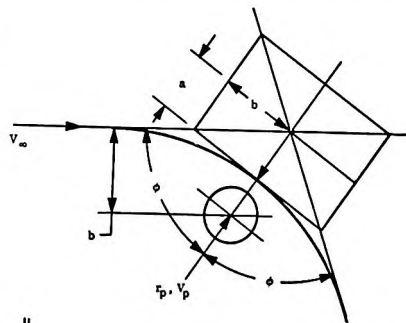
$$\frac{a(e^2 - 1)}{1 + e \cos f}$$

$$\left[\mu \left(\frac{2}{r} + \frac{1}{a} \right) \right]^{1/2}$$

$$a(e^2 - 1)$$

$$V_\infty^2 = \frac{\mu}{a}$$

HYPERBOLIC ENCOUNTER



$$V_\infty^2 = V_p^2 - 2\mu/r_p = \mu/a$$

$$r_p V_p = b V_\infty$$

$$\tan \phi = b/a = b V_\infty^2 / \mu$$

$$\mu = GM_M \quad \text{ft}^3/\text{s}^2$$

$$M_M = \text{Mass of the Moon}$$

P30-EXTERNAL ΔV

LOI 1

V37 Enter, 30 Enter

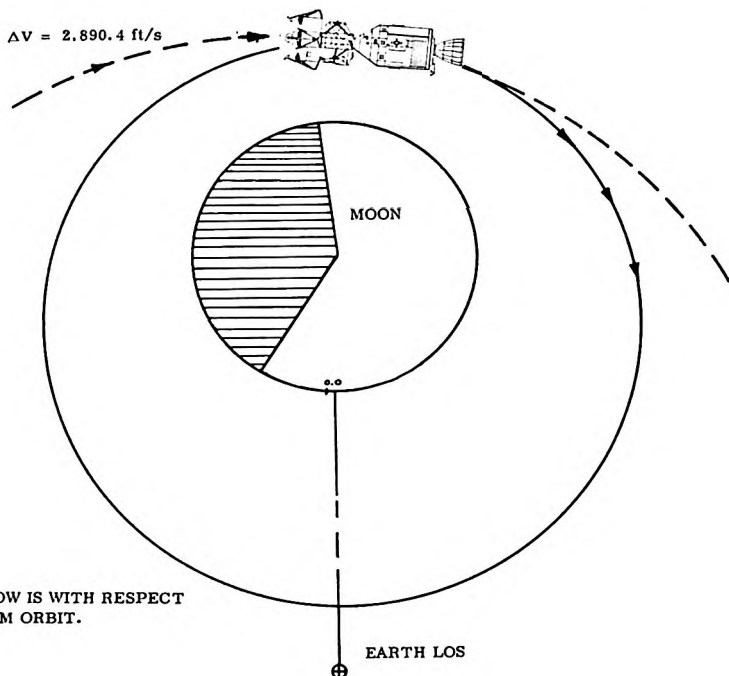
V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
/						/			
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y LV					
				ΔV_Z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				HPerigee nmi					
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				LONG (degrees)					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g					
				Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

LUNAR ORBIT INSERTION

EVENT	BT/ ΔV	G. E. T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
LOI ₁ (RETROGRADE)	360.2/ 2890.4	83:28:47.5	SPS/G & N EXT ΔV (P-40)	P-30
	ΔV_X N85		+ X X	h
	ΔV_Y RESIDUALS	FT/S	+ X X X	min GET
	ΔV_Z (BODY AXIS)		+ X	s
$-----\bullet-V_{X\text{TRIM}}$ $-----\bullet-V_{Y\text{TRIM}}$ $-----\bullet-V_{Z\text{TRIM}}$ ft/s				



V06 N81 Flashing. Load Desired ΔV

			/			Purpose Prop/Guidance				/				
+						Weight (lb)	N47	+						
	0	0		.		PTrim	N48		0	0		.		
	0	0		.		(degrees) YTrim			0	0		.		
+	0	0				Hours	N33	+	0	0				
+	0	0	0			Minutes GETI		+	0	0	0			
+	0			.		Seconds		+	0			.		
				.		ΔV_x	N81					.		
				.		ΔV_y LV						.		
				.		ΔV_z (ft/s)						.		
X	X	X				R		X	X	X				
X	X	X				P IMU Gimbal Angles (deg)		X	X	X				
X	X	X				Y		X	X	X				
+				.		HApogee	N44	+				.		
				.		nmi HPerigee						.		
+				.		ΔVT (ft/s)		+				.		
X	X	X		.		BT (min:s)		X	X	X		.		
X				.		ΔVC (ft/s)		X				.		
X	X	X	X			SXT Star		X	X	X	X			
+			.		0	SFT (degrees)		+			.			0
+		.		0	0	TRN (degrees)		+		.		0		0
X	X	X				BSS (Coas Star)		X	X	X				
X	X			.		SPA (Coas Pitch, deg)		X	X			.		
X	X	X		.		SXP (Coas X Pos, deg)		X	X	X		.		
	0			.		LAT	N61		0			.		
				.		(degrees) LONG						.		
+				.		RTGO (nmi) EMS		+				.		
+				.		VIO (ft/s)		+				.		
			.	.	.	GET 0.05 g Hr:min:s			.	.	.	.	.	.
						SET STARS								
X	X	X				RAlign		X	X	X				
X	X	X				PAlign		X	X	X				
X	X	X				YAlign		X	X	X				
						ULLAGE								

NOTES:

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+			/	Weight (lb)	N47	+			/
	0	0		P Trim	N48		0	0	
	0	0		(degrees)			0	0	
+	0	0		Y Trim			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_x	N81				
				ΔV_y LV					
				ΔV_z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				H Apogee	N44	+			
				nmi					
+				H Perigee					
				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+				SFT (degrees)		+			0
+			0	TRN (degrees)		+			0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				(degrees)					
+				LONG					
+				RTGO (nmi) EMS		+			
				VIO (ft/s)		+			
				GET 0.05 g					
				Hr:min:s					
				SET STARS					
X	X	X		R Align		X	X	X	
X	X	X		P Align		X	X	X	
X	X	X		Y Align		X	X	X	
				ULLAGE					

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

LUNAR ORBIT CIRCULARIZATION MANEUVER

In order to transfer from an elliptical orbit about the moon to a circular orbit, a ΔV is applied tangentially to affect a "Hohmann transfer." The ΔV is applied at pericynthion of the ellipse to bring the apocynthion equal to pericynthion, thereby achieving a circular orbit. The targeting equation for ΔV is

$$\Delta V = V_E - V_C \quad \text{ft/s at pericynthion}$$

where

$$V_E = \left(\frac{\mu}{r_P} \right)^{1/2} \left(\frac{2r_{AE}}{r_{AE} + r_P} \right)^{1/2} = \text{elliptical velocity in ft/s at pericynthion}$$

$$V_C = \left(\frac{\mu}{r_P} \right)^{1/2} \left(\frac{2r_{AC}}{r_{AC} + r_P} \right)^{1/2} = \text{circular velocity in ft/s at pericynthion}$$

If after the ΔV burn, the new apocynthion, r_{AC} , is equal to pericynthion, r_P , then the targeting equation becomes

$$\Delta V = \left(\frac{\mu}{r_P} \right)^{1/2} \left[\left(\frac{2r_{AE}}{r_{AE} + r_P} \right)^{1/2} - 1 \right] \quad \text{ft/s at pericynthion}$$

where

$$r_{AE} = \text{elliptical apocynthion.}$$

To obtain a linearized error equation relating the errors in ΔV burned to errors in apocynthion and pericynthion, a Taylor series expansion may be employed. Thus, ignoring all of the higher order terms about the point $(X+\Delta X, Y+\Delta Y)$, the Taylor series is

$$f(X+\Delta X, Y+\Delta Y) = f(X, Y) + \left[\Delta X \frac{\partial}{\partial X} + \Delta Y \frac{\partial}{\partial Y} \right] f(X, Y)$$

where

$$f(X, Y) = f(r_{AC}, r_P) = \Delta V$$

$$f(r_{AC} + \Delta r_{AC}, r_P + \Delta r_P) = \Delta V + \delta$$

The linearized error equation becomes

$$\Delta V + \delta = \Delta V + \left[\Delta r_{AC} \frac{\partial}{\partial r_{AC}} + \Delta r_P \frac{\partial}{\partial r_P} \right] f(r_{AC}, r_P)$$

$$\delta = \Delta r_{AC} \frac{\partial}{\partial r_{AC}} [f(r_{AC}, r_P)] + \Delta r_P \frac{\partial}{\partial r_P} [f(r_{AC}, r_P)]$$

where

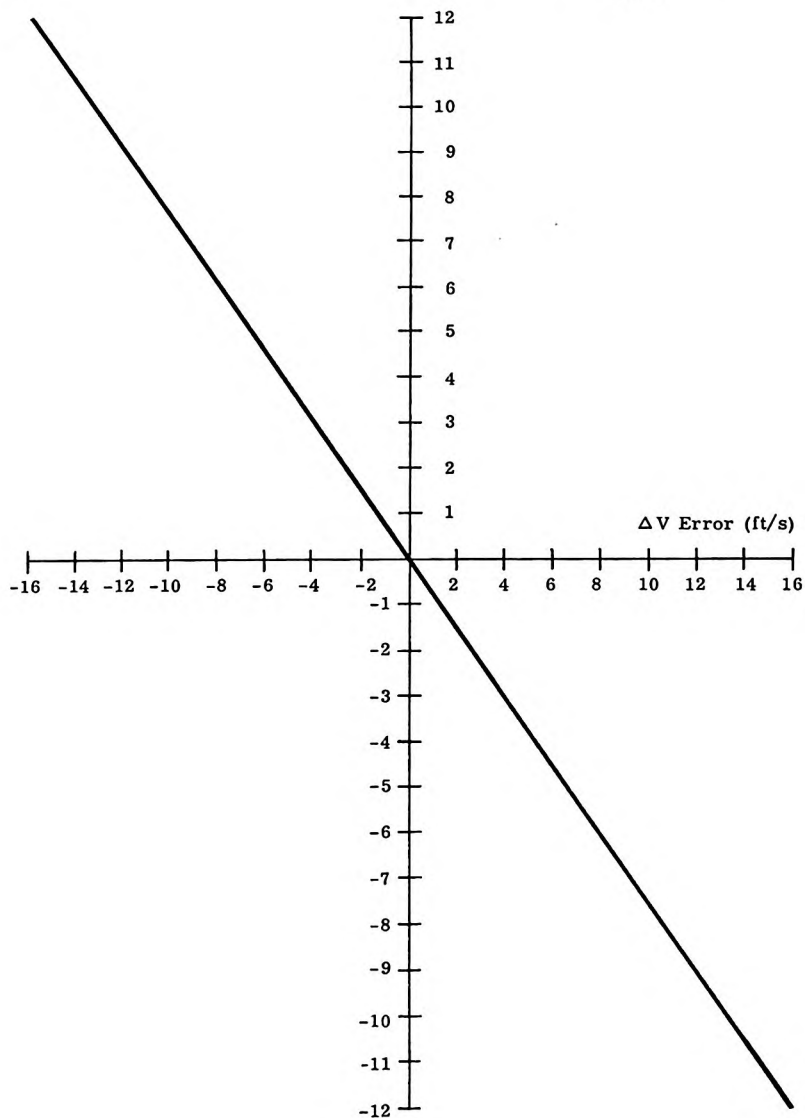
$$\frac{\partial}{\partial r_{AC}} = - \left(\frac{\mu r_P}{2 r_{AC} (r_{AC} + r_P)^3} \right)^{1/2}$$

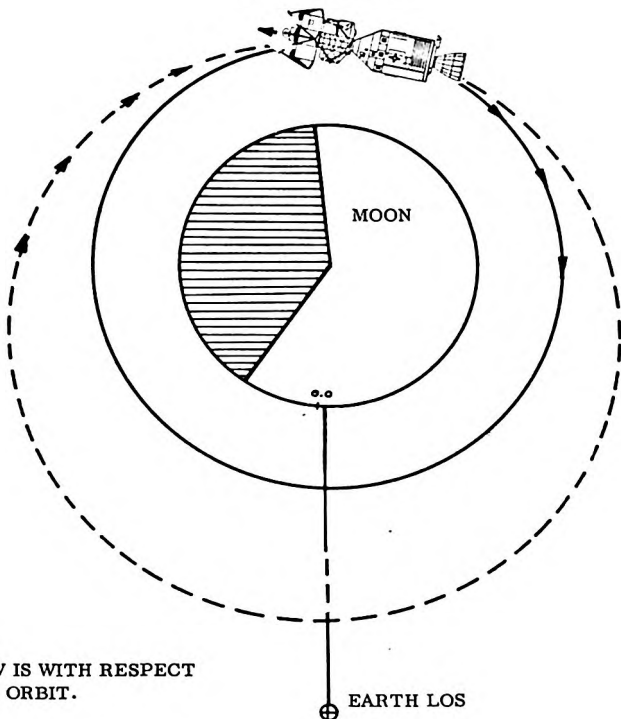
$$\frac{\partial}{\partial r_P} = \left(\frac{-(r_{AE}^2 + 2 r_{AE} r_P)}{(r_{AE} r_P + r_P^2)^2} \right) \left(\frac{\mu (r_{AE} r_P + r_P^2)}{2 r_{AE}} \right)^{1/2}$$

$$+ \left(\frac{r_{AC}^2 + 2 r_{AC} r_P}{(r_{AC} r_P + r_P^2)^2} \right) \left(\frac{\mu (r_{AC} r_P + r_P^2)}{2 r_{AC}} \right)^{1/2}$$

A graph of this function illustrates the relationship between errors in ΔV burned and errors in the resulting apocynthion. The term $\partial/\partial r_P$ is very small and is assumed equal to zero.

Apogee Altitude Error
(nmi)



$$\Delta V = 169.3 \text{ ft/s}$$


NOTE: SHADOW IS WITH RESPECT
TO CSM ORBIT.

P22—ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 — Known, A2 — Unknown

B — Index of offset designator

DE — Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing — Please Mark

+	0	0				Hours	T1 GET at 0 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
+	0	0				Hours	T2 GET at 35 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P		X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT Angles	X	X	X	X		
X	X	X	X			Trun		X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown
 B - Index of offset designator
 DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours	T1 GET at	+	0	0			
+	0	0	0			Minutes	0 degree	+	0	0	0		
+	0					Seconds	Elevation	+	0				
+	0	0				Hours	T2 GET at	+	0	0			
+	0	0	0			Minutes	35 degrees	+	0	0	0		
+	0					Seconds	Elevation	+	0				
X	X	X				R	IMU Gimbal	X	X	X			
X	X	X				p	Angles (deg)	X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT	X	X	X	X		
X	X	X	X			Trun	Angles	X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P30-EXTERNAL ΔV
TEI 11 & TEI 34

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

						Purpose									
						Prop/Guidance									
+						Weight (lb)	N47	+							
	0	0				PTrim	N48		0	0					
	0	0				YTrim (degrees)			0	0					
+	0	0				Hours	N33	+	0	0					
+	0	0	0			Minutes GETI		+	0	0	0				
+	0					Seconds		+	0						
						ΔV_X	N81								
						ΔV_Y LV									
						ΔV_Z (ft/s)									
X	X	X				R		X	X	X					
X	X	X				P IMU Gimbal Angles (deg)		X	X	X					
X	X	X				Y		X	X	X					
+						HApogee	N44	+							
						Hperigee nmi									
+						ΔVT (ft/s)		+							
X	X	X				BT (min:s)		X	X	X					
X						ΔVC (ft/s)		X							
X	X	X	X			SXT Star		X	X	X	X				
+					0	SFT (degrees)		+						0	
+				0	0	TRN (degrees)		+				0	0		
X	X	X				BSS (Coas Star)		X	X	X					
X	X					SPA (Coas Pitch, deg)		X	X						
X	X	X				SXP (Coas X Pos, deg)		X	X	X					
	0					LAT	N61		0						
						LONG (degrees)									
+						RTGO (nmi) EMS		+							
+						VIO (ft/s)		+							
						GET 0.05 g									
						Hr:min:s									
						SET STARS									
X	X	X				RAlign		X	X	X					
X	X	X				PAlign		X	X	X					
X	X	X				YAlign		X	X	X					
						ULLAGE									

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

AN ALIGNMENT PROCEDURE

The relationship between a vector defined in a fixed coordinate system and the same vector defined in a coordinate system which has undergone some arbitrary change in orientation is generally expressed as

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_M = \begin{bmatrix} Z \\ Y \\ X \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_F = \begin{bmatrix} Q \\ Y \\ Z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_F \quad (1)$$

where

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{ is a vector defined in the fixed coordinate system}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_M \text{ is the vector } \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_F \text{ defined in the coordinate system which has moved.}$$

$[X]$, $[Y]$, $[Z]$ represent Euler rotations about the X, Y, and Z axes, respectively, of the moving coordinate system

and $[Q]$ is a transformation that relates elements of a vector defined in the fixed coordinate system to equivalent elements in the "moved" coordinate system.

Since $[Q]$ is orthogonal, the inverse of Equation 1 is

$$[Q]^T \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_M = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_F \quad (2)$$

The arbitrary change in orientation of a moving coordinate system can also be represented by a single rotation vector, R_F , defined in the fixed coordinate system. R_F can in turn be determined from the Euler angles which describe the initial and final position of an arbitrary vector v_M fixed to the moving coordinate system. In equation form:

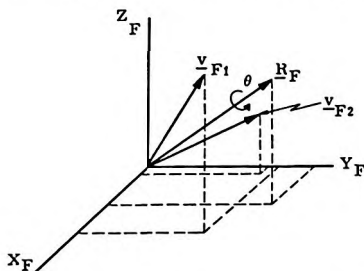
$$v_{F1} = [Q_1]^T v_M \quad (3)$$

where

$[Q_1]^T$ is the transpose of a Euler angle transformation as defined in Equation 1.

\underline{v}_M is the arbitrary vector defined in the moving coordinate system which remains invariant.

\underline{v}_{F1} is the initial orientation of \underline{v}_M in the fixed coordinate system.



After the moving coordinate system has undergone some arbitrary motion, the following relationship applies.

$$\underline{v}_{F2} = [Q_2]^T \underline{v}_M \quad (4)$$

where

$[Q_2]^T$ is the transpose of a Euler angle transformation as defined in Equation 1.

\underline{v}_{F2} is the final orientation of \underline{v}_M with respect to the fixed coordinate system.

From Equations 3 and 4, the following relationship between \underline{v}_{F1} and \underline{v}_{F2} can be obtained.

$$\underline{v}_{F2} = [Q_2]^T [Q_1] \underline{v}_{F1} = [M] \underline{v}_{F1} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \underline{v}_{F1} \quad (5)$$

where

$[M]$ represents the relationship between the initial and final positions (in fixed space) of the arbitrary vector \underline{v}_M fixed in moving space.

The rotation vector \underline{R}_F can now be defined as follows:

$$\underline{R}_F = \cos^{-1} \{1/2 (m_{11} + m_{22} + m_{33})\} \text{ UNIT } [(m_{32} - m_{23}), (m_{13} - m_{31}), (m_{21} - m_{12})] \quad (6)$$

This relationship between a transformation matrix derived from three successive Euler rotations and a corresponding single rotation vector can be utilized to align the LM IMU. The technique consists of performing two distinct, successive rotations of the docked CSM/LM spacecraft configuration.

Each spacecraft rotation will yield an R_F vector in both LM and CM stable member coordinates. The two rotation vectors defined in LM stable member coordinates are analogous to two AOT sightings. The two rotation vectors in CM stable member coordinates are analogous to the reference vectors (star catalog) corresponding to the AOT sightings. With this information, it is possible to determine how the LM stable member is aligned with respect to the CM stable member in a manner similar to the way P52 uses optical sightings to determine the absolute alignment of a stable member.

Implementation of this technique requires the determination of the $\{Q\}$ transformations of Equation 5 for each IMU and for each spacecraft rotation. Examination of Equation 1 shows that the $\{Q\}$ transformation is identical to the stable member (fixed) to navigation base (moving) transformation $\{SMNB\}$ used on the Apollo program. The $\{SMNB\}$ transformation is typically defined as:

$$\{SMNB\} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos A_O & \sin A_O \\ 0 & -\sin A_O & \cos A_O \end{bmatrix} \begin{bmatrix} \cos A_m & \sin A_m & 0 \\ -\sin A_m & \cos A_m & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos A_i & 0 & -\sin A_i \\ 0 & 1 & 0 \\ \sin A_i & 0 & \cos A_i \end{bmatrix}$$

where

A_O , A_m , and A_i are the outer, middle, and inner gimbal angles, respectively.

and

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_M = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{NB} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_F = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}$$

Thus, three gimbal angles for each IMU must be recorded at the beginning and end of each spacecraft rotation.

Hence, four $\{M\}$ transformations can be developed using the gimbal angles recorded. They are

$$\left. \begin{aligned} \{M_1\}_{LM} &= \{SMNB_2\}_{LM}^T \{SMNB_1\}_{LM} \\ \{M_1\}_{CM} &= \{SMNB_2\}_{CM}^T \{SMNB_1\}_{CM} \end{aligned} \right\} \text{First spacecraft rotation}$$

$$\left. \begin{aligned} \{M_2\}_{LM} &= \{SMNB_4\}_{LM}^T \{SMNB_3\}_{LM} \\ \{M_2\}_{CM} &= \{SMNB_4\}_{CM}^T \{SMNB_3\}_{CM} \end{aligned} \right\} \text{Second spacecraft rotation}$$



Although the above relationships indicate the need for four different $\{SMNB\}$ transformations for each IMU, only three are required since $\{SMNB_3\}$ could be equal to $\{SMNB_2\}$ without affecting the results.

Once the $\{M\}$ transformation matrices have been determined, four R_F inertial reference lines can be determined using Equation 6. These reference lines, as shown below, can then be used in a program analogous to P52 to determine the inertial attitude of the LM stable member.

	First Spacecraft Rotation	Second Spacecraft Rotation
CM IMU		
LM IMU		
The stable member reference coordinate system of the CM need not be coincident with that of the LM stable member coordinate system.		

These four \underline{R}_F vectors are then used in an orthogonalization process to determine two orthogonal coordinate systems, one in CM stable member space and one in LM stable member space. Using the coordinate system in CM stable member space as a reference, the alignment of the LM stable member with respect to the CM stable member can be determined in the same manner that P52 determines the absolute alignment of a stable member.

$$\underline{R}_{F1CM} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}_{CM}$$

$$\underline{R}_{F2CM} = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}_{CM}$$

\underline{R}_{F1CM} and \underline{R}_{F2CM} are the unit vectors defining the two spacecraft rotations in CM stable member coordinates and are considered to be the reference vectors (equivalent star catalog vectors)

$$\underline{R}_{F1LM} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}_{LM}$$

$$\underline{R}_{F2LM} = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}_{LM}$$

\underline{R}_{F1LM} and \underline{R}_{F2LM} are the unit vectors defining the two spacecraft rotations in LM stable member coordinates and are considered to be the measures vectors.

$$[R_{CM}] = \begin{bmatrix} \underline{R}_{F1CM} \\ (\underline{R}_{F1CM} \times \underline{R}_{F2CM}) \times \underline{R}_{F1CM} \\ \underline{R}_{F1CM} \times \underline{R}_{F2CM} \end{bmatrix} [SM]_{CM} \quad [R_{LM}] = \begin{bmatrix} \underline{R}_{F1LM} \\ (\underline{R}_{F1LM} \times \underline{R}_{F2LM}) \times \underline{R}_{F1LM} \\ \underline{R}_{F1LM} \times \underline{R}_{F2LM} \end{bmatrix} [SM]_{LM}$$

$$[R_{CM}] = [M_{CM}] [SM]_{CM} \quad [R_{LM}] = [M_{LM}] [SM]_{LM}$$

$$[R_{CM}] = [R_{LM}]$$

$$[M_{CM}] [SM]_{CM} = [M_{LM}] [SM]_{LM}$$

$$[SM]_{CM} = [M_{CM}]^{-1} [M_{LM}] [SM]_{LM}$$

$$[M_{LMCM}] = [M_{CM}]^{-1} [M_{LM}]$$

The transformation $[M_{LMCM}]$ represents the three Euler rotations (gyro torquing angles) necessary to align the LM stable member to the CM stable member.

Since it is assumed that the CM stable member is accurately aligned, the $[REFSMMAT]_{CM}$ in the CM computer is a valid one and therefore the actual $[REFSMMAT]_{LM}$ for the LM can be determined.

$$[SM]_{CM} = [M_{LMCM}] [SM]_{LM}$$

$$[REFSMMAT]_{CM} [ECI]_{CM} = [M_{LMCM}] [REFSMMAT]_{LM} [ECI]_{LM}$$

$$[ECI]_{CM} = [ECI]_{LM}$$

$$[REFSMMAT]_{LM} = [M_{LMCM}]^{-1} [REFSMMAT]_{CM}$$

The transformation $[REFSMMAT]_{LM}$ represents the actual $[REFSMMAT]$ for the LM.

LM IMU FINE ALIGNMENT (WHEN LM DOCKED TO CSM)

CSM						LM								
+				•		Outer	IMU Gimbal Angles (deg)	N20	+				•	
+				•		Inner		+					•	
+				•		Middle		+					•	
+				•		Outer	IMU Gimbal Angles (deg)	N20	+				•	
+				•		Inner		+					•	
+				•		Middle		+					•	
+				•		Outer	IMU Gimbal Angles (deg)	N20	+				•	
+				•		Inner		+					•	
+				•		Middle		+					•	
+				•		Outer	IMU Gimbal Angles (deg)	N20	+				•	
+				•		Inner		+					•	
+				•		Middle		+					•	
+				•		Outer	IMU Gimbal Angles (deg)	N20	+				•	
+				•		Inner		+					•	
+				•		Middle		+					•	
						Calculated	X					•		
						Gyro Torquing	Y					•		
						Angles (deg)	Z					•		

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours		+	0	0				
+	0	0	0			Minutes	TI GET at 0 degree Elevation	+	0	0	0			
+	0					Seconds		+	0					
+	0	0				Hours	T2 GET at 35 degrees Elevation	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0					Seconds		+	0					
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X				
X	X	X				P		X	X	X				
X	X	X				Y		X	X	X				
X	N	or	S			nmi		X	N	or	S			
X	X	X	X			Shaft	SXT Angles	X	X	X	X			
X	X	X	X			Trun		X	X	X	X			
						Control Point								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						ΔR nmi	N49							
						ΔV ft/s								

NOTES:

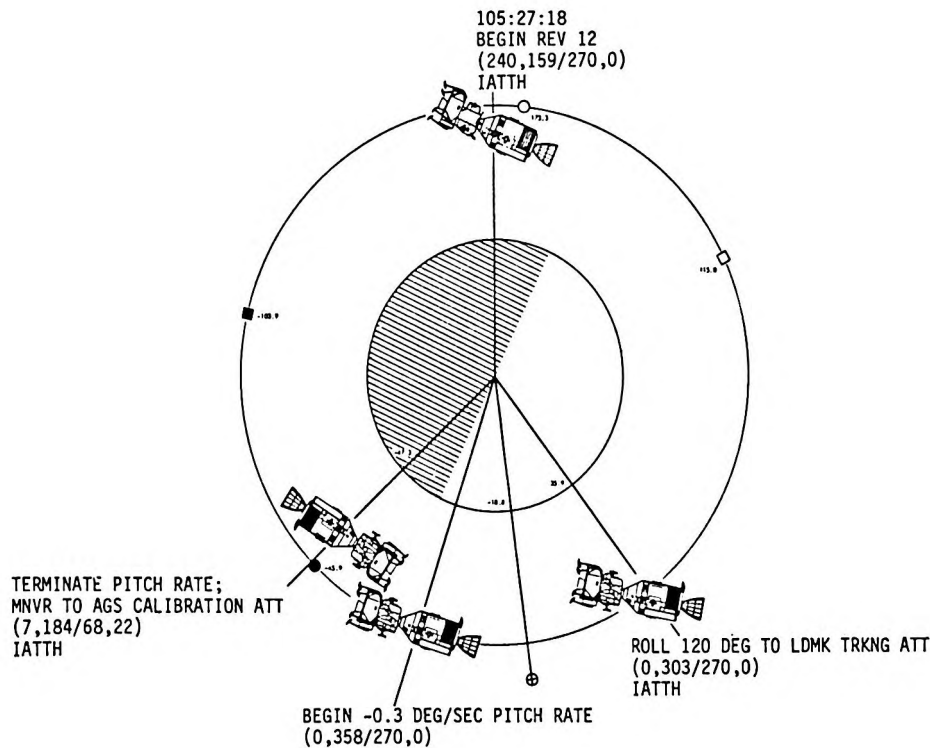
P30-EXTERNAL ΔV
Separation

V37 Enter, 30 Enter

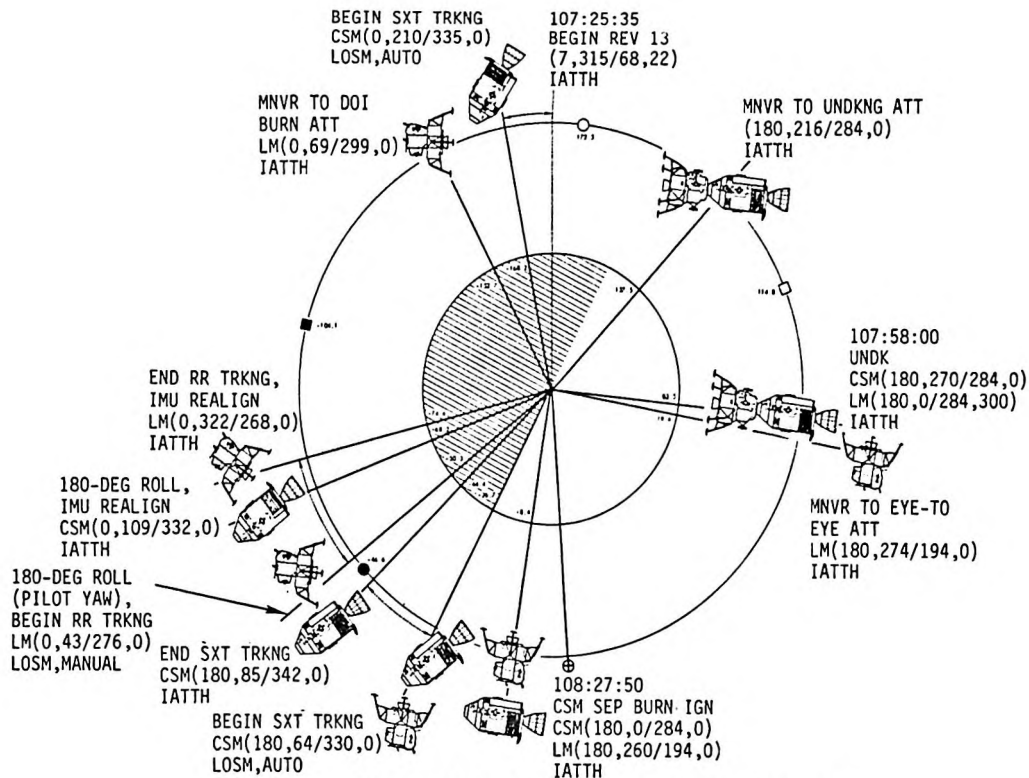
V08 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		(degrees)			0	0	
+	0	0		YTrim					
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y LV					
				ΔV_Z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				nmi					
+				HPerigee					
				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+				SFT (degrees)		+			0
+			0	TRN (degrees)		+			0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				(degrees)					
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g					
				Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					



Twelfth Revolution Major Events and Attitudes



Thirteenth Revolution Major Events and Attitudes

P30 – EXTERNAL ΔV (LM)

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

						Purpose									
+	0	0				Hours	N33	+	0	0					
+	0	0	0			Minutes GETI		+	0	0	0				
+	0					Seconds		+	0						
						ΔV_X	N81								
						ΔV_Y LV									
						ΔV_Z (ft/s)									
+						ΔV_R (ft/s)		+							
X	X	X				BT (min:s)		X	X	X					
X	X	X				R FDI Inertial Angles		X	X	X					
X	X	X				P (degrees)		X	X	X					
						ΔV_X	N86								
						ΔV_Y AGS Targeting (ft/s)									
						ΔV_Z									
X	X	X	X			COAS Star		X	X	X	X				
X	X					COAS Az (degrees)		X	X						
X	X					COAS EL (degrees)		X	X						
+						HApogee	N42	+							
						HPerigee (nmi)									
+						ΔVT (ft/s)		+							

NOTES:

P63—BRAKING PHASE

V37 Enter, 63 Enter

V06 N61 Flashing

TG, TFI, crossrange (min/s, min/s, 0.1 nmi)

V50 N25 Flashing

R1: 0 0 0 1 4 Fine align option

V50 N25 Flashing

R1: 0 0 5 0 0 (position LR to Position 1)

V50 N25 Flashing

R1: 0 0 2 0 3 (switch Guidance Control to PGNS, Mode to Auto, Thrust Control to Auto)

V06 N62 Flashing

Inertial velocity, time from ignition, ΔV (accumulated) (0.1 ft/s, min/s, 0.1 ft/s)

V99 N62 Flashing

Enable on enable

V06 N63 Flashing

Inertial velocity, HDOT, H (0.1 ft/s, 0.1 ft/s, ft)

V16 N68

Slant range, TG, LR Alt - computed altitude (0.1 nmi, min/s, ft)

+	0	0				Hours	TIG for PDI	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					min:s	TGO	N61	X	X			
						nmi	Crossrange						
X	X	X				Roll	FDAI inertial angles at PDI (deg)		X	X	X		
X	X	X				Pitch			X	X	X		
X	X	X				Yaw			X	X	X		
						231 Landing Site Radius (AGS) IF RQD							

NOTES;

NO PDI +12 ABORT PAD

+	0	0			Hours	N33	+	0	0			
+	0	0	0		Minutes GETI		+	0	0	0		
+	0				Seconds		+	0				
					ΔV_X	N81						
					ΔV_Y LV (ft/s)							
					ΔV_Z							
+					H_{Apogee} (nmi)	N42	+					
					$H_{Perigee}$							
+					ΔV_R (ft/s)		+					
X	X	X			BT (min:s)		X	X	X			
X	X	X			R FDAI Inertial Angles (degrees)		X	X	X			
X	X	X			P		X	X	X			
					ΔV_X	N86						
					ΔV_Y AGS Targeting (ft/s)							
					ΔV_Z							
+	0	0			Hours	N11	+	0	0			
+	0	0	0		Minutes TIG of CSI		+	0	0			
+	0				Seconds		+	0				
+	0	0			Hours	N37	+	0	0			
+	0	0	0		Minutes TIG of TPI		+	0	0	0		
+	0				Seconds		+	0				

PDI < 10 MINUTES ABORT PAD

							Log Insertion GET (h:min:s)								
		+	5	0	0	0									
							TIG of CSI (h:min:s)								
+	0	0					Hours		N37	+	0	0			
+	0	0	0				Minutes	TIG		+	0	0	0		
+	0						Seconds	of		+	0				
								TPI							

T1-1 (PDI > 10:30) ABORT PAD

							Log Insertion GET (h:min:s)								
		+	5	0	0	0									
							Boost GET (h:min:s)								
		+	5	5	0	0									
							CSI, 1 GET (h:min:s)								
		+	5	5	0	0									
							CSI, 2 GET (h:min:s)								
+	0	0					Hours		N37	+	0	0			
+	0	0	0				Minutes	TIG		+	0	0	0		
+	0						Seconds	of		+	0				
								TPI							

CSM RENDEZVOUS RESCUE PAD

CSM SEP PAD

33			
81			2.5
22	0	18	0

CSI

11			
81			
N			

CSM RESCUE ONE

33			
81			
22	180		0
ΔV_c			
11			
37			

CDH

13			
81			

DOI P76 PAD

33			
84			

TPI

37			
81			
59			

11 GETI XX:XX:XX
 13 GETI XX:XX:XX
 22 R XXX.XX (deg)
 P XXX.XX (deg)
 Y XXX.XX (deg)
 33 GETI XX:XX:XX
 37 GETI XX:XX:XX
 59 Delta V LOS 1 XX.X (ft/s)
 Delta V LOS 2 XX.X (ft/s)
 Delta V LOS 3 XX.X (ft/s)
 81 Delta VX XX.X (ft/s)
 Delta VY XX.X (ft/s)
 Delta VZ XX.X (ft/s)
 84 Delta VX (0 VEH) XX.X (ft/s)
 Delta VY (0 VEH) XX.X (ft/s)
 Delta VZ (0 VEH) XX.X (ft/s)
 N XX

ΔV_c XX.X (ft/s)

Time of Ignition of CSI (h:min:s)
 Time of Ignition of CDH (h:min:s)
 New ICDU Angles

Time of Ignition (h:min:s)
 Time of Ignition of TPI (h:min:s)
 Delta V Line of Sight Components

Local Vertical Components of Velocity

Components of ΔV Applied Along Local Vertical Axis at TIG

The Future Apsidal Crossing (Apolune or Perilune) of the Active Vehicle at Which CDH Should Occur

Velocity to be Set in EMS Counter

P41 – RCS THRUSTING

V37 Enter, 41 Enter

V50 N18 Flashing, Request Maneuver to FDI R, P, Y Angles

V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude

V06 N85, X, Y, Z Body Axes Velocity to be Gained

V16 N85 (Average G on at TIG -30) Velocity to be Gained

V16 N85 Flashing, Body Axes Residuals (to be Nulled)

			.		50-18	Roll				.		
			.			Pitch (deg)				.		
			.			Yaw				.		
			.		06-18	Roll				.		
			.			Pitch (deg)				.		
			.			Yaw				.		
			.		06-85	X					.	
			.			Y VG (ft/s)					.	
			.			Z					.	
			.		16-85	X					.	
			.			Y VG (ft/s)					.	
			.			Z					.	
			.		16-85	X					.	
			.			Y Residuals (ft/s)					.	
			.			Z					.	
			.		X						.	
			.		Y Trim (ft/s)						.	
			.		Z						.	

LUNAR SURFACE
T3 ABORT PAD

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	Liftoff Time	+	0	0	0		
+	0					Seconds	Touchdown +1 Revolution	+	0				
+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	CSM Period	+	0	0	0		
+	0					Seconds		+	0				
+	0	0				Hours	CSM Period Plus the Time Interval Between Closest Approach and Liftoff Time	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
+	0	0				Hours	TIG	N11	+	0	0		
+	0	0	0			Minutes	of CSI		+	0	0	0	
+	0					Seconds			+	0			
+	0	0				Hours	TIG	N37	+	0	0		
+	0	0	0			Minutes	of TPI		+	0	0	0	
+	0					Seconds			+	0			

NOTES:

P52-IMU REALIGN (LM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal
3 - REFSMMAT, 4 - Landing Site

V01 N70 Flashing

R1: 0 0 C D E

C - AOT Detent
0 - COAS CAL, 1 - FL, 2 - FC, 3 - FR,
4 - RR, 5 - RC, 6 - RL, 7 - COAS
DE - Celestial Body Code

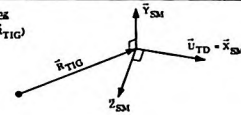
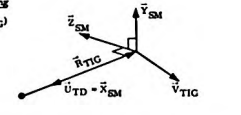
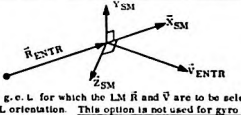
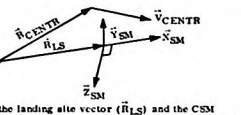
V51 Flashing - Please Mark

X	0	0	0	0	P52 Option	X	0	0	0	0	0
+	0	0			Hours	GET	+	0	0		
+	0	0	0		Minutes		+	0	0	0	
+	0				Seconds		+	0			
X	0	0			AOT Detent and Star 1 ID	N71	X	0	0		
X	0	0			AOT Detent and Star 2 ID	N71	X	0	0		
					Star Angle Difference (degrees)	N05					
					X	Gyro Torquing Angles (degrees)					
					Y						
					Z						
					X	Calculated Gyro Drift (meru)					
					Y						
					Z						

X	0	0	0	0	P52 Option	X	0	0	0	0	0
+	0	0			Hours	GET	+	0	0		
+	0	0	0		Minutes		+	0	0	0	
+	0				Seconds		+	0			
X	0	0			AOT Detent and Star 1 ID	N71	X	0	0		
X	0	0			AOT Detent and Star 2 ID	N71	X	0	0		
					Star Angle Difference (degrees)	N05					
					X	Gyro Torquing Angles (degrees)					
					Y						
					Z						
					X	Calculated Gyro Drift (meru)					
					Y						
					Z						

NOTES:

LM IMU REALIGNMENT - P52

OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	<p>PREFERRED Thrusting (\vec{U}_{TD} not parallel to \vec{R}_{TIG})</p>  <p>PREFERRED Thrusting (\vec{U}_{TD} parallel to \vec{R}_{TIG})</p>  <p>The PREFERRED option refers to one of two possibilities:</p> <ol style="list-style-type: none"> The PREFERRED thrusting orientation which is calculated and stored by P40, P41, and P42. Any orientation uplinked by MSFN via P27. <p>The LGC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40, P41, or P42 and stored, or uplinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the LGC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. This option is not used for gyro drift determination.</p>	<p>PREFERRED REFSMAT (Thrusting)</p> $\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \vec{U}_{TD} \\ \text{Unit}(\vec{U}_{TD} \times \vec{K}) \\ \text{Unit}(\vec{U}_{TD} \times (\vec{U}_{TD} \times \vec{K})) \end{bmatrix}$ <p>where</p> <p>\vec{U}_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.</p> <p>$\vec{K} = \vec{R}_{TIG}$ if \vec{R}_{TIG} is not parallel to \vec{U}_{TD} $\vec{K} = \vec{V}_{TIG}$ if \vec{R}_{TIG} is parallel to \vec{U}_{TD}</p> <p>$\left. \begin{matrix} \vec{R}_{TIG} \\ \vec{V}_{TIG} \end{matrix} \right\}$ are the position and velocity vectors of the LM at ignition, expressed in the basic reference system.</p>
00002 (NOMINAL)	<p>NOMINAL</p>  <p>The LGC requests the g.e.l. for which the LM \vec{R} and \vec{V} are to be selected to define the NOMINAL orientation. This option is not used for gyro drift determination.</p>	<p>NOMINAL REFSMAT</p> $\begin{bmatrix} \text{NOMINAL} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit}(\vec{R}_{ENTR}) \\ \text{Unit}(\vec{V}_{ENTR} \times \vec{R}_{ENTR}) \\ \text{Unit}(\vec{X}_{SM} \times \vec{Y}_{SM}) \end{bmatrix}$ <p>where</p> <p>$\left. \begin{matrix} \vec{R}_{ENTR} \\ \vec{V}_{ENTR} \end{matrix} \right\}$ are the position and velocity vectors of the LM at the time specified.</p>
00003 (REFSMAT)	<p>This option is used for gyro drift determination. This option realigns the platform to the platform orientation currently maintained in the LGC. The actual platform orientation differs from the LGC maintained orientation due to gyro drift.</p>	<p>REFSMAT</p> $\begin{bmatrix} \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \text{Current LGC maintained} \\ \text{platform orientation} \end{bmatrix}$
00004 (Landing Site)	<p>Landing Site</p>  <p>The g.e.l. for which the landing site vector (\vec{R}_{LS}) and the CSM \vec{R} and \vec{V} are to be selected must be entered. This option is not used for gyro drift determination.</p>	<p>Landing Site REFSMAT</p> $\begin{bmatrix} \text{Landing Site} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit}(\vec{R}_{LS}(\text{TENTR})) \\ \text{Unit}(\vec{V}_{CENTR} \times \vec{R}_{CENTR}) \\ \text{Unit}((\vec{R}_{CENTR} \times \vec{V}_{CENTR}) \times \vec{X}_{SM}) \end{bmatrix}$ <p>where</p> <p>$\vec{R}_{LS}(\text{TENTR})$ is the landing site position vector at the time entered</p> <p>$\left. \begin{matrix} \vec{R}_{CENTR} \\ \vec{V}_{CENTR} \end{matrix} \right\}$ are the CSM position and velocity vectors at the time specified.</p>

PROCEDURE FOR SPECIFYING OPTIONS

- When P52 is entered, the LGC checks the PREFERRED ATTITUDE flag.
- If the flag is set, the DSKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
- If the flag is not set, the DSKY flashes Verb 04, Noun 06, R2 = 00002, indicating the PREFERRED option may not be selected.
- The desired option is loaded into R2 via Verb 22.

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

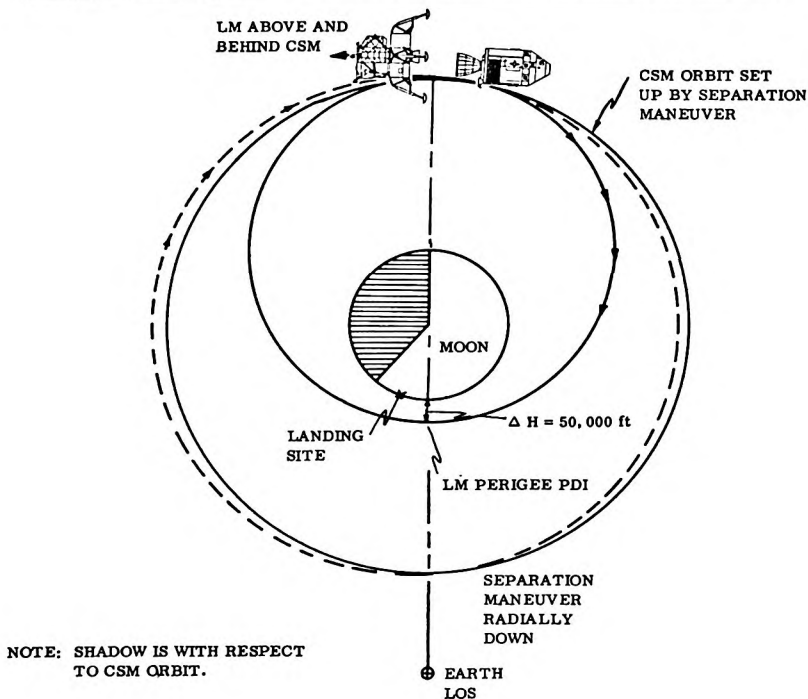
OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	<p><u>PREFERRED Thrusting</u></p> <p>The PREFERRED option refers to one of two possibilities:</p> <ol style="list-style-type: none"> The PREFERRED thrusting orientation which is calculated and stored by P40 and P41. Any orientation uplinked by MSFN via P27. <p>The CMC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40 or P41 and stored, or uplinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the CMC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. This option is not used for gyro drift determination.</p>	$\begin{bmatrix} \text{PREFERRED REFMMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} U_{TD} \\ U_{TD} \times \vec{R}_{TIG} \\ U_{TD} \times (U_{TD} \times \vec{R}_{TIG}) \end{bmatrix}$ <p>where</p> <p>\vec{U}_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.</p> <p>\vec{R}_{TIG} is the position vector of the vehicle at ignition expressed in the basic reference system.</p>
00002 (NOMINAL)	<p><u>Nominal</u></p> <p>The CMC requests the g.e.i. for which the vehicle \vec{R} and \vec{V} are to be selected to define the NOMINAL orientation. This option is not used for gyro drift determination.</p>	$\begin{bmatrix} \text{NOMINAL REFMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \vec{V}_{ENTR} \times \vec{R}_{ENTR} \\ U_{ENTR} (\vec{V}_{ENTR} \times \vec{R}_{ENTR}) \\ U_{ENTR} (-\vec{R}_{ENTR}) \end{bmatrix}$ <p>where</p> <p>$\begin{Bmatrix} \vec{R}_{ENTR} \\ \vec{V}_{ENTR} \end{Bmatrix}$ are position and velocity vectors of vehicle at the time specified.</p>
00003 (REFMMAT)	<p>This option is used for gyro drift determination. This option realigns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.</p>	$\begin{bmatrix} \text{REFMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{orientation} \end{bmatrix}$
00004 (Landing Site)	<p><u>Landing Site</u></p> <p>The latitude, longitude/2, and altitude above the mean lunar radius of the landing site must be entered to determine \vec{R}_{LS}. The g.e.i. for which the CSM \vec{R} and \vec{V} are to be selected must also be entered. This option is not used for gyro drift determination.</p>	$\begin{bmatrix} \text{Landing Site REFMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} U_{LS} (\vec{R}_{LS}) \\ \vec{Z}_{SM} \times \vec{X}_{SM} \\ U_{ENTR} ((\vec{R}_{ENTR} \times \vec{V}_{ENTR}) \times \vec{X}_{SM}) \end{bmatrix}$ <p>where</p> <p>\vec{R}_{LS} is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system.</p> <p>$\begin{Bmatrix} \vec{R}_{ENTR} \\ \vec{V}_{ENTR} \end{Bmatrix}$ are the CSM position and velocity vectors at the time specified.</p>

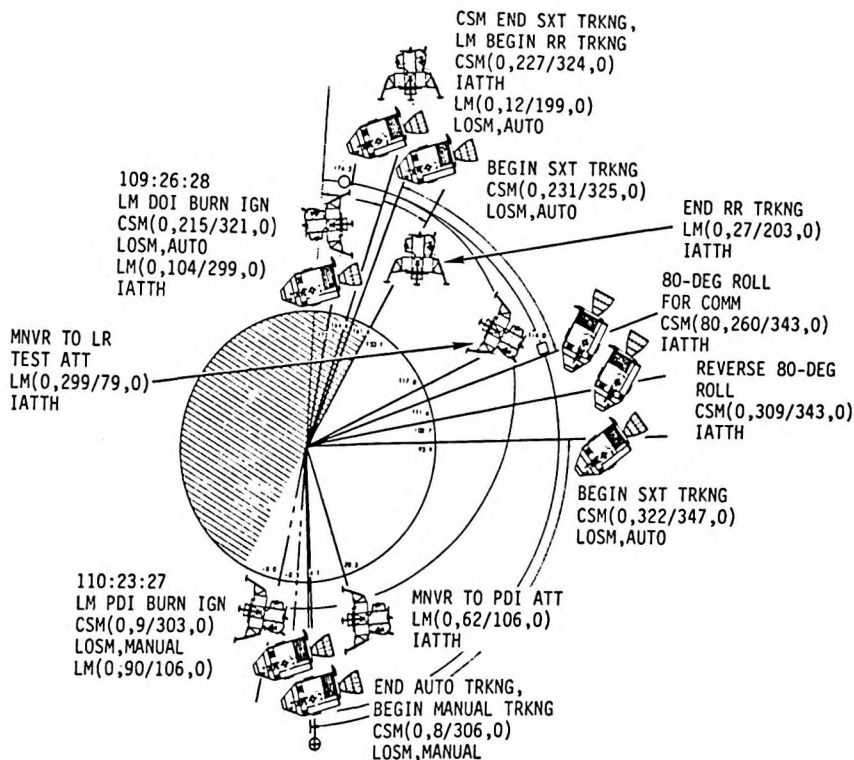
PROCEDURE FOR SPECIFYING OPTIONS

- When P52 is entered, the CMC checks the PREFERRED ATTITUDE flag.
- If the flag is set, the DSKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
- If the flag is not set, the DSKY flashes Verb 04, Noun 04, R2 = 00003, indicating the PREFERRED option may not be selected.
- The desired option is loaded into R2 via Verb 22.

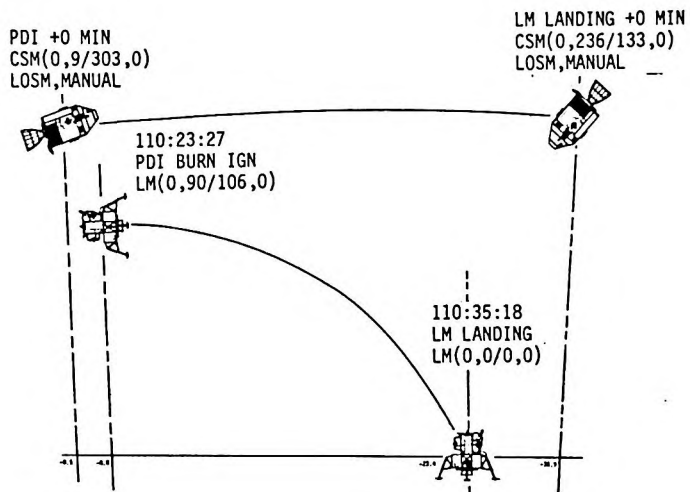
DESCENT ORBIT INITIATION

EVENT				BT/Δ V		G. E. T.		PROPULSION/ GUIDANCE				PRETHRUST TARGETING	
DOI (RETROGRADE)				28.0/ 72.1		109:26:27.0		LM-DPS/PGNS EXT ΔV (P-40)				P-30	
RESIDUALS													
ΔVX								+	X	X			h
ΔVY	PGNS	N85				ACS	500	+	X	X	X		min GET
ΔVZ							501	+	X				s
							502	+	X				
----- • ----- V _{XTRIM} ----- • ----- V _{YTRIM} ----- • ----- V _{ZTRIM} ft/s													





Fourteenth Revolution to PDI

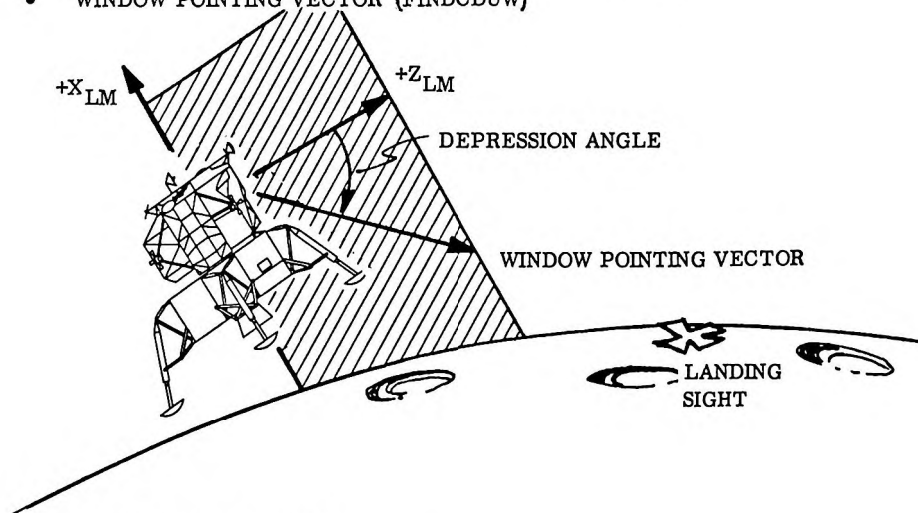


PDI Burn Ignition to LM Landing

LUNAR LANDING

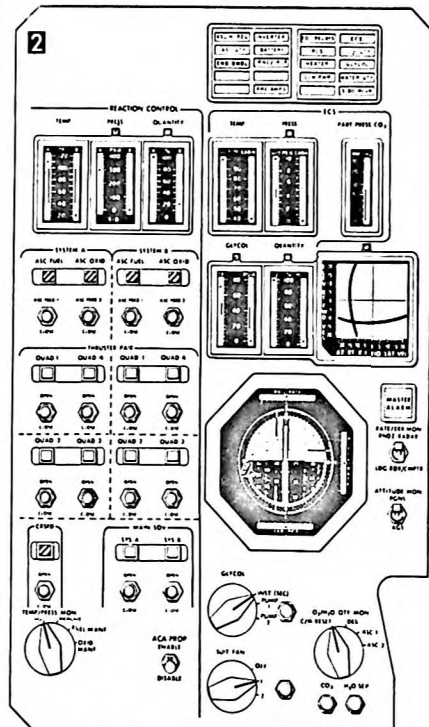
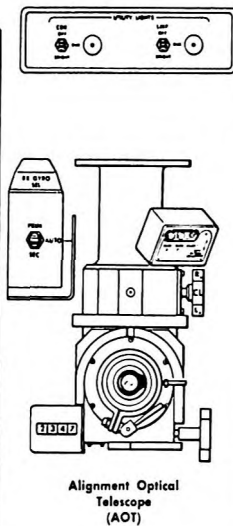
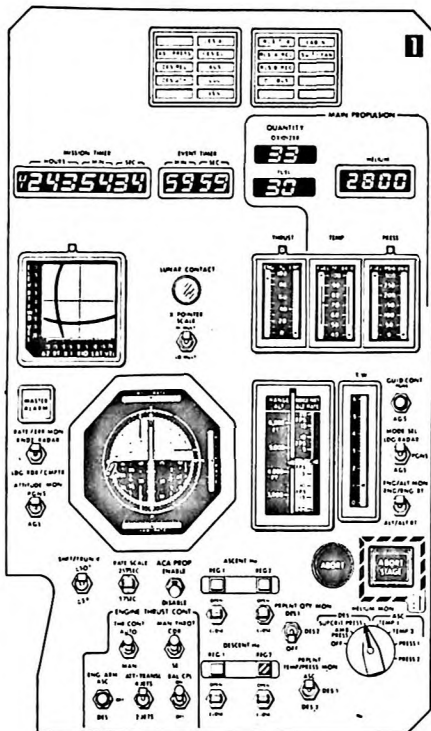
EACH GUIDANCE CYCLE COMPUTATION PRODUCES:

- THE TIME AT WHICH THE STATE VECTOR IS VALID (PIPTIME)
- THE CORRESPONDING STATE VECTOR
- SPECIFIC FORCE (COMMAND THRUST ACCELERATION)
- WINDOW POINTING VECTOR (FINDCDUW)

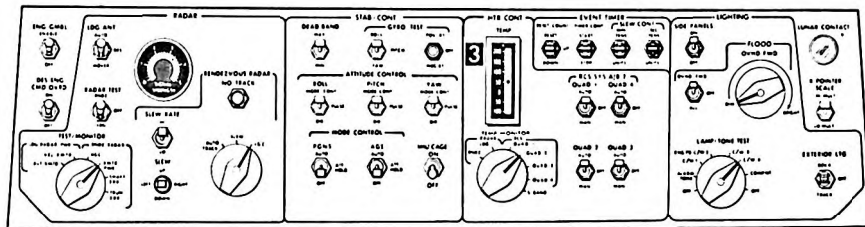


- THROTTLE COMMANDS
- DIGITAL AUTOPILOT COMMANDS

LM CONTROLS AND DISPLAYS



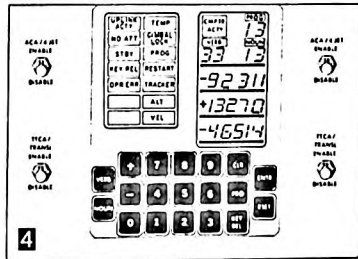
LM CONTROLS AND DISPLAYS



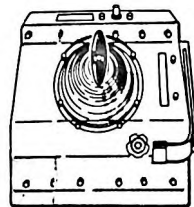
Display Keyboard Assembly (DSKY)



Attitude Controller Assembly (ACA)



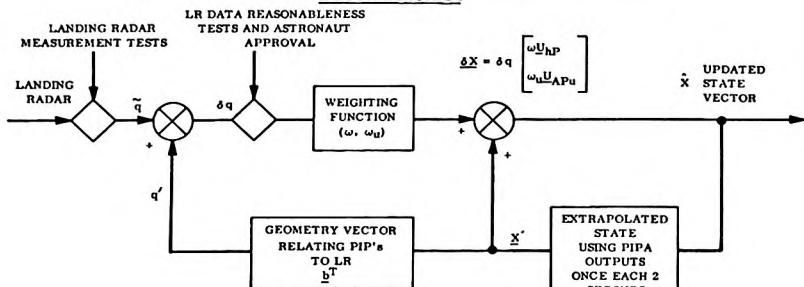
Cabin Controls and Displays



Thrust/Translation Controller Assembly (TTCA)

LUNAR LANDING - STATE VECTOR UPDATE RECURSIVE FILTER

BLOCK DIAGRAM



STATE VECTOR EXTRAPOLATION

$$\hat{X}' = \begin{bmatrix} \hat{X}_P \\ \hat{V}_P \end{bmatrix} = \begin{bmatrix} \hat{X}_{P-1} + (t_n - t_{n-1}) \left(\hat{V}_{P-1} + \frac{\Delta \hat{V}_P}{2} + \frac{\hat{X}_{n-1} \Delta t}{2} \right) \\ \hat{V}_{P-1} + \Delta \hat{V}_P + \left(\hat{X}_P + \hat{X}_{n-1} \right) \frac{\Delta t}{2} \end{bmatrix}$$

P = PLATFORM FRAME

STATE VECTOR UPDATE

$$\hat{X} = \begin{bmatrix} \hat{X}_P \\ \hat{V}_P \end{bmatrix} + \begin{bmatrix} \delta q_h \omega_{hP} \\ \delta q_u \omega_u u_{APu} \end{bmatrix}$$

CONDITIONS NECESSARY TO UPDATE STATE USING LR RANGE DATA:

- LANDING RADAR IS NOT BEING SWITCHED FROM POSITION NO. 1 TO POSITION NO. 2
- RANGE DATA MEASUREMENT TESTS ARE SATISFIED.
DATA GOOD DISCRETE HAS BEEN PRESENT FOR 4 SECONDS OR MORE.
LR RANGE SCALE HAS NOT BEEN CHANGED WITHIN LAST SECOND.
- MEASUREMENT RESIDUAL (δq) IS WITHIN SPECIFIED LIMITS $|\delta q| \leq \text{DELQFIX} * 0.125 (q')$
- ASTRONAUT APPROVAL FOR UPDATING HAS BEEN GIVEN (V57).

CONDITIONS NECESSARY TO UPDATE STATE USING LR VELOCITY DATA:

- ESTIMATED VELOCITY IS LESS THAN 6,000 ft/s. (VUP)
- LANDING RADAR IS NOT BEING SWITCHED FROM POSITION NO. 1 TO POSITION 2.
- VELOCITY DATA MEASUREMENT TESTS ARE SATISFIED:
DATA GOOD DISCRETE HAS BEEN PRESENT FOR AT LEAST 4 SECONDS.
- MEASUREMENT RESIDUAL IS WITHIN SPECIFIED LIMITS $|\delta q_u| \leq 7.5 + 0.125 (\hat{V}_u' - \omega_P \times \hat{X}_P)$.
- ASTRONAUT APPROVAL FOR UPDATING HAS BEEN GIVEN (V57).

*DELQFIX = 200 ft

STATE VECTOR EXTRAPOLATION

State vector extrapolation is accomplished by an Average G routine at 2-second intervals coincident with PIPA ΔV processing.

LM position vector (\underline{r}_p) is extrapolated assuming constant velocity and acceleration over the 2-second interval

$$\underline{r} = \underline{r}_0 + \underline{v}_0 \Delta t + \frac{1}{2} \underline{a} \Delta t^2$$

$$\underline{r}_p = \underline{r}_{n-1} + \underline{v}_{n-1}(t_n - t_{n-1}) + \frac{\underline{\Delta \tilde{v}}_p}{2} \Delta t + \frac{\underline{g}_{n-1}}{2} \Delta t^2$$

where

\underline{r}_{n-1} = position vector (\underline{r}_p) at end of previous interval

\underline{v}_{n-1} = velocity vector (\underline{v}_p) at end of previous interval

$\underline{\Delta \tilde{v}}_p$ = accumulated PIPA ΔV pulses during 2-second interval

\underline{g}_{n-1} = lunar gravitational acceleration at end of previous interval

LM velocity vector (\underline{v}_p) is extrapolated using PIPA ΔV pulses and the average gravitational acceleration over the 2-second interval

$$\underline{v} = \underline{v}_0 + \underline{a} \Delta t$$

$$\underline{v}_p = \underline{v}_{n-1} + \underline{\Delta \tilde{v}}_p + \left[\frac{\underline{g}_{n-1} + \underline{g}_p}{2} \right] \Delta t$$

where

\underline{v}_{n-1} = velocity (\underline{v}_p) at end of previous interval

$\underline{\Delta \tilde{v}}_p$ = accumulated PIPA ΔV pulses over 2-second interval

\underline{g}_{n-1} = lunar gravitational acceleration at end of previous interval

\underline{g}_p = lunar gravitational acceleration at end of present interval

$$\underline{g}_p = -\frac{\mu M}{r_p^3} \underline{r}_p$$

In addition to the state vector update, the following terms are computed

Altitude $h' = r_p - r_{LS}$

where

r_p = magnitude of position, \underline{r}_p

r_{LS} = magnitude of landing site, \underline{r}_{LS}

Velocity $\underline{v}' = \underline{v}_p$

Mass $m_n = m_{n-1} - \frac{|\underline{\Delta \tilde{v}}_p|}{V_e} m_{n-1} / V_e$ (V_e = Exhaust Velocity Constant)

Velocity Increment $\Delta V = \Delta V + |\underline{\Delta \tilde{v}}_p|$

UPDATE THE STATE VECTOR USING
LR RANGE DATA

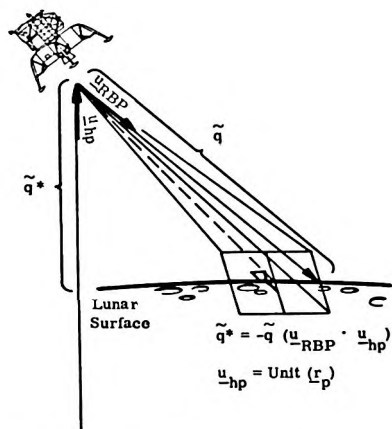
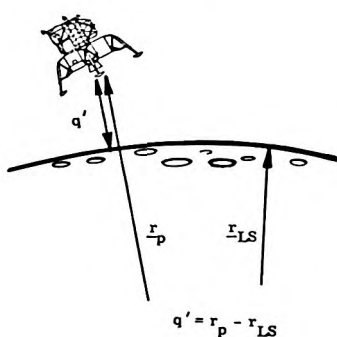
- Compute the measurement residual

$$\delta q = \tilde{q}^* - q'$$

where

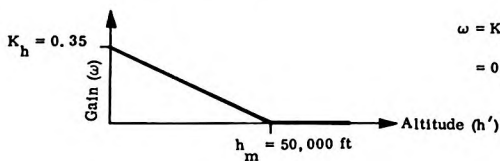
\tilde{q}^* = altitude derived from LR slant range (corrected for doppler effect)

q' = estimated altitude



- Update the position vector using the precomputed gain and measurement residual

$$\underline{r}_p = \underline{r}_p + \omega \delta q \underline{u}_{hp}$$

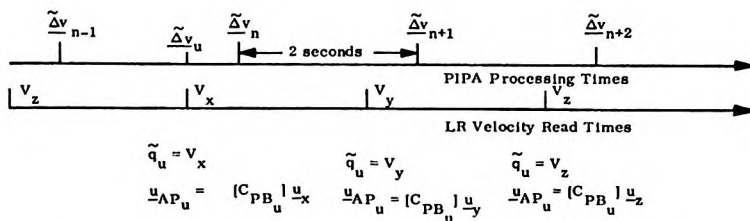


$$\omega = K_h \left(1 - \frac{h'}{h_m} \right), \quad h' \leq h_m$$

$$= 0, \quad h' > h_m$$

UPDATE THE STATE VECTOR USING LR VELOCITY DATA

The Landing Radar has three velocity components. They are used (one during each 2-second interval) to update state according to the time line shown below.



