APOLLO 13

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	60 n mi	16.4 n mi
μ	0.3986032×10^{15} m^3/sec^2	0.4902778×10^{13} m^3/sec^2
RADIUS	6,378,165 m	1,738,090 m
	20,925,738 ft	5,702,395 ft
	3,444 n mi	938.5 n mi
ORBIT CHARACTERISTICS	EARTH ABOUT SUN	MOON ABOUT EARTH
SEMI MAJOR AXIS	1.496×10^{11} m	384,400,000 m
	4.908×10^{11} ft	1,261,139,500 ft
	8.073×10^{7} n mi	207,430 n mi
ECCENTRICITY	0.0167	0.055
MEAN VELOCITY	29,770 m/sec	1,022 m/sec
	97,702 ft/sec	3,353 ft/sec
	57,888 n mi/hr	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)

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

1 meter = 3.2808 ft
= 5.3961×10^{-4} n mi
= 6.2137×10^{-4} s mi

1 arc-second = 4.8481×10^{-6} rad
= 2.7778×10^{-4} deg

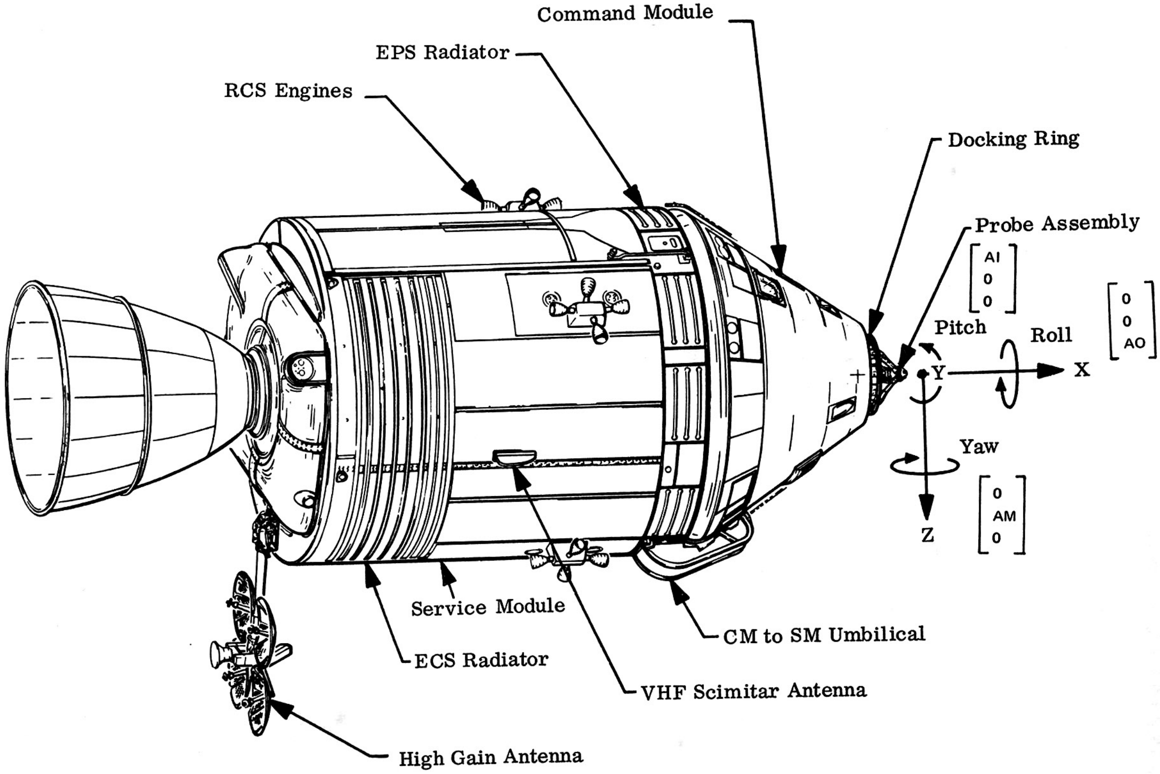
1 meru = 7.292115×10^{-8} rad/sec
= 4.178×10^{-6} deg/sec
= 2.507×10^{-4} arc-min/sec
= 0.01504 arc-sec/sec

1 cm/sec^2 = 3.281×10^{-2} ft/sec^2
= 1.0197×10^{-3} g

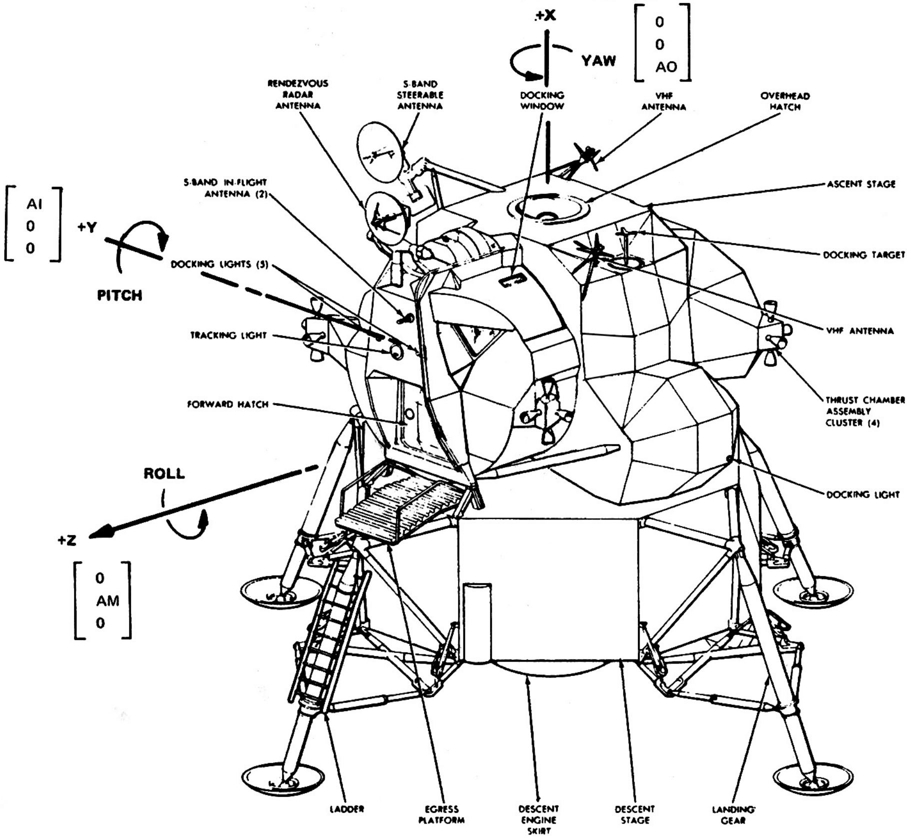
GUIDANCE AND NAVIGATION SUMMARY

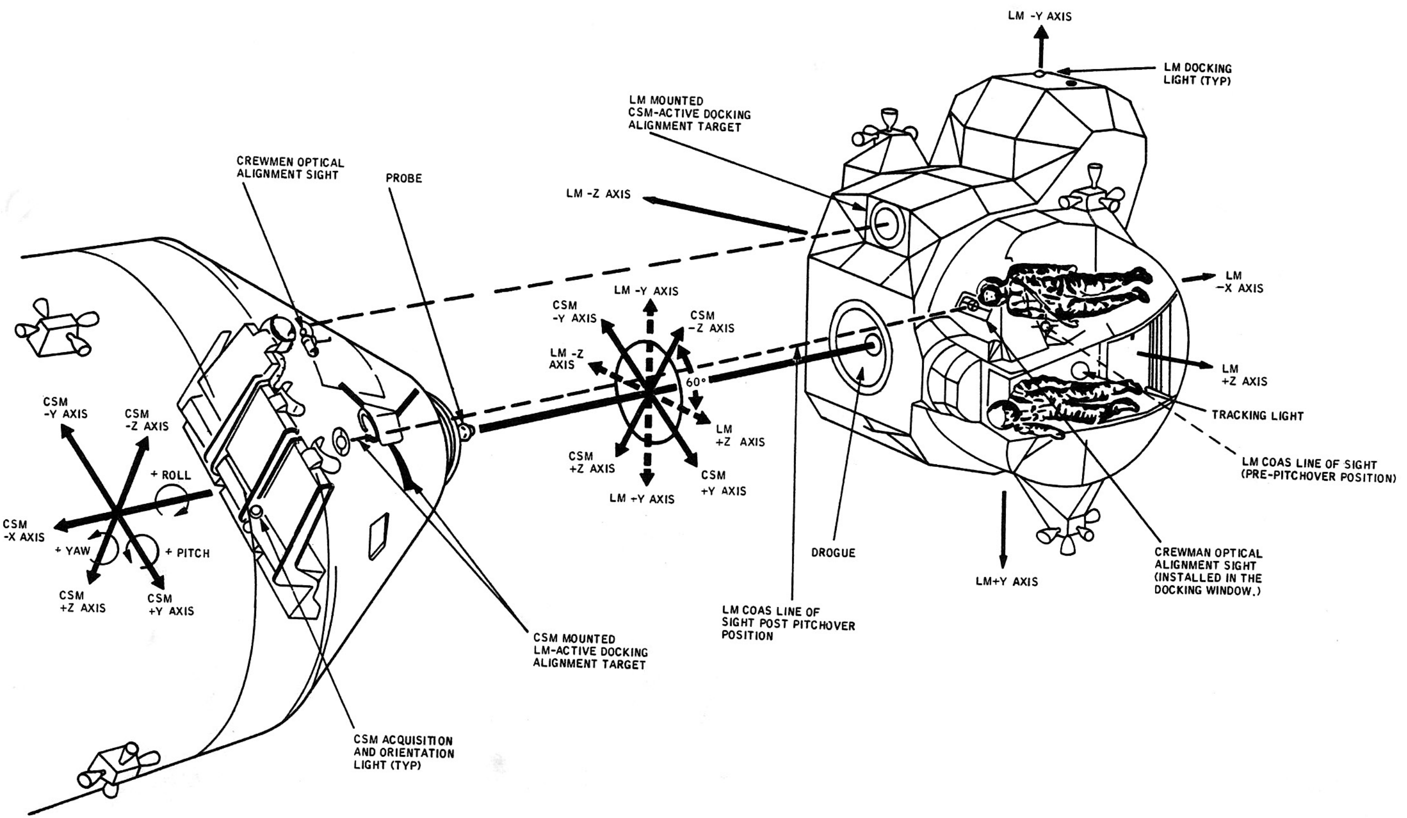
CM SOFTWARE
LM SOFTWARE
ASPO 45 CRT DISPLAYS
LAUNCH AND BURN SCHEDULE
BURN PERTURBATIONS
HARDWARE

CM/SM CONFIGURATION



LM CONFIGURATION





LM -Y AXIS
LM DOCKING LIGHT (TYP)
LM MOUNTED CSM-ACTIVE DOCKING ALIGNMENT TARGET
CREWMEN OPTICAL ALIGNMENT SIGHT
PROBE
LM -Z AXIS
LM -Y AXIS
CSM -Y AXIS
CSM -Z AXIS
LM -Z AXIS
60°
LM +Z AXIS
CSM +Z AXIS
CSM +Y AXIS
LM +Y AXIS
LM -X AXIS
LM +Z AXIS
TRACKING LIGHT
LM COAS LINE OF SIGHT (PRE-PITCHOVER POSITION)
CSM -Y AXIS
CSM -Z AXIS
+ ROLL
CSM -X AXIS
+ YAW
+ PITCH
CSM +Z AXIS
CSM +Y AXIS
DROGUE
LM+Y AXIS
CREWMAN OPTICAL ALIGNMENT SIGHT (INSTALLED IN THE DOCKING WINDOW.)
LM COAS LINE OF SIGHT POST PITCHOVER POSITION
CSM MOUNTED LM-ACTIVE DOCKING ALIGNMENT TARGET
CSM ACQUISITION AND ORIENTATION LIGHT (TYP)

CM SOFTWARE

COLOSSUS 2D
(REV 003 OF MANCHE72)
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 V50 N18 flag is not set.

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 examole,
      (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 (except when the S-IVB is attached). 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.
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.

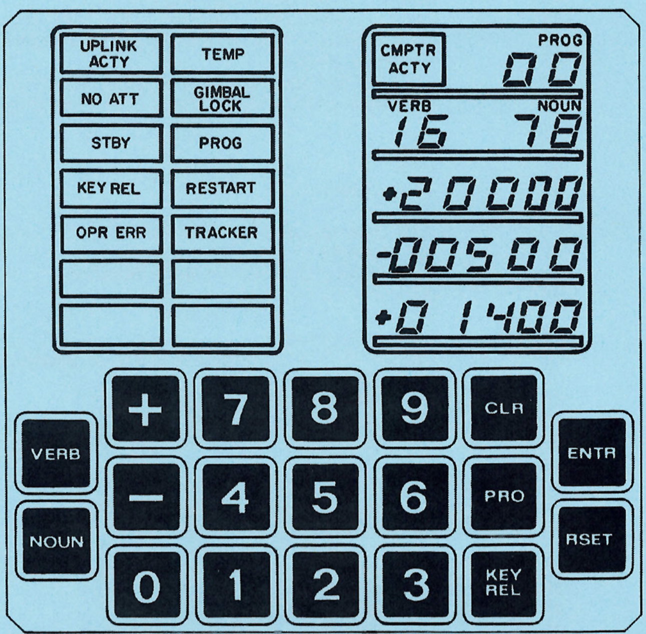
   b1. When the AGC is in the Operate mode but Program 06 is not selected, pressing the button will provide the "Proceed" function. If the proceed button is pressed when VERB lights contain 21, 22, or 23, the action is rejected and the OPR ERR light is energized.

   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 2D

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
Align-ment	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	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 2D

ROUTINE	ROUTINE TITLE
00	Final Automatic Request Terminate
01	Erasable and Channel Modification Routine
02	IMU Status Check
03	Digital Autopilot Data Load
04	Saturn Time Base 6 Initiation Routine
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 2D

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	Pulse torque gyros
43	Load IMU attitude error needles (test only)
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 2D

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 2D

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 P Y	XXX.XX deg XXX.XX deg XXX.XX deg

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2D

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	R (OG) P (IG) Y (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	R (OG) P (IG) Y (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	PRIO/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 2D

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 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 (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	XXXXX. lbs XXXXX. lbs
48	Gimbal pitch trim Gimbal yaw trim	XXX.XX deg XXX.XX deg
49	Delta R Delta V VHF or optics code	XXXX.X nmi XXXX.X ft/s XXXXX.
50 *	Splash error Perigee TFF	XXXX.X nmi XXXX.X nmi XX b XX min/s
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	Range Range rate Phi	XXX.XX nmi XXXX.X 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 2D

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

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

LIST OF NOUNS USED IN PROGRAM COLOSSUS 2D

70	Celestial body code (before mark)		Octal
	Landmark data		Octal
	Horizon data		Octal
71	Celestial body code (after mark)		Octal
	Landmark data		Octal
	Horizon data		Octal
72	Delta angle (TPI)		XXX.XX deg (+ active vehicle ahead)
	Delta altitude (TPI)		XXXX.X nmi (+ passive vehicle above)
	Search option		XXXXX.
73	Altitude		XXXXXb. nmi
	Velocity		XXXXX. ft/s
	Flight path angle		XXX.XX deg
74	Commanded bank angle		XXX.XX deg
	Inertial velocity		XXXXX. ft/s
	Drag acceleration		XXX.XX g
75 *	Delta altitude (CDH)		XXXX.X nmi
	Delta time (CDH-CSI or TPI-CDH)		XX b XX min/s
	Delta time (TPI-CDH or TPI-NOMTPI)		XX b XX min/s
76	Spare		
77	Spare		
78	Spare		
79	Orbrate or PTC rate		X.XXXX deg/s
	Orbrate or PTC deadband		XXX.XX deg
	Orbrate or PTC axis option		XXXXX.
80 *	Time from ignition/cutoff		XX b XX min/s
	Velocity to be gained		XXXXX. ft/s
	Delta V (accumulated)		XXXXX. ft/s
81	Delta VX (LV)		XXXX.X ft/s
	Delta VY (LV)		XXXX.X ft/s
	Delta VZ (LV)		XXXX.X ft/s
82	Delta VX (LV)		XXXX.X ft/s
	Delta VY (LV)		XXXX.X ft/s
	Delta VZ (LV)		XXXX.X ft/s
83	Delta VX (body)		XXXX.X ft/s
	Delta VY (body)		XXXX.X ft/s
	Delta VZ (body)		XXXX.X ft/s
84	Delta VX (LV of other vehicle)		XXXX.X ft/s
	Delta VY (LV of other vehicle)		XXXX.X ft/s
	Delta VZ (LV of other vehicle)		XXXX.X ft/s
85	VGX (body)		XXXX.X ft/s
	VGY (body)		XXXX.X ft/s
	VGZ (body)		XXXX.X ft/s
86	Delta VX (LV)		XXXXX. ft/s
	Delta VY (LV)		XXXXX. ft/s
	Delta VZ (LV)		XXXXX. ft/s
87	Mark data		
	Shaft angle		XXX.XX deg
	Trunnion angle		XX.XXX deg
88	Celestial body ½ 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 2D

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		XXXX.X ft/s
	PSI		XXX.XX deg
91	Present 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		XXXX.X ft/s
	RMS option code		XXXXX.

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

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
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
00421		W-Matrix overflow	INTEGRV
00600	*	Imaginary roots on first interation	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 2D

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, P23

2XXXX—Indicates a go-to-routine 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).
Depressing the RSET key on the DSKY will set R1 and R2 to zero, but not affect R3.

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

**This alarm is displayed without the astronaut having to key in V05 N09E. No DSKY response is required by this alarm.

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

(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 2D

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	Key in 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 2D

ADVTRK	FW8	B10
AMOONFLG	FW0	B2
APSESW	FW8	B5
ASTENFLAG*	FW7	B12
ATTCHFLG*	FW7	B2
AVEGBIT	FW1	B1
AVEGFLAG	FW1	B1
AVEMIDSW	FW9	B1
AVFLAG	FW2	B5
CALCMAN2	FW2	B2
CMDAPARM*	FW6	B12
CMOONFLG	FW8	B12
CM/DSTBY	FW6	B2
COGAFLAG	FW8	B4
COMPUTER	FW5	B8
CPHIFLAG	FW0	B15
CULTFLAG	FW3	B7
D6OR9FLG	FW3	B2
DAPBIT1	FW6	B15
DAPBIT2	FW6	B14
DIMOFLAG	FW3	B1
DMENFLG	FW5	B9
DRIFTFLG	FW2	B15
DSKYFLAG*	FW5	B15
EGSW	FW6	B8
ENG2FLAG	FW1	B11
ENGONBIT	FW5	B7
ENTRYDSP	FW6	B13
ERADFLAG	FW1	B13
ETPIFLAG	FW2	B7
FINALFLG	FW2	B6
FIRSTFLG	FW2	B7
FREEFLAG	FW0	B3
F2RTE	FW0	B5
GAMDIFSW*	FW6	B11
GLOKFAIL	FW3	B14
GLOKFBIT	FW3	B14
GONEBY	FW7	B8
GONEPAST	FW6	B10
GRRBKBIT	FW5	B5
GRRBKFLG	FW5	B5
GUESSW	FW1	B2
GYMDIFSW*	FW6	B1
HIND	FW6	B6
IDLEFAIL	FW1	B6
IGNFLAG*	FW7	B13
IMPULSW	FW2	B9
IMUSE	FW0	B8
IMUSEFLG	FW0	B8
INCORFLG	FW5	B11
INFINFLG	FW8	B7
INRLSW	FW6	B5
INTFLBIT	FW10	B14
INTYPFLG	FW3	B4
ITSWICH	FW7	B14
JSWITCH	FW0	B14
KFLAG	FW0	B1
KNOWNFLG	FW6	B8
LATSW	FW6	B4
LMOONFLG	FW8	B11
LUNAFLAG	FW3	B12
MAXDBBIT	FW9	B12
MAXDBFLG	FW9	B12
MGLVFLAG	FW5	B2
MID1FLAG	FW9	B3
MIDAVFLG	FW9	B2
MIDFLAG	FW0	B13
MKOVFLAG*	FW4	B3
MOONFLAG	FW0	B12
MRKIDFLG*	FW4	B15
MRKNVFLG	FW4	B9
MRUPTFLG*	FW4	B5
MWAITFLG*	FW4	B11
NEEDLFLG	FW0	B9
NEWIFLG	FW8	B13
NJETSFLG	FW1	B15
NODOBIT	FW2	B1
NODOFLAG	FW2	B1
NODOP01	FW1	B12
NOP01BIT	FW1	B12
NORFHOR	FW0	B11
NORMSW	FW7	B10
NOSWITCH	FW6	B7
NRMIDFLG*	FW4	B13
NRMNVFLG	FW4	B8
NRUPTFLG*	FW4	B4
NWAITFLG*	FW4	B10
N22ORN17	FW9	B6
OPTNSW	FW2	B7
ORBWFLAG	FW3	B6
ORDERSW	FW8	B6
PDSPFBIT	FW4	B12
PDSPFLAG	FW4	B12
PFRATFLG	FW2	B4
PINBRFLG	FW4	B6
PRECIFLG	FW3	B8
PRFTRKAT	FW5	B10
PRIODFLG*	FW4	B14
PRONVFLG	FW4	B7
P00FLAG	FW3	B9
P21FLAG	FW2	B12
P22MKFLG	FW3	B11
P39/79SW	FW8	B9
QUITFLAG	FW9	B5
REFSMFLG	FW3	B13
REINTBIT	FW10	B7
REINTFLG	FW10	B7
RELVELSW	FW6	B9
RENDWFLG	FW5	B1
RETROFLG	FW5	B14
RNDVZBIT	FW0	B7
RNDVZFLG	FW0	B7
RNGSCFLG	FW5	B10
RPQFLAG	FW8	B15
RVSW	FW7	B9
R21MARK	FW2	B14
R22CAFLG*	FW9	B7
R23BIT	FW1	B9
R23FLG	FW1	B9
R31FLAG	FW9	B4
R53FLAG	FW0	B6
R57FLAG	FW6	B8
R60FLAG*	FW5	B4
SAVECBIT	FW9	B10
SAVECFLG	FW9	B10
SKIPBIT	FW2	B10
SKIPVHF	FW2	B10
SLOPESW	FW1	B3
SLOWFLG	FW5	B13
SOLNSW	FW5	B3
SOURCBIT	FW9	B8

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS (ALPHABETICAL) FOR COLOSSUS 2D

SOURCFLG	FW9	B8
STATEFLG	FW3	B5
STEERSW	FW2	B11
STIKBIT	FW1	B14
STIKFLAG	FW1	B14
STRULLSW	FW6	B13
SURFFLAG	FW8	B8
SWTOVER*	FW9	B15
S32.1F1	FW11	B15
S32.1F2	FW11	B14
S32.1F3A	FW11	B13
S32.1F3B	FW11	B12
TARG1FLG	FW1	B10
TARG2FLG	FW1	B9
TERMIFLG	FW7	B15
TFFSW	FW7	B1
TIMRFLAG	FW7	B11
TRACKBIT	FW1	B5
TRACKFLG	FW1	B5
TRM03BIT	FW1	B4
TRM03FLG	FW1	B4
TRUNFLAG	FW0	B4
UPDATBIT	FW1	B7
UPDATFLG	FW1	B7
UPLOCKFL*	FW7	B4
VEHUPFLG	FW1	B8
VERIFLAG*	FW7	B3
VFLAG	FW3	B10
VHFRFLAG	FW9	B9
VINTFLAG	FW3	B3
V37FLAG	FW7	B6
V37FLBIT	FW7	B6
V50N18BT	FW3	B15
V50N18FL	FW3	B15
V59FLAG	FW5	B12
V67FLBIT*	FW9	B14
V82EMFLG	FW9	B13
V94FLAG	FW9	B11
V94FLBIT	FW9	B11
V96ONFLG	FW8	B3
XDELVFLG	FW2	B8
XDSPFLAG*	FW4	B1
ZMEASURE	FW0	B10
.05GSW	FW6	B3
22DSPFLG	FW2	B13
360SW	FW8	B1
3AXISFLG	FW5	B6

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2D

(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	NEEDLFLG	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 2D

(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 2D

(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	DIMOFLAG	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	P00FLAG	Inhibit backwards integration.	Allow backwards integration.
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	LUNAFLAG	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 2D

(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 interferred with existing display.	Astronaut has not interferred 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 PDSPFLAG	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 2D

(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 2D

(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 15	DAPBIT2 DAPBIT1	(see table below)	DAP selection indicator.