- Compute the measurement residual corresponding to the time that the velocity data is read (t_u).

$$\delta q = \tilde{q}_u - q'_u$$

$$\tilde{q}_u = \text{LR velocity component read at time } t_u$$

$$q'_u = \text{estimated component of LM relative velocity in the direction of } \tilde{q}_u$$

$$q'_u = (\underline{v}'_u - \omega_p \times \underline{r}_p) \cdot \underline{u}_{AP_u}$$

where

$$\omega_p \times \underline{r}_p = \text{velocity of lunar surface}$$

$$\underline{u}_{AP_u} = \text{unit vector in direction of LM velocity data}$$

$$\underline{v}'_u - \omega_p \times \underline{r}_p = \text{velocity of LM relative to lunar surface}$$

$$\underline{v}'_u = \text{estimated LM velocity at time } t_u$$

$$\underline{v}'_u = \underline{v}_{n-1} + \tilde{\Delta \underline{v}}_u + \underline{g}_{n-1} (t_u - t_{n-1})$$

where

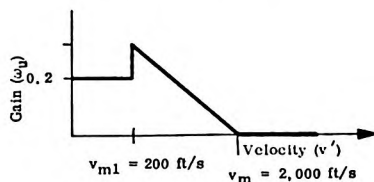
$$\underline{v}_{n-1} = \text{LM velocity at end of previous update cycle}$$

$$\tilde{\Delta \underline{v}}_u = \text{PIPA } \Delta \underline{v} \text{ read at time of LR velocity data } t_u$$

$$\underline{g}_{n-1} = \text{lunar gravitational acceleration at end of previous cycle}$$

- Update the LM velocity vector at time t_n using measurement residual and extrapolate velocity (\underline{v}_p)

$$\underline{v}_p = \underline{v}_p + \omega_u \delta q \underline{u}_{AP_u}$$



$$\omega_u = 0, v' > v_m$$

$$\omega_u = 0.3 (1 - v'/v_m), v_{m1} \leq v' \leq v_m$$

$$\omega_u = 0.2, v' < v_{m1}$$

LUNAR DESCENT GUIDANCE AND CONTROL LAWS

The control law for each phase of the descent to the lunar surface is designed such that certain terminal conditions in position, velocity, and acceleration are achieved. During the braking and approach phases (P63, P64) of lunar descent, a guidance law which is a quadratic in "time-to-go" is used to regulate thrust and provide steering. A deviation of these guidance equations constrained, as outlined above, is shown below:

$$\begin{aligned}\text{Given:} \quad \underline{\dot{X}}(T_F) &= \underline{R_D} \text{ ft} \\ \underline{\dot{X}}(T_F) &= \underline{V_D} \text{ ft/sec} \\ \underline{\ddot{X}}(T_F) &= \underline{A_D} \text{ ft/sec}^2\end{aligned}$$

Where: $\underline{R_D}$, $\underline{V_D}$, $\underline{A_D}$ are the desired terminal target vectors of position, velocity and acceleration at T_F . T_F is the final time at which the terminal conditions are achieved.

The three independent differential equations which arise as a result of the above constraints are:

$$\begin{aligned}1. \quad \int_{T_D}^{T_F} \underline{\ddot{X}}(T) dT &= \underline{\dot{X}}(T_F) - \underline{\dot{X}}(T_0) \\ 2. \quad \int_{T_0}^{T_F} \left[\int_{T_0}^T \underline{\ddot{X}}(U) dU \right] dT &= \int_{T_0}^{T_F} \left[\underline{\dot{X}}(T) - \underline{\dot{X}}(T_0) \right] dT \\ &= \underline{X}(T_F) - \underline{X}(T_0) - \underline{\dot{X}}(T_0) (T_F - T_0) \\ 3. \quad \underline{\ddot{X}}(T_F) &= \underline{A_D} + \underline{G}\end{aligned}$$

Where: T_F = final or terminal time of the guidance phases

T_0 = initial time of the guidance phase

U = dummy variable of integration

In terms of the terminal conditions equations 1, 2, and 3 can be rewritten as:

$$\begin{aligned}1. \quad \int_{T_0}^{T_F} \underline{\ddot{X}}(T) dT &= \underline{V_D} - \underline{\dot{X}}(T_0) \\ 2. \quad \int_{T_0}^{T_F} \int_{T_0}^T \underline{\ddot{X}}(U) dU dT &= \underline{R_D} - \underline{X}(T_0) - \underline{\dot{X}}(T_0) [T_F - T_0] \\ 3. \quad \underline{\ddot{X}}(T_F) &= \underline{A_D} + \underline{G}\end{aligned}$$

Since three independent equations of $\underline{\ddot{X}}(T)$ exist, $\underline{\ddot{X}}(T)$ can be of a three dimensional form. Assume $\underline{\ddot{X}}(T)$ couched in terms of T and T_F would be of the form.

$$\underline{\ddot{X}}(T) = \underline{K_1} + \underline{K_2} (T_F - T) + \underline{K_3} (T_F - T)^2$$

Substituting into equations 1, 2, and 3 yields: where $T_{GO} = T_F - T_0$

$$\begin{aligned}\int_{T_0}^{T_F} \underline{\ddot{X}}(T) dT &= \int_{T_0}^{T_F} \left[\underline{K_1} + \underline{K_2} (T_F - T) + \underline{K_3} (T_F - T)^2 \right] dT = \underline{V_D} - \underline{\dot{X}}(T_0) \\ &= \underline{K_1} (T_F - T_0) + \underline{K_2} \frac{(T_F - T_0)^2}{2} + \underline{K_3} \frac{(T_F - T_0)^3}{3} = \underline{V_D} - \underline{\dot{X}}(T_0) \\ 1. \quad &= \underline{K_1} T_{GO} + \frac{\underline{K_2} T_{GO}^2}{2} + \frac{\underline{K_3} T_{GO}^3}{3} = \underline{V_D} - \underline{\dot{X}}(T_0) \\ \int_{T_0}^{T_F} \int_{T_0}^T \underline{\ddot{X}}(U) dU dT &= \int_{T_0}^{T_F} \int_{T_0}^T \left[\underline{K_1} + \underline{K_2} (T_F - U) + \underline{K_3} (T_F - U)^2 \right] dU dT \\ &= \int_{T_0}^{T_F} \left\{ \underline{K_1} (T - T_0) + \underline{K_2} \left[T_F (T - T_0) - \frac{T^2}{2} + \frac{T_0^2}{2} \right] + \underline{K_3} \left[T_F^2 (T - T_0) - T_F (T^2 - T_0^2) \right. \right. \\ &\quad \left. \left. + \frac{T^3}{3} - \frac{T_0^3}{3} \right] \right\} dT\end{aligned}$$

$$2. \quad = \frac{K_1 T_{GO}^2}{2} + \frac{K_2 T_{GO}^3}{3} + \frac{K_3 T_{GO}^4}{4} = R_D - \underline{X}(T_0) - \dot{\underline{X}}(T_0) T_{GO}$$

$$\ddot{\underline{X}}(T_F) = A_D + \underline{G}(T_F)$$

$$3. \quad K_1 = A_D + \underline{G}(T_F)$$

Setting the above equations in matrix form.

$$\begin{bmatrix} \underline{Y}_D - \dot{\underline{X}}(T_0) \\ R_D - \underline{X}(T_0) - \dot{\underline{X}}(T_0) T_{GO} \\ A_D + \underline{G} \end{bmatrix} = \begin{bmatrix} T_{GO} + T_{GO}^2/2 + T_{GO}^3/3 \\ T_{GO}^2/2 + T_{GO}^3/3 + T_{GO}^4/4 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix}$$

Inverting yields:

$$\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 18/T_{GO}^2 - 24/T_{GO}^3 - 6/T_{GO} \\ -24/T_{GO}^3 & 36/T_{GO}^4 & 6/T_{GO}^2 \end{bmatrix} \begin{bmatrix} \underline{Y}_D - \dot{\underline{X}}(T_0) \\ R_D - \underline{X}(T_0) - \dot{\underline{X}}(T_0) T_{GO} \\ A_D + \underline{G} \end{bmatrix}$$

Solving for K_1 , K_2 and K_3 , provides values which can be inserted into the expression:

$$\ddot{\underline{X}}(T) = K_1 + K_2 (T_F - T) + K_3 (T_F - T)^2$$

This yields an expression for the required thrust at the beginning of each iteration cycle which is necessary to achieve the desired terminal conditions:

$$1.e. \quad \ddot{\underline{X}}(T) = A_D + \underline{G} + 12 (\underline{X}(T_0) - R_D) / T_{GO}^2 - 6 (\underline{Y}_D + \dot{\underline{X}}(T_0)) / T_{GO}$$

Where: $\ddot{\underline{X}}(T_0)$ = acceleration vector at the beginning of the iteration cycle

A_D = Desired acceleration at the end of N iteration cycles

$$\underline{G} = \underline{U} \underline{X}(T_0) / X^3(T_0)$$

$\underline{X}(T_0)$ = Position vector at the beginning of the iteration cycle

R_D = Desired position at the end of N iteration cycles

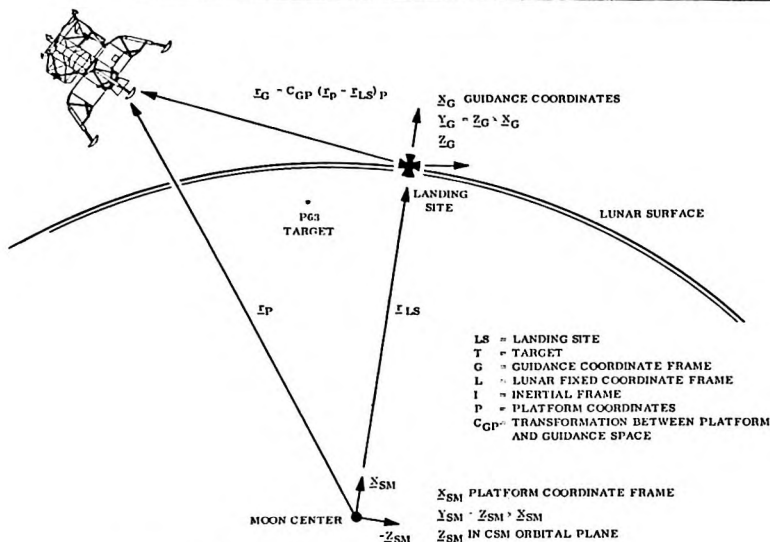
$\dot{\underline{X}}(T_0)$ = Velocity vector at the beginning of the iteration cycle

\underline{Y}_D = Desired velocity vector at the end of N iteration cycles

T_{GO} = Time remaining to terminal condition $T_{GO} + (T_F - T_0)$

$T_0 = 1, 2, \dots, N \dots T_F$ iteration cycle times

LUNAR LANDING SPECIFIC FORCE (COMMAND THRUST) EQUATIONS



P63 and P64 QUADRATIC GUIDANCE

REQUIRED SPECIFIC FORCE = $\vec{a}_p = (C_{PG} \vec{a}_g - \vec{g}_p)$ UNIT MASS (11/s²) IN PLATFORM SPACE

WHERE \vec{a}_g IS THRUST ACCELERATION

$$\text{AND } \vec{g}_p = \frac{-\mu_m \vec{r}_p}{r_p^3}$$

$$\vec{a}_g = \Sigma$$

BASIC GUIDANCE TERMS	+LAG COMPENSATION TERMS
\vec{a}_{TG}	+LEADTIME $\cdot 1(\vec{v}_{TG})$
$-6 (\vec{y}_G + \vec{y}_{TG}) / T_{C-0}$	+LEADTIME $\cdot 2(\vec{y}_G + \vec{y}_{TG})$
$-12 (\vec{r}_G - \vec{r}_{TG}) / T_{C-0}^2$	+LEADTIME $\cdot 3(\vec{r}_G - \vec{r}_{TG})$

LEADTIME: 1 NO UNITS
 LEADTIME: 2 1/s
 LEADTIME: 3 1/s²

LEADTIME 1, 2, AND 3 ARE POLYNOMIAL FUNCTIONS IN THE VARIABLE t_{GO} EVALUATED ONCE EACH ITERATION CYCLE (2 s).
 LEADTIME 1, 2, AND 3 ARE USED TO COMPENSATE FOR COMPUTATION, THROTTLE CHANGE, AND ATTITUDE CHANGE DELAYS.

$$\vec{a}_{TG} = \vec{v}_{TG} \cdot \vec{r}_{TG} \cdot \vec{r}_{TG} \text{ PHASE DEPENDENT TARGET TERMS (P63, P64, P65)}$$

T_{GO} TIME REMAINING TO TARGET STATE

μ_m = LUNAR GRAVITATIONAL CONSTANT

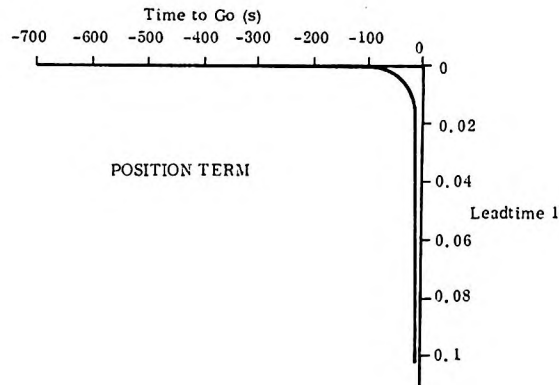
P65 LINEAR GUIDANCE

REQUIRED SPECIFIC FORCE = $\vec{a}_p = C_{PG} \vec{a}_G(T) - \vec{g}_p$

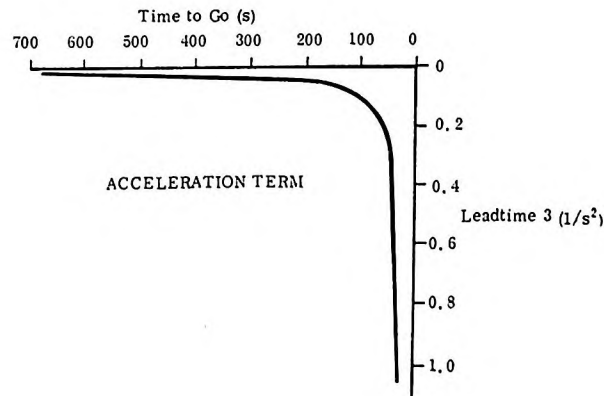
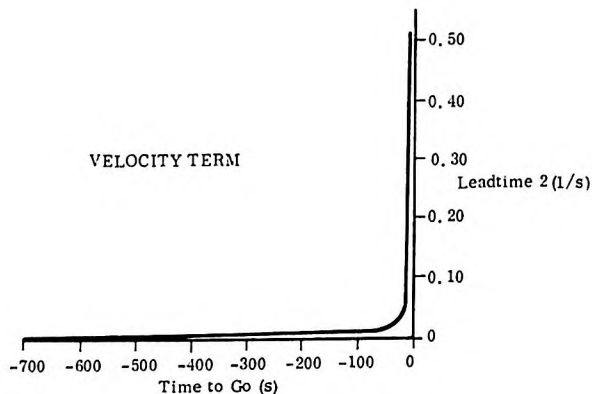
$$\vec{a}_G(T) = (\vec{v}_G - \vec{v}_{TG}) / \tau$$

τ = CONSTANT WHICH CONTROLS RATE AT WHICH DESIRED VELOCITY IS REACHED.

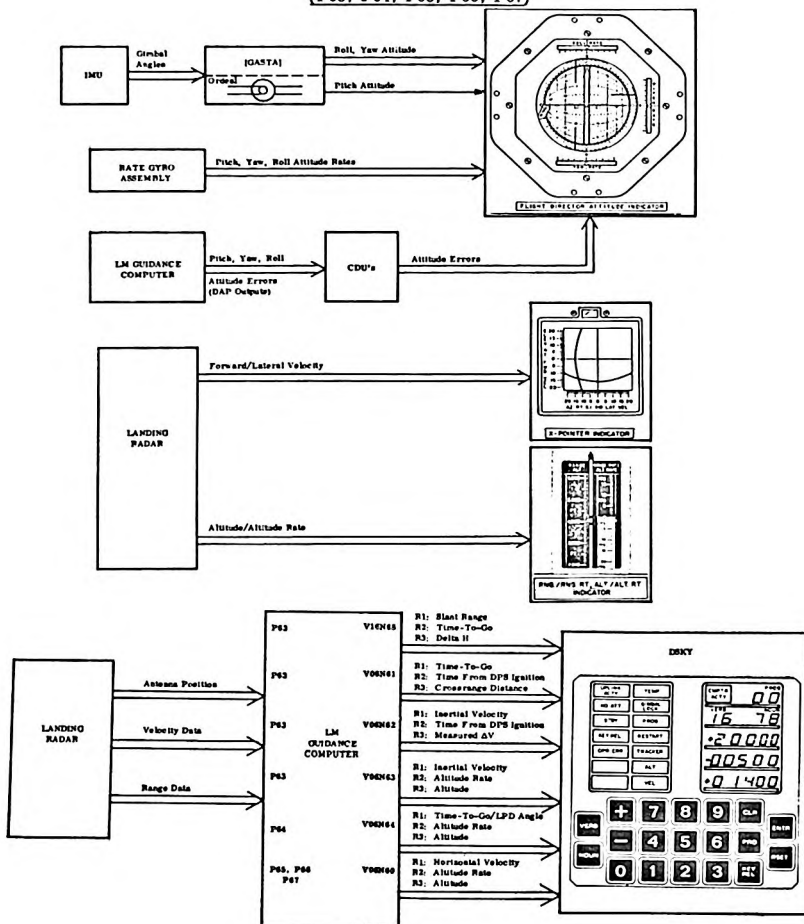
TARGET STATE GUIDANCE COORDINATE FRAME				
		P63	P64	P65
r_{-TG}^*	X	-3562.0 ft	82.9 ft	0 ft
	Y	0 ft	0 ft	0 ft
	Z	-13705.5 ft	-20.2 ft	0 ft
v_{-TG}^*	X	-186.9 ft/s	-0.31 ft/s	-3.0 ft/s
	Y	0 ft/s	0 ft/s	0 ft/s
	Z	-98.7 ft/s	0.31 ft/s	0 ft/s
a_{-TG}^*	X	-0.45 ft/s ²	0.30 ft/s ²	0 ft/s ²
	Y	0 ft/s ²	0 ft/s ²	0 ft/s ²
	Z	-9.51 ft/s ²	-0.40 ft/s ²	0 ft/s ²



PLOTS FOR THE COMPENSATION TERMS LEADTIME 1, 2, AND 3
VERSUS TIME REMAINING IN THE PHASE.

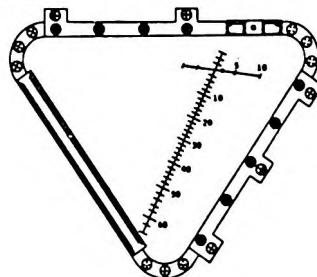
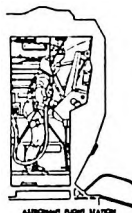


LM LANDING DISPLAYS (P63, P64, P65, P66, P67)

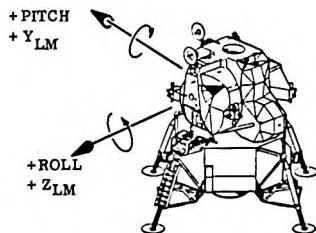
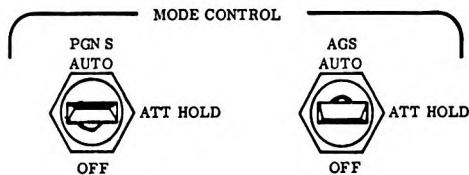


LANDING SITE REDESIGNATION

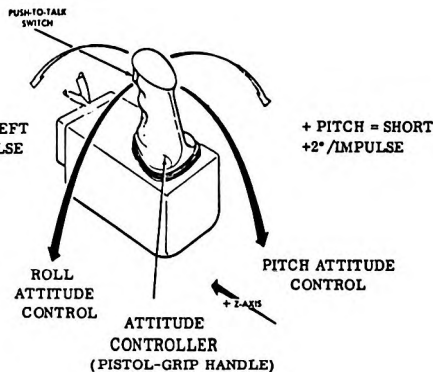
P64 ONLY



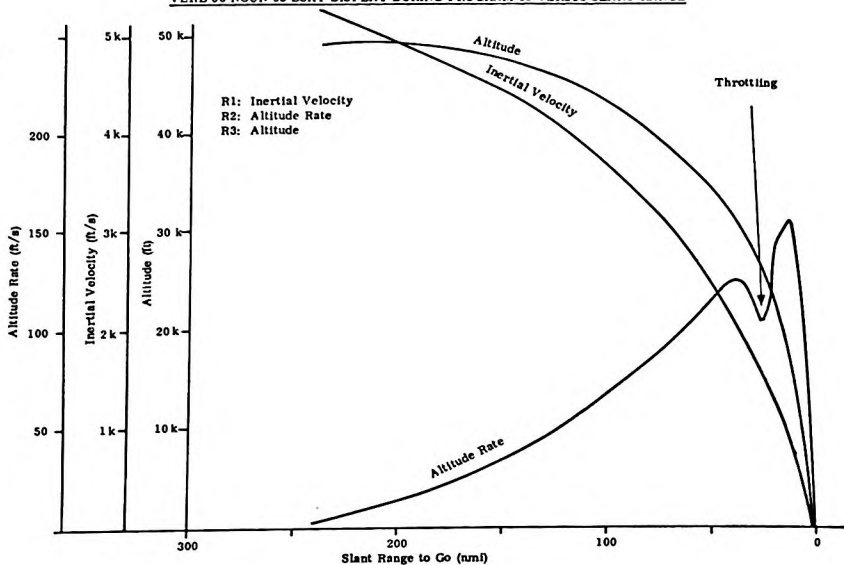
COMMANDER'S WINDOW
(LANDING POINT DESIGNATOR ON
COMMANDER'S WINDOW ONLY)



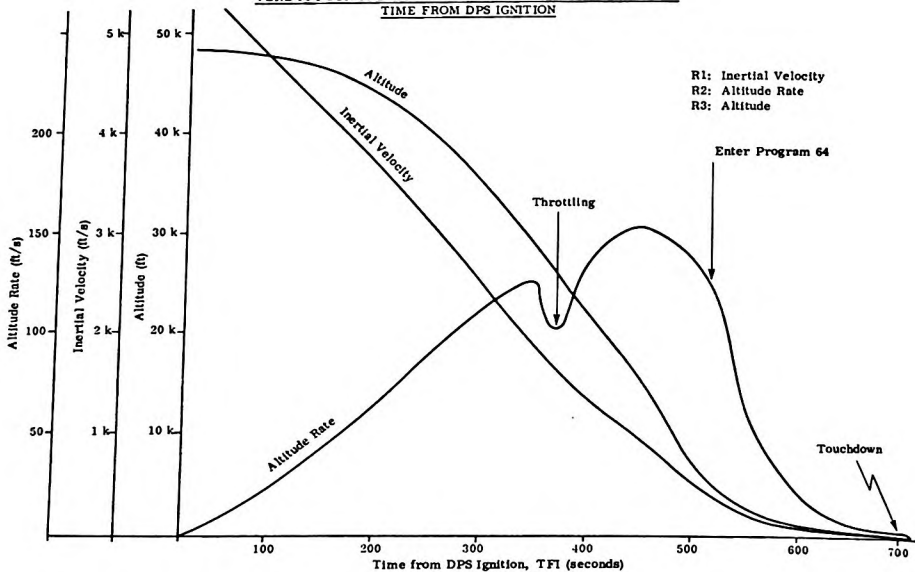
- ROLL = LEFT
1/2° / IMPULSE



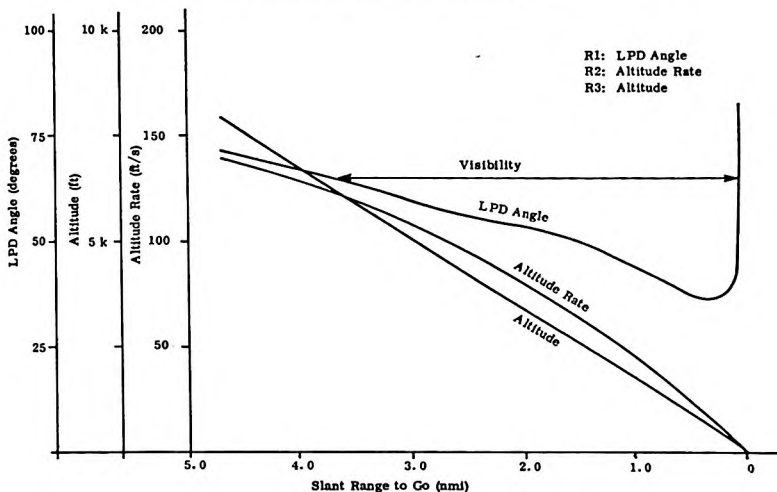
VERB 06 NOUN 63 DSKY DISPLAY DURING PROGRAM 63 VERSUS SLANT RANGE



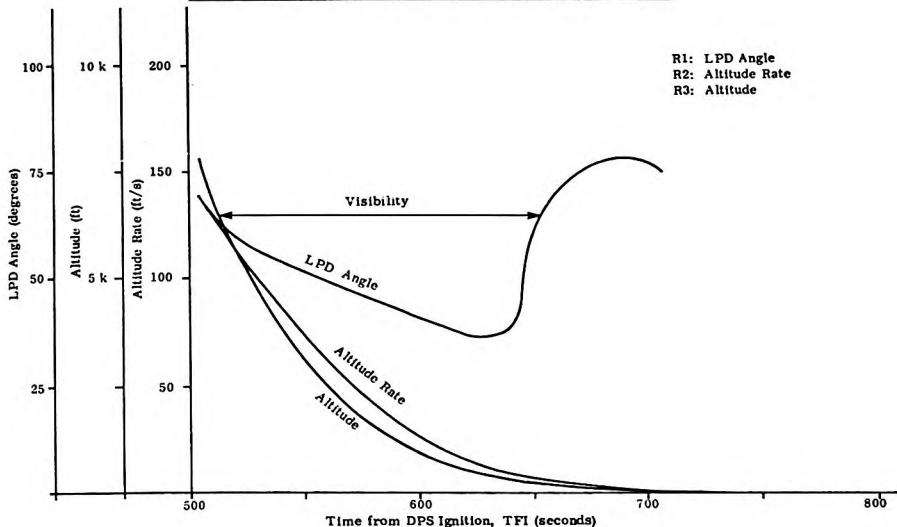
VERB 06 NOUN 63 DSKY DISPLAY DURING PROGRAM 63 VERSUS TIME FROM DPS IGNITION



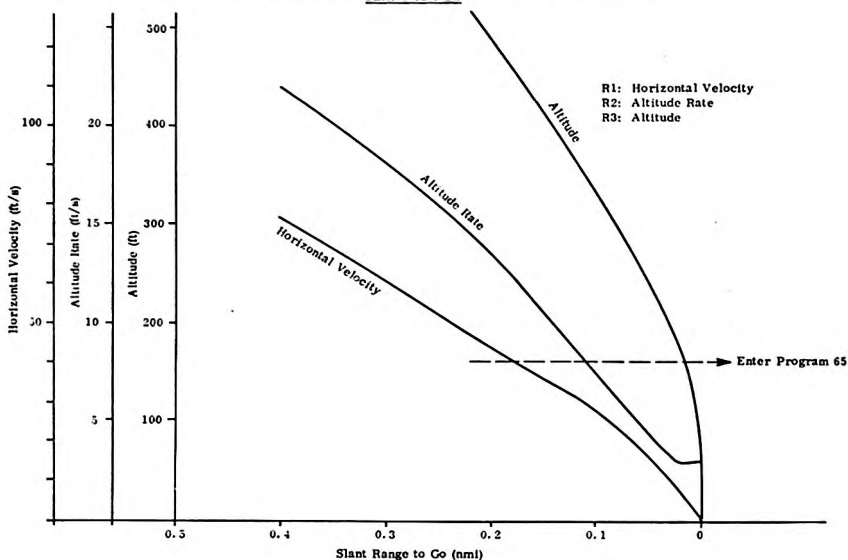
VERB 06 NOUN 64 DSKY DISPLAY DURING PROGRAM 64 VERSUS SLANT RANGE



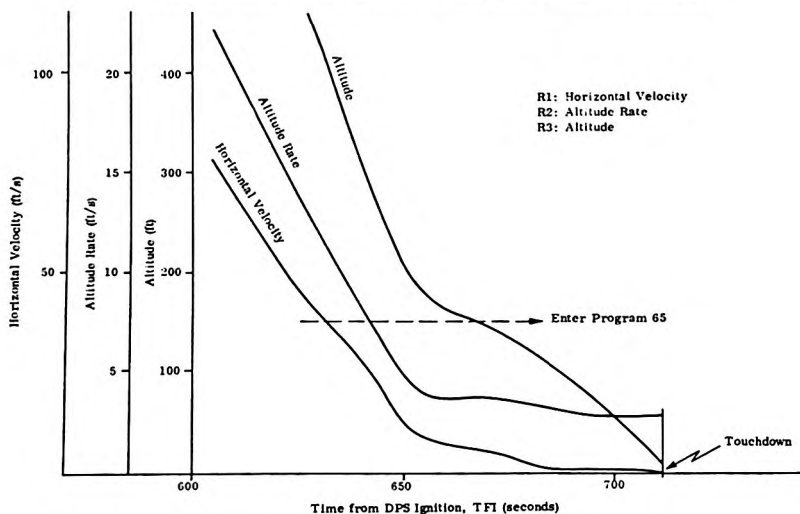
VERB 06 NOUN 64 DSKY DISPLAY DURING PROGRAM 64 VERSUS TFI



VERB 06 NOUN 60 DSKY DISPLAY DURING PROGRAM 65 AND PROGRAM 66 VERSUS
SLANT RANGE



VERB 06 NOUN 60 DSKY DISPLAY DURING PROGRAM 65 OR PROGRAM 66 VERSUS TFI



P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,
3 - REFSMMAT, 4 - Landing Site

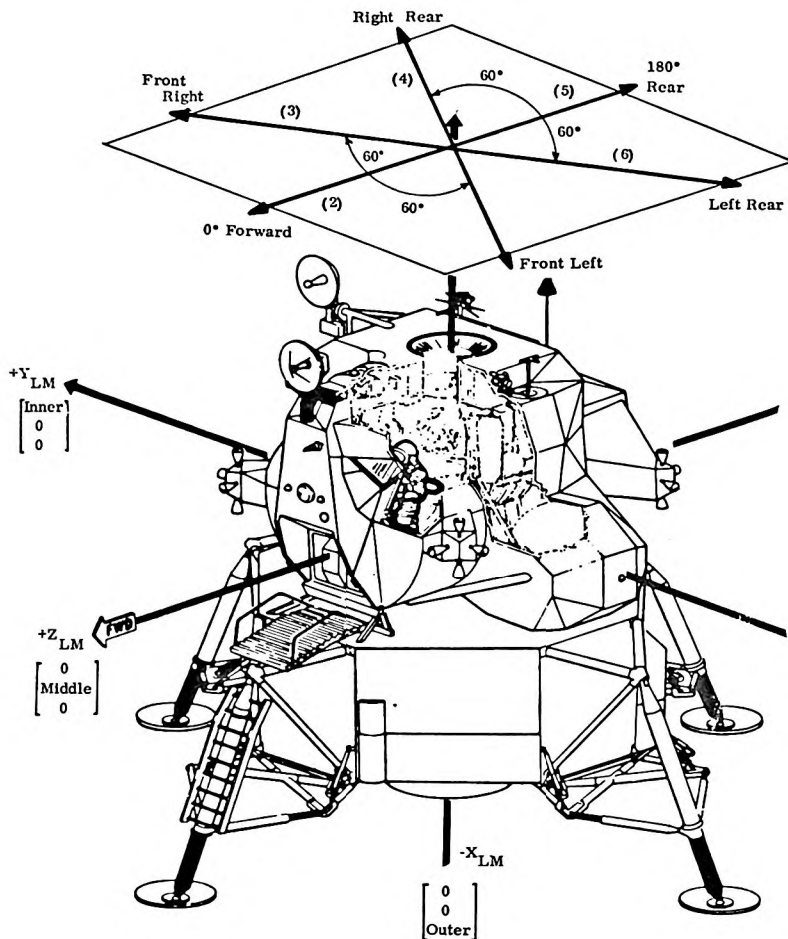
V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

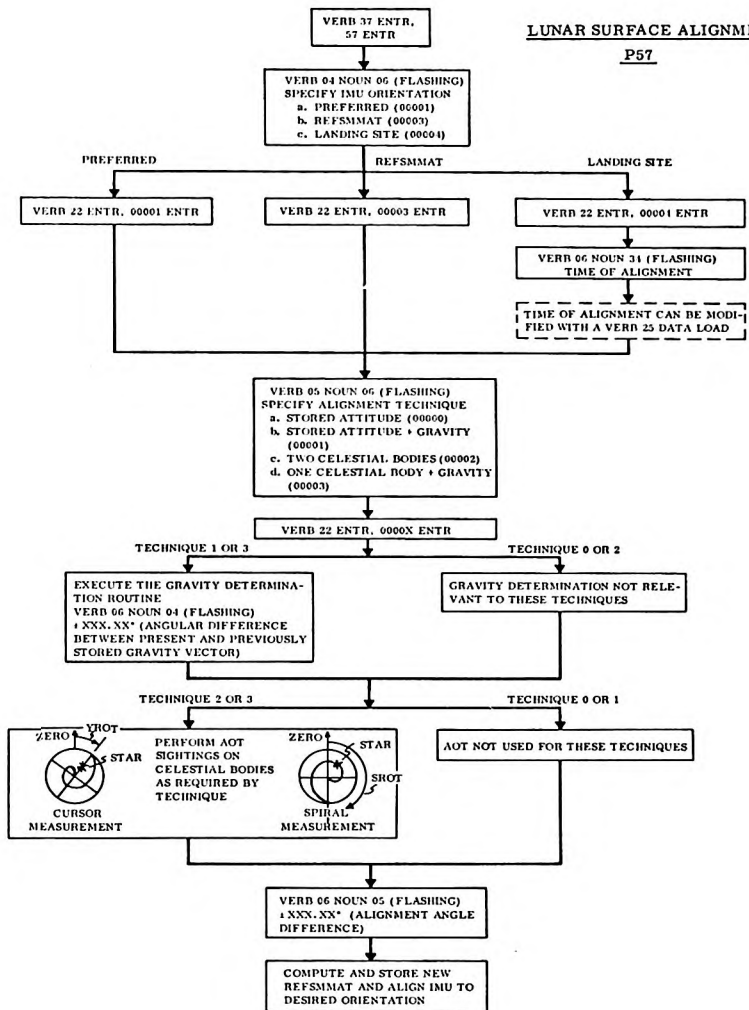
NOTES:

LUNAR SURFACE ALIGNMENT
AOT DETENT POSITIONS

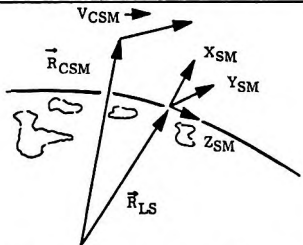


LUNAR SURFACE ALIGNMENT

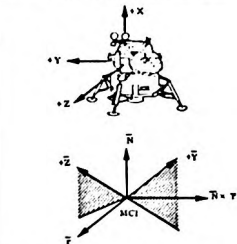
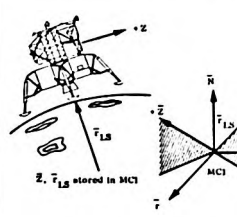
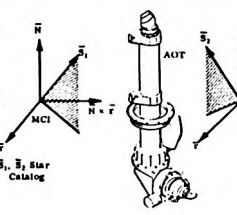
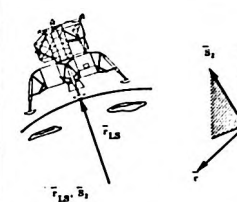
P57



LUNAR SURFACE ALIGNMENT - P57

OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	ANY ORIENTATION UPLINKED BY MSFN VIA P-27	$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} x_{SM} \\ y_{SM} \\ z_{SM} \end{bmatrix}$
00003 (REFSMMAT)	THIS OPTION REALIGNS THE SM TO THE SM ORIENTATION CURRENTLY MAINTAINED IN THE LGC. THE ACTUAL SM ORIENTATION DIFFERS FROM THE LGC MAINTAINED ORIENTATION DUE TO GYRO DRIFT.	$[\text{REFSMMAT}] = \begin{bmatrix} \bar{x}_{SM} \\ y_{SM} \\ z_{SM} \end{bmatrix} = \begin{bmatrix} \text{CURRENTLY MAINTAINED} \\ \text{LGC SM ORIENTATION} \end{bmatrix}$
00004 (LANDING SITE)	 <p>THIS OPTION ALIGNS THE x_{SM} ALONG \bar{R}_{LS} AND z_{SM} DOWNRANGE.</p>	$\begin{bmatrix} \text{LANDING SITE} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} x_{SM} \\ y_{SM} \\ z_{SM} \end{bmatrix} = \begin{bmatrix} \text{UNIT } (\bar{R}_{LS}) \\ \text{UNIT } (\bar{z}_{SM} \times \bar{x}_{SM}) \\ \text{UNIT } (\bar{R}_{CSM} \times \bar{V}_{CSM}) \times \bar{x}_{SM} \end{bmatrix}$ <p>WHERE</p> <p>\bar{R}_{LS} IS THE LANDING SITE POSITION VECTOR</p> <p>\bar{R}_{CSM}, \bar{V}_{CSM} ARE THE POSITION AND VELOCITY VECTORS FOR THE CSM AT TIME OF ALIGNMENT</p>

LUNAR SURFACE ALIGNMENT - P57

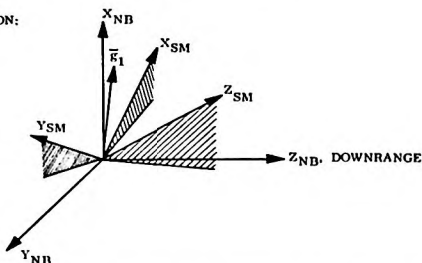
OPTION	LOS DIRECTION IN BASIC REF. COORD.	CALCULATE REFSMMAT
0	 <p>LM = \bar{Y} and \bar{Z} stored from previous alignment (P57, P68)</p>	$\bar{S}_A = \begin{bmatrix} \bar{Y} \\ (\bar{Y} \times \bar{Z}) \times \bar{Y} \\ \bar{Y} \times \bar{Z} \end{bmatrix} \bar{T}_{MCI} \hat{=} [A] \bar{T}_{MCI}$ $\bar{S}_B = \begin{bmatrix} \bar{Y}_M \\ (\bar{Y}_M \times \bar{Z}_M) \times \bar{Y}_M \\ \bar{Y}_M \times \bar{Z}_M \end{bmatrix} \bar{T}_{SMCS} \hat{=} [B] \bar{T}_{SMCS}$ $\bar{S}_A = [A] \bar{T}_{MCI} = \bar{S}_B = [B] \bar{T}_{SMCS}$ $\bar{T}_{SMCS} = [\text{REFSMMAT}] \bar{T}_{MCI} = [B]^{-1} [A] \bar{T}_{MCI}$
1	 <p>\bar{Z}, \bar{Y}_{LB} stored in MCI</p>	$\bar{S}_A = \begin{bmatrix} \bar{Y}_{LB} \\ (\bar{Y}_{LB} \times \bar{Z}) \times \bar{Y}_{LB} \\ \bar{Y}_{LB} \times \bar{Z} \end{bmatrix} \bar{T}_{MCI} \hat{=} [A] \bar{T}_{MCI}$ $\bar{S}_B = \begin{bmatrix} \bar{Y}_{LB} \\ (\bar{Y}_{LB} \times \bar{Z}_M) \times \bar{Y}_{LB} \\ \bar{Y}_{LB} \times \bar{Z}_M \end{bmatrix} \bar{T}_{SMCS} \hat{=} [B] \bar{T}_{SMCS}$ $\bar{T}_{SMCS} = [\text{REFSMMAT}] \bar{T}_{MCI} = [B]^{-1} [A] \bar{T}_{MCI}$
2	 <p>\bar{S}_1, \bar{S}_2 Star Catalog</p>	$\bar{S}_A = \begin{bmatrix} \bar{S}_1 \\ (\bar{S}_1 \times \bar{S}_2) \times \bar{S}_1 \\ \bar{S}_1 \times \bar{S}_2 \end{bmatrix} \bar{T}_{MCI} = [A] \bar{T}_{MCI}$ $\bar{S}_B = \begin{bmatrix} \bar{S}_{1M} \\ (\bar{S}_{1M} \times \bar{S}_{2M}) \times \bar{S}_{1M} \\ \bar{S}_{1M} \times \bar{S}_{2M} \end{bmatrix} \bar{T}_{SMCS} = [B] \bar{T}_{SMCS}$ $\bar{T}_{SMCS} = [\text{REFSMMAT}] \bar{T}_{MCI} = [B]^{-1} [A] \bar{T}_{MCI}$
3	 <p>\bar{Y}_{LB}, \bar{S}_1</p>	$\bar{S}_A = \begin{bmatrix} \bar{Y}_{LB} \\ (\bar{Y}_{LB} \times \bar{S}_1) \times \bar{Y}_{LB} \\ \bar{Y}_{LB} \times \bar{S}_1 \end{bmatrix} \bar{T}_{MCI} = [A] \bar{T}_{MCI}$ $\bar{S}_B = \begin{bmatrix} \bar{Y}_{LB} \\ (\bar{Y}_{LB} \times \bar{S}_{1M}) \times \bar{Y}_{LB} \\ \bar{Y}_{LB} \times \bar{S}_{1M} \end{bmatrix} \bar{T}_{SMCS} = [B] \bar{T}_{SMCS}$ $\bar{T}_{SMCS} = [\text{REFSMMAT}] \bar{T}_{MCI} = [B]^{-1} [A] \bar{T}_{MCI}$

MCI = Moon Centered Inertial; SMCS = Stable Member Coordinate System

LUNAR SURFACE ALIGNMENT GRAVITY DETERMINATION ROUTINE

1. COARSE ALIGN THE IMU TO THE FIRST ORIENTATION:

$$\begin{aligned} \text{OGA} &\approx +42^\circ \\ \text{MGA} &\approx +35.25^\circ \\ \text{IGA} &\approx -42^\circ \end{aligned}$$



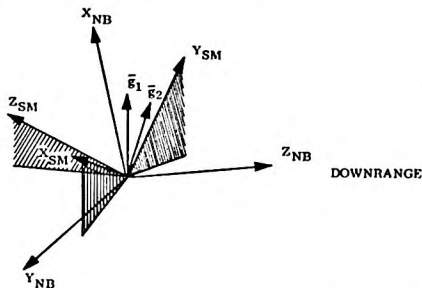
2. PLACE THE IMU IN AN INERTIAL MODE AND SAMPLE THE OUTPUT OF THE PIPA'S OVER A PERIOD OF 40 SECONDS. (PIPA_X, PIPA_Y, PIPA_Z). FORM A UNIT VECTOR \vec{e}_1

$$\vec{e}_1 = \frac{\text{PIPA}_X \hat{x}_{SM} + \text{PIPA}_Y \hat{y}_{SM} + \text{PIPA}_Z \hat{z}_{SM}}{\sqrt{\text{PIPA}_X^2 + \text{PIPA}_Y^2 + \text{PIPA}_Z^2}}$$

WHERE \vec{e}_1 INDICATES THE DIRECTION OF THE FIRST ESTIMATE OF THE LUNAR GRAVITY VECTOR IN SM COORDINATES.

3. COARSE ALIGN THE STABLE MEMBER 180° ABOUT THE MEASURED GRAVITY VECTOR.

$$\begin{aligned} \text{OGA} &\approx -138^\circ \\ \text{MGA} &\approx +35.25^\circ \\ \text{IGA} &\approx -42^\circ \end{aligned}$$



4. PLACE THE IMU IN AN INERTIAL MODE AND SAMPLE THE OUTPUT OF THE PIPA'S OVER A PERIOD OF 40 SECONDS (PIPA_X, PIPA_Y, PIPA_Z). FORM A UNIT VECTOR \vec{e}_2

$$\vec{e}_2 = \frac{\text{PIPA}_X \hat{x}_{SM} + \text{PIPA}_Y \hat{y}_{SM} + \text{PIPA}_Z \hat{z}_{SM}}{\sqrt{\text{PIPA}_X^2 + \text{PIPA}_Y^2 + \text{PIPA}_Z^2}}$$

WHERE \vec{e}_2 INDICATES THE DIRECTION OF THE SECOND ESTIMATE OF THE LUNAR GRAVITY VECTOR IN SM COORDINATES.

5. DEFINE A UNIT VECTOR \vec{U}_G OUT OF \vec{e}_1 AND \vec{e}_2 WHICH REPRESENTS THE DIRECTION OF THE LUNAR GRAVITY VECTOR.

$$\vec{U}_G = \text{UNIT} (\vec{e}_1 + \vec{e}_2)$$

NOTE: THE \vec{R}_{LS} VECTOR IS CONSIDERED TO BE COLINEAR WITH THE GRAVITY VECTOR.

P57-LUNAR SURFACE ALIGNMENT

V37 Enter, 57 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X Alignment option

0 - Landing Site, 1 - Preferred

2 - Invalid, 3 - REFSMMAT

V05 N06 Flashing

R1: 00010

R2: 0000X Alignment Mode

0 - REFSMMAT or Stored, 1 - REFSMMAT + g

2 - Two Bodies, 3 - One Body + g

R3: 00AB0 Data Code

A = 0 - REFSMMAT Not Defined, A = 1 - REFSMMAT Defined,

B = 0 - LM Attitude Not Available, B = 1 - LM Attitude Available

V06 N04 Flashing

Gravity Error Angle (0.01 deg)

V06 N22 Alignment Final OG, IG, MG ICDU Angles (XXX XX deg)

V06 N93 Flashing

X, Y, and Z Gyro Torquing Angles (0.001 deg)

V50 N25 Flashing

R1: 00014 Fine Align Option

V06 N09 Flashing

Latitude, longitude, attitude landing site (0.001 deg, 0.001 deg, 0.01 nmi)

X	0	0	0	0	1	Alignment Option	N06	X	0	0	0	0	1
X	0	0	0	0				X	0	0	0	0	
+	0	0				Hours	N34	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0	0		Alignment Mode		X	0	0	0	0	
						Gravity Error Angle (deg)							
						OG	N22						
						IG							
						MG							
X	0	0				Star Code 1	N71	X	0	0			
						Cursor Angle (deg)	N79						
						Spiral Angle (deg) Star No. 1							
X	0	0	0	0		Position Code		X	0	0	0	0	
X	0	0				Star Code 2	N71	X	0	0			
						Cursor Angle (deg)	N79						
						Spiral Angle (deg) Star No. 2							
X	0	0	0	0		Position Code		X	0	0	0	0	
						Star Angle Difference (deg)	N05						
						X	N93						
						Y							
						Z							
						X							
						Y							
						Z							
						Latitude (deg)	N89						
						Longitude/2 (deg) Landing Site							
						Altitude (nmi)							

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbel Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours	T1 GET at 0 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds		+	0			.	
+	0	0				Hours	T2 GET at 35 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds		+	0			.	
X	X	X				R	IMU Gimbel Angles (deg)	X	X	X			
X	X	X				P		X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT Angles	X	X	X	X		
X	X	X	X			Trun		X	X	X	X		
						Control Point							
			.			LAT (+ north)	N89				.		
			.			LONG/2 (+ east)					.		
			.			ALT (nmi)					.		
			.			LAT (+ north)	N89				.		
			.			LONG/2 (+ east)					.		
			.			ALT (nmi)					.		
			.			ΔR nmi	N49				.		
			.			ΔV ft/s					.		

NOTES:

P22—LUNAR SURFACE NAVIGATION

V37 Enter, 22 Enter

V04 N06 Flashing

R1: 0 0 0 1 2

R2: 0 0 0 0 X (1—CSM will not change orbit,
2—CSM will change orbit)

V06 N33 Flashing

Time of ascent (h, min, 0.01 s)

V50 N25 Flashing (if RR Auto mode not selected)

R1: 0 0 2 0 1 — switch RR mode to Auto

X	0	0	0	0		Option Code	N06	X	0	0	0	0	
+	0	0				Hours	N33	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds		+	0			.	
X	0	0	0	0		Option Code	N06	X	0	0	0	0	0
+	0	0				Hours	N33	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds		+	0			.	
X	0	0	0	0		Option Code	N06	X	0	0	0	0	0
+	0	0				Hours	N33	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds		+	0			.	

NOTES:

P30-EXTERNAL ΔV

Plane Change

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		(degrees)			0	0	
+	0	0		YTrim					
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes	GETI	+	0	0	0
+	0			Seconds		+	0		
				ΔV_x	N81				
				ΔV_y	LV				
				ΔV_z	(ft/s)				
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal		X	X	X	
X	X	X		Angles (deg)		X	X	X	
				Y		X	X	X	
+				HApogee	N44	+			
				HPerigee	nmi				
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				(degrees)					
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g					
				Hr.min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option		X	0	0	0	0
+	0	0			Hours Minutes Seconds	GET	+	0	0		
+	0	0	0				+	0	0	0	
+	0						+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	
					Star Angle Difference (degrees)	N05					
					X Y Z	Gyro Torquing Angles (degrees)					
					X Y Z	Calculated Gyro Drift (meru)					

X	0	0	0	0	P52 Option		X	0	0	0	0
+	0	0			Hours Minutes Seconds	GET	+	0	0		
+	0	0	0				+	0	0	0	
+	0						+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	
					Star Angle Difference (degrees)	N05					
					X Y Z	Gyro Torquing Angles (degrees)					
					X Y Z	Calculated Gyro Drift (meru)					

NOTES:

V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

[illegible]

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option		X	0	0	0	0			
+	0	0			Hours Minutes Seconds	GET	+	0	0					
+	0	0	0				+	0	0	0				
+	0						+	0						
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0				
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0				
					Star Angle Difference (degrees)	N05								
					X	Gyro Torquing Angles (degrees)	N93							
					Y									
					Z									
					X	Calculated Gyro Drift (meru)								
					Y									
					Z									

X	0	0	0	0	P52 Option		X	0	0	0	0			
+	0	0			Hours Minutes Seconds	GET	+	0	0					
+	0	0	0				+	0	0	0				
+	0						+	0						
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0				
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0				
					Star Angle Difference (degrees)	N05								
					X	Gyro Torquing Angles (degrees)	N93							
					Y									
					Z									
					X	Calculated Gyro Drift (meru)								
					Y									
					Z									

NOTES:

P22—ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 — Known, A2 — Unknown

B — Index of offset designator

DE — Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing — Please Mark

+	0	0				Hours	T1 GET at	+	0	0			
+	0	0	0			Minutes	0 degree	+	0	0	0		
+	0					Seconds	Elevation	+	0				
+	0	0				Hours	T2 GET at	+	0	0			
+	0	0	0			Minutes	35 degrees	+	0	0	0		
+	0					Seconds	Elevation	+	0				
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P		X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT Angles	X	X	X	X		
X	X	X	X			Trun		X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option		X	0	0	0	0	
+	0	0			Hours Minutes Seconds	GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	0				
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0		
					Star Angle Difference (degrees)	N05						
					X Y Z Gyro Torquing Angles (degrees)	N93						
					X Y Z Calculated Gyro Drift (meru)							

X	0	0	0	0	P52 Option		X	0	0	0	0	
+	0	0			Hours Minutes Seconds	GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	0				
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0		
					Star Angle Difference (degrees)	N05						
					X Y Z Gyro Torquing Angles (degrees)	N93						
					X Y Z Calculated Gyro Drift (meru)							

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 – Known, A2 – Unknown

B – Index of offset designator

DE – Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing – Please Mark

+	0	0				Hours	TI GET at 0 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
+	0	0				Hours	T2 GET at 35 degrees Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X			
X	X	X				p		X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT Angles	X	X	X	X		
X	X	X	X			Trun		X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P57-LUNAR SURFACE ALIGNMENT

V37 Enter, 57 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X Alignment option

0 - Landing Site, 1 - Preferred

2 - Invalid, 3 - REFSMMAT

V05 N06 Flashing

R1: 00010

R2: 0000X Alignment Mode

0 - REFSMMAT or Stored, 1 - REFSMMAT + g

2 - Two Bodies, 3 - One Body + g

R3: 00AB0 Data Code

A = 0 - REFSMMAT Not Defined, A = 1 - REFSMMAT Defined,

B = 0 - LM Attitude Not Available, B = 1 - LM Attitude Available

V06 N04 Flashing

Gravity Error Angle (0.01 deg)

V06 N22 Alignment Final OG, IG, MG ICDU Angles (XXX.XX deg)

V06 N93 Flashing

X, Y, and Z Gyro Torquing Angles (0.001 deg)

V50 N25 Flashing

R1: 00014 Fine Align Option

V06 N09 Flashing

Latitude, longitude, attitude landing site (0.001 deg, 0.001 deg, 0.01 nmi)

X	0	0	0	0	1	Alignment Option	N06	X	0	0	0	0	0	1
X	0	0	0	0				X	0	0	0	0	0	
+	0	0				Hours	N34	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0					Seconds		+	0					
X	0	0	0	0		Alignment Mode		X	0	0	0	0	0	
						Gravity Error Angle (deg)								
						OG	N22							
						IG								
						MG								
X	0	0				Star Code 1	N71	X	0	0				
						Cursor Angle (deg)	N79							
						Spiral Angle (deg) Star No. 1								
X	0	0	0	0		Position Code		X	0	0	0	0	0	
X	0	0				Star Code 2	N71	X	0	0				
						Cursor Angle (deg)	N79							
						Spiral Angle (deg) Star No. 2								
X	0	0	0	0		Position Code		X	0	0	0	0	0	
						Star Angle Difference (deg)	N05							
						X	N93							
						Y								
						Z								
						X								
						Y								
						Z								
						Latitude (deg)	N89							
						Longitude/2 (deg)								
						Altitude (nmi)								

P22—LUNAR SURFACE NAVIGATION

V37 Enter, 22 Enter

V04 N06 Flashing

R1: 0 0 0 1 2

R2: 0 0 0 0 X (1—CSM will not change orbit,
2—CSM will change orbit)

V06 N33 Flashing

Time of ascent (h, min, 0.01 s)

V50 N25 Flashing (if RR Auto mode not selected)

R1: 0 0 2 0 1 — switch RR mode to Auto

X	0	0	0	0		Option Code	N06	X	0	0	0	0		
+	0	0				Hours	N33	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0			.		Seconds		+	0			.		
X	0	0	0	0		Option Code	N06	X	0	0	0	0	0	
+	0	0				Hours	N33	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0			.		Seconds		+	0			.		
X	0	0	0	0		Option Code	N06	X	0	0	0	0	0	
+	0	0				Hours	N33	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0			.		Seconds		+	0			.		
X	0	0	0	0		Option Code	N06	X	0	0	0	0	0	
+	0	0				Hours	N33	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0			.		Seconds		+	0			.		

NOTES:

P22—ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 — Known, A2 — Unknown

B — Index of offset designator

DE — Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing — Please Mark

+	0	0				Hours	T1 GET at 0 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds		+	0			.	
+	0	0				Hours	T2 GET at 35 degrees Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds		+	0			.	
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P		X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT Angles	X	X	X	X		
X	X	X	X			Trun		X	X	X	X		
						Control Point							
			.			LAT (+ north)	N89				.		
			.			LONG/2 (+ east)					.		
			.			ALT (nmi)					.		
			.			LAT (+ north)	N89				.		
			.			LONG/2 (+ east)					.		
			.			ALT (nmi)					.		
			.			ΔR nmi	N49				.		
			.			ΔV ft/s					.		

NOTES:

P12-POWERED ASCENT

V37 Enter, 12 Enter

V06 N33 Flashing

Time of ascent (h, min, 0.01 s)

V06 N76 Flashing

Downrange velocity, radial velocity, crossrange (0.1 ft/s, 0.1 ft/s, 0.1 nmi)

V50 N25 Flashing

R1: 0 0 2 0 3 (switch Guidance Control to PGNS, Mode to Auto, Thrust Control to Auto)

V06 N74 Flashing

TFI, yaw after rise, pitch after rise (min/s, 0.01 deg, 0.01 deg)

V99 N74 Flashing

Engine on enable

V06 N63 Flashing

VI, HDOT, H (0.1 ft/s, 0.1 ft/s, ft)

V06 N85 Flashing

VGX (LM), VGY (LM), VGZ (LM) (0.1 ft/s)

V82 Enter

V04 N06 Flashing

R1: 0 0 0 0 2

R2: 0 0 0 0 X (1—this vehicle, 2—other vehicle)

V16 N44 Flashing

Apocenter altitude, pericenter altitude, TFF (0.1 nmi, 0.1 nmi, min/s)

+	0	0				Hours		N33	+	0	0				
+	0	0	0			Minutes	TIG		+	0	0	0			
+	0					Seconds	of		+	0					
							Ascent		+	0					
+						Desired Downrange		N76	+						
						Velocity (ft/s)									
+						Desired Radial Velocity			+						
						(ft/s)									
	0					*Crossrange Distance (nmi)				0					
						047 Sine of Azimuth Angle									
						(AGS)									
						053 Cosine of Azimuth									
						Angle (AGS)									
						225/226 Lower/Upper Limit									
						of Semi-Major Axis at Inser-									
						tion (AGS)									
						231 Landing Site Radius (AGS)									

*Load 8 nmi if crossrange is greater than 8 nmi.

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option		X	0	0	0	0
+	0	0			Hours Minutes Seconds	GET	+	0	0		
+	0	0	0				+	0	0	0	
+	0						+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	
					Star Angle Difference (degrees)	N05					
					X Y Z	Gyro Torquing Angles (degrees)					
					X Y Z	Calculated Gyro Drift (meru)					

X	0	0	0	0	P52 Option		X	0	0	0	0
+	0	0			Hours Minutes Seconds	GET	+	0	0		
+	0	0	0				+	0	0	0	
+	0						+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	
					Star Angle Difference (degrees)	N05					
					X Y Z	Gyro Torquing Angles (degrees)					
					X Y Z	Calculated Gyro Drift (meru)					

NOTES:

P57--LUNAR SURFACE ALIGNMENT

V37 Enter, 57 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X Alignment option

0 - Landing Site, 1 - Preferred
2 - Invalid, 3 - REFSMMAT

V05 N06 Flashing

R1: 00010

R2: 0000X Alignment Mode

0 - REFSMMAT or Stored, 1 - REFSMMAT + g
2 - Two Bodies, 3 - One Body + g

R3: 00A80 Data Code

A = 0 - REFSMMAT Not Defined, A = 1 - REFSMMAT Defined,
B = 0 - LM Attitude Not Available, B = 1 - LM Attitude Available

V06 N04 Flashing

Gravity Error Angle (0.01 deg)

V06 N22 Alignment Final OG, IG, MG ICDU Angles (XXX.XX deg)

V06 N93 Flashing

X, Y, and Z Gyro Torquing Angles (0.001 deg)

V50 N25 Flashing

R1: 00014 Fine Align Option

V06 N09 Flashing

Latitude, longitude, attitude landing site (0.001 deg, 0.001 deg, 0.01 nmi)

X	0	0	0	0	1	Alignment Option	N06	X	0	0	0	0	1
X	0	0	0	0				X	0	0	0	0	
+	0	0				Hours	N34	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0	0		Alignment Mode		X	0	0	0	0	
						Gravity Error Angle (deg)							
						OG	N22						
						IG							
						MG							
X	0	0				Star Code 1	N71	X	0	0			
						Cursor Angle (deg)	N79						
						Spiral Angle (deg) Star No. 1							
X	0	0	0	0		Position Code		X	0	0	0	0	
X	0	0				Star Code 2	N71	X	0	0			
						Cursor Angle (deg)	N79						
						Spiral Angle (deg) Star No. 2							
X	0	0	0	0		Position Code		X	0	0	0	0	
						Star Angle Difference (deg)	N05						
						X	N93						
						Y							
						Z							
						X							
						Y							
						Z							
						Latitude (deg)	N89						
						Longitude/2 (deg) Landing Site							
						Altitude (nmi)							

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

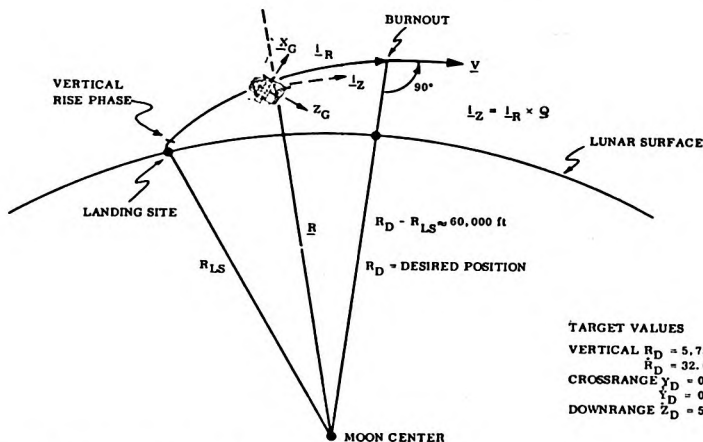
R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours	T1 GET at 0 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
+	0	0				Hours	T2 GET at 35 degrees Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P		X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT Angles	X	X	X	X		
X	X	X	X			Trun		X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						Δ R nmi	N49						
						Δ V ft/s							

NOTES:

LUNAR ASCENT GUIDANCE (P12)



TARGET VALUES

VERTICAL $R_D = 5,752,316.9$ ft
 $R_D = 32.04$ ft/s
 CROSSRANGE $\dot{Y}_D = 0$
 $\dot{Y}_D = 0$
 DOWNRANGE $\dot{Z}_D = 5,535.62$ ft/s
 $\dot{Z}_D = 0$

VERTICAL RISE: PHASE LASTS UNTIL $\dot{R} \sim 40$ ft/s or $h \approx 25,000$ ft

$$a_{TR} = 1/r (A + (t - t_0) B) - g_{eff}$$

COMMAND SPECIFIC FORCE (VERTICAL)

$$a_{TY} = 1/r (C + (t - t_0) D)$$

COMMAND SPECIFIC FORCE (CROSSRANGE)

$$a_{TZ} = (a_T^2 - a_h^2)^{1/2} \text{SGN}(\dot{Z}_D - \dot{Z})$$

COMMAND SPECIFIC FORCE (DOWNRANGE)

$$A = \text{PITCH ATTITUDE CONSTANT} = (-K_1 B - (\dot{R}_D - \dot{R})/L)$$

$$B = \text{PITCH RATE CONSTANT} = [K_2 (\dot{R}_D - \dot{R}) - (R_D - R - \dot{R} T_{GO})/T_{GO} E]$$

$$C = \text{YAW ATTITUDE CONSTANT} = [K_1 D - (\dot{Y}_D - \dot{Y})/L]$$

$$D = \text{YAW RATE CONSTANT} = [K_2 (\dot{Y}_D - \dot{Y}) - (Y_D - Y - \dot{Y} T_{GO})/T_{GO} E]$$

$$g_{eff} = \text{EFFECTIVE GRAVITY} = |\underline{x} \times \underline{y}|^2 / r^3 - \mu_m / r^2$$

WHERE

$(t - t_0) = \text{DELAY TERMS} = 1 \text{ SECOND}$

$\underline{Q} = \text{TARGET COORDINATE VECTOR} = (\underline{V}_C \times \underline{R}_C)$ OF COMMAND MODULE

$a_h = \text{SPECIFIC FORCE IN RY PLANE}$

$\tau = \text{MASS/MASS FLOW RATE } \dot{m} \text{ (THE AVERAGE OF THE LAST FOUR PIP READINGS, EXHAUST VELOCITY, PREVIOUS } \tau)$

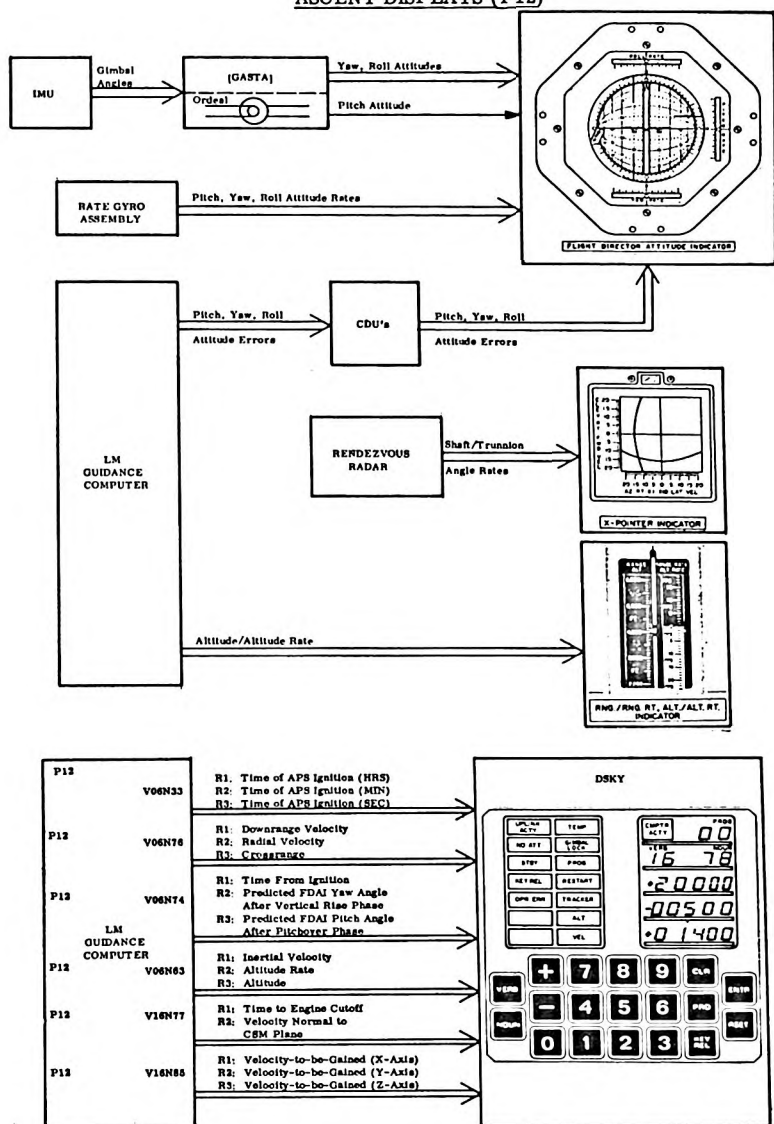
$T_{GO} = (\text{APS TAIL OFF, MASS/MASS FLOW RATE, EXHAUST VELOCITY, VELOCITY TO BE GAINED})$

L. E. $K_1, K_2 \approx f$ (MASS/MASS FLOW RATE, EXHAUST VELOCITY, TIME TO GO)

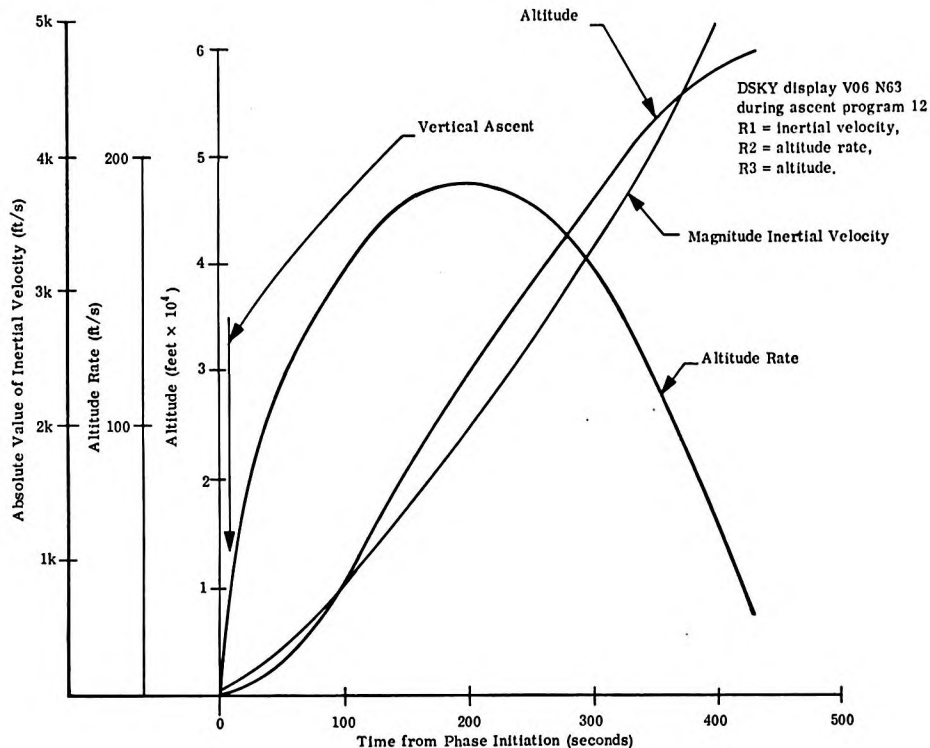
$a_T = \text{AVAILABLE SPECIFIC FORCE}$

$\mu_m = \text{LUNAR GRAVITATIONAL CONSTANT}$

ASCENT DISPLAYS (P12)



LUNAR ASCENT (P12) DISPLAYS



P12-POWERED ASCENT

V37 Enter, 12 Enter

V06 N33 Flashing

Time of ascent (h, min, 0.01 s)

V06 N76 Flashing

Downrange velocity, radial velocity, crossrange (0.1 ft/s, 0.1 ft/s, 0.1 nmi)

V50 N25 Flashing

R1: 0 0 2 0 3 (switch Guidance Control to PGNS, Mode to Auto, Thrust Control to Auto)

V06 N74 Flashing

TFI, yaw after rise, pitch after rise (min/s, 0.01 deg, 0.01 deg)

V99 N74 Flashing

Engine on enable

V06 N63 Flashing

VI, HDOT, H (0.1 ft/s, 0.1 ft/s, ft)

V16 N85 Flashing

VGX (LM), VGY (LM), VGZ (LM) (0.1 ft/s)

V82 Enter

V04 N06 Flashing

R1: 0 0 0 0 2

R2: 0 0 0 0 X (1—this vehicle, 2—other vehicle)

V16 N44 Flashing

Apocenter altitude, pericenter altitude, TFF (0.1 nmi, 0.1 nmi, min/s)

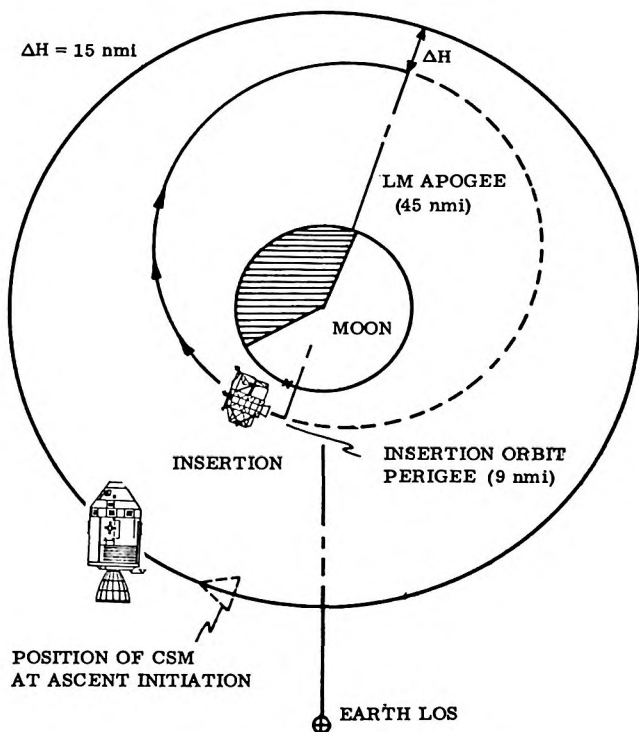
+	0	0				Hours	N33	+	0	0				
+	0	0	0			Minutes	TIG of Ascent	+	0	0	0			
+	0					Seconds		+	0					
+						Desired Downrange Velocity (ft/s)	N76	+						
+						Desired Radial Velocity (ft/s)		+						
	0					*Crossrange Distance (nmi)			0					
						047 Sine of Azimuth Angle (AGS)								
						053 Cosine of Azimuth Angle (AGS)								
						225/226 Lower/Upper Limit of Semi-Major Axis at Inser- tion (AGS)								
						231 Landing Site Radius (AGS)								

*Load 8 nmi if crossrange is greater than 8 nmi.

NOTES:

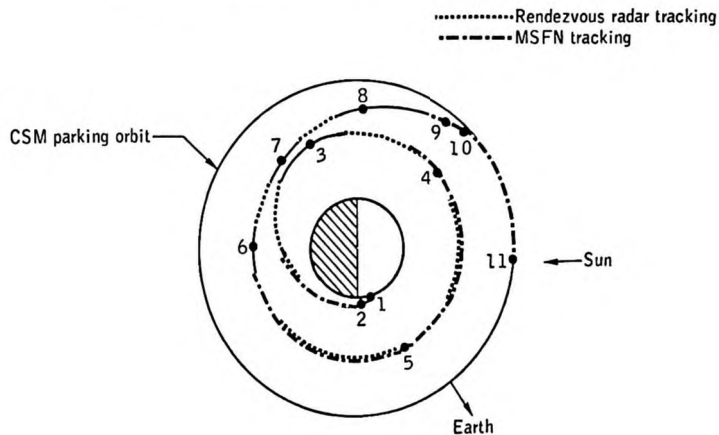
LM INSERTION

EVENT				BT/ ΔV				G. E. T.				PROPULSION/ GUIDANCE				PRETHRUST TARGETING			
INSERTION				430.59/ 6049				142:04:37.1				LM-APS/PGNS				P-12			
RESIDUALS																			
ΔV_X												+	X	X					h
ΔV_Y	PGNS	N85						AGS	500				+	X	X	X			min GET
ΔV_Z									501				+	X					s
									502				+	X					
----- \cdot ----- V_{XTRIM} ----- \cdot ----- V_{YTRIM} ----- \cdot ----- V_{ZTRIM} ft/s																			



NOTE: SHADOW IS WITH RESPECT
TO CSM ORBIT.

ORBITAL SCHEMATIC OF ASCENT THROUGH DOCKING

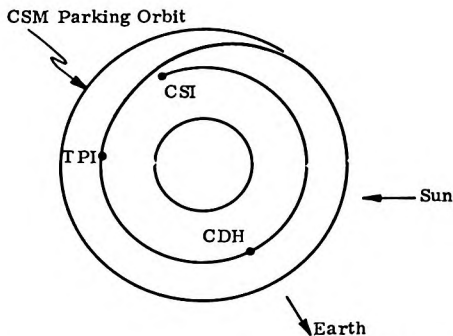


Event	Time, hr:min:sec g.e.t.	Event	Time, hr:min:sec g.e.t.
1. Lift-off	147:04:37.1	7. MC-1	144:53:56.1
2. LM insertion	142:11:47.7	8. MC-2	145:08:56.1
3. CSI	143:01:25.3	9. Begin braking	145:17:44.5
4. PC	143:30:37.6	10. Begin stationkeeping	145:24:26.7
5. CDH	143:59:49.9	11. Docking	145:40:00.0
6. TPI	144:38:56.1		

RENDEZVOUS

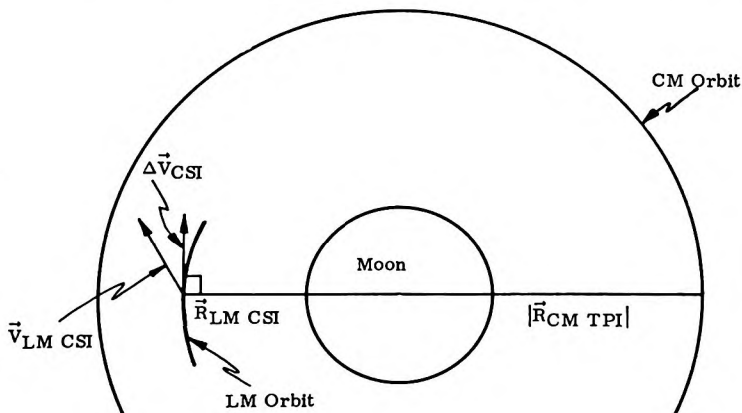
The Concentric Flight Plan Rendezvous scheme requires the active vehicle to make three maneuvers to establish a rendezvous intercept trajectory with the target vehicle. These maneuvers are:

- a. Coelliptic Sequence Initiation (CSI),
- b. Constant Delta Height (CDH),
- c. Transfer Phase Initiation (TPI).



The CSI maneuver is performed in the orbital plane and normal to the position vector.

An initial estimate of the ΔV impulse for CSI is determined from the following relation.



RENDEZVOUS (CONTINUED)

$$\Delta \vec{V}_{\text{CSI}} = \left[\left(\frac{2\mu}{|\vec{R}_{\text{LM CSI}}| \left(\frac{|\vec{R}_{\text{LM CSI}}|}{|\vec{R}_{\text{CM TPI}}|} + 1 \right)} \right)^{1/2} - \vec{V}_{\text{LM CSI}} \cdot \vec{h} \right] \vec{h} \quad \text{ft/s} \quad (1)$$

where

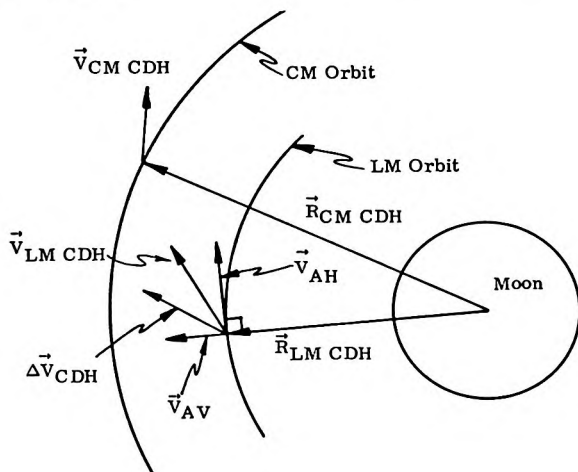
$\vec{R}_{\text{LM CSI}}$, $\vec{V}_{\text{LM CSI}}$ — position and velocity vectors for the LM at the time of the CSI maneuver (ft, ft/s).

$\vec{R}_{\text{CM TPI}}$ — position vector of the CM at the time of the TPI maneuver (ft).

\vec{h} — unit vector normal to $\vec{R}_{\text{LM CSI}}$ and in the orbital plane.

$\Delta \vec{V}_{\text{CSI}}$ — impulsive ΔV required to perform the CSI maneuver (ft/s).

The initial value for $\Delta \vec{V}_{\text{CSI}}$ is then utilized by the CSI targeting program to determine the time at which the CDH maneuver is to occur. Knowing TIG_{CDH} , the following equations are used by the CSI targeting program to determine the required ΔV for the CDH maneuver.



RENDEZVOUS (CONTINUED)

$$\vec{V}_{AV} = \left\{ \vec{V}_{CM \text{ CDH}} \cdot \text{Unit} [\vec{R}_{CM \text{ CDH}}] \left(\frac{a_{CM \text{ CDH}}}{a_{LM \text{ CDH}}} \right)^{3/2} \right\} \text{Unit} [\vec{R}_{LM \text{ CDH}}] \quad \text{ft/s} \quad (2)$$

$$\vec{V}_{AH} = \left[\mu \left(\frac{2}{|\vec{R}_{LM \text{ CDH}}|} - \frac{1}{a_{LM \text{ CDH}}} \right) - |\vec{V}_{AV}|^2 \right]^{1/2} \text{Unit} [\vec{U} \times \vec{R}_{LM \text{ CDH}}] \quad \text{ft/s} \quad (3)$$

$$\Delta \vec{V}_{CDH} = \vec{V}_{AH} + \vec{V}_{AV} - \vec{V}_{LM \text{ CDH}} \quad \text{ft/s} \quad (4)$$

where

$\vec{R}_{LM \text{ CDH}}$, $\vec{V}_{LM \text{ CDH}}$ — position and velocity vectors of the LM at the time of CDH (ft, ft/s).

$\vec{R}_{CM \text{ CDH}}$, $\vec{V}_{CM \text{ CDH}}$ — position and velocity vectors of the CM at the time of CDH (ft, ft/s).

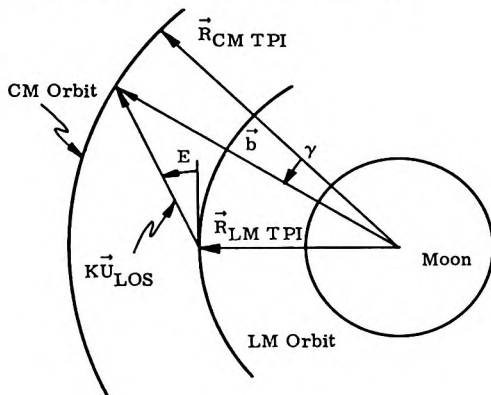
$a_{LM \text{ CDH}}$, $a_{CM \text{ CDH}}$ — semi-major axis of the LM and CM orbits, respectively, at the time of CDH (ft).

\vec{V}_{AV} , \vec{V}_{AH} — desired vertical and horizontal velocities, respectively, of the LM after completion of the CDH maneuver (ft/s).

\vec{U} — unit vector normal to the orbital plane and in the direction of the angular momentum vector of the CM.

$\Delta \vec{V}_{CDH}$ — impulsive ΔV required to perform the CDH maneuver (ft/s).

After the value for $\Delta \vec{V}_{CDH}$ has been determined and added impulsively to the LM velocity vector, the state vector of the LM is then integrated to the desired time of the TPI maneuver. This information is then used in the following CSI targeting equations to determine the adequacy of the CSI and CDH solutions.



RENDEZVOUS (CONTINUED)

$$\vec{b} = \vec{R}_{LM \text{ TPI}} + K \vec{U}_{LOS} \quad \text{ft} \quad (5)$$

$$\gamma = \cos^{-1} [\text{Unit}(\vec{b} \cdot \vec{R}_{CM \text{ TPI}})] \text{ Sign} [\vec{U} \cdot (\vec{b} \times \vec{R}_{CM \text{ TPI}})] \quad \text{radians} \quad (6)$$

where

$\vec{R}_{LM \text{ TPI}}, \vec{R}_{CM \text{ TPI}}$ —LM and CM position vectors, respectively, at the time of TPI (ft).

\vec{U}_{LOS} —unit vector along the line of sight (determined by the elevation angle E).

K—scale factor representing the magnitude of a vector from the LM, along the desired LOS to its intersection with the CM orbit. K is the solution of

$$K^2 + 2K \vec{R}_{LM \text{ TPI}} \cdot \vec{U}_{LOS} + (|\vec{R}_{LM \text{ TPI}}|^2 - |\vec{R}_{CM \text{ TPI}}|^2) = 0$$

whose absolute value is a minimum (ft).

\vec{b} —position vector representing the desired position of the CM at the time of TPI (ft).

\vec{U} —unit vector normal to the orbital plane and in the direction of the angular momentum vector of the CM.

γ —angular error between the desired and actual position of the CM at the time of TPI (rad).

The angle γ indicates the adequacy of the CSI and CDH solutions. If γ is not near zero, a perturbation of $\Delta \vec{V}_{CSI}$ is made and Equations 2 - 6 are executed again. This procedure will continue until γ is sufficiently small.

Once a satisfactory solution for the CSI maneuver has been obtained, the computed $\Delta \vec{V}_{CSI}$ and computed TIG_{CDH} are stored, and the CSI program is terminated.

CDH is an impulsive ΔV maneuver performed in the orbital plane. This maneuver will fix the altitude of separation of the two orbits and determine the time at which the TPI maneuver should be executed.

The following equations are used by the CDH program to determine the required $\Delta \vec{V}_{CDH}$. The TIG_{CDH} is either the one calculated previously by the CSI targeting program or one loaded by the astronaut.

RENDEZVOUS (CONTINUED)

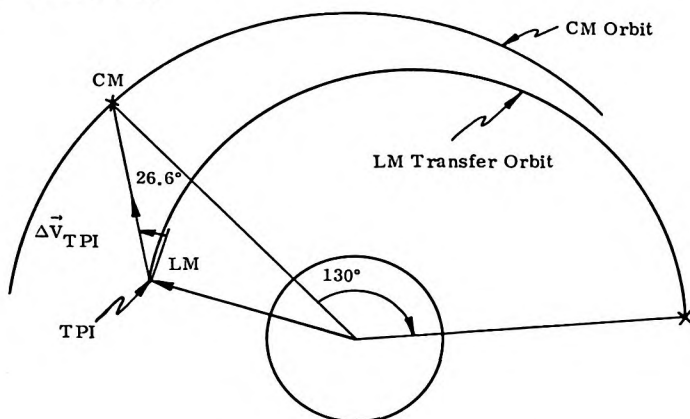
\vec{V}_{AV} , \vec{V}_{AH} — desired vertical and horizontal velocities, respectively, of the LM after completion of the CDH maneuver (ft/s).

\vec{U} — unit vector normal to the orbital plane and in the direction of the angular momentum vector of the CM.

$\vec{\Delta V}_{CDH}$ — impulsive ΔV required to perform the CDH maneuvers (ft/s).

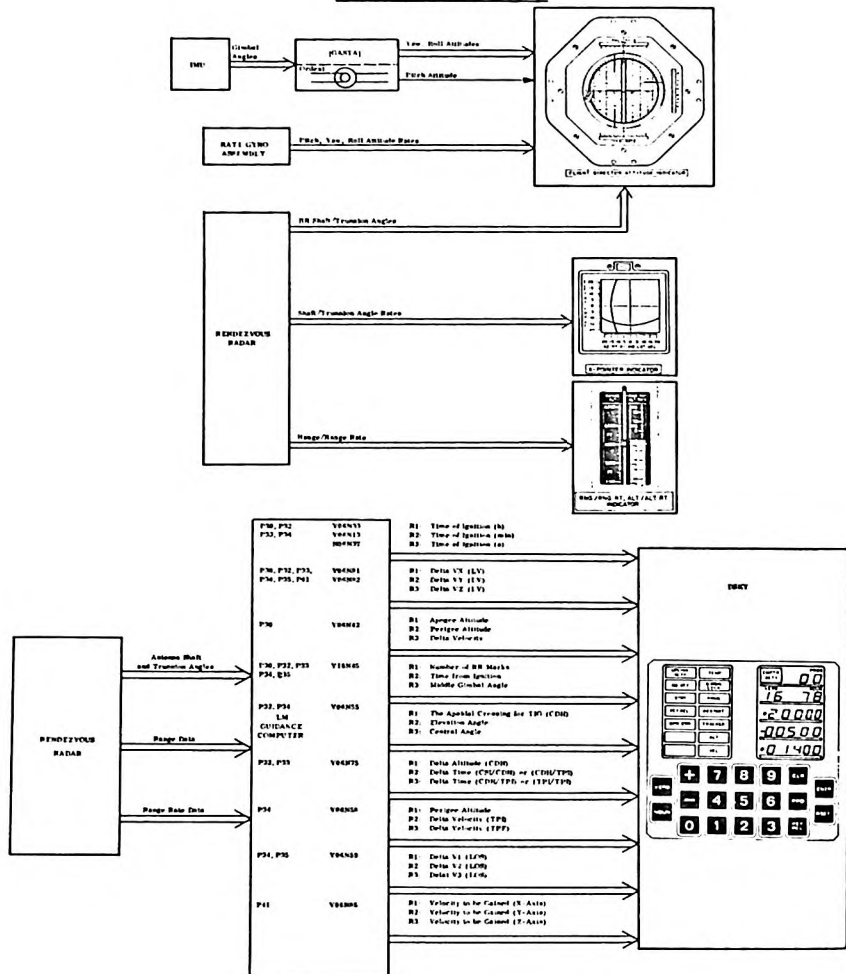
The $\vec{\Delta V}_{CDH}$ is added impulsively to the LM velocity vector. The CDH targeting program then advances the state of both the LM and CM until a time is found at which the geometry requirements of the TPI maneuver are satisfied. This time is stored as TIG_{TPI} and the CDH targeting program terminated.

The purpose of the TPI maneuver is to place the LM on a transfer orbit such that it will intercept the CM. The CM will travel approximately 130 degrees of central angle during this transfer time.



The TIG_{TPI} is such that the LOS elevation angle between the LM and CSM is 26.6 degrees. TIG_{TPI} is determined by manipulating the state of both the LM and CM until the geometry requirements have been satisfied. Once the execution time for TPI is known, the $\vec{\Delta V}_{TPI}$ is calculated and the program is terminated.

RENDEZVOUS DISPLAYS



P52-IMU REALIGN (LM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal
3 - REFSMMAT, 4 - Landing Site

V01 N70 Flashing

R1: 0 0 C D E

C - AOT Detent

0 - COAS CAL, 1 - FL, 2 - FC, 3 - FR,

4 - RR, 5 - RC, 6 - RL, 7 - COAS

DE - Celestial Body Code

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0				AOT Detent and Star 1 ID	N71	X	0	0			
X	0	0				AOT Detent and Star 2 ID	N71	X	0	0			
						Star Angle Difference (degrees)	N05						
						X	Gyro Torquing Angles (degrees)	N93					
						Y							
						Z							
						X	Calculated Gyro Drift (meru)						
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0				AOT Detent and Star 1 ID	N71	X	0	0			
X	0	0				AOT Detent and Star 2 ID	N71	X	0	0			
						Star Angle Difference (degrees)	N05						
						X	Gyro Torquing Angles (degrees)	N93					
						Y							
						Z							
						X	Calculated Gyro Drift (meru)						
						Y							
						Z							

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

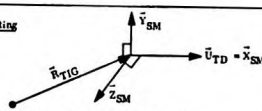
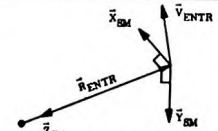
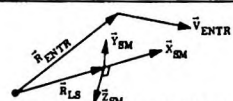
3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X	Gyro Torquing Angles (degrees)	N93					
						Y							
						Z							
						X	Calculated Gyro Drift (meru)						
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X	Gyro Torquing Angles (degrees)	N93					
						Y							
						Z							
						X	Calculated Gyro Drift (meru)						
						Y							
						Z							

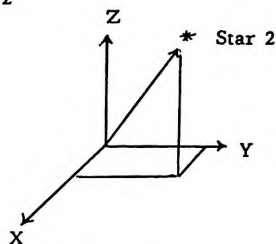
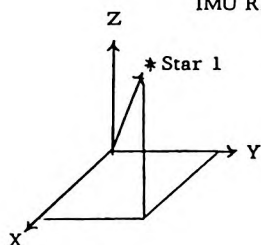
NOTES:

OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	<p><u>PREFERRED Thrusting</u></p>  <p>The PREFERRED option refers to one of two possibilities:</p> <ol style="list-style-type: none"> The PREFERRED thrusting orientation which is calculated and stored by P40 and P41. Any orientation uplinked by MSFN via P27. <p>The CMC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40 or P41 and stored, or uplinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the CMC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} U_{TD} \\ \text{Unit} (U_{TD} \times R_{TIG}) \\ \text{Unit} (U_{TD} \times (U_{TD} \times R_{TIG})) \end{bmatrix}$ <p>where</p> <p>U_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.</p> <p>R_{TIG} is the position vector of the vehicle at ignition expressed in the basic reference system.</p>
00002 (NOMINAL)	<p><u>Nominal</u></p>  <p>The CMC requests the g.e.l. for which the vehicle R and V are to be selected to define the NOMINAL orientation. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{NOMINAL} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} V_{SM} \times Z_{SM} \\ V_{ENTR} \times R_{ENTR} \\ \text{Unit} (-R_{ENTR}) \end{bmatrix}$ <p>where</p> <p>$\begin{Bmatrix} R_{ENTR} \\ V_{ENTR} \end{Bmatrix}$ are position and velocity vectors of vehicle at the time specified.</p>
00003 (REFSMAT)	<p><u>This option is used for gyro drift determination.</u> This option realigns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.</p>	$\begin{bmatrix} \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{orientation} \end{bmatrix}$
00004 (Landing Site)	<p><u>Landing Site</u></p>  <p>The latitude, longitude/2, and altitude above the mean lunar radius of the landing site must be entered to determine R_{LS}. The g.e.l. for which the CSM R and V are to be selected must also be entered. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{Landing Site} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit} (R_{LS}) \\ Z_{SM} \times X_{SM} \\ \text{Unit} ((R_{ENTR} \times V_{ENTR}) \times Z_{SM}) \end{bmatrix}$ <p>where</p> <p>R_{LS} is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system.</p> <p>$\begin{Bmatrix} R_{ENTR} \\ V_{ENTR} \end{Bmatrix}$ are the CSM position and velocity vectors at the time specified.</p>

PROCEDURE FOR SPECIFYING OPTIONS

- When P52 is entered, the CMC checks the PREFERRED ATTITUDE flag.
- If the flag is set, the DSKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
- If the flag is not set, the DSKY flashes Verb 04, Noun 06, R2 = 00003, indicating the PREFERRED option may not be selected.
- The desired option is loaded into R2 via Verb 22.

IMU REALIGNMENT - P52



$$\underline{U}_{S1} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}_{ECI}$$

$$\underline{U}_{S2} = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}_{ECI}$$

\underline{U}_{S1} and \underline{U}_{S2} are known unit vectors in ECI space of the stars and are stored in the AGC.

$$\underline{U}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix}_{SM}$$

$$\underline{U}_{S2M} = \begin{bmatrix} X_{2M} \\ Y_{2M} \\ Z_{2M} \end{bmatrix}_{SM}$$

\underline{U}_{S1M} and \underline{U}_{S2M} are the measured unit vectors (optics mark) in stable member (SM) space of the stars.

$$[S_A] = \begin{bmatrix} \underline{U}_{S1} \\ (\underline{U}_{S1} \times \underline{U}_{S2}) \times \underline{U}_{S1} \\ \underline{U}_{S1} \times \underline{U}_{S2} \end{bmatrix} [ECI] \quad [S_B] = \begin{bmatrix} \underline{U}_{S1M} \\ (\underline{U}_{S1M} \times \underline{U}_{S2M}) \times \underline{U}_{S1M} \\ \underline{U}_{S1M} \times \underline{U}_{S2M} \end{bmatrix} [SM]$$

$$[S_A] = [A] [ECI]$$

$$[S_B] = [B] [SM]$$

$$[S_A] = [S_B]$$

$$[A] [ECI] = [B] [SM]$$

$$[SM] = [B]^{-1} [A] [ECI]$$

$$[REFSMMAT] = [B]^{-1} [A]$$

P32-COELLIPTIC SEQUENCE INITIATION (CSI)

V37 Enter, 32 Enter

V06 N11 Flashing

TIG of CSI (h, min, 0.01 s)

V06 N55 Flashing

Number of apsidal crossings, elevation angle for TPI (+0 0 0 X, 0.01 deg)

V06 N37 Flashing

TIG of TPI (h, min, 0.01 s)

V16 N45 Flashing

Marks, time from ignition, middle gimbal angle (marks, min/s, 0.01 deg)

V06 N75 Flashing

 ΔH (CDH), ΔT (CDH-CSI), ΔT (TPI-CDH) (0.1 nmi, min/s, min/s)

V06 N81 Flashing

 ΔV_X (LV), ΔV_Y (LV), ΔV_Z (LV) of CSI (0.1 ft/s)

V06 N82 Flashing

 ΔV_X (LV), ΔV_Y (LV), ΔV_Z (LV) of CDH (0.1 ft/s)

V90 Enter (out of plane correction in final computation only)

V06 N16 Flashing

Time of event (h, min, 0.01 s)

V06 N90 Flashing

Y, YDOT, PSI (0.01 min, 0.1 ft/s, 0.01 deg)

+	0	0				Hours	TIG	N11	+	0	0				
+	0	0	0			Minutes	for		+	0	0	0			
+	0					Seconds	(LGC)		+	0					
N55 (+00001) No. of Apsidal Crossings (+026.60) Elevation Angle (+130.00) Central Angle															
+	0	0				Hours	TIG	N37	+	0	0				
+	0	0	0			Minutes	for		+	0	0	0			
+	0					Seconds	(LGC)		+	0					
+	0					ΔV_X Components of	ΔV in local	N81	+	0					
	0					ΔV_Y vertical coordinates (ft/s)			0						
+						373 TIG for CSI (AGS)	(minutes)	+							
+						275 TIG for TPI (AGS)	(minutes)	+							
410 +1(AGS-CSI), 605 + 00777 (desired cotan of LOS angle between LM and CSM at desired TPI in octal), 416 + 1(compute CSI with CDH at 1/2 orbit after CSI), 623 + 0 (orient Z body-axis parallel to CSM orbit plane.)															
	0					ΔV_X Components of	ΔV in local	N86		0					
	0					ΔV_Y vertical coordinates	used in AGS (ft/s)			0					
	0					ΔV_Z				0					

NOTES:

CSI

PGNS

ΔH (15.0)	N75 CSI/CDH (58:20)	CDH/TPI (38:47)
•	•	•
•	•	•
•	•	•

ΔVX CSI (49.4)	N81 YDOT N90 CSI (+0.0)
•	•
•	•
•	•

ΔVX CDH (-1.9)	N82 ΔVY CDH (+0.0)	ΔVZ CDH (+4.1)
•	•	•
•	•	•
•	•	•

AGS

402 ΔH	372 CSI-CDH	267/450 ΔVG (CSI)
_____	_____	_____
_____	_____	_____
_____	_____	_____

263 Y DOT CSI	371 ΔV CDH
_____	_____
_____	_____
_____	_____

CSM SOLUTION (change sign and subtract 1 ft/s ΔVX)	
ΔVX CSI	ΔVY CSI
•	•

N86 (AGS)		
ΔVX	ΔVY	ΔVZ
_____	_____	_____

BURN RULES	
CRITERIA:	3 ft/s
COMPARE:	1 PGNS vs CMC
	2 CHARTS vs CMC
	3 Burn CMC
	4 AGC vs CMC
	5 CRD vs CMC

P30 – EXTERNAL ΔV (LM)

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

					Purpose								
+	0	0			Hours	N33	+	0	0				
+	0	0	0		Minutes GETI		+	0	0	0			
+	0			.	Seconds		+	0			.		
				.	ΔV_X	N81						.	
				.	ΔV_Y LV							.	
				.	ΔV_Z (ft/s)							.	
+				.	ΔVR (ft/s)		+					.	
X	X	X	.		BT (min:s)		X	X	X	.			
X	X	X			R FDAI Inertial Angles (degrees)		X	X	X				
X	X	X			p		X	X	X				
				.	ΔV_X	N86						.	
				.	ΔV_Y AGS Targeting (ft/s)							.	
				.	ΔV_Z							.	
X	X	X	X		COAS Star		X	X	X	X			
X	X			.	COAS Az (degrees)		X	X			.		
X	X			.	COAS EL (degrees)		X	X			.		
i				.	HApogee	N42	+					.	
				.	HPerigee (nmi)							.	
+				.	ΔVT (ft/s)		+					.	

NOTES.

V50 N18 Flashing, Request Maneuver to FDAI R, P, Y Angles
V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
V06 N85, X, Y, Z Body Axes Velocity to be Gained
V16 N85 (Average G on at TIG -30) Velocity to be Gained
V16 N85 Flashing, Body Axes Residuals (to be Nullified)

[illegible]

P33—CONSTANT DELTA HEIGHT (CDH)

V37 Enter, 33 Enter

V06 N13 Flashing

TIG of CDH (h, min, 0.01 s)

V16 N45 Flashing

Marks, time from ignition, middle gimbal angle (marks, min/s, 0.01 deg)

V06 N75 Flashing

 $\Delta H(CDH)$, $\Delta T(TPI-CDH)$, $\Delta T(TPI-TPINOM)$ (0.1 nmi, min/s, min/s)

V06 N81 Flashing

 ΔV_X (LV), ΔV_Y (LV), ΔV_Z (LV) for CDH (0.1 ft/s)

V90 Enter (out of plane correction in final computation)

V06 N16 Flashing

Time of event (h, min, 0.01 s)

V06 N90 Flashing

Y, YDOT, PSI (0.01 nmi, 0.1 ft/s, 0.01 deg)

+	0	0				Hours	TIG for CDH (LGC)	N13	+	0	0				
+	0	0	0			Minutes			+	0	0	0			
+	0					Seconds			+	0					
	0					ΔV_X (LV)	Components of ΔV in local vertical coordinates (ft/s)	N81		0					
	0					ΔV_Y (LV)				0					
	0					ΔV_Z (LV)				0					
X	X	X				FDAI inertial pitch angle for CDH (deg)			X	X	X				
+						373 TIG for CDH (AGS) (minutes)			+						
	0					ΔV_X (LV)	Components of ΔV in local vertical coordinates used in AGS (ft/s)	N86		0					
	0					ΔV_Y (LV)				0					
	0					ΔV_Z (LV)				0					

NOTES:

CDH

PGNS

N75		
$\frac{\Delta H}{(15.0)}$	$\frac{\Delta T \text{ TPI/CDH}}{(38.47)}$	$\frac{\text{TPI SLIP}}{(0:00)}$
•	•	•
•	•	•
•	•	•

AGS

$\frac{402}{\Delta H}$	$\frac{450}{\Delta VX}$	$\frac{452}{\Delta VZ}$
_____	_____	_____
_____	_____	_____
_____	_____	_____

N81		
$\frac{\Delta VX}{(-1.9)}$	$\frac{\text{YDOT N90 CDH (+0.0)}}{}$	$\frac{\Delta VZ}{(+4.1)}$
•		•
•	(-) •	•
•	(-) •	•

$\frac{263}{\Delta VY \text{ (CDH)}}$	$\frac{270}{\Delta VY \text{ (NOW)}}$
_____	_____
_____	_____
_____	_____

CSM SOLUTION (change sign)		
$\frac{\Delta VX}{}$	$\frac{\Delta VY}{}$	$\frac{\Delta VZ}{}$
•	•	•

N86 (AGS)		
$\frac{\Delta VX}{}$	$\frac{\Delta VY}{}$	$\frac{\Delta VZ}{}$
•	•	•

BURN RULES	
CRITERIA:	$\dot{X} = 2 \text{ ft/s}$ and $\dot{Z} = 6 \text{ ft/s}$
COMPARE:	1. PGNS vs CMC 2. PGNS vs CHART 3. CHARTS vs CMC 4. If all above fail burn CMC solution.

V50 N18 Flashing, Request Maneuver to FDAI R, P, Y Angles
V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
V06 N85, X, Y, Z Body Axes Velocity to be Gained
V16 N85 (Average G on at TIG -30) Velocity to be Gained
V16 N85 Flashing, Body Axes Residuals (to be Nulled)

			.		50-18	Roll				.		
			.			Pitch (deg)				.		
			.			Yaw				.		
			.		06-18	Roll				.		
			.			Pitch (deg)				.		
			.			Yaw				.		
			.		06-85	X					.	
			.			Y VG (ft/s)					.	
			.			Z					.	
			.		16-85	X					.	
			.			Y VG (ft/s)					.	
			.			Z					.	
			.		16-85	X					.	
			.			Y Residuals (ft/s)					.	
			.			Z					.	
			.		X						.	
			.		Y Trim (ft/s)						.	
			.		Z						.	

P34—TRANSFER PHASE INITIATION (TPI)

V37 Enter, 34 Enter

V06 N37 Flashing

TIG of TPI (h, min, 0.01 s)

V06 N35 Flashing

R2: Elevation angle, R3: Central angle (0.01 deg, 0.01 deg)

V16 N45 Flashing

Marks, time from ignition, middle gimbal angle (marks, min/s, 0.01 deg)

V06 N58 Flashing

Pericenter altitude, ΔV (TPI), ΔV (TPF) (0.1 nmi, 0.1 ft/s, 0.1 ft/s)

V06 N81 Flashing

 ΔV_X (LV), ΔV_Y (LV), ΔV_Z (LV) for TPI (0.1 ft/s)

V06 N59 Flashing

 ΔV_X (LOS), ΔV_Y (LOS), ΔV_Z (LOS) for TPI (0.1 ft/s)

+	0	0				Hours		N37	+	0	0				
+	0	0	0			Minutes	TIG of TPI		+	0	0	0			
+	0					Seconds			+	0					
N55 (+00000) No. of Apsidal Crossings, (+026.60) Elevation Angle (+130.00) Central Angle															
	0					ΔV_X (LV)		N81		0					
	0					ΔV_Y (LV)	Components of ΔV in local vertical coordinates (ft/s)			0					
	0					ΔV_Z (LV)				0					
+	0					Total ΔV required for TPI (ft/s)		N42	+	0					
X	X	X				R	LM FDAI inertial roll and pitch angles at TPI (deg)		X	X	X				
X	X	X				P			X	X	X				
+	0					Range at TIG-5 min (nmi)		N54	+	0					
	0					Range rate at TIG-5 min (ft/s)				0					
	0					ΔV_X (LOS)		N59		0					
	0					ΔV_Y (LOS)	Components of ΔV in line of sight coordinates (ft/s)			0					
	0					ΔV_Z (LOS)				0					
X	X					Burn time (min/s)			X	X					
307 + 043.00 (AGS—Desired Transfer Time), 314 + 0 (LM-CSM Differential Altitude at TIG)															

NOTES:

TPI

PGNS

N37		
TIG TPI		
(126.58.27)		
_____	•	_____
_____	•	_____
_____	•	_____

N58		
HP	ΔV TPI	ΔV TPF
(43.7)	(24.8)	(31.4)
_____	•	_____
_____	•	_____
_____	•	_____

N81		
ΔVX	ΔVY	ΔVZ
(21.8)	(-0.1)	(-11.0)
_____	•	_____
_____	•	_____
_____	•	_____
N90		
_____	•	_____
_____	•	_____
_____	•	_____

N59		
$\Delta VF/A$	$\Delta VR/L$	$\Delta VR/L$
(24.8)	(0.0)	(0.0)
_____	•	_____
_____	•	_____
_____	•	_____

AGS

373
TIG TPI
_____ (+0418.5)

267	371
ΔV TPI	ΔV TPI + TPF
_____	_____
_____	_____
_____	_____

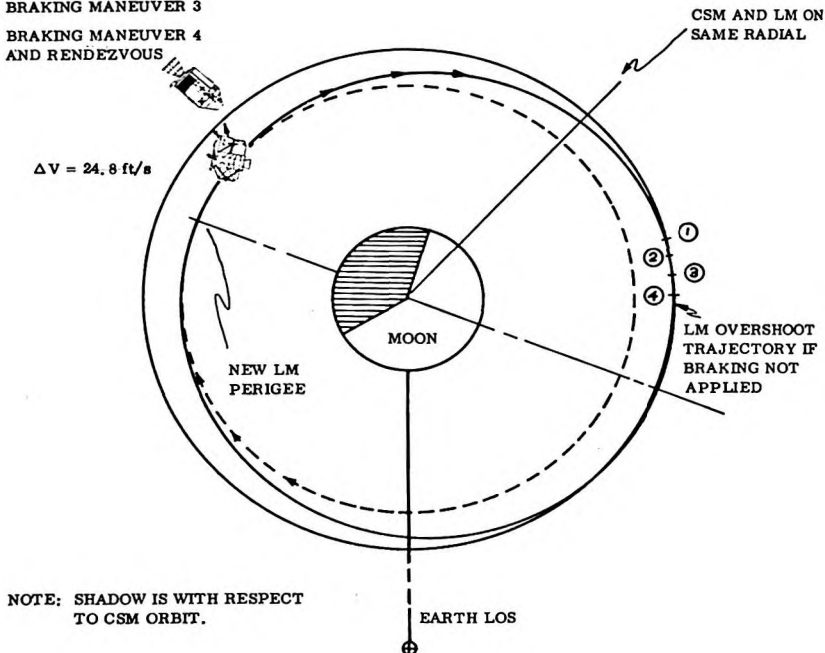
CSM SOLUTION (change sign)		
ΔVX	ΔVY	ΔVZ
_____	_____	_____
_____	_____	_____
_____	_____	_____
N86 (AGS)		
ΔVX	ΔVY	ΔVZ
_____	_____	_____
_____	_____	_____
_____	_____	_____

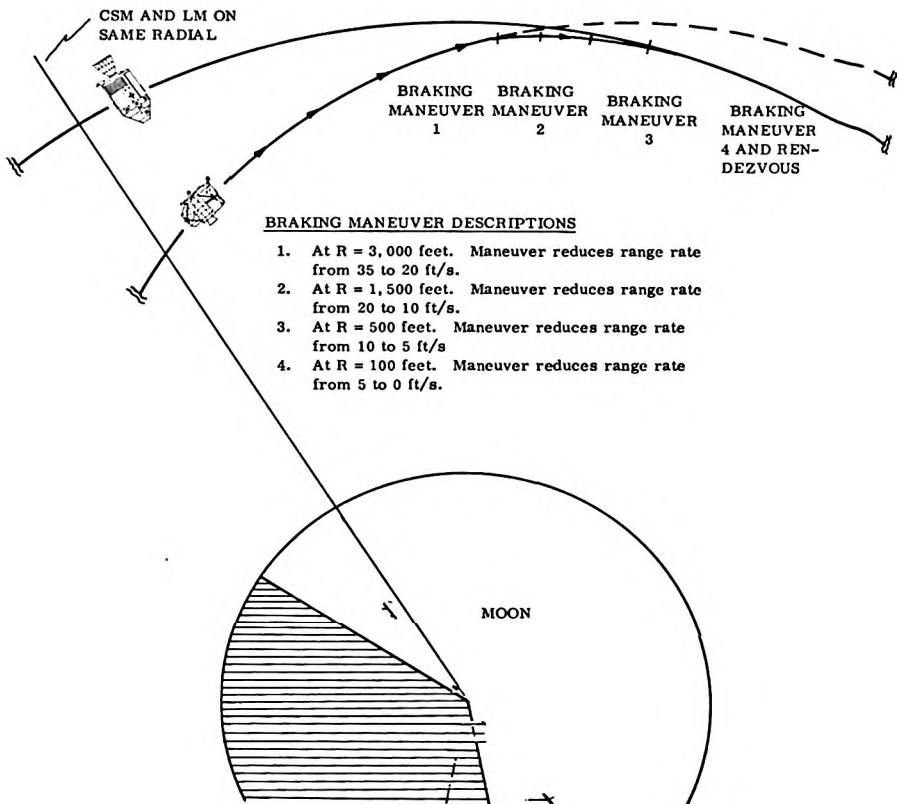
BURN RULES	
CRITERIA: $\dot{X} = 2$ ft/s, $\dot{Y} = 5$ ft/s, $\dot{Z} = 6$ ft/s	
COMPARE:	
1. PGNS vs CMC	
2. PGNS vs CHARTS	
3. CHARTS vs CMC	
4. If all above fail burn CMC solution.	
If TIG TPI ≥ 8 minutes early, recycle P32 with TIG equal to nominal TIG - 8 minutes.	

TERMINAL PHASE INITIATION

EVENT				BT/ΔV		G. E. T.				PROPULSION/ GUIDANCE				PRETHRUST TARGETING				
TPI (ALONG 26.6 DEGREE LINE OF SIGHT)				22. 2/24. 8		144:38:56. 1				LM-RCS/PGNS LAMBERT (P-41)				P-34				
RESIDUALS																		
ΔVX	PGNS	N85				AGS	500					+	X	X			h	
ΔVY							501					+	X	X	X			min GET
ΔVZ							502					+	X					
-----•---V _X TRIM -----•---V _Y TRIM -----•---V _Z TRIM ft/s																		

- ① BRAKING MANEUVER 1
- ② BRAKING MANEUVER 2
- ③ BRAKING MANEUVER 3
- ④ BRAKING MANEUVER 4
AND RENDEZVOUS



LM RENDEZVOUS FINAL PHASE

P47—THRUST MONITOR

V37 Enter, 47 Enter

V16 N83 Flashing, ΔV XYZ Body Axes

N62 Enter

V16 N62 Flashing, Inertial Velocity, Altitude Rate, Altitude

X					TB 6p* (h:min:s)	X					
X	X	X			R	Predicted Spacecraft	X	X	X		
X	X	X			P	IMU Gimbal Angles	X	X	X		
X	X	X			Y	at TLI Ignition	X	X	X		
X	X	X				(degrees)	X	X	X		
X	X	X			BT	Duration of TLI (min:s)	X	X	X		
					ΔVC^{**} (ft/s)						
+					V_I^\dagger (ft/s)		+				
X	X	X			R SEP	Predicted S/C IMU	X	X	X		
X	X	X			P SEP	Gimbal Angles at	X	X	X		
X	X	X			Y SEP	Completion of S-IVB	X	X	X		
X	X	X				Maneuver to CSM/SIV-B					
X	X	X				Separation Attitude					
X	X	X				(degrees)					
X	X	X			R	Predicted S/C IMU	X	X	X		
X	X	X			P	Gimbal Angles at	X	X	X		
X	X	X			Y	Extraction	X	X	X		
					X						
					Y	ΔV ft/s					
					Z						
					V	ft/s					
					HDOT	ft/s					
					H	nmi					

*Predicted Time of Beginning of S-IVB Restart Preparation for TLI (TB6 = TLI Ignition - 9 minutes)

**Nominal TLI ΔV Set into EMS ΔV Control † Nominal Inertial Velocity Displayed on DSKY at TLI Cutoff

P30 – EXTERNAL ΔV (LM)

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

						Purpose									
+	0	0				Hours	N33	+	0	0					
+	0	0	0			Minutes GETI		+	0	0	0				
+	0					Seconds		+	0						
						ΔV_X	N81								
						ΔV_Y LV									
						ΔV_Z (ft/s)									
+						ΔV_R (ft/s)		+							
X	X	X				BT (min·s)		X	X	X					
X	X	X				R FDAI Inertial Angles (degrees)		X	X	X					
X	X	X				P		X	X	X					
						ΔV_X AGS Targeting (ft/s)	N86								
						ΔV_Y									
						ΔV_Z									
X	X	X	X			COAS Star		X	X	X	X				
X	X					COAS Az (degrees)		X	X						
X	X					COAS EL (degrees)		X	X						
+						HApogee	N42	+							
						HPerigee (nmi)									
+						ΔV_T (ft/s)		+							

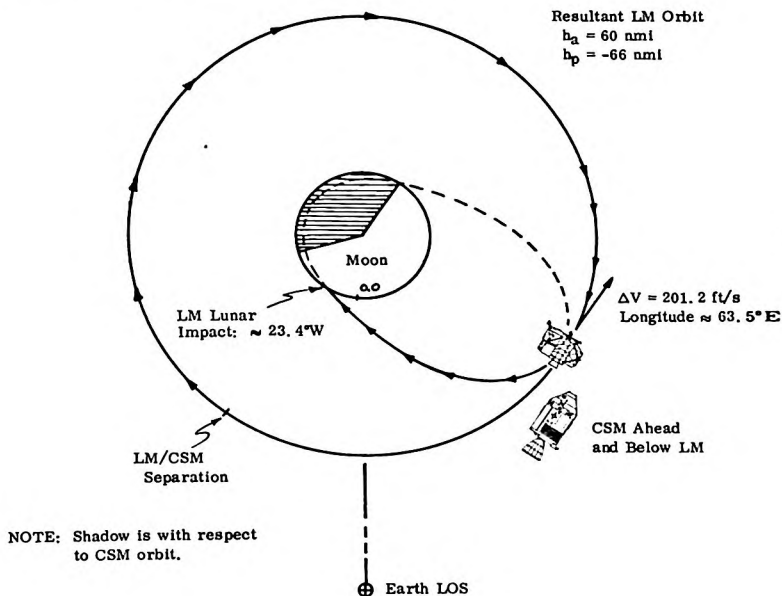
NOTES:

V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

[illegible]

LM Lunar Impact

EVENT		BT/ ΔV	G. E. T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
LM Lunar Impact Maneuver		80.4/201.2	149:28:08.9	LM-RCS/PGNS Ext ΔV (P-42)	P-30
RESIDUALS					
ΔV_X				+	h
ΔV_Y				+	min <u>GET</u>
ΔV_Z				+	s
----- V_{XTrim} ----- V_{YTrim} ----- V_{ZTrim} ft/s					



P30-EXTERNAL ΔV

TEI 39

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_x	N81				
				ΔV_y LV					
				ΔV_z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				Hperigee nmi					
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT (degrees)	N61		0		
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g Hr min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

NOTES:

P30-EXTERNAL ΔV
Plane Change & TEI 41

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y LV					
				ΔV_Z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee nmi	N44	+			
				HPerigee					
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT (degrees)	N61		0		
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g Hr min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours	} GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0	0		Celestial Body Code 1	N71	X	0	0	0	0	
X	0	0	0	0		Celestial Body Code 2	N71	X	0	0	0	0	
						Star Angle Difference (degrees)	N05						
						X	} Gyro Torquing Angles (degrees)						
						Y							
						Z							
						X	} Calculated Gyro Drift (meru)						
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours	} GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0	0		Celestial Body Code 1	N71	X	0	0	0	0	
X	0	0	0	0		Celestial Body Code 2	N71	X	0	0	0	0	
						Star Angle Difference (degrees)	N05						
						X	} Gyro Torquing Angles (degrees)						
						Y							
						Z							
						X	} Calculated Gyro Drift (meru)						
						Y							
						Z							

NOTES:

V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit,
300 K ft Earth Orbit

	50-18	Roll	
		Pitch (deg)	
		Yaw	
	06-18	Roll	
		Pitch (deg)	
		Yaw	
	06-40	TFI (min:s)	
		VG (ft/s)	
		ΔVM (ft/s)	
	06-40	TFC (min:s)	
	VG (ft/s)		
	ΔVM (ft/s)		
16-40	TFC (min:s)		
	VG (ft/s)		
	ΔVM (ft/s)		
85	X	Residuals (ft/s)	
	Y		
	Z		
85	X	TRIM (ft/s)	
	Y		
	Z		
44	HA (nmi)		
	HP (nmi)		
	TFF (min:s)		

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

					Purpose						
					Prop/Guidance						
+					Weight (lb)	N47	+				
	0	0			PTrim	N48		0	0		
	0	0			(degrees)			0	0		
+	0	0			YTrim						
+	0	0	0		Hours	N33	+	0	0		
+	0	0	0		Minutes	GETI	+	0	0	0	
+	0				Seconds		+	0			
					ΔV_x	N81					
					ΔV_y	LV					
					ΔV_z	(ft/s)					
X	X	X			R		X	X	X		
X	X	X			P	IMU Gimbal	X	X	X		
X	X	X			Angles (deg)		X	X	X		
					Y		X	X	X		
+					HApogee	N44	+				
					HPerigee	nmi					
+					ΔVT (ft/s)		+				
X	X	X			BT (min:s)		X	X	X		
X					ΔVC (ft/s)		X				
X	X	X	X		SXT Star		X	X	X	X	
+				0	SFT (degrees)		+				0
+				0 0	TRN (degrees)		+				0 0
X	X	X			BSS (Coas Star)		X	X	X		
X	X				SPA (Coas Pitch, deg)		X	X			
X	X	X			SXP (Coas X Pos, deg)		X	X	X		
	0				LAT	N61		0			
					(degrees)						
+					LONG						
+					RTGO (nmi) EMS		+				
+					VIO (ft/s)		+				
					GET 0.05 g						
					Hr:min:s						
					SET STARS						
X	X	X			RAlign		X	X	X		
X	X	X			PAlign		X	X	X		
X	X	X			YAlign		X	X	X		
					ULLAGE						

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0			Hours	TI GET at	+	0	0			
+	0	0	0		Minutes	0 degree	+	0	0	0		
+	0				Seconds	Elevation	+	0				
+	0	0			Hours	T2 GET at	+	0	0			
+	0	0	0		Minutes	35 degrees	+	0	0	0		
+	0				Seconds	Elevation	+	0				
X	X	X			R	IMU Gimbal	X	X	X			
X	X	X			P	Angles (deg)	X	X	X			
X	X	X			Y		X	X	X			
X	N	or	S		nmi		X	N	or	S		
X	X	X	X		Shaft	SXT	X	X	X	X		
X	X	X	X		Trun	Angles	X	X	X	X		
					Control Point							
					LAT (+ north)	N89						
					LONG/2 (+ east)							
					ALT (nmi)							
					LAT (+ north)	N89						
					LONG/2 (+ east)							
					ALT (nmi)							
					Δ R nmi	N49						
					Δ V ft/s							

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option	X	0	0	0	0
+	0	0			Hours } GET Minutes } Seconds }	+	0	0		
+	0	0	0			+	0	0	0	
+	0					+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0
					Star Angle Difference (degrees)	N05				
					X } Gyro Torquing Angles (degrees) Y } Z }	N93				
					X } Calculated Gyro Drift (meru) Y } Z }					

X	0	0	0	0	P52 Option	X	0	0	0	0
+	0	0			Hours } GET Minutes } Seconds }	+	0	0		
+	0	0	0			+	0	0	0	
+	0					+	0			
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0
					Star Angle Difference (degrees)	N05				
					X } Gyro Torquing Angles (degrees) Y } Z }	N93				
					X } Calculated Gyro Drift (meru) Y } Z }					

NOTES:

P22—ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 — Known, A2 — Unknown
 B — Index of offset designator
 DE — Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing — Please Mark

+	0	0				Hours	T1 GET at	+	0	0				
+	0	0	0			Minutes	0 degree	+	0	0	0			
+	0					Seconds	Elevation	+	0					
+	0	0				Hours	T2 GET at	+	0	0				
+	0	0	0			Minutes	35 degrees	+	0	0	0			
+	0					Seconds	Elevation	+	0					
X	X	X				R	IMU Gimbal	X	X	X				
X	X	X				P	Angles (deg)	X	X	X				
X	X	X				Y		X	X	X				
X	N	or	S			nmi		X	N	or	S			
X	X	X	X			Shaft	SXT	X	X	X	X			
X	X	X	X			Trun	Angles	X	X	X	X			
						Control Point								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						Δ R nmi	N49							
						Δ V ft/s								

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours	T1 GET at	+	0	0			
+	0	0	0			Minutes	0 degree	+	0	0	0		
+	0					Seconds	Elevation	+	0				
+	0	0				Hours	T2 GET at	+	0	0			
+	0	0	0			Minutes	35 degrees	+	0	0	0		
+	0					Seconds	Elevation	+	0				
X	X	X				R	IMU Gimbal	X	X	X			
X	X	X				P	Angles (deg)	X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT	X	X	X	X		
X	X	X	X			Trun	Angles	X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown
 B - Index of offset designator
 DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours	TI GET at	+	0	0				
+	0	0	0			Minutes	0 degree	+	0	0	0			
+	0					Seconds	Elevation	+	0					
+	0	0				Hours	T2 GET at	+	0	0				
+	0	0	0			Minutes	35 degrees	+	0	0	0			
+	0					Seconds	Elevation	+	0					
X	X	X				R	IMU Gimbal	X	X	X				
X	X	X				P	Angles (deg)	X	X	X				
X	X	X				Y		X	X	X				
X	N	or	S			nmi		X	N	or	S			
X	X	X	X			Shaft	SXT	X	X	X	X			
X	X	X	X			Trun	Angles	X	X	X	X			
						Control Point								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						Δ R nmi	N49							
						Δ V ft/s								

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours		+	0	0				
+	0	0	0			Minutes	T1 GET at 0 degree Elevation	+	0	0	0			
+	0					Seconds		+	0					
+	0	0				Hours	T2 GET at 35 degrees Elevation	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0					Seconds		+	0					
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X				
X	X	X				P		X	X	X				
X	X	X				Y		X	X	X				
X	N	or	S			nmi		X	N	or	S			
X	X	X	X			Shaft	SXT	X	X	X	X			
X	X	X	X			Trun	Angles	X	X	X	X			
						Control Point								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						Δ R nmi	N49							
						Δ V ft/s								

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 - Preferred, 2 - Nominal,
3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours	} GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X	} Gyro Torquing Angles (degrees)						
						Y							
						Z							
						X	} Calculated Gyro Drift (meru)						
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours	} GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X	} Gyro Torquing Angles (degrees)						
						Y							
						Z							
						X	} Calculated Gyro Drift (meru)						
						Y							
						Z							

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours	T1 GET at	+	0	0			
+	0	0	0			Minutes	0 degree	+	0	0	0		
+	0					Seconds	Elevation	+	0				
+	0	0				Hours	T2 GET at	+	0	0			
+	0	0	0			Minutes	35 degrees	+	0	0	0		
+	0					Seconds	Elevation	+	0				
X	X	X				R	IMU Gimbal	X	X	X			
X	X	X				P	Angles (deg)	X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT	X	X	X	X		
X	X	X	X			Trun	Angles	X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P22-ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 - Known, A2 - Unknown

B - Index of offset designator

DE - Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing - Please Mark

+	0	0				Hours	T1 GET at	+	0	0				
+	0	0	0			Minutes	0 degree	+	0	0	0			
+	0					Seconds	Elevation	+	0					
+	0	0				Hours	T2 GET at	+	0	0				
+	0	0	0			Minutes	35 degrees	+	0	0	0			
+	0					Seconds	Elevation	+	0					
X	X	X				R	IMU Gimbal	X	X	X				
X	X	X				P	Angles (deg)	X	X	X				
X	X	X				Y		X	X	X				
X	N	or	S			nmi		X	N	or	S			
X	X	X	X			Shaft	SXT	X	X	X	X			
X	X	X	X			Trun	Angles	X	X	X	X			
						Control Point								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						LAT (+ north)	N89							
						LONG/2 (+ east)								
						ALT (nmi)								
						Δ R nmi	N49							
						Δ V ft/s								

NOTES:

P22—ORBITAL NAVIGATION

V37 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B O D E Landmark Code

A1 — Known, A2 — Unknown

B — Index of offset designator

DE — Landmark ID

V06 N89 Flashing Landmark Coordinates

R1: Latitude

R2: Longitude/2

R3: Altitude

V51 Flashing — Please Mark

+	0	0				Hours	T1 GET at 0 degree Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
+	0	0				Hours	T2 GET at 35 degrees Elevation	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X	X				R	IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P		X	X	X			
X	X	X				Y		X	X	X			
X	N	or	S			nmi		X	N	or	S		
X	X	X	X			Shaft	SXT Angles	X	X	X	X		
X	X	X	X			Trun		X	X	X	X		
						Control Point							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						LAT (+ north)	N89						
						LONG/2 (+ east)							
						ALT (nmi)							
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option		X	0	0	0	0	0
+	0	0			Hours Minutes Seconds	GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	0				
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	0	
					Star Angle Difference (degrees)	N05						
					X Y Z	Gyro Torquing Angles (degrees)	N93					
					X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0	P52 Option		X	0	0	0	0	0
+	0	0			Hours Minutes Seconds	GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	0				
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0	0	
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0	0	
					Star Angle Difference (degrees)	N05						
					X Y Z	Gyro Torquing Angles (degrees)	N93					
					X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P30-EXTERNAL ΔV
TEI 45 (Nominal) & TEI 46

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

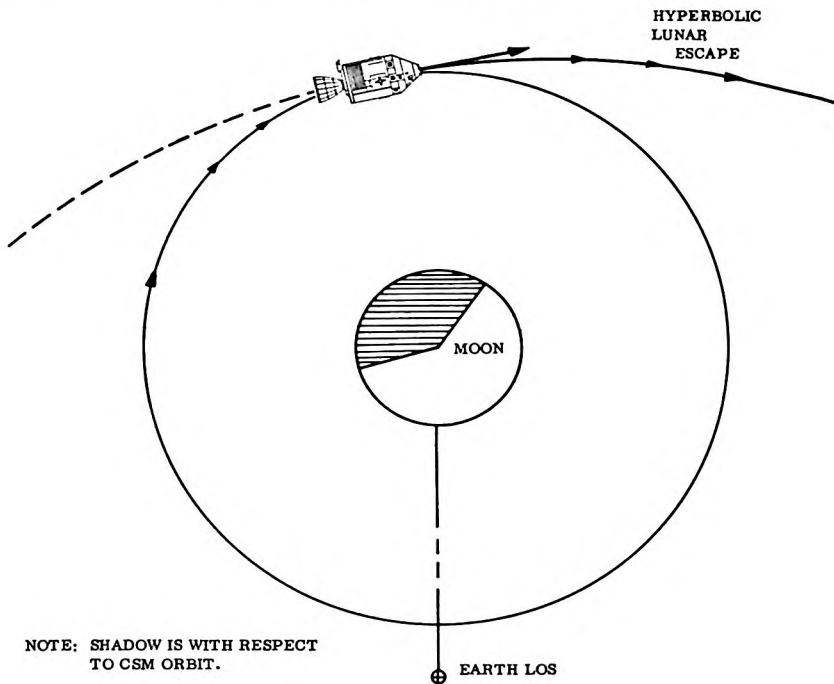
				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		(degrees)			0	0	
+	0	0		YTrim					
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes	GETI	+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y	LV				
				ΔV_Z	(ft/s)				
X	X	X		R		X	X	X	
X	X	X		P	IMU Gimbal Angles (deg)	X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	nmi	N44	+		
+				HPerigee					
				ΔVT	(ft/s)		+		
X	X	X		BT	(min:s)		X	X	X
X				ΔVC	(ft/s)		X		
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT	(degrees)	+			0
+			0 0	TRN	(degrees)	+			0 0
X	X	X		BSS	(Coast Star)	X	X	X	
X	X			SPA	(Coast Pitch, deg)	X	X		
X	X	X		SXP	(Coast X Pos, deg)	X	X	X	
	0			LAT	(degrees)	N61	0		
				LONG					
+				RTGO	(nmi) EMS	+			
+				VIO	(ft/s)	+			
				GET	0.05 g				
				Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

NOTES:

TRANSEARTH INJECTION

EVENT		BT/ΔV	G. E. T.	PROPULSION/ GUIDANCE						PRETHRUST TARGETING	
TEI (POSIGRADE)		136. 2/ 3044, 6	172:24:47. 8	SP6/G & N EXT ΔV (P-40)						P-30	
		ΔV _X	N85	+	X	X					h
		ΔV _Y	RESIDUALS	+	X	X	X				min GET
		ΔV _Z	(BODY AXIS)	+	X						s
-----V _X TRIM -----V _Y TRIM -----V _Z TRIM ft/s											

$$\Delta V = 3044, 6$$



P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal.