B14	0	1	1	1
B15	0	0	0	1
A/P	None	RCS	TVC	Saturn

(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-$\bar{K}$-K fail.	No K-$\bar{K}$-K fail.
5	Not Assigned		
6	V37FLAG V37FLBIT	AVERAGEG (SERVICER) running.	AVERAGEG (SERVICER) off.
7	Not Assigned		
8	GONEBY	Passed target.	Approaching target.
9	RVSW	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 2D

(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	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 2D

(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	SAVECBIT 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	MAXDBBIT 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 13	S32.1F3B S32.1F3A	(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.)	
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 2D

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 13 (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. No Verb 37 inputs will be processed while bit is equal to 1 and alarm 01520_8 is generated.
5	Bit is set to 1 to inhibit the generation of program alarm 0212_8 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 0207_8 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 2D

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 PRO 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 2D

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 0120_8 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 0116_8 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 0116_8 (see Bit 3) is inhibited.

FLAGWORD BIT ASSIGNMENTS FOR COLOSSUS 2D

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) automaneuver is in progress. Bit is reset to 0 to indicate that a high rate automaneuver 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 2D

DAPDATR1, a flagword for RCS-CSM DAP interface.

Bits	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 $\pm$ 0.5 degree
- 1 $\pm$ 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.

Bits	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 Counters
3	Not Used
4	Coarse Align Enable
5	Zero IMU CDU's
6	Enable IMU CDU Error Counters
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 Code Bit
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 T6RUPT

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 1001_8 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 (1 = 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	CM/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 (Standby button)
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

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

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

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 selecton of P00, P06, P22, P23, V34E from R60 or R22, or by V56E.

Selected Displays:

1. V50 N18

Desired FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (MG)	XXX.XX deg

2. V06 N18

Final FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (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	XXXXXb. 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 attitutde 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 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. 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 ½ unit vector		.XXXXX

4. V50 N25 (perform GNCS auto maneuver)

Checklist code		00202

5. V50 N18

Desired FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (MG)	XXX.XX deg

6. V06 N18

Final FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (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 UPTEL 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 $\Delta V(LV)$) 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 CSM and the LM 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 CSM and the LM 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

5. V04 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 Δ V (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 exectuion 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 AUGE 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	XXXXX. 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 from 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 (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. 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 erorr 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 FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (MG)	XXX.XX deg

2. V06 N18

Final FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (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 FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (MG)	XXX.XX deg

2. V06 N18

Final FDAI angles	R (OG)	XXX.XX deg
	P (IG)	XXX.XX deg
	Y (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 ½ 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 or previously uplinked via P27.

P52 (continued)

b. Landing Site Orientation (00004)

X_{SM} = Unit (R_{LS})

Y_{SM} = Unit (Z_{SM} x X_{SM})

Z_{SM} = Unit (H_{CSM} x 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} x V_{CSM}) at time T (align) selected by the astronaut.

c. Nominal Orientation (00002)

X_{SM} = Unit (Y_{SM} x Z_{SM})

Y_{SM} = Unit (V x R)

Z_{SM} = 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 IG MG	XXX.XX deg XXX.XX deg 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 ½ unit vector		.XXXXX
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 or previously uplinked via P27.

   b. Landing Site Orientation (00004)

   X_{SM} = Unit (R_{LS})

   Y_{SM} = Unit (Z_{SM} x X_{SM})

   Z_{SM} = Unit (H_{CSM} x 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} x V_{CSM}) at time T (align) selected by the astronaut.

   c. Nominal Orientation (00002)

   X_{SM} = Unit (Y_{SM} x Z_{SM})

   Y_{SM} = Unit (V x R)

   Z_{SM} = 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 ½ unit vector	.XXXXX

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.

Assmptions:

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	XXXX.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/s^2) 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	XXXX.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 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 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	XXXX.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/s^2 (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/s^2 (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 LM and the CSM 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 LM and the CSM 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. 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

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 N33

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

2. V06 N84

Components of ΔV (OV)	XXXX.X ft/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:

1. 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:
   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 LGC for LM 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.

Assumptions:

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

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)

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 from 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

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

3. V06 N52 (astronaut initiated)

Central angle of active vehicle	XXX.XX deg

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LM SOFTWARE

LUMINARY 1C
(REV 131A 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 acutated.

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

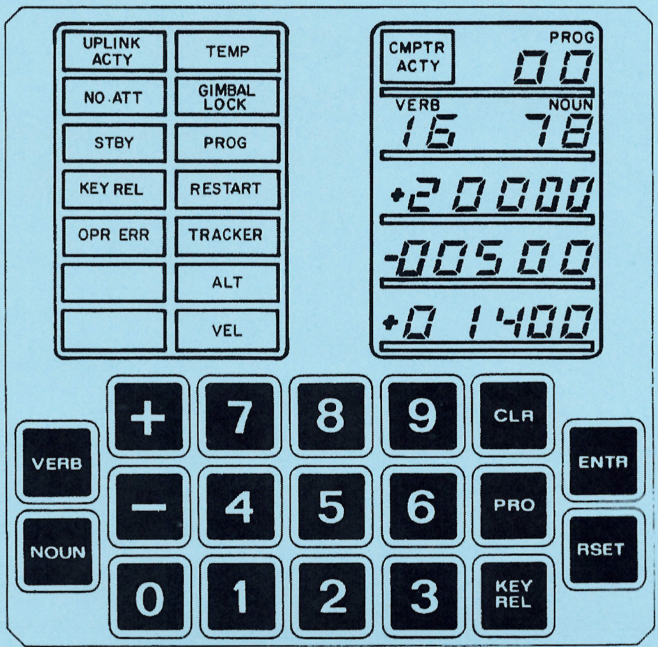
LM DSKY (continued)

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 1C

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
Align-ments	51	IMU Orientation Determination
	52	IMU Realign
	57	Lunar Surface Align
Descent	63	Braking Phase
	64	Approach Phase
	66	Landing Phase (ROD)
	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 1C

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	Rendevzous 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 1C

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)
08-10	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)
18-20	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
28-29	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)
38-39	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)
45-46	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 Positon 2
60	Display vehicle attitude rates on FDAI error needles

LIST OF VERBS USED IN PROGRAM LUMINARY 1C

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
86-88	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 1C

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 1C

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.
28-31	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		

LIST OF NOUNS USED IN PROGRAM LUMINARY 1C

40	*	Time from ignition/cutoff	XX b XX min/s
		VG	XXXX.X ft/s
		Delta V (accumulated)	XXXX.X ft/s
41		Target	
		Azimuth	XXX.XX deg
		Elevation	XX.XXX deg
42		Apocenter altitude	XXXX.X nmi
		Pericenter altitude	XXXX.X nmi
		Delta V (required)	XXXX.X ft/s
43		Latitude	XXX.XX deg (+ north
		Longitude	XXX.XX deg (+ east)
		Altitude	XXXX.X nmi
44	*	Apocenter altitude	XXXX.X nmi
		Pericenter altitude	XXXX.X nmi
		TFF	XX b XX min/s
45	*	Marks	XXXXX.
		Time from ignition of next burn	XX b XX min/s
		Middle gimbal angle	XXX.XX deg
46		DAP configuration	Octal
47		LM weight	XXXXX. lb
		CSM weight	XXXXX. lb
48		Gimbal pitch trim	XXX.XX deg
		Gimbal roll trim	XXX.XX deg
49		Delta R	XXXX.X nmi
		Delta V	XXXX.X ft/s
		Radar data source code	0000X
50		Spare	
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		Spare	
54		Range	XXX.XX nmi
		Range rate	XXXX.X ft/s
		Theta	XXX.XX deg
55		Number of apsidal crossings	XXXXX.
		Elevation angle	XXX.XX deg
		Central angle of passive vehicle	XXX.XX deg
56		RR LOS	
		Azimuth	XXX.XX deg
		Elevation	XXX.XX deg
57		Spare	
58		Pericenter altitude (post TPI)	XXXX.X nmi
		Delta V (TPI)	XXXX.X ft/s
		Delta V (TPF)	XXXX.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 1C

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

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

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

LIST OF NOUNS USED IN PROGRAM LUMINARY 1C

92	Percent of full thrust (10,500 lb) Altitude rate Computed altitude	00XXX % XXXX.X ft/s XXXXX. ft
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 XXXX.X ft/s XXXXX. milliradians

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

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	SELFCHECK
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 1C

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, P66
01412		Descent ignition algorithm not converging	P63
01466		Throttle servicing insufficient	P66
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		SQRT called with negative argument	INTERPRETER
21406		Bad return from ROOTSPS 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—0XXXX (first alarm to occur after last RSET)
R2—0XXXX (second alarm to occur after last RSET)
R3—XXXXX (alarm which occured 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 1C

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 1C

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 1C

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

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS (ALPHABETICAL) FOR LUMINARY 1C

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

*These switches are never called by name.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1C

(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 resposition 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 1C

(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 1C

(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.	TPI 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 1C

(FLAGWORD 3)

Bit	Name	1	0
1	DIMOFLAG	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	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 1C

(FLAGWORD 4)

Bit	Name	1	0
1	XDSPBIT XDSPFLAG	Mark display not to be interruped.	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 interferred with existing display.	Astronaut has not interferred 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 1C

(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 1C

(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 13	S32.1F3B S32.1F3A	(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.)	
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 1C

(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-$\overline{K}$-K fail.	No K-$\overline{K}$-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	RVSW	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 1C

(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 1C

(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	ABTTFLAG	J2, K2 parameters used for abort targeting.	J1, K1 parameters used for abort targeting.
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
1-6	Not Assigned		
7	REINTBIT REINTFLG	Integration routine to be RESTARTED.	Integration routine not to be RESTARTED.
8-12	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 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.
13-14	Not Assigned		
15	LRBYBIT LRBYPASS	Bypass all LR updates.	Do not bypass LR updates.

FLAGWORD BIT ASSIGNMENTS FOR LUMINARY 1C

(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 resposition taking place.
12	ANTENBIT	RR antenna is in Mode 2.	RR antenna is in Mode 1.
13	RCDUOBIT	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 1C

(FLAGWORD 13, DAPBOOLS)

Bit	Name	1	0
1 2	AUTR1FLG* AUTR2FLG*	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.	
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 1C

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 0212_8 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 0207_8 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 LUMINARY 1C

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.

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
11-12	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	
1-2	Spare
3	Mark X
4	Mark Y
5	Mark reject
6	Descent +
7	Descent -
8-15	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
11-13	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. If the IMU is on, the DAP is available for manually controlled attitude maneuvers. Care must be taken to avoid IMU gimbal lock by observing the ICDU's (V16 N20) or monitoring the FDAI ball.
2. This program uses the Coasting Integration routine periodically to update the LM and CSM state vectors to the present time and inhibits selecting any other LGC program (V37EXXE) during the integration. While the LGC is integrating, attempts to select another program results in program alarm 1520.
3. P00 is automatically selected by V96E (possible during any program), and state vector integration is permanently inhibited. Normal integration functions will resume after selection of another program. Since state vector synchronization is not maintained, use of V96 can cause incorrect W-matrix extrapolation.

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. Both the IMU and LGC are off, with power applied only to the IMU heat control circuitry, the LGC timing circuitry, and gyro and accelerometer suspension.
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.

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 that will result in in an orbit coplanar with the CSM orbit and an apolune of 45 nmi. These values at orbit insertion are altitude, distance between the LM and CSM orbital planes, LM vertical (V(R)), LM horizontal (V(Y)), and (V(Z)). All altitudes are measured with respect to the LGC stored landing site vector.

   The predefined ascent trajectory may be partially modified during this program by the astronaut.
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 consists of two phases:
   a. Vertical Rise Phase – From TIG until the LM radial velocity (V(R)) exceeds 40 ft/s. During this phase, the PGNCS holds the LM attitude with the +X axis parallel to the LM position vector at TIG. At TIG the PGNCS commands 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 X axis is within 5 degrees of the desired attitude. During this phase, the PGNCS commands the LM to pitch down (about the Y axis) an amount defined 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, changes the relative phasing of the ascent trajectory with respect to the CSM and alters 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 controls the total vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control about only the yaw axis with the ACA (X-axis override) provided the X-axis override capability is permitted (see Assumption 4).

   If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about all vehicle axes with the ACA using either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode.

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

   The AGS is capable of taking control of the LM during any phase of the lunar ascent and guiding it to a state orbit and should be initialized by manual selection of R47, the AGS Initialization routine, prior to the selection of P12.

   If the Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC continues computation of position, velocity, desired thrust vector, and desired attitude errors.

9. The PGNS generates two types of errors for display on the FDAI as selected by the astronaut:

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

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

10. The Landing Analog Displays routine (R10) is enabled at TIG. However, R10 use of the Rendezvous Radar CDU's is inhibited by P12. The Powered Flight Rendezvous Radar Designate routine (R29) is enabled after the pitchover phase. R10 and R29 are terminated after the Average G is stopped.

11. For each burn a total allowable ignition delay time will be specified in the mission rules. If engine restarts are involved, the accounting of the total time is an option of the crew.

12. Either the Load DAP Data routine (R03) or the Landing Confirmation program (P68) has been performed prior to selection of this program.

    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 autocheck 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.

13. The LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40) which is called at APS ignition by P12.

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

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

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

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. Normally the IMU would be on and the IMU Orientation Determination program (P51) completed before using P20. A preferred orientation is not required for this program because 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 appropriate program alarm will be issued by P20 if the ISS is off or on and not aligned since turn-on. If the ISS has drifted from its initial alignment, the LGC may or may not have a satisfactory inertial reference for satisfactory completion of the program.

P20 (continued)

2. The CSM is maintaining a preferred tracking attitude that correctly orients the CSM radar transponder for RR tracking by the LM.
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 be selected only if P20 is not running in conjunction with another program.

10. When P20 is selected any time prior to the landing phase in the lunar mission, this program must be operated in the no update mode to prevent modifying a precision state vector for landing.

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

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

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 automaneuver 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

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	XXXX.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. Vehicle whose ground track parameters are calculated remains in freefall from start of program until T LAT/LONG.
2. 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	XXXX.X nmi

4. V06 N91 (astronaut initiated)

Altitude	XXXXb. 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. Normally the IMU would be on and the Lunar Surface Alignment program (P57) completed before using P22. The appropriate program alarm will be issued by P22 if the ISS is off or on and not aligned since turn-on. If the ISS has drifted from its initial alignment, the LGC may or may not have a satisfactory inertial reference for satisfactory completion of the program.
2. The CSM may be above or below the horizon, outside the available RR coverage sector, or outside the allowable RR coverage sector.

   The program will always track the CSM with the radar in Mode 2, whose available coverage is always less than horizon to horizon.
3. The CSM is maintaining a preferred tracking attitude that correctly orients the CSM transponder for RR tracking of the LM.
4. At the beginning of the program the state vector update option is automatically set to the CSM, which 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 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).
6. 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).
7. 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.
8. 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.

9. State vector integration may be permanently inhibited by V96E. This entry terminates all present programs and selects 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 initialization because state vector synchronization is not maintained.

Selected Displays:

1. V04 N06

Option code ID	00012
Option code	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)	XXXXX
Angle between RR LOS and +Z axis	XXX.XX deg

7. V50 N25 (manual RR acqusition of CSM)

Checklist code	00205

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	XXXX.X 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. Normally the IMU would be on and the IMU Orientation Determination program (P51) completed before using P25. A preferred orientation is not required for this program because 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 appropriate program alarm will be issued by P25 if the ISS is off or on and not aligned since turn-on. If the ISS has drifted from its initial alignment, the LGC may or may not have a satisfactory inertial reference for satisfactory completion of 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 implusive 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.

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.

P32 (continued)

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.

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 ignitiion	XX b XX min/s
Middle gimbal angle	XXX.XX deg

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.

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

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.

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 atronaut 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

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 maneuer is performed with the Guidance Control switch in PGNS and the Mode Control Switch in Auto, the PGNCS controls the total vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control about only the yaw axis with the ACA (X-axis override) provided the X-axis override capability is permitted (see Assumption 4).

   If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about the vehicle axes with the ACA using either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode.

   If Guidance Control switch is changed from PGNS to AGS during a thrusting maneuver, the LGC continues computation of position, velocity, desired thrust vector, and desired attitude errors.
7. The PGNS generates two types of errors for display on the FDAI as selected by the astronaut.
   a. Mode 1 – Selected by Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
   b. Mode 2 – Selected by Verb 62. Total attitude errors used to assist the 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 a total allowable ignition delay time will be specified in the mission rules. If engine restarts are involved, the accounting of the time is an option of the crew.

13. The LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40) which is called by P40.

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. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.

17. 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

P40 (continued)

4. V06 N40	
Time from DPS 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
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

P41—RCS PROGRAM

Purpose:

1. To compute a preferred IMU orientation and a vehicle attitude for an RCS thrusting maneuver.
2. To perform the vehicle maneuver to the thrusting attitude.
3. To provide suitable displays for manual execution of the thrusting maneuver in the Attitude Hold mode.

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 until the crew notifies the LGC that RCS 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.

6. The event timer is set to count to zero at TIG.
7. RCS ignition may be slipped beyond the established TIG if desired by the crew, or if state vector integration cannot be completed on time.

P41 (continued)

6. If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about all vehicle axes with the ACA using either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode.
7. The PNGS generates two types of errors for display on the FDAI as selected by the astronaut.
   a. Mode 1 – Selected by Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
   b. Mode 2 – Selected by Verb 62. Total attitude errors used to assist the crew in manually maneuvering the vehicle.
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 PGNS 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. The Load DAP Data routine (R03) has been performed prior to selection of this program.
10. The LGC will neither designate nor read the Rendezvous Radar (RR) during this program.
11. This program should be selected by the astronaut by DSKY entry at least 5 minutes before the estimated time of ignition.
12. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
13. 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 in V06 N81E.

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

3. V16 N85

Components of VG (LM body axis) for thrusting maneuver	XXXX.X ft/s

4. V06 N81 (astronaut initiated)

Components of VG (LV) for thrusting maneuver	XXXX.X ft/s

5. V06 N38 (astronaut initiated)

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

6. V04 N12 (results from V82E)

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

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 controls the total vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control about only the yaw axis with the ACA (X-axis override) provided the X-axis override capability is permitted.

   If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about all vehicle axes with the ACA using either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode.
7. The PGNS generates two types of errors for display on the FDAI as selected by the astronaut:
   a. Mode 1 – Selected by Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track atuomatic steering commands.
   b. Mode 2–Selected by Verb 62. Total attitude errors used to assist the 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 a total allowable ignition delay time will be specified in the mission rules. If engine restarts are involved, the accounting of the total time is an option of the crew.

10. The Load DAP Data routine (R03) may have been performed prior to selection of this program.

11. The LGC and crew procedures in cases of LGC-assumed thrust failure are defined by the DPS/APS Thrust Fail routine (R40), which is called at APS ignition by P42.

12. The LGC will neither designate nor read the Rendezvous Radar (RR) during the program.

13. This program should be selected by the astronaut by DSKY entry at least 5 minutes before the estimated time of ignition.

14. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.

15. 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

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 PGNCS 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 must be turned on before this program can be completed.
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.
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 the AOT Mark routine (R53).

Selected Displays:

1. V50 N25 (star acquisiton)

   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 otpics 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

P51 (continued)

8. V06 N05

   Star angle difference XXX.XX deg

9. V06 N88

   Components of celestial body ½ 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} = Unit (R_{LS})

   Y_{SM} = Unit (Z_{SM} x X_{SM})

   Z_{SM} = Unit (H_{CSM} x 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(align) selected by the crew.

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

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

   c. Nominal Orientation (Option 00002)

   X_{SM} = Unit (R)

   Y_{SM} = Unit (V x R)

   Z_{SM} = Unit (X_{SM} x Y_{SM})

   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 (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 the AOT Mark routine (R53).

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)
Desginated 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 Site (Option 4)

      X_{SM} = Unit (R_{LS})
      Y_{SM} = Unit (Z_{SM} x X_{SM})
      Z_{SM} = Unit (H_{CSM} x 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(align) selected by the crew.

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

b. Preferred Orientation (Option 1)

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 Lunar Surface Sighting Mark routine (R59) because of possible interference with the AOT Mark routine (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 celetial 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	00010
LGC assumed IMU orientation	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	XXX.XX deg
Spiral angle	XXX.XX deg
Position code	0000X

7. V01 N71

R1: ABCDE (see Item 5 above)

8. V06 N87 (LOS definition)

Azimuth	XXX.XX deg
Elevation	XXX.XX deg

9. V52 (Mark X)

P57 (continued)

10. V06 N88		
Components of celestial body ½ 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 REFSMMAT.
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. Corrections to the landing site position R_{LS} may be made by keying V21 through V25 N69 and entering the appropriate correction.
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 or P64, 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.

15. The crew can select a display of the LGC computed throttle setting by keying V16 N92.

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), or (P66).

    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 PGNCS controls the total vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control about only the yaw axis with the ACA (X-axis overrride) provided the X-axis override capability is permitted.

    If a thrusting maneuver is performed with the Guidance Control switch in PNGS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about all vehicle axes with the ACA using 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 astronaut is responsible for maintaining small enough attitude errors to achieve guidance objectives.

18. Control of LM DPS, RCS, and APS is transferred from PGNCS 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). However, it is not recommended that the AGS be initialized during powered flight because DAP attitude control is interrupted during the CDU zero part of the routine.

    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.

19. The PGNS generates two types of errors for display on the FDAI as selected by the astronaut.

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

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

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

P63 (continued)

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 nonminal 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, or P66.

28. This program allows manual control of LM attitude and the selection of P66.

    During P63 (P64) 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 and P64) 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 (astronuat initiated)

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

3. V50 N25 (fine align)

Checklist code		00014

4. V50 N18

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

P63 (continued)

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.

13. V21 N69 (astronaut initiated)

Landing site correction	Z	XXXXX ft
	Y	XXXXX ft
	X	XXXXX ft

14. V16 N92 (astronaut initiated)

Percent full thrust (10,500 lb)	00XXX %
Altitude rate	XXXXX. ft/s
Altitude	XXXXX. ft

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 throttlable 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 redesgination 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 (½ 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 or P64, 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), or (P66).

    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 PGNCS controls the total vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control about only the yaw axis with the ACA (X-axis override) provided the X-axis override capability is permitted.

    If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about all vehicle axes with the ACA using either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode.

18. 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.

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). However, it is not recommended that the AGS be initialized during powered flight because DAP attitude control is interrupted during the CDU zero part of the routine.

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.

19. The PGNS generates two types of errors for display on the FDAI as selected by the astronaut:
    a. Mode 1—Selected by Verb 61. Autopilot following errors are used as a monitor of the DAP's ability to track automatic steering commands.
    b. Mode 2—Selected by Verb 62. Total attitude errors used to assist the 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 PGNCS 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, or P66.

24. This program allows manual control of the LM attitude. If manual control is desired, put the PGNCS 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 PGNCS 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.

    NOTE: Landing Site Redesignation must be completed before P66 is selected because P64 cannot be reentered once it has been exited.

25. The crew can select a display of the LGC computed throttle setting by keying V16 N92.

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

2. V16 N92 (astronaut initiated)

Percent full thrust (10,500 lb)	00XXX %
Altitude rate	XXXX.X ft/s
Altitude	XXXXX ft.