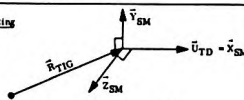
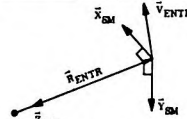
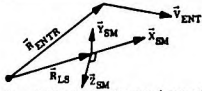
3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option	X	0	0	0	0
+	0	0			Hours	GET	+	0	0	
+	0	0	0		Minutes		+	0	0	0
+	0				Seconds		+	0		
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0
					Star Angle Difference (degrees)	N05				
					X	Gyro Torquing Angles (degrees) N93				
					Y					
					Z					
					X	Calculated Gyro Drift (meru)				
					Y					
					Z					

X	0	0	0	0	P52 Option	X	0	0	0	0
+	0	0			Hours	GET	+	0	0	
+	0	0	0		Minutes		+	0	0	0
+	0				Seconds		+	0		
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0
					Star Angle Difference (degrees)	N05				
					X	Gyro Torquing Angles (degrees) N93				
					Y					
					Z					
					X	Calculated Gyro Drift (meru)				
					Y					
					Z					

NOTES:

OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	<p><u>PREFERRED Thrusting</u></p>  <p>The PREFERRED option refers to one of two possibilities:</p> <ol style="list-style-type: none"> The PREFERRED thrusting orientation which is calculated and stored by P40 and P41. Any orientation uplinked by MSFN via P27. <p>The CMC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40 or P41 and stored, or uplinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the CMC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} U_{TD} \\ \text{Unit}(\vec{U}_{TD} \times \vec{R}_{TIG}) \\ \text{Unit}(\vec{U}_{TD} \times (\vec{U}_{TD} \times \vec{R}_{TIG})) \end{bmatrix}$ <p>where</p> <p>\vec{U}_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.</p> <p>\vec{R}_{TIG} is the position vector of the vehicle at ignition expressed in the basic reference system.</p>
00002 (NOMINAL)	<p><u>Nominal</u></p>  <p>The CMC requests the g. e. l. for which the vehicle \vec{R} and \vec{V} are to be selected to define the NOMINAL orientation. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{NOMINAL} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \vec{V}_{SM} \times \vec{Z}_{SM} \\ \text{Unit}(\vec{V}_{ENTR} \times \vec{R}_{ENTR}) \\ \text{Unit}(-\vec{R}_{ENTR}) \end{bmatrix}$ <p>where</p> <p>\vec{R}_{ENTR} and \vec{V}_{ENTR} are position and velocity vectors of vehicle at the time specified.</p>
00003 (REFSMAT)	<p><u>This option is used for gyro drift determination.</u> This option realigns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.</p>	$\begin{bmatrix} \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{orientation} \end{bmatrix}$
00004 (Landing Site)	<p><u>Landing Site</u></p>  <p>The latitude, longitude/2, and altitude above the mean lunar radius of the landing site must be entered to determine \vec{R}_{LS}. The g. e. l. for which the CSM \vec{R} and \vec{V} are to be selected must also be entered. <u>This option is not used for gyro drift determination.</u></p>	$\begin{bmatrix} \text{Landing Site} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit}(\vec{R}_{LS}) \\ \vec{Z}_{SM} \times \vec{X}_{SM} \\ \text{Unit}[(\vec{R}_{ENTR} \times \vec{V}_{ENTR}) \times \vec{X}_{SM}] \end{bmatrix}$ <p>where</p> <p>\vec{R}_{LS} is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system.</p> <p>\vec{R}_{ENTR} and \vec{V}_{ENTR} are the CSM position and velocity vectors at the time specified.</p>

PROCEDURE FOR SPECIFYING OPTIONS

- When P12 is entered, the CMC checks the PREFERRED ATTITUDE flag.
- If the flag is set, the DSKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
- If the flag is not set, the DSKY flashes Verb 04, Noun 06, R2 = 00003, indicating the PREFERRED option may not be selected.
- The desired option is loaded into R2 via Verb 22.

P30-EXTERNAL ΔV
MCC 5

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		(degrees)			0	0	
+	0	0		YTrim					
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_X	N81				
				ΔV_Y LV					
				ΔV_Z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				nmi					
+				HPerigee					
				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
	0			LAT	N61		0		
				(degrees)					
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g					
				Hr:min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P40 - SPS THRUSTING CSM

V37 Enter, 40 Enter

V50 N18 Flashing, Request Maneuver to FDAI R, P, Y Angles

V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude

V50 N25 Flashing, R1 = 0 0 2 0 4, Gimbal Actuator Test Option

V06 N40, Time from Ignition, Velocity to be Gained, Measured Change in Velocity

V99 N40 Flashing, Engine On Enable Request

V06 N40, Time from Cutoff, Velocity to be Gained, Measured Change in Velocity

V16 N40 Flashing, Final Values at Engine Cutoff

V16 N85 Flashing, Body Axes Residuals (to be Nulled)

V37 Flashing, V82 Enter

V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-40	TFI (min:s)
						VG (ft/s)
						ΔVM (ft/s)
					06-40	TFC (min:s)
						VG (ft/s)
						ΔVM (ft/s)
					16-40	TFC (min:s)
						VG (ft/s)
						ΔVM (ft/s)
					85	X
						Y Residuals (ft/s)
						Z
					85	X
						Y TRIM (ft/s)
						Z
					44	HA (nmi)
						HP (nmi)
						TFF (min:s)

P41 - RCS THRUSTING

V37 Enter, 41 Enter

V50 N18 Flashing, Request Maneuver to FDAI R, P, Y, Angles

V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude

V06 N85, X, Y, Z Body Axes Velocity to be Gained

V16 N85 (Average G on at TIG -30) Velocity to be Gained

V16 N85 Flashing, Body Axes Residuals (to be Nulled)

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y Residuals (ft/s)
						Z
						X
						Y Trim (ft/s)
						Z

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)	N47	+			
	0	0		PTrim	N48		0	0	
	0	0		YTrim (degrees)			0	0	
+	0	0		Hours	N33	+	0	0	
+	0	0	0	Minutes GETI		+	0	0	0
+	0			Seconds		+	0		
				ΔV_x	N81				
				ΔV_y LV					
				ΔV_z (ft/s)					
X	X	X		R		X	X	X	
X	X	X		P IMU Gimbal Angles (deg)		X	X	X	
X	X	X		Y		X	X	X	
+				HApogee	N44	+			
				HPerigee nmi					
+				ΔVT (ft/s)		+			
X	X	X		BT (min:s)		X	X	X	
X				ΔVC (ft/s)		X			
X	X	X	X	SXT Star		X	X	X	X
+			0	SFT (degrees)		+			0
+			0 0	TRN (degrees)		+			0 0
X	X	X		BSS (Coas Star)		X	X	X	
X	X			SPA (Coas Pitch, deg)		X	X		
X	X	X		SXP (Coas X Pos, deg)		X	X	X	
0				LAT	N61		0		
				LONG					
+				RTGO (nmi) EMS		+			
+				VIO (ft/s)		+			
				GET 0.05 g Hr min:s					
				SET STARS					
X	X	X		RAlign		X	X	X	
X	X	X		PAlign		X	X	X	
X	X	X		YAlign		X	X	X	
				ULLAGE					

NOTES:

V37 Enter, 61 Enter
V06 N61 Flashing
V06 N60 Flashing, Record
V06 N63 Flashing, Used for EMS if no Communication

V50 N25 Flashing, Request CM/SM Separation
V06 N61 Flashing
V06 N22, Monitor

V06 N64, Monitor

V00 N64, N60M04					Area						
X	X	X			R 0.05 g	X	X	X			
X	X	X			P 0.05 g	X	X	X			
X	X	X			Y 0.05 g	X	X	X			
					GET Hor Ck						
X	X	X			P EI-17	X	X	X			
	0				Lat N61		0				
					Long						
X	X	X			Max g	X	X	X			
+					V400K N60	+					
-	0	0			7400K	-	0	0			
+					RTGO EMS	+					
+					VIO	+					
					RTT						
X	X				RET 0.05 g	X	X				
+	0	0			D _L Max N69	+	0	0			
+	0	0			D _L Min	+	0	0			
+					V _L Max	+					
+					V _L Min	+					
X	X	X			D ₀	X	X	X			
X	X				RET V _{Circ}	X	X				
X	X				RET8BO	X	X				
X	X				RETEBO	X	X				
X	X				RETDRO	X	X				
X	X	X	X		SXTS	X	X	X	X		
+				0	SFT EI-2	+				0	
+			0	0	TRN	+				0 0	
X	X	X			BSS	X	X	X			
X	X				SPA EI-2	X	X				
X	X	X			SXP	X	X	X			
X	X	X	X		Lift Vector	X	X	X	X		

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	0
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

X	0	0	0	0		P52 Option		X	0	0	0	0	0
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Y Z	Gyro Torquing Angles (degrees)	N93					
						X Y Z	Calculated Gyro Drift (meru)						

NOTES:

P40 - SPS THRUSTING CSM

V37 Enter, 40 Enter

V50 N18 Flashing, Request Maneuver to FDAI R, P, Y Angles

V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude

V50 N25 Flashing, R1 = 0 0 2 0 4, Gimbal Actuator Test Option

V06 N40, Time from Ignition, Velocity to be Gained, Measured Change in Velocity

V99 N40 Flashing, Engine On Enable Request

V06 N40, Time from Cutoff, Velocity to be Gained, Measured Change in Velocity

V16 N40 Flashing, Final Values at Engine Cutoff

V16 N85 Flashing, Body Axes Residuals (to be Nulled)

V37 Flashing, V82 Enter

V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

						50-18	Roll
							Pitch (deg)
							Yaw
						06-18	Roll
							Pitch (deg)
							Yaw
						06-40	TFI (min:s)
							VG (ft/s)
							ΔVM (ft/s)
						06-40	TFC (min:s)
							VG (ft/s)
							ΔVM (ft/s)
						16-40	TFC (min:s)
							VG (ft/s)
							ΔVM (ft/s)
						85	X
							Y Residuals (ft/s)
							Z
						85	X
							Y TRIM (ft/s)
							Z
						44	HA (nmi)
							HP (nmi)
							TFF (min:s)

P41 - RCS THRUSTING

V37 Enter, 41 Enter

V50 N18 Flashing, Request Maneuver to FDAI R, P, Y, Angles

V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude

V06 N85, X, Y, Z Body Axes Velocity to be Gained

V16 N85 (Average G on at TIG-30) Velocity to be Gained

V16 N85 Flashing, Body Axes Residuals (to be Nulled)

						50-18	Roll
							Pitch (deg)
							Yaw
						06-18	Roll
							Pitch (deg)
							Yaw
						06-85	X
							Y VG (ft/s)
							Z
						16-85	X
							Y VG (ft/s)
							Z
						16-85	X
							Y Residuals (ft/s)
							Z
						X	
						Y	Trim (ft/s)
						Z	

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

V06 N81 Flashing, Load Desired ΔV

				Purpose					
				Prop/Guidance					
+				Weight (lb)		N47	+		
	0	0		PTrim		N48		0	0
	0	0		(degrees)				0	0
+	0	0		YTrim					
+	0	0		Hours		N33	+	0	0
+	0	0	0	Minutes GETI			+	0	0
+	0			Seconds			+	0	
				ΔV_x		N81			
				ΔV_y LV					
				ΔV_z (ft/s)					
X	X	X		R			X	X	X
X	X	X		P IMU Gimbal			X	X	X
X	X	X		Angles (deg)			X	X	X
+				Y			X	X	X
+				HApogee		N44	+		
				HPerigee nmi					
+				ΔVT (ft/s)			+		
X	X	X		BT (min:s)			X	X	X
X				ΔVC (ft/s)			X		
X	X	X	X	SXT Star			X	X	X
+			0	SFT (degrees)			+		0
+			0	TRN (degrees)			+		0
X	X	X		BSS (Coas Star)			X	X	X
X	X			SPA (Coas Pitch, deg)			X	X	
X	X	X		SXP (Coas X Pos, deg)			X	X	X
0				LAT		N61		0	
				(degrees)					
+				LONG					
+				RTGO (nmi) EMS			+		
+				VIO (ft/s)			+		
				GET 0.05 g					
				Hr min:s					
				SET STARS					
X	X	X		RAlign			X	X	X
X	X	X		PAlign			X	X	X
X	X	X		YAlign			X	X	X
				ULLAGE					

NOTES:

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X	Gyro Torquing Angles (degrees)						
						Y							
						Z							
						X	Calculated Gyro Drift (meru)						
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET	+	0	0			
+	0	0	0					+	0	0	0		
+	0							+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X	Gyro Torquing Angles (degrees)						
						Y							
						Z							
						X	Calculated Gyro Drift (meru)						
						Y							
						Z							

NOTES.

P40 - SPS THRUSTING CSM

V37 Enter, 40 Enter
 V50 N18 Flashing, Request Maneuver to FDAI R, P, Y Angles
 V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
 V50 N25 Flashing, R1 = 0 0 2 0 4, Gimbal Actuator Test Option
 V06 N40, Time from Ignition, Velocity to be Gained, Measured Change in Velocity
 V99 N40 Flashing, Engine On Enable Request
 V06 N40, Time from Cutoff, Velocity to be Gained, Measured Change in Velocity
 V16 N40 Flashing, Final Values at Engine Cutoff
 V16 N85 Flashing, Body Axes Residuals (to be Nulled)
 V37 Flashing, V82 Enter
 V16 N44 Flashing, Apogee Altitude, Perigee Altitude, Time to Freefall to 35 K ft Moon Orbit, 300 K ft Earth Orbit

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-40	TFI (min:s)
						VG (ft/s)
						Δ V (ft/s)
					06-40	TFC (min:s)
						VG (ft/s)
						Δ V (ft/s)
					16-40	TFC (min:s)
						VG (ft/s)
						Δ V (ft/s)
					85	X
						Y Residuals (ft/s)
						Z
					85	X
						Y TRIM (ft/s)
						Z
					44	HA (nmi)
						HP (nmi)
						TFF (min:s)

P41 - RCS THRUSTING

V37 Enter, 41 Enter
 V50 N18 Flashing, Request Maneuver to FDAI R, P, Y, Angles
 V06 N18, FDAI R, P, Y Angles After Maneuver to Burn Attitude
 V06 N85, X, Y, Z Body Axes Velocity to be Gained
 V16 N85 (Average G on at TIG -300) Velocity to be Gained
 V16 N85 Flashing, Body Axes Residuals (to be Nulled)

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y VG (ft/s)
						Z
					16-85	X
						Y Residuals (ft/s)
						Z
					X	
					Y	Trim (ft/s)
					Z	

P52-IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 1

R2: 0 0 0 X IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT, 4 - Landing Site

V51 Flashing - Please Mark

X	0	0	0	0	P52 Option		X	0	0	0	0	0
+	0	0			Hours } Minutes } Seconds }	GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	0				
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0		
					Star Angle Difference (degrees)	N05						
					X } Y } Z }	Gyro Torquing Angles (degrees)	N93					
					X } Y } Z }	Calculated Gyro Drift (meru)						

X	0	0	0	0	P52 Option		X	0	0	0	0	0
+	0	0			Hours } Minutes } Seconds }	GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	0				
X	0	0	0		Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0		Celestial Body Code 2	N71	X	0	0	0		
					Star Angle Difference (degrees)	N05						
					X } Y } Z }	Gyro Torquing Angles (degrees)	N93					
					X } Y } Z }	Calculated Gyro Drift (meru)						

NOTES:

APOLLO EARTH ENTRY

Aerodynamic Forces

The earth entry trajectory is shaped by the forces of gravity and atmospheric flow over the spacecraft surface. The latter force has two components, lift and drag.

Drag is a force directed opposite to the relative velocity vector and equal to:

$$\vec{D} = \frac{1}{2} \frac{SC_D}{M} \rho v^2 \vec{T}_D \text{ (ft/s}^2\text{)}$$

Lift is a force perpendicular to the relative velocity vector and equal to:

$$\vec{L} = \frac{1}{2} \frac{SC_L}{M} \rho v^2 \vec{T}_L \text{ (ft/s}^2\text{)}$$

where,

ρ = Atmospheric density (slugs/ft³)⁽¹⁾

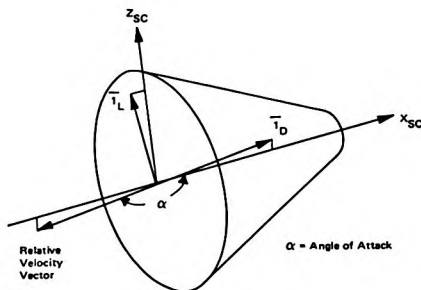
v = Relative velocity magnitude (ft/s)

C_D = Coefficient of drag (unitless)

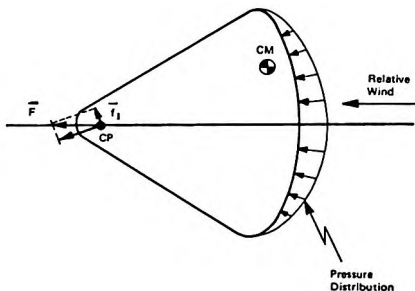
C_L = Coefficient of lift (unitless)

M = Mass of spacecraft (slugs)

S = Surface area presented to atmospheric flow (ft²)



Aerodynamic lift (or C_L) is a consequence of the vehicle center-of-mass (CM)⁽²⁾ being offset from its axis of symmetry. With the relative velocity vector along the axis of symmetry, the resulting symmetrical pressure distribution produces a resultant force (\vec{F}) through the center-of-pressure (CP)⁽³⁾. The component of this force (\vec{F}_1) perpendicular to the line joining the CP and CM causes a torque about the CM. The spacecraft will rotate about the CM until a stable attitude is reached where the force \vec{F} is fully along the line joining the CM and CP.

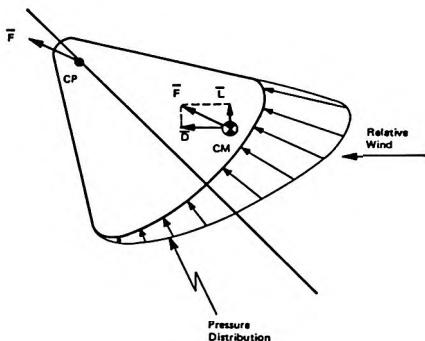


Notes:

1. A slug is a constant, relating units in the equation

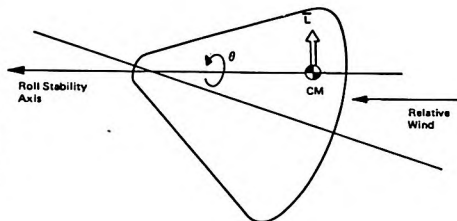
$$F(\text{pound-force}) = M(\text{slugs}) \times a(\text{ft/s}^2)$$
2. Center-of-mass: The point where the mass of a body may be regarded as being concentrated, insofar as motion of translation is concerned.
3. Center-of-pressure: The point where the resultant of all aerodynamic forces apparently operates.

In this stable attitude, the component of \vec{F} perpendicular to the relative velocity vector produces lift. Because of the spherical shape of the heat shield, the stable attitude remains relatively unchanged throughout the entry phases.

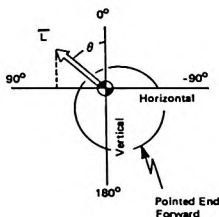


Lift Modulated Entry

During earth entry, steering is accomplished by orienting the lift vector (\vec{L}) so that the resulting specific forces satisfy the entry guidance objectives. The lift vector is rotated about the Roll Stability Axis according to roll commands issued by the AGC.

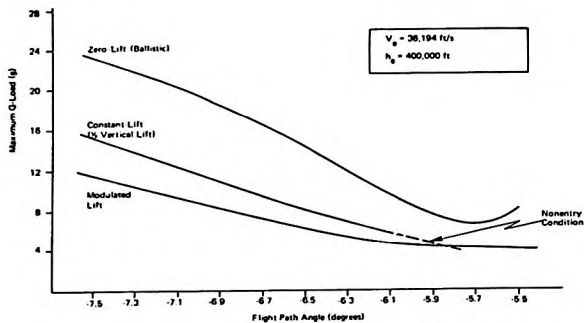


A roll angle (θ) of 0 degrees causes the lift vector to be up along the vertical and produces maximum downrange flight. A roll angle of ± 90 degrees puts the lift vector in the local horizontal plane, producing maximum crossrange (or lateral) flight.

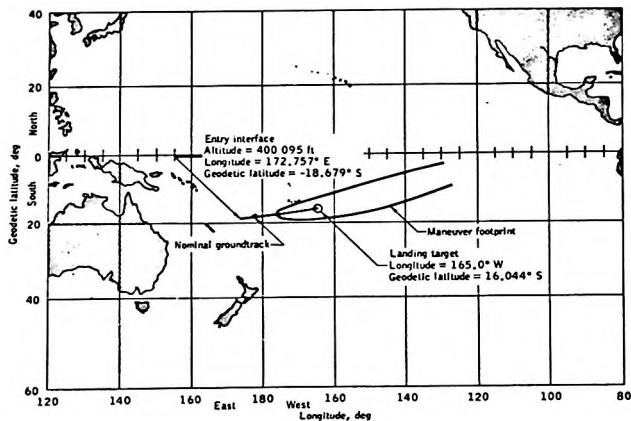


The entry control programs are designed to calculate the roll angle (θ) which will produce the vertical component of lift necessary to satisfy a guidance objective (constant drag flight, downrange target acquisition, and so forth). Crossrange control is maintained by choosing the proper sign of roll angle in order to reduce lateral errors.

Lift modulated flight can significantly reduce the peak accelerations experienced during entry, as shown below.



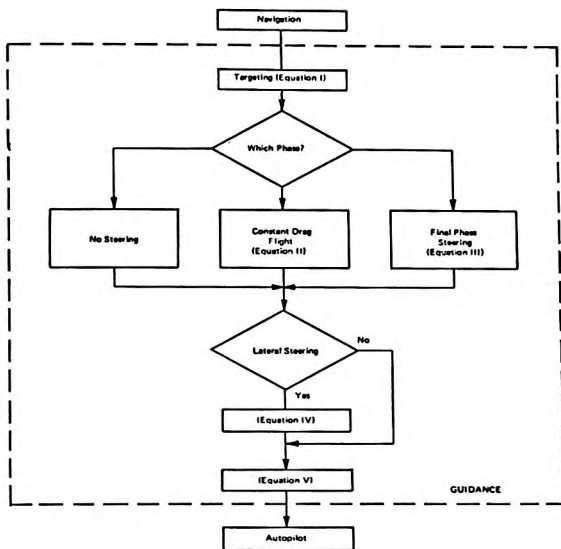
The maneuver footprint for the Apollo Command Module utilizing modulated lift is approximately 2,500 nautical miles in downrange and 250 nautical miles in crossrange. A typical entry footprint for a lunar return mission is shown below.



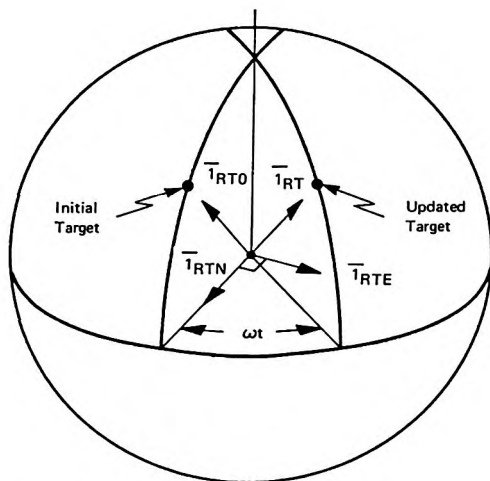
Entry Control Equations

The entry guidance equations are solved every 2 seconds in the AGC. Navigation and autopilot functions are also performed during this computation cycle.

The guidance equations below are used during the entry phases associated with a nominal lunar return entry. Equation I (targeting) is executed every pass through the computation loop. Equations II and III are executed during their particular entry phases for downrange steering. Lateral steering is done by Equation IV dependent upon certain logic constraints in the AGC. The roll angle needed to meet the above equations is calculated using Equation V.

Equation I: Landing Point Targeting Equations

During the early entry phases, a unit vector is calculated which points from the earth's center to an estimated splash point. This initial target vector (\hat{T}_{RT0}), together with unit vectors in the equatorial plane directed easterly (\hat{T}_{RTE}) and in the target meridian (\hat{T}_{RTN}), is used as a reference from which a new target vector (\hat{T}_{RT}) is calculated based on an updated estimate of time-to-splash.



$$\vec{r}_{RT} = \vec{r}_{RT0} + \vec{r}_{RTN} [\cos(\omega t) - 1] + \vec{r}_{RTE} \sin(\omega t)$$

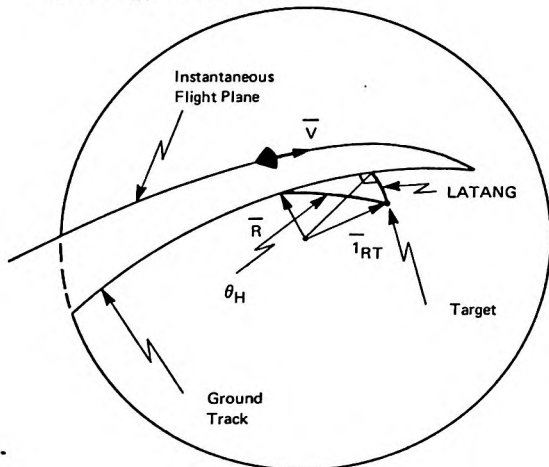
where (ωt) is the amount of earth's rotation for the difference between the old and new estimate of time-to-splash.

Based upon the new target vector (\vec{r}_{RT}) , the downrange angle from the spacecraft to the splash point is computed using:

$$\theta_H = \arccos\{\vec{r}_{RT} \cdot \text{Unit } \vec{R}\} \text{ (radians)}$$

The crossrange error from the present flight plane is calculated as follows:

$$\text{LATANG} = \vec{r}_{RT} \cdot \text{Unit}(\vec{V} \times \vec{R}) \text{ (radians)}$$



Equation II: Constant-Drag Flight Equation

Reduction of near-parabolic velocities (associated with the lunar return mission) to a point where capture in the earth's atmosphere is assured, is accomplished by flying a constant-drag trajectory.

Constant-drag guidance is achieved using an on-board computed reference trajectory and constant guidance factors for compensation of off-nominal conditions. The control reference parameters are computed using the following constant drag relationships.

$$(L/D)_{\text{Ref}} = - \left(\frac{V^2}{R} - g \right) \frac{1}{D_0} \text{ (unitless)}$$

$$R_{\text{Ref}} = \frac{2D_0}{\beta V} \text{ (ft/s)}$$

$$D_{\text{Ref}} = D_0 \text{ (ft/s}^2\text{)}$$

where

V = velocity (ft/s)

R = radial distance (ft)

g = gravity (ft/s²)

D_0 = desired drag level (ft/s²)

β = constant associated with atmosphere ($\frac{1}{\text{ft}}$)

Gain factors were chosen which relate perturbations in drag and altitude rate to the reference L/D .

$$(L/D)_{\text{control}} = (L/D)_{\text{Ref}} + 0.01 (D - D_{\text{Ref}}) - 0.001 (\dot{R} - \dot{R}_{\text{Ref}})$$

Equation III: Final Phase Equation

Steering through the denser portions of atmosphere is accomplished using a terminal control method of guidance. A mean terminal glide trajectory is prestored into the AGC. Linear perturbation coefficients, used to adjust for deviations in flight parameters from nominal values, are also stored. Using velocity as the independent variable, the various quantities in storage are chosen which are used in the basic control equation:

$$(L/D)_{\text{control}} = (L/D)_{\text{Ref}} + K_1 \{ (R - R_{\text{Ref}}) + K_2 (D - D_{\text{Ref}}) + K_3 (\dot{R} - \dot{R}_{\text{Ref}}) \}$$

where

$$(L/D)_{\text{Ref}} = \text{constant value } (\approx 0.27)$$

R_{Ref} = reference range-to-go (radiants)

D_{Ref} = reference drag (ft/s²)

\dot{R}_{Ref} = reference altitude rate (ft/s)

K_1 = sensitivity of L/D to deviations in range (unitless)

K_2 = sensitivity of range to deviations in drag level (radiants/ft/s²)

K_3 = sensitivity of range to deviations in altitude rate (radiants/ft/s)

Equation IV: Crossrange (or Lateral) Control

Crossrange control is maintained only when the lateral error (LATANG) is in excess of a computed deadband limit. This limit (somewhat less than the crossrange capability of the spacecraft) is computed every 2 seconds as a function of spacecraft velocity.

When this limit is exceeded the sign of the commanded roll angle (K2ROLL) is changed so that the horizontal component of lift causes the spacecraft to steer laterally toward the target.

Equation V: Commanded Roll Angle Equation

Using previously determined quantities (K2ROLL and L/D_{control}) the commanded roll angle is calculated by

$$\text{ROLLC} = (\text{K2ROLL}) \arccos \left[\frac{L/D_{\text{control}}}{L/D_{\text{Ref}}} \right] \quad (\text{degrees})$$

where

$$L/D_{\text{Ref}} \approx 0.3 \text{ (unitless)}$$

Entry Control Programs

The guidance function, which incorporates the entry control equations previously described together with certain logic decisions, can be considered as a basic set of AGC software programs (P60's). The programs are associated with various phases of the entry profile as described below.

P61 — Entry Preparation Program

- a. Purpose: Start navigation, check IMU alignment, and provide EMS initialization data in case of communications failures.
- b. Initiation: Astronaut keys DSKY — V37E 61E
- c. Steering: None, lift vector is oriented full-up (0 degrees) or full-down (180 degrees), according to the astronaut specifications.
- d. DSKY Displays:

V06N61

R1 — Impact latitude	Latitude of splash point
R2 — Impact longitude	Longitude of splash point
R3 — Heads up/down	±1

V06N90

R1 — G max	Maximum predicted g-load
R2 — V predicted	Predicted velocity at EI (400 K ft)
R3 — γ_{EI}	Predicted entry angle at EI

V06N63

R1 — RTOGO	Range-to-go from 297,431-foot altitude
R2 — V_{io}	Predicted velocity at 297,431-foot altitude
R3 — T_{fe}	Time to 297,431-foot altitude

P62 — CM/SM Separation and Preentry Maneuver Program

- a. Purpose: Notifies crew when GNCS is prepared for CM/SM separation. Also orients the spacecraft to the entry attitude.
- b. Initiation: P62 entered when P61 completed and the astronaut keys PROCEED after final P61 display.
- c. Steering: None, lift vector orientation maintained.
- d. DSKY Displays:

V50N25	
R1 — 00041	Request to separate CM/SM
R2	Blank
R3	Blank

V06N61	
R1 — Impact latitude	
R2 — Impact longitude	
R3 — Heads up/down	

V06N22	
R1 — AOG	} Desired final gimbal angles at EI
R2 — AIG	
R3 — AMG	

P63 — Entry Control Initialization Program

- a. Purpose: Initializes the entry targeting and guidance equations.
- b. Initiation: P63 entered automatically when P62 achieves the entry attitude.
- c. Steering: None, lift vector orientation maintained.
- d. DSKY Displays:

V06N64	
R1 — G	Present g-load
R2 — V_i	Present velocity
R3 — RTOGO	Range to the target

P64 — Post 0.5 g Program

- a. Purpose: Perform initial steering while awaiting subsequent phases.
- b. Initiation: P64 is entered automatically when 0.05 g is sensed by the GNCS.
- c. Steering:

When 0.05 g is sensed, a calculation is made to determine position of spacecraft in the entry corridor, and the lift vector is positioned full-up or full-down accordingly. The orientation is maintained until a precomputed drag level is exceeded (somewhat less than 1.5 g).

A constant drag trajectory is flown (≈ 4 g) until the altitude rate becomes greater (more positive) than -700 ft/s.

Range-to-go checks are made to determine whether the available range will permit a controlled skip maneuver. Because the nominal range-to-target at EI is 1,350 nmi, this requirement is never satisfied and the constant-drag flight is continued.

A predicted exit velocity for the hypothetical skip maneuver will decrease below 18,000 ft/s and exit is made to the final phase.

d. DSKY Displays

V06N74

R1 – BETA	Commanded roll
R2 – V_i	Inertial velocity
R3 – G	Present g-load

P67 – Final Phase Program

- Purpose: Steer through the dense portion of atmosphere and achieve the planned splash point.
- Initiation: P67 is entered automatically from P64 for the nominal lunar return entry.
- Steering: Steering is done using a terminal type controller based on a prestored nominal trajectory.

Guidance is terminated when velocity drops below 1,000 ft/s.

d. DSKY Displays:

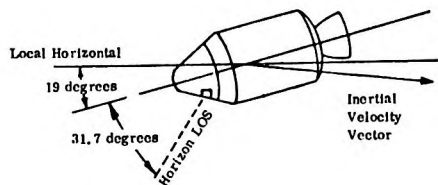
V06N66

R1 – BETA	Commanded roll angle
R2 – XRNERR	Crossrange error
R3 – DWRNGER	Downrange error

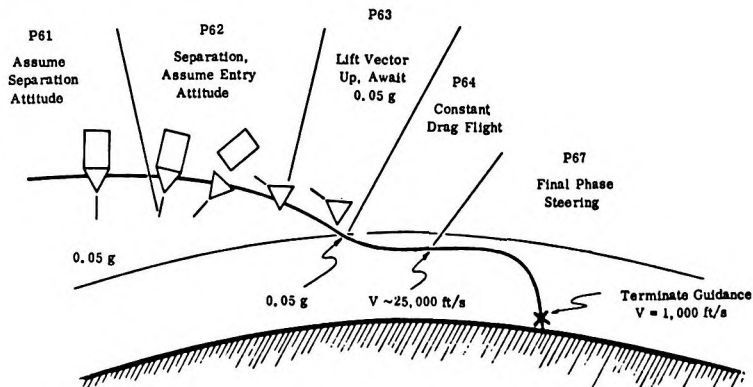
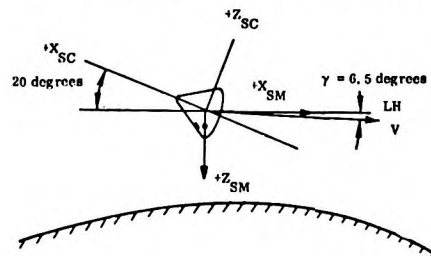
V16N67

R1 – RTOGO	Range to target
R2 – LAT	Present latitude
R3 – LONG	Present longitude

TYPICAL CM/SM SEPARATION ATTITUDE

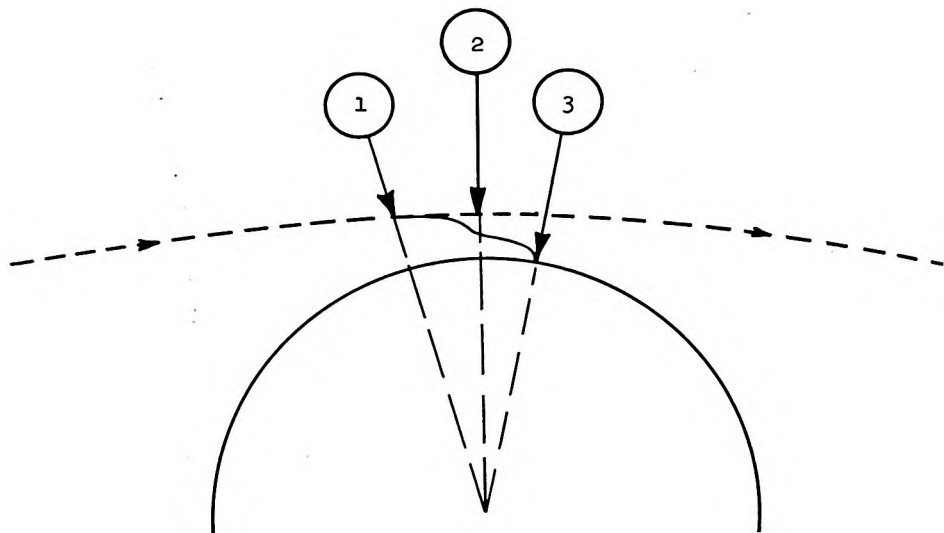


TYPICAL ATTITUDE AT ALTITUDE OF 400,000 FEET



TYPICAL ENTRY PROGRAM SEQUENCE OF EVENTS

TYPICAL LUNAR RETURN ENTRY INERTIAL RANGE PROFILE



1

Atmospheric Interface (400,000 feet)
 Inertial Range 0.0 nmi
 Central Angle 0.0 degrees

2

Vacuum Perigee (19.2 nmi)
 Inertial Range ~791 nmi
 Central Angle ~13.2 degrees

3

Nominal Entry Touchdown
 Inertial Range ~1,340 nmi
 Central Angle ~22.4 degrees

ENTRY

P61

V37 Enter, 61 Enter

V06 N61 Flashing

V06 N60 Flashing, Record

V06 N63 Flashing, Used for EMS if no Communication

P62

V50 N25 Flashing, Request CM/SM Separation

V06 N61 Flashing

V06 N22, Monitor

P63

V06 N64, Monitor

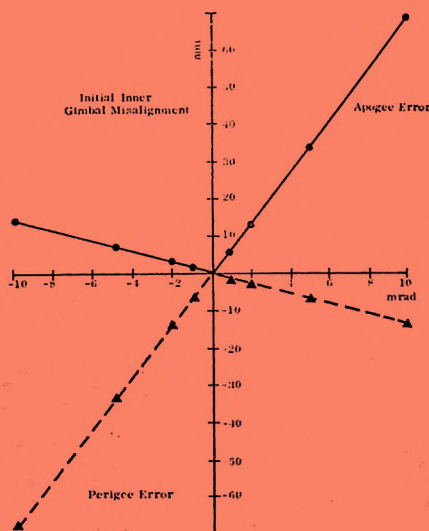
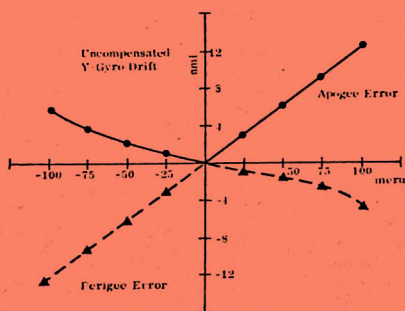
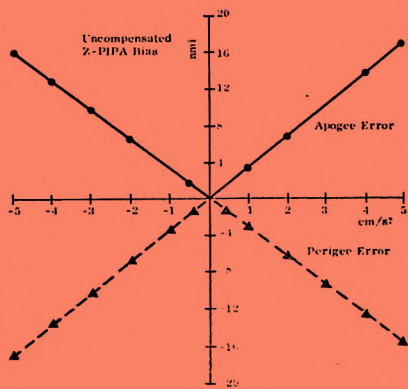
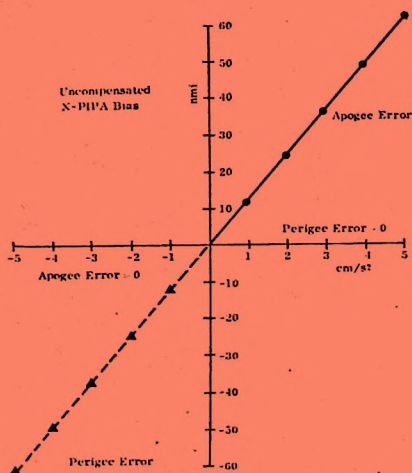
						Area					
	X	X	X			R 0.05 g	X	X	X		
	X	X	X			P 0.05 g	X	X	X		
	X	X	X			Y 0.05 g	X	X	X		
						GET Hor Ck					
	X	X	X			P EI-17	X	X	X		
		0				Lat N61		0			
						Long					
	X	X	X			Max g	X	X	X		
	+					V400K N60	+				
	-	0	0			Y400K	-	0	0		
	+					RTGO EMS	+				
	+					VIO	+				
						RTT					
	X	X				RET 0.05 g	X	X			
	+	0	0			D _L Max N69	+	0	0		
	+	0	0			D _L Min	+	0	0		
	+					V _L Max	+				
	+					V _L Min	+				
	X	X	X			D _O	X	X	X		
	X	X				RET V _{Circ}	X	X			
	X	X				RETBBO	X	X			
	X	X				RETEBO	X	X			
	X	X				RETDRO	X	X			
	X	X	X	X		SXTS	X	X	X	X	
	+				0	SFT EI-2	+				0
	+			0	0	TRN	+			0	0
	X	X	X			BSS	X	X	X		
	X	X				SPA EI-2	X	X			
	X	X	X			SXP	X	X	X		
	X	X	X	X		Lift Vector	X	X	X	X	

AREA	XXX	Splashdown Area Defined by Target Line.
R .05G	XXX (deg)	Spacecraft IMU Gimbal Angles Required for Aerodynamic Trim at 0.05 g
P .05G	XXX (deg)	
Y .05G	XXX (deg)	
GET (HOR CK)	XX:XX:XX (h:min:s)	Time of Entry Attitude Horizon Check at EI -17 Minutes.
P (HOR CK)	XXX (deg)	Pitch Attitude for Horizon Check at EI -17 Minutes.
LAT	±XX.XX (deg)	Latitude of Target Point.
LONG	±XX.XX (deg)	Longitude of Target Point.
MAX G	XX.X (g)	Predicted Maximum Reentry Acceleration.
V400K	XXXXX (ft/s)	Inertial Velocity at Entry Interface.
7400K	X.XX (deg)	Inertial Flight Path Angle at Entry Interface.
RTGO	XXXX.X (nmi)	Range to Go from 0.05 g to Target for EMS Initialization.
VIO	XXXXX (ft/s)	Inertial Velocity at 0.05 g for EMS Initialization.
RRT	XX:XX:XX (h:min:s)	Reentry Reference Time Based on GET of Predicted 400K (DET Start).
RET .05G	XX:XX (min:s)	Time of 0.05 g from 400K (RRT).
D _L MAX	X.XX (g)	Maximum Acceptable Value of Predicted Drag Level (from CMC).
D _L MIN	X.XX (g)	Minimum Acceptable Value of Predicted Drag Level (from CMC).
V _L MAX	XXXXX (ft/s)	Maximum Acceptable Value of Exit Velocity (from CMC).
V _L MIN	XXXXX (ft/s)	Minimum Acceptable Value of Exit Velocity (from CMC).
DO	X.XX (g)	Planned Drag Level During Constant g.
RET V _{CIRC}	XX:XX (min:s)	Time from EI that S/C Velocity Becomes Circular.
RETBBO	XX:XX (min:s)	Time from EI to the Beginning of Blackout.
RETEBO	XX:XX (min:s)	Time from EI to the End of Blackout.
RETDRO	XX:XX (min:s)	Time from EI to Drogue Deployment.
SXTS	XX (octal)	Sextant Star for Entry Attitude Check.
SFT	XXX.X (deg)	Sextant Shaft Setting for Entry Attitude Check.
TRN	XX.X (deg)	Sextant Trunnion Setting for Entry Attitude Check.
BSS	XXX (octal)	Boresight Star for Entry Attitude Check Using the COAS.
SPA	XX.X (deg)	BSS Pitch Angle on COAS.
SXP	X.X (deg)	BSS X Position on COAS.
LIFT VECTOR	XX	Lift Vector Desired at 0.05 g Based on Entry Corridor.

PERTURBATIONS

**BOOST MONITOR
TLI
LUNAR ORBIT
LM DESCENT
LM ASCENT
TEI
ENTRY**

BOOST MONITOR ERRORS (Significant IMU Errors Only)

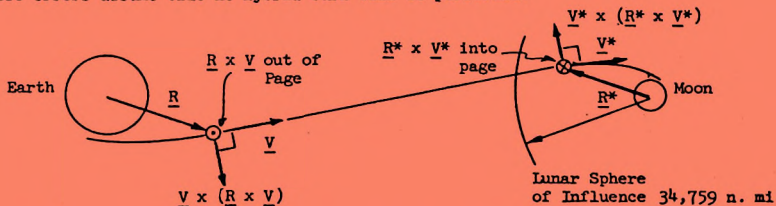


ERRORS IN PERICYNTION
DUE TO VELOCITY ERRORS DURING TRANSLUNAR COAST

DIRECTION OF VELOCITY ERROR	ERROR IN PERICYNTION (n.mi/ft/sec)
ERROR EXISTING AT TLI CUTOFF** (02:52:43 GET)	
Along \underline{V}	262.9
Along $\underline{R} \times \underline{V}$	.69
Along $\underline{V} \times (\underline{R} \times \underline{V})$	- 1.85
ERROR EXISTING AT MCC-1 (TLI + 9 hours)**(11:52:43 GET)	
Along \underline{V}	58.73
Along $\underline{R} \times \underline{V}$	10.26
Along $\underline{V} \times (\underline{R} \times \underline{V})$	-3.13
ERROR EXISTING AT HYBRID CUTOFF (TLI + 24 hours) (26:52:53 GET)	
Along \underline{V}	27.7
Along $\underline{R} \times \underline{V}$	9.05
Along $\underline{V} \times (\underline{R} \times \underline{V})$	2.97
ERROR EXISTING AT MCC-3 (LOI - 22 hours) (61:28:47 GET)	
Along \underline{V}	9.21
Along $\underline{R} \times \underline{V}$	3.98
Along $\underline{V} \times (\underline{R} \times \underline{V})$	2.81
ERROR EXISTING AT MCC-4 (LOI - 5 hours) (78:28:47 GET)	
Along \underline{V}^*	.34
Along $\underline{R}^* \times \underline{V}^*$	0
Along $\underline{V}^* \times (\underline{R}^* \times \underline{V}^*)$	2.74

* \underline{R} and \underline{V} are with respect to moon centered inertial system.

** These errors assume that no hybrid burn will be performed.

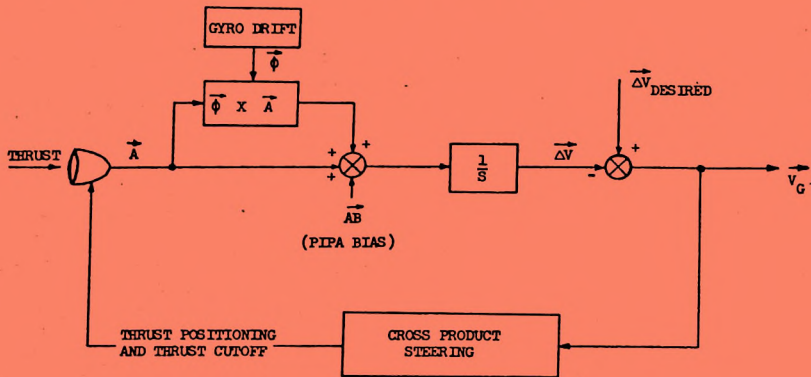


Transformation at TLI from stable member to \underline{V} , $\underline{R} \times \underline{V}$, and $\underline{V} \times (\underline{R} \times \underline{V})$.

$$\begin{bmatrix} \text{UNIT } (\underline{V}) \\ \text{UNIT } (\underline{R} \times \underline{V}) \\ \text{UNIT } (\underline{V} \times (\underline{R} \times \underline{V})) \end{bmatrix} = \begin{bmatrix} .766 & -.066 & .639 \\ -.059 & -.998 & -.033 \\ .640 & -.012 & -.768 \end{bmatrix} \begin{bmatrix} x_{SM} \\ y_{SM} \\ z_{SM} \end{bmatrix}$$

EFFECT OF INSTRUMENT ERRORS ON THRUST GUIDANCE

The thrust guidance used on Apollo, in simplified form, is as follows



The above steering loop attempts to drive V_g (velocity to be gained) to zero. The inability of the steering loop to drive V_g to zero will result in velocity residuals at the end of the burn as displayed in P-40.

Since the thrust guidance loop performs its calculations on the difference between ΔV measured and ΔV desired, the velocity residuals displayed by P-40 at the end of each burn are not caused by instrument errors but by the inability of the steering loop to drive V_g to zero.

Instrument errors result in a difference between the measured incremental velocity change and the true incremental velocity change. Assuming perfect cross product steering ($V_{\text{Residuals}} = 0$ in P-40) the resultant orbit will differ from the planned orbit. A measure of the difference between the actual and planned orbits is the error between actual and planned apogee and perigee.

The following tables relate incremental spacecraft velocity errors, during lunar orbit maneuvers, to errors in apogee and perigee. Knowing apogee and perigee errors, the table is used to obtain the required error in velocity, expressed in body axes coordinates. This velocity error is then converted to possible instrument errors by using the table relating PIPA bias and gyro drift to spacecraft velocity.

For Example: Assume a perigee error of +5.0 n mi and zero spacecraft residuals, as shown in P-40, after the DOI maneuver.

1. From the "Lunar Orbit Maneuver Perturbation" table, the most sensitive spacecraft velocity error is ΔV_X .
2. The required velocity error is

$$\Delta V_X = \frac{5.0 \text{ n mi}}{-0.68 \text{ n mi/ft/sec}} = -7.35 \text{ ft/sec}$$

3. The weighting factors relating instrument errors to velocity errors yield

$$-1.60 \times 10^{-2} AB_X \times 58.2 - 2.86 \times 10^{-2} AB_Z \times 58.2 = -7.35 \text{ ft/sec}$$

$$-0.93 AB_X - 1.66 AB_Z = -7.35 \text{ ft/sec}$$

Therefore:

$$\text{Uncompensated } AB_X = +7.9 \text{ cm/sec}^2 \text{ assuming } AB_Z = 0$$

$$\text{Uncompensated } AB_Z = +4.4 \text{ cm/sec}^2 \text{ assuming } AB_X = 0$$

or a combination of the above could have caused the 5 n mi error in perigee.

EFFECT OF INSTRUMENT ERRORS ON THRUST GUIDANCE (CONTINUED)

The "Lunar Orbit Maneuver Perturbation" table also gives the transformation from stable member space to spacecraft body control axes space as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S/C \text{ CSM}} = \begin{bmatrix} R_X (-7.25^\circ) \end{bmatrix} \begin{bmatrix} SM-NB \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}$$

where:

- $\begin{bmatrix} SM-NB \end{bmatrix}$ = Transformation from stable member to the nav base using gimbal angles
- $\begin{bmatrix} R_X (-7.25^\circ) \end{bmatrix}$ = Rotation matrix about X_{NB} of -7.25 degrees to transform from nav base space to spacecraft control axes space for the CSM.

For the LM

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S/C \text{ LM}} = \begin{bmatrix} SM-NB \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}$$

The purpose of this transformation is to indicate the location of the stable member with respect to thrust. The assumed gimbal angles are as follows:

	OUTER GIMBAL (degrees)	INNER GIMBAL (degrees)	MIDDLE GIMBAL (degrees)
LOI ₁	4	260	19
LOI ₂	0	231	0
LM DOI	0	299	0
LM CSI	0	191	0
LM CDH	0	38	0
LM TPI	0	276	0
TEI	0	3	0

For all maneuvers thrust is assumed along $+X_{S/C}$ axis with the exceptions of the CSI and TPI maneuvers where thrust was assumed along the $+Z_{S/C}$ axis.

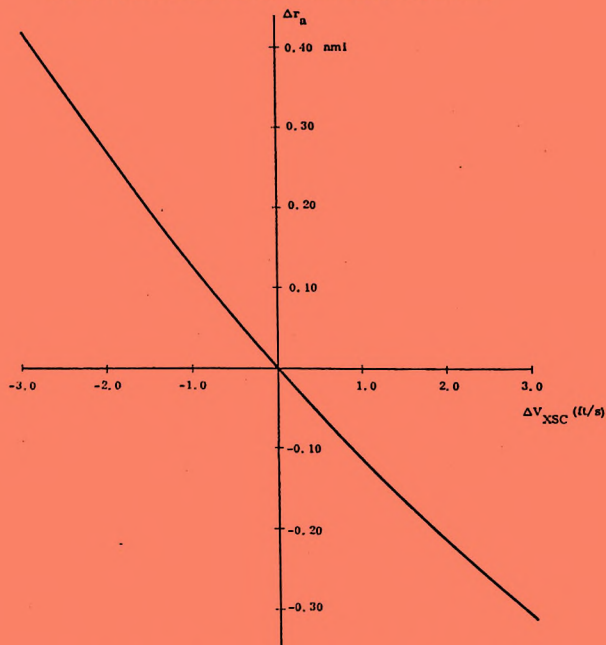
APOLLO 12 LUNAR ORBIT MANEUVER PERTURBATIONS

MANEUVER	BODY AXES VELOCITY ERRORS	ERROR IN PERIGEE (nmi/ft/s)	ERROR IN APOGEE (nmi/ft/s)	STABLE MEMBER TO SPACECRAFT CONTROL AXES TRANSFORMATION [SC] = [M] [SM]			REFSMMAT [SM] = [REFSMMAT] [BRS] BRS = BASIC REFERENCE SYSTEM				
LOI ₁	ΔV_X	—	-0.80	-0.156	0.324	0.933	-0.880	0.455	0.134	=	Lunar
	ΔV_Y	—	0.28	0.114	0.944	-0.309	-0.160	-0.551	0.818		Landing
	ΔV_Z	—	-0.09	-0.981	0.059	-0.185	0.446	0.699	0.558		Site
LOI ₂	ΔV_X	-0.49	Graph A	-0.624	-0.005	0.781	Same as Above				
	ΔV_Y	—	—	0.099	0.991	0.086					
	ΔV_Z	0.13	0.32	-0.775	0.131	-0.681					
LM DOI	ΔV_X	-0.68	—	0.488	0	0.873	Same as Above				
	ΔV_Y	—	—	0	1	0					
	ΔV_Z	-0.16	—	-0.873	0	0.488					
LM* CSI	ΔV_X	-0.17	0.19	-0.981	0	0.194	-0.980	0.193	0.029	=	Lunar
	ΔV_Y	—	—	0	1	0	-0.089	-0.575	0.813		Liftoff
	ΔV_Z	Graph B	Graph B	-0.194	0	-0.981	0.174	0.795	0.581		Off
LM CDH	ΔV_X	Graph C	Graph C	0.783	0	-0.621	Same as CSI				
	ΔV_Y	—	—	0	1	0					
	ΔV_Z	Graph D	Graph D	0.621	0	0.783					
LM* PDI	ΔV_X	—	-0.29	0.113	0	0.994	Same as CSI				
	ΔV_Y	—	—	0	1	0					
	ΔV_Z	—	0.67	-0.994	0	0.113					

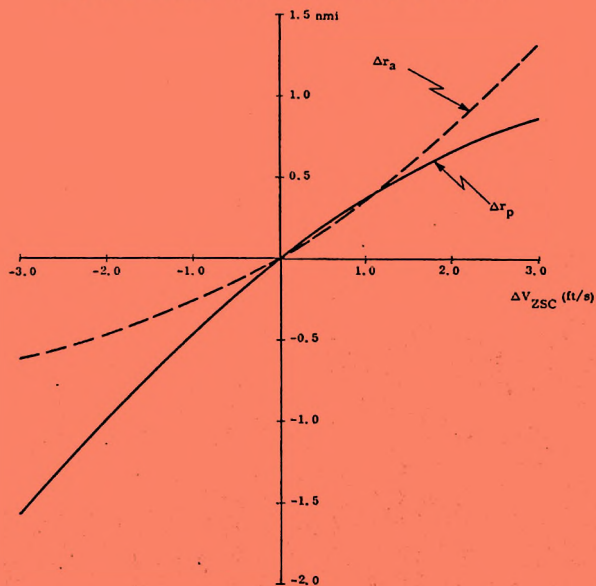
NOTES: *Thrust is along + Z SC axis. For all other maneuvers, thrust is along + X SC axis.

-Indicates coefficient is less than 0.05 nmi/ft/s.

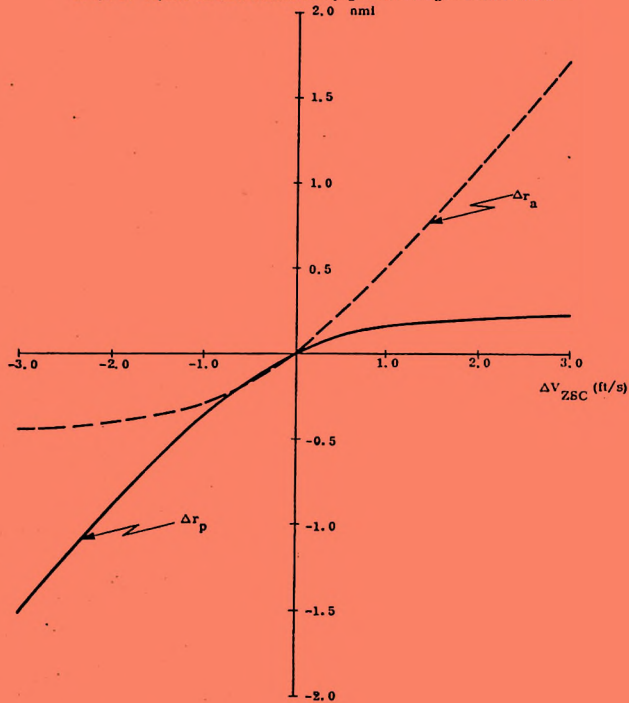
Graph A. Apollo 12 Lunar Orbit Circularization Apogee Perturbations



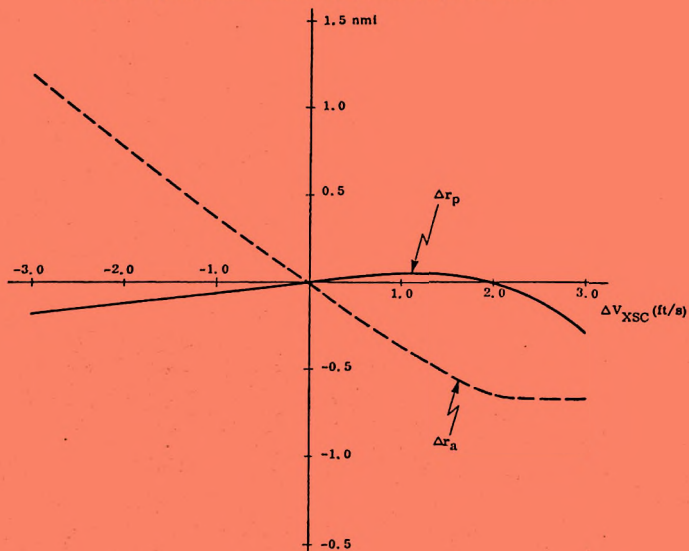
Graph B. Apollo 12 CSI Maneuver Apogee and Perigee Perturbations



Graph C. Apollo 12 CDH Maneuver Apogee and Perigee Perturbations



Graph D. Apollo 12 CDH Maneuver Apogee and Perigee Perturbations



ΔV_{SC} ERRORS CAUSED BY GYRO DRIFTS $[\beta \times \lambda]$ AND PIPA BIASES

GYRO DRIFTS - MERU

PIPA BIASES - CM/SEC²

ΔV_{SC} - FT/SEC

ΔT_P - SEC (LENGTH OF RUN + 30 SECONDS FOR STARTUP OF AVERAGE ROUTINE)

ΔT_G - SEC (TIME FROM LAST ALIGNMENT TO RUN)

WEIGHT FACTORS RELATE PIPA BIAS AND GYRO DRIFTS TO VELOCITY ERROR.