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 (ROD) 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. To null the forward and lateral surface velocities of the LM when the Mode Control switch is in Auto and still respond to the Rate of Descent (ROD) switch inputs.
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 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)).
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 during the program.
5. The entire powered landing maneuver (braking, approach, and landing) will be accomplished using the DPS engine.
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 throttlable 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.

   In the Auto Stabilization mode, the PGNS will operate to null the forward and lateral surface velocities by controlling the inertial attitude of the spacecraft.

   In the Attitude Hold mode, the LGC will hold an inertial attitude. However, the attitude may be changed by manual control via the attitude controller.
9. The LPD option is not provided to the crew during this program.
10. The crew can display LGC calculated value of forward velocity, lateral velocity altitude, and altitude rate during this program. The calculation of these parameters is under the control of the Landing Analog Displays routine (R10) which is already in process.
11. 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-of-window references and LM/DSKY displays.

    Switch operation is on an incremental basis: - (increase ROD) or + (decrease ROD). Each command results in an LGC–commanded change of "ROD SCALE" in LM rate of descent. (ROD SCALE is a value loaded into erasable storage prior to flight. Presently 1 foot per second.)
12. An abort from the lunar descent may be required at any time during descent coast or powered descent (P63, P64, or P66).

P66 (continued)

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.

13. 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 vertical 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.

    The LGC is not permitted to compute body rates via V60 during this program. The attitude will always be available for astronaut display so that they are aware of the impending S/C motion when switching from Attitude Hold to Auto.

14. 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). However, it is not recommended that the AGS be initialized during powered flight because DAP attitude control is interrupted during CDU Zero in that routine.

    In the event 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.

15. 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.

16. This program is automatically selected by the Landing Auto Modes Monitor routine (R13) during the powered landing maneuver when:

    a. The targeted conditions for P64 are met (either automatically or astronaut flown).

    b. When the Rate of Descent (ROD) switch is activated by the astronaut after P63 throttle up in Attitude Hold.

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

17. The crew has the capability to select a display of the LGC computed throttle setting by keying V16 N92.

Selected Displays:

1. V06 N60

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

2. V16 N92 (astronaut initiated)

Percent full thrust (10,500 lb)	00XXX%
Altitude rate	XXXX.X ft/s
Computed rate	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 (Program P66).
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 PGNCS controlled DPS abort from the powered landing maneuver (P63, P64, or P66) 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 iginition for the maneuver (P63) and DPS shutdown on the lunar surface (P66).
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 controls the total vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control about only the yaw axis with the ACA (X-axis override) provided the X-axis override capability is permitted.

   If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about all vehicle axes with the ACA using either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode.
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 PGNS generates two types of errors for display on the FDAI as selected by the astronaut:
    a. Mode 1—Selected by Verb 61. Autopilot following errors used as a monitor of the DAP's ability to track automatic steering commands.
    b. Mode 2—Selected by Verb 62. Total attitude errors used to assist the 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

3. V50 N25 (change guidance control mode)

Checklist code	00203

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, or P66) 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 perferred 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 controls the total vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise control about only the yaw axis with the ACA (X-axis override) provided the X-axis override capability is permitted.

   If a thrusting maneuver is performed with the Guidance Control switch in PGNS and the Mode Control switch in Attitude Hold, the PGNCS holds the vehicle attitude and generates either Mode 1 or Mode 2 attitude errors for display on the FDAI. The crew may exercise manual control about all vehicle axes with the ACA using either the Rate Command or Minimum Impulse mode. However, it is strongly recommended that powered flight not be attempted in the Minimum Impulse mode.

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 PGNS generates two types of errors for display on the FDAI as selected by the astronaut.

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

    b. Mode 2—Selected by Verb 62. Total attitude errors used to assit the 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:

    a. 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.

    b. V37E71E—This program may be called by the same procedure as other programs are manually called.

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
3. V50 N25 (change guidance control mode)	
Checklist code	00203
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

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

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

5. V06 N59

Components of ΔV (LOS) for TPI	XXXX.X ft/s

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)	XXXXX.
Time of TPM ignition	XX b XX min/s
Middle gimbal angle	XXX.XX deg

4. V06 N52 (astronuat 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-1

ASPO 45 CRT DISPLAYS

MSK-683 (CM)
MSK-966 (CM)
MSK-1123 (LM)
MSK-1137 (LM)

CSM GNC PRIMARY TAB 0683

GMT ______ SITE ______

GETA ______

CTE ______

CMC ______

GETC ______

CMC ΔT ______

ISS ______ M

OPT ______ D

CMC ______ E

ID ______

VERB ___ NOUN ___ PRGM ___

REG 1 ______

REG 2 ______

REG 3 ______

—— DAP ——

RATE ___ DB ___

VEH ACC ______

VG X ______

VG Y ______

VG Z ______

PIPX ______

PIPY ______

PIPZ ______

PIP T ______

TEV ______

TIG ______

			QUADA	QUADB	QUADC	QUADD
WPU	CAL C	LBS	___	___	___	___
HE	P/T R	PCT	___	___	___	___
PKG	TEMP	°F	___	___	___	___
HE	TK P	PSIA	___	___	___	___
HE	TK T	°F	___	___	___	___
HE	MN P	PSIA	___	___	___	___
FU	MN P	PSIA	___	___	___	___
OX	MN P	PSIA	___	___	___	___

CM-RCS			SYS A	SYS B
HE	TK P	PSIA	___	___
HE	MN P	PSIA	___	___

	PITCH	YAW	ROLL
ISS ATT	___	___	___
ACDU	___	___	___
FCDU	___	___	___
ERR CMC	___	___	___
ERR SCS	___	___	___
RATE ENT	___	___	___
RATE G/N	___	___	___
RATE SCS	___	___	___
GMB CMD	___	___	___
OCDU DC	___	___	
SPS GMB	___	___	
AT TVC	___	___	
MN TVC	___	___	___

SPS				
OX	TK		PSI	___
OX	IN		PSI	___
EG	CH		PSI	___
FU	TK		PSI	___
FU	IN		PSI	___
HE	TK		PSI	___
HE	TK	T	°F	___
OX	FD	LN	°F	___
FU	FD	LN	°F	___
OX	LN	I	°F	___
FU	LN	I	°F	___
EG	VLV		°F	___
N2	T1		PSI	___
N2	T2		PSI	___
OX	T1		PCT	___
OX	T2		PCT	___
FU	T1		PCT	___
FU	T2		PCT	___

GMT	-	GREENWICH MEAN TIME	D H M S XX:XX:XX:XX
GETA	-	GROUND ELAPSED TIME (RECEIPT OF ANALOG DATA)	H M S XXXX:XX:XX
CTE	-	CENTRAL TIMING EQUIPMENT TIME	H M S XXXX:XX:XX
CMC	-	CM COMPUTER CLOCK	H M S XXXX:XX:XX
GETC	-	GROUND ELAPSED TIME (RECEIPT OF COMPUTER WORDS)	H M S XXXX:XX:XX
CMC ΔT	-	DIFFERENCE BETWEEN GETC AND CMC	S XXX.XXX
ISS	-	ISS MODE	OFF/TRN ON/CDU ZR/CO ALN/FN ALN/INTERTL/CAGE
OPT	-	OPTICS MODE	OFF/ZERO/CMC/MAN
CMC	-	RCS CONTROL MODE	AUTO/HOLD/FREE/SCS
ID	-	IDENTIFICATION OF DOWNLIST BEING TRANSMITTED	
*VERB	-	DSKY VERB DISPLAY	XX
*NOUN	-	DSKY NOUN DISPLAY	XX
*PRGM	-	DSKY PROGRAM NUMBER DISPLAY	XX
REG1, REG2, REG3	-	DSKY ROWS 1, 2, AND 3	±XXXXX
RATE	-	SELECTED MAXIMUM DAP RATE	X.X DEG/SEC
DB	-	SELECTED DAP DEADBAND	X.X DEG
VEH ACC	-	VEHICLE ACCELERATION	±XXX.X FPS^2
VG X, VG Y, VG Z	-	VELOCITY TO BE GAINED IN SM COORDINATES	±XXXX. FPS

PIPX, PIPY, PIPZ	-	X, Y, AND Z PIPA COUNTS	±XXXXX	COUNTS
PIP T	-	PIPA TEMPERATURE	+XXX.X	°F
TEV	-	TIME OF EVENT	H M S XXXX:XX:XX	
TIG	-	TIME TO/FROM IGNITION	H M S XXXX:XX:XX	
ISS	-	ISS RESOLVER INDICATED ATTITUDE	+XXX.X	DEG
ACDU	-	ACTUAL CDU ANGLES	+XXX.X	DEG
FCDU	-	FINAL DESIRED CDU ANGLES	+XXX.X	DEG
ERR CMC	-	COMPUTED ATTITUDE ERRORS TO FDAI	±XX.X	DEG
ERR SCS	-	SCS ATTITUDE ERRORS	±XX.X	DEG
RATE ENT	-	RATES COMPUTED IN ENTRY DAP	±XX.X	DEG/SEC
RATE G/N	-	DAP COMPUTED BODY RATES	±XX.X	DEG/SEC
RATE SCS	-	SCS DETERMINED BODY RATES	±XX.X	DEG/SEC
GMB CMD	-	COMPUTER COMMANDED SPS ENGINE COMMANDS	±XX.XX	DEG
OCDU DC	-	OCDU DAC OUTPUT FOR GMB CMD	±XX.XX	DEG
SPS GMB	-	SPS GIMBAL POSITION OUTPUTS FOR GMB CMD	±XX.XX	DEG
AT TVC	-	SCS AUTOMATIC CONTROL SPS	±X.XX	DEG
MN TVC	-	SCS MANUAL CONTROL SPS GIMBAL COMMANDS	±X.XX	DEG
SITE	-	SITE FROM WHICH DATA IS BEING RECEIVED		

*SEE CM SOFTWARE SECTION FOR FURTHER DEFINITION

CMC COMMON H/S

ID ________ GMT ________ SITE ________ X/ROLL Y/PITCH Z/YAW

CTE ________ PIPA ____ ____ ____

FGWD 0 ____ GETA ________ DELV ____ ____ ____

FGWD 1 ____ GETC ________ VGIMU ____ ____ ____

FGWD 2 ____ GETH ________

FGWD 3 ____ CMC ________ FCDU ____ ____ ____

FGWD 4 ____ TCMSV ________ DCDU ____ ____ ____

FGWD 5 ____ TLMSV ________ 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 __ LM ____ ACTOFF ____ ____

CHNL 13 ____ R3 ____ CMD __ CSM ____ GMBCMD ____ ____

CHNL 14 ____

CHNL 30 ____ REDO DSTB11 ____ HAPO ____ TMRK ________

CHNL 31 ____ ____ FAIRG CDRFL HPER ____ VHFRNG NM ____

CHNL 32 ____ RSBBQ ____ ____ LAT ____ RANGE NM ____

CHNL 33 ____ ____ ____ ____ LONG ____ RRATE FPS ____

____ ____ ____ THETAH DEG ____

IMDE 30 ____ HLDFG CRSTR ____ ELEVN DEG ____

IMDE 33 ____ ____ CDH △ ALT NM ____ OFSTPT NM ____

OPTMDE ____ RCSFG STARID1 ____ VGTIGX ____ CNTL DEG ____

DPDTR1 ____ ____ STARID2 ____ VGTIGY ____ TRNF ________

DPDTR2 ____ CDU SHFT ____ VGTIGZ ____ TTPI ________

CDU TRUN ____ TTPF ________

ID	-	IDENTIFICATION OF DOWNLIST BEING TRANSMITTED	
GMT	-	GREENWICH MEAN TIME	D H M S XX:XX:XX:XX
CTE	-	CENTRAL TIMING EQUIPMENT TIME	H M S XXXX:XX:XX
GETA	-	GROUND ELAPSED TIME (RECEIPT OF ANALOG DATA)	H M S XXXX:XX:XX
GETC	-	GROUND ELAPSED TIME (RECEIPT OF COMPUTER WORDS)	H M S XXXX:XX:XX
GETH	-	GROUND ELAPSED TIME (RTCC)	H M S XXXX:XX:XX
CMC	-	CM COMPUTER CLOCK	H M S XXX:XX:XX.XX
TCMSV	-	TIME OF CM STATE VECTOR	H M S XXX:XX:XX.XX
TLMSV	-	TIME OF LM STATE VECTOR	H M S XXX:XX:XX.XX
TGO	-	TIME TO CUTOFF	H M S XXX:XX:XX
TIG	-	TIME TO/FROM IGNITION	H M S XXX:XX:XX.XX
TEVNT	-	TIME OF EVENT	H M S XXX:XX:XX.XX
SITE	-	SITE FROM WHICH DATA IS BEING RECEIVED	
PIPA	-	PIPA COUNTS	±XXXXX COUNTS
DELV	-	VALUES OF PIPA'S AT LAST READING, CORRECTED FOR SCALE FACTOR ERROR AND BIAS	±XXXXX FPS
VGIMU	-	VELOCITY TO BE GAINED IN SM COORDINATES	±XXXX.X FPS
FCDU	-	FINAL DESIRED CDU ANGLES	+XXX.XX DEG
DCDU	-	DESIRED CDU ANGLES	+XXX.XX DEG
ACDU	-	ACTUAL CDU ANGLES	+XXX.XX DEG
ERROR	-	ATTITUDE ERRORS COMPUTED BY RCS DAP	±XX.XX DEG
CDRFL	-	RETURN ADDRESS INFORMATION ASSOCIATED WITH DSKY DISPLAYS	$XXXXX_8$
AK	-	RCS DAP FOLLOWING ERRORS OR TVC DAP ATTITUDE ERRORS	±XX.XX DEG

ADOT	-	DAP COMPUTED BODY RATES	XX.XX DEG/SEC
OMGAC	-	COMMANDED BODY RATES FROM CROSS PRODUCT STEERING	XX.XX DEG/SEC
BIAS	-	COMPUTED PIPA BIAS	±X.XXXX FT/SEC
*FGWD 0 - FGWD 11	-	COMPUTER FLAGWORDS 0 THRU 11	$XXXXX_8$
*CHAN 11 - CHAN 14	-	COMPUTER OUTPUT CHANNELS	$XXXXX_8$
*CHAN 30 - CHAN 33	-	COMPUTER INPUT CHANNELS	$XXXXX_8$
*IMDE30, IMDE33	-	COMPUTER IMU STATUS REGISTERS	$XXXXX_8$
*OPTMDE	-	COMPUTER OPTICS STATUS REGISTER	$XXXXX_8$
*DPDTR1, DPDTR2	-	DATA FOR DAP SELECTION AND OPERATION	$XXXXX_8$
*PG	-	COMPUTER PROGRAM NUMBER	XX
FL	-	VERB/NOUN FLASHER STATUS	
WARN	-	CMC WARNING LAMP STATUS	
PRG	-	PROGRAM ALARM LAMP STATUS	
$\overline{\text{KKK}}$	-	UPLINK DATA STATUS	
UPFST	-	BLOCK INLINK DISCRETE STATUS	
UPSW	-	UPLINK ACCEPT/BLOCK SWITCH STATUS	
CMD	-	UPLINK TOO FAST STATUS	
*VB	-	DSKY VERB DISPLAY	XX
*NN	-	DSKY NOUN DISPLAY	XX
R1, R2, & R3	-	DSKY ROW 1, ROW 2, AND ROW 3 DISPLAYS	±XXXXX
REDO	-	NUMBER OF RESTARTS	$XXXXX_8$
RSBBQ	-	VALUE OF BBANK AND Q REGISTERS AT THE TIME OF A RESTART	$XXXXX_8$
DSTB11	-	DISPLAY TABLE OF DSKY STATUS LIGHTS $X0400_8$ = PROGRAM CAUTION, $X0200_8$ = TRACKER WARNING, $X0020_8$ = NO ATTITUDE, $X0040_8$ = GIMBAL LOCK	$XXXXX_8$
*FALRG	-	1ST, 2ND, AND MOST RECENT ALARM CODES	$XXXXX_8$

*SEE CM SOFTWARE SECTION FOR FURTHER DEFINITION

MSK-966 (CONTINUED)

*HLDFG	-	STATUS OF ATTITUDE HOLD CONTROL MODE OF CSM RCS DAP	$XXXXX_8$
*RCSFG	-	DATA FOR RCS DAP	$XXXXX_8$
STARID1	-	IDENTIFICATION NUMBER OF STAR 1	XXX_8
STARID2	-	IDENTIFICATION NUMBER OF STAR 2	XXX_8
CDU SHFT	-	OPTICS SHAFT ANGLE DIVIDED BY TEN	±XX.XXX DEG
CDU TRUN	-	OPTICS TRUNNION ANGLE	±XX.XXX DEG
LM	-	PRESENT MASS OF THE LM	XXXXX LBS
CSM	-	PRESENT MASS OF THE CSM	XXXXX LBS
ACTOFF	-	SPS GIMBAL TRIMS	±XX.XXX DEG
GMBCMD	-	COMPUTER COMMANDED SPS ENGINE COMMANDS	±XX.XXX DEG
HAPO	-	ALTITUDE AT APOGEE	+XXXX.X NM
HPER	-	ALTITUDE AT PERIGEE	+XXXX.X NM
LAT	-	LATITUDE OF LANDMARK	±XX.XXX DEG
LONG	-	LONGITUDE OF LANDMARK	±XXX.XX DEG
CRSTR	-	CROSS PRODUCT STEERING CONSTANT	±X.XXXX
CDH △ ALT	-	DIFFERENCE IN ALTITUDE BETWEEN VEHICLES AT CDH	±XX.XX NM
VGTIGX, VGTIGY, VGTIGZ	-	COMPONENTS OF VELOCITY TO BE GAINED IN ECI COORDINATES	±XXXX.X FPS
TMRK	-	TIME OF LAST MARK (OPTICS/VHF)	H M S XXX:XX:XX.XX
VHFRNG	-	RANGE TO OTHER VEHICLE AS DETERMINED BY VHF RANGING SYSTEM	±XXX.XX NM
RANGE	-	COMPUTED RANGE TO OTHER VEHICLE	±XXX.XX NM
RRATE	-	COMPUTED RANGE RATE WITH RESPECT TO OTHER VEHICLE	±XXXX.X FPS
THETAH	-	RANGE BETWEEN PRESENT POSITION AND ESTIMATED LANDING SITE	XXX.X DEG
ELEVN	-	DESIRED LOS ANGLE AT TPI	±XXX.XX DEG
OFSTPT	-	DESIRED SEPARATION OF THE TWO VEHICLES AT RENDEZVOUS	±XXX.XX NM
CNTL ANG	-	ORBITAL CENTRAL ANGLE OF THE PASSIVE VEHICLE DURING TRANSFER FROM TPI TO INTERCEPT	+XXX.XX DEG
TRNF	-	DESIRED TRANSFER TIME FOR LAMBERT MANEUVER	H M S XXX:XX:XX.XX
TTPI	-	TIME OF INITIATION OF TPI MANEUVER	H M S XXX:XX:XX.XX
TTPF	-	TIME OF INTERCEPT	H M S XXX:XX:XX.XX

*SEE CM 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 ______ SITE ______

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 ______ ______ F0 ______

R ______ ATT H ______ ______ F1 ______

P ______ F2 ______

Y ______

RR ______

TRK ______

R ______

RDT ______

SH ______

TR ______

LR

AP ______

VD ______

RD ______

R ______

VX ______

VY ______

VZ ______

DEDA

AD ______

RO ______

CLR ______

M ______

______

REDO ______

DSKY

P ______

V ______

N ______

1 ______

2 ______

3 ______

GET	-	GROUND ELAPSED TIME	H M S XXX:XX:XX
MET	-	MISSION ELAPSED TIME	H M S XXX:XX:XX
AGS	-	ABORT GUIDANCE SYSTEM TIME	H M S XXX:XX:XX
LGC	-	LM GUIDANCE COMPUTER TIME	H M S XXX:XX:XX
LGC FMT	-	IDENTIFICATION OF DOWNLIST BEING TRANSMITTED	
SITE	-	IDENTIFICATION OF SITE FROM WHICH DATA IS BEING RECEIVED	
TGO	-	TIME TO GO UNTIL ENGINE CUTOFF	M S XX:XX
TTF/8	-	TIME TO GO UNTIL END OF PHASE (DESCENT PROGRAMS)	M S XX:XX
PGNS RATE	-	ROLL, PITCH, YAW DAP RATES	XX.X DEG/SEC
RGA	-	AGS BODY MOUNTED RATE GYRO OUTPUT	XX.X DEG/SEC
ASA	-	AGS ABORT SENSING ASSEMBLY BODY RATES	XX.X DEG/SEC
ATT CMDS	-	LGC ATTITUDE COMMANDS	XX.X DEG
LOC VER/HOR	-	BODY ANGLES FROM THE LOCAL VERTICAL COORDINATE SYSTEM	XX.X DEG
RSVR GMBL	-	1X RESOLVER GIMBAL ANGLES	XXX.X DEG
ICDUD ATT	-	DESIRED CDU ANGLES TO THE DAP	XXX.X DEG
CDUA ATT	-	ACTUAL CDU ANGLES	XXX.X DEG
IMU ATT	-	1X RESOLVER GIMBAL ANGLES	XXX.X DEG
AGS ATT	-	ABORT GUIDANCE SYSTEM BODY ANGLES	XXX.X DEG
PGNS ERR	-	CDU-DAC OUTPUT	XX.X DEG
AGC ERR	-	ABORT GUIDANCE SYSTEM ATTITUDE ERRORS	XXX.X DEG
MMNT OFFSET	-	ANGULAR ACCELERATION ABOUT ROLL AND PITCH	XX.X DEG/SEC^2
AGS VEL	-	ABORT GUIDANCE SYSTEM INDICATED VELOCITY	XXXX FT/SEC
LGC DEL VEL	-	PIPA OUTPUT FOR A 2 SECOND INTERVAL	XX.X FT/SEC

AGS DEL VEL	-	ABORT GUIDANCE SYSTEM MEASURED VELOCITY	XX.X FT/SEC
AGS ULL	-	ABORT GUIDANCE ULLAGE MEASUREMENT	XX.X FT/SEC
ACT VEL	-	ACCUMULATED VELOCITY ALONG THRUST	XX.X FT/SEC
AUTO	-	AUTO STABILIZATION MODE STATUS	XX/BLANK
R P Y	-	ROLL, PITCH AND YAW ACHIEVED FROM PULSES, DIRECT OR AUTO (NORM)	±XXX.X DEG
ATT H	-	ATTITUDE HOLD MODE STATUS	XX/BLANK
*F0 (ALARM CODES)	-	FIRST	
*F1 (ALARM CODES)	-	SECOND	
*F2 (ALARM CODES)	-	MOST RECENT	
*RR	-	RADAR MODE FLAGWORD (RADMODES)	$XXXXX_8$
TRK	-	RADAR TRACK ENABLE	CH 12 B 14
RDT	-	RENDEZVOUS RADAR RANGE RATE	XXXX FT/SEC
R	-	RENDEZVOUS RADAR RANGE	XXX.XX NM
SH	-	RENDEZVOUS RADAR SHAFT ANGLE	±XXX DEG
TR	-	RENDEZVOUS RADAR TRUNNION ANGLE	±XXX DEG
AP	-	LANDING ANTENNA POSITION	1 OR 2
VD	-	LANDING VELOCITY DATA GOOD	GOOD/BAD
RD	-	LANDING RANGE DATA GOOD	GOOD/BAD
R	-	LANDING RADAR RANGE	X NM
V_X V_Y V_Z	-	LANDING RADAR VELOCITIES	±XXXXX FT/SEC
DEDA	-	AGS DSKY	
AD	-	ADDRESS	
RO	-	READOUT	
CLR	-	CLEAR	
M	-	REGISTER 5 DIGIT CONTENTS	
REDO	-	NUMBER OF LGC RESTARTS	
DSKY			
*P	-	PROGRAM	
*V	-	VERB	
*N	-	NOUN	
1 2 3	-	ROW 1, 2, AND 3	

*SEE LM SOFTWARE SECTION FOR FURTHER DEFINITION

1137

GET ____ LGC ____ GMT ____ AEA LGC PCM SITE ____

D/L ____
RTCC ____
RATE ____ D/S
X-TRANS

THRT ____ ROLL-R PITCH-Q YAW-P

SELECT ____
DECA ____
MAN THR ____
AUTO THR ____
CMD THR ____
VAR ACT ____
GUID CMD ____
TCP ____

LGC WXXXXX ___.___ ___.___ ___.___
AGS ERR ___.___ ___.___ ___.___
OMEGA-D ___.___ ___.___ ___.___
OFFSET ___.___ ___.___
GMBL DR ____ ____

SC TORQ-U TORQ-V TORQ-P
AUTO ____ + ___.___ + ___.___ + ___.___
A/H ____ - ___.___ - ___.___ - ___.___

WT ____
CSM ____
RHC ____
DAP ____ ____ CH 30
CH 11 ____ ____ CH 31
CH 12 ____ ____ CH 32
CH 13 ____ ____ CH 33
CH 14 ____ ____ RAD

ATTITUDES

	ROLL-Z	PITCH-Y	YAW-X
LOCAL			
BIAS			
OCTAL			
RSVR-S			
RSVR-F			
ACT-F			
IDES-F			
FDES-F			
AGS-F			
ΔERR-S			

RATES

PGNS-B			
RGA-B			

DELTA VELOCITIES

AGS-B			
LGC-B			
ACT ΔV			
PIP-S			
SM			

STATUS

DAP
TIG ____
TGO ____
TEVT ____
T/P ____
LGC ____
ISS ____
PGNS ____
PROG ____
FREG0 ____
FREG1 ____
FREG2 ____
REDO ____
PROG ____
VERB ____
NOUN ____
FL ____
R1 ____
R2 ____
R3 ____

VEL GAIN

LR

LR RNG ____ VEL ____

	LR	PGNSΔ	AGSΔ
VXS			
VYS			
VZS			

RNG ____ ΔH ____ RNG ____

RR

RR ____ CNTRL ____ ____
DATA ____ MODE ____
____ SHFT ____ TRUN ____

LGC		
RR		
ERR		
RANGE		M
RNGRT		K

POWER

800 ~ ____
3200~ ____
120V ____
BIAS ____

TEMPS

LR ____
RR ____
PIP ____

GET	-	GROUND ELAPSED TIME	H M S XXX:XX:XX
LGC	-	LM COMPUTER CLOCK	H M S XXX:XX:XX
GMT	-	GREENWICH MEAN TIME	H M S XXX:XX:XX
SITE	-	SITE FROM WHICH DATA IS BEING RECEIVED	
D/L	-	DOWNLIST IDENTIFICATION	
SELECT	-	THROTTLE SELECT SWITCH STATUS	AUTO/BLANK
DECA	-	DESCENT THROTTLE COMMAND	±XXX.XX%
MAN THR	-	MANUAL THROTTLE COMMAND	XXX%
AUTO THR	-	AUTO THROTTLE COMMAND	XXX%
CMD THR	-	TOTAL THROTTLE COMMAND (MAN THR + AUTO THR)	XXX%
VAR ACT	-	VARIABLE ACTUATOR POSITION	XXX%
GUID CMD	-	LGC COMMANDED THRUST	XXX%
TCP	-	THRUST CHAMBER PRESSURE	XXX%
LGC XXXXX - ERR	=	TOTAL OR DAP FOLLOWING ATTITUDE ERRORS	±XX.X DEG
- RATES	=	LGC COMPUTED BODY RATES	
AGS ERR	-	AGS POSITIONAL ERROR	±XXX.X DEG
OMEGA-D	-	DESIRED BODY RATES FOR AUTOMATIC MANEUVER	±X.XX DEG/SEC
OFFSET	-	COMPUTED ANGULAR ACCELERATION ABOUT Y AND Z BODY AXES DUE TO THE ENGINE	±XX.XXX DEG/SEC^2
GMBL DR	-	DIRECTION OF ENGINE BELL MOTION	±R & ±P
A/H	-	ATTITUDE HOLD MODE STATUS	XX/BLANK
AUTO	-	AUTO STABILIZATION MODE STATUS	XX/BLANK
+ TORQ-U, TORQ-V, TORQ-P	-	CUMMULATIVE SUM OF POSITIVE COMMANDED TORQUE ABOUT CONTROL AXES U, V, AND P RESPECTIVELY	XX.XX SECS
- TORQ-U, TORQ-V, TORQ-P	-	CUMMULATIVE SUM OF NEGATIVE COMMANDED TORQUE ABOUT CONTROL AXES U, V, AND P RESPECTIVELY	XX.XX SECS

WT	-	MASS OF THE LM	XXXXX LBS
RTCC	-	RTCC COMPUTED MASS OF THE LM OR LM + CSM	XXXXX LBS
CSM	-	MASS OF THE CSM	XXXXX LBS
PIP-S	-	PIPA COUNTS	$XXXXX_{10}$
RATE	-	DESIRED RATES FOR AUTOMATIC MANEUVERS	±XX.X DEG/SEC
RHC	-	SCALING STATUS ON RHC	NORM/FINE
X-TRANS	-	RCS FUEL SYSTEM SELECTION/NUMBER OF JETS TO BE USED FOR X-TRANSLATION	A OR B/2 OR 4
*DAP	-	DAP FLAGWORD (DAPBOOLS)	$XXXXX_8$
*CH 11 - CH 14	-	LM COMPUTER OUTPUT CHANNELS	$XXXXX_8$
*CH 30 - CH 33	-	LM COMPUTER INPUT CHANNELS	$XXXXX_8$
*RAD	-	RADAR FLAGWORD (RADMODES)	$XXXXX_8$
LOCAL	-	BODY ATTITUDE ABOUT LOCAL HORIZONTAL	±XXX.X DEG
BIAS	-	Δ PIPA COUNTS/Δ TIME, PIPA FREE FALL BIAS (GROUND COMPUTED)	±X.XXX CM/SEC^2
	-		
OCTAL	-	COMPUTED OCTAL LOADS FOR LGC PIPA BIAS REGISTERS	$XXXXX_8$
RSVR-S	-	GIMBAL RESOLVER INDICATED ANGLES	+XXX.XX DEG
RSVR-F	-	GIMBAL RESOLVER INDICATED ANGLES IN FDAI COORDINATES	±XXX.XX DEG
ACT-F	-	LM ATTITUDE TRANSFORMED TO FDAI COORDINATES	+XXX.XX DEG
IDES-F	-	INTERMEDIATE DESIRED CDU ANGLES TRANSFORMED TO FDAI COORDINATES	+XXX.XX DEG
FDES-F	-	FINAL DESIRED CDU ANGLES TRANSFORMED TO FDAI COORDINATES	+XXX.XX DEG
AGS-F	-	AGS EULER ANGLES TRANSFORMED TO FDAI COORDINATES	+XXX.XX DEG
ΔERR-S	-	DIFFERENCE BETWEEN PGNS EULER ANGLES AND AGS EULER ANGLES	±XX.XX DEG

*SEE LM SOFTWARE SECTION FOR FURTHER DEFINITION

MSK-1137 (CONTINUED)

PGNS-B	- DAP COMPUTED BODY RATES	±XX.XX	DEG/SEC
RGA-B	- AGS RATE GYRO OUTPUTS IN BODY COORDINATES	±XX.X	DEG/SEC
AGS-B	- AGS INDICATED LINEAR VELOCITY IN BODY COORDINATES	±XX.X	FT/SEC
LGC-B	- ACCUMULATED PIPA COUNTS WHILE SERVICER IS RUNNING IN BODY AXIS COORDINATES	±XX.X	FT/SEC
ACT ΔV	- ACTUAL DELTA V GAINED (GROUND COMPUTED)	XX.X	FT/SEC
SM	- ACCUMULATED PIPA COUNTS OVER 2 SECONDS IN STABLE MEMBER COORDINATE	±XX.X	FT/SEC
DAP	- LEFT - POSITION OF GUIDANCE AND CONTROL SWITCH	AGS/PGNS	
	RIGHT - STATUS OF THE DAP	ON/OFF	
TIG	- TIME OF IGNITION	H M S XXX:XX:XX	
TGO	- TIME TO ENGINE CUTOFF	S XXXXX.	
TEVT	- TIME OF LAST/NEXT SIGNIFICANT EVENT	H M S XXX:XX:XX	
T/P	- TIME TO END OF PHASE (DESCENT ONLY)	S XXXXX.	
LGC	- LGC WARNING LAMP STATUS		
ISS	- ISS WARNING LAMP STATUS		
PGNS	- PGNS CAUTION LAMP STATUS		
PROG	- PROGRAM CAUTION LAMP STATUS		
*FREGO, FREG1, FREG2	- 1ST, 2ND, AND MOST RECENT ALARM CODE	$XXXXX_8$	
*REDO	- NUMBER OF RESTARTS	$XXXXX_8$	
*PROG	- COMPUTER PROGRAM NUMBER	XX	
*VERB	- DSKY VERB DISPLAY	XX	
*NOUN	- DSKY NOUN DISPLAY	XX	
FL	- INDICATES WHETHER OR NOT VERB/NOUN FLASHER IS ON	FLSH/BLANK	
*R1, R2, R3	- DSKY ROW 1, ROW 2, AND ROW 3 DISPLAYS	±XXXXX	

LR RNG	- STATUS OF LANDING RADAR RANGE DATA	GOOD/BAD	
VEL	- STATUS OF LANDING RADAR VELOCITY DATA	GOOD/BAD	
VXS, VYS, VZS	- LR VELOCITY DATA CONVERTED TO STABLE MEMBER COORDINATES	±XXXX	FT/SEC
RANGE	- LANDING RADAR SLANT RANGE	XXXXX	FT
ΔH	- LR MINUS LGC COMPUTED ALTITUDE (MIDDLE COLUMN)	XXXXX	FT
ΔH	- LR MINUS AGS COMPUTED ALTITUDE (RIGHT COLUMN)	XXXXX	FT
PGNS	- LR MINUS PGNS VELOCITIES CORRECTED FOR LUNAR GRAVITY IN STABLE MEMBER COORDINATES	±XXXX	FT/SEC
ΔAGS	- LR MINUS AGS VELOCITIES CORRECTED FOR LUNAR GRAVITY IN STABLE MEMBER COORDINATES	±XXXX	FT/SEC
RR	- STATUS OF RENDEZVOUS RADAR	ON/OFF	
CNTRL	- MODE STATUS OF RENDEZVOUS RADAR	AUTO/MAN	
DATA	- STATUS OF RENDEZVOUS RADAR DATA	GOOD/BAD	
MODE	- MODE STATUS OF RENDEZVOUS RADAR ANTENNA	1/2	
LGC	- RENDEZVOUS RADAR ANTENNA POSITION (CDU)	±XXX.X	DEG
RR	- RENDEZVOUS RADAR ANTENNA POSITION IN FDAI COORDINATES	±XXX.X	DEG
ERR	- COMPUTER COMMANDED RENDEZVOUS RADAR ANTENNA RATE	±XX.XX	DEG/SEC
RANGE	- RENDEZVOUS RADAR RANGE	XXX.XX	NMI
RNGRT	- RENDEZVOUS RADAR RANGE RATE	±XXXX	FT/SEC
800 ∿	- 800 ∿ VOLTAGE	XX.X	VOLTS
3200 ∿	- 3200 ∿ VOLTAGE	XX.X	VOLTS
120V	- 120 VDC PIPA SUPPLY VOLTAGE	XXX	VOLTS
BIAS	- TM BIAS VOLTAGE	X.XX	VOLTS
LR	- LANDING RADAR ANTENNA TEMPERATURE	±XXX.X	°F
RR	- RENDEZVOUS RADAR ANTENNA TEMPERATURE	±XXX.X	°F
PIP	- PIPA TEMPERATURE	+XXX.X	°F

*SEE LM SOFTWARE SECTION FOR FURTHER DEFINITION

LAUNCH AND BURN SCHEDULE

STABLE MEMBER ORIENTATIONS
TRANSLUNAR INJECTION
MIDCOURSE CORRECTIONS
LUNAR ORBIT INSERTION
DESCENT ORBIT INSERTION
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					

APOLLO 13 CM POWERED MANEUVER SUMMARY

EVENT	TYPICAL G.E.T. (h:min:s)	PROPULSION SYSTEM	BURN DURATION (s)	ULLAGE DURATION (s)	TOTAL ΔV (ft/s)	RESULTANT hp/ha* (nmi)	GUIDANCE MODE	REFSMMAT
ORBIT INSERTION	00:11:39.6	-	-	-	-	100/100		LAUNCH PAD
TLI	02:35:23.5	S-IVB	325.4	-	10,437	-	S-IVB/IU	LAUNCH PAD
CSM/LM EJECTION	04:00:41	SM-RCS	3	-	1.2	-	EXT ΔV	LAUNCH PAD
S-IVB EVASIVE MANEUVER	04:12:30	S-IVB APS	80	-	9.35	-	S-IVB/IU	-
S-IVB LOX DUMP	04:34:00	S-IVB LOX	-	-	-	LUNAR IMPACT	S-IVB/IU	-
S-IVB IMPACT MANEUVER	09:19:00	S-IVB APS	-	-	-	IMPACT (30° W, 3° S)	S-IVB/IU	-
MCC_1	11:40:49	SPS/RCS	NOM ZERO	0	NOM ZERO	-	EXT ΔV	PTC
MCC_2	TBD	SPS	TBD	0	TBD	-	EXT ΔV	PTC
MCC_3	55:24:53	SPS/RCS	NOM ZERO	0	NOM ZERO	-	EXT ΔV	PTC
MCC_4	72:24:53	SPS/RCS	NOM ZERO	0	NOM ZERO	-	EXT ΔV	PTC
S-IVB LUNAR IMPACT	77:41:00							
LOI	77:24:52.9	SPS	356.6	0	2,815.3	58.8/170.2	EXT ΔV	LANDING SITE
DOI	81:45:20.5	SPS	23.1	19	212.9	9.0/59.2	EXT ΔV	LANDING SITE
UNDOCKING & CSM/LM SEP	99:16:21	SM-RCS	6.7	0	1.0	8.2/59.5	EXT ΔV	LANDING SITE
CSM CIRCULARIZATION	100:35:05.2	SPS	3.9	-	70.3	54.3/63.6	EXT ΔV	LANDING SITE
CSM PLANE CHANGE NO. 1	113:42:02.7	SPS	10.0	15	183.6	55.7/61.8	EXT ΔV	PREFERRED
LM JETTISON	143:04:00							
CSM SEPARATION	143:09:14.7	SM-RCS	6.1	0	1.0	58.0/59.6	EXT ΔV	LIFTOFF
CSM PLANE CHANGE NO. 2	154:13:10.8	SPS	43	15	824.6	55.5/61.3	EXT ΔV	PREFERRED
TEI	167:28:58.3	SPS	135.0	17	3,147.7	-	EXT ΔV	PREFERRED
MCC_5	182:28.58.3	SPS/RCS	NOM ZERO	0	NOM ZERO	-	-	PREFERRED
MCC_6	218:49:37.6	SPS/RCS	NOM ZERO	0	NOM ZERO	-	-	PTC
MCC_7	237:49:37.6	SPS/RCS	NOM ZERO	0	NOM ZERO	-	-	ENTRY
ENTRY	240:49:37.6							ENTRY

*ABOVE LUNAR LANDING SITE (LUNAR ORBIT)

APOLLO 13 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 hp/ha* (nmi)	GUIDANCE MODE	REFSMMAT
PDI	103:30:35.3	DPS	686	7.5	6,625	-	PGNCS	LANDING SITE
TOUCHDOWN	103:42:01.5							
ASCENT	137:09:15.8	APS	427.3	0	6,044.4	8.7/43.9	PGNCS	LIFTOFF
INSERTION	137:16:23.1							
CSI	138:06:00.9	RCS	44.4	0	49.6	43.5/45.0	EXT ΔV	LIFTOFF
LM PLANE CHANGE	138:35:07.5	RCS	NOM ZERO	0	NOM ZERO	43.5/45.0	EXT ΔV	LIFTOFF
CDH	139:04:14.1	RCS	NOM ZERO	0	NOM ZERO	43.5/45.0	EXT ΔV	LIFTOFF
TPI	139:45:13.8	RCS	22.1	0	24.8	43.8/60.8	LAMBERT	LIFTOFF
MCC_1	140:00:13.8	RCS	NOM ZERO	0	NOM ZERO	43.8/60.8	LAMBERT	LIFTOFF
MCC_2	140:15:13.8	RCS	NOM ZERO	0	NOM ZERO	43.8/60.8	LAMBERT	LIFTOFF
1ST BRAKING MANEUVER	140:26:29.2	RCS	10.2	0	11.4	49.6/59.1	MANUAL	LIFTOFF
2ND BRAKING MANEUVER	140:27:42.7	RCS	8.8	0	9.9	53.6/58.8	MANUAL	LIFTOFF
3RD BRAKING MANEUVER	140:29:21.1	RCS	4.3	0	4.8	56.1/58.7	MANUAL	LIFTOFF
4TH BRAKING MANEUVER	140:30:40.7	RCS	4.1	0	4.7	58.0/59.4	MANUAL	LIFTOFF
LM DEORBIT	144:32:20.2	RCS	75.2	75.2	185.5	-63.1/59.5	PGNCS	LIFTOFF
LM IMPACT	145:00:18.2	-	-	-	-	-	-	-

*ABOVE LUNAR LANDING SITE (LUNAR ORBIT)

STABLE MEMBER ORIENTATION

- CSM IMU IS LEFT ON FOR ENTIRE FLIGHT.
- LM IMU IS TURNED OFF FOR 31 HOURS OF 34-HOUR LUNAR STAY.
- ORIENTATION OF PLATFORM.
  1. LAUNCH ORIENTATION THROUGH TLI.
  2. PTC THROUGH MCC_4
  3. LANDING SITE REFSMMAT THROUGH LM TOUCHDOWN.
  4. PREFERRED THRUSTING ORIENTATION (CSM ONLY) FOR PLANE CHANGE MANEUVER 1.
  5. LIFTOFF ORIENTATION (BOTH VEHICLES) FROM LM ASCENT THROUGH LM JETTISON AND SEPARATION.
  6. PREFERRED THRUSTING ORIENTATION FOR PLANE CHANGE MANEUVER 2 AND TEI.
  7. PTC ORIENTATION THROUGH MCC_6.
  8. ENTRY REFSMMAT, FROM MCC_7 THROUGH ENTRY.
- REFSMMAT MATRICES

1. LAUNCH
   - U XSM = DOWNRANGE
   - U YSM = U ZSM x U XSM
   - U ZSM = UNIT (-r LAUNCH)
2. PTC
   - U XSM = IN ECLIPTIC PLANE AND PERPENDICULAR TO EARTH-MOON LINE PROJECTION IN ECLIPTIC PLANE AT AVERAGE TIME OF TRANSEARTH INJECTION FOR MONTHLY LAUNCH WINDOW AND AZIMUTH RANGE
   - U YSM = U ZSM x U XSM
   - U ZSM = PERPENDICULAR TO ECLIPTIC PLANE AND DIRECTED SOUTH
3. LANDING SITE
   - U XSM = UNIT (r LANDING)
   - U YSM = U ZSM x U XSM
   - U ZSM = UNIT [(r CSM x V CSM) x U XSM]
4. PREFERRED (THRUSTING)
   - U XSM = UNIT (ΔV COMPENSATED)
   - U YSM = UNIT (U XSM x r TIG)
   - U ZSM = U XSM x U YSM
5. LIFTOFF
   - U XSM = UNIT (r LIFTOFF)
   - U YSM = U ZSM x U XSM
   - U ZSM = UNIT [(r CSM x V CSM) x U XSM]
6. ENTRY
   - U XSM = U YSM x U ZSM
   - U YSM = UNIT (V ENTRY x r ENTRY)
   - U ZSM = UNIT (-r ENTRY)

BOOST MONITOR ERROR ANALYSIS

The equation for the time history of thrust applied to achieve earth orbital insertion is

$$\overline{A}_T\ (t) = \overline{A}_V(t) - \overline{G}$$

where

$\overline{A}_T(t)$ = measured acceleration

$\overline{A}_V(t)$ = vehicle acceleration

$\overline{G}$ = 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, $\overline{R}$, is

$$\overline{R} = \overline{X} + \overline{Y} + \overline{Z}$$

$$|\overline{R}| = R = (\overline{X}^2 + \overline{Y}^2 + \overline{Z}^2)^{1/2}$$

Thus, vehicle acceleration and gravitational acceleration are

$$\overline{A}_V = \ddot{\overline{X}} + \ddot{\overline{Y}} + \ddot{\overline{Z}}$$

$$\overline{G} = -\frac{\mu}{R^3}\ \overline{R}$$

Propagation of errors to the thrust profile due to initial misalignments and inertial instrument anomalies may be evaluated from the perturbation equation

$$\Delta\overline{G} = \frac{\partial\overline{G}}{\partial\overline{R}}\ \Delta\overline{R}$$

$$\Delta\overline{G} = -\mu\ \frac{\partial}{\partial\overline{R}}\ \left(\frac{\overline{R}}{R^3}\right)\ \Delta\overline{R}$$

$$\Delta\overline{G} = -\mu\frac{\Delta\overline{R}}{R^3} - \mu\overline{R}\ \frac{\partial}{\partial\overline{R}}\ (R^{-3}) \cdot \Delta\overline{R}$$

$$\Delta\overline{G} = -\mu\frac{\Delta\overline{R}}{R^3} + 3\,\mu\,\frac{\overline{R}}{R^4}\ \frac{\partial R}{\partial\overline{R}} \cdot \Delta\overline{R}$$

Since $\partial R/\partial \overline{R} = \overline{U}_R$,

$$\Delta\overline{G} = -\mu\frac{\Delta\overline{R}}{R^3} + 3\mu\frac{\overline{R}}{R^4}(\overline{U}_R \cdot \Delta\overline{R})$$

$$\Delta\overline{G} = -\mu\frac{\Delta\overline{R}}{R^3} + 3\frac{\mu}{R^5}(\overline{R} \cdot \Delta\overline{R})\,\overline{R}$$

The perturbation equations for measured acceleration and vehicle acceleration are

$$\Delta\overline{A}_T = \Delta\overline{A}_V - \Delta\overline{G}$$

$$\Delta\overline{A}_V = \Delta\overline{\ddot{X}} + \Delta\overline{\ddot{Y}} + \Delta\overline{\ddot{Z}}$$

Combine the last three equations and form the three component equations.

$$\Delta A_X = \Delta\ddot{X} + \frac{\mu}{R^3}\Delta X - \frac{3\mu}{R^5}(\overline{R} \cdot \Delta\overline{R})\,X$$

$$\Delta A_Y = \Delta\ddot{Y} + \frac{\mu}{R^3}\Delta Y - \frac{3\mu}{R^5}(\overline{R} \cdot \Delta\overline{R})\,Y$$

$$\Delta A_Z = \Delta\ddot{Z} + \frac{\mu}{R^3}\Delta Z - \frac{3\mu}{R^5}(\overline{R} \cdot \Delta\overline{R})\,Z$$

The expression $(\overline{R} \cdot \Delta\overline{R})$ can be written as

$$(\overline{R} \cdot \Delta\overline{R}) = X\Delta X + Y\Delta Y + Z\Delta Z$$

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

$$\epsilon_X = \theta A_Y - \beta A_Z$$

$$\epsilon_Y = -\theta A_X + \alpha A_Z$$

$$\epsilon_Z = \beta A_Z - \alpha A_Y$$

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,

$$\delta_X = \dot{\alpha}$$
$$\delta_Y = \dot{\beta}$$
$$\delta_Z = \dot{\theta}$$

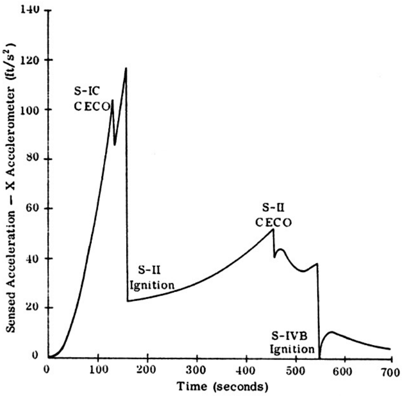
The complete set of error equations are obtained by adding in the misalignment error and gyro drift rate error. These three equations are

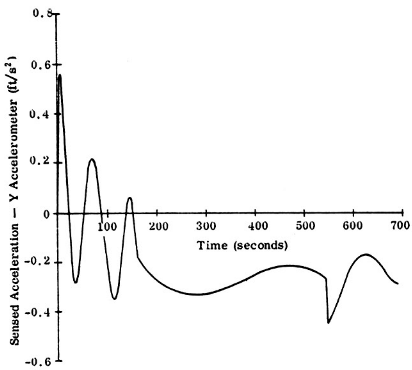
$$\Delta A_X = \Delta\ddot{X} + \frac{\mu}{R^3}\Delta X - \frac{3\mu}{R^5}(X^2\Delta X + XY\Delta Y + XZ\Delta Z) + \theta A_Y - \beta A_Z$$

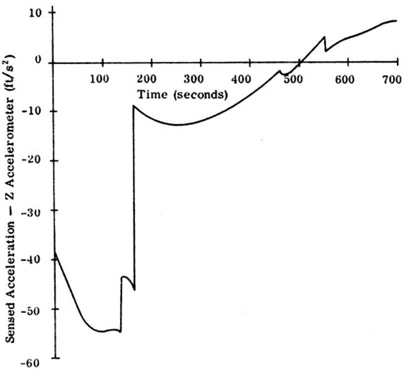
$$\Delta A_Y = \Delta\ddot{Y} + \frac{\mu}{R^3}\Delta Y - \frac{3\mu}{R^5}(XY\Delta X + Y^2\Delta Y + YZ\Delta Z) - \theta A_X + \alpha A_Z$$

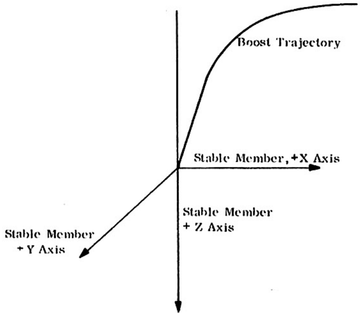
$$\Delta A_Z = \Delta\ddot{Z} + \frac{\mu}{R^3}\Delta Z - \frac{3\mu}{R^5}(XZ\Delta X + YZ\Delta Y + Z^2\Delta Z) - \alpha A_Y + \beta A_X$$

The following graphs illustrate how these errors propagate with time during boost.