LOI₁

$$\begin{aligned}\Delta V_{XSC} &= +6.83 \times 10^{-5} \text{ NEHZ } \Delta T_G + 0.51 \times 10^{-2} \text{ AB}_X \Delta T_P - 1.06 \times 10^{-2} \text{ AB}_Y \Delta T_P - 3.06 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{YSC} &= -1.89 \times 10^{-4} \text{ NEHZ } \Delta T_G - 0.33 \times 10^{-2} \text{ AB}_X \Delta T_P - 3.10 \times 10^{-2} \text{ AB}_Y \Delta T_P + 1.01 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{ZSC} &= +6.83 \times 10^{-5} \text{ NEDX } \Delta T_G - 1.89 \times 10^{-4} \text{ NEDY } \Delta T_G + 3.22 \times 10^{-2} \text{ AB}_X \Delta T_P - 0.19 \times 10^{-2} \text{ AB}_Y \Delta T_P \\ &\quad + 0.60 \times 10^{-2} \text{ AB}_Z \Delta T_P\end{aligned}$$

LOI₂

$$\begin{aligned}\Delta V_{XSC} &= +2.05 \times 10^{-2} \text{ AB}_X \Delta T_P - 2.56 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{YSC} &= -1.23 \times 10^{-5} \text{ NEHZ } \Delta T_G - 0.33 \times 10^{-2} \text{ AB}_X \Delta T_P - 3.25 \times 10^{-2} \text{ AB}_Y \Delta T_P - 0.28 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{ZSC} &= -1.23 \times 10^{-5} \text{ NEDY } \Delta T_G + 2.54 \times 10^{-2} \text{ AB}_X \Delta T_P - 0.43 \times 10^{-2} \text{ AB}_Y \Delta T_P + 2.03 \times 10^{-2} \text{ AB}_Z \Delta T_P\end{aligned}$$

IM DOI

$$\begin{aligned}\Delta V_{XSC} &= +1.60 \times 10^{-2} \text{ AB}_X \Delta T_P - 2.86 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{YSC} &= +5.35 \times 10^{-6} \text{ NEHZ } \Delta T_G - 3.28 \times 10^{-2} \text{ AB}_Y \Delta T_P \\ \Delta V_{ZSC} &= +5.35 \times 10^{-6} \text{ NEDY } \Delta T_G + 2.86 \times 10^{-2} \text{ AB}_X \Delta T_P - 1.60 \times 10^{-2} \text{ AB}_Z \Delta T_P\end{aligned}$$

IM CSI

$$\begin{aligned}\Delta V_{XSC} &= +3.64 \times 10^{-6} \text{ NEDY } \Delta T_G + 3.22 \times 10^{-2} \text{ AB}_X \Delta T_P - 0.64 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{YSC} &= +3.64 \times 10^{-6} \text{ NEDX } \Delta T_G - 3.28 \times 10^{-2} \text{ AB}_Y \Delta T_P \\ \Delta V_{ZSC} &= +0.64 \times 10^{-2} \text{ AB}_X \Delta T_P + 3.25 \times 10^{-2} \text{ AB}_Z \Delta T_P\end{aligned}$$

IM CDM

$$\begin{aligned}\Delta V_{XSC} &= -2.57 \times 10^{-2} \text{ AB}_X \Delta T_P + 2.64 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{YSC} &= -3.26 \times 10^{-7} \text{ NEHZ } \Delta T_G - 3.28 \times 10^{-2} \text{ AB}_Y \Delta T_P \\ \Delta V_{ZSC} &= -3.26 \times 10^{-7} \text{ NEDY } \Delta T_G - 2.64 \times 10^{-2} \text{ AB}_X \Delta T_P - 2.57 \times 10^{-2} \text{ AB}_Z \Delta T_P\end{aligned}$$

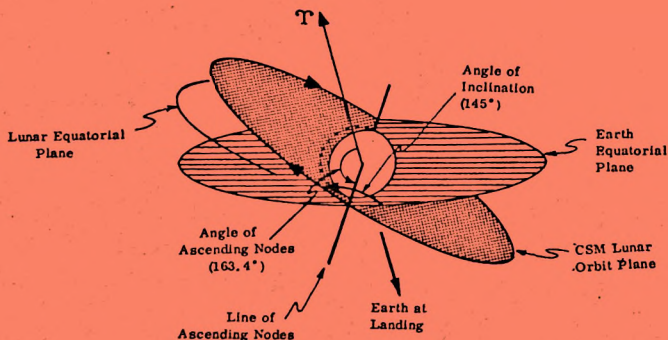
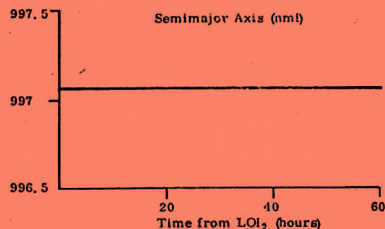
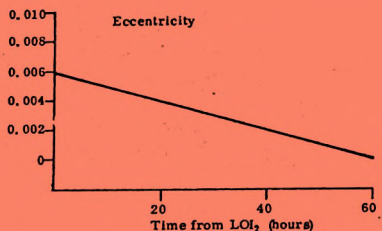
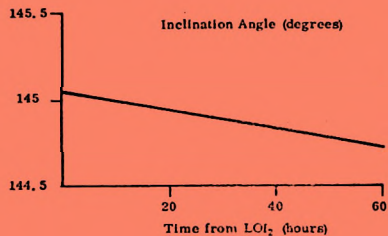
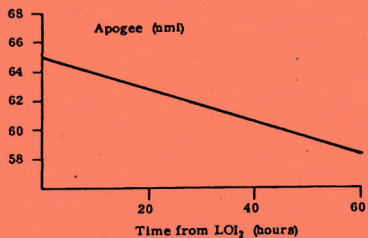
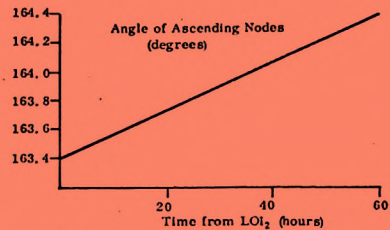
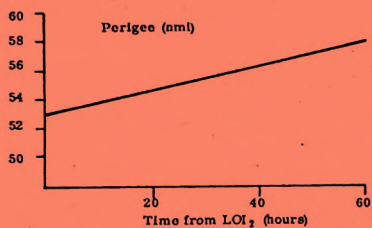
IM TPI

$$\begin{aligned}\Delta V_{XSC} &= -1.80 \times 10^{-6} \text{ NEDY } \Delta T_G - 0.37 \times 10^{-2} \text{ AB}_X \Delta T_P - 3.26 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{YSC} &= -1.80 \times 10^{-6} \text{ NEDX } \Delta T_G - 3.28 \times 10^{-2} \text{ AB}_Y \Delta T_P \\ \Delta V_{ZSC} &= +3.26 \times 10^{-2} \text{ AB}_X \Delta T_P - 0.37 \times 10^{-2} \text{ AB}_Z \Delta T_P\end{aligned}$$

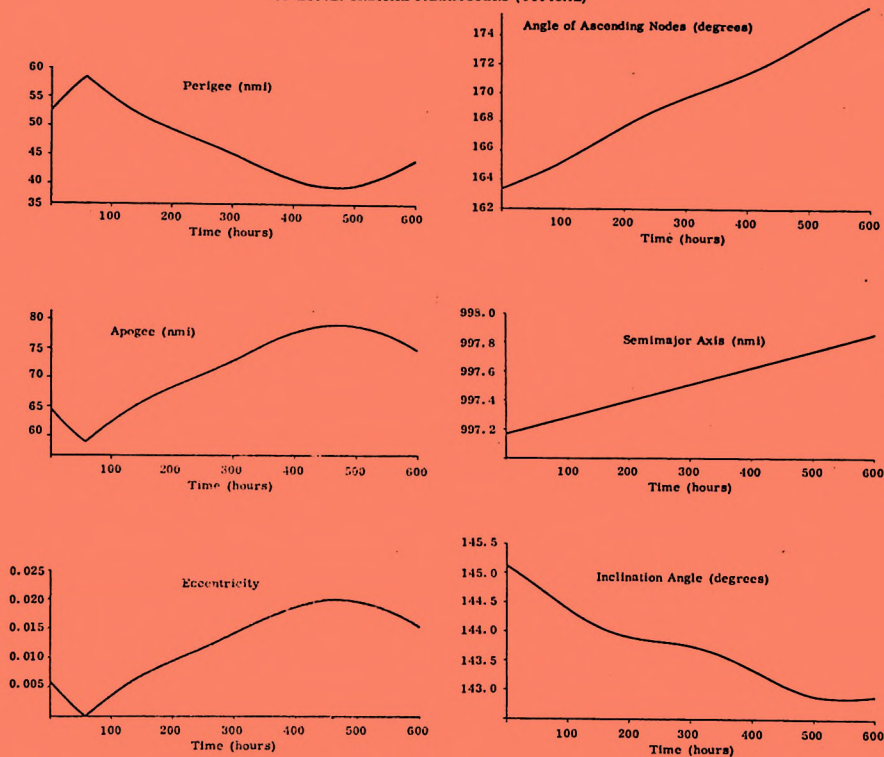
TEI

$$\begin{aligned}\Delta V_{XSC} &= -3.28 \times 10^{-2} \text{ AB}_X \Delta T_P \\ \Delta V_{YSC} &= -2.27 \times 10^{-4} \text{ NEHZ } \Delta T_G - 3.25 \times 10^{-2} \text{ AB}_Y \Delta T_P + 0.41 \times 10^{-2} \text{ AB}_Z \Delta T_P \\ \Delta V_{ZSC} &= -2.27 \times 10^{-4} \text{ NEDY } \Delta T_G - 0.41 \times 10^{-2} \text{ AB}_Y \Delta T_P - 3.25 \times 10^{-2} \text{ AB}_Z \Delta T_P\end{aligned}$$

APOLLO 12 LUNAR ORBIT PARAMETERS (TYPICAL)



EFFECT OF LUNAR DISTURBANCE ACCELERATION
ON LUNAR ORBITAL PARAMETERS (TYPICAL)



$$\begin{aligned} \Delta dM = & \frac{\mu_M}{r^3} \left\{ \sum_{i=2}^4 J_{iM} \left(\frac{r_M}{r} \right)^i [P'_{i+1} (\cos \phi) \underline{u}_r - P'_i (\cos \phi) \underline{u}_Z] \right. \\ & + 3 J_{22} \left(\frac{r_M}{r} \right)^2 \left[\frac{-5(X_M^2 - Y_M^2)}{r^2} \underline{u}_Z + \frac{2X_M}{r} \underline{i}_M - \frac{2Y_M}{r} \underline{j}_M \right] \\ & + \frac{3}{2} C_M \left(\frac{r_M}{r} \right)^3 \left[\frac{5X_M}{r} (1 - 7 \cos^2 \phi) \underline{u}_r + (5 \cos^2 \phi - 1) \underline{j}_M \right. \\ & \left. \left. + \frac{10X_M Z_M}{r^3} \underline{k}_M \right] \right\} \end{aligned}$$

where

r_M = mean lunar radius

$\underline{r} = X_M \underline{i}_M + Y_M \underline{j}_M + Z_M \underline{k}_M$ = spacecraft position vector in moon-fixed coordinates

$\cos \phi = \underline{u}_r \cdot \underline{u}_Z$

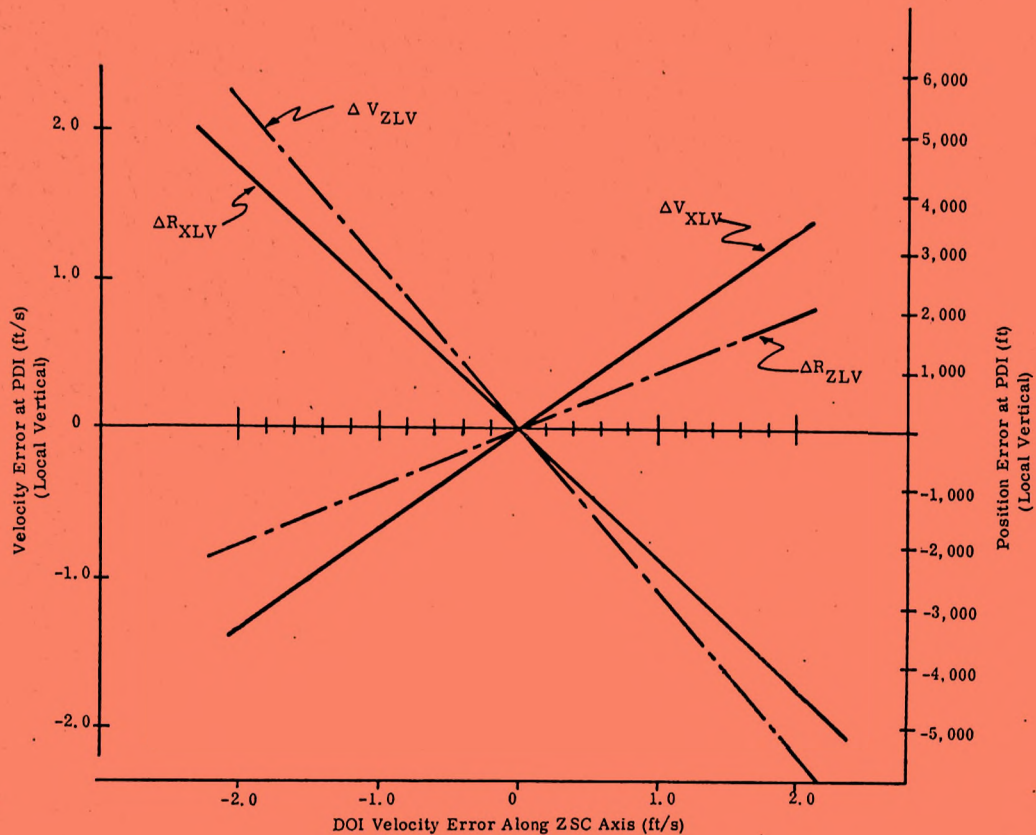
$J_{2M} = 2.07108 \times 10^{-4}$

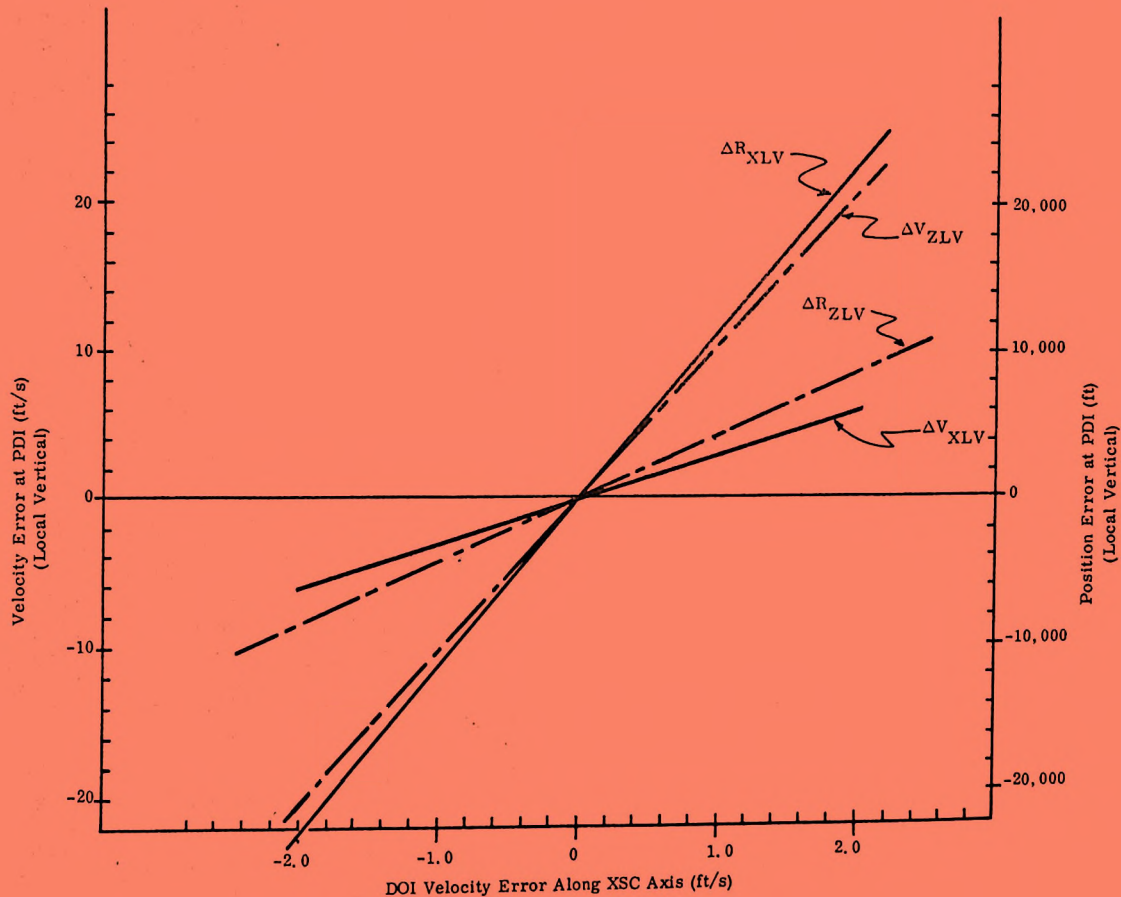
$J_{3M} = -2.1 \times 10^{-5}$

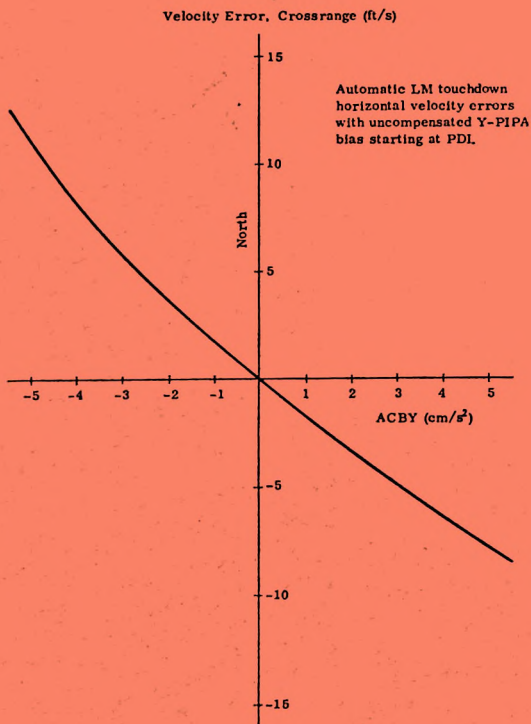
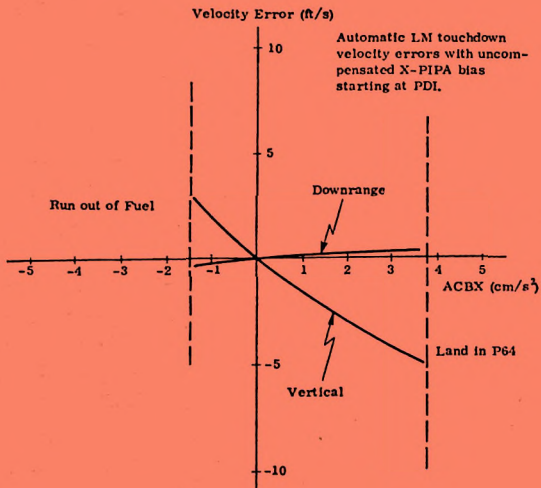
$J_{4M} = 0$

$J_{22} = 2.0716 \times 10^{-5}$

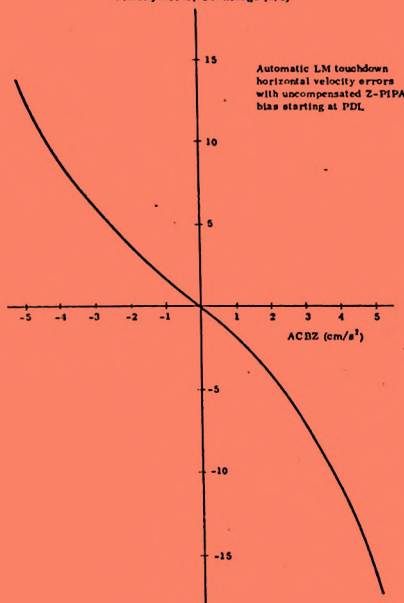
$C_M = 3.82 \times 10^{-5}$



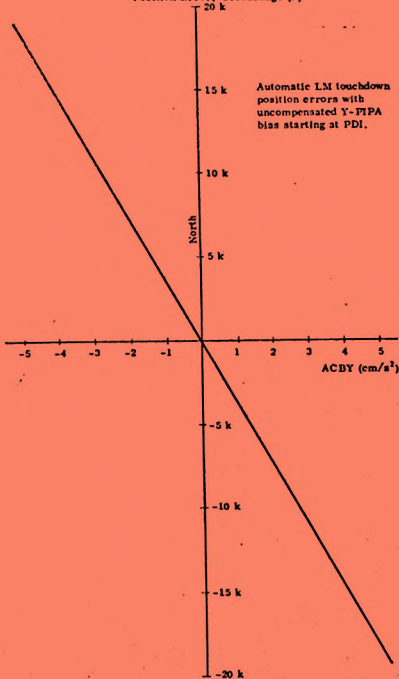


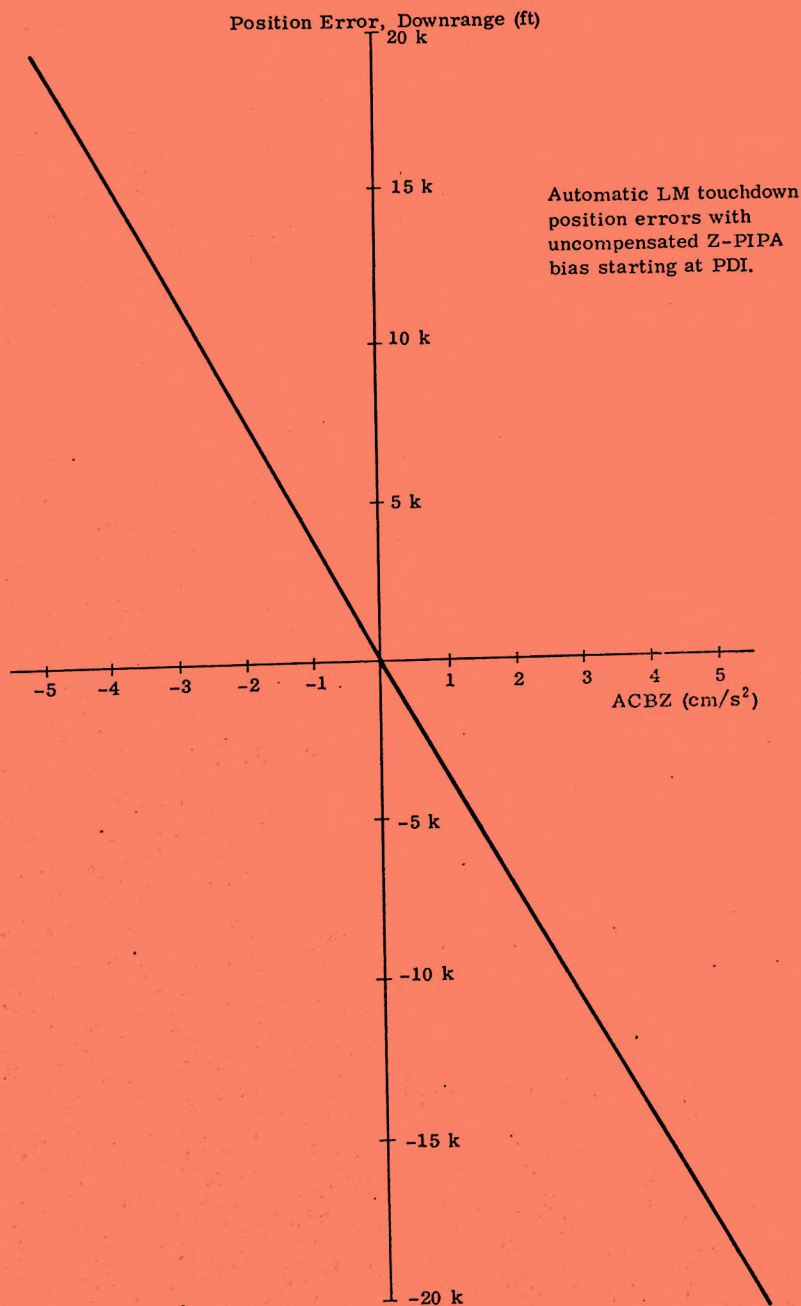


Velocity Error, Downrange (ft/s)



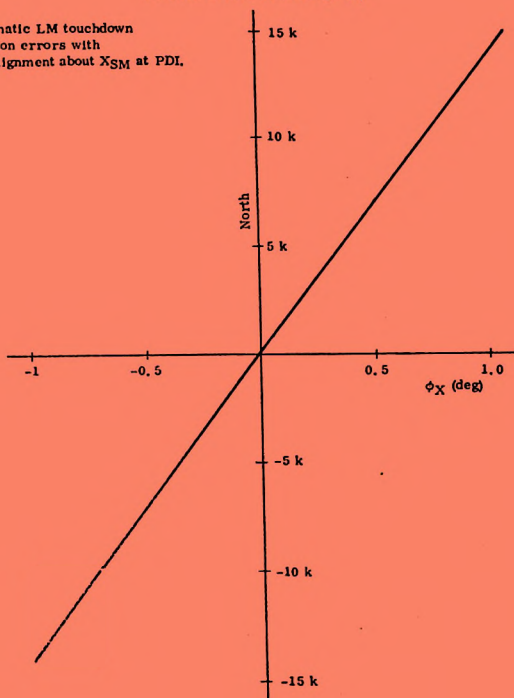
Position Error, Crossrange (ft)





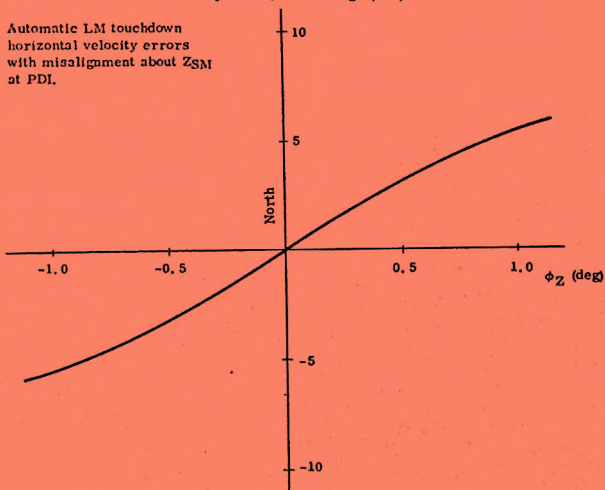
Position Error, Crossrange (ft)

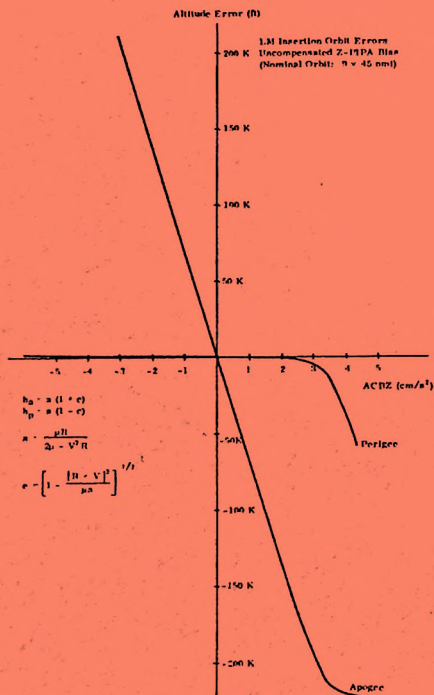
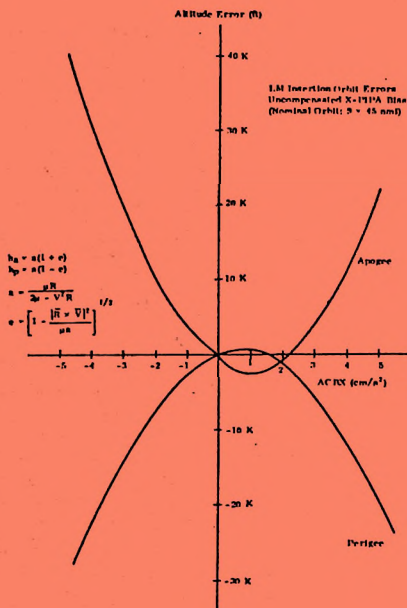
Automatic LM touchdown
position errors with
misalignment about X_{SM} at PDI.

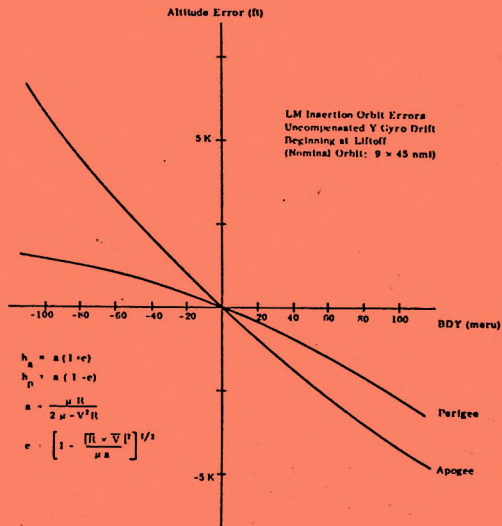
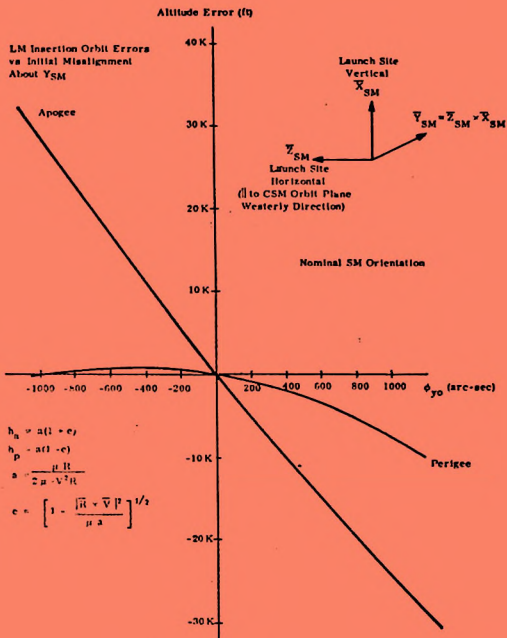


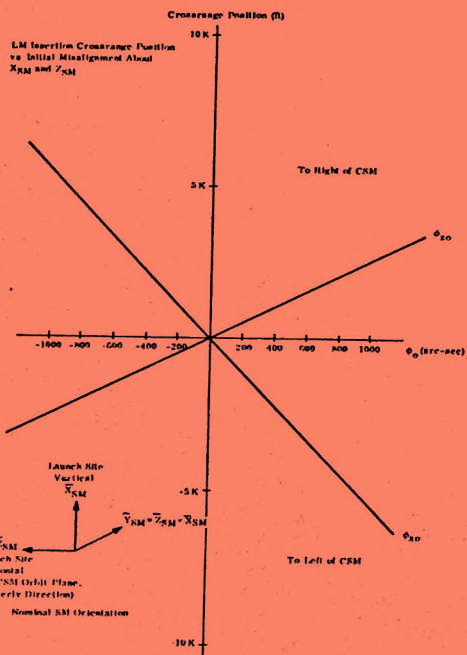
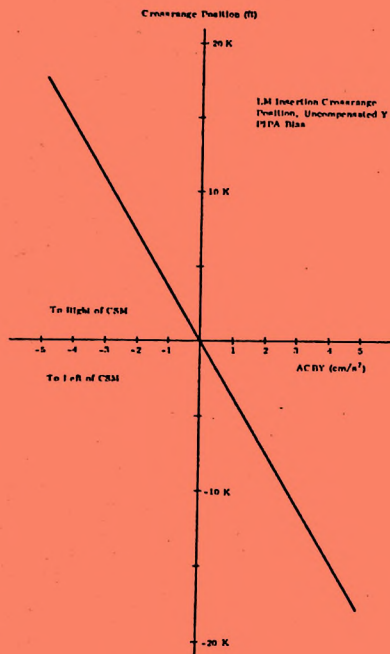
Velocity Error, Crossrange (ft/s)

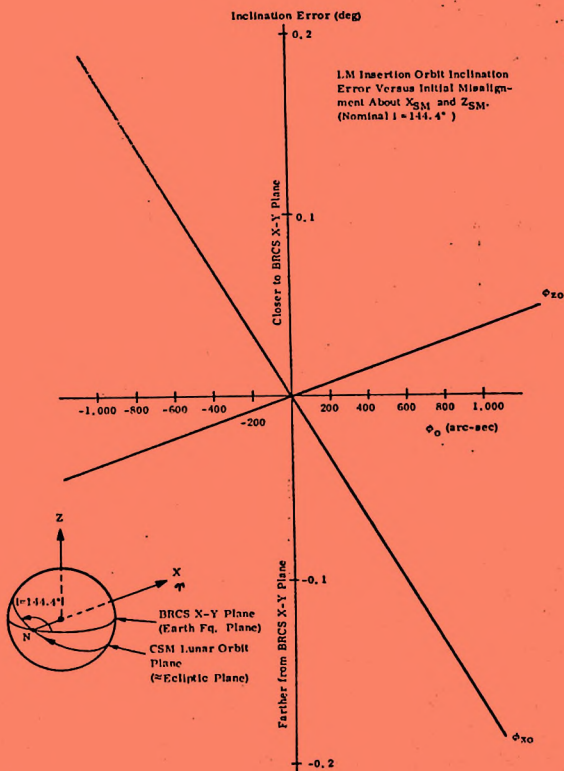
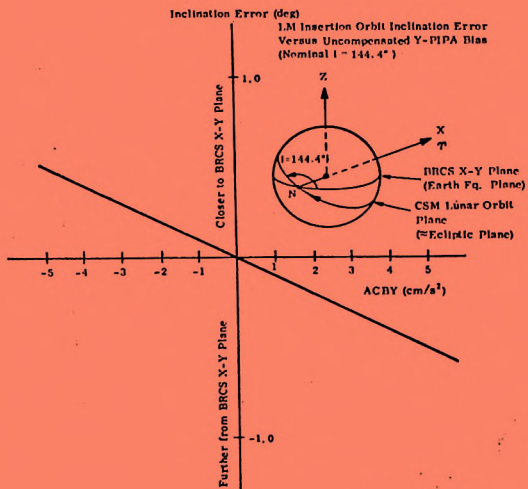
Automatic LM touchdown
horizontal velocity errors
with misalignment about Z_{SM}
at PDI.



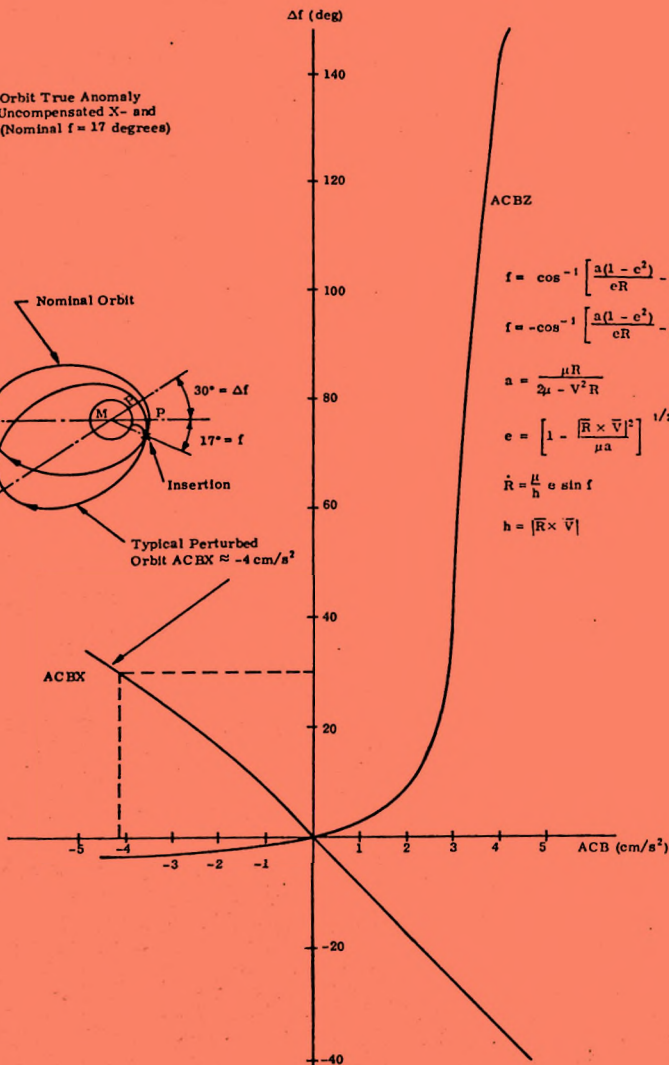
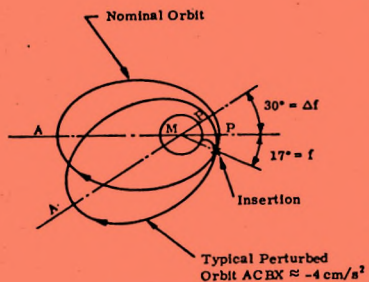








LM Insertion Orbit True Anomaly
(f) Variation, Uncompensated X- and
Z-PIPA Bias (Nominal $f = 17^\circ$ degrees)



$$f = \cos^{-1} \left[\frac{a(1-e^2)}{eR} - \frac{1}{e} \right] \quad (\dot{R} \text{ Pos})$$

$$f = -\cos^{-1} \left[\frac{a(1-e^2)}{eR} - \frac{1}{e} \right] \quad (\dot{R} \text{ Neg})$$

$$a = \frac{\mu R}{2\mu - V^2 R}$$

$$e = \left[1 - \frac{|\dot{R} \times \dot{V}|^2}{\mu a} \right]^{1/2}$$

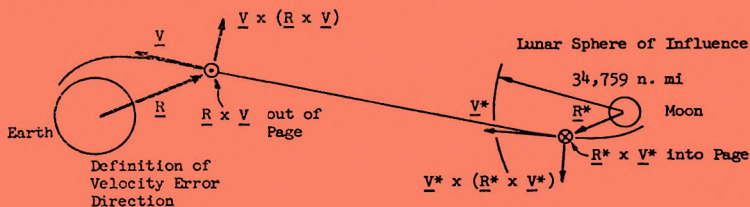
$$\dot{R} = \frac{\mu}{h} e \sin f$$

$$h = |\dot{R} \times \dot{V}|$$

ERRORS AT THE ENTRY INTERFACE (400,000 FT. ALT.)
DUE TO VELOCITY ERRORS DURING TRAISEARTH COAST

DIRECTION OF VELOCITY ERROR	ERROR IN VACUUM PERIGEE (n.mi/ft/sec)	ERROR IN TIME OF ARRIVAL (sec/ft/sec)	ERROR IN VELOCITY AT EI (ft/sec/ft/sec)	ERROR IN FLIGHT PATH ANGLE AT EI (degrees/ft/sec)
ERROR EXISTING AT TEI CUTOFF (174:27:04 GET)				
Along \underline{V}^*	-22.19	-82.15	1.02	-1.59
Along $\underline{R}^* \times \underline{V}^*$	2.6	8.6	- .10	.16
Along $\underline{V}^* \times (\underline{R}^* \times \underline{V}^*)$	- 4.86	11.45	.14	- .31
ERROR EXISTING AT MCC-5 (TEI + 15 hours) (189:27:04 GET)				
Along \underline{V}	1.84	-22.50	.15	.12
Along $\underline{R} \times \underline{V}$	.98	2.7	- .08	.06
Along $\underline{V} \times (\underline{R} \times \underline{V})$	9.9	32.25	- .34	.65
ERROR EXISTING AT MCC-6 (EI - 22 hours) (222:26:36 GET)				
Along \underline{V}	1.30	- 5.35	.24	.09
Along $\underline{R} \times \underline{V}$	.02	.05	.03	0
Along $\underline{V} \times (\underline{R} \times \underline{V})$	5.8	14.2	- .17	- .37
ERROR EXISTING AT MCC-7 (EI - 3 hours) (241:26:36 GET)				
Along \underline{V}	.51	.25	.29	.03
Along $\underline{R} \times \underline{V}$	0	0	0	0
Along $\underline{V} \times (\underline{R} \times \underline{V})$	1.46	2.55	.06	.10

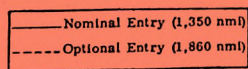
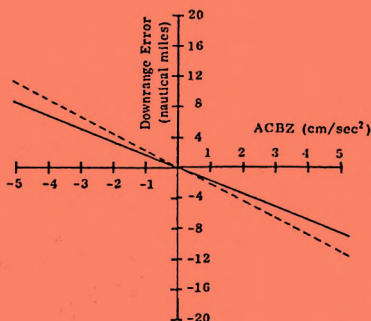
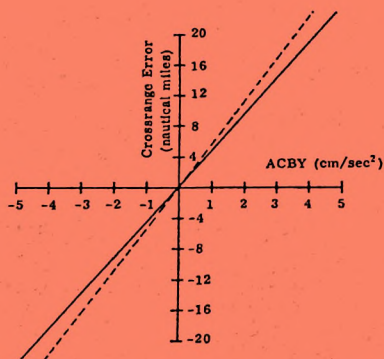
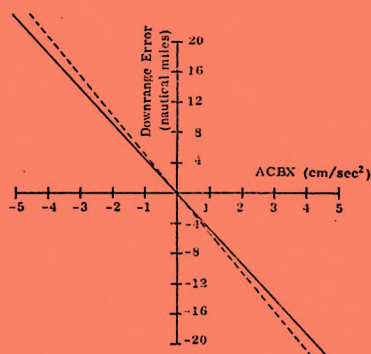
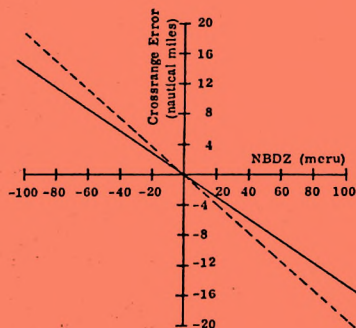
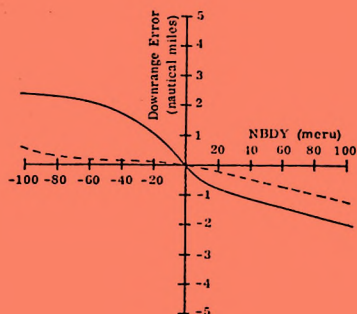
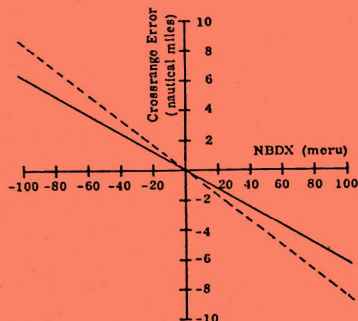
* \underline{R} and \underline{V} are with respect to moon centered inertial system



Transformation at TEI from stable member to \underline{V} , $\underline{R} \times \underline{V}$ and $\underline{V} \times (\underline{R} \times \underline{V})$.

$$\begin{bmatrix} \text{UNIT } (\underline{V}) \\ \text{UNIT } (\underline{R} \times \underline{V}) \\ \text{UNIT } (\underline{V} \times (\underline{R} \times \underline{V})) \end{bmatrix} = \begin{bmatrix} .995 & -.059 & +.073 \\ .060 & +.998 & -.003 \\ -.073 & +.007 & +.997 \end{bmatrix} \begin{bmatrix} x_{SM} \\ y_{SM} \\ z_{SM} \end{bmatrix}$$

TYPICAL LUNAR RETURN ENTRY
POSITION DEVIATIONS AT GUIDANCE TERMINATION



Notes:

1. Crossrange errors for NBDY, ACBX, and ACBZ are negligible.
2. Downrange errors for NBDX, NBDZ, and ACBY are negligible.

**TYPICAL LUNAR RETURN ENTRY POSITION ERROR SENSITIVITIES
AT GUIDANCE TERMINATION**

ERROR SOURCE (ϵ)		NOMINAL 1,350 NMI ENTRY		OPTIONAL 1,680 NMI ENTRY	
		Downrange Error (nmi/ ϵ)	Crossrange Error (nmi/ ϵ)	Downrange Error (nmi/ ϵ)	Crossrange Error (nmi/ ϵ)
GYRO BIAS DRIFT (meru)	NBDX	0.0	-0.06	0.0	-0.09
	NBDY	-0.05	0.0	-0.01	0.0
	NBDZ	0.0	-0.15	0.0	-0.19
ACCELEROMETER BIAS (cm/sec ²)	ACBX	-4.62	0.0	-5.16	0.0
	ACBY	0.0	4.74	0.0	5.50
	ACBZ	-1.66	0.0	-2.26	0.0

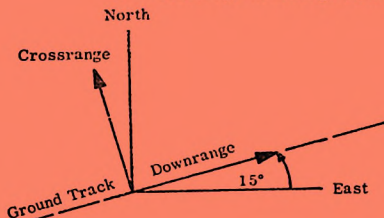
- NOTES: 1. All sensitivities above are the slopes (about the origin) of those perturbation plots presented previously.
2. Assumed accelerometer operation 15 minutes prior to EI (altitude of 400,000 feet).
3. Assumed IMU drift from 1.5 hours prior to EI.
4. Assumed IMU orientation such that at EI:

$$\bar{z}_{SM} = -\text{Unit}(\bar{R})$$

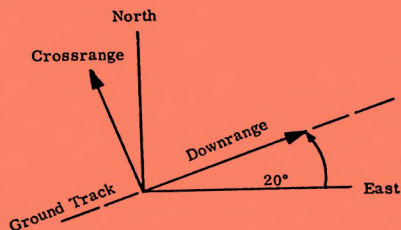
$$\bar{y}_{SM} = -\text{Unit}(\bar{R} \times \bar{V})$$

$$\bar{x}_{SM} = \bar{V}_{SM} \times \bar{z}_{SM}$$

5. Crossrange-downrange definition:



Nominal 1,350 nmi Entry



Optional 1,680 nmi Entry

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CISLUNAR NAVIGATION STAR/LANDMARK MEASUREMENT PROCESSING

The guidance computer utilizes a modified Kalman filter to incorporate the star/landmark measurement into estimates of the Spacecraft state vector. The state vector in this case is the deviation of the Spacecraft position and velocity from a reference conic.

$$\text{State Vector} = \underline{x}(t) = \begin{bmatrix} \underline{\delta r} \\ \underline{\delta v} \end{bmatrix} = \begin{bmatrix} \delta r_x \\ \delta r_y \\ \delta r_z \\ \delta v_x \\ \delta v_y \\ \delta v_z \end{bmatrix} = \begin{bmatrix} \text{Deviations from} \\ \text{conic position} \\ \text{Deviations from} \\ \text{conic velocity} \end{bmatrix}$$

Deviations from the reference conic are assumed to be Gaussian distributed with a known mean and variance. The mean is estimated via the precision integration routines or obtained from MSFN. The variance is given by the error covariance matrix, which is precomputed and entered via erasable data load.

The basic recursive procedure of Kalman Filtering is as follows.

STAR/LANDMARK MEASUREMENT PROCESSING (CONTINUED)

1. Extrapolate the state vector ahead to time t_n , using the best estimate of the state at time t_{n-1} .

$$\hat{\underline{X}}'_n = [\phi_{n-1}] \hat{\underline{X}}_{n-1}$$

2. Extrapolate the error covariance matrix in a similar manner.

$$[E'_n] = [\phi_{n-1}] [E_{n-1}] [\phi_{n-1}]^T + [U_{n-1}] \quad (U_{n-1} = \text{process noise})$$

3. Compute the optimal gain matrix.

$$[K_n^*] = [E'_n] [H_n]^T [H_n E'_n H_n^T + V_n]^{-1} \quad (V_n = \text{measurement noise})$$

4. Calculate a measurement vector for time t_n .

$$\hat{\underline{Y}}'_n = [H_n] \hat{\underline{X}}'_n$$

5. Update the estimate of the state vector, using the extrapolated state $\hat{\underline{X}}'_n$, the optimal gain $[K_n^*]$, the extrapolated measurement $\hat{\underline{Y}}'_n$, and the actual measurement at time t_n , \underline{Y}_n .

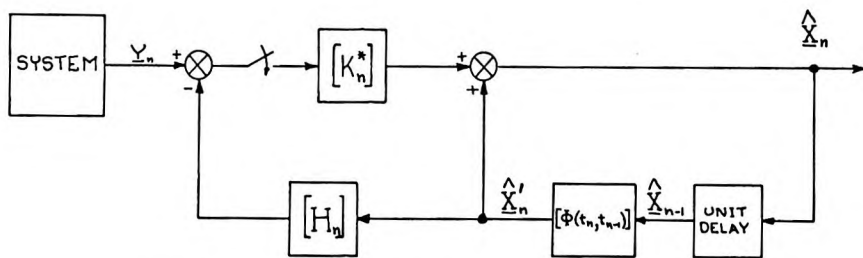
$$\hat{\underline{X}}_n = \hat{\underline{X}}'_n + [K_n^*] (\underline{Y}_n - \hat{\underline{Y}}'_n)$$

6. Update the error covariance matrix in a similar manner.

$$[E_n] = [E'_n] - [K_n^*] [H_n] [E'_n]$$

The following diagram illustrates this procedure.

BASIC RECURSIVE PROCEDURE OF KALMAN FILTERING



EXTRAPOLATE THE STATE VECTOR AND ERROR COVARIANCE MATRIX.

$$\hat{\underline{x}}'_n = [\Phi(t_n, t_{n-1})] \hat{\underline{x}}_{n-1}$$

$$[E'_n] = [\Phi(t_n, t_{n-1})][E_{n-1}][\Phi(t_n, t_{n-1})]^T + [U_{n-1}]$$

UPDATE THE STATE VECTOR AND ERROR COVARIANCE MATRIX.

$$\hat{\underline{x}}_n = \hat{\underline{x}}'_n + [K_n^*](Y_n - [H_n]\hat{\underline{x}}'_n)$$

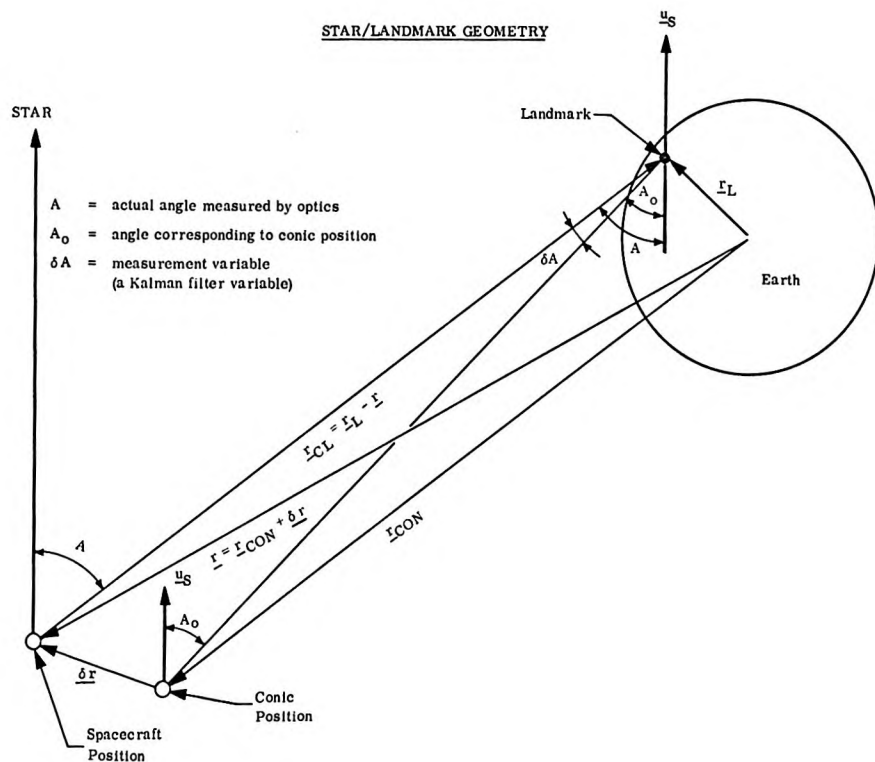
$$[E_n] = [E'_n] - [K_n^*][H_n][E'_n]$$

CORRELATION BETWEEN KALMAN FILTER TERMINOLOGY AND CELESTIAL
NAVIGATION TERMINOLOGY

THIS TABLE AND THE FOLLOWING FIGURE SHOW THE DIFFERENCE BETWEEN CLASSIC
KALMAN FILTERING TERMINOLOGY AND THE ACTUAL APOLLO NAVIGATION PROCEDURE.

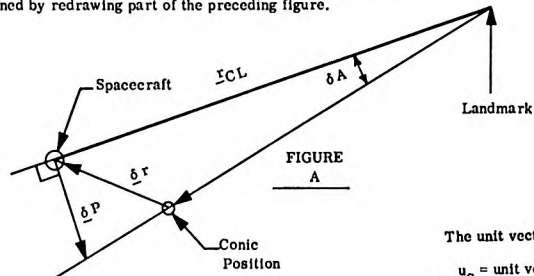
Celestial Navigation Terminology	Kalman Filter Terminology	Correlation
\underline{b} = geometry vector of dimension "D"	$[H]$ = measurement matrix	$\underline{b}^T \Rightarrow [R]$
ω = weighting vector of dimension "D"	$[K_n^*]$ = optimal gain matrix	$\omega \Rightarrow [K_n]$
$[W]$ = error transition matrix of dimension "D x D"	$[E]$ = error covariance matrix	$[E] \Rightarrow [W W^T]$
\underline{x} = state vector	\underline{x} = state vector	$\underline{x} \Rightarrow \underline{x}$
$\bar{\alpha}^2$ = a priori measurement error variance (scalar)	$[V]$ = covariance of the measurement noise	$\bar{\alpha}^2 \Rightarrow [V]$
SQ = measurement deviation (scalar)	$(\hat{y}_n' - \underline{y}_n)$ = measurement residual	$SQ \Rightarrow (\hat{y}_n' - \underline{y}_n)$

STAR/LANDMARK GEOMETRY



STAR/LANDMARK GEOMETRY (cont.)

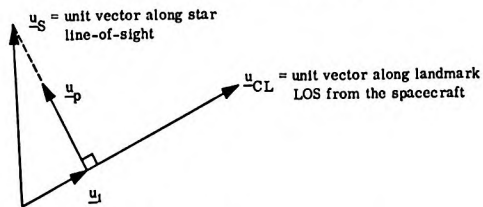
The relationship between the state vector and measurement variable can be determined by redrawing part of the preceding figure.



$$\delta A = \frac{|\delta \underline{p}|}{|\underline{r}_{CL}|} = \frac{\underline{u}_p^T \delta \underline{r}}{|\underline{r}_{CL}|} = \frac{\underline{u}_p^T}{|\underline{r}_{CL}|} \delta \underline{r} \quad \delta \underline{r} = \underline{b}^T \delta \underline{x}$$

where \underline{u}_p is a unit vector perpendicular to \underline{r}_{CL}

The unit vector, \underline{u}_p , can be determined from Figure A



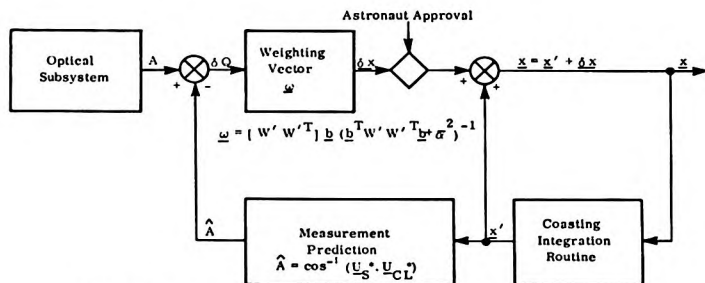
$$\underline{u}_p = \text{Unit} (\underline{u}_S - \underline{u}_1)$$

$$\underline{u}_1 = \text{Component of } \underline{u}_S \text{ along } \underline{u}_{CL} = (\underline{u}_S \cdot \underline{u}_{CL}) \underline{u}_{CL}$$

$$\underline{u}_p = \text{Unit} (\underline{u}_S - (\underline{u}_S \cdot \underline{u}_{CL}) \underline{u}_{CL})$$

$$\therefore \underline{b} = \frac{1}{|\underline{r}_{CL}|} \begin{bmatrix} \text{Unit} (\underline{u}_S - (\underline{u}_S \cdot \underline{u}_{CL}) \underline{u}_{CL}) \\ 0 \end{bmatrix}$$

CISLUNAR NAVIGATION (P23) — INFORMATION PROCESSING



EXTRAPOLATE THE STATE VECTOR AND ERROR TRANSITION MATRIX:

Extrapolation is accomplished via the Coasting Integration routine.

UPDATE THE STATE VECTOR AND ERROR TRANSITION MATRIX:

$$\underline{x} = \underline{x}' + \Delta \underline{x} = \underline{x}' + \underline{w} \delta Q$$

$$[W] = [W'] - \frac{\underline{w} \underline{Z}^T}{1 + \frac{\underline{Z}^T \underline{Z}}{\alpha^2}}$$

ORBITAL NAVIGATION — STATE VECTOR DEFINITION

FOR LANDMARK TRACKING THE STATE VECTOR IS DEFINED AS FOLLOWS.

$$\underline{X} = \begin{bmatrix} \underline{r}_c \\ \underline{v}_c \\ \underline{r}_L \end{bmatrix} = \begin{bmatrix} \text{POSITION OF SPACECRAFT} \\ \text{VELOCITY OF SPACECRAFT} \\ \text{INERTIAL POSITION OF LANDMARK} \end{bmatrix}$$

WHERE:

\underline{r}_c = SPACECRAFT POSITION VECTOR

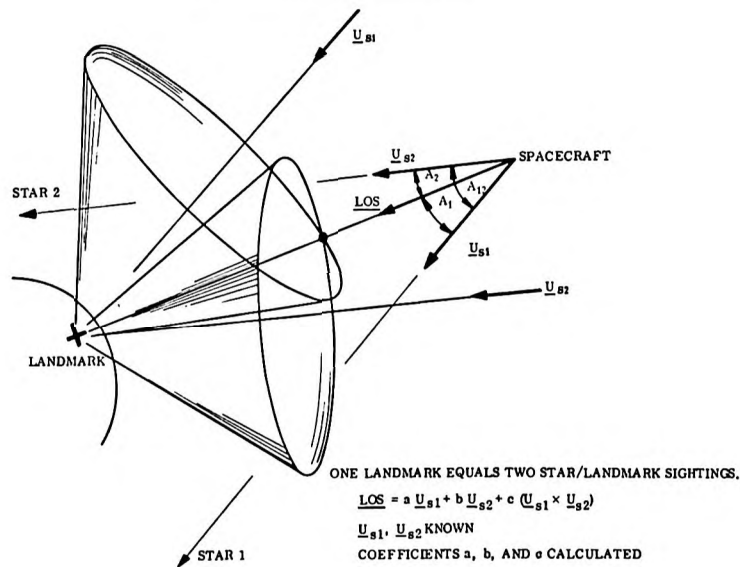
$$= \underline{r}_{con} + \underline{\delta r}$$

\underline{v}_c = SPACECRAFT VELOCITY VECTOR

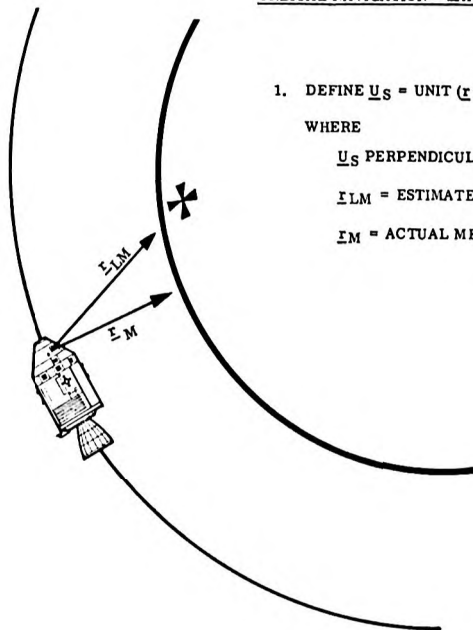
$$= \underline{v}_{con} + \underline{\delta v}$$

\underline{r}_L = LANDMARK POSITION VECTOR

ORBITAL NAVIGATION - LANDMARK TRACK



ORBITAL NAVIGATION — LANDMARK TRACK



1. DEFINE $\underline{u}_S = \text{UNIT}(\underline{\hat{e}}_{LM} \times \underline{\hat{e}}_M)$

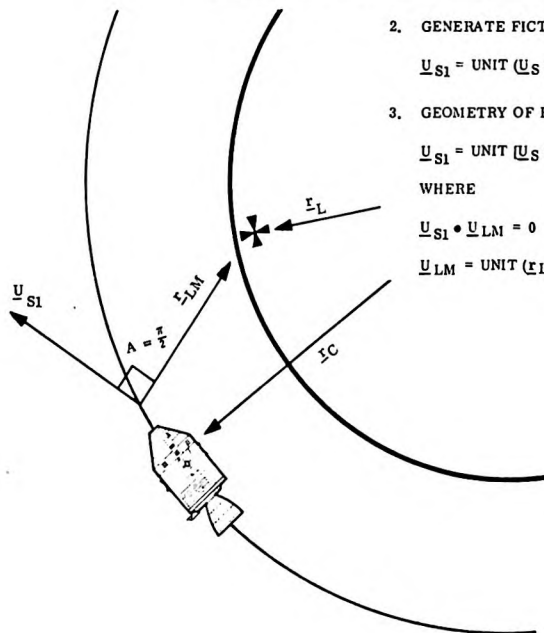
WHERE

\underline{u}_S PERPENDICULAR TO MEASUREMENT PLANE

$\underline{\hat{e}}_{LM}$ = ESTIMATED LOS FROM SPACECRAFT TO LANDMARK

$\underline{\hat{e}}_M$ = ACTUAL MEASURED LOS FROM SPACECRAFT TO LANDMARK

ORBITAL NAVIGATION — LANDMARK TRACK (CONTINUED)



2. GENERATE FICTITIOUS STAR

$$\underline{u}_{S1} = \text{UNIT} (\underline{u}_S \times \underline{i}_{LM}) \begin{cases} \underline{u}_{S1} \text{ PERPENDICULAR TO } \underline{i}_{LM} \\ \underline{u}_{S1} \text{ IN MEASUREMENT PLANE} \end{cases}$$

3. GEOMETRY OF FICTITIOUS STAR AND STATE VECTOR

$$\underline{u}_{S1} = \text{UNIT} [\underline{u}_S \times (\underline{i}_L - \underline{i}_C)]$$

WHERE

$$\underline{u}_{S1} \cdot \underline{u}_{LM} = 0$$

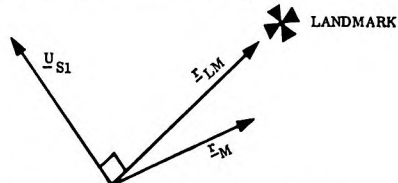
$$\underline{u}_{LM} = \text{UNIT} (\underline{i}_{LM})$$

ORBITAL NAVIGATION — LANDMARK TRACK (CONTINUED)

4. IN TERMS OF STATE VECTOR

$$\underline{U}_{S1} \cdot \underline{U}_{LM} = 0 = \frac{1}{|\underline{r}_{LM}|} \begin{bmatrix} -\underline{U}_{S1} \\ 0 \\ +\underline{U}_{S1} \end{bmatrix} \cdot \begin{bmatrix} \underline{r}_C \\ \underline{v}_C \\ \underline{r}_L \end{bmatrix}$$

5. CONSIDERING ACTUAL MEASUREMENT \underline{r}_M



6. MEASUREMENT RESIDUAL IN TERMS OF STATE VECTOR

$$\underline{U}_{S1M} = \text{UNIT}(\underline{U}_S \times \underline{r}_M)$$

$$\delta Q = 0 - \frac{1}{|\underline{r}_M|} \begin{bmatrix} -\underline{U}_{S1M} \\ 0 \\ \underline{U}_{S1M} \end{bmatrix} \cdot \begin{bmatrix} \underline{r}_C \\ \underline{v}_C \\ \underline{r}_L \end{bmatrix} \quad \text{A SCALAR DEVIATION FROM ZERO.}$$

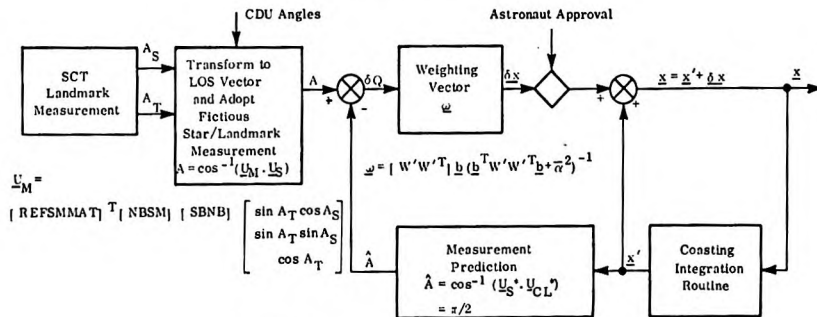
UPDATE STATE

$$\underline{X} = \underline{X}' + \omega \delta Q$$

\underline{X}' = EXTRAPOLATED ESTIMATE OF STATE

ω = OPTIMAL WEIGHT FACTOR

ORBITAL NAVIGATION (P22) - INFORMATION PROCESSING



EXTRAPOLATE THE STATE VECTOR AND ERROR TRANSITION MATRIX.

Extrapolation is accomplished via the Coasting Integration routine.

UPDATE THE STATE VECTOR AND ERROR TRANSITION MATRIX.

$$\begin{aligned} \hat{x} &= \hat{x}' + \delta x = \hat{x}' + \omega \delta Q \\ [W] &= [W'] - \frac{\omega^2 T}{1 + \frac{\sigma^2}{2z^2 + \sigma^2}} \end{aligned}$$

RENDEZVOUS NAVIGATION PROGRAM (CSM)

P-20

MEASUREMENT VARIANCE

OPTICAL TRACKING

$$\begin{aligned}\bar{\sigma}^2 &= \text{Var}_{\text{SXT}} + \text{Var}_{\text{IMU}} + \frac{\text{Var}_{\text{INT}}^*}{r_{\text{CL}}^2} \\ &= (0.2 \text{ mr})^2 + (0.2 \text{ mr})^2 + \frac{(14 \text{ m})^2}{r_{\text{CL}}^2}\end{aligned}$$

VHF RANGING

$$\begin{aligned}\bar{\sigma}^2 &= \text{Max} \left\{ \text{Var}_{\text{R}}^*, \frac{\text{Var}_{\text{R min}}^*}{r_{\text{CL}}^2} \right\} \\ &= \text{Max} \left\{ 0.0\%, \frac{-83.6127 \text{ m}^2}{r_{\text{CL}}^2} \right\}\end{aligned}$$

ALTERNATE LOS

$$\begin{aligned}\bar{\sigma}^2 &= \text{Var}_{\text{ALT}}^* + \text{Var}_{\text{IMU}} \\ &= 12 \text{ mr}^2 + (0.2 \text{ mr})^2\end{aligned}$$

INITIAL "W" MATRIX

$$[W] = \begin{bmatrix} w_{\text{rr}}^{\text{I}} & 0 \\ \vdots & \vdots \\ 0 & w_{\text{rv}}^{\text{I}} \end{bmatrix}$$

$$w_{\text{rr}}^* = 3,048 \text{ m} = 10^4 \text{ ft/s}$$

$$w_{\text{rv}}^* = 3,048 \text{ m/s} = 10 \text{ ft/s}$$

*These values are stored in erasable memory.

RENDEZVOUS NAVIGATION PROGRAM (LEM)
P-20

MEASUREMENT VARIANCE

RANGE MEASUREMENT

$$\bar{\sigma}^2 = \text{Max} \left\{ \text{Var}_R^*, \frac{\text{Var}_{R\min}^*}{r_{CL}^2} \right\} = \text{Max} \left\{ 0.11111 \times 10^{-4}, \frac{66 \text{ m}^2}{r_{CL}^2} \right\}$$

RANGE RATE MEASUREMENT

$$\bar{\sigma}^2 = \text{Max} \left\{ \dot{r}^2 \text{Var}_V^*, \text{Var}_{V\min}^* \right\} = \text{Max} \left\{ \dot{r}^2 1.8777 \times 10^{-5}, 0.017445 \text{ m}^2/\text{s}^2 \right\}$$

SHAFT ANGLE MEASUREMENT

$$\bar{\sigma}^2 = \text{Var}_\beta^* + \text{Var}_{IMU} = (1 \text{ mr})^2 + (0.2 \text{ mr})^2$$

TRUNNION ANGLE MEASUREMENT

$$\bar{\sigma}^2 = \text{Var}_\theta^* + \text{Var}_{IMU} = (1 \text{ mr})^2 + (0.2 \text{ mr})^2$$

INITIAL "W" MATRICES

FOR RENDEZVOUS

$$[W] = \begin{bmatrix} w_{rr}^* & 0 & 0 \\ 0 & w_{rv}^* & 0 \\ \hline 0 & 0 & w_\beta^* \\ 0 & 0 & w_\theta^* \end{bmatrix}$$

$$w_{rr}^* = 3,048 \text{ m} = 10^4 \text{ ft}$$

$$w_{rv}^* = 3,048 \text{ m/s} = 10 \text{ ft/s}$$

$$w_\beta^* = 15 \text{ mrad}$$

$$w_\theta^* = 15 \text{ mrad}$$

FOR LUNAR SURFACE NAVIGATION

$$[W] = \begin{bmatrix} w_{Lr}^* & 0 \\ 0 & w_{Lv}^* \end{bmatrix}$$

$$w_{Lr}^* = 1,524 \text{ m} = 5,000 \text{ ft}$$

$$w_{Lv}^* = 1,524 \text{ m/s} = 5 \text{ ft/s}$$

*These values are stored in erasable memory.