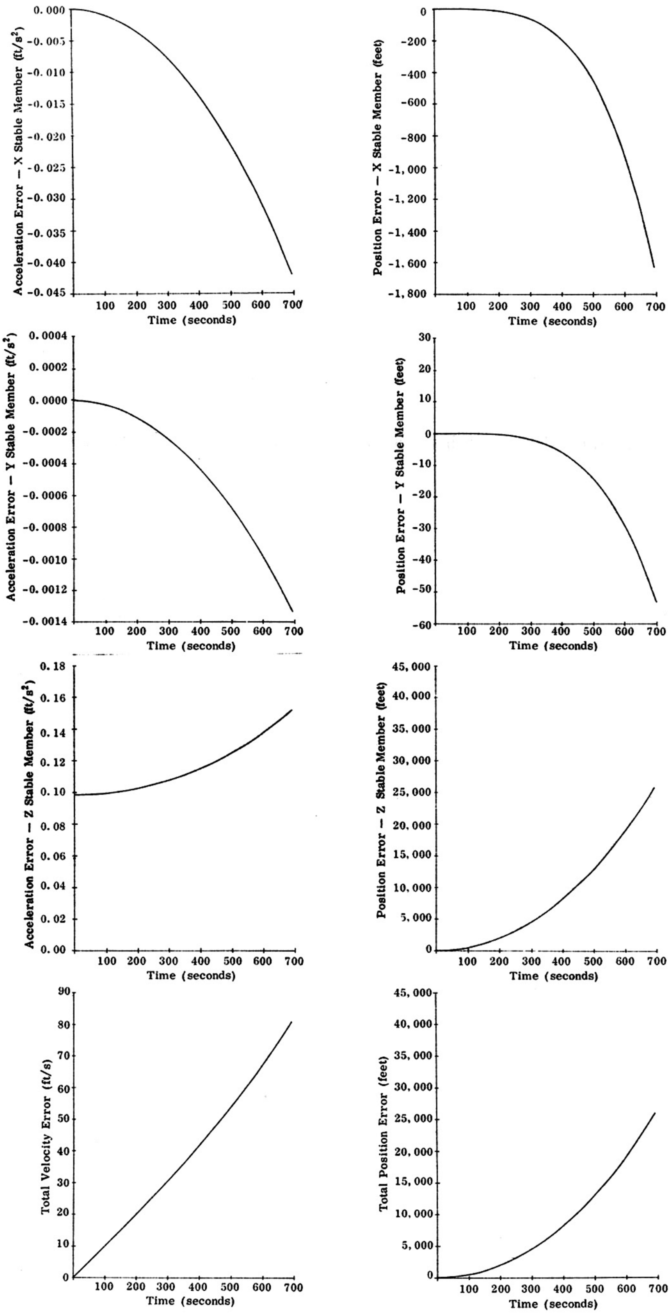




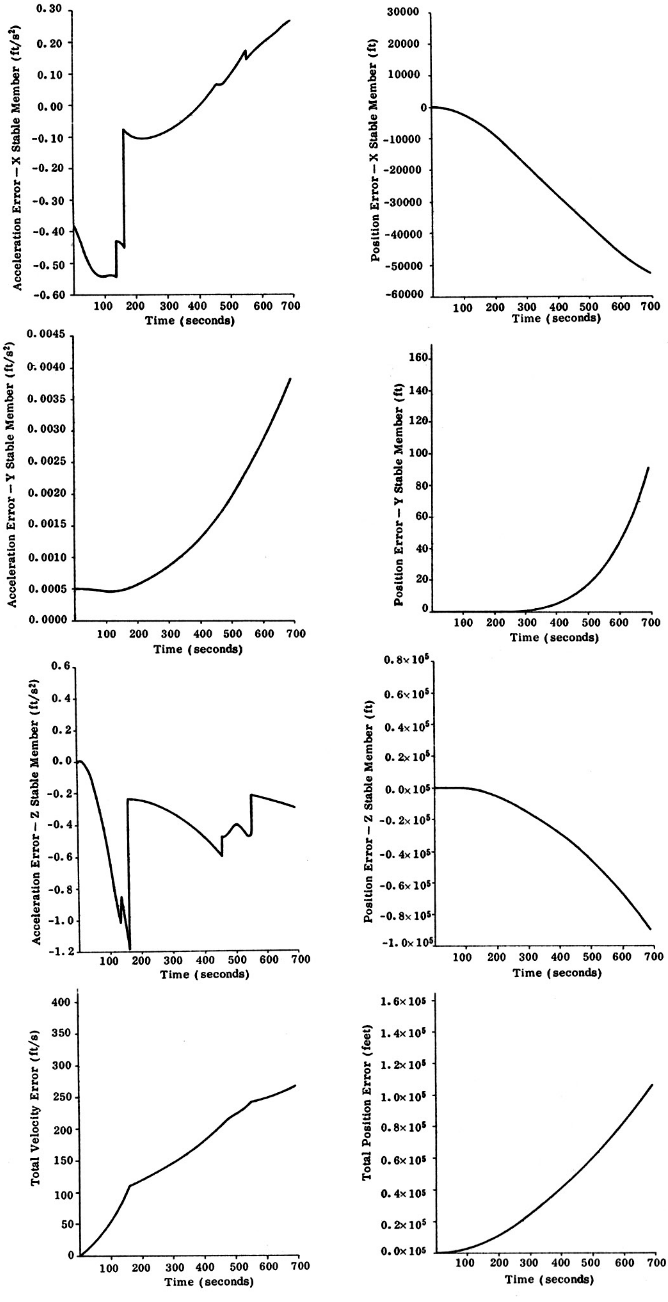


IMU Orientation During Boost

BOOST MONITOR ERRORS
Uncompensated Z PIPA Bias (3 cm/s^2)



BOOST MONITOR ERRORS
Inner Gimbal Misalignment (10 mrad)



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

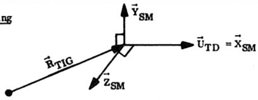
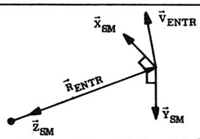
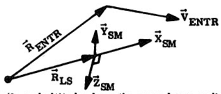
V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

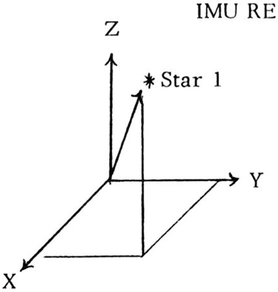
CSM IMU REALIGNMENT – P52

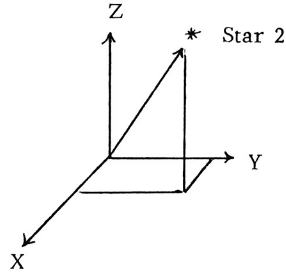
OPTION	DESCRIPTION	CALCULATION OF ORIENTATION
00001 (PREFERRED)	PREFERRED Thrusting  The PREFERRED option refers to one of two possibilities: a. The PREFERRED thrusting orientation which is calculated and stored by P40 and P41, b. Any orientation uplinked by MSFN via P27. The CMC is unable to distinguish 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.	$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \vec{U}_{TD} \\ \text{Unit}\,(\vec{U}_{TD} \times \vec{R}_{TIG}) \\ \text{Unit}\,(\vec{U}_{TD} \times (\vec{U}_{TD} \times \vec{R}_{TIG})) \end{bmatrix}$ where $\vec{U}_{TD}$ is a unit vector in the desired thrust direction expressed in the basic reference system. $\vec{R}_{TIG}$ is the position vector of the vehicle at ignition expressed in the basic reference system.
00002 (NOMINAL)	Nominal  The CMC requests the g.e.t. 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.	$\begin{bmatrix} \text{NOMINAL} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \vec{Y}_{SM} \times \vec{Z}_{SM} \\ \text{Unit}\,(\vec{V}_{ENTR} \times \vec{R}_{ENTR}) \\ \text{Unit}\,(-\vec{R}_{ENTR}) \end{bmatrix}$ where $\left.\begin{matrix} \vec{R}_{ENTR} \\ \vec{V}_{ENTR} \end{matrix}\right\}$ are position and velocity vectors of vehicle at the time specified.
00003 (REFSMMAT)	This option is used for gyro drift determination. 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.	$\begin{bmatrix} \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{orientation} \end{bmatrix}$
00004 (Landing Site)	Landing Site  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.t. 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.	$\begin{bmatrix} \text{Landing Site} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} \vec{X}_{SM} \\ \vec{Y}_{SM} \\ \vec{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit}\,(\vec{R}_{LS}) \\ \vec{Z}_{SM} \times \vec{X}_{SM} \\ \text{Unit}\,[(\vec{R}_{ENTR} \times \vec{V}_{ENTR}) \times \vec{X}_{SM}] \end{bmatrix}$ where $\vec{R}_{LS}$ is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system. $\left.\begin{matrix} \vec{R}_{ENTR} \\ \vec{V}_{ENTR} \end{matrix}\right\}$ are the CSM position and velocity vectors at the time specified.

PROCEDURE FOR SPECIFYING OPTIONS

a. When P52 is entered, the CMC checks the PREFERRED ATTITUDE flag.
b. If the flag is set, the DSKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
c. If the flag is not set, the DSKY flashes Verb 04, Noun 06, R2 = 00003, indicating the PREFERRED option may not be selected.
d. The desired option is loaded into R2 via Verb 22.

IMU REALIGNMENT - P52





$$\underline{U}_{S1} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}_{ECI} \qquad \underline{U}_{S2} = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}_{ECI}$$

$\underline{U}_{S1}$ and $\underline{U}_{S2}$ are known unit vectors in ECI space of the stars and are stored in the AGC.

$$\underline{U}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix}_{SM} \qquad \underline{U}_{S2M} = \begin{bmatrix} X_{2M} \\ Y_{2M} \\ Z_{2M} \end{bmatrix}_{SM}$$

$\underline{U}_{S1M}$ and $\underline{U}_{S2M}$ are the measured unit vectors (optics mark) in stable member (SM) space of the stars.

$$\left[S_A\right] = \begin{bmatrix} \underline{U}_{S1} \\ (\underline{U}_{S1} \times \underline{U}_{S2}) \times \underline{U}_{S1} \\ \underline{U}_{S1} \times \underline{U}_{S2} \end{bmatrix} \left[ECI\right] \qquad \left[S_B\right] = \begin{bmatrix} \underline{U}_{S1M} \\ (\underline{U}_{S1M} \times \underline{U}_{S2M}) \times \underline{U}_{S1M} \\ \underline{U}_{S1M} \times \underline{U}_{S2M} \end{bmatrix} \left[SM\right]$$

$$\left[S_A\right] = \left[A\right] \left[ECI\right] \qquad \left[S_B\right] = \left[B\right] \left[SM\right]$$

$$\left[S_A\right] = \left[S_B\right]$$

$$\left[A\right]\left[ECI\right] = \left[B\right]\left[SM\right]$$

$$\left[SM\right] = \left[B\right]^{-1} \left[A\right]\left[ECI\right]$$

$$\left[REFSMMAT\right] = \left[B\right]^{-1} \left[A\right]$$

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)						
+						VI† (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 — ΔV ft/s — N83						
						Y						
						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

P30–EXTERNAL ΔV

TLI + 90

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				Y_{Trim} (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			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		X	X	X			
						ULLAGE							

NOTES:

PRO/GUID		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 MNVR IGNITION
ΔVX ΔVY ΔVZ	XXXX.X (fps) XXXX.X (fps) XXXX.X (fps)	P30 VELOCITY TO BE GAINED COMPONENTS IN LOCAL VERTICAL COORDINATES
R P Y	XXX (DEG) XXX (DEG) XXX (DEG)	IMU GIMBAL ANGLES OF MANEUVER ATTITUDE
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 USSAGE
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

ΔVX (LV), ΔVY (LV), ΔVZ (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			
						ΔVC'** (ft/s)						
+						VI† (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 — ΔV ft/s — N83						
						Y						
						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 (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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:

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

ΔVX (LV), ΔVY (LV), ΔVZ (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)				:		

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

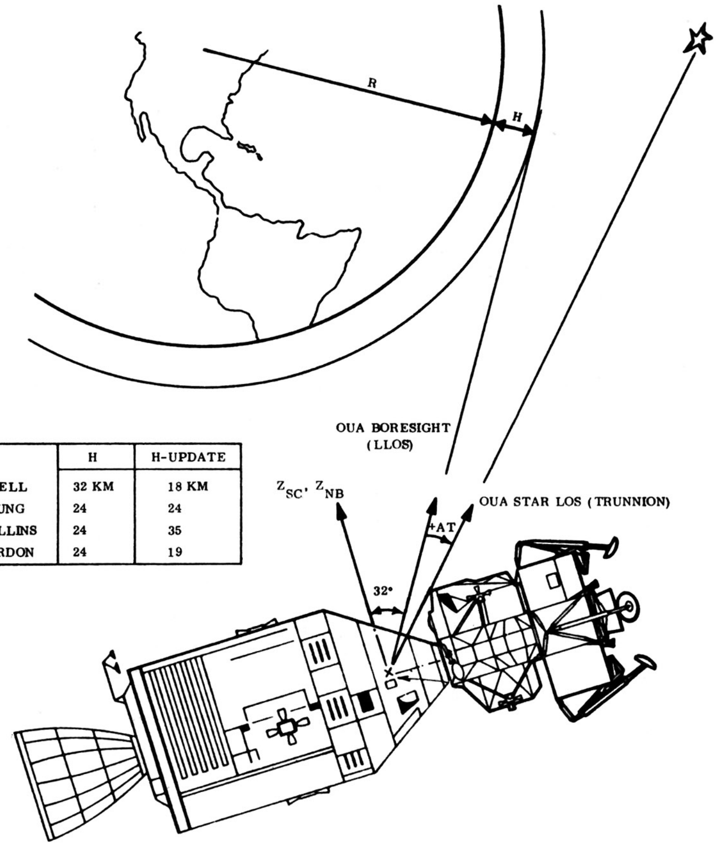
+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0			Star ID	N70	X	0	0	0		
+						Trun Angle Bias	N87 R2	+					
+						Trun Angle Bias	N87 R2	+					
+						Trun Angle Bias	N87 R2	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P23 — ASTRONAUT LOCATOR CALIBRATION



	H	H-UPDATE
APOLLO 8 LOVELL	32 KM	18 KM
APOLLO 10 YOUNG	24	24
APOLLO 11 COLLINS	24	35
APOLLO 12 GORDON	24	19

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes			+	0	0	0		
+	0					Seconds			+	0				
X	X					R	IMU		X	X				
X	X					P	Gimbal Angles		X	X				
X	X					Y	(degree)		X	X				
+						Pos Err (ft)	W Matrix	V67	+					
+						Vel Err (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
						Celestial		N88						
						Body								
						Vector								
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0				
+	0	0	0			Minutes GET		+	0	0	0			
+	0					Seconds		+	0					
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	+						

MIDCOURSE NAVIGATION

+	0	0				Hours			+	0	0				
+	0	0	0			Minutes	GET		+	0	0	0			
+	0					Seconds			+	0					
X	X					R	IMU		X	X					
X	X					P	Gimbal Angles		X	X					
X	X					Y	(degree)		X	X					
+						Pos Err (ft)	W Matrix	V67	+						
+						Vel Err (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	
						Celestial		N88							
						Body									
						Vector									
+						Trun Angle Degrees		N92 R2	+						
						ΔR nmi		N49							
						ΔV ft/s									

NOTES:

P30–EXTERNAL ΔV

MCC 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				P_{Trim} N48		0	0			
	0	0				Y_{Trim} (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			
+						H_{Apogee} N44	+					
						$H_{Perigee}$ 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				R_{Align}	X	X	X			
X	X	X				P_{Align}	X	X	X			
X	X	X				Y_{Align}	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		+	0	0			
+	0	0	0			Minutes GET		+	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		+	0	0			
+	0	0	0			Minutes GET		+	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:

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

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
						06-40	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)

						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

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

ΔVX (LV), ΔVY (LV), ΔVZ (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)					

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		+	0	0			
+	0	0	0			Minutes	GET	+	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	N93						
						Y Gyro Torquing Angles (degrees)							
						Z							
						X							
						Y Calculated Gyro Drift (meru)							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	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	N93						
						Y Gyro Torquing Angles (degrees)							
						Z							
						X							
						Y Calculated Gyro Drift (meru)							
						Z							

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				P_{Trim} N48		0	0			
	0	0				Y_{Trim} (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 IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P	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		
+					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				R_{Align}	X	X	X			
X	X	X				P_{Align}	X	X	X			
X	X	X				Y_{Align}	X	X	X			
						ULLAGE						

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
			X			06-40	TFI (min:s)
							VG (ft/s)
							ΔVM (ft/s)
			X			06-40	TFC (min:s)
							VG (ft/s)
							ΔVM (ft/s)
			X			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)
			X				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

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

V59 Flashing, Perform Optics Calibration D-1 Near Horizon D-2 Far Horizon

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0				
+	0	0	0			Minutes GET		+	0	0	0			
+	0					Seconds		+	0					
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	+						

MIDCOURSE NAVIGATION

+	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		X	X					
X	X					Y (degree)		X	X					
+						Pos Err (ft)	V67	+						
+						W Matrix Vel Err (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	
						Celestial	N88							
						Body								
						Vector								
+						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

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R IMU Gimbal Angles (degree)		X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

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				P_{Trim} N48		0	0			
	0	0				Y_{Trim} (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			
+						H_{Apogee} N44	+					
						$H_{Perigee}$ 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				R_{Align}	X	X	X			
X	X	X				P_{Align}	X	X	X			
X	X	X				Y_{Align}	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 (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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:

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				P_{Trim}	N48		0	0			
	0	0				Y_{Trim} (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			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		X	X	X			
						ULLAGE							

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

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
			X			06-40	TFI (min:s)
							VG (ft/s)
							ΔVM (ft/s)
			X			06-40	TFC (min:s)
							VG (ft/s)
							ΔVM (ft/s)
			X			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)
			X				TFF (min:s)

						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	

P30–EXTERNAL ΔV
MCC-4 & PERICYNTHION + 2HR

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				Y_{Trim} (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			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		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		+	0	0			
+	0	0	0			Minutes GET		+	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		+	0	0			
+	0	0	0			Minutes GET		+	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:

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

P30–EXTERNAL ΔV
LOI (PRELIMINARY)

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} (degrees)	N48		0	0			
	0	0				Y_{Trim}			0	0			
+	0	0				Hours GETI	N33	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
						ΔV_X LV (ft/s)	N81						
						ΔV_Y							
						ΔV_Z							
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			
+						H_{Apogee} nmi	N44	+					
						$H_{Perigee}$							
+						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		
+					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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		X	X	X			
						ULLAGE							

NOTES:

P30–EXTERNAL ΔV
TEI 1 & TEI 4

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				Y_{Trim} (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 IMU Gimbal		X	X	X			
X	X	X				P Angles (deg)		X	X	X			
X	X	X				Y		X	X	X			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		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 GET		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours GET		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P30–EXTERNAL ΔV
LOI

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				Y_{Trim} (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				
+						H_{Apogee}	N44	+						
						$H_{Perigee}$ 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				R_{Align}		X	X	X				
X	X	X				P_{Align}		X	X	X				
X	X	X				Y_{Align}		X	X	X				
						ULLAGE								

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

$$V_H = \left(\frac{2\mu}{r_P}\right)^{1/2} \left(1 + \frac{r_P V_\infty^2}{2\mu}\right)^{1/2} \qquad \text{ft/s}$$

and V_E is the desired elliptical velocity at pericynthion

$$V_E = \left(\frac{2\mu}{r_P}\right)^{1/2} \left(\frac{r_A}{r_A + r_P}\right)^{1/2} \qquad \text{ft/s}$$

The complete equation for ΔV is

$$\Delta V = \left(\frac{2\mu}{r_P}\right)^{1/2} \left[\left(1 + \frac{r_P V_\infty^2}{2\mu}\right)^{1/2} - \left(\frac{r_A}{r_A + r_P}\right)^{1/2}\right] \qquad \text{ft/s}$$

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

$$\Delta V = V_H - \left(\frac{2\mu}{r_P}\right)^{1/2} \left(\frac{r_A}{r_A + r_P}\right)^{1/2} \qquad \text{ft/s}$$

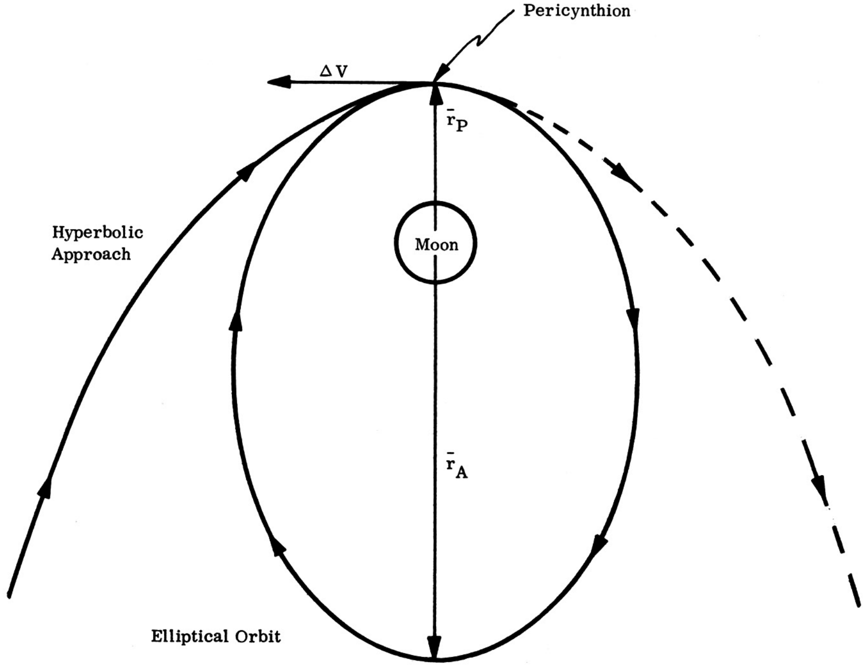


Figure A. Celestial Mechanics of a Transfer From a Hyperbola to an Ellipse

For V_H constant, the targeting equation for execution of an orbital transfer has the following functional form.

$$\Delta V = f\ (r_A,\ r_P) \qquad \text{ft/s}$$

Errors in r_A and r_P which are caused by anomalies in the ΔV achieved are evaluated from the perturbed targeting equation.

$$\Delta V + \delta = f\ (r_A + \Delta r_A,\ r_P + \Delta r_P) \qquad \text{ft/s}$$

Expanding the function on the right into a Taylor series and ignoring all higher order terms results in a linearized error relation.

$$\Delta V + \delta = f\ (r_A,\ r_P) + \left(\Delta r_A \frac{\partial}{\partial r_A} + \Delta r_P \frac{\partial}{\partial r_P}\right) f\ (r_A,\ r_P) \qquad \text{ft/s}$$

This reduces to

$$\delta = \frac{\partial}{\partial r_A} [f\ (r_A,\ r_P)]\ \Delta r_A + \frac{\partial}{\partial r_P} [f\ (r_A,\ r_P)]\ \Delta r_P \qquad \text{ft/s}$$

where

$$\frac{\partial}{\partial r_A} [f\ (r_A,\ r_P)] = -\left(\frac{\mu r_P}{2r_A\ (r_A + r_P)^3}\right)^{1/2} \qquad \text{ft/s/nmi}$$

$$\frac{\partial}{\partial r_P} [f(r_A,\ r_P)] = \left(\frac{(r_A^2 + 2r_A\, r_P)}{(r_A^2 + r_A\, r_P)^2}\right)\left(\frac{\mu r_A\, r_P + \mu r_P^2}{2r_A}\right)^{1/2} \qquad \text{ft/s/nmi}$$

The total linearized error equation relating errors in ΔV burned to errors in apocynthion and pericynthion is

$$\delta = \Delta\ (\Delta V) = -\left(\frac{\mu r_P}{2r_A\ (r_A + r_P)^3}\right)^{1/2} \Delta r_A$$
$$+\left(\frac{(r_A^2 + 2r_A\, r_P)}{(r_A^2 + r_A\, r_P)^2}\right)\left(\frac{\mu r_A\, r_P + \mu r_P^2}{2r_A}\right)^{1/2} \Delta r_P \qquad \text{ft/s}$$

A graph illustrating these relationships is shown on the next page (Figure B).

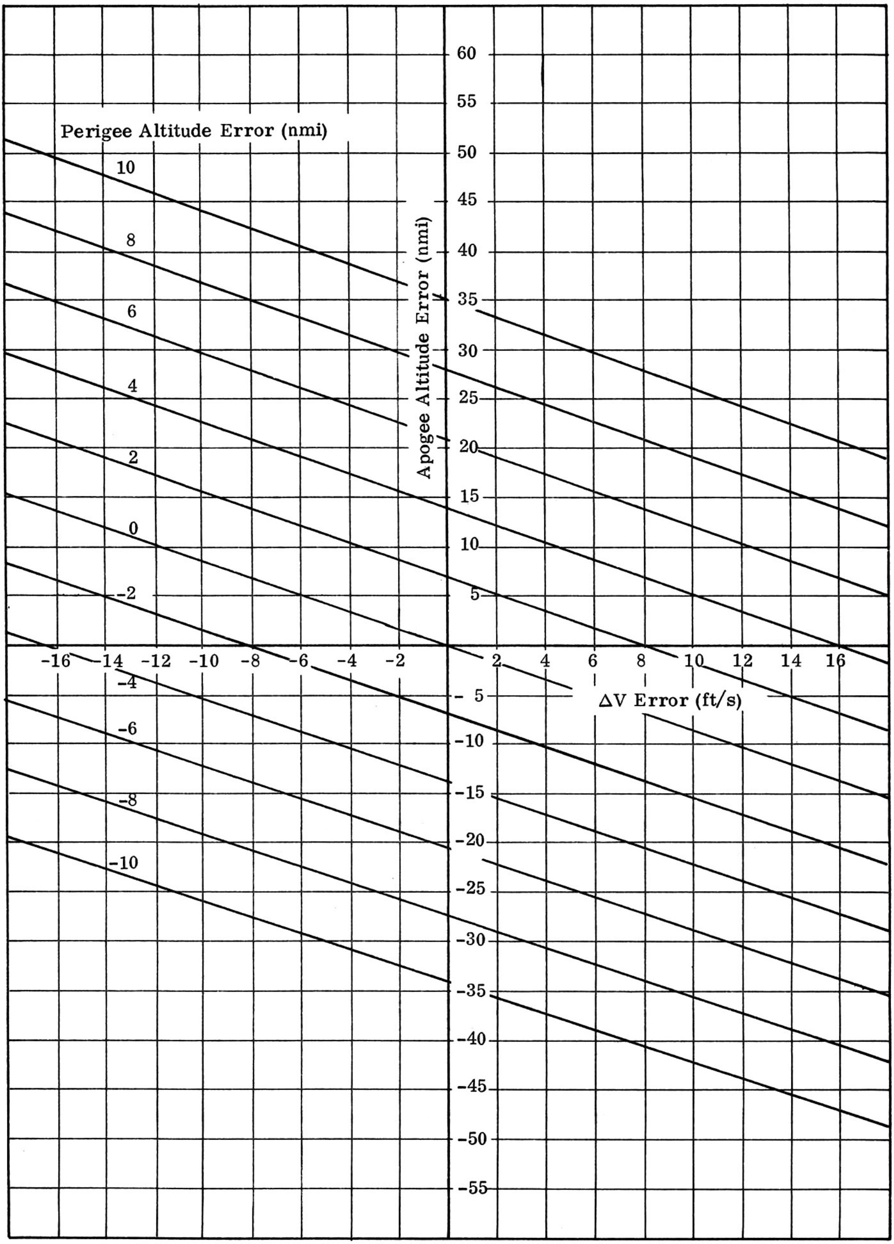
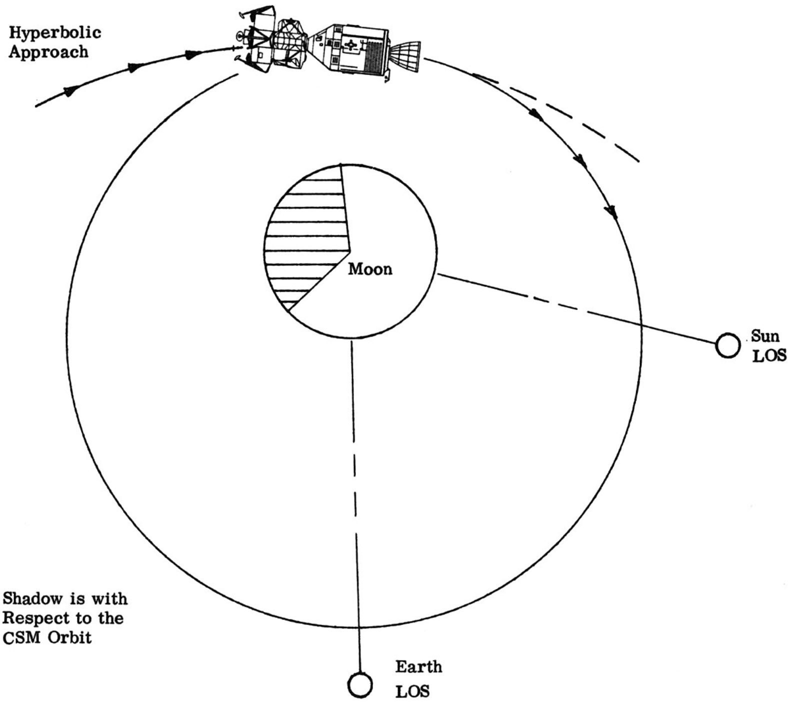

Perigee Altitude Error (nmi)
10
8
6
4
2
0
-2
-4
-6
-8
-10
Apogee Altitude Error (nmi)
60
55
50
45
40
35
30
25
20
15
10
5
- 5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-16
-14
-12
-10
-8
-6
-4
-2
2
4
6
8
10
12
14
16
ΔV Error (ft/s)

Figure B

LUNAR ORBIT INSERTION

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
LOI (RETROGRADE)	356.6/2815.3	77:24:52.9	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
— — — . — $V_{x_{TRIM}}$		— — — . — $V_{y_{TRIM}}$		— — — . — $V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

P22–ORBITAL NAVIGATION

REV 2

V32 Enter, 22 Enter
V06 N45 Flashing, R3: Middle Gimbal Angle
V05 N70 Flashing, R2: A B 0 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	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)							

+	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	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)							

NOTES:

P22–ORBITAL NAVIGATION
MARK DATA
REV 2

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles (degree)	+					
+						Trunnion		+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles (degree)	+					
+						Trunnion		+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles (degree)	+					
+						Trunnion		+					

NOTES:

P30–EXTERNAL ΔV

DOI & TEI 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				P_{Trim} (degrees) N48		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} nmi N44	+					
						$H_{Perigee}$						
+						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		
+					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				R_{Align}	X	X	X			
X	X	X				P_{Align}	X	X	X			
X	X	X				Y_{Align}	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

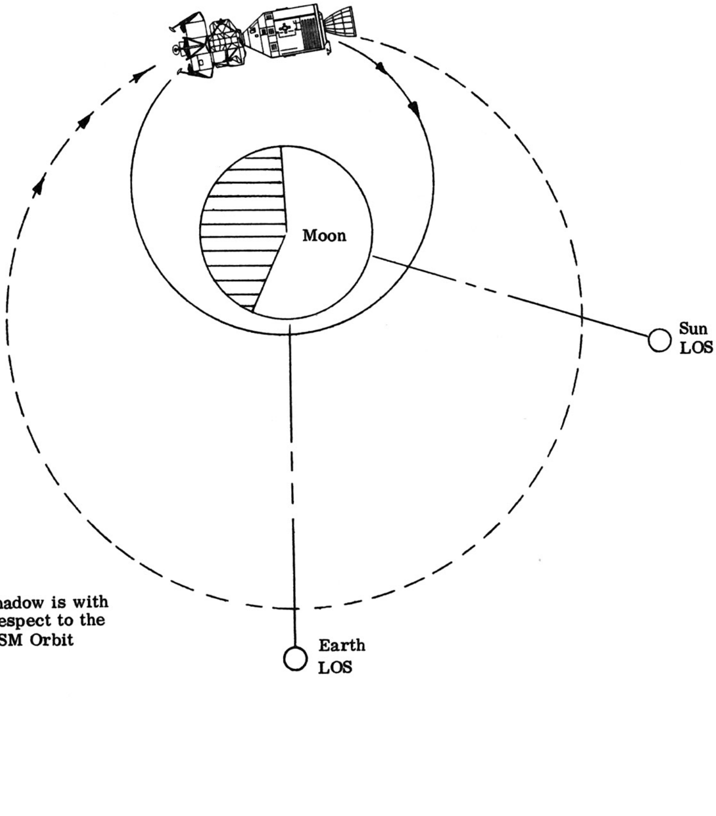
X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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:

DESCENT ORBIT INSERTION

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
DOI (RETROGRADE)	23.1/212.9	81:45:20.5	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
———.— $V_{x_{TRIM}}$	———.— $V_{y_{TRIM}}$	———.— $V_{z_{TRIM}}$ (ft/s)		



NOTE: Shadow is with Respect to the CSM Orbit

P22–ORBITAL NAVIGATION

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)								

+	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	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)								

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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P30–EXTERNAL ΔV
TEI 11 & TEI 35

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				Y_{Trim} (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				
+						H_{Apogee}	N44	+						
						$H_{Perigee}$ 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				R_{Align}		X	X	X				
X	X	X				P_{Align}		X	X	X				
X	X	X				Y_{Align}		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	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:

LM DOCKED ALIGNMENT

Docking Tunnel Index Angle:

R_c = ______________ deg. (Recorded during 1st IVT to LM Verified during succeeding IVT's)

Docked Coarse Align:

1. CSM should be in Min. Deadband, Attitude Hold.

2. CMP executes V06N20E and reports ICDU angles.

3. CDR calculates coarse align angles:

Outer Gimbal	Inner Gimbal	Middle Gimbal
300.00°	180.00°	360.00°
+ ______ . ______ R_c		
- ______ . ______ X_{cm}	+ ______ . ______ Y_{cm}	- ______ . ______ Z_{cm}
= ______ . ______ X_{lm}	= ______ . ______ Y_{lm}	= ______ . ______ Z_{lm}

4. CDR executes V41N20E and loads X, Y, Z CDU angles.

5. CDR executes V40N20E -- IMU goes inertial.

NOTE: The accuracy of this procedure is limited by
(a) the coarse align accuracy of the ISS
(b) vehicle attitude changes between steps 2 and 5.

Docked Fine Align:

6. CMP and CDR enter simultaneous V06N20 in CM and LM. The ICDU angles are recorded and reported to MCC.

GET = ______:______:______ (for gyro drift calculation)

	Outer Gimbal	Inner Gimbal	Middle Gimbal
CM:	______ . ______	______ . ______	______ . ______
LM:	______ . ______	______ . ______	______ . ______

7. MCC calculates gyro torquing angles and reports them to LM.

LM GTA's = ___ . ___ X, ___ . ___ Y, ___ . ___ Z

8. CDR disables jet firings and performs fine align (V42E), loading the gyro torquing angles voiced up from MCC.

P22–ORBITAL NAVIGATION

REV 12

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)								

+	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	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)								

NOTES:

LM GYRO DRIFT

Docked (Noun 20 Method)

The LM IMU drift check is performed by MCC using a set of simultaneous CM and LM ICDU angles.

Crew Report: GET ________:________:________ Δ T = ____.____ hrs.
(Time since previous Noun 20)

	Outer Gimbal	Inner Gimbal	Middle Gimbal
CM:	____.____	____.____	____.____
LM:	____.____	____.____	____.____

MCC calculates gyro torquing angles: ☐ ____.____ X, ☐ ____.____ Y, ☐ ____.____ Z

If GTA's exceed .230°X, .520°Y, 1.90°Z, MCC will calculate and uplink new gyro compensation values.

The above limits are based on the following requirements:

1. Maximum platform misalignment at PDI = .19° about X_{sm} to assure that crossrange error at touchdown < 1 kilometer.
2. Maximum platform misalignment at PDI = .5° about Y_{sm} to assure a safe descent abort capability.
3. PGNCS is No/Go if drift rate > 100 meru about any axis.

Although the restrictive requirements concern the state of platform alignment at PDI, high drift rate can negate a perfect platform realignment (P52) performed 80 minutes before PDI.

The equivalent drift rates allowable are:

.145 deg/hr (X) .376 deg/hr (Y) 1.5 deg/hr (Z)

The GTA limits utilize these drift rates, assume 75 minutes between Noun 20 entries, and allow .05° for total measurement error.

Undocked (P52 Method)

The gyro torquing angles obtained during the IMU realignment program (P52) can be used to calculate the rate of platform drift since the last realignment.

Rev. 12 P52 GET = ________:________:________

Time of previous align = ________:________:________

Δ T (difference) = ________:________ = ____.____ hours

Gyro Torquing Angles ☐ ____.____ °(X) ☐ ____.____ °(Y) ☐ ____.____ °(Z)

÷ (.015)ΔT (S) S = -1 S = -1 S = +1

= Drift Rate (meru): ________(X) ________(Y) ________(Z)

NOTE: As presently planned, the Rev. 12 GTA's will be torqued out to serve as a baseline for the Rev 13 P52. The time-of-previous-align used in the Rev 12 drift calculation will nominally be the GET of the Noun 20 during Docked Fine Align. However, allowance must be made for any changes in the compensation values during this period. In spite of the GTA limits defined for Docked Gyro Drift (above), Mission Rules provide for uplinking new compensation values whenever the drift rate exceeds 5 meru on any axis.

Rev. 13 P52 GET = ________:________:________

Time of Previous Align = ________:________:________

Δ T (difference) = ________:________ = ____.____ hours
(2.0)

Gyro Torquing Angles ☐ ____.____ °(X) ☐ ____.____ °(Y) ☐ ____.____ °(Z)
Limits .370° .830° 3.000°

GTA ÷ (.015) Δ T (S) S = -1 S = -1 S = +1

= Drift Rate (meru): ________(X) ________(Y) ________(Z)

NOTE: The Rev 13 GTA's will be torqued if they do not exceed the limits shown. These limits are based on the equivalent drift rates allowed during the Docked Gyro Drift measurement (above). They assume 2.0 hours between the two P52's, and allow .08° for AOT measurement errors. If the limits are exceeded PDI will be delayed 1 Rev.

P30–EXTERNAL ΔV
Separation

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} (degrees)	N48		0	0			
	0	0				Y_{Trim}			0	0			
+	0	0				Hours GETI	N33	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
						ΔV_X LV (ft/s)	N81						
						ΔV_Y							
						ΔV_Z							
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			
+						H_{Apogee} nmi	N44	+					
						$H_{Perigee}$							
+						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		
+					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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		X	X	X			
						ULLAGE							

NOTES:

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	(deg)							
							Pitch								
							Yaw								
						06-18	Roll	(deg)							
							Pitch								
							Yaw								
						06-85	X	VG (ft/s)							
							Y								
							Z								
						16-85	X	VG (ft/s)							
							Y								
							Z								
						16-85	X	Residuals (ft/s)							
							Y								
							Z								
						X		Trim (ft/s)							
						Y									
						Z									

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	X	X				R	X	X	X			
X	X	X				P IMU Gimbal Angles (degrees)	X	X	X			
X	X	X				Y	X	X	X			
X	X	X				BT (min:s)	X	X	X			
						VI (ft/s)						
						X N83						
						Y ΔV ft/s						
						Z						
						V ft/s N62						
						HDOT ft/s						
						H nmi						

NOTES:

P22–ORBITAL NAVIGATION
MARK DATA
REV 12

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles	+					
+						Trunnion	(degree)	+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles	+					
+						Trunnion	(degree)	+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles	+					
+						Trunnion	(degree)	+					

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		+	0	0			
+	0	0	0			Minutes GET		+	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		+	0	0			
+	0	0	0			Minutes GET		+	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:

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				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P30–EXTERNAL ΔV
CIRCULARIZATION

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} (degrees) N48		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 IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P	X	X	X			
X	X	X				Y	X	X	X			
+						H_{Apogee} nmi N44	+					
						$H_{Perigee}$						
+						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		
+					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				R_{Align}	X	X	X			
X	X	X				P_{Align}	X	X	X			
X	X	X				Y_{Align}	X	X	X			
						ULLAGE						

NOTES:

P22–ORBITAL NAVIGATION

REV 13

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)							

+	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	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)							

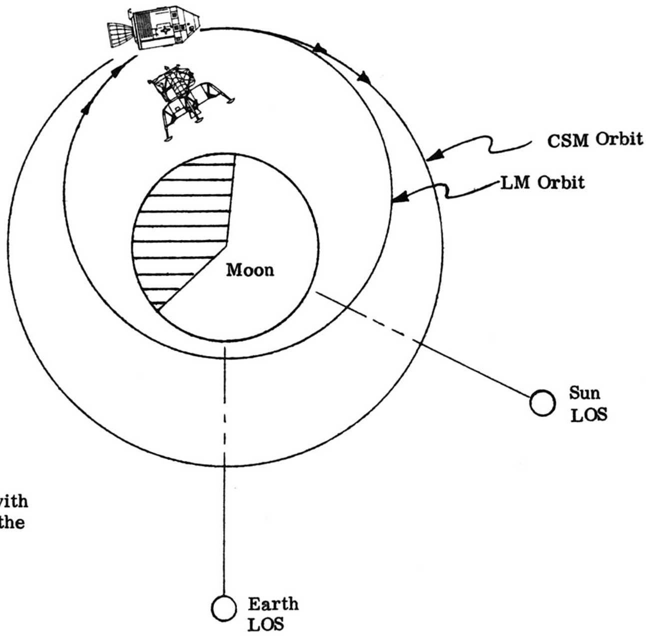
NOTES:

PDI 0 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}		N42	+					
						$H_{Perigee}$	(nmi)							
+						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				

CSM CIRCULARIZATION

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
CSM CIRCULARIZATION (POSIGRADE)	3.9/70.3	100:35:05.2	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
$V_{x_{TRIM}}$		$V_{y_{TRIM}}$		$V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

NO PDI +12 ABORT PAD

+	0	0				Hours	GETI	N33	+	0	0				
+	0	0	0			Minutes			+	0	0	0			
+	0					Seconds			+	0					
						ΔV_X	LV (ft/s)	N81							
						ΔV_Y									
						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	AGS Targeting (ft/s)	N86							
						ΔV_Y									
						ΔV_Z									
+	0	0				Hours	TIG of CSI	N11	+	0	0				
+	0	0	0			Minutes			+	0	0				
+	0					Seconds			+	0					
+	0	0				Hours	TIG of TPI	N37	+	0	0				
+	0	0	0			Minutes			+	0	0	0			
+	0					Seconds			+	0					

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	N33	+	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;

(1 < PDI ≤ 5) ABORT PAD

							Log Insertion GET (h:min:s)
	+	1	0	0	0	0	
							Boost GET (h:min:s)
	+	1	0	0	0	0	
							HAM, GET (h:min:s)
	+	1	0	0	0	0	
							CSI, GET (h: min:s)

+	0	0				Hours	TIG	N37	+	0	0			
+	0	0	0			Minutes	of		+	0	0	0		
+	0					Seconds	TPI		+	0				

T1 (5 < PDI ≤ 15) MIN ABORT PAD

							Log Insertion GET (h:min:s)
		+	5	5	0	0	
							TIG of CSI (h:min:s)

+	0	0				Hours	TIG	N37	+	0	0			
+	0	0	0			Minutes	of		+	0	0	0		
+	0					Seconds	TPI		+	0				

T2 (PDI + 20:45) ABORT PAD

							Log Insertion GET (h:min:s)
		+	5	0	0	0	
							Boost GET (h:min:s)
	+	1	0	0	0	0	
							HAM, GET (h:min:s)
		+	5	0	0	0	
							CSI, GET (h:min:s)

+	0	0				Hours	TIG	N33	+	0	0			
+	0	0	0			Minutes			+	0	0	0		
+	0					Seconds			+	0				
+	0	0				Hours	TIG	N37	+	0	0			
+	0	0	0			Minutes	of		+	0	0	0		
+	0					Seconds	TPI		+	0				

P22–ORBITAL NAVIGATION
MARK DATA
REV 13

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

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 GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

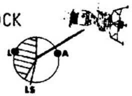
X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours GET		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds GET		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

UNDOCK & SEPARATION TO REV12 LS TCA

99:00

PREP FOR UNDOCKING
USE ACTIVATION & C.O.
C/L TO 10 MIN BEFORE UNDOCK
+50 CHECK ATT (0, 150/282,060)
(-10) V62
V48 21002
LM WT _____ (33,731)
PRO, V34
HELMETS AND GLOVES - ON
*S-BD ANT - AFT, VERIFY COMM *
*√S-BD P ____(+130) *
* Y ____(+40) *
*S-BD ANT - SLEW (>3.0) *
*TRACK MODE - AUTO (>4.0) *
*VHF B XMTR - OFF *
*BIOMED - LEFT, PCM-HI *
*UPLINK SQUELCH - OFF *
GO/NO GO FOR UNDOCKING
VOICE DRIFT √ GIMBAL ANGLES TO MSFN (ACT-48)
*TAPE RECORDER - ON *