ORBITAL NAVIGATION ROUTINE
P-22

MEASUREMENT VARIANCE

$$\begin{aligned}\bar{\sigma}^2 &= \text{Var}_{\text{SCT}} + \text{Var}_{\text{IMU}} \\ &= (1 \text{ mr})^2 + (0.2 \text{ mr})^2\end{aligned}$$

INITIAL "W" MATRIX

$$[W] = \begin{bmatrix} w_{lr}^I & 0 & 0 \\ 0 & w_{lv}^I & 0 \\ 0 & 0 & w_l^I \end{bmatrix}$$

$$w_{lr}^* = 0.0$$

$$w_{lv}^* = 0.0$$

$$w_l^* = 10,000 \text{ meters}$$

*These values are stored in erasable memory.

CISLUNAR MIDCOURSE NAVIGATION ROUTINE
P-23

MEASUREMENT VARIANCE

$$\begin{aligned}\bar{\sigma}^2 &= \text{Var}_{\text{Trun}} + \text{Var}_L / r_{CL}^2 \\ &= (0.05 \text{ mr})^2 + \frac{1 \text{ nm}^2}{r_{CL}^2}\end{aligned}$$

INITIAL "W" MATRIX

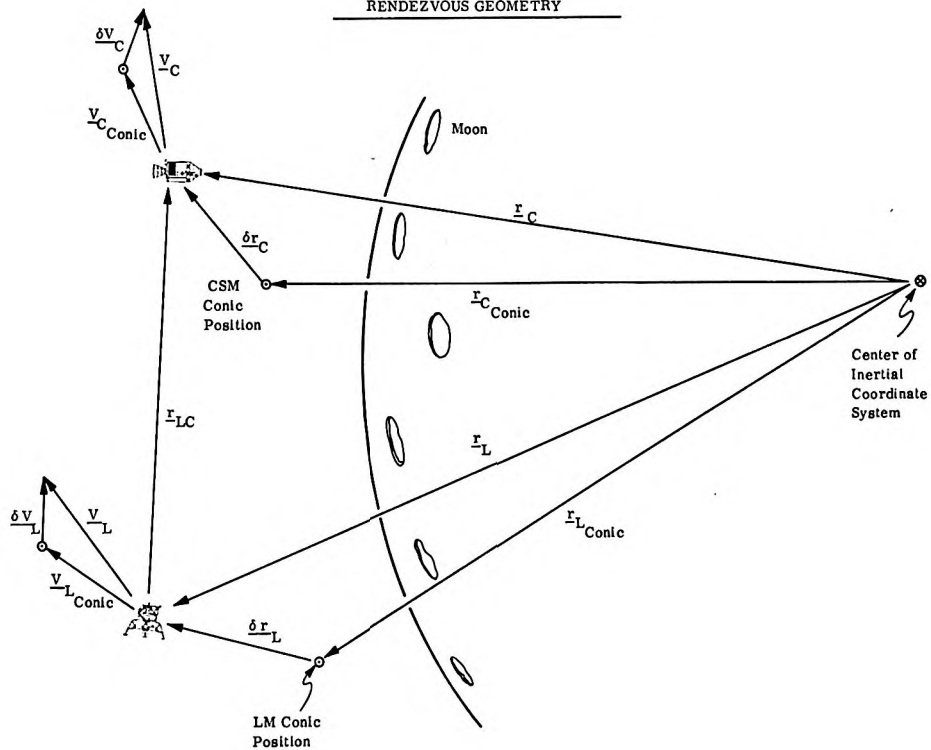
$$[W] = \begin{bmatrix} w_{mr}^I & 0 \\ 0 & w_{mv}^I \end{bmatrix}$$

$$w_{mr}^* = 1,005.84 \text{ m} = 3,300 \text{ ft}$$

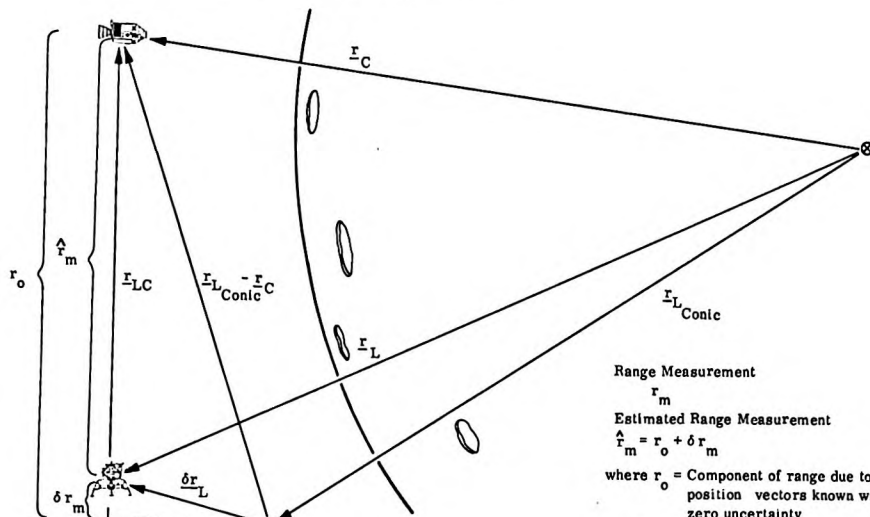
$$w_{mv}^* = 1.00584 \text{ m/s} = 3.3 \text{ ft/s}$$

*These values are stored in erasable memory.

RENDEZVOUS GEOMETRY



RENDEZVOUS RANGE (r_m) MEASUREMENT



Range Measurement

r_m

Estimated Range Measurement

$$\hat{r}_m = r_o + \delta r_m$$

where r_o = Component of range due to position vectors known with zero uncertainty

δr_m = Kalman filter measurement variable
 $= \underline{b}^T \underline{x}$

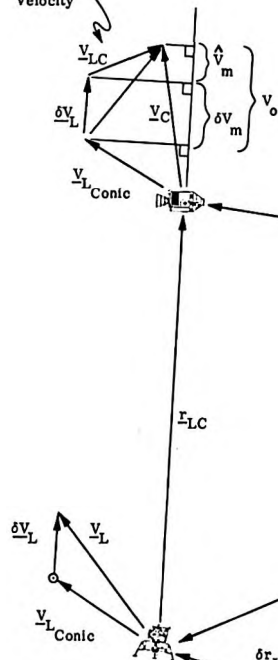
$$\begin{aligned}\hat{r}_m &= \underline{u}_{LC} \cdot \underline{r}_{LC} = \underline{u}_{LC} \cdot (\underline{r}_C - \underline{r}_{L_{Conic}} - \underline{\delta r}_L) \\ &= \underline{u}_{LC} \cdot (\underline{r}_C - \underline{r}_{L_{Conic}}) - \underline{u}_{LC} \cdot \underline{\delta r}_L \\ &= r_o - \underline{u}_{LC} \cdot \underline{\delta r}_L \\ \delta r_m &= -\underline{u}_{LC} \cdot \underline{\delta r}_L = \underline{b}^T \underline{x}\end{aligned}$$

$$\underline{b} = \begin{bmatrix} -\underline{u}_{LC} \\ 0 \\ 0 \end{bmatrix} \underline{x} = \begin{bmatrix} \underline{\delta r}_L \\ \underline{\delta V}_L \\ \underline{\delta \beta} \\ 0 \end{bmatrix}$$

RENDEZVOUS RANGE RATE (\dot{V}_m) MEASUREMENT

Rendezvous range rate measurement has a term due to deviation from conic velocity ($\delta \underline{V}_L$) and a term due to deviation from conic position ($\delta \underline{r}_L$). The term due to velocity deviation ($\delta \underline{V}_L$) is:

LM/CSM Relative Velocity



$$\hat{\underline{V}}_m = \underline{V}_{LC} \cdot \underline{u}_{LC}$$

$$= \underline{u}_{LC} \cdot (\underline{V}_C - \underline{V}_{LC_{Conic}} - \frac{\delta \underline{V}_L}{\underline{r}_L}) = \underline{u}_{LC} \cdot (\underline{V}_C - \underline{V}_{LC_{Conic}}) - \underline{u}_{LC} \cdot \frac{\delta \underline{V}_L}{\underline{r}_L}$$

$$\hat{\underline{V}}_m = \underline{V}_o + \delta \underline{V}_m$$

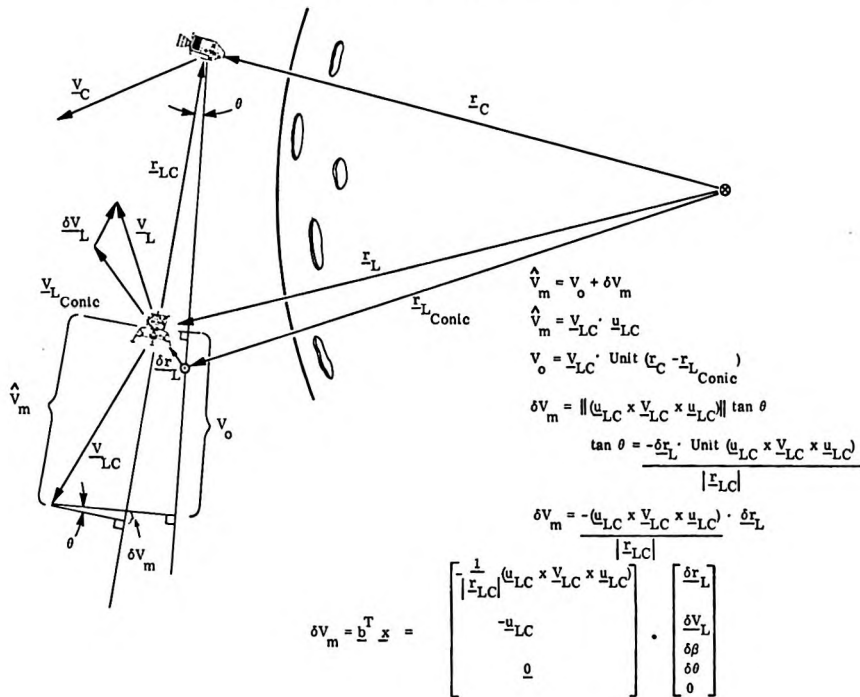
where \underline{V}_o = component of range rate due to Vectors known with zero uncertainty

$$= \underline{u}_{LC} \cdot (\underline{V}_C - \underline{V}_{LC_{Conic}})$$

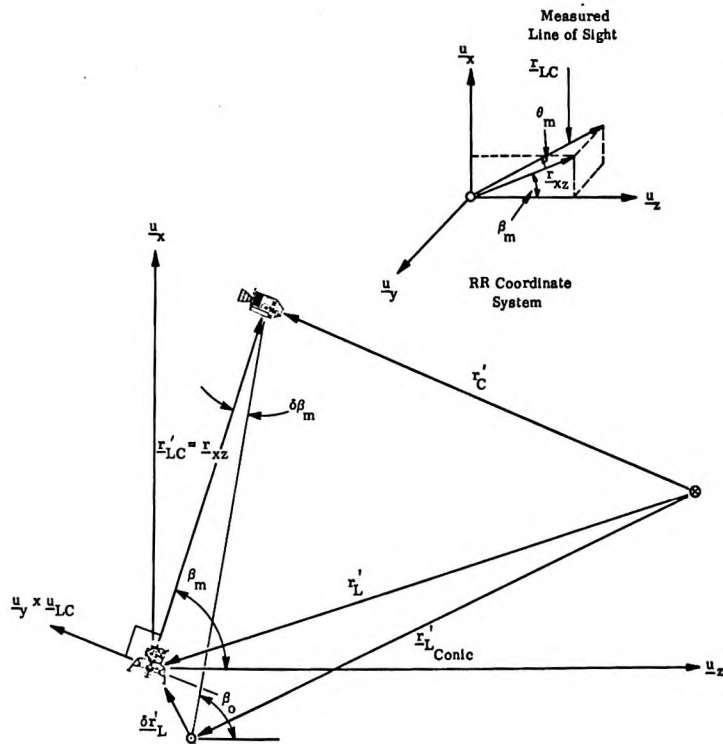
$\delta \underline{V}_m$ = Kalman filter measurement variable

$$= -\underline{u}_{LC} \cdot \frac{\delta \underline{V}_L}{\underline{r}_L}$$

RENDEZVOUS RANGE RATE (\dot{V}_m) MEASUREMENT continued



RENDEZVOUS RADAR SHAFT ANGLE (β_m) MEASUREMENTS



The Rendezvous Radar shaft angle is defined in the radar X-Z coordinate plane. The effect of LM and CSM position vectors on the shaft angle can be determined by looking at the projection of these vectors on the x-z plane:

$$\beta_m = \beta_o + \delta\beta_m$$

where β_m = estimate of RR shaft angle due to r_{LC}

β_o = portion of RR shaft angle due to r_{LC} and r_{LConic}

$$\delta\beta_m = \frac{1}{r_{xz}} \left[\text{Unit} (u_y \times u_{LC}) \cdot \frac{\delta r_L}{r_L} \right]$$

The actual measured shaft angle has two components a nominal one due to spacecraft position and an additional deviation term ($\delta\beta$) which is an element of the state vector.

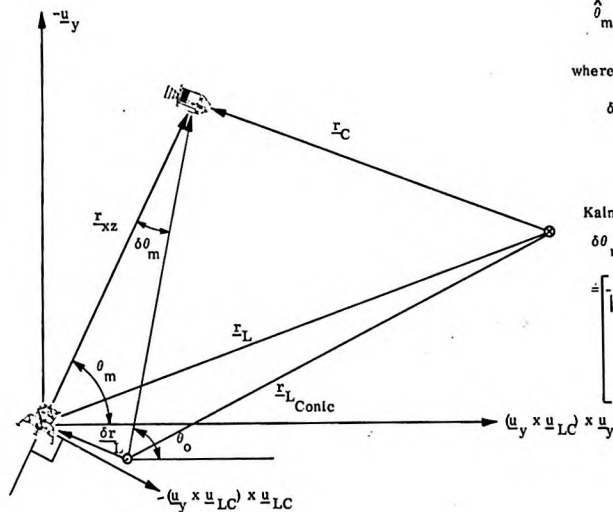
$$\hat{\beta}_m = \beta_m + \delta\beta = \beta_o + \delta\beta_m + \delta\beta$$

The Kalman filter measurement variable, $= \delta\beta_m + \delta\beta_o = \underline{b}^T \underline{x}$

$$= \begin{bmatrix} \frac{1}{r_{xz}} \left[\text{Unit} (u_y \times u_{LC}) \right] \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \frac{\delta r_L}{r_L} \\ \frac{\delta v_L}{r_L} \\ \delta\beta \\ \delta\theta \\ 0 \end{bmatrix}$$

RENDEZVOUS RADAR TRUNNION ANGLE (θ) MEASUREMENTS

The rendezvous radar trunnion angle is defined in the \underline{u}_{LC} , \underline{u}_y plane and can be illustrated by projecting the spacecraft position vectors onto this plane. Like the shaft angle it is divided into two components, a nominal one due to spacecraft positions and a deviation term ($\delta\theta$) which is an element of the state vector.



$$\begin{aligned}\hat{\theta}_m &= \theta_m + \delta\theta \\ &= \theta_o + \delta\theta_m + \delta\theta\end{aligned}$$

where θ_o = component of θ_m due to $\underline{r}_C - \underline{r}_{LConic}$

$\delta\theta_m$ = component of θ_m due to $\delta\underline{r}_L$

$$= \delta\underline{r}_L \cdot \frac{1}{|\underline{r}_{xz}|} \text{Unit}[(\underline{u}_y \times \underline{u}_{LC}) \times \underline{u}_{LC}]$$

Kalman filter measurement variable =

$$\delta\theta_m + \delta\theta = \underline{h}^T \underline{x}$$

$$= \begin{bmatrix} \frac{1}{|\underline{r}_{xz}|} \text{Unit}[(\underline{u}_y \times \underline{u}_{LC}) \times \underline{u}_{LC}] \\ 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} \cdot \begin{bmatrix} \delta\underline{r}_L \\ \delta\underline{v}_L \\ \delta\beta \\ \delta\theta \\ 0 \end{bmatrix}$$

A. ORBITAL RELATIONSHIPS

Assuming a spherical planet, the equation of motion for a satellite is given by

$$\frac{d^2 \vec{r}}{dt^2} = - \frac{\mu}{r^3} \vec{r} \quad (1)$$

where

$$\mu = (M_{\text{Planet}} + M_{\text{Satellite}}) G$$

G = gravitational constant

The solution of Equation 1 is:

$$r = \frac{h^2/\mu}{1 + e \cos f} \quad (2)$$

where

h = angular momentum of the satellite

e = eccentricity of the orbit

f = true anomaly

which is the polar equation of a conic. The conic will be an ellipse, a parabola, or a hyperbola. Treating the parabola as a special case of the ellipse and considering only the hyperbola and ellipse, the following relationships are obtained:

Angular Momentum	$\vec{h} = \vec{r} \times \vec{v} = r^2 \dot{f} = \text{constant}$
Velocity	$v^2 = \mu (2/r - 1/a)$
Apogee	$r_a = a (1 + e)$
Semilatus Rectum	$p = h^2/\mu$
Semimajor Axis	$a = r\mu / (2\mu - rv^2)$ Negative for hyperbola
Eccentricity	$e = (1 - h^2/\mu a)^{1/2}$
Perigee	$r_p = a (1 - e)$
True Anomaly	$\cos f = \frac{p}{re} - \frac{1}{e}, \sin f = \frac{h}{\mu re} \vec{r} \cdot \vec{v}$

Ellipse Only

Period	$P = 2\pi (a^3/\mu)^{1/2}$
Mean Motion	$n = \mu^{1/2}/a^{3/2}$
Mean Anomaly	$M = n(t - \tau)$
	$\tau = \text{time of perigee passage}$
Eccentric Anomaly	$E - e \sin E = M \text{ (Kepler's Equation)}$
	$\tan(E/2) = [(1 - e)/(1 + e)]^{1/2} \tan(f/2)$

Hyperbola Only

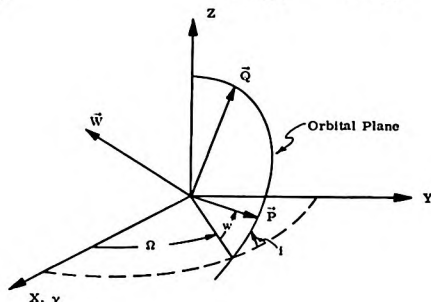
Mean Motion	$\gamma^2 = \mu/a^3$
Mean Anomaly	$M = \gamma(t - \tau)$
	$\tau = \text{time of perigee passage}$
Eccentric Anomaly	$H - e \sinh H = M$
	$\tanh(H/2) = [(e - 1)/(e + 1)]^{1/2} \tan(f/2)$

From these relationships, given an initial position and velocity vector, the orbit and orbit parameters are uniquely determined.

B. THE ORBIT IN SPACE

The orbit in space is defined by an orthogonal set of axes along perigee, the semilatus rectum, and the angular momentum vector. The ordered set of right hand rotations (Euler angles) to achieve this orientation from the earth-centered-inertial (ECI) frame are illustrated in Figure 1 and given by the expression

$$\begin{bmatrix} P \\ Q \\ W \end{bmatrix}_{\text{Orbit}} = [R_Z(w)] [R_X(i)] [R_Z(\Omega)] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} = [A] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} \quad (3)$$



where

Ω = longitude of ascending node

i = angle of incidence

w = argument of perigee

Figure 1. The Orbit in Space

The angles Ω , i , and w are generally unknowns; therefore, the elements in $[A]$ must be evaluated by some other means. To this end, Equation 3 is expressed as follows:

$$\begin{bmatrix} P \\ Q \\ W \end{bmatrix} = \begin{bmatrix} P_X & P_Y & P_Z \\ Q_X & Q_Y & Q_Z \\ W_X & W_Y & W_Z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} = [B] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} \quad (4)$$

The unit vector along perigee (that is, P_X , P_Y , P_Z) can be determined by Equation 141, Page 20 of Battin as follows:

$$\vec{P} = \frac{1}{\mu e} \left[(v^2 - \frac{\mu}{r}) \vec{r} - (\vec{r} \cdot \vec{v}) \vec{v} \right] \quad (5)$$

where

v = absolute magnitude of velocity

r = absolute magnitude of the radius vector

\vec{v} = inertial velocity

\vec{r} = radius vector

This relationship is obtained as follows:

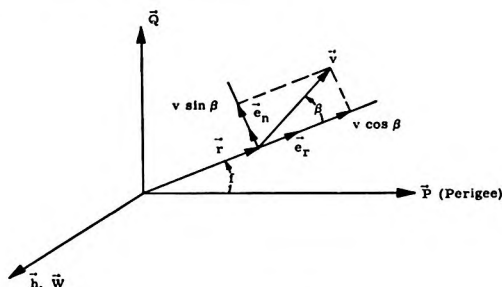


Figure 2

$$\vec{P} = \vec{e}_r \cos f - \vec{e}_n \sin f \quad (6)$$

$$(1) \quad \vec{e}_r = \frac{\vec{r}}{r}; \quad \vec{e}_h = \frac{\vec{h}}{h}; \quad \vec{e}_n = \frac{\vec{h}}{h} \times \frac{\vec{r}}{r}$$

$$(2) \quad r = \frac{h^2/\mu}{1 + e \cos f}; \quad \cos f = \frac{h^2}{\mu e} r^{-1} - \frac{1}{e}; \quad \sin f = \frac{h}{\mu e} \dot{r};$$

$$\text{but } \dot{r} = v \vec{e}_r = v \cos \beta = \frac{\vec{r} \cdot \vec{v}}{r}$$

$$(3) \quad \sin f = \frac{h}{\mu e} \frac{\vec{r} \cdot \vec{v}}{r}$$

Combining 1, 2, and 3 into Equation 6

$$\vec{P} = \frac{\vec{r}}{r} \left[\frac{h^2}{\mu e r} - \frac{1}{e} \right] - \left(\frac{\vec{h}}{h} \times \frac{\vec{r}}{r} \right) \left[\frac{h}{\mu e} \frac{\vec{r} \cdot \vec{v}}{r} \right]$$

By substituting

$$h = r v \sin \beta, \quad \cos \beta = \frac{\vec{r} \cdot \vec{v}}{rv}$$

and adding the factor

$$r v^2 \cos^2 \beta \vec{e}_r - r v^2 \cos^2 \beta \vec{e}_r$$

the above equation reduces to

$$\vec{P} = \frac{1}{\mu e} \left[\left(v^2 - \frac{\mu}{r} \right) \vec{r} - (\vec{r} \cdot \vec{v}) (v \cos \beta \vec{e}_r + v \sin \beta \vec{e}_n) \right]$$

but

$$\vec{v} = v \cos \beta \vec{e}_r + v \sin \beta \vec{e}_n$$

therefore

$$\vec{P} = \frac{1}{\mu e} \left[\left(v^2 - \frac{\mu}{r} \right) \vec{r} - (\vec{r} \cdot \vec{v}) \vec{v} \right]$$

Since \vec{h} is constant, the unit vector along \vec{h} (that is, W_X, W_Y, W_Z) is determined given any \vec{r} and corresponding \vec{v} in the orbit. That is

$$\vec{W} = \frac{\vec{h}}{h} = \frac{\vec{r} \times \vec{v}}{rv \sin \beta} \quad (7)$$

Having determined \vec{P} and \vec{W} , the remaining unit vector, \vec{Q} , is calculated as follows:

$$\vec{Q} = \vec{W} \times \vec{P} \quad (8)$$

By using Equations 6, 7, and 8 the matrix $[B]$ is determined. That is, the orbit is defined in inertial space. From Equations 3 and 4, $[A] = [B]$. By equating elements and by using the constraint $0^\circ \leq i \leq 180^\circ$, the Euler angles Ω, i , and w are determined.

C. ORBIT DETERMINATION

The problem of orbit determination can be stated as follows: Given an initial \vec{r}_1 and corresponding \vec{v}_1 vector expressed in ECI coordinates, determine the position and velocity in ECI coordinates at some time, t_2 .

From what has been presented so far, the approach would be to determine if the conic is a hyperbola or an ellipse. Then use the corresponding form of Kepler's equation to solve for the true anomaly and through the orbit-in-space-transformation determine the position and velocity at t_2 .

This method has the undesirable feature of first determining if the conic is a hyperbola or an ellipse and requires two sets of equations.

A more unified approach as presented by Battin is the universal conic equations which are given by

$$\vec{r}(t_2) = \left[1 - \frac{X^2}{r_1} C(X^2 \alpha_1) \right] \vec{r}_1 + \left[\Delta t - \frac{X^3}{\sqrt{\mu}} S(X^2 \alpha_1) \right] \vec{v}_1 \quad (9)$$

$$\vec{v}(t_2) = \frac{\sqrt{\mu}}{r_1} \left[\alpha_1 X^3 S(X^2 \alpha_1) - X \right] \vec{r}_1 + \left[1 - \frac{X^2}{r_1} C(X^2 \alpha_1) \right] \vec{v}_1 \quad (10)$$

where

$$C(X^2 \alpha_1) = \frac{1}{2!} - \frac{X^2 \alpha_1}{4!} + \frac{(X^2 \alpha_1)^2}{6!} - \dots$$

$$S(X^2 \alpha_1) = \frac{1}{3!} - \frac{X^2 \alpha_1}{5!} + \frac{(X^2 \alpha_1)^2}{7!} - \dots$$

$$\Delta t = t_2 - t_1$$

$$\alpha_1 = \frac{1}{a} = \frac{2}{r_1} - \frac{v_1^2}{\mu}$$

$$X = \frac{E_2 - E_1}{\sqrt{\alpha_1}} \quad \text{for ellipse}$$

$$X = \frac{H_2 - H_1}{\sqrt{-\alpha_1}} \quad \text{for hyperbola}$$

The parameter X which is required for Equations 9 and 10 is determined as follows: An initial guess for X is given by

$$X = X_1 + S \left[1 - F_3 S(1 - 2 F_3 S) - \frac{1}{6} \left(\frac{1}{r_1} - \alpha_1 \right) S^2 \right] \quad (11)$$

where

$$X_1 = 0 \text{ for the first iteration and } X \text{ for subsequent iterations}$$

$$F_3 = \frac{\vec{r}_1 \cdot \vec{v}_1}{2 r_1 \sqrt{\mu}}$$

$$S = \frac{\sqrt{\mu}}{2 r_1} (t_2 - t_1)$$

Having an initial guess for X, an improved value is obtained by a Newton-Raphson iteration scheme as follows:

$$X_{n+1} = X_n - \frac{F(X_n)}{F'(X_n)} \quad (12)$$

where

$$F(X_n) = \left[\frac{\vec{r}_1 \cdot \vec{v}_1}{\sqrt{\mu}} X_n^2 C(X_n^2 \alpha_1) + (1 - r_1 \alpha_1) X_n^3 S(X_n^2 \alpha_1) + r_1 X_n \right] - \sqrt{\mu} \Delta t$$

$$F'(X_n) = \frac{\vec{r}_1 \cdot \vec{v}_1}{\sqrt{\mu}} \left[X_n - \alpha_1 X_n^3 S(X_n^2 \alpha_1) \right] + \left[(1 - r_1 \alpha_1) X_n^2 C(X_n^2 \alpha_1) + r_1 \right]$$

The iteration scheme of Equation 12 continues until $X_{n+1} - X_n$ is sufficiently small. The good initial guess provided by Equation 11 limits the iteration to two or three in most cases. The value for X_{n+1} is then substituted into Equations 9 and 10, thereby specifying \vec{r}_2 and \vec{v}_2 in ECI coordinates. Following the universal conic method just described, the position and velocity vectors referred to ECI space can be determined for any time t during freefall.

D. DISTURBANCE ACCELERATIONS

So far the planet in question has been assumed to be spherical which is not the case for either the earth or the moon. Nor have the effects of the sun and the moon on the earth or vice versa been considered. Therefore, Equation 1 must be modified as follows

$$\frac{d^2 \vec{r}}{dt^2} + \frac{\mu}{r^3} \vec{r} = \vec{a}_d \quad (13)$$

where

\vec{a}_d is the disturbance acceleration due to

1. oblateness of the earth or the nonspherical shape of the moon depending on which reference body is used,
2. the effects of the sun,
3. the effects of the secondary body on the primary body; that is, effects of moon on earth if earth is primary body and vice versa.

Analytical expressions for \vec{a}_d are given in R-577, Section 5. Since \vec{a}_d is small in comparison to $\frac{\mu}{r^3}$, the two-body orbit given by Equation 1 is used as a reference or osculating orbit which is perturbed by \vec{a}_d . The actual position and velocity vectors are, therefore, given by

$$\begin{aligned} \vec{r} &= \vec{r}_c + \vec{\delta} \\ \vec{v} &= \vec{v}_c + \vec{\sigma} \end{aligned} \quad (14)$$

where

\vec{r}_c and \vec{v}_c are the position and velocity of the two-body conic solutions,

$\vec{\delta}$ and $\vec{\sigma}$ are the deviations from the two-body conic solutions of position and velocity, respectively.

Differentiating Equation 14 and substituting into Equation 13 gives the following expression for the differential acceleration

$$\frac{d^2 \vec{\delta}}{dt^2} = \frac{\mu}{r_c^3} \left[\left(1 - \frac{r_c^3}{r^3} \right) \vec{r} - \vec{\delta} \right] + \vec{a}_d \quad (15)$$

subject to the initial conditions

$$\vec{\delta}(t_0) = 0, \quad \frac{d\vec{\delta}}{dt}(t_0) = \vec{\sigma}(t_0) = 0$$

This method (Equation 15) is known as Encke's method of differential accelerations.

Since the coefficient of \vec{r} in Equation 15 requires the subtraction of nearly equal quantities, prohibitive errors are introduced by solving Equation 15 in its present form. This difficulty can be overcome by making the substitution

$$\left(1 - \frac{r_c^3}{r^3} \right) = \frac{\vec{r}}{r^2} \left(1 + \frac{\rho^2}{1 + \rho} \right) \quad [(\vec{r}_c + \vec{r}) \cdot \vec{\delta}] \quad \text{where } \rho = r_c/r$$

Equation 15, therefore, becomes

$$\frac{d^2 \vec{\delta}}{dt^2} = \frac{\mu}{r_c^3} \left\{ \frac{\vec{r}}{r^2} \left(1 + \frac{\rho^2}{1 + \rho} \right) [(\vec{r}_c + \vec{r}) \cdot \vec{\delta}] - \vec{\delta} \right\} + \vec{a}_d \quad (16)$$

Equation 16 can be solved by any number of numerical integration schemes. The method used in the Apollo Guidance Computer (AGC) is the Nystrom method.

In order to maintain the efficiency of Encke's method of differential accelerations, $\delta(t)$ must remain small. Therefore, a new osculating conic must be defined by the total position and velocity vectors $\vec{r}(t)$ and $\vec{v}(t)$ when $\delta(t)$ reaches a predetermined limit (8 Km for example). The process of selecting a new conic orbit from which to calculate deviations is called rectification.

To sum up, the position and velocity, during freefall, at time t_2 , given the position and velocity at time t_1 , are computed as follows:

1. Position and velocity in the osculating orbit at time t_2 are calculated according to Equations 9 and 10.
2. Deviations are then obtained by numerical integration of Equation 16.
3. A new conic from which to calculate deviations is defined each time the deviations ($\delta(t)$) reach a predetermined limit.

E. DISTURBING FUNCTIONS AND THEIR APPLICABILITY

We define the following disturbance accelerations as applicable to Apollo:

- \vec{a}_{dE} = acceleration due to the nonspherical gravitational perturbations of the earth
- \vec{a}_{dm} = acceleration due to the nonspherical gravitational perturbations of the moon
- \vec{a}_{dq} = acceleration due to the secondary body on the primary body; that is, moon is secondary body when earth is used as reference and vice versa
- \vec{a}_{ds} = acceleration due to the sun

analytical expressions for which are given in R-577, Section 5.

The applicable disturbance accelerations and their region of applicability for Apollo are given in Figure 3.

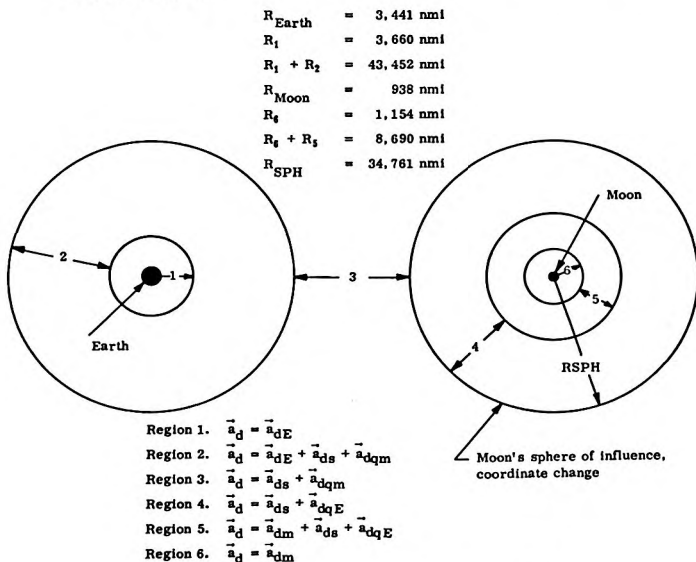


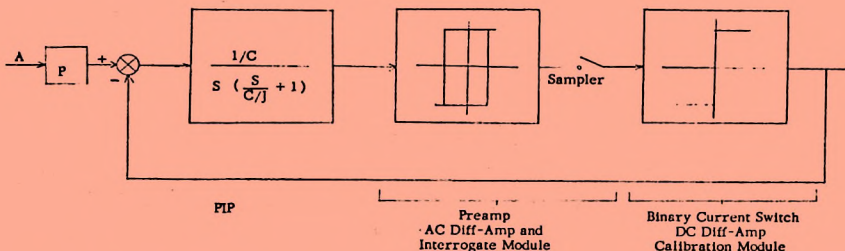
Figure 3. Apollo Disturbance Acceleration Regions

HW-1

HARDWARE

PIPA
COARSE ALIGN - FINE ALIGN
ECDU
IRIG
OPTICS
OUA
AOT
DIGITAL AUTOPILOT

PIPA LOOP



P = Pendulosity
 C = Coefficient of Viscous Damping
 J = Float Inertia

The PIP Signal Generator Ducosyn provides information on rotor position in the form of a 3200 hertz output. The stable limit cycle in rotor position is converted to an AC suppressed carrier modulated signal.

The PIP Preamp amplifies the SG output (14 V/V gain) and phase shifts the 3200 hertz carrier 45° lag.

The AC Diff-Amp and Interrogate Module provides additional amplification (3050 V/V), peak detects float position, and sets a flip-flop. One state of the flip-flop indicates float position on the plus side of null and the other state means float position on the minus side of null.

The Binary Current Switch provides discrete current pulse outputs of appropriate phase as determined by the state of the flip-flop in the AC Diff-Amp Module.

The Calibration Module is the passive circuit interface between the BCS and the PIP torquer. The circuitry introduces bias and scale factor adjust capability into the PIPA loop.

The PIP Torque Ducosyn converts current pulses from the Calibration Module to torque about the PIP OA axis.

The DC Diff-Amp and PVR Module is the mechanism which regulates current and hence PIP torque to precisely controlled values.

PIPA CHARACTERISTICS

PARAMETER		CM		LM	
1.	Maximum measurable acceleration	19.1	g's	3.26	g's
2.	Pendulosity P	0.25	$\frac{\text{dyne cm}}{\text{cm/sec}^2}$	0.25	$\frac{\text{dyne cm}}{\text{cm/sec}^2}$
3.	Torque to balance T	4680	dyne cm	800	dyne cm
4.	PIP float inertia J	14.0	$\frac{\text{dyne cm}}{\text{rad/sec}^2}$	14.0	$\frac{\text{dyne cm}}{\text{rad/sec}^2}$
5.	PIP viscous damping C	12×10^4	$\frac{\text{dyne cm}}{\text{rad/sec}}$	12×10^4	$\frac{\text{dyne cm}}{\text{rad/sec}}$
6.	PIP break point C/J	8550	rad/sec	8550	rad/sec
7.	PIP time constant J/C	.117	ms	.117	ms
8.	Total torque constant	.42	dyne cm/ma ²	.42	dyne cm/ma ²
9.	Nominal torque current	105	ma	44	ma

SUSPENSION CHARACTERISTICS

- Radial Force 2.3 grams per .0001" min
- Suspension current 65 ± 6 ma
the two ends (SG & TG) matched within 3 ma
- Phase angle of current lags $45^\circ \pm 2.8^\circ$
- Suspension stiffness 30×10^{-3} grams/micro-inch

TYPICAL TEMPERATURE CHARACTERISTICS

- Scale Factor 150 ppm/ $^\circ$ F CM
300 ppm/ $^\circ$ F LM
- Bias .05 cm/sec²/ $^\circ$ F LM/CM

$^\circ$ F Actual PIPA Temperature

PIPA PARAMETERS

Primary PIPA parameters are scale factor and bias. Specification values across ISS, G&N, and S/C testing are as shown in Table I-1.

Table I-1

PIPA Coefficient Stability Criteria				
Coefficient	Units	D ₁	D ₂	D ₃
PIPA Bias (A _b)	cm/sec ²	0.50	0.70	0.90
PIPA Scale Factor SF	ppm	400	500	600

PIPA bias in a unity gravity field (A_b) must be within 0.30 cm/sec² of that evaluated in a zero gravity (a₀) field at the ISS level of test.

The maximum value of PIPA parameters which can be compensated for by the computer is as shown in Table I-2.

Table I-2

Coefficient	Units	Max Value (CM)	Max Value (LM)
A _b	cm/sec ²	±9.14	±12.50
SF	ppm	±1900	±1900

PIPA COMPENSATION

	Register
X PIPA Bias	1452
Y PIPA Bias	1454
Z PIPA Bias	1456

$$\begin{aligned} \text{PIPA Bias CM} &= (.0005569) (\text{Reg Contents in Decimal}) \text{ cm/sec}^2 \\ \text{PIPA Bias LM} &= (.0007628) (\text{Reg Contents in Decimal}) \text{ cm/sec}^2 \end{aligned}$$

The correction to the PIPA's is

$$\text{PIPA}_C = (1 + \text{SFE}_I) \text{PIPA}_I - \text{BIAS}_I \Delta t$$

where

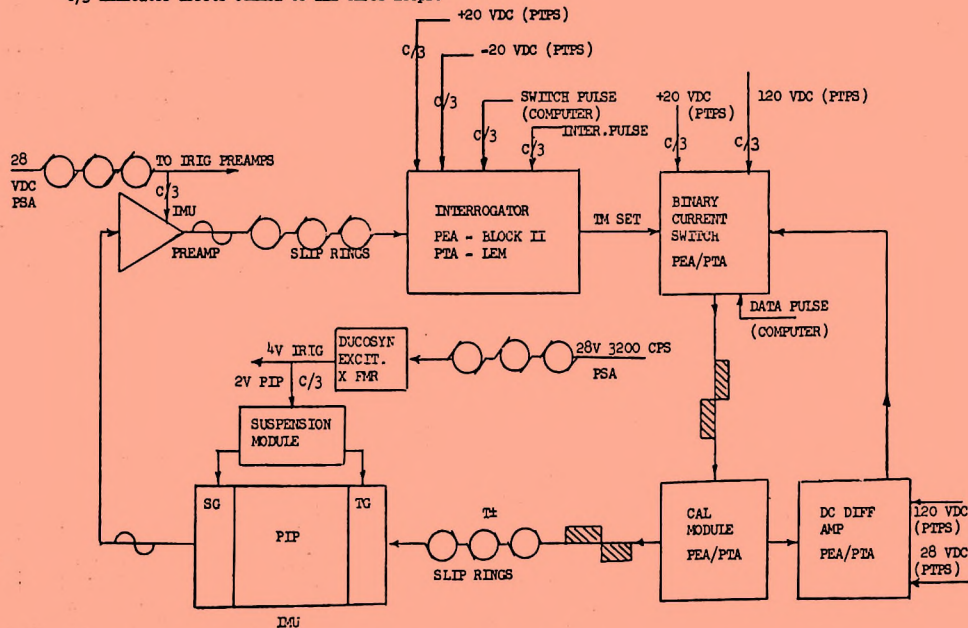
PIPA_C is the compensated data for the Ith PIPA denoted PIPAX_C, PIPAY_C, PIPAZ_C

$$\text{SFE} = \frac{\text{SF} - \text{SF}_{\text{nom}}}{\text{SF}_{\text{nom}}} \quad (\text{erasable load})$$

$$\text{SF} = \text{Scale-factor} \frac{\text{CM/Sec}}{\text{Pulse}}$$

BIAS_I is the bias for the Ith PIPA (an erasable load)

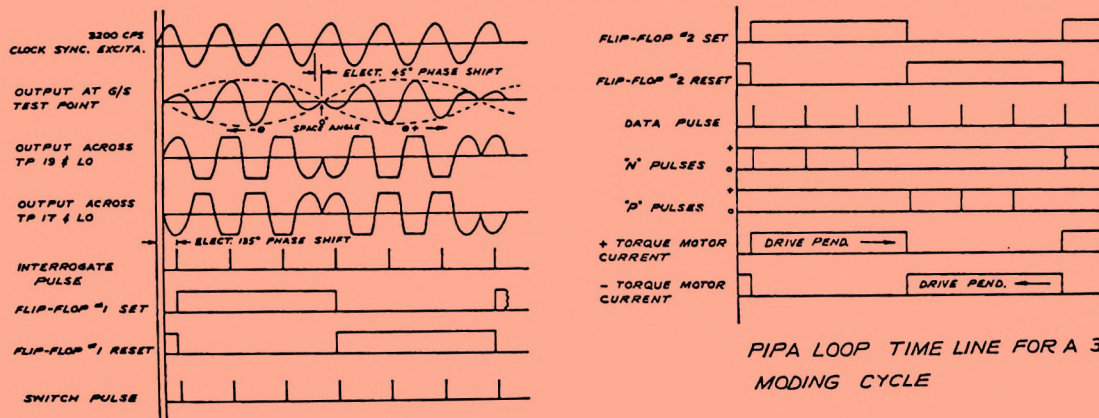
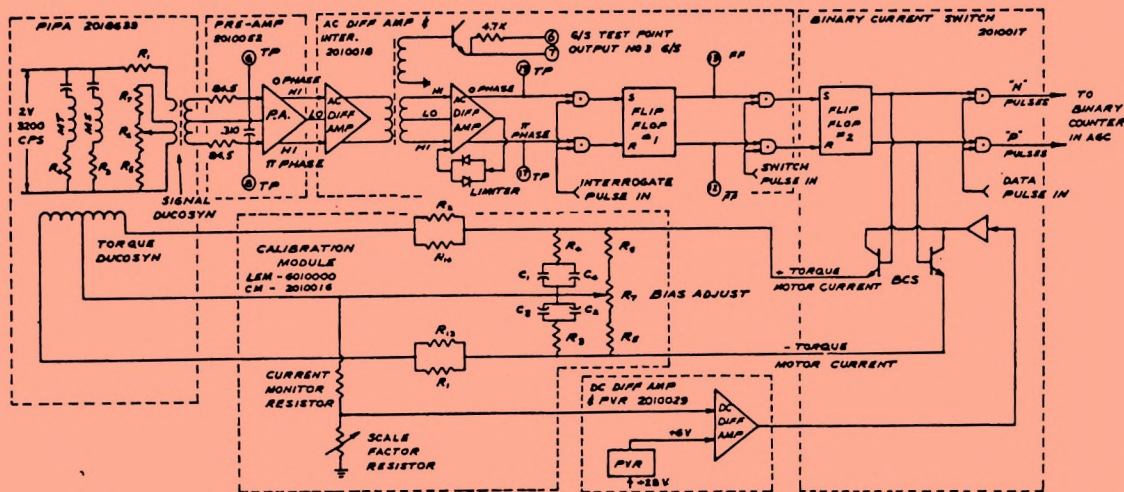
C/3 indicates assets common to all three loops.

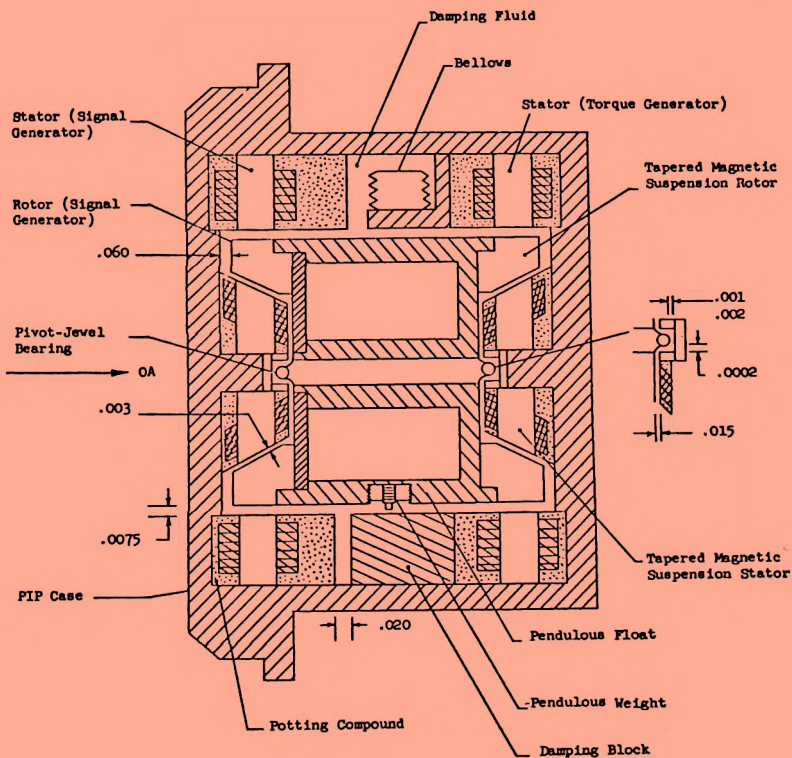


PTFS = Pulse Torque Power Supply. For Block II PTFS is in the PSA
For LEM PTFS is in the PTA

PEA = PIPA Electronics Header Assembly (CM); PTA = Pulse Torque Header Assembly (LEM).

PIPA LOOP





APOLLO PIP

PIPA DEADZONE

Digital interrogation of PIPA float position with zero acceleration applied will generally yield 3 clock pulses for each half cycle of float position. This is called 3:3 moding.

During initial build-up, torque imbalance is minimized by artificially inducing 2:2 or 4:4 moding and adjusting the zero g null to coincidence with the 3:3 moding zero g null. The null coincidence between a stable 2:2 and a stable 3:3 null must be less than 20 arc seconds in build-up (Figure 1).

PIPA near null operation at PIPA level testing.

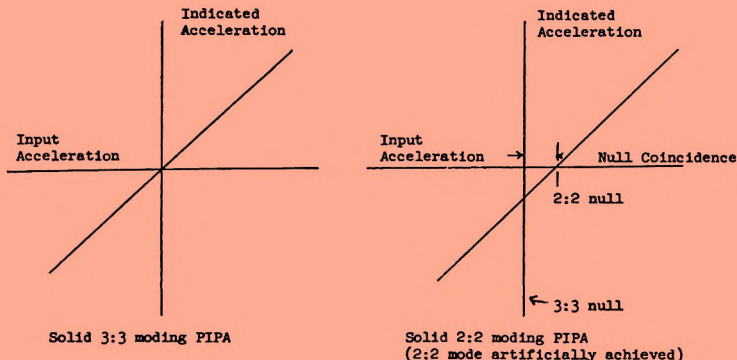


Figure 1

At higher levels of test, subtle changes in configuration due to integration of the PIPA loop into the G&N System can cause the PIPA to dual mode, i.e. the stable 3:3 mode may be replaced by a bistable 2:2 and 3:3 mode. Bistable moding causes no net delta V output and is manifest as a deadzone to near null inputs. This deadzone is checked at the ISS level of test to assure that it is less than 50 arc seconds (0.0075 ft/sec^2 or 0.23 cm/sec^2).

For an input acceleration of A_{33} (Figure 2), a dual moding PIPA will issue zero ΔV 's and mode 3:3.

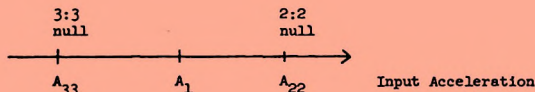
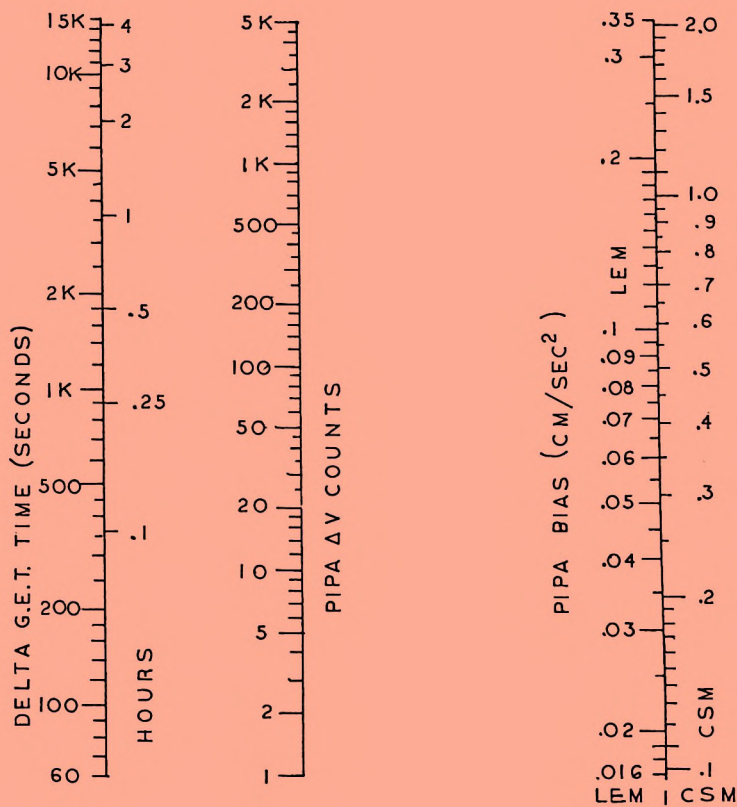
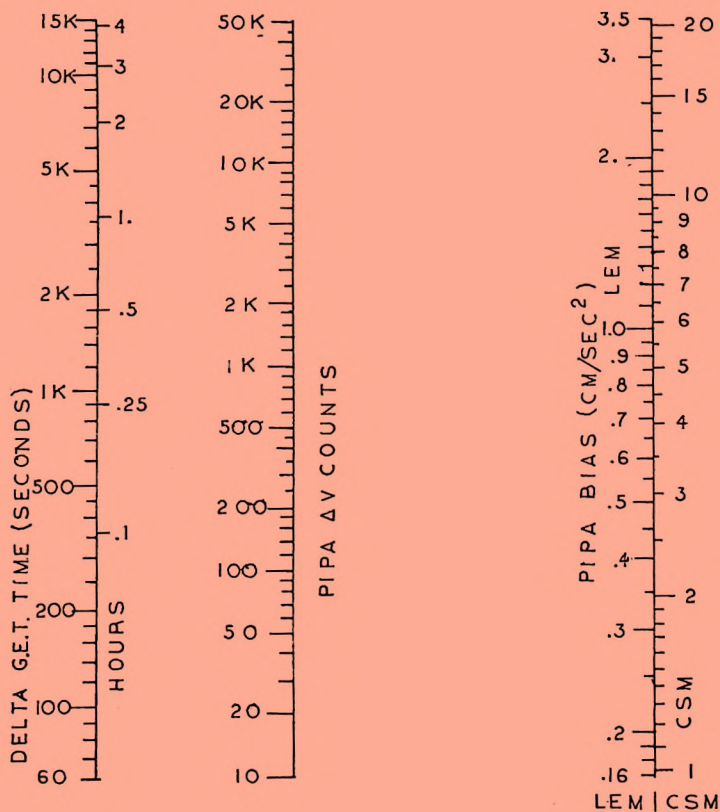


Figure 2

For an input acceleration of A_{22} , a dual moding PIPA will also issue zero ΔV 's and mode 2:2. For an input acceleration between the A_{33} and A_{22} limits, the PIPA will issue zero ΔV 's and dual mode from 2:2 to 3:3 at a rate of 5 or 6 times per second. The amount of time spent in 2:2 or 3:3 moding is dependent on the input acceleration A_1 .



NOMOGRAPH FOR ZERO GRAVITY PIPA BIAS



NOMOGRAPH FOR ZERO GRAVITY PIPA BIAS

IMU COARSE ALIGN LOOP

The coarse align loop drives the IMU gimbals to the angles commanded by the computer with an accuracy of $\pm 1.5^\circ$. The coarse align mode also acts as a caging mode when a gimbal lock condition is approached.

The three basic elements of the coarse align loop are the Digital Computer which issues angle commands ($\Delta\theta_c$) and moding discretes, the IMU, and the ECDU which encodes gimbal position and provides position and rate feedback for proper loop operation.

IMU FINE ALIGN LOOP

The fine align loop drives the IMU gimbals to the computer commanded angles $\pm 80''$ by pulse torquing the gyros. Pulse torquing is a computer controlled switching of a constant current source to a gyro torquer winding. The current produces gyro torque, a corresponding precession rate, and hence, gimbal position.

IMU INERTIAL MODE

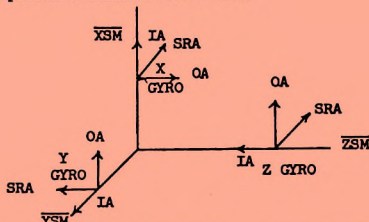
The elements of the inertial mode are the gyro, stabilization amplifier, and gimbal torque motor. The gyro senses inertial rotation about its input axis and supplies torquing to the gimbal via the stabilization amplifier to compensate for the motion.

APOLLO INERTIAL INSTRUMENTATION/STABLE MEMBER ORIENTATION DIAGRAM

Gyro drift is positive when the SM drift rate is about the positive gyro input (IA) axis.

Drift Rate About SM Axes	Gyro Drift Coefficient		
	NBD	ADIA	ADSRA
W_{XSM}	+NBDX	+ADIAX (a_{XSM})	-ADSRAX (a_{YSM})
W_{YSM}	+NB DY	+ADIAY (a_{YSM})	-ADSRAY (a_{ZSM})
W_{ZSM}	-NBDZ	+ADIAZ (a_{ZSM})	+ADSRZ (a_{XSM})

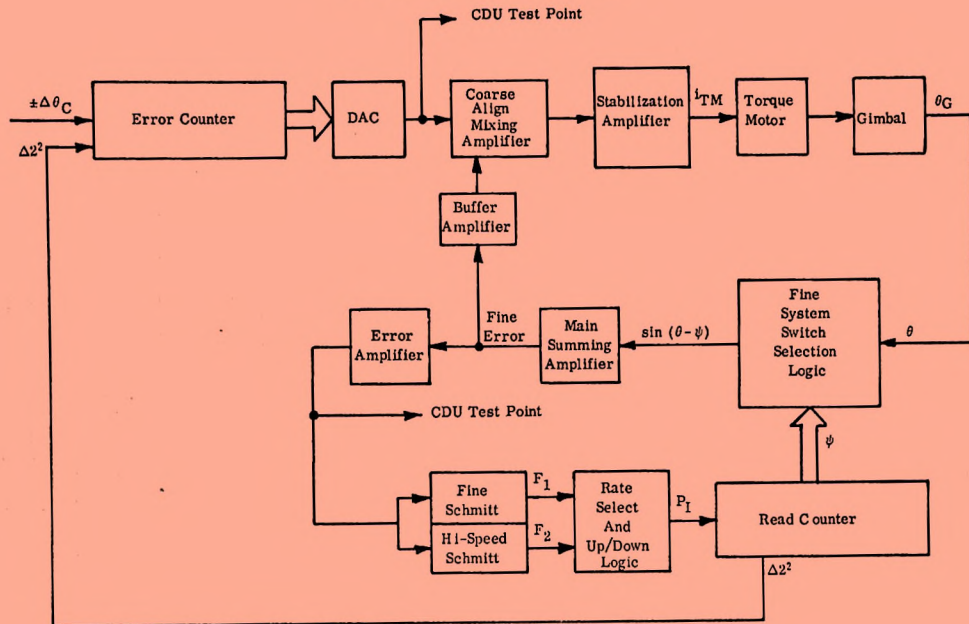
a_{XSM} , a_{YSM} , a_{ZSM} is positive along positive stable member axes.



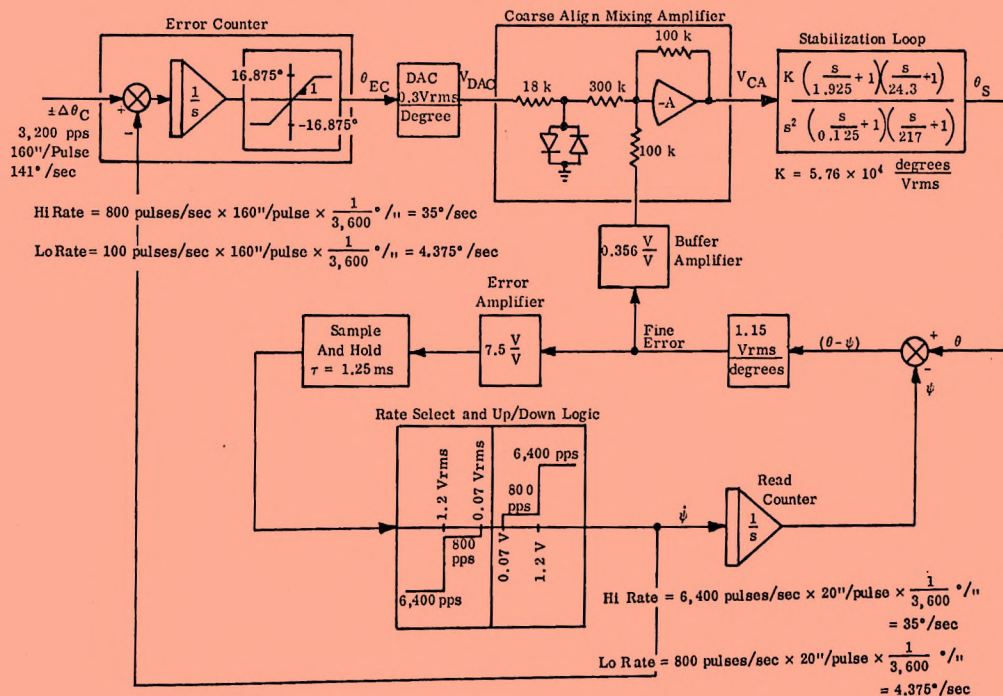
Gyro	IA Along	SRA Along	OA Along
X	+XSM	-YSM	+ZSM
Y	+YSM	-ZSM	+XSM
Z	-ZSM	-YSM	+XSM

Input axes of the X, Y, Z accelerometers lie respectively along positive XSM, YSM, ZSM axes.