AOS
99
+10

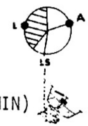
+59 P47
(-1) *ZERO 404, 405, 406 *
*470R *
INSERT V77 (DO NOT ENTR)
UNDOCK & SEPARATION ____:___:___ (99:16:21)
ENTR V77
DEADBAND - MIN
P00, V60
YAW LT 60°
PITCH UP 90°
*SEQUENCE CAMERA - ON (1 MIN) *
+3 FDAI (0, 280/012,0)
*VERIFY TRACKING LT-ON,THEN OFF *
*VHF ANT - FWD *
*SEQUENCE CAMERA - OFF *
*TAPE RECORDER - OFF *
*S-BD P +94, Y -45 *
HELMETS & GLOVES - OFF (OPT)
UPDATE FROM MSFN
*COPY REV 12 LS TCA ___:___:___ *

99:30

99:30

*UPDATA LINK - DATA *
*UPLINK CSM S.V., PIPA BIAS, *
* GYRO DRIFT COMP *
*UPDATA LINK - OFF *
AGS INITIALIZE AND ALIGN
*V47, 414+1, 400+3 *
V83, SET ORDEAL ON LMP FDAI
*317R,440R, 277R
*400+2, 507+0 *
*CAMERA SETTINGS *
LM3/DAC/10/CEX-ULC (f2.8,250,∞)
* 1 FPS, .05 MAG, (5 MIN) *
*LM /DC/60/HCEX-(f2.8,500,∞)5 *
DPS THROTTLE CHECK
THROT CONT - MAN/CDR
TTCA (BOTH) - THROTTLE (MIN)
(SET FRICTION)
*VERIFY MSFN CONTACT *
ENG STOP - PUSH
ENG ARM - DES (DES REG LT - ON)
TTCA MIN (6.6% - 13.4%)
THEN SOFT STOP (46.2% - 59.2%)
THEN MAX (93.6% - 100+%)
THEN MIN
ADJUST FRICTION
MAN THROT- LMP
*REPEAT TEST FOR LMP TTCA *
ENG ARM - OFF
CYCLE CWEA (DES REG LT - OFF)
ENG STOP - RESET
THROT CONT - AUTO/CDR
TTCA (BOTH) - JETS

APPROACH TO LANDING SITE
PITCH TO OBSERVE LS
FDAI (0, 325/XXX, 0)



+28 SEQUENCE CAMERA - ON(5-MIN)
+32 REV 12 LANDING SITE TCA ____:___:___ (99:48)

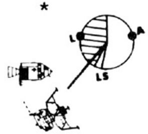
99:50

REV 12 LS TCA TO CSM CIRCULARIZATION

99:50

REV 12 LANDING SITE TCA

+33 *SEQUENCE CAMERA - OFF *



RENDEZVOUS RADAR CHECKOUT

+35 MNVR TO FDAI (0,342/331,0)
CB RR(2) CLOSE,√TEMP (10°-75°)
RR-SLEW, MANUAL LOCK-ON
SS 99 RR-LGC
V63, TM-R/Ṙ
+53 AGS-AUTO,√ERROR NEEDLE,-ATT HOLD
*VHF A XMTR - VOICE/RNG *
COMPARE V63, TM, V83, AGS
V34

MAX Δ	R .27 N M	Ṙ 7 FPS
V63		
TM		
V83		
317-440		

*VHF A XMTR - VOICE *
*400+0 *
V41N72E (+00000TRUN,+28300 SHFT)
CB RR(2)-OPEN,V44
COPY CSM CIRC P76 & PDI$_0$ ABORT PADS
*SET DET TO COUNT UP TO ^{0}CSM CIRC *
*CAMERA SETTINGS FOR CSM CIR *
*LM3/DAC/10/CEX-ULC (ƒ8 ,250,∞) *
6 FPS, .03 MAG, (30 SEC) *
*LM1/DC/60/HCEX-(ƒ11 ,250,∞)2 *

+22 **IMU FINE ALIGN**
V76
P52 OPT3
CB AOT LAMP CLOSE
AOT - DETENT F/0.0°
LOS 100 PGNS MODE CONT - AUTO
1ST STAR SPICA (#226)
+15 PRO, RCD GET ___:___:___
2ND STAR ANTARES (#233)
N05 ANGLE DIFF________
PRO
N93 TORQUING ANG
X________
Y________
Z________
PRO

100:20

CONFIGURE COMM FOR LOS
*MATCH INDICATED ANGLES *
*TRACK MODE - SLEW *
*SET P ____ (+14) *
* Y ____ (-14) *
*S-BD ANT - AFT *
*VHF B XMTR - DATA *
*BIOMED - OFF, PCM - LO *
UPLINK SQUELCH - ENABLE
S-BD ANT-FWD(AFTER LOS)

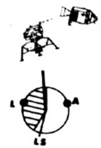
100:20

LPD CALIBRATION
PRO, ENTR
N70, ENTR 022 (REGULUS), PRO BIAS AZ____
N87, (+35580,+32040) PRO,PRO EL____
*DETENT CL *
*CB AOT LAMP - OPEN *
V34, P00
PGNS MODE CONT - AUTO
*400+3 *

AGS CALIBRATION
+44 V49, +33750 OGA YAW + 21
+24750 IGA PITCH +239 } FDAI
+02250 MGA ROLL + 24
*READ AND RECORD INITIAL VALUES *
*V40N20E *
*WAIT 20 SEC *
*V48,21022,PRO,V34 *
*PGNCS MODE CONT - ATT HOLD *
*V76, V60 *
*RATES < 0.1°/SEC *
*400+6 *

	INIT	CAL	Δ LIM
540			± .039
541			± .039
542			± .039
544			2
545			2
546			2

*WAIT 35 SEC, THEN V77 *
*WAIT 2 MIN, THEN V76 *
*CHECK DPS, APS, RCS, EPS *
*CYCLE CWEA CB *
*400R+0 *
*READ AND RECORD CAL VALUES *
*RE-LOAD INITIAL VALUES *



TRACKING ATTITUDE FOR CSM CIR
+55 MNVR TO (0, XXX/234, 0) TO TRACK CSM
(-5) *V48, 21012, PRO, V34 *
*SEQUENCE CAMERA-ON *
0 **CSM CIRCULARIZATION** ___:___:___ (100:35:05.2)
*SEQUENCE CAMERA-OFF

100:40

CSM CIRCULARIZATION TO PDI_0

100:40

CSM CIRCULARIZATION

*SEQUENCE CAMERA - OFF *
P76,(UPDATE CSM S.V.)

SR 100 +42

P00
*410+0 *
*VHF A XMTR - VOICE/RANGE *
* B XMTR - OFF, PCM-HI *
*V47,414+1,400+3,PCM-LO *
V83, SET ORDEAL
*317R, 440R, 277R *
MNVR TO (0, 325/XXX, 0)
ESTABLISH ORBITAL RATE
TO OBSERVE GROUND TRACK
V82, N12-00002, PRO
√CSM HA/HP

*RESET DET TO COUNT UP TO PDI_0 *
*S-BD ANT - FWD, VERIFY COMM *
*√S-BD P ____(+14) *
* Y ____(-14) *

AOS 101 +27
+04

*S-BD ANT - SLEW (>3.0) *
*TRACK MODE - AUTO (>4.0) *
*VHF A XMTR - VOICE *
*BIOMED - RIGHT, PCM-HI *
*UPLINK SQUELCH - OFF *
VOICE N93, GET, AND LPD BIAS TO MSFN

+31 **DPS PRESS + C. O.**
PRPLNT TEMP/PRESS MON - DES 1 & 2
FUEL 50-90°F 70-160 PSI
OXID 50-90°F 39-254 PSI
HELIUM MON: AMB PRESS 1495-1750
: SUPCRIT PRESS 700-1275
DES HE REG 1 tb-gray, REG 2 tb-bp
MASTER ARM - ON
DES PRPLNT ISOL VLV - FIRE
HE PRESS/DES START - FIRE
MASTER ARM - OFF
PRPLNT TEMP/PRESS MON: DES 1&2
FUEL & OXID 50-90°F 242-253 PSI
HELIUM MON: AMB PRESS 200-1110
: SUPCRIT PRESS 700-1275

101:20

101:20

LANDING RADAR CHECKOUT
+37 CB LR CLOSE, CK TEMP (60° - 95°)
RATE ERR MON-LDG RDR/CMPTR

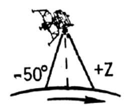
X-PNTRS-HI MULT, TM SW-H/$\dot{H}$
LDG ANT-AUTO, MODE SEL-LR
RDR TEST - LDG
TEST MON-ALT/VEL XMTR (2.1 - 5.0), AGC

TM (8000 ± 100)/H (-480 ±2)
V63, N12 OPT 2, PRO
N66 8286 ± 10, ANT POS 1 (00001), PRO
N67 V_x (-00495 ±2), V_y (+01862 ±2)
V_z (+01331 ±2)
V34, RDR TEST OFF
CB LR - OPEN

UPDATE FROM MSFN
*UPDATA LINK - DATA *
UPLINK CSM/LM S. V., PIPA BIAS,
* DESCENT TARGETING, LPD BIAS *
* (IF $\Delta > 2°$ IN AZ OR 1° IN EL) *
*COPY PADS FOR *
* NO PDI + 12 ABORT, *
* PDI, *
* PDI EARLY ABORT, *
* PDI LATE ABORT, *
* T2 ABORT *
* T3 TIG *
* UPDATA LINK - OFF *
*V47, 414+1, 400+3 *
V83, SET ORDEAL
*317R, 440R, 277R *
VERIFY NO PDI_0 ABORT WITH MSFN

LPD ALT CHECK
+45 MNVR TO AND MAINTAIN FDAI (0,295/XXX,0)

+55 BEGIN LPD ALT MARKS (IF DESIRED)
PDI LMK LPD ALT CHECK



$\boxed{PDI_0}$ ____:____:____ (101:36:53.4)

PITCH TO OBSERVE LS

101:40

PDI_0 TO BACKSIDE

101:40

+8 START PITCH TO P52 ATT (0, XXX/325, 0)

SS
101
+47

*CAMERA SETTINGS (PDI) *
*LM3/DAC/10/CEX- *
*(f2.8, 500, ∞) 12 FPS, *
* 0.75 MAG, (6 MIN) *
*LM3/DC/60/HCEX-(f5.6,250,∞)10 *
*RELOCATE CAMERA *

IMU FINE ALIGN

+30 P52 OPT3
CB AOT LAMP CLOSE
LOS AOT - DETENT F/0.0°
102 PGNS MODE CONT-AUTO
+09
1ST STAR SPICA (#226)
PRO, RCD GET ___:___:___
2ND STAR REGULUS (#222)
ALT STAR ARCTURUS (#231)
N05 ANG DIFF ________

CONFIGURE COMM FOR LOS

*MATCH INDICATED ANGLES *
*TRACK MODE - SLEW *
*SET P ____ (-2) *
Y ____ (+2) *
*S-BD ANT - FWD *
*VHF B XMTR - DATA *
*BIOMED - OFF, PCM - LO *
UPLINK SQUELCH - ENABLE

02:15

102:15

PRO
N93 TORQUING ANG MAX
X ________ (.370)
Y ________ (.830)
Z ________ (3.000)
PRO
N25
*DETENT CL *
*CB AOT LAMP - OPEN *
V34, P00
PGNS MODE CONT - ATT HOLD
START MNVR TO PDI ATT
FDAI (0, XXX/110,0)

AGS ALIGN

*400+3 *
P30 TGT PGNS FOR NO PDI+12 ABORT

P00
*VERIFY LOOSE GEAR STOWED *
*RESTRAINTS ATTACHED *
VERIFY FDAI'S INERTIAL
V48,21112, PRO
V34

P63 IGNITION ALGORITHM TEST

P63
*RESET DET UP *
ENTR-BYPASS ALIGN, PGNS MODE CONT - AUTO
N18 R, P, Y (0, 110, 0) PRO
P00, PGNS MODE CONT - ATT HOLD,V77
COAS TO OVERHEAD WINDOW

PRE-PDI ECS CHECKOUT

*HELMETS AND GLOVES ON *
*CABIN REPRESS-CLOSE *
*SUIT GAS DIVERTER - EGRESS *
*CABIN GAS RETURN - EGRESS *
*PRESS REGS A&B - EGRESS *

SR
102
+36
+15

102:40

BACKSIDE TO PDI

102:40

PRE-PDI SWITCH SETTING CHECK

*VHF ANT - FWD *
*VHF A XMTR - VOICE/RNG *
CB INV 1 - CLOSED
*SELECT INV 1 *
+20 CB AELD (2) - CLOSE
CB ABORT STAGE (2) - CLOSE
*CYCLE CWEA CB *
*BATS 5&6 NORM FEED - ON *
RESET ENG STOP PB
SET WINDOW BARS
*S-BD ANT - FWD, VERIFY COMM
AOS
102
+57
*√S-BD P _____ (-2) *
Y _____ (+2) *
*S-BD ANT - SLEW (>3.0) *
*TRACK MODE - AUTO (>4.0) *
*VHF B XMTR - OFF *
*BIOMED - LEFT, PCM - HI *
*UPLINK SQUELCH - OFF *
VOICE N93 AND GET TO MSFN
THROT CONT - AUTO
CDR TTCA - THROTTLE - MIN
LMP TTCA - THROTTLE - SOFT STOP
*ACA PROP (LMP) - ENABLE *
*ACA/4JET (LMP) - ENABLE *
*TTCA/TRANSL (LMP) - ENABLE *
*CHECK DPS, APS, RCS, ECS, EPS *

UPDATE FROM MSFN

+30 *UPDATA LINK - DATA *
*UPLINK LM S.V., RLS, *
MSFN GYRO DRIFT COMP *
*UPDATA LINK - VOICE BU *
*COPY AGS RLS (231) *
PRPLNT QYT MON - DES 1
MODE SEL - PGNS
PGNS MODE CONT - AUTO
AGS MODE CONT - AUTO
V77
√BURN ABORT RULES

103:10

103:10
*AUDIO MODE (BOTH) - VOX *
*TAPE RECORDER - ON *

AGS INITIALIZE

+42 *V47, 414+1 *
(-18) *V83, 317R, 440R, 277R *
*240 + (231 RLS PAD) *
*254+04925 *
*261-00013 *
*262-00151 *
*404-12345 *

POWERED DESCENT INITIATION

+50 CB LR - CLOSE
(-10) √ALT XMTR
P63
√DPS CONFIG CARD
+52 *RESET DET UP *
(-8) ENTR-BYPASS ALIGN
N18 R, P, Y (0, 110, 0)
VERIFY FDAI
*V40N20E, 400+3 *
*400+1, 433R VI *
+56 PRO-FINAL TRIM
(-4) ENTR, √DET
GO/NO-GO FOR PDI
COMM CHECK WITH CSM
RESET WATCH
-1:00 MASTER ARM - ON
-0:30 ENG ARM - DES
-0:07.5 ULLAGE
-0:05 PRO
0:00 PDI ____:____:____ (103:30:35.3)
+0:02 (NO IGN) - START PB - PUSH
+0:05 DES ENG CMD OVRD - ON
MASTER ARM - OFF

PDI THRU TD+3 MIN

-1:00 RESET WATCH
MASTER ARM-ON
- :30 ENG ARM-DES
- :07.5 ULLAGE
- :05 PRO
+ :00 PDI
+ :02 (NO IGN) - START PB - PUSH

+ :05 DES ENG OVRD -ON
MASTER ARM-OFF
+0:26 THROTTLE UP
✓T/W > 1.6

V21N69

V57E - (+) LR HIGHER THAN LGC PRO TO PERMIT LR DATA

✓ ED BATTS

N68
223+00060 (DO NOT ENTR)

SEQ CAMR - ON

θ	TFI	VI	(-HMAX) -HDOT	(ΔH) H	DPS	SBD P/Y
110	0:00	5562.0	3.8	50700	100	-2/2
109	0:30	5492.0	6.0	50595	99	
104	1:00	5205.1	25.4	50111	93	2/-2
98	1:30	4909.9	40.2	49116	88	
94	2:00	4606.7	51.2	47738	83	10/-9
90	2:30	4295.5	60.0	46064	77	
86	3:00	3976.3	67.5	44151	72	15/-14
83	3:30	3648.3	74.5	42020	67	
81	4:00	3310.8	81.7	39675	61	19/-18
79	4:30	2962.9	89.5	37007 (+17000)	56	
77	5:00	2603.5	97.4	33795	51	23/-21
75	5:30	2231.6	104.1	(+15600) 30329	45	
72	6:00	1846.9	105.4	(+13500) 27542	40	26/-24
70	6:30	1449.7	93.8	(+11800) 25071	35	
66	7:00	1209.8	(434.6) 134.1	(+ 9800) 21962	32	32/-28
64	7:30	969.5	(388.8) 159.9	(+ 7600) 17928	28	
60	8:00	726.5	(321.0) 173.3	(+ 6000) 12704	25	37/-31

P64

223E @ 6K

P64 + 15 SEC:
NO THROTTLE DN
- ABORT

523 ALARM
V58
PRO
RESET
LDG ANT-HOVER

PGNS MODE CONT-ATT HOLD

P66

X-PNTR-LO MULT

BINGO FUEL
DES QTY LT+1+34

TOUCHDOWN

ENG STOP - PUSH
PRO
MODE CONTROL (BOTH) - AUTO
DES ENG CMD OVRD - OFF
ENG ARM - OFF
413 + 1

RECYCLE PARKER VALVE

H	(-Ḣ MAX) -H DOT)	DPS	LPD TERR CORR
7000	(228.2) 165.0	22	(TBD)
5000	(186.9) 134.4	20	
4000	(163.2) 110.9	20	
3000	(136.3) 85.8	19	
2000	(104.6) 52.4	17	
1000	(63.8) 28.0	15	
500	(35.7) 18.5	14	
400	(28.7) 16.0	13	
300	(21.0) 12.8	12	
200	(12.2) 9.7	12	

ABORT STAGE - PUSH
ENG ARM - ASC
ENG STOP - RESET
ENG START - PUSH
MODE CONTROL(2)- AUTO

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

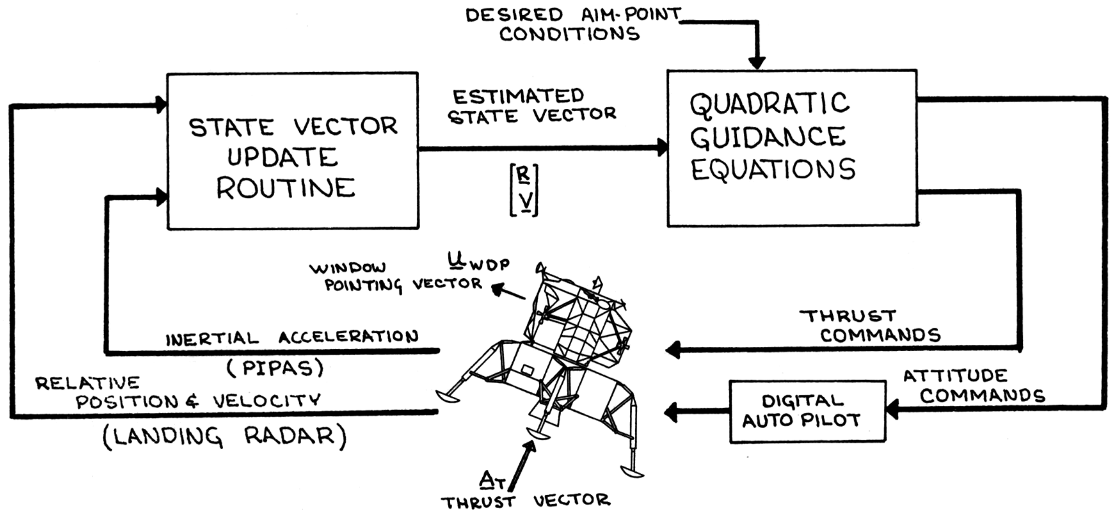
C – AOT Detent
0–COAS CAL, 1 – FL, 2 – FC, 3 – FR,
4 – RR, 5 – RC, 6 – RL, 7 – COAS
DE – Celestial Body Code

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option			X	0	0	0	0	
+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes	GET		+	0	0	0		
+	0					Seconds	GET		+	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	Gyro Torquing Angles (degrees)							
						Z	Gyro Torquing Angles (degrees)							
						X	Calculated Gyro Drift (meru)							
						Y	Calculated Gyro Drift (meru)							
						Z	Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option			X	0	0	0	0	
+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes	GET		+	0	0	0		
+	0					Seconds	GET		+	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	Gyro Torquing Angles (degrees)							
						Z	Gyro Torquing Angles (degrees)							
						X	Calculated Gyro Drift (meru)							
						Y	Calculated Gyro Drift (meru)							
						Z	Calculated Gyro Drift (meru)							

LUNAR LANDING GUIDANCE & NAVIGATION



LUNAR LANDING NAVIGATION

NAVIGATION IS PERFORMED BY THE STATE VECTOR UPDATE ROUTINE WHICH USES A MODIFIED KALMAN FILTER TO ESTIMATE THE VEHICLE STATE VECTOR BASED ON PIPA & LANDING RADAR MEASUREMENTS.

LUNAR LANDING GUIDANCE

THE QUADRATIC GUIDANCE EQUATIONS GENERATE THRUST & ATTITUDE COMMANDS BASED ON THE PRESENT VEHICLE STATE VECTOR AND THE DESIRED AIM POINT CONDITIONS. THE THRUST & ATTITUDE COMMANDS ARE EXECUTED BY THE SPACECRAFT TO ACHIEVE THE DESIRED TRAJECTORY.

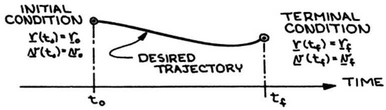
PRIMARY CONSTRAINTS ON LUNAR LANDING

THE TERMINAL POINT IS CONSTRAINED IN POSITION AND VELOCITY

$\underline{r}(t_f) = \underline{R}_{LS}$ (LANDING SITE)
$\underline{v}(t_f) \approx \underline{0}$ (SOFT LANDING)

THE INITIAL POINT IS CONSTRAINED IN POSITION AND VELOCITY

$\underline{r}(t_o) = \underline{r}_o$ = PRESENT POSITION
$\underline{v}(t_o) = \underline{v}_o$ = PRESENT VELOCITY



BASIC GUIDANCE SCHEME

EXPRESS LEM POSITION AS A TAYLOR SERIES IN TIME EXPANDED ABOUT THE TERMINAL TIME t_f.

$$r(t) = r(t_f) + \dot{r}(t_f)(t-t_f) + \ddot{r}(t_f)\frac{(t-t_f)^2}{2} + \dots$$
$$= r(t_f) + v(t_f)(t-t_f) + a(t_f)\frac{(t-t_f)^2}{2} + \dots$$

EXPRESS VELOCITY AND ACCELERATION AS THE FIRST AND SECOND DERIVATIVES OF POSITION.

$$v(t) = v(t_f) + a(t_f)(t-t_f) + j(t_f)\frac{(t-t_f)^2}{2} + \dots$$
$$a(t) = a(t_f) + j(t_f)(t-t_f) + \dots$$

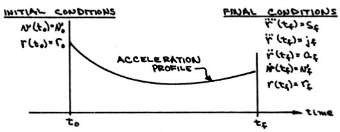
COMPUTE THRUST COMMANDS FROM THE ACCELERATION PROFILE AND GRAVITY.

$$a(t_1) = a(t)\Big|_{t=t_1} = a(t_f) + j(t_f)(t_1-t_f) + \dots$$
$$\text{THRUST}(t_1) = a_T(t_1) = a(t_1) - g(t_1)$$

CAPABILITY OF THE BASIC GUIDANCE SCHEME

THE FORM OF THE ACCELERATION PROFILE IS DETERMINED BY THE NUMBER OF TERMS INCLUDED IN THE TAYLOR SERIES EXPANSION OF $\underline{r}(t)$.