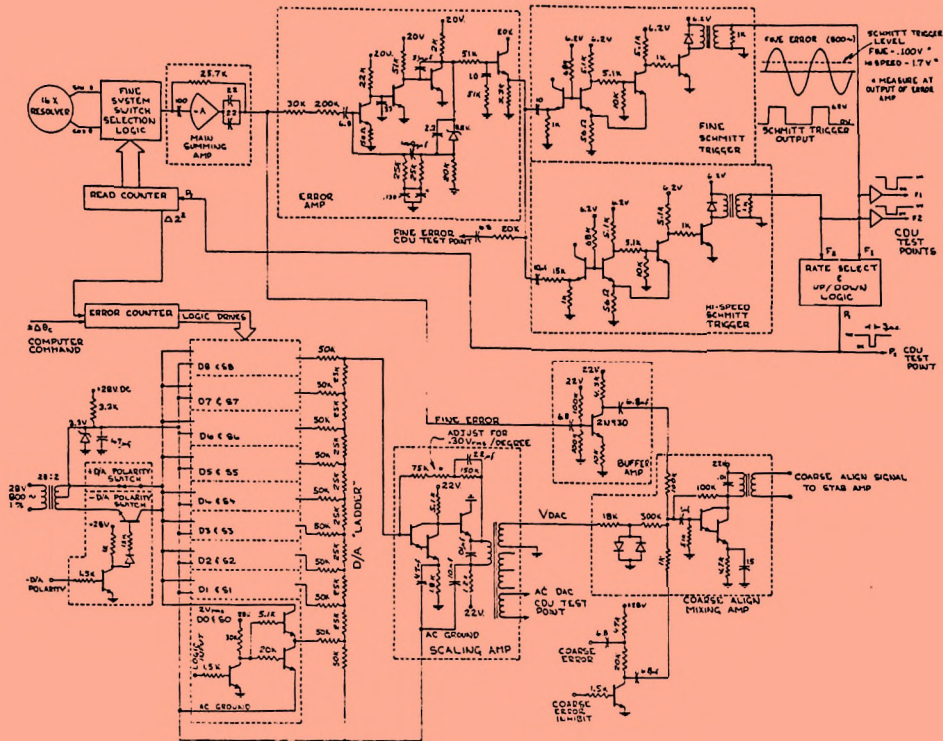
IMU COARSE ALIGN BLOCK DIAGRAM



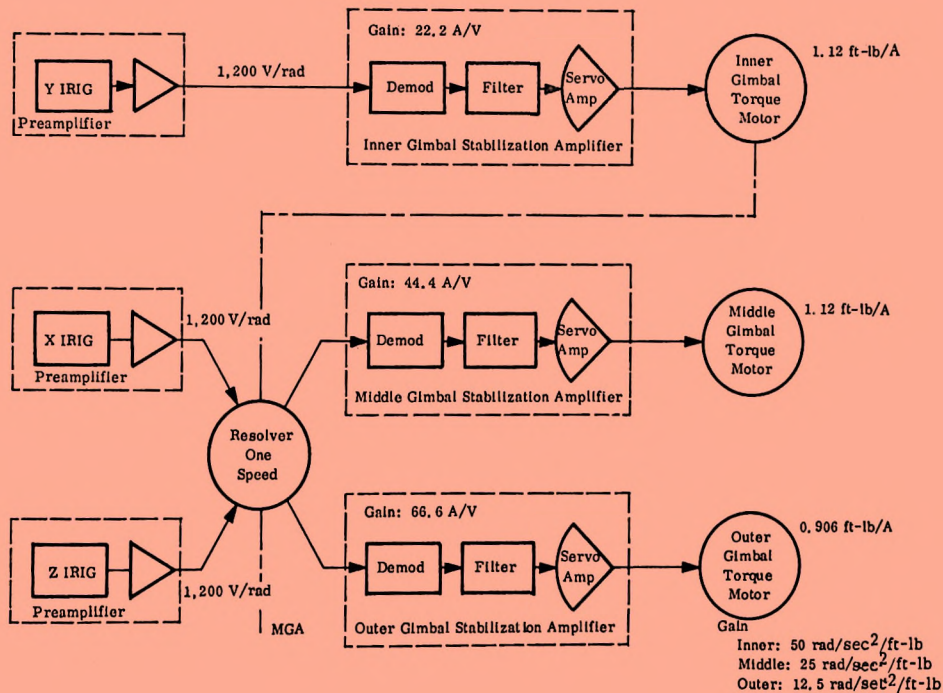
IMU COARSE ALIGN FUNCTIONAL BLOCK DIAGRAM



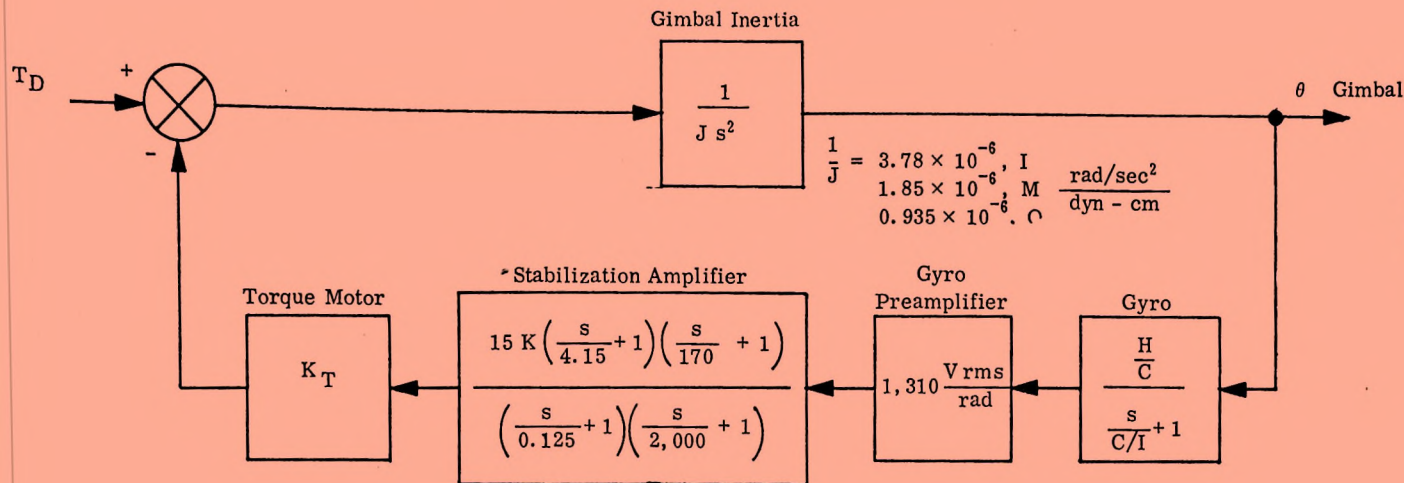
ECDU COARSE ALIGN NETWORK



IMU "INERTIAL MODE" BLOCK DIAGRAM



IMU "INERTIAL MODE" FUNCTIONAL BLOCK DIAGRAM



$$\frac{1}{J} = \begin{matrix} 3.78 \times 10^{-6}, I \\ 1.85 \times 10^{-6}, M \\ 0.935 \times 10^{-6}, O \end{matrix} \frac{rad/sec^2}{dyn - cm}$$

$$K_T = \begin{matrix} 1.52 \times 10^7 \frac{dyn - cm}{A}, I \\ 1.52 \times 10^7 \frac{dyn - cm}{A}, M \\ 1.23 \times 10^7 \frac{dyn - cm}{A}, O \end{matrix}$$

$$K = \begin{matrix} 1 \frac{A}{V_{rms}}, I \\ 2 \frac{A}{V_{rms}}, M \\ 3 \frac{A}{V_{rms}}, O \end{matrix}$$

$$H = 0.434 \times 10^6 \frac{dyn - cm}{rad/sec}$$

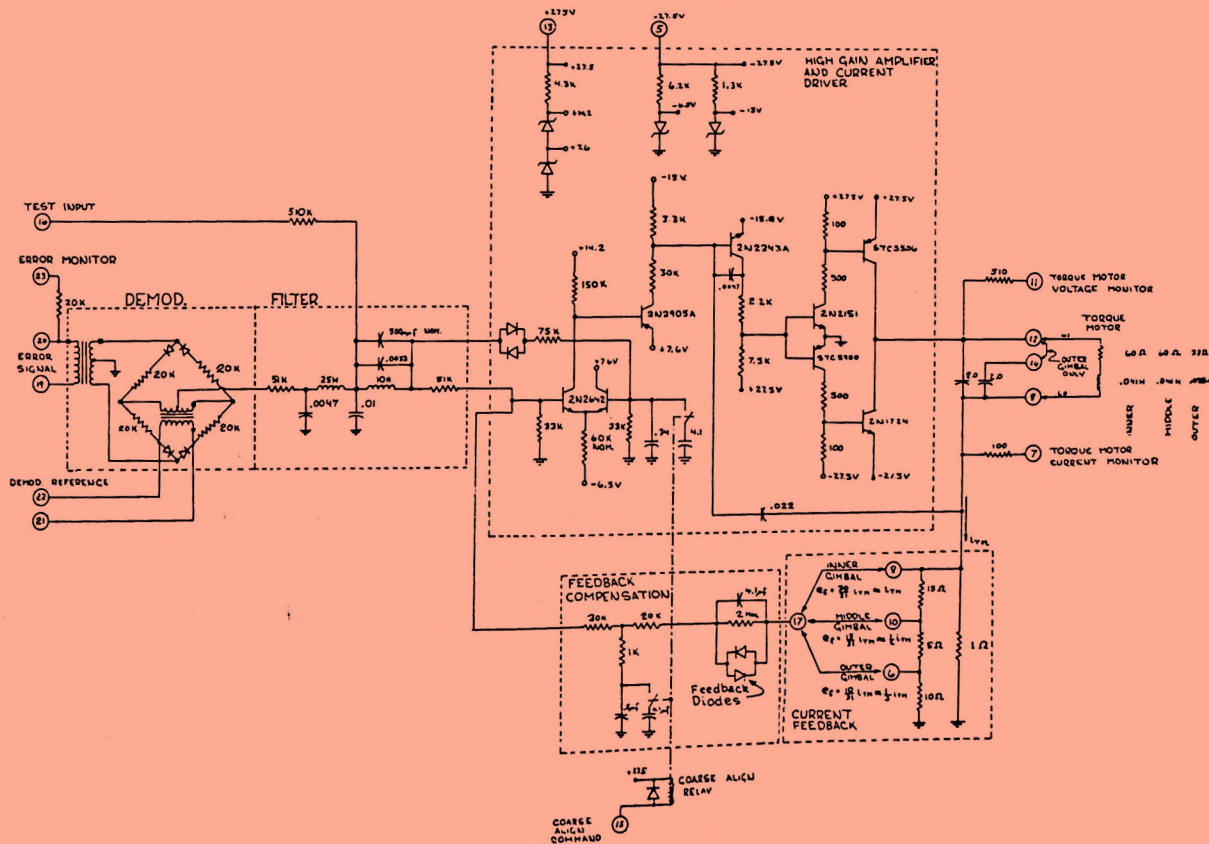
$$C = 0.475 \times 10^6 \frac{dyn - cm}{rad/sec}$$

$$I = 367 \text{ gm} - \text{cm}^2$$

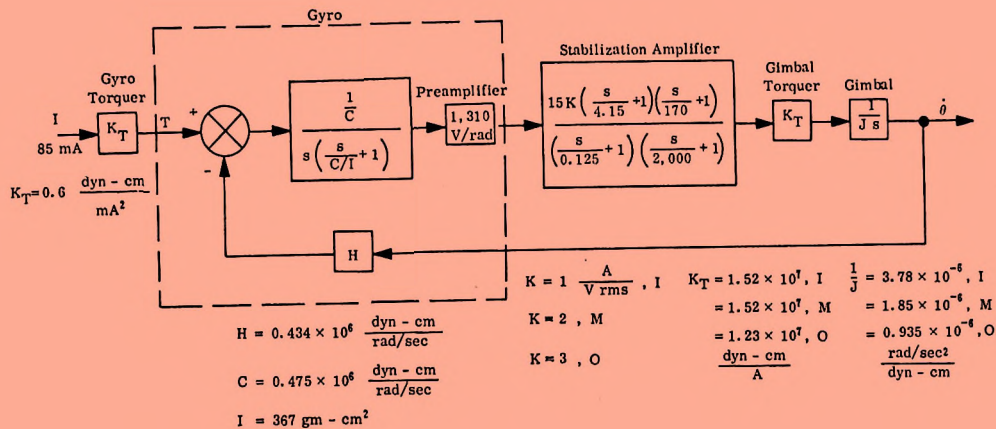
$$H/C = 0.915$$

$$C/I = 1,290 \text{ rad/sec}$$

IMU STABILIZATION AMPLIFIER



IMU FINE ALIGN FUNCTIONAL BLOCK DIAGRAM



$$\text{Gyro Torque} = K_T I^2 = 0.6 (85)^2 = 4,335 \text{ dyn-cm}$$

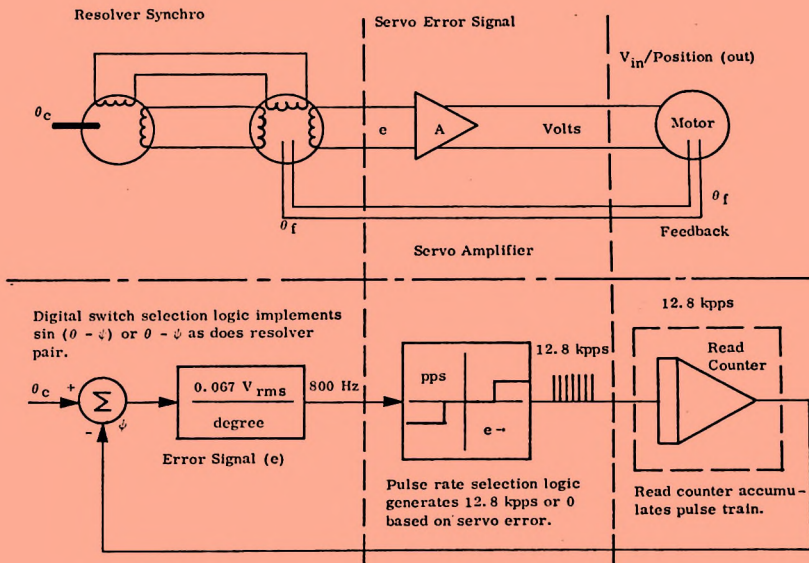
ELECTRONICS COUPLING DISPLAY UNIT (ECDU)

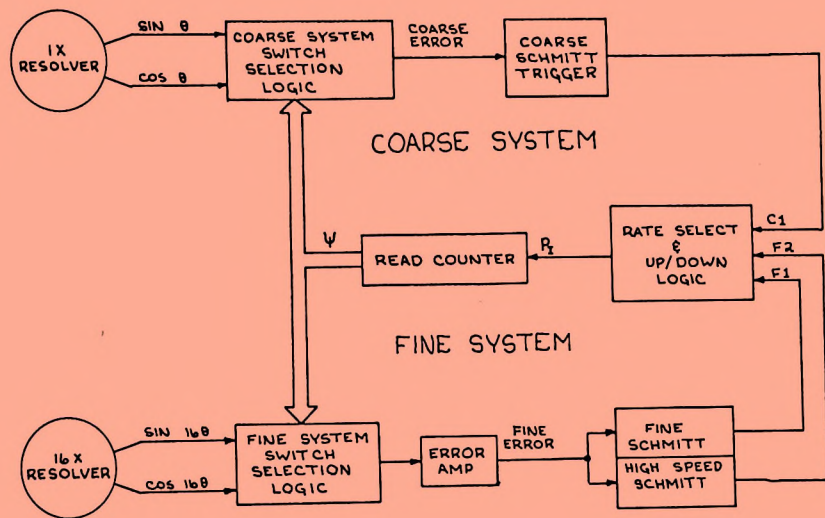
The ECDU encodes and scales the IMU gimbal angles and transfers the angles to the computer in the proper format.

The ECDU is an analog-to-digital converter which utilizes two encoding loops and one read counter which can be accessed by the computer.

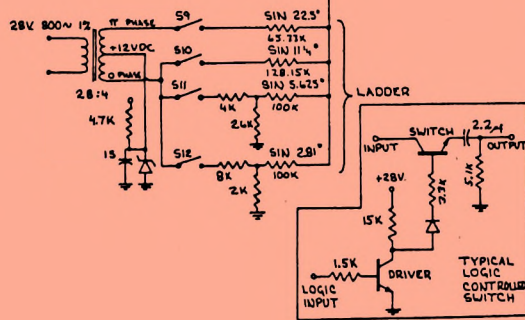
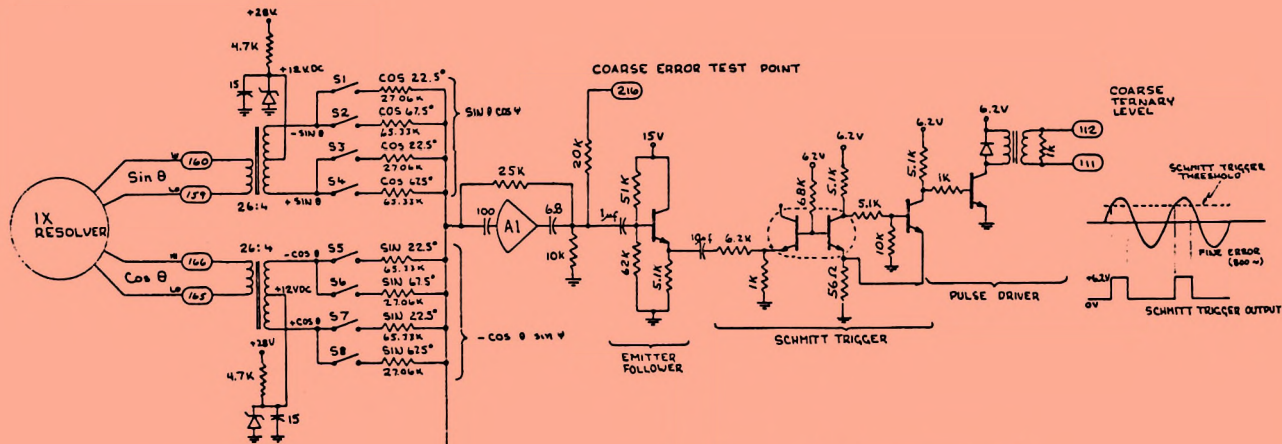
One encoding loop is used with the $16 \times$ gimbal resolver (the fine system); the other encoding loop is used with the $1 \times$ gimbal resolver (the coarse system).

The ECDU digital servo is analogous to a resolver synchro illustrated by the following diagram.





ECDU
READ COUNTER LOOP
BLOCK DIAGRAM



COARSE SYSTEM
READ COUNTER WEIGHT
FACTOR

2°	
2'	
2"	
2'''	
2 ^{iv}	
2 ^v	
2 ^{vi}	
2 ^{vii}	
2 ^{viii}	
2 ^{ix}	
2 ^x	
2 ^{xi}	
2 ^{xii}	
2 ^{xiii}	
2 ^{xiv}	
2 ^{xv}	
2 ^{xvi}	
2 ^{xvii}	
2 ^{xviii}	
2 ^{xix}	
2 ^{xx}	
2 ^{xxi}	
2 ^{xxii}	
2 ^{xxiii}	
2 ^{xxiv}	
2 ^{xxv}	
2 ^{xxvi}	
2 ^{xxvii}	
2 ^{xxviii}	
2 ^{xxix}	
2 ^{xxx}	

COARSE SYSTEM
SWITCH CONTROL
LOGIC *

S1	= 13·14·15 + 13·14·15
S2	= 13·14·15 + 13·14·15
S3	= 13·14·15 + 13·14·15
S4	= 13·14·15 + 13·14·15
S5	= 13·14·15 + 13·14·15
S6	= 13·14·15 + 13·14·15
S7	= 13·14·15 + 13·14·15
S8	= 13·14·15 + 13·14·15
S9	= 13
S10	= 11
S11	= 10
S12	= 9

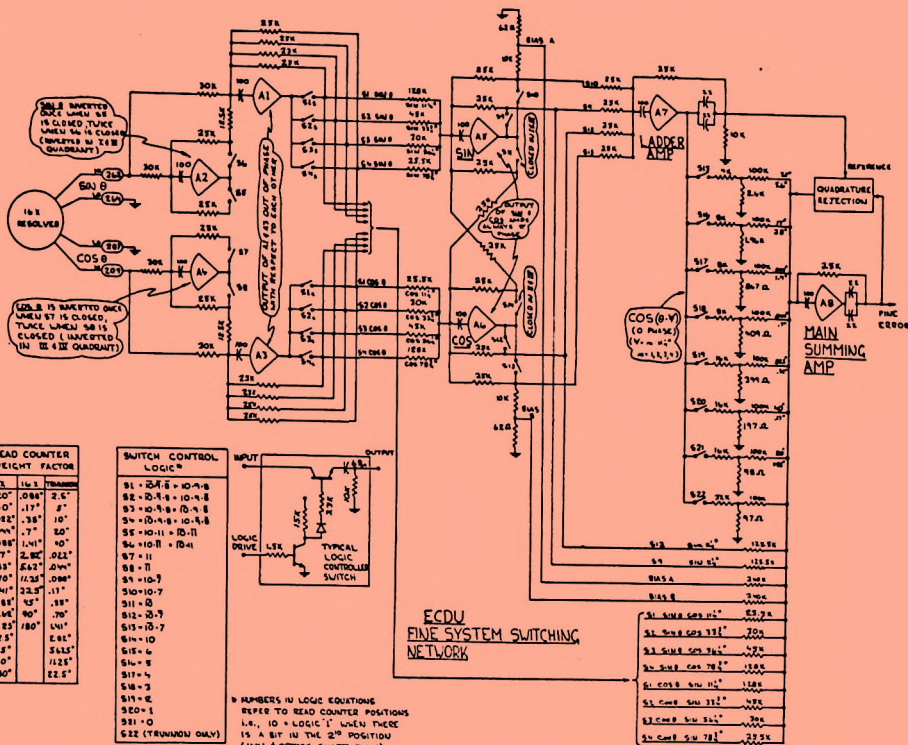
* NUMBERS IN LOGIC EQUATIONS
REFER TO READ COUNTER POSITIONS
I.E. 13 = LOGIC "1" WHEN THERE IS
A BIT IN THE 2¹³ POSITION

ECDU COARSE SYSTEM SWITCHING NETWORK

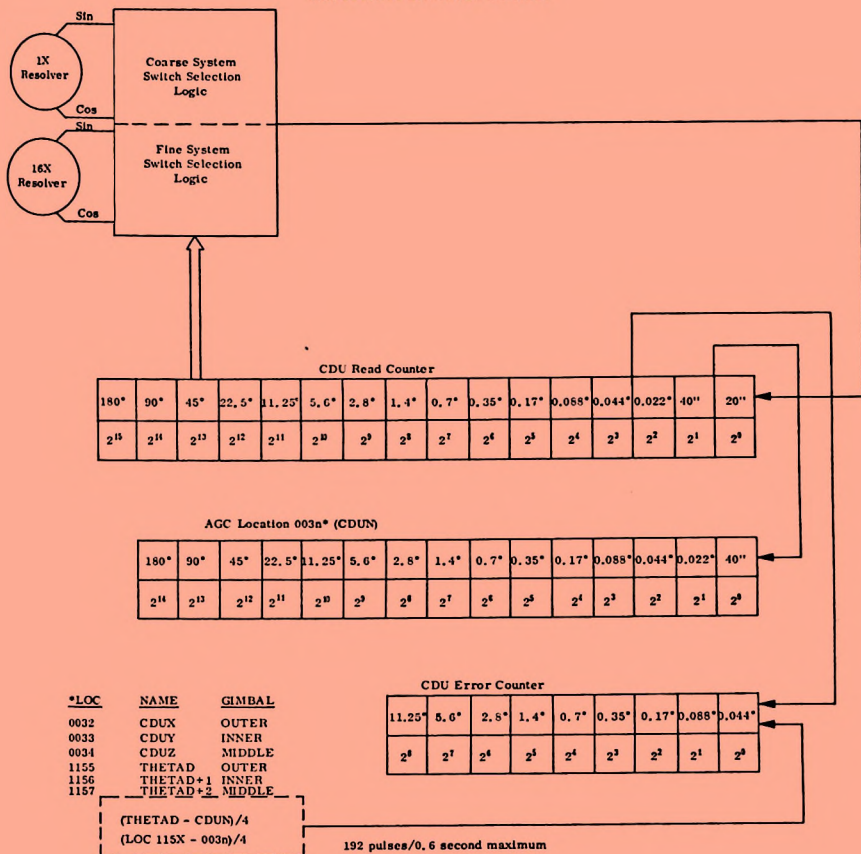
RESOLVER	10°	10°	TRUNNION
2°	20°	0.084°	2.5°
2°	40°	0.17°	5°
2°	60°	0.25°	7.5°
2°	80°	0.33°	10°
2°	100°	0.41°	12.5°
2°	120°	0.49°	15°
2°	140°	0.57°	17.5°
2°	160°	0.65°	20°
2°	180°	0.73°	22.5°

SWITCH CONTROL LOGIC
S1 = 2A 8 + 10 + 8
S2 = 2A 8 + 10 + 8
S3 = 10 + 8 + 10 + 8
S4 = 10 + 8 + 10 + 8
S5 = 10 + 11 + 10 + 11
S6 = 10 + 11 + 10 + 11
S7 = 11
S8 = 11
S9 = 10 + 10
S10 = 10 + 7
S11 = 10
S12 = 10 + 7
S13 = 10 + 7
S14 = 10
S15 = 6
S16 = 6
S17 = 4
S18 = 3
S19 = 6
S20 = 1
S21 = 10
S22 (TRUNNION ONLY)

NUMBERS IN LOGIC EQUATIONS REFER TO READ COUNTER POSITIONS
 I.E., 10 = LOGIC 10 WHEN THERE IS A BIT IN THE 2ND POSITION (1MU OPTICS SHAFT ONLY)

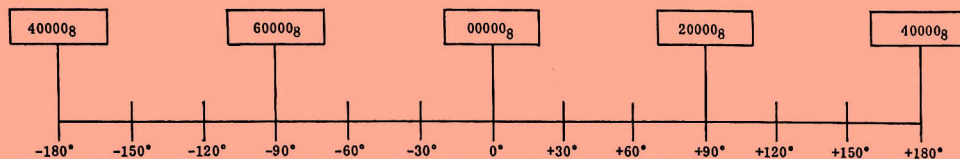


IMU/CDU/AGC INTERFACE DIAGRAM



IMU GIMBAL ANGLE AND OPTICS SHAFT SCALING DIAGRAM

Contents of Respective Location in AGC



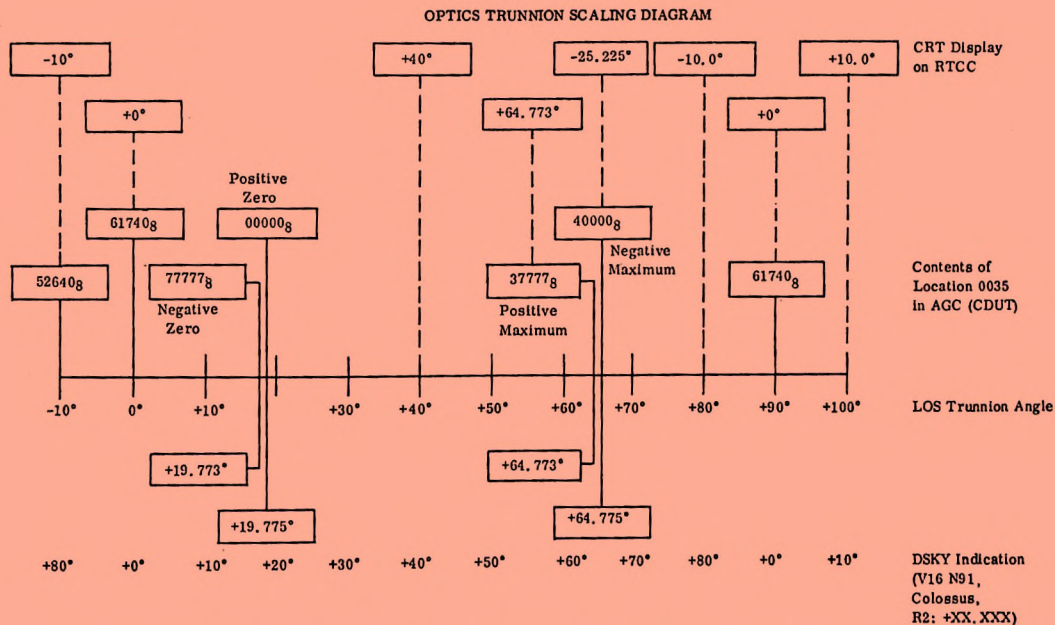
Actual Optics Shaft Angle or IMU Gimbal Angle

DSKY Indication and CRT Display on RTCC

+180° +210° +240° +270° +300° +330° 0° +30° +60° +90° +120° +150° +180°

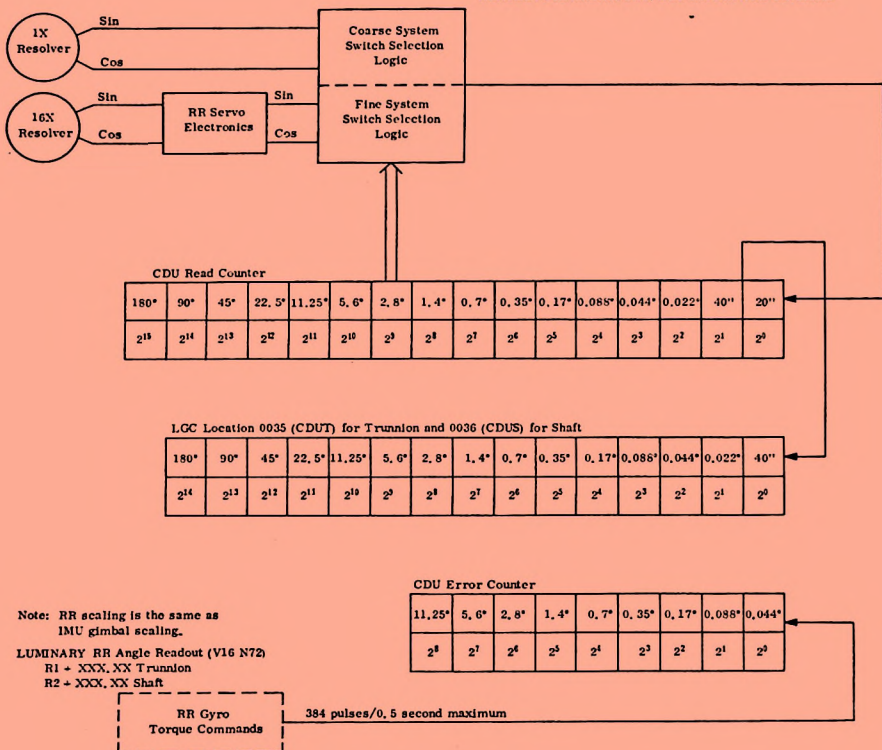
NOTE: For Colossus, V16 N91 monitors the optics shaft angle in R1 (+XXX.XX); V16 N20 monitors the IMU gimbal angles as follows:

- R1: Outer Gimbal (+XXX.XX)
- R2: Inner Gimbal (+XXX.XX)
- R3: Middle Gimbal (+XXX.XX)

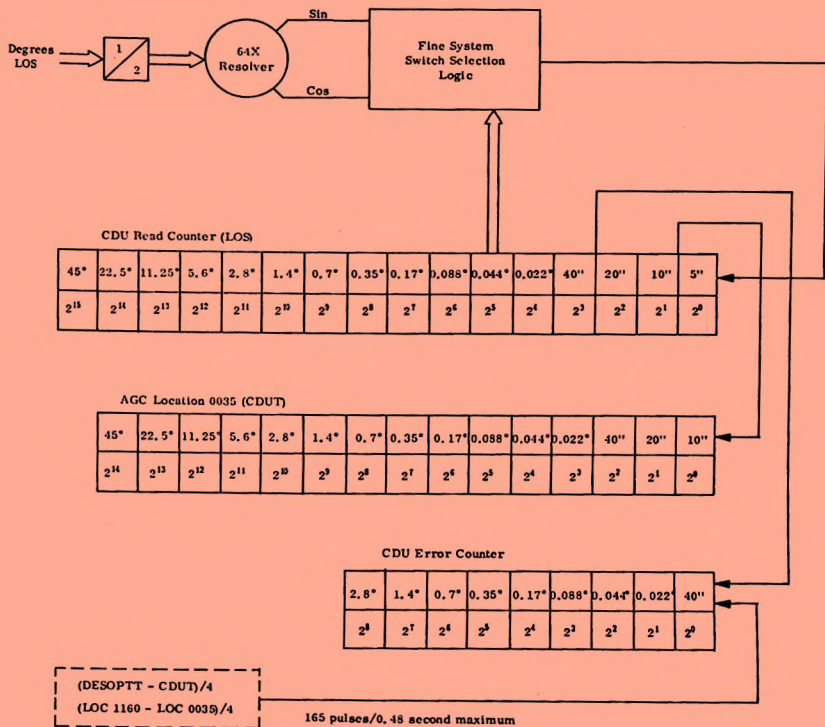


NOTE: CDUT (LOC 0035) is loaded with a -19.775° bias during ZERO OPTICS. This bias produces positive driving commands for angles up to +64.775° in the CMC mode. Without the bias, the CMC mode would drive the trunnion to the negative stop for command angles of 45° or greater.

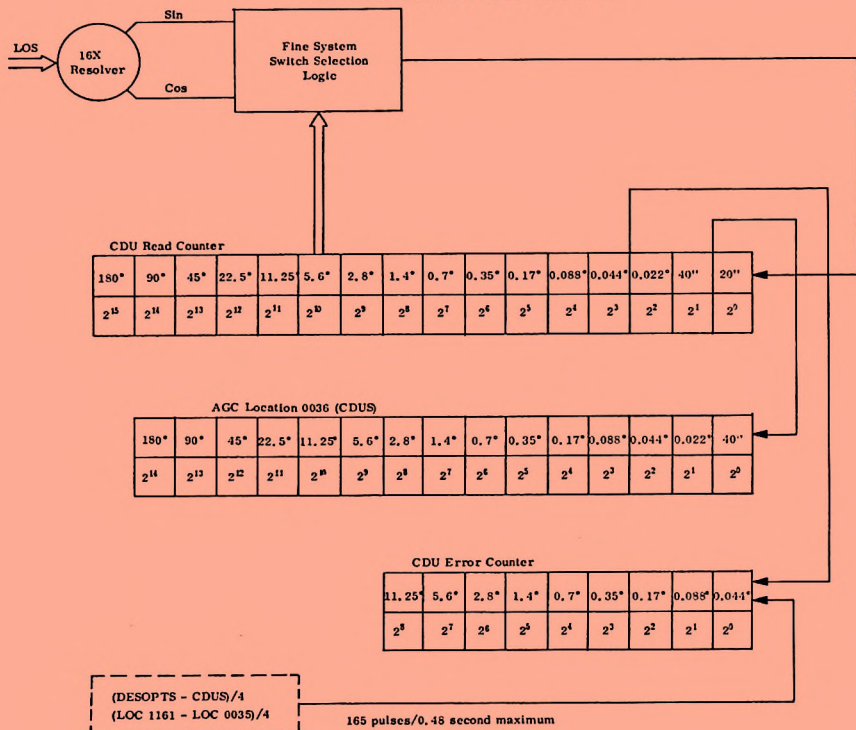
RENDEZVOUS RADAR/CDU/LGC INTERFACE DIAGRAM



OPTICS TRUNNION/CDU/AGC INTERFACE DIAGRAM



OPTICS SHAFT/CDU/AGC INTERFACE DIAGRAM



APOLLO 25 IRIG

Moments of Inertia:

about OA: 367.3 gram-cm²
 about IA: 650.8 gram-cm²
 about SRA: 724.9 gram-cm²

Damping Coefficients:

about OA: 4.75×10^5 dyne-cm/rad/sec
 about IA: 1.5×10^9 dyne-cm/rad/sec
 about SRA: 1.5×10^9 dyne-cm/rad/sec

Wheel Excitation: 28 volts, 800 cps, 4.5 watts at synchronism

Wheel Speed: 24,000 rpm

Angular Momentum at 24,000 rpm: 434×10^3 gram-cm² sec

Signal Generator:

Input: 4 volts, 3200 cps
 Sensitivity: 10 mv/mrad

Torque Generator Sensitivity: 0.6 dyne-cm/ma²

Pulse Torque Scale Factor: $\pi/2^{20}$ rad/pulse at 3200 pps

Magnetic Suspension:

Input: 4 volts, 3200 cps
 Stiffness: 6 gm/0.0001 inches Radial
 0.8 gm/0.0001 inches Axial

Typical Temperature Sensitivity

Scale Factor: 400 ppm/^oF
 Drift: 0.2 meru/^oF

Actual IRIG temperature

GYRO PARAMETERS

Primary gyro parameters are ADIA, ADSRA, NBD and scale factor. Specification values across ISS, G&N, and S/C testing are as shown in Table II-1.

Table II-1 Gyro Coefficient Stability Criteria					
Coefficient	Units	D1	D2	D3	Max
Acceleration Drift along the IA (ADIA)	meru/g	17	33	40	100
Acceleration Drift along the SRA (ADSRA)	meru/g	14	21	25	40
Non-Acceleration Bias Drift (NBD)	meru	6	9	11	15

Gyro scale factor limits are ± 1750 ppm.

The maximum value of gyro performance parameters which can be compensated for by the computer is shown in Table II-2.

Table II-2		
Coefficient	Units	Max Value CM/IM
ADIA	meru/g	862
ADSRA	meru/g	862
NBD	meru	128.7

IMU GYRO COMPENSATION

The compensated PIPA data is used to compute the IRIG torquing necessary to cancel the NBD, ADIA and ADSRA gyro coefficients. The computations are

$$XIRIG = -ADIA \cdot PIPAX_C + ADSRAX \cdot PIPAY_C - NBDX \Delta t$$

$$YIRIG = -ADIA \cdot PIPAY_C + ADSRAY \cdot PIPAZ_C - NBDY \Delta t$$

$$ZIRIG = -ADIA \cdot PIPAZ_C - ADSRAZ \cdot PIPAY_C + NBDZ \Delta t$$

where

XIRIG, YIRIG, ZIRIG are gyro drift compensations

NBDX, NBDY, NBDZ are gyro bias drifts (an erasable load)

ADSRAX, ADSRAY, ADSRAZ are gyro drifts due to acceleration in spin reference axis
(an erasable load)

ADIA, ADIA, ADIAZ are gyro drifts due to acceleration in the input axis
(an erasable load)

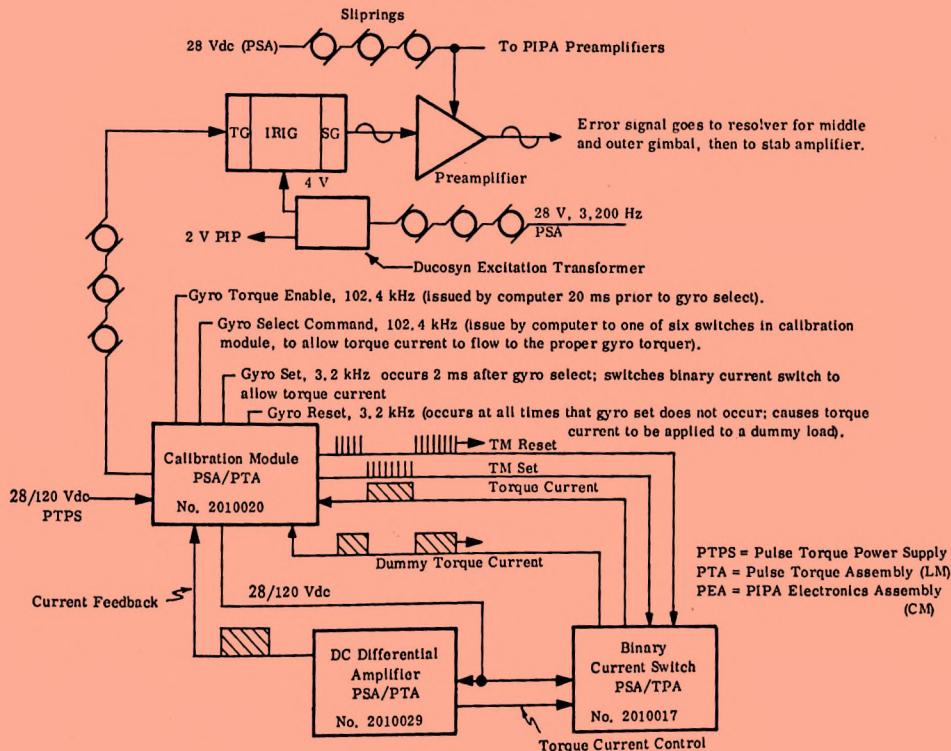
When the magnitude of any IRIG command exceeds two pulses, the commands are sent to the gyros.

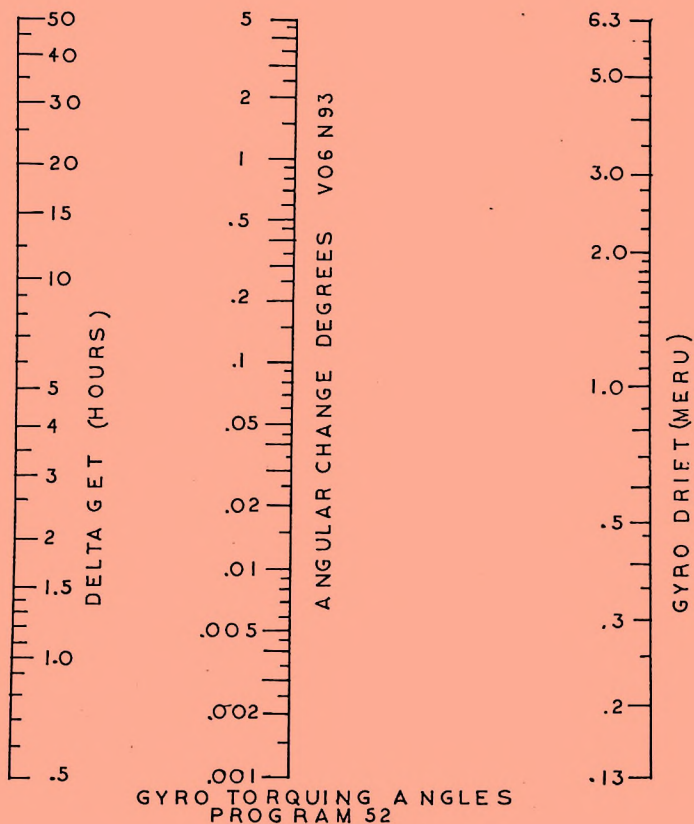
During free-fall only the NBDX, NBDY, NBDZ are the relevant coefficients and the routine is so ordered that only these terms are calculated for the gyro compensation.

The computer NBD registers are 1460, 1461, and 1462 for the X, Y, and Z gyros respectively.

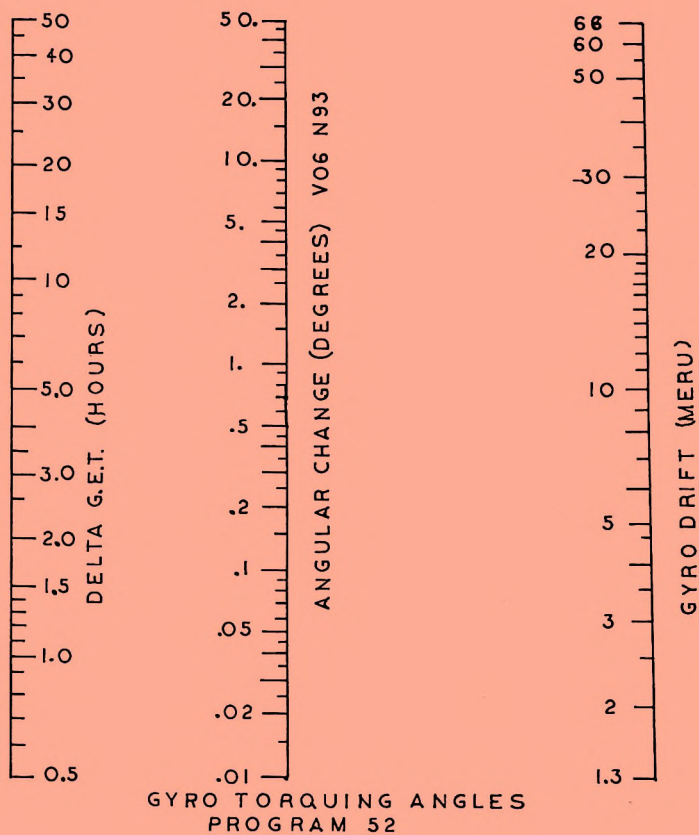
$$GYRO \text{ DRIFT } NBD = (.007835) (\text{Reg Contents in Decimal}) \text{ MERU}$$

GYRO PULSE TORQUING LOOP



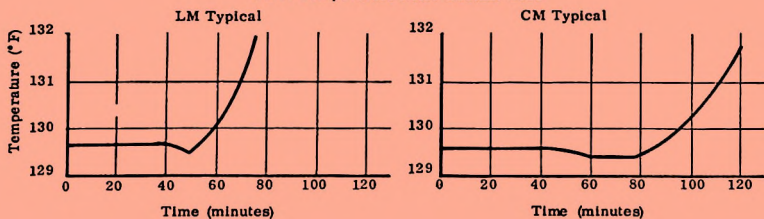
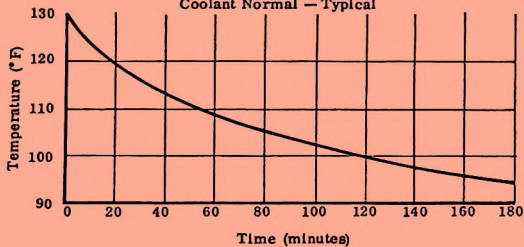


NOMOGRAPH FOR GYRO DRIFT(NBD)



TYPICAL IMU TEMPERATURE

PIPA Temperature After Coolant Loss

PIPA Temperature After Power Loss
Coolant Normal - Typical

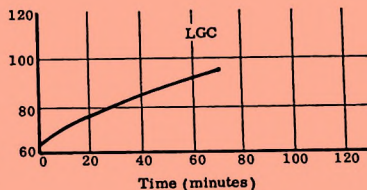
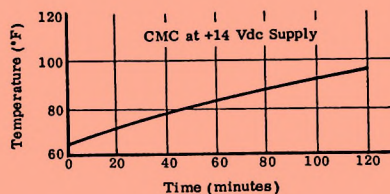
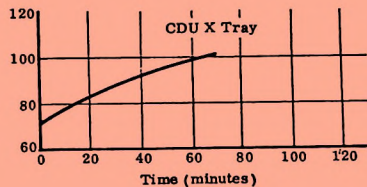
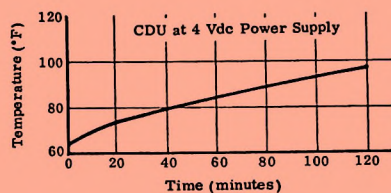
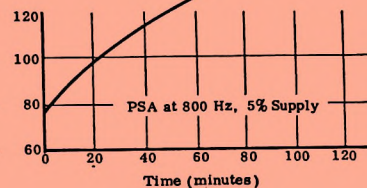
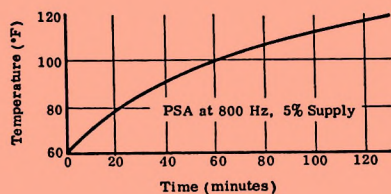
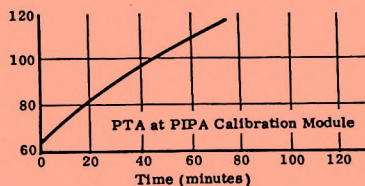
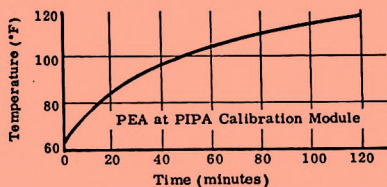
NOMINAL PARAMETERS

- PIPA Temperature — $130 \pm 1.5^{\circ}\text{F}$
- Low Temperature Alarm — $126 \pm 2.5^{\circ}\text{F}$ (PIPA Temperature)
- High Temperature Alarm — $135 \pm 2.5^{\circ}\text{F}$ (PIPA Temperature)
- Safety Thermostat Opens — $140^{+5}_{-2}^{\circ}\text{F}$ (PIPA Temperature)
- Safety Thermostat Hysteresis — $2 - 5^{\circ}\text{F}$

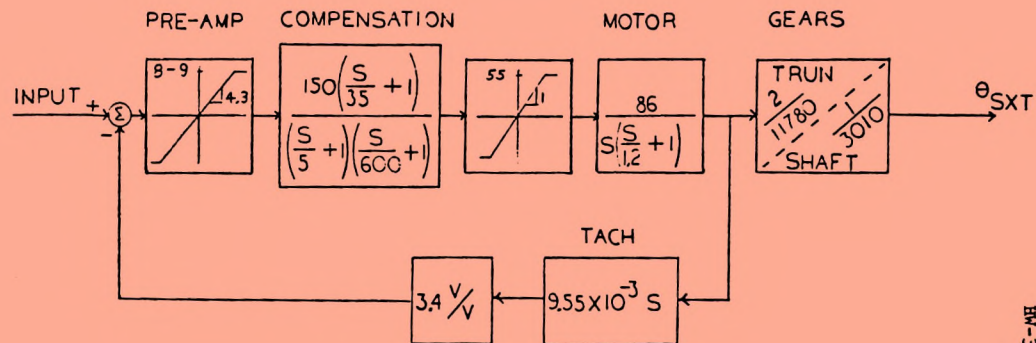
TYPICAL HEADER TEMPERATURES AFTER COOLANT LOSS

CM

LM

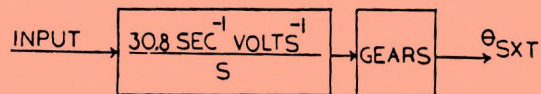




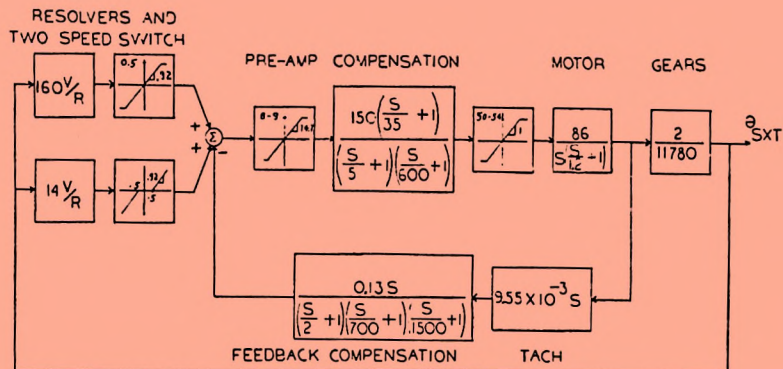


IM-39

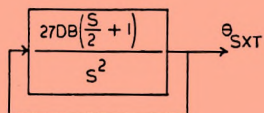
IDEAL VERSION



SXT INTEGRATORS

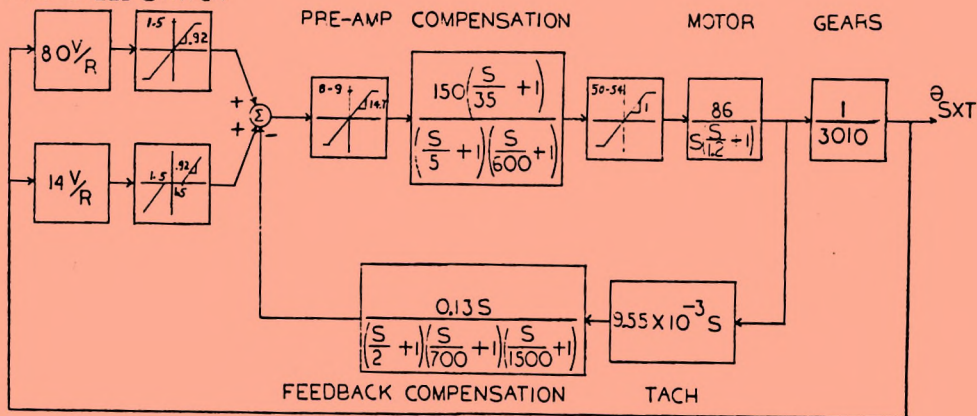


IDEAL VERSION



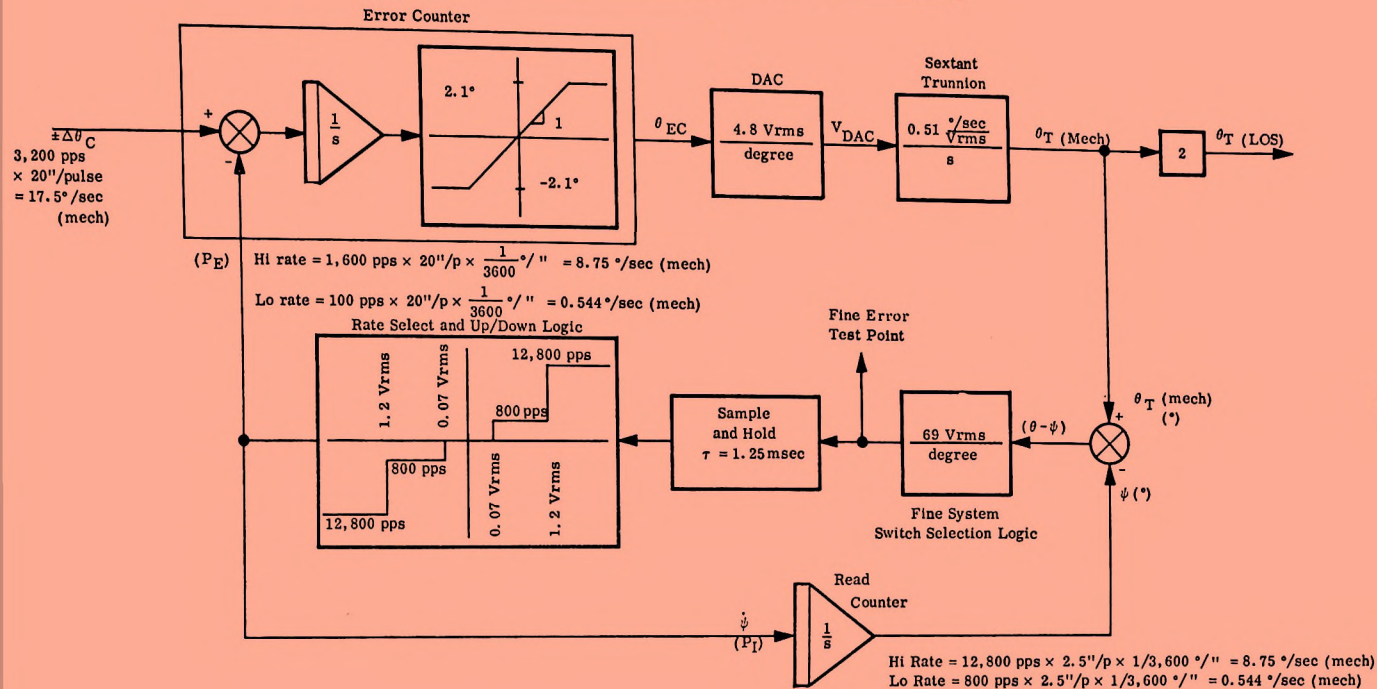
TRUNNION ZERO OPTICS SERVO

RESOLVERS AND
TWO SPEED SWITCH

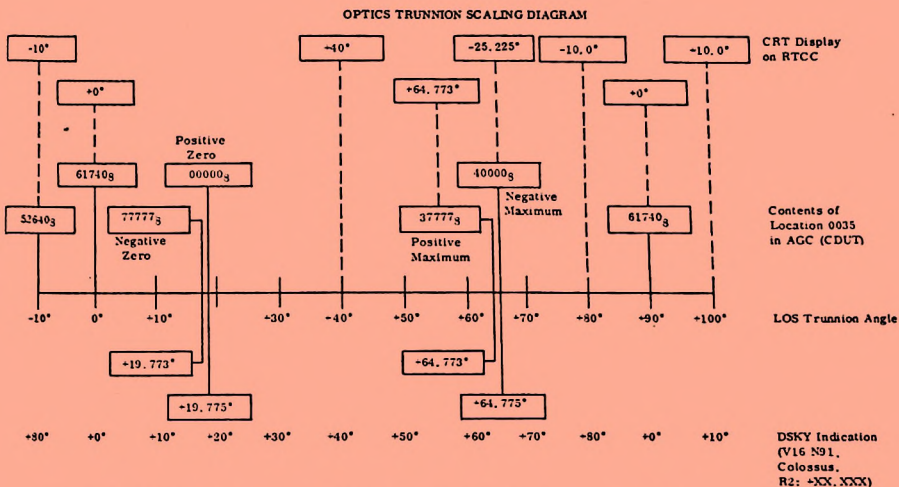


SHAFT ZERO OPTICS SERVO

TRUNNION COMPUTER OPERATE MODE FUNCTIONAL BLOCK DIAGRAM



OPTICS TRUNNION DRIVING LIMITATIONS



NOTE: CDUT (LOC 0035) is loaded with a -19.775° bias during ZERO OPTICS. This bias produces positive driving commands for angles up to -64.775° in the CMC mode. Without the bias, the CMC mode would drive the trunnion to the negative stop for command angles of 45° or greater.

Since optics trunnion scaling is 9.88 arc-sec per data bit, the 14-bit CDUT register in the Computer will overflow (40000g) at 45 degrees LOS*. This overflow is interpreted by the Computer as a negative angle when in reality it is not. By biasing the CDUT location (register 035) in the Computer by -19.775 degrees, the counter (035) will not overflow until an LOS angle of 64.775 degrees (40000g) is reached. In this case, the Computer (optics trunnion driving routine) interprets an overflow as -45.000 degrees + 19.775 degrees or -25.225 degrees.

The maximum usable trunnion angle is approximately 57 degrees. Beyond this angle the line of sight is completely vignettged.

*LOS = Line of Sight

The operational effects of trunnion biased overflow on the CMC Operate Optics mode is summarized below.

1. OPTICS CMC TRUNNION POSITIONING BETWEEN 0 AND 64.773 DEGREES

Any angle in this range can be commanded from within the 0 to 64.7-degree range and the Computer will drive the trunnion to the correct position. If an angle greater than 64.773 degrees is commanded from within the 0 to 64.7-degree range, the trunnion will be driven into the 0-degree mechanical stop. This is because the Computer thinks a negative angle has been commanded.

2. OPTICS CMC TRUNNION POSITIONING BETWEEN 64.775 AND 90 DEGREES

Any angle in this range can be commanded from within this range and the Computer will drive the trunnion to the correct position. If an angle less than 64.775 degrees is commanded from within the 64.775 to 90-degree range, the trunnion will be driven into the 90-degree mechanical stop. This is because the Computer thinks a positive angle has been commanded.

3. OPTICS LOOP AMBIGUITY AT 64.775 DEGREES

The Computer Operate Optics mode is a multiloop position followup servo operated under control of the Computer. The Computer supplies a maximum of 165 command pulses (1.83 degrees) each 480 milliseconds (ms) in the form of a 3,200 pps burst. The response of the Optics is then measured by the Computer once each 480 ms and appropriate correction commands are issued. This sample data loop has an ambiguity at 64.775 degrees for the following two cases.

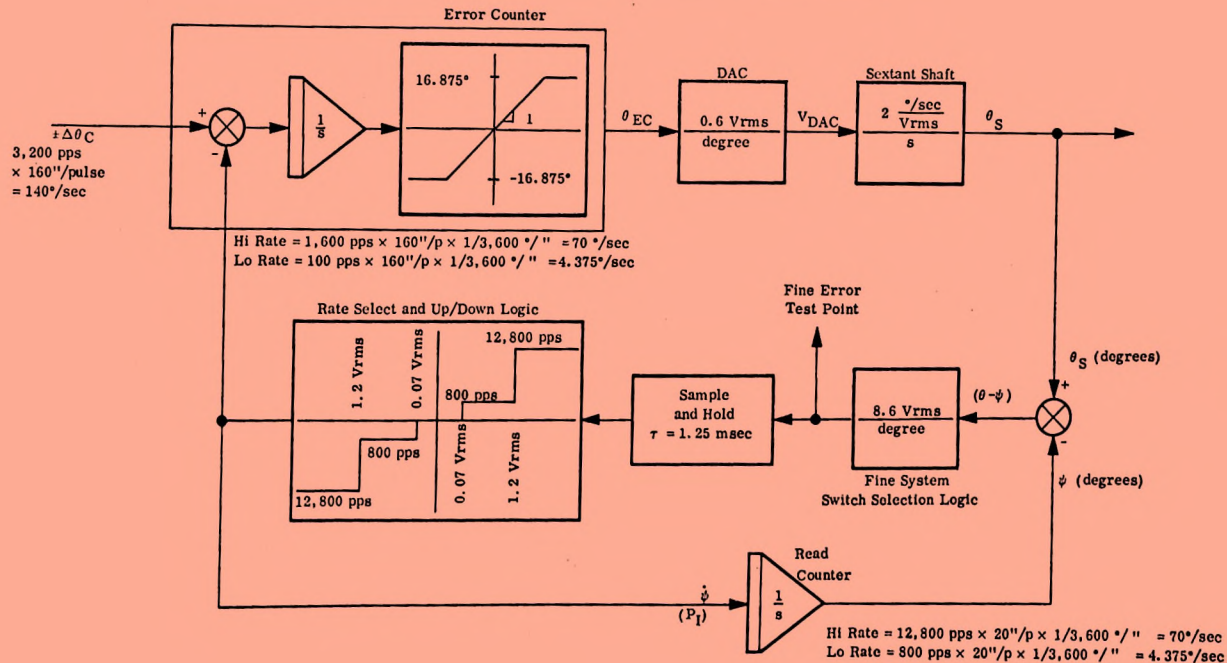
a. Case 1: Initial Trunnion Between 0 and 64.773 Degrees and Angle Close to 64.773 Degrees is Commanded

The Optics will begin driving correctly. If a servo overshoot beyond 64.773 degrees occurs, the CDUT will overflow with the result that the trunnion is driven into the 90-degree mechanical stop.

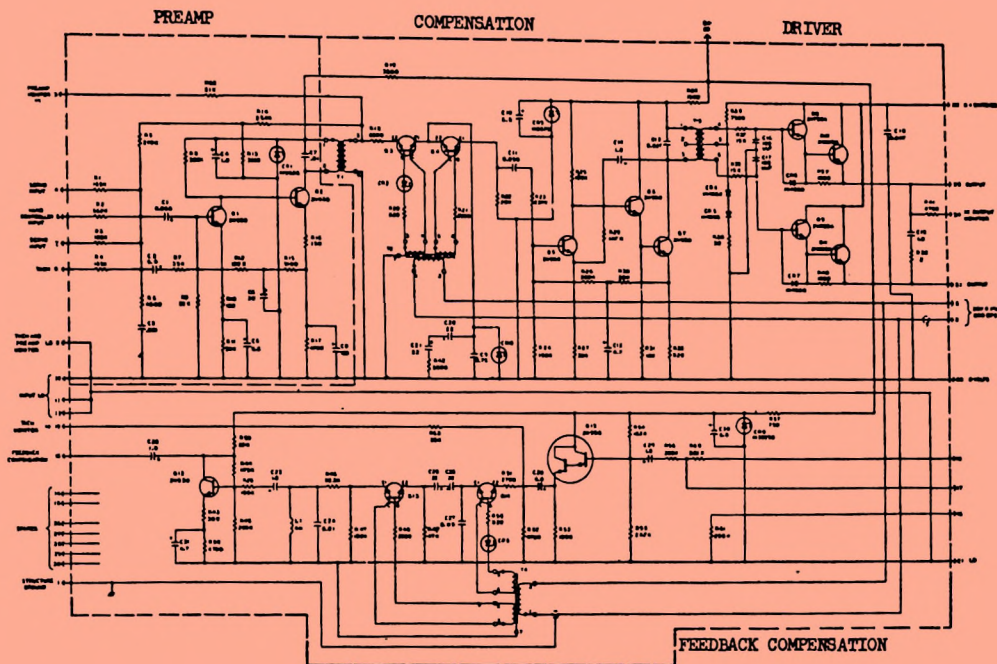
b. Case 2: Initial Trunnion Between 64.775 and 90 Degrees and Angle Close to 64.775 Degrees is Commanded

If the servo overshoot is of sufficient magnitude such that a CDUT angle of less than 64.775 degrees is detected, the trunnion is driven into the 0-degree mechanical stop.

SHAFT COMPUTER OPERATE MODE FUNCTIONAL BLOCK DIAGRAM



OPTICS MOTOR DRIVE AMPLIFIER



BLOCK II SERVO PARAMETERS

MOTOR SPEEDS VERSUS LOS RATES

LOS RATES		MOTOR SPEEDS			
TRUNNION	SHAFT	SXT		SCT	
		rpm	rad/sec	rpm	rad/sec
10.0 deg/sec		9817	1028	4960	519
1.0 deg/sec		982	103	496	51.9
0.1 deg/sec		98	10.3	49.6	5.2
25.0 deg/sec		6.8	0.71	3.4	0.36
19.5 deg/sec		9870	1024	9670	1013
2.0 deg/sec		1003	105	992	104
0.2 deg/sec		100	10.5	99	10.4
50.0 deg/sec		7.0	0.73	6.9	0.72

SERVO SENSITIVITY

	CALCULATION	SENSITIVITY
<u>SXT TRUNNION</u>		
Hand Controller	$105 \frac{\text{mv}}{\text{mv}} \times 205 \times \frac{2}{3.4} = 11,780$	$1.08 \frac{\text{sec/sec}}{\text{mv}}$
Tachometer	3.4×1.08	$3.68 \frac{\text{sec/sec}}{\text{mv}}$
<u>SXT SHAFT</u>		
Hand Controller	$105 \frac{\text{mv}}{\text{mv}} \times 205 \times \frac{1}{3010}$	$2.1 \frac{\text{sec/sec}}{\text{mv}}$
Tachometer	3.4×2.1	$7.14 \frac{\text{sec/sec}}{\text{mv}}$

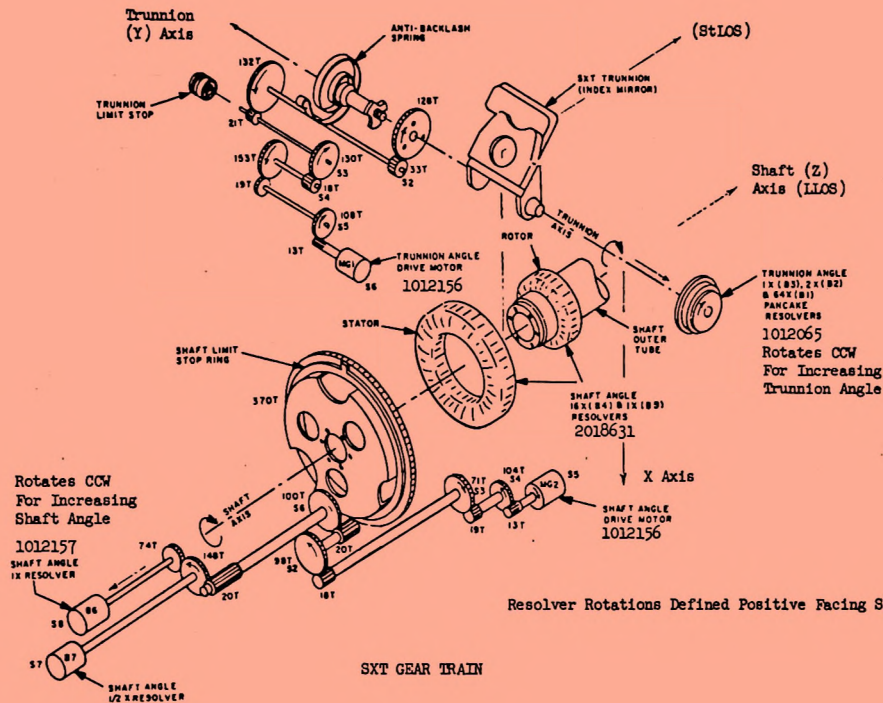
MAXIMUM CREEP RATES DUE TO RESIDUALS

	MAXIMUM RESIDUAL	SERVO SENSITIVITY	THEORETICAL MAXIMUM RATE
<u>SXT TRUNNION</u>			
Hand Controller	3 mv rms PS 2014550	$1.08 \frac{\text{sec/sec}}{\text{mv}}$	$3 \frac{\text{sec/sec}}{\text{mv}}$
Tachometer	15 mv rms PS 2016207	$3.70 \frac{\text{sec/sec}}{\text{mv}}$	$55 \frac{\text{sec/sec}}{\text{mv}}$
<u>SXT SHAFT</u>			
Hand Controller	3 mv rms PS 2014550	$2.1 \frac{\text{sec/sec}}{\text{mv}}$	$6 \frac{\text{sec/sec}}{\text{mv}}$
Tachometer	15 mv rms PS 2016207	$7.2 \frac{\text{sec/sec}}{\text{mv}}$	$108 \frac{\text{sec/sec}}{\text{mv}}$

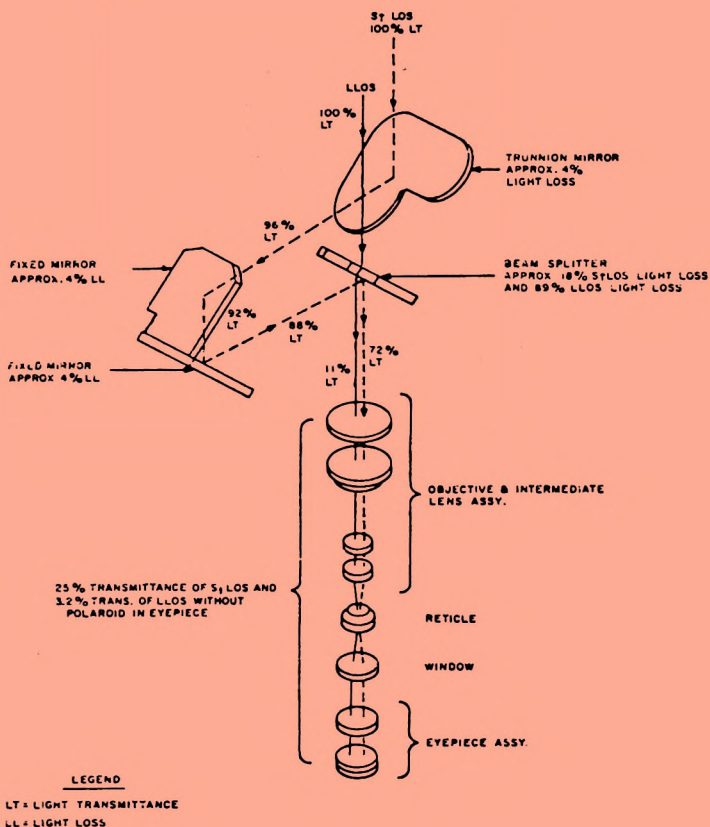
OPTICAL SUBSYSTEM PHASING (ROTATIONS DEFINED FACING SHAFT)

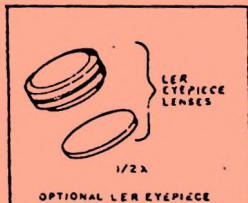
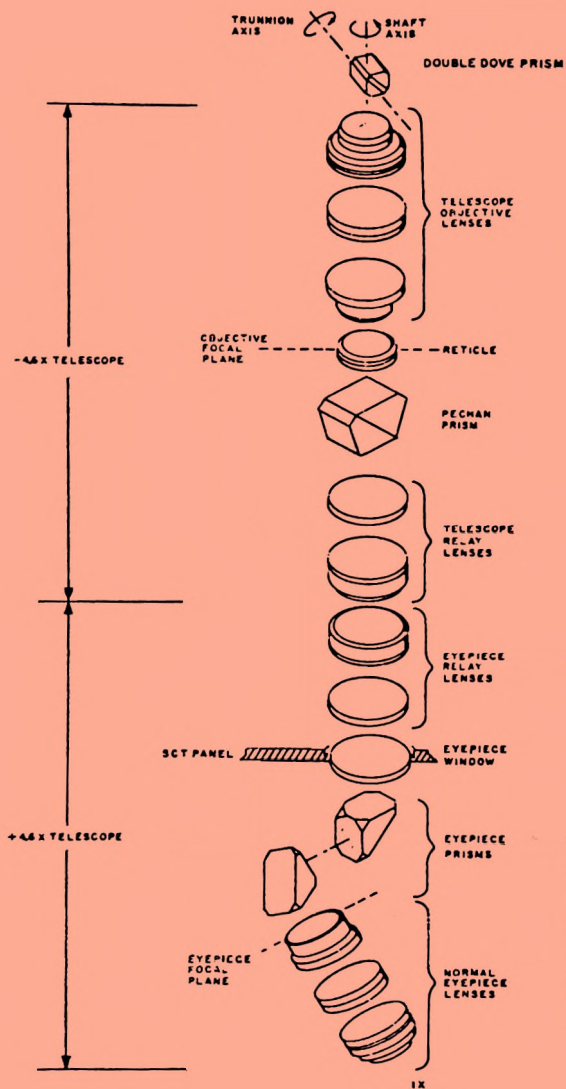
Integrator	Direct Mode		Resolved Mode*		MDA Input	Motor Rotation	Tach Output	Resolver Rotation	LOS Angle
	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position					
<u>SXT TRUNNION</u>	DOWN	0°	UP	180°	0°	CCW	180°	CCW	Decreasing
	UP	180°	DOWN	0°	180°	CW	0°	CCW	Increasing
<u>SCT TRUNNION (slaved to SXT TRUNNION)</u>	DOWN	0°	UP	180°	180°	CW	0°	CCW	Decreasing
	UP	180°	DOWN	0°	0°	CCW	180°	CW	Increasing
<u>SXT SHAFT</u>	Left	0°	Right	180°	0°	CCW	180°	CCW	Decreasing
	Right	180°	Left	0°	180°	CW	0°	CW	Increasing
<u>SCT SHAFT (slaved to SXT Shaft)</u>	Left	0°	Right	180°	180°	CW	0°	CCW	Decreasing
	Right	180°	Left	0°	0°	CCW	180°	CW	Increasing

*1st quadrant only $0 < \theta < 90^\circ$



Resolver Rotations Defined Positive Facing Shaft





NOUN 70 CODES

R1: CELESTIAL BODY CODE 0000E P22 R2: LANDMARK DATA

00 PLANET	27 ALKAIID	LANDING SITE	10001
01 ALPHERATZ	30 MENKENT	KNOWN SITE	10000
02 DIPHDA	31 ARCTURUS	UNKNOWN SITE	20000
03 NAVI	32 ALPHECCA		
04 ACHERNAR	33 ANTARES	P23 R1: 0000E STAR ID	
05 POLARIS	34 ATRIA		
06 ACAMAR	35 RASALHAGUE	R2: 00000 LDMK ID	
07 MENKAR	36 VEGA	1 EARTH, 2 LUNAR	
10 MIRFAK	37 NUNKI		
11 ALDEBARAN	40 ALTAIR	R3: 00000 HORIZ ID	
12 RIGEL		C=1 EARTH, 2 LUNAR	
13 CAPELLA		D=1 NEAR, 2 FAR	
14 CANOPUS			
15 SIRIUS			
16 PROCYON			
17 REGOR	41 DABIH		
20 DNOCES	42 PEACOCK		
21 ALPHARD	43 DENEK		
22 REGULUS	44 ENIF		
23 DENEKOLA	45 FOMALHAUT		
24 GIENAH	46 SUN		
25 AGRUX	47 EARTH		
26 SPICA	50 MOON		

P23 (CALIBRATE FIRST) CMC-FREE
 OPT ZRO-MAN-DIR-LO
 MAN TO ACQUIRE STAR IN SXT
 F05 70 (STAR, LDMK, HOR ID) LD & PRO
 F50 25 00202 E F59
 OPT ZRO-OFF-MARK
 F06 87 (R2=BIAS)
 V32 TIL 2 <.003' PRO V37E 23E
 OPT ZRO, OPT MODE-CMC
 F05 70 (H0EN, I20F, 210LN, 220F) PRO
 F50 25 00202 PRO
 F50 18 CMC, AUTO-PRO
 WHEN MANEUVER COMPLETE. E
 F59-OPT ZRO OFF-E 06 92
 (FREE-IF MIC REQD)
 OPT-MAN-F51-MARK
 F50 25 00016 -PRO
 F05 71 VERIFY & PRO
 F06 49 Δ R, I, Δ V, I, RCD
 REJ-V37E 23E, ACC-PRO
 F37 23E NEXT STAR, 00E

P22 (AUTO OPT)
 RESOLVED-MED-ZRO-CMC
 F06 45 (R3-MGA) PRO
 F05 70 LD 10000CP/1000HRS PRO
 F06 89 LAT, LONG/2, ALT (CP ONLY)
 OPT ZRO-OFF PRO
 06 92 SHAFT TRUN MODE-MAN
 F51 5 MARKS 30 SEC APART
 F50 25 00016-PRO
 F05 71 CONFIRM-PRO
 F06 89 CONFIRM-PRO
 F06 49 Δ R, Δ V (INM, IFPS)
 WAIT 30 SEC, PRO OR V32E
 F06 89 RCD, V34E

P52 (NO PLANETS) CMC-FREE
 OPT ZRO, OPT MODE-CMC
 F04 06: V22E LD 1 OR 3-PRO
 PREF, NOM, REFSMMAT, LDG SITE

↓
 F06 22 (NEW GIMBAL ANG)
 PRO IF MGA OK, OR MANEUVER
 F50 25 00013 (TOR)
 GYRO TOR-E
 COARSE ALIGN-PRO
 IG 20 WHILE MOVING
 F50 25 00014 (ALIGN CK)
 (TO BYPASS, E TO F37)
 PRO (FOR OPT VERIF)
 F50 25 00015 STAR SEL
 (TO ACQ MANUALLY, E)
 PRO-PICAPAR (ZRO-OFF)
 F01 70 LD STAR PRO
 06 92 SHAFT & TRUN ↑
 OPT-MAN-F51-MARK
 F50 25 00016 PRO
 F01 71 STAR#-PRO 1ST, 2ND
 F06 05 STAR ANG DIFF ◀
 ACC, PRO (REJ, V32E)
 F06 93 TOR ANGLES
 TOR, PRO, BYPASS, V32E
 F50 25 00014, E (F37) RECK PRO

DAP	V48E	A/C	X	B/D	X	D	B	RATE
0-NONE	0	FAIL	0	FAIL	0	0-0.5		.05°/S
1-CSM	1	USE	1	USE	1	1-5.0		.2°/S
2-CSM/LM								.5°/S
3-CSM/SIVB						6-CSM/ASC		2.0°/S
ROLL	QUAD	A	B	C	D			
0	B/D	0	FAIL	0	FAIL	0	FAIL	0
1	A/C	1	USE	1	USE	1	USE	1

CHECKLIST REF CODES (V50N25)

R1 CODE	ACTION
00013	PERFORM COARSE ALIGN
00014	PERFORM FINE ALIGN
00015	ACQUIRE CELESTIAL BODY
00016	TERMINATE MARKS
00041	CM/SM SEP
00062	KEY CMC TO STBY
00202	G&N AUTO MNVR
00204	SPS GMBL TRIM

ALARM CODES (V05N09)

CODE	DESCRIPTION	CORRECTIVE ACTION
00110	MARK REJECT UNNECESSARY	RSET/CONT
00112	MARK NOT ACCEPTED	RSET/CONT
00113	NO INBITS	RSET/REATTEMPT ENTRY
00114	MARK NOT DESIRED	RSET/CONT
00115	TOR REQ-OSS NOT IN CMC	SET OSS TO CMC/RSET/CONT
00116	OSS SW BEFORE 15 SEC	SET OSS TO ZERO/RSET/CONT
00117	TOR REQ-OSS NOT AVAIL	RSET
00120	TOR REQ-OSS NOT ZEROED	SET OSS TO ZERO/RSET/CONT
00121	CDUS NO GO AT MARK	RSET/REPEAT MARK
00122	MARKING NOT CALLED FOR	RSET/CONT
00124	NO SOLUTION TO TPI	RSET/V32E
00205	PIPA SATURATED	RSET/SWITCH TO SCS
00206	ZERO ENCODE NOT ALLOWED	RSET/V41/V40
00211	COARSE ALIGN ERROR	RSET/REPEAT AND/OR FA CK
00217	ISS MODE SWITCH FAIL	RSET/REINITIATE PROG, CONT

00220	IMU NOT ALIGNED	RSET/PS1 OR SET FLAG
00401	DESIRED ANGLES GMBL LOCK	RSET/AVOID GMBL LOCK
00404*	TARGET OUT OF 90 DEG	RSET/MNVR NEW TGT
00405	TWO STARS NOT AVAIL	MNVR/RSET/V32E/NEW STAR
00406	P20 NOT OPERATING	RSET
00407	TARGET OUT OF 50 DEG	RSET/MNVR
00421	W MATRIX OVERFLOW	RSET/NOTIFY MSFN, CONT
20430**	ACC OVERFLOW IN INTEG	RSET/REINITIATE PROG
00600	IMAG ROOTS FIRST ITER	
00601	HP POST CSI LOW	
00602	HP POST CDH LOW	
00603	TIG CSI-CDH < 10 MIN	
00604	TIG CDH-TPI < 10 MIN	
00605	ITER > LOOP MAX	
00606	ΔV EXCEEDS MAX	
20607**	NO SOL TIME 8 OR R	
00611	NO TIG FOR ELEV ANGLE	
01105	DOWN TEL TOO FAST	
01106	UP TEL TOO FAST	
31207*	NO VAC AREA FOR MARKS	
31211*	ILLEGAL RUPT OF EXT D VERB	
21302**	NO SOLUTION	
01407	VG INCREASING	
01426	IMU UNSAT	
01427	IMU REVERSED	
01520	V37 NOT ALLOWED	
21521**	POT ILLEG SELECT	
01703	CANNOT INTEG SV TO TIG	

RSET/PS1 OR SET FLAG
RSET/AVOID GMBL LOCK
RSET/MNVR NEW TGT
MNVR/RSET/V32E/NEW STAR
RSET
RSET/MNVR
RSET/NOTIFY MSFN, CONT
RSET/REINITIATE PROG

RSET/V32E ADJUST
INPUT PARAMETERS

RSET/REINITIATE PROG
PRO NEW ELEV/RSET
RSET
RSET/RETRANSMIT
RSET/TERM, REINITIATE P51/P52
RSET/TERM, REINITIATE PROG
RSET/NOB, NOTIFY MSFN, CONT
TERMINATE THRUST/RSET
RSET/REALIGN IMU
RSET/CONT/O DEG = LIFT DN
RSET/RESELECT V37
RSET/REINITIATE PROG
RSET/AUTO TIG SLIP

* PRIORITY ALARM * RESTART ** POODOO

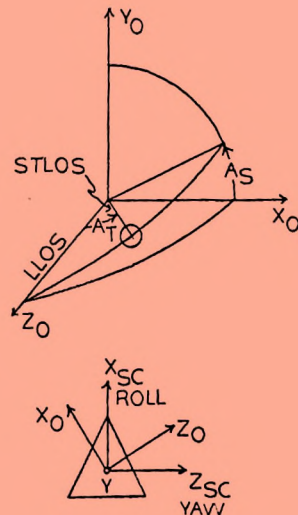
SXT FIELD OF VIEW

A diagram of a circular field of view. In the center is a crosshair symbol. Below the circle, a horizontal double-headed arrow indicates a width of 1.8 DEG. To the left of the circle, a vertical line with two arrows pointing towards the circle's edge is shown.

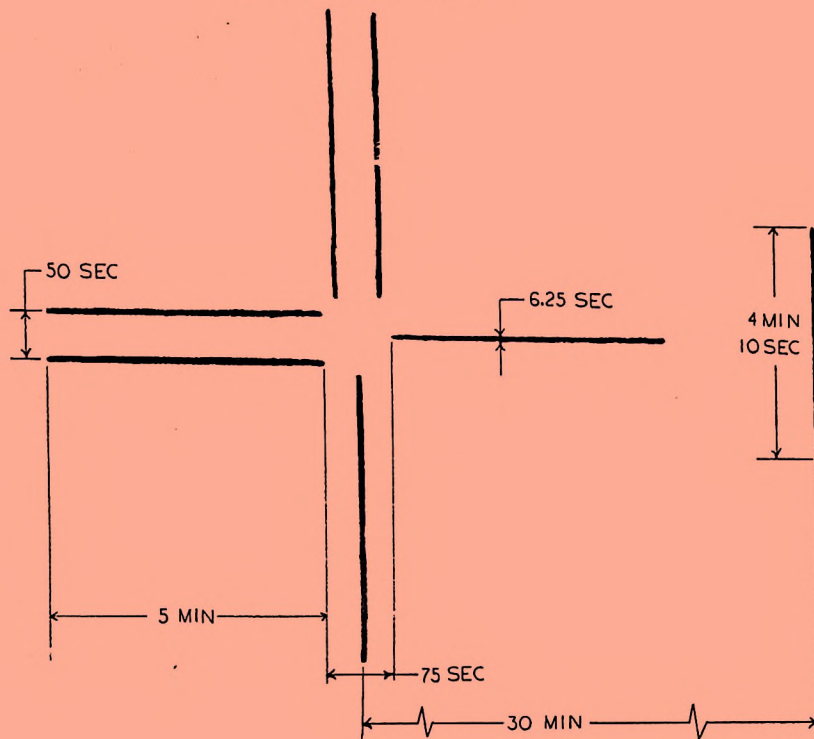
← 1.8 DEG →

TRUNNION 0(0,-10) TO 90(10,0) DEG
SHAFT 270(0,-10) TO -270(-10,0) DEG

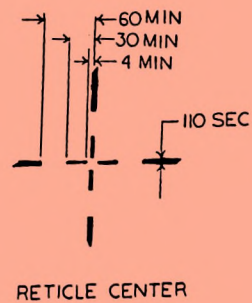
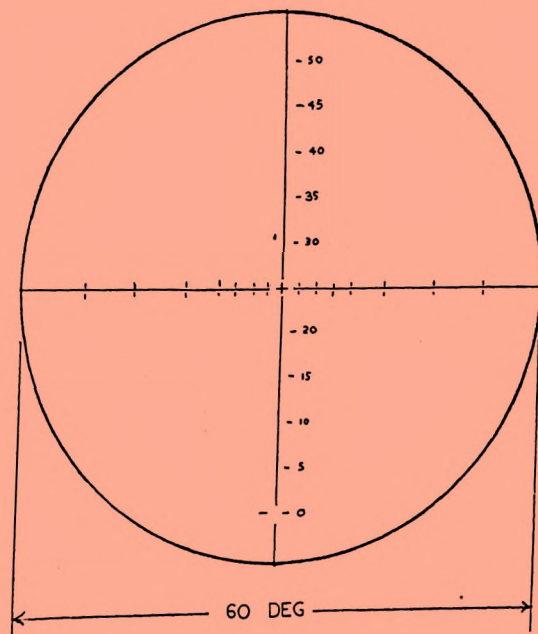
TRUNNION 0(0,-10) TO 90(10,0) DEG
SHAFT 270(0,-10) TO -270(-10,0) DEG



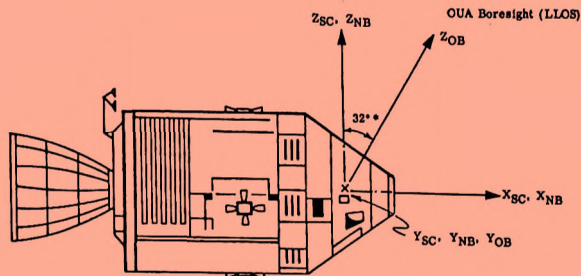
SXT VACUUM RETICLE



SCT RETICLE



OVA LINE OF SIGHT TO IMU STABLE MEMBER TRANSFORMATIONS



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos A_I & 0 & \sin A_I \\ 0 & 1 & 0 \\ -\sin A_I & 0 & \cos A_I \end{bmatrix} \begin{bmatrix} \cos A_M & -\sin A_M & 0 \\ \sin A_M & \cos A_M & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos A_O & -\sin A_O \\ 0 & \sin A_O & \cos A_O \end{bmatrix} \begin{bmatrix} \cos 32^\circ & 0 & \sin 32^\circ \\ 0 & 1 & 0 \\ -\sin 32^\circ & 0 & \cos 32^\circ \end{bmatrix} \begin{bmatrix} \cos A_S & -\sin A_S & 0 \\ \sin A_S & \cos A_S & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos A_T & 0 & \sin A_T \\ 0 & 1 & 0 \\ -\sin A_T & 0 & \cos A_T \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ St \ LOS \end{bmatrix}$$

* Nominal Angle 32° 31' 23"

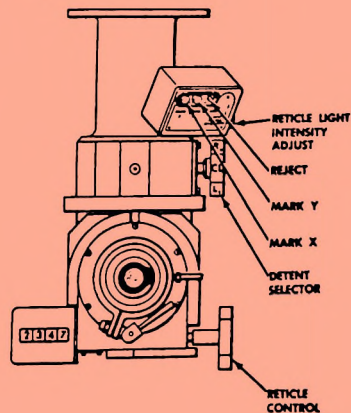
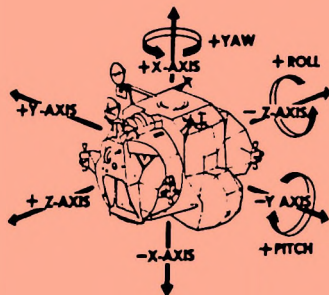
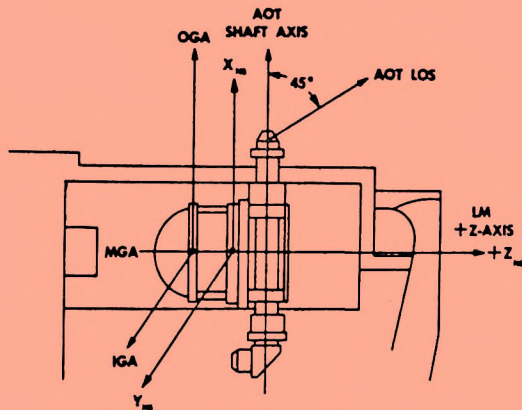
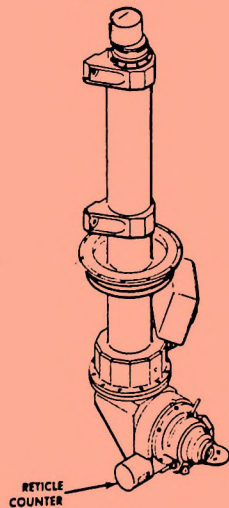
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos A_I & 0 & \sin A_I \\ 0 & 1 & 0 \\ -\sin A_I & 0 & \cos A_I \end{bmatrix} \begin{bmatrix} \cos A_M & -\sin A_M & 0 \\ \sin A_M & \cos A_M & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos A_O & -\sin A_O \\ 0 & \sin A_O & \cos A_O \end{bmatrix} \begin{bmatrix} \cos 32^\circ & 0 & \sin 32^\circ \\ 0 & 1 & 0 \\ -\sin 32^\circ & 0 & \cos 32^\circ \end{bmatrix} \begin{bmatrix} \cos A_S & \sin A_T \\ \sin A_S & \sin A_T \\ \cos A_T \end{bmatrix}$$

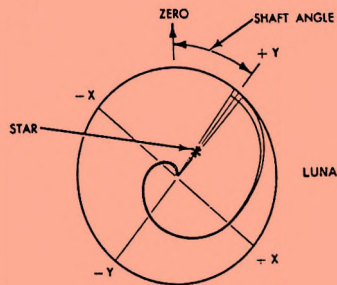
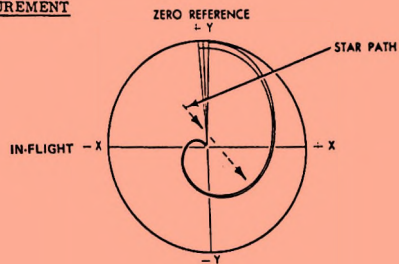
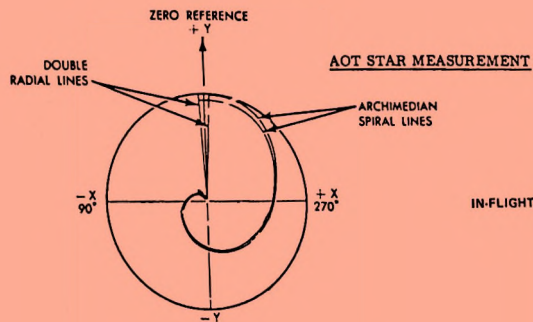
where

A_I, A_M and A_O are the inner, middle, and outer gimbal angles as indicated by the CMG

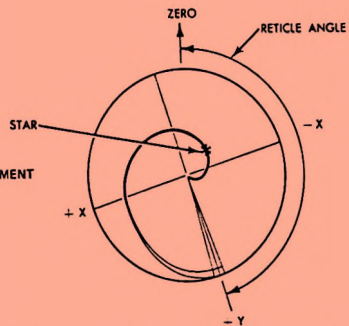
A_S and A_T are the SXT LOS shaft and trunnion angles

ALIGNMENT OPTICAL TELESCOPE

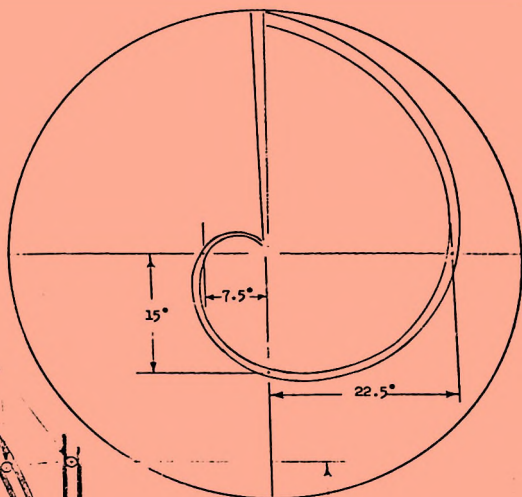




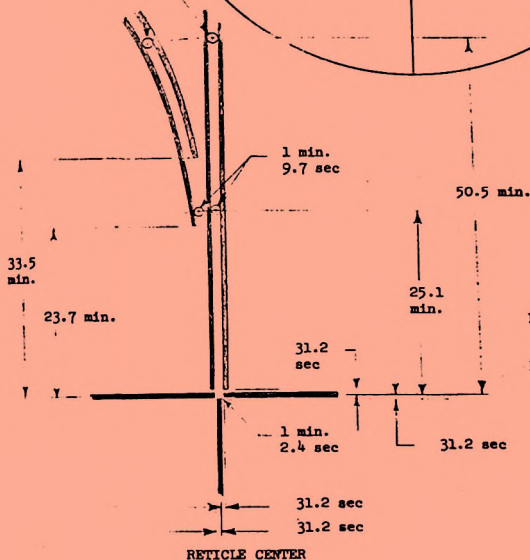
LUNAR SURFACE ALIGNMENT



BW-61



1 min.
15.9 sec

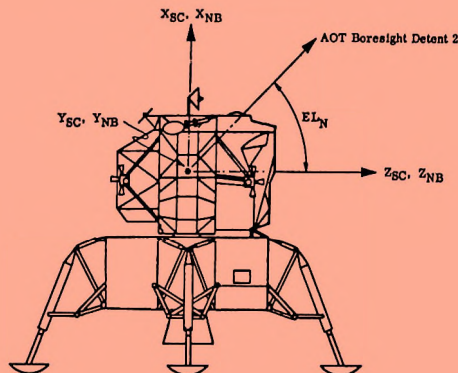


Line Width = 10.4 - 52 sec

Line Width Uniform Within 20.8 sec

AOT RETICLE

AOT LINE OF SIGHT TO IMU STABLE MEMBER TRANSFORMATIONS



Orbital Alignment

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AZ_N & \sin AZ_N \\ 0 & -\sin AZ_N & \cos AZ_N \end{bmatrix} \begin{bmatrix} \cos EL_N & 0 & \sin EL_N \\ 0 & 1 & 0 \\ -\sin EL_N & 0 & \cos EL_N \end{bmatrix} \begin{bmatrix} \cos R_N & -\sin R_N & 0 \\ \sin R_N & \cos R_N & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{\text{Reticle Plane}} \\ Y_{\text{Reticle Plane}} \\ LOS \end{bmatrix}$$

N = Detent Position

$$R_N = AZ_2 - AZ_N$$

(Note: R_N is a correction for the apparent rotation of the star field about the optical axis when the AOT is moved to different detent positions.)

Lunar Surface Alignment

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AZ_N & \sin AZ_N \\ 0 & -\sin AZ_N & \cos AZ_N \end{bmatrix} \begin{bmatrix} \cos EL_N & 0 & \sin EL_N \\ 0 & 1 & 0 \\ -\sin EL_N & 0 & \cos EL_N \end{bmatrix} \begin{bmatrix} \cos R_N & -\sin R_N & 0 \\ \sin R_N & \cos R_N & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos AS & -\sin AS & 0 \\ \sin AS & \cos AS & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos AT & 0 & \sin AT \\ 0 & 1 & 0 \\ -\sin AT & 0 & \cos AT \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ LOS \end{bmatrix}$$

where

AI, AM, and AO are the inner, middle, and outer gimbal angles as indicated by the LGC

AZ_N and EL_N are the AOT azimuth and elevation angles at the Nth detent.

$EL_N \approx 45^\circ$, $N = 1, 2, \dots, 6$; $AZ_1 \approx -60^\circ$; $AZ_2 \approx 0^\circ$; $AZ_3 \approx 60^\circ$; $AZ_4 \approx 120^\circ$; $AZ_5 \approx 180^\circ$; $AZ_6 \approx -120^\circ$

AS = Y Reticle Angle

$$AT = \frac{360 + S \text{ Reticle Angle} - Y \text{ Reticle Angle}}{12}$$

CSM DAP CONTROL

Flashing V04 N46

	A	B	C	D	E
Register 1:	CONFIG	XTAC	XTBD	DB	RATE

CONFIG - Vehicle Configuration

- 0 = No DAP is requested
- 1 = CSM alone
- 2 = CSM and LM
- 3 = SIVB, CSM and LM (SIVB control)
- 6 = CSM and LM (ascent stage only)

XTAC - X-Translations Using Quads AC

- 0 = Do not use AC
- 1 = Use AC

XTBD - X-Translations Using Quads BD

- 0 = Do not use BD
- 1 = Use BD

DB - Angular Deadband for Attitude Hold and Automatic Maneuvers

- 0 = ± 0.5 degree
- 1 = ± 5.0 degrees

RATE - Rotational Rate for RHC in HOLD or AUTO Mode and for Automatic Maneuvers.

- 0 = 0.05 deg/s
- 1 = 0.2 deg/s
- 2 = 0.5 deg/s
- 3 = 4.0 deg/s

Register 2:	AC Roll	Quad A	Quad B	Quad C	Quad D
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AC Roll - Roll-Jet selection

- 0 = Use BD roll Quads
- 1 = Use AC roll Quads

A, B, C, D - Quad fails

- 0 = Quad has failed
- 1 = Quad operational

Flashing V06 N47

Register 1: CSM weight in pounds

Register 2: LM weight in pounds

Flashing V06 N48

Register 1: Pitch-trim gimbal offset, in 1/100 degree

Register 2: Yaw-trim gimbal offset, in 1/100 degree

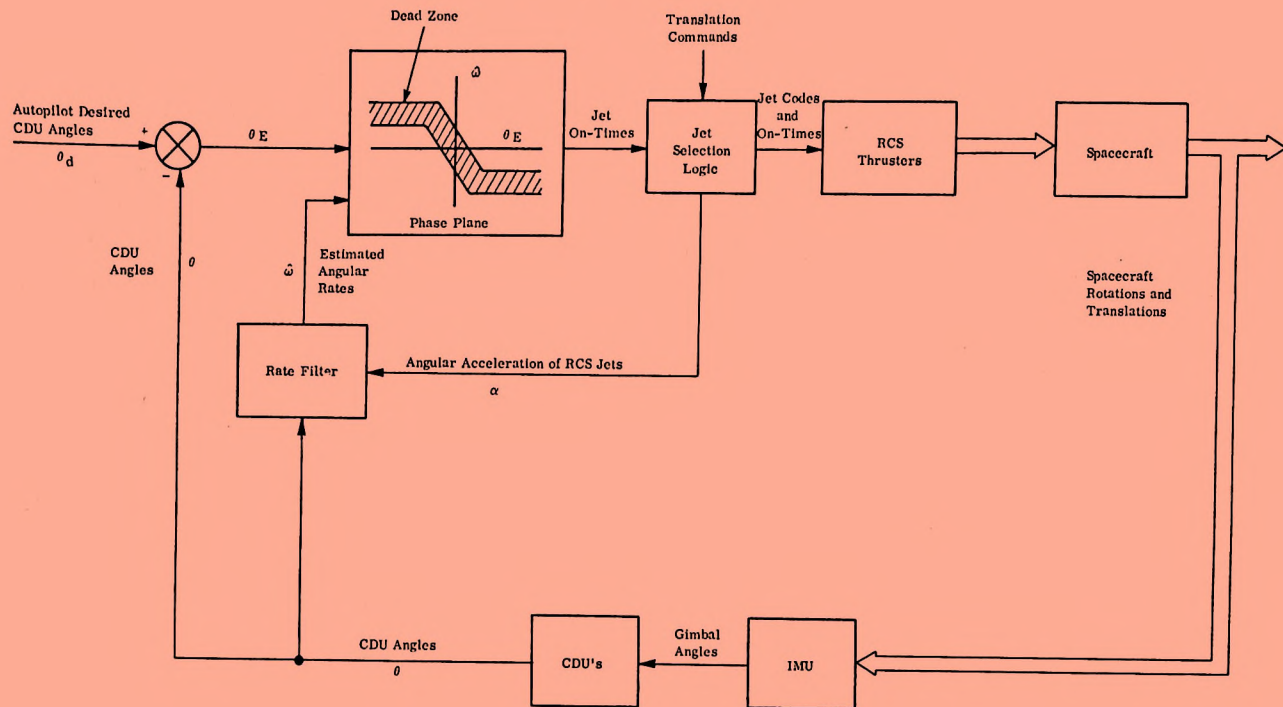
AUTOMATIC MODE

- Automatic three-axis rotation.
- Manual three-axis rotation and translation
- Attitude hold to program or manual defined attitude.
- Automatic rate damping.

ATTITUDE HOLD MODE

- Manual three-axis rotation and translation.
- RHC produces a rotational rate as specified by N46 while out of detent.
- Attitude hold to attitude selected via hand controller.
- Automatic rate damping.

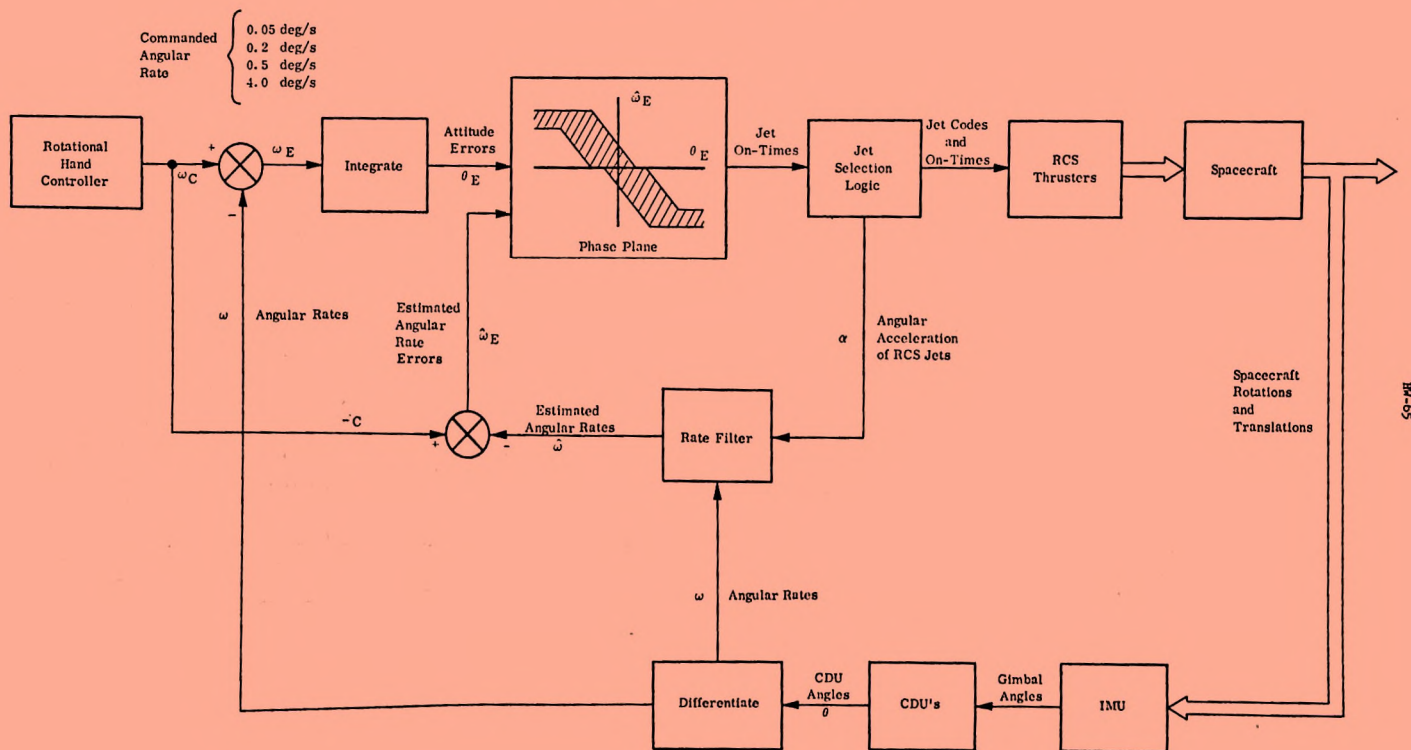
CSM DIGITAL AUTOPILOT
COASTING FLIGHT
AUTOMATIC ATTITUDE HOLD MODE



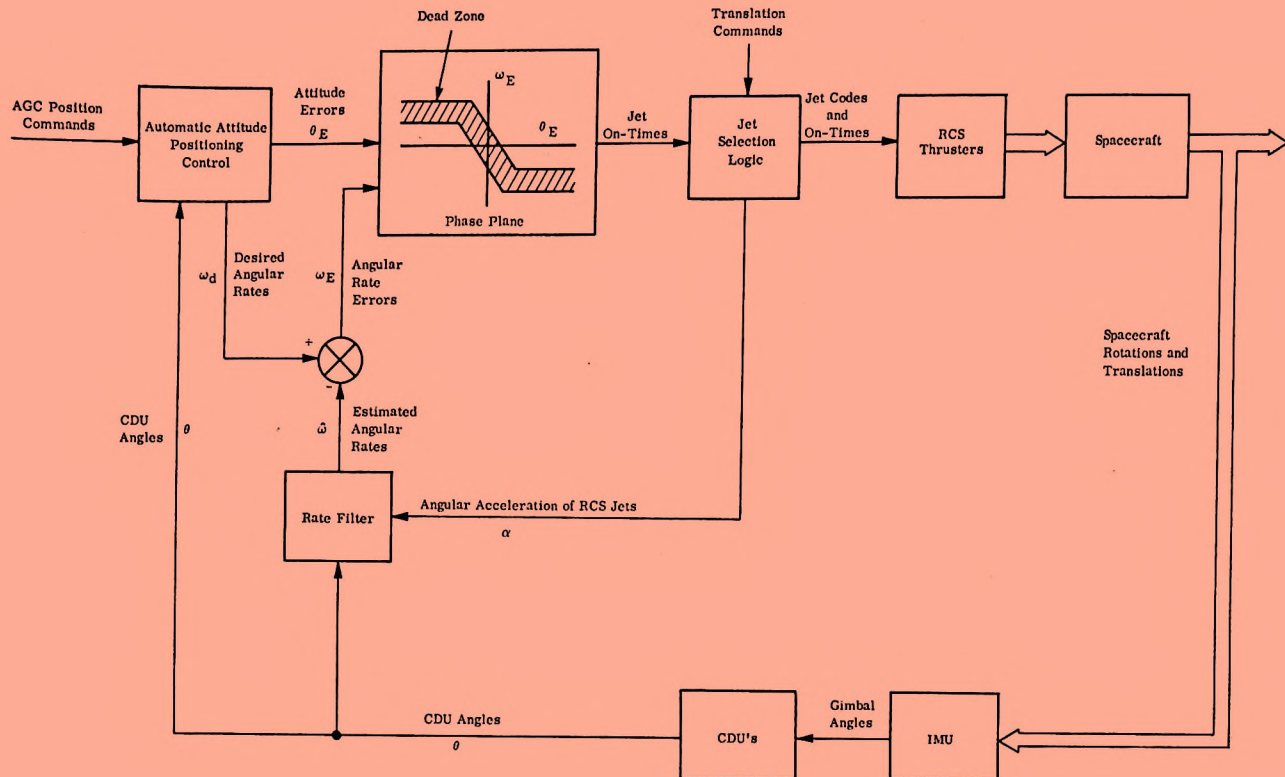
CSM DIGITAL AUTOPILOT
COASTING FLIGHT
MANUAL ANGULAR RATE CONTROL MODE

Commanded
Angular
Rate

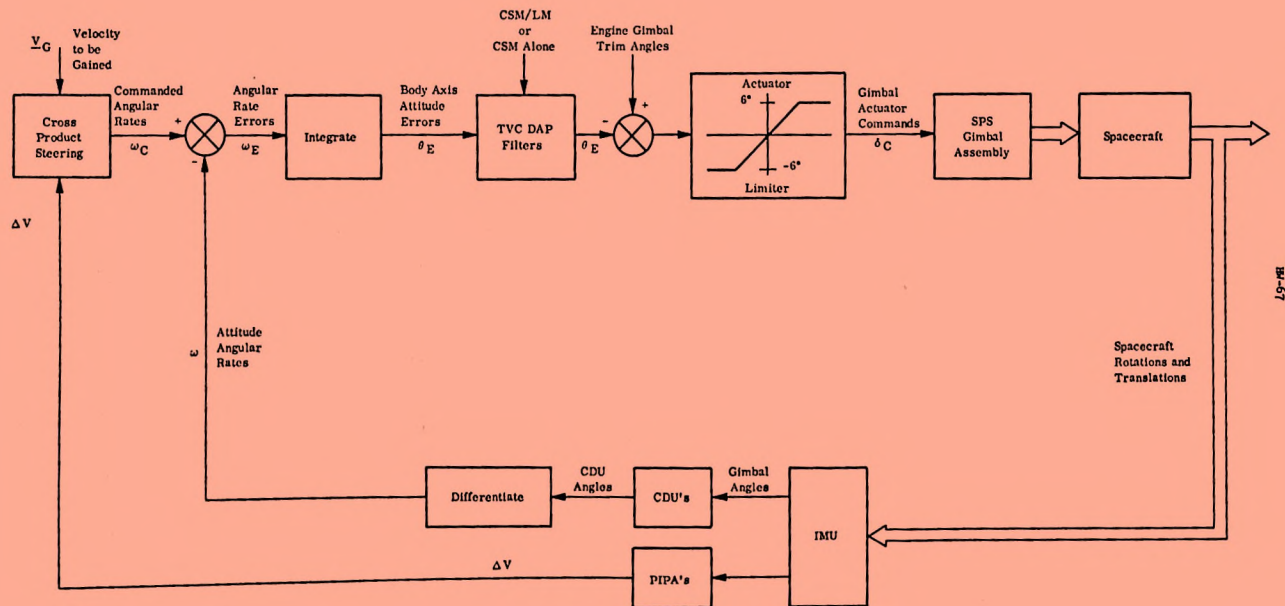
- 0.05 deg/s
- 0.2 deg/s
- 0.5 deg/s
- 4.0 deg/s



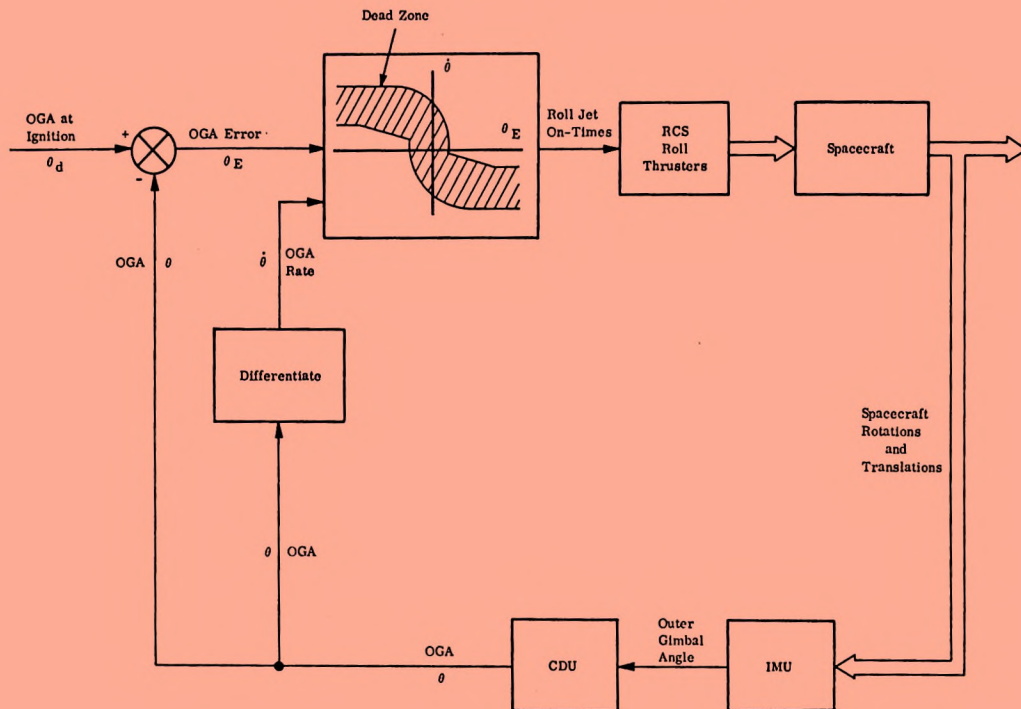
CSM DIGITAL AUTOPILOT
COASTING FLIGHT
AUTOMATIC ATTITUDE POSITIONING MODE



CSM DIGITAL AUTOPILOT
POWERED FLIGHT
THRUST VECTOR ATTITUDE CONTROL



CSM DIGITAL AUTOPILOT
POWERED FLIGHT
TVC ROLL ATTITUDE HOLD CONTROL



LM DAP CONTROL

Flashing V01 N46

	A	B	C	D	E
Register 1:	CONFIG	ACC	ACA	DB	RATE

CONFIG - Vehicle Configuration

- 1 = Ascent stage only
- 2 = Ascent and descent stages
- 3 = LM and CSM docked

ACC - Acceleration Code

- 0 = Two-jet translation (RCS System A)
- 1 = Two-jet translation (RCS System B)
- 2 = Four-jet translation (RCS System A and B)

ACA - ACA Scaling

- 0 = Docked (4 deg/s, max. rate)
- 1 = Normal (20 deg/s, max. rate)

DB - Deadband

- 0 = 0.3 degree
- 1 = 1.0 degree
- 2 = 5.0 degrees

RATE - Maneuver Rate (Automatic Mode)

- 0 = 0.2 deg/s
- 1 = 0.5 deg/s
- 2 = 2.0 deg/s
- 3 = 10.0 deg/s

Flashing V06 N47

Register 1: LM weight in pounds

Register 2: CSM weight in pounds

Flashing V06 N48

Register 1: Pitch-trim engine gimbal angle, in 0.01 degree

Register 2: Roll-trim engine gimbal angle, in 0.01 degree

AUTOMATIC MODE

1. Automatic three-axis rotation and translation.
2. Manual three-axis translation.
3. Manual X-axis rate command (inhibited in LPD phase)
4. Attitude hold to program defined attitude
5. Automatic rate damping

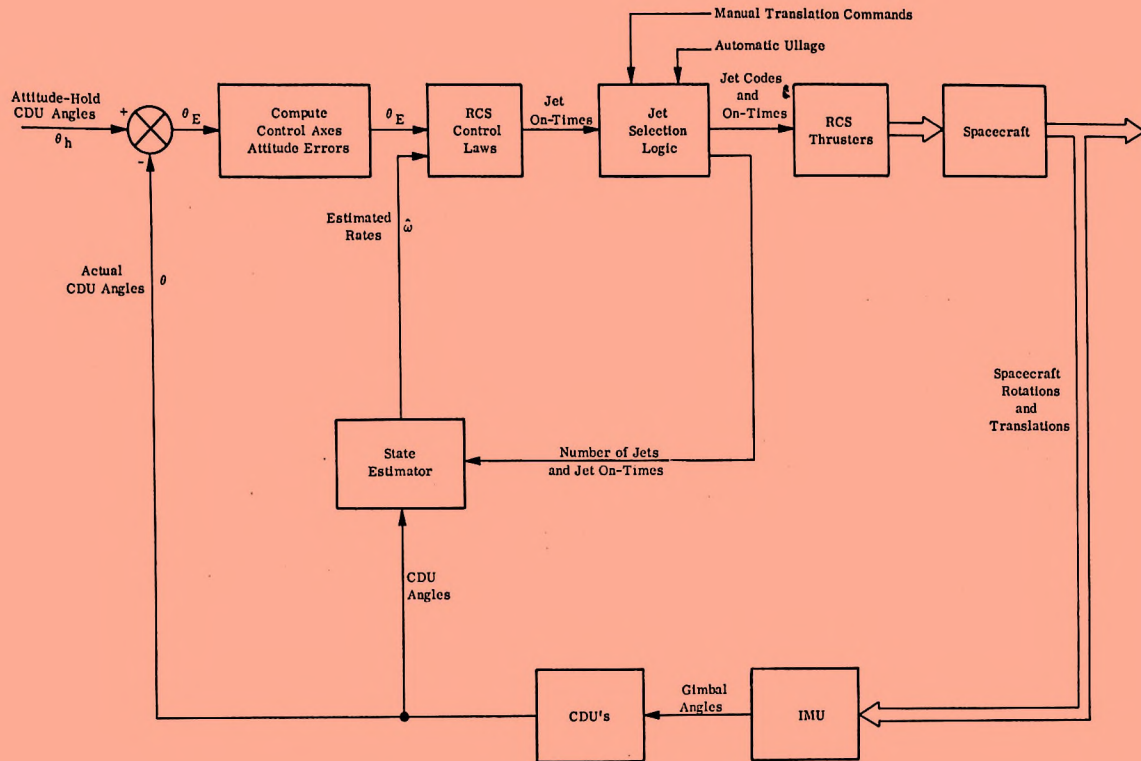
ATTITUDE HOLD MODE

1. Manual three-axis translation.
2. Manual three-axis rate command using V77
3. Manual minimum impulse command using V76.
4. Attitude hold to attitude selected via hand controller
5. Automatic rate damping

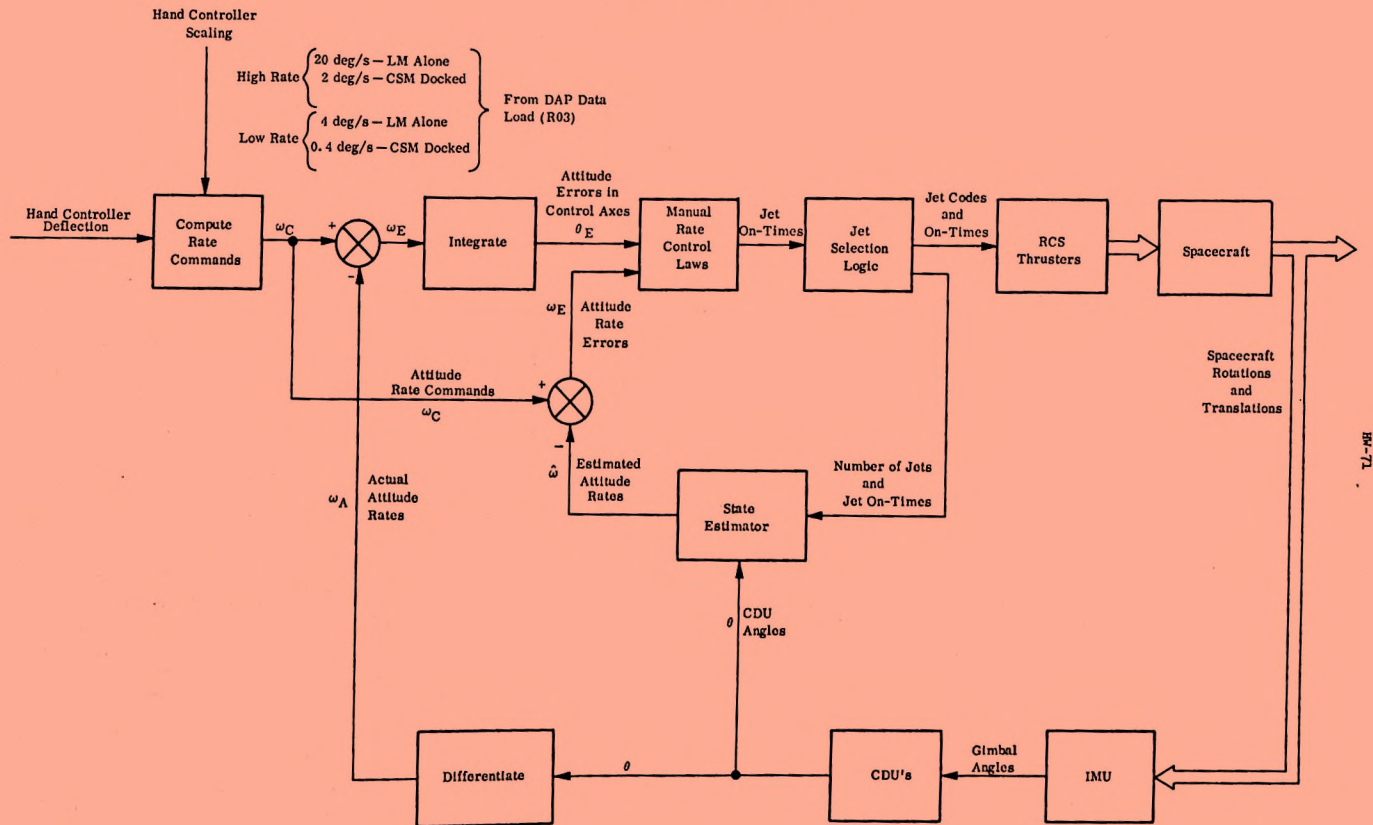
V77 - Used to provide a manual rate command. Commanded rotational rate is proportional to hand controller (ACA) deflection. Maximum commanded rotational rate is either 4 deg/s or 20 deg/s as chosen in DAP Data Load routine.

V76 - Used to provide a minimum impulse command. Releases Attitude Hold mode and allows vehicle to drift freely. One impulse is produced for each hand controller (ACA) deflection greater than 2.5 degrees.

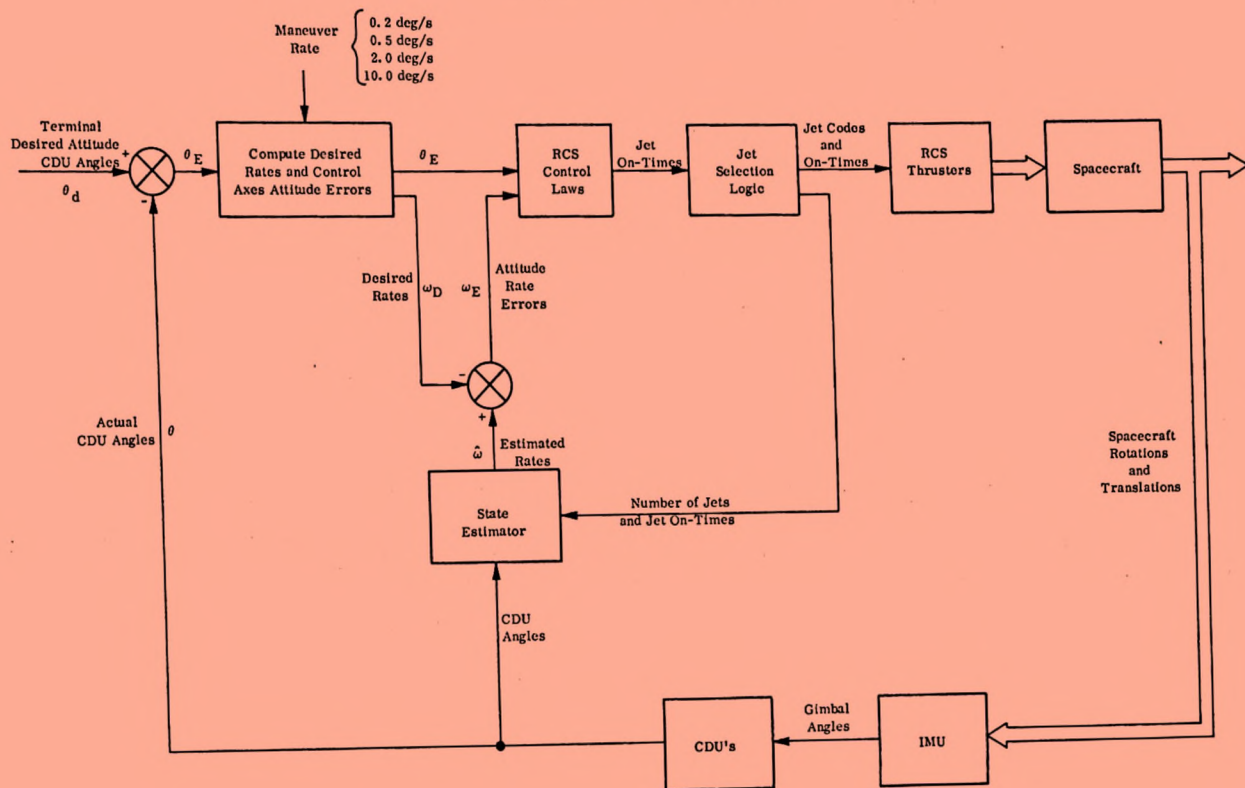
LM DIGITAL AUTOPILOT
COASTING FLIGHT
ATTITUDE-HOLD CONTROL MODE



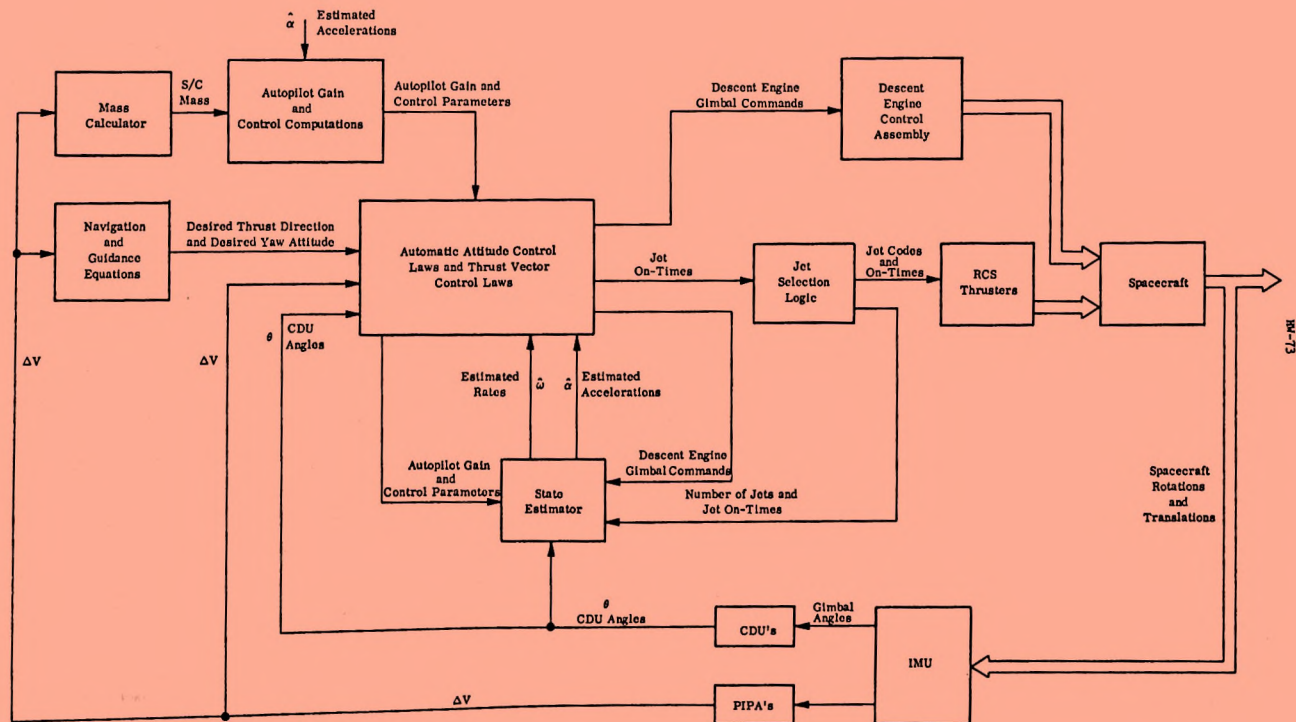
LM DIGITAL AUTOPILOT
COASTING FLIGHT
MANUAL ATTITUDE RATE MODE



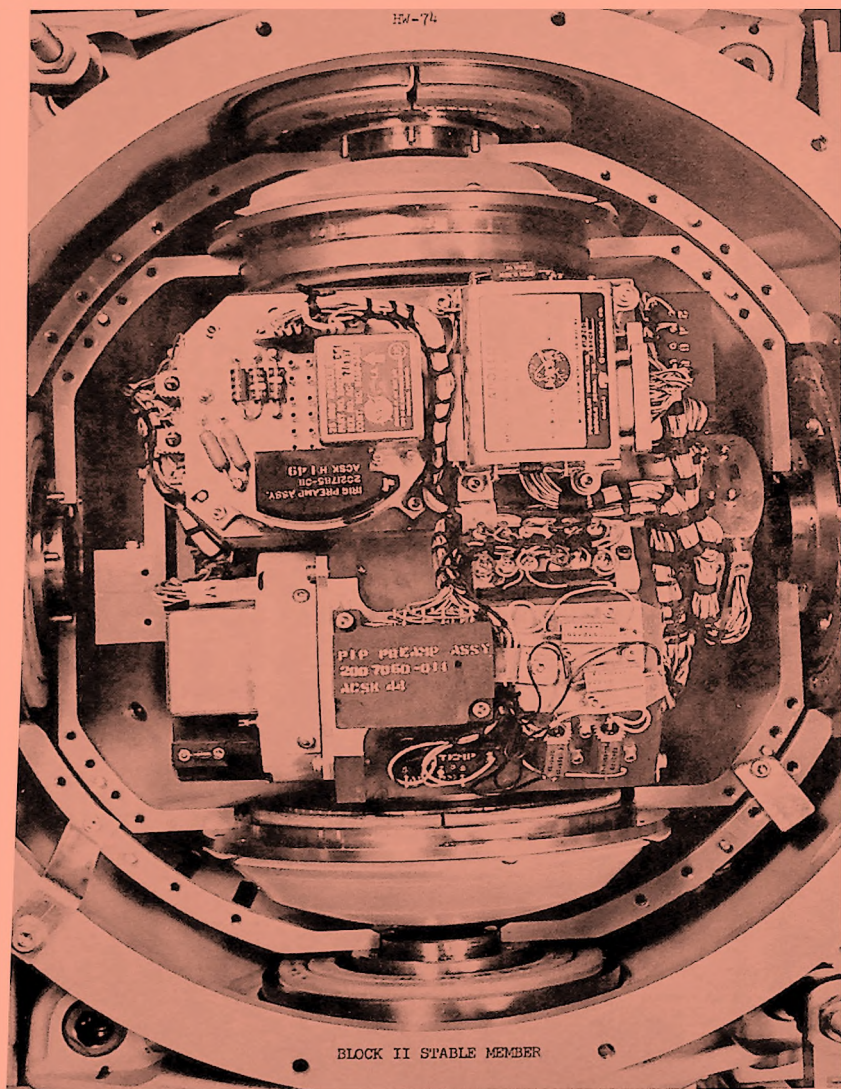
LM DIGITAL AUTOPILOT
COASTING FLIGHT
AUTOMATIC ATTITUDE POSITIONING MODE



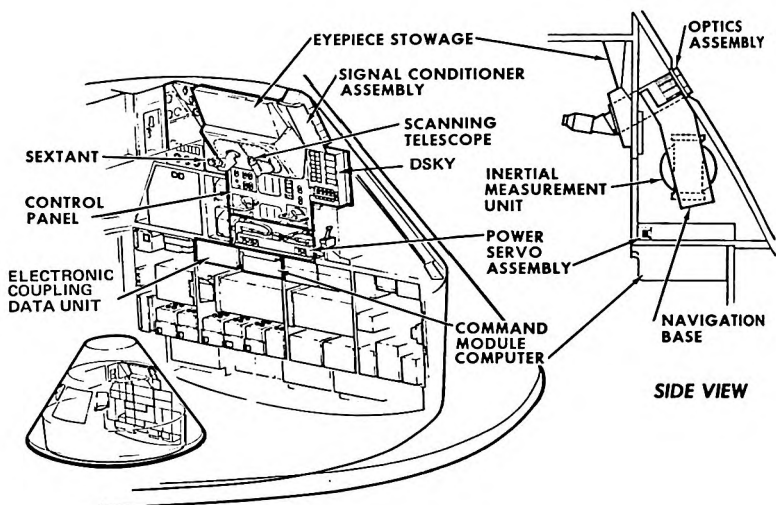
LM DIGITAL AUTOPILOT
POWERED FLIGHT
AUTOMATIC ATTITUDE AND STEERING CONTROL MODE



74-74



BLOCK II STABLE MEMBER

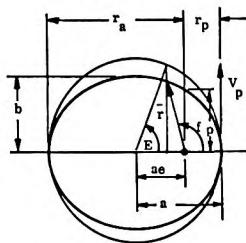


G & N EQUIPMENT LOCATION

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ELLIPSE



Semiminor Axis

$$b = \sqrt{a r_p}$$

Semimajor Axis

$$a = \frac{r_a + r_p}{2}$$

Eccentricity

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} < 1$$

Position

$$r = \frac{a(1-e^2)}{1+e \cos f} = a(1-e \cos E)$$

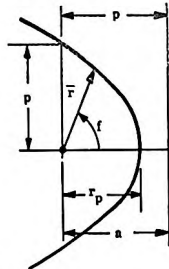
Velocity

$$V = \left[\frac{\mu}{a} \left(\frac{1+2e \cos f + e^2}{1-e^2} \right) \right]^{1/2}$$

Semilatus Rectum

$$p = a(1-e^2)$$

PARABOLA



$$2 r_p$$

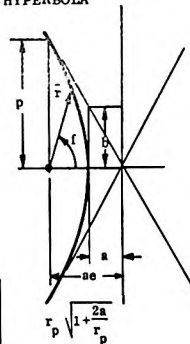
$$1$$

$$\frac{p}{1+\cos f}$$

$$\left[\frac{2\mu(1+\cos f)}{p} \right]^{1/2}$$

$$2 r_p$$

HYPERBOLA



$$\frac{\mu}{V_\infty^2}$$

$$\sqrt{1 + \left(\frac{b}{a}\right)^2} > 1$$

$$\frac{a(e^2 - 1)}{1 + e \cos f}$$

$$\left[\mu \left(\frac{2}{r} + \frac{1}{a} \right) \right]^{1/2}$$

$$a(e^2 - 1)$$

$$V_\infty^2 = \frac{\mu}{a}$$