ORDER OF EXPANSION	$N = 2$	$N = 3$	$N = 4$
POSITION EQUATION	$r(t) = r_f + v_f(t-t_f) + a_f\frac{(t-t_f)^2}{2}$	$r(t) = r_f + v_f(t-t_f) + a_f\frac{(t-t_f)^2}{2} + j_f\frac{(t-t_f)^3}{6}$	$r(t) = r_f + v_f(t-t_f) + a_f\frac{(t-t_f)^2}{2} + j_f\frac{(t-t_f)^3}{6} + s_f\frac{(t-t_f)^4}{24}$
VELOCITY EQUATION	$v(t) = v_f + a_f(t-t_f)$	$v(t) = v_f + a_f(t-t_f) + j_f\frac{(t-t_f)^2}{2}$	$v(t) = v_f + a_f(t-t_f) + j_f\frac{(t-t_f)^2}{2} + s_f\frac{(t-t_f)^3}{6}$
ACCELERATION PROFILE	$a(t) = a_f$	$a(t) = a_f + j_f(t-t_f)$	$a(t) = a_f + j_f(t-t_f) + s_f\frac{(t-t_f)^2}{2}$



EFFECT OF INITIAL CONSTRAINTS ON THE ACCELERATION PROFILE

POSITION CONSTRAINT $r(t_o) = r_o$; $T_{go} = t_o - t_f$	$a_f = \left[(r_o - r_f) - v_f T_{go}\right]\frac{2}{T_{go}^2}$	$a_f = \left[(r_o - r_f) - v_f T_{go} - j_f\frac{T_{go}^2}{6}\right]\frac{2}{T_{go}^2}$	$a_f = \left[(r_o - r_f) - v_f T_{go} - j_f\frac{T_{go}^3}{6} - s_f\frac{T_{go}^4}{24}\right]\frac{2}{T_{go}^2}$
VELOCITY CONSTRAINT $v(t_o) = v_o$; $T_{go} = t_o - t_f$	$a_f = (v_o - v_f)\frac{1}{T_{go}}$	$a_f = \left[(v_o - v_f) - j_f\frac{T_{go}^2}{2}\right]\frac{1}{T_{go}}$	$a_f = \left[(v_o - v_f) - j_f\frac{T_{go}^2}{2} - s_f\frac{T_{go}^3}{6}\right]\frac{1}{T_{go}}$
	2 EQUATIONS / 2 UNKNOWNS A_f, T_{go}	2 EQUATIONS / 3 UNKNOWNS A_f, j_f, T_{go}	2 EQUATIONS / 4 UNKNOWNS A_f, j_f, s_f, T_{go}
COMMENTS:	A_f & T_{go} ARE UNIQUELY DETERMINED BY INITIAL CONSTRAINTS	— 1 DEGREE of FREEDOM — j_f CAN BE PRESPECIFIED, THEN A_f & T_{go} ARE UNIQUELY DETERMINED	— 2 DEGREES of FREEDOM — A_f & j_f CAN BE PRESPECIFIED, THEN s_f & T_{go} ARE UNIQUELY DETERMINED.

SECONDARY CONSTRAINTS OF LUNAR LANDING

- REACH TERMINAL CONDITIONS WITH HIGH ACCURACY
- VERTICAL DESCENT FOR LAST 100 ft. AT A RATE OF -3 ft/SEC.
- LANDING SITE VISIBILITY FOR 200 SEC. BEFORE TOUCHDOWN

MODIFICATIONS TO BASIC GUIDANCE SCHEME

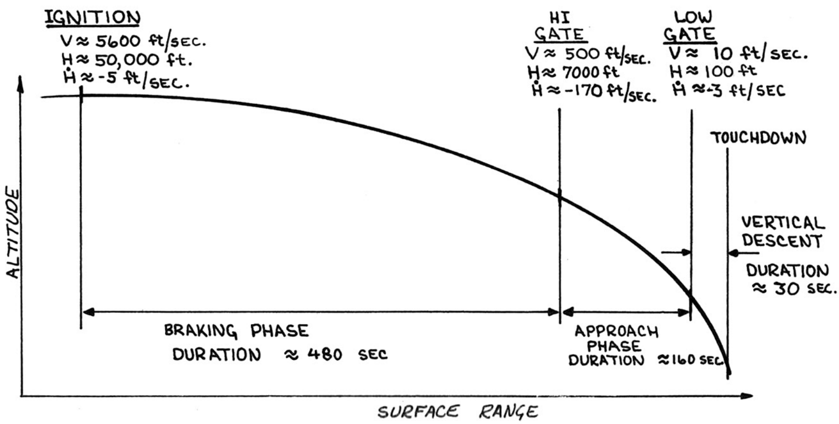
THE FOLLOWING MODIFICATIONS WERE MADE TO THE BASIC QUADRATIC GUIDANCE SCHEME IN ORDER TO ACHIEVE THE SECONDARY CONSTRAINTS OF LUNAR LANDING

- THE DESIRED TRAJECTOR IS REDEFINED ON EVERY ITERATION CYCLE (2 SEC.) SUCH THAT THE INITIAL CONDITIONS $(\underline{r}(t_0), \underline{v}(t_0))$ ARE THE CURRENT BEST ESTIMATE OF VEHICLE STATE AS DETERMINED BY THE STATE VECTOR UPDATE ROUTINE. THIS ENABLES PIN-POINT ACCURACY BY ELIMINATING CUMULATIVE ERRORS IN THE IMPLEMENTATION OF THE BASIC SCHEME.
- THE LANDING SEQUENCE IS DIVIDED INTO THREE PHASES EACH WITH ITS OWN FINAL CONDITIONS OR AIM POINTS.

1. BRAKING PHASE
   THIS PHASE BRAKES THE LEM DOWN FROM ORBITAL VELOCITY AND IS TARGETED SUCH THAT THE LANDING SITE VISIBILITY CONSTRAINTS CAN BE MET DURING THE VISIBILITY PHASE.

2. VISIBILITY PHASE (APPROACH PHASE)
   THIS PHASE IS FLOWN WITH THE LEM ORIENTED SUCH THAT THE LANDING SITE IS VISIBLE FOR LANDING SITE RE-DESIGNATION. TARGETING IS CHOSEN TO YIELD THE PROPER INITIAL CONDITIONS FOR VERTICAL DESCENT CONSISTENT WITH THE VISIBILITY CONSTRAINTS.

3. VERTICAL DESCENT PHASE
   THIS PHASE REDUCES THE SPACECRAFT HORIZONTAL VELOCITY TO ZERO AND VERTICAL VELOCITY TO -3 ft/SEC. QUADRATIC GUIDANCE IS NOT USED.



DERIVATION OF QUADRATIC GUIDANCE LAW

EXPRESS THE POSITION, VELOCITY & ACCELERATION EQUATIONS IN MATRIX FORM

$$\begin{bmatrix} \underline{a}(t) \\ \hline \underline{v}(t) \\ \underline{r}(t) \end{bmatrix} = \left[\begin{array}{cc|ccc} T_{go}^2/2 & T_{go} & 1 & 0 & 0 \\ \hline T_{go}^3/6 & T_{go}^2/2 & T_{go} & 1 & 0 \\ T_{go}^4/24 & T_{go}^3/6 & T_{go}^2/2 & T_{go} & 1 \end{array}\right] \begin{bmatrix} \underline{s}_f \\ \underline{j}_f \\ \hline \underline{a}_f \\ \underline{v}_f \\ \underline{r}_f \end{bmatrix}$$

WHERE : $T_{go} = t - t_f$

REARRANGE THE MATRIX EQUATION SUCH THAT $\underline{a}(t)$, $\underline{s}_f$ & $\underline{j}_f$, THE DEPENDANT VARIABLES, ARE EXPRESSED IN TERMS OF $\underline{v}(t)$, $\underline{r}(t)$, $\underline{a}_f$, $\underline{r}_f$ & $\underline{v}_f$, THE INDEPENDANT VARIABLES.

$$\left[\begin{array}{c|cc} 1 & -T_{go}^2/2 & -T_{go} \\ \hline 0 & -T_{go}^3/6 & -T_{go}^2/2 \\ 0 & -T_{go}^4/24 & -T_{go}^3/6 \end{array}\right] \begin{bmatrix} \underline{a}(t) \\ \underline{s}_f \\ \underline{j}_f \end{bmatrix} = \left[\begin{array}{cc|ccc} 0 & 0 & 1 & 0 & 0 \\ \hline -1 & 0 & T_{go} & 1 & 0 \\ 0 & -1 & T_{go}^2/2 & T_{go} & 1 \end{array}\right] \begin{bmatrix} \underline{v}(t) \\ \underline{r}(t) \\ \hline \underline{a}_f \\ \underline{v}_f \\ \underline{r}_f \end{bmatrix}$$

$$\begin{bmatrix} A \\ B \end{bmatrix} = \begin{bmatrix} C & D \\ E & F \end{bmatrix} \begin{bmatrix} G \\ H \end{bmatrix}$$

$$A = CG + DH$$
$$B = EG + FH$$
$$A - CG = DH$$
$$-EG = -B + FH$$

$$\begin{bmatrix} I & -C \\ O & -E \end{bmatrix} \begin{bmatrix} A \\ G \end{bmatrix} = \begin{bmatrix} O & D \\ -I & F \end{bmatrix} \begin{bmatrix} B \\ H \end{bmatrix}$$

SOLVE THE ABOVE EQUATION FOR $\underline{a}(t)$, $\underline{s}_f$, $\underline{j}_f$.

$$\begin{bmatrix} \underline{a}(t) \\ \underline{s}_f \\ \underline{j}_f \end{bmatrix} = \begin{bmatrix} 6/T_{go} & -12/T_{go}^2 & 1 & 6/T_{go} & 12/T_{go}^2 \\ 24/T_{go}^3 & -72/T_{go}^4 & 12/T_{go}^2 & 48/T_{go}^3 & 72/T_{go}^4 \\ -6/T_{go}^2 & 24/T_{go}^3 & -6/T_{go} & -18/T_{go}^2 & -24/T_{go}^3 \end{bmatrix} \begin{bmatrix} \underline{v}(t) \\ \underline{r}(t) \\ \underline{a}_f \\ \underline{v}_f \\ \underline{r}_f \end{bmatrix}$$

$$[X]\,\underline{A} = [Y]\,\underline{B}$$
$$\underline{A} = [X]^{-1}[Y]\,\underline{B}$$

QUADRATIC ACCELERATION EQUATION

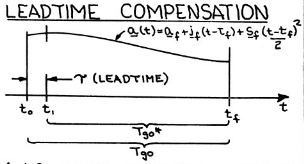
$$\underline{a}(t) = \underline{a}_f + \underline{j}_f (t - t_f) + \underline{s}_f \frac{(t - t_f)^2}{2}$$

WHERE :

$$\underline{j}_f = -\frac{24}{T_{go}^3}(\underline{r}_f - \underline{r}_o) - \frac{6}{T_{go}^2}(\underline{v}_o + 3\underline{v}_f) - \frac{6}{T_{go}}\underline{a}_f$$

$$\underline{s}_f = \frac{72}{T_{go}^4}(\underline{r}_f - \underline{r}_o) + \frac{24}{T_{go}^3}(\underline{v}_o + 2\underline{v}_f) + \frac{12}{T_{go}^2}\underline{a}_f$$

LEADTIME COMPENSATION



$\underline{j}_f$ & $\underline{s}_f$ ARE EVALUATED AT t_o. $\underline{a}(t)$ IS EVALUATED A t_1 TO YIELD LEADTIME COMPENSATION.

$$\underline{a}(t_1) = \underline{a}_f + \underline{j}_f T_{go}^* + \underline{s}_f \frac{T_{go}^{*2}}{2}$$

$$= \left(-24\frac{T_{go}^*}{T_{go}^3} + 36\frac{T_{go}^{*2}}{T_{go}^4}\right)(\underline{r}_f - \underline{r}_o)$$

$$+ \left(-18\frac{T_{go}^*}{T_{go}^2} + 24\frac{T_{go}^{*2}}{T_{go}^3}\right)\underline{v}_f$$

$$+ \left(-6\frac{T_{go}^*}{T_{go}^2} + 12\frac{T_{go}^{*2}}{T_{go}^3}\right)\underline{v}_o$$

$$+ \left(6\frac{T_{go}^{*2}}{T_{go}^2} - 6\frac{T_{go}^*}{T_{go}} + 1\right)\underline{a}_f$$

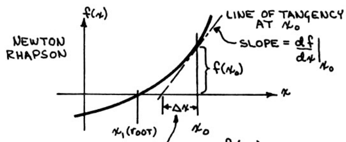
TIME-TO-GO COMPUTATION

TIME TO GO IS COMPUTED TO SATISFY THE REQUIRED FINAL VALUE OF DOWN-RANGE JERK.

FROM THE ABOVE EQUATIONS :

$$j_{f_z} = \frac{24}{T_{go}^3}(r_{o_z} - r_{f_z}) - \frac{6}{T_{go}^2}(v_{o_z} + 3v_{f_z}) - \frac{6}{T_{go}}a_{f_z}$$

THIS EQUATION IS SOLVED FOR T_{go} BY A NEWTON-RHAPSON ITERATION TECHNIQUE.



$$\Delta x = \frac{f(x_o)}{\left.df/dx\right|_{x_o}}$$

TO FIND x_1 :

INITIAL GUESS = x_o

NEW APPROXIMATION = $x_o - \Delta x$

TO FIND TIME-TO-GO :

INITIAL GUESS = TTT

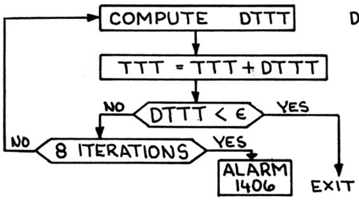
NEW APPROXIMATION = TTT − ΔTTT

$$\Delta TTT = \frac{j_{f_z}TTT^3 + 6a_{f_z}TTT^2 + 6(v_{o_z} + 3v_{f_z})TTT - 24(r_{o_z} - r_{f_z})}{3j_{f_z}TTT^2 + 12a_{f_z}TTT + 6(v_{o_z} + 3v_{f_z})}$$

BASIC MECHANIZATION OF QUADRATIC GUIDANCE (P63, P64)

THE FOLLOWING SEQUENCE OF COMPUTATIONS IS PERFORMED DURING EACH TWO SECOND GUIDANCE CYCLE.

1. COMPUTE TIME-TO-GO



$$DTTT = -\frac{j_{f_z} TTT^3 + 6 a_{f_z} TTT^2 + (18 v_{f_z} + 6 v_{o_z}) TTT + 24 (r_{f_z} - r_{o_z})}{3 j_{f_z} TTT^2 + 12 a_{f_z} TTT + (18 v_{f_z} + 6 v_{o_z})}$$

ϵ IS INITIALIZED ON EACH 2 SEC. CYCLE

$\epsilon = TTT/128$

2. COMPUTE ACCELERATION COMMAND

$$\underline{a}_G = \left(-24 \frac{T_{go}^*}{T_{go}^3} + 36 \frac{T_{go}^{*2}}{T_{go}^4}\right)(\underline{r}_f - \underline{r}_o) + \left(-18 \frac{T_{go}^*}{T_{go}^2} + 24 \frac{T_{go}^{*2}}{T_{go}^4}\right) \underline{v}_f$$
$$+ \left(-6 \frac{T_{go}^*}{T_{go}^2} + 12 \frac{T_{go}^{*2}}{T_{go}^3}\right) \underline{v}_o + \left(6 \frac{T_{go}^{*2}}{T_{go}^2} - 6 \frac{T_{go}^*}{T_{go}} + 1\right) \underline{a}_f - \underline{g}$$

WHERE:

$\left.\begin{matrix}\underline{r}_o \\ \underline{v}_o\end{matrix}\right\}$ PRESENT VEHICLE POSITION & VELOCITY FROM STATE-VECTOR UPDATE ROUTINE

$\left.\begin{matrix}\underline{a}_f \\ \underline{v}_f \\ \underline{r}_f\end{matrix}\right\}$ DESIRED AIM-POINT CONDITIONS FOR P63 or P64. (ERASABLE LOAD)

T_{go} = TTT AS DETERMINED ABOVE

T_{go}^* = TTT + LEADTIME (LEADTIME = 2.2 SEC ERASABLE LOAD)

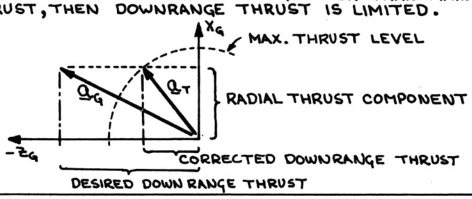
$\underline{g}$ = GRAVITY VECTOR

ERASABLE DATA LOAD AIM-POINTS

	P63	P64
$\underline{r}_f$ = (ft)	$\begin{bmatrix}-3562.05 \\ 0 \\ -13705.71\end{bmatrix}$	$\begin{bmatrix}8.292 \\ 0 \\ -20.16\end{bmatrix}$
$\underline{v}_f$ = (ft/sec)	$\begin{bmatrix}-186.903 \\ 0 \\ -98.738\end{bmatrix}$	$\begin{bmatrix}-.319 \\ 0 \\ .3123\end{bmatrix}$
$\underline{a}_f$ = (ft/sec²)	$\begin{bmatrix}-.450249 \\ 0 \\ -9.51509\end{bmatrix}$	$\begin{bmatrix}.2998 \\ 0 \\ -.4016\end{bmatrix}$
j_{f_z} = (ft/sec³)	$-.0147$	$+.0376$

RADIAL GUIDANCE

IF THE DESIRED ACCELERATION IS GREATER THAN MAX. ENGINE THRUST, THEN DOWNRANGE THRUST IS LIMITED.



BASIC MECHANIZATION (CONT.)

3. ALIGN THE GUIDANCE COORDINATE FRAME

THE GUIDANCE FRAME IS ALIGNED SO THAT THE CROSS-RANGE (Y-COMPONENT) OF JERK IS ZERO AT PHASE TERMINUS. THE Y-COMPONENT OF $\underline{j}_f$ IS GIVEN BY THE QUADRATIC GUIDANCE EQUATIONS.

$$j_{f_Y} = -\frac{6}{T_{go}^2}\left(v_{0_Y} + 3v_{f_Y}\right) - \frac{24}{T_{go}^3}\left(r_{f_Y} - r_{0_Y}\right) - \frac{6}{T_{go}} a_{f_Y}$$

THE Y-COMPONENTS OF THE AIM-POINT VECTORS ARE SPECIFIED AS ZERO : $r_{f_Y} = v_{f_Y} = a_{f_Y} = 0$

$$\therefore \quad 0 = -\frac{6}{T_{go}^2} v_{0_Y} + \frac{24}{T_{go}^3} r_{0_Y}$$

$$\text{or:} \quad r_{0_Y} - \frac{T_{go}}{4} v_{0_Y} = 0 \Rightarrow \left(\underline{r}_0 - \underline{v}_0 \frac{T_{go}}{4}\right)_Y = 0$$

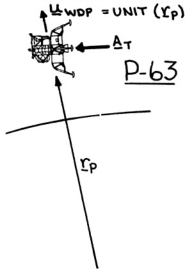
THUS, THE GUIDANCE FRAME IS ALIGNED WITH ITS Y-AXIS PERPENDICULAR TO THE VECTOR $\left(\underline{r}_0 - \underline{v}_0 \frac{T_{go}}{4}\right)$

$$\underline{u}_{X_G} = \text{UNIT}\left(\underline{r}_{LS}\right)$$

$$\underline{u}_{Y_G} = \text{UNIT}\left(\underline{r}_{LS} \times \left(\underline{r}_0 - \underline{v}_0 \frac{T_{go}}{4}\right)\right)$$

$$\underline{u}_{Z_G} = \underline{u}_{X_G} \times \underline{u}_{Y_G}$$

4. COMPUTE THE WINDOW POINTING VECTOR

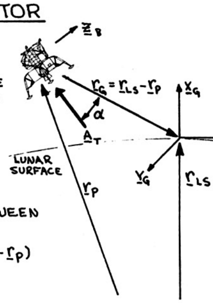


P-64

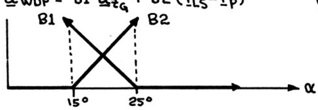
IF $\alpha \leq 15°$ THE LANDING SITE IS NOT VISIBLE AND THE WINDOW-POINTING VECTOR IS ALIGNED ALONG $\underline{Z}_G$.

IF $\alpha \geq 25°$ THE LANDING SITE IS VISIBLE AND THE WINDOW-POINTING VECTOR IS ALIGNED ALONG $\underline{r}_G$.

IF $15° < \alpha < 25°$ A SMOOTH TRANSITION IS MADE BETWEEN THE ABOVE TWO CASES.



$$\underline{u}_{WDP} = B1\ \underline{u}_{Z_G} + B2\left(\underline{r}_{LS} - \underline{r}_P\right)$$



$$\alpha = \left(\text{UNIT}(\underline{r}_G) \times \underline{u}'_{XBP}\right) \cdot \underline{u}_{Y_G}$$

= ANGLE BETWEEN $\underline{r}_G$ & A_T NORMALIZED FOR ANY CROSS-RANGE THRUSTING.

SPACE-CRAFT ORIENTATION

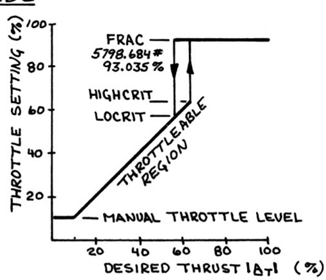
THE X-BODY AXIS IS ALIGNED ALONG THE DESIRED THRUST VECTOR $\underline{A}_T$.

THE Z-BODY AXIS IS ALIGNED IN THE PLANE CONTAINING $\underline{A}_T$ & $\underline{u}_{WDP}$

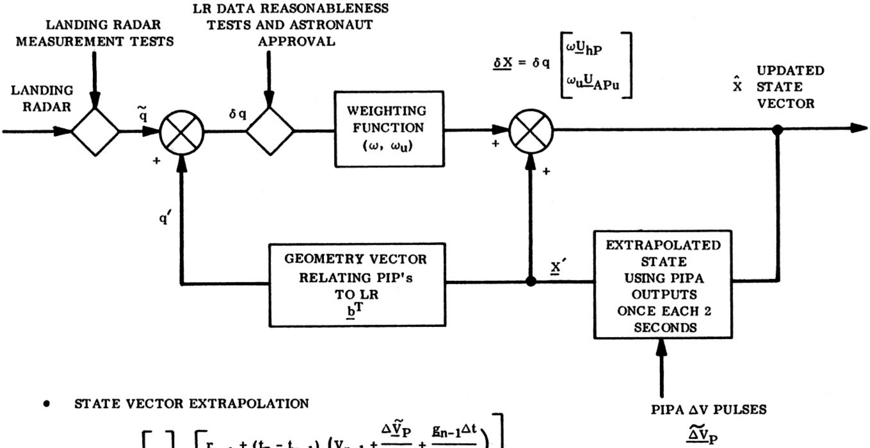
5. COMPUTE THRUST MAGNITUDE

ACTUAL THROTTLE SETTINGS ARE LIMITED BY ENGINE CONSIDERATIONS TO ≈93 % OF FULL SCALE OR LESS THAN 63 %.

ERASABLE DATA LOAD PARAMETERS			
LOCRIT	5985 LBS	=	57 %
HIGHCRIT	6615 LBS	=	63 %



LUNAR LANDING – STATE VECTOR UPDATE RECURSIVE FILTER BLOCK DIAGRAM



- STATE VECTOR EXTRAPOLATION

$$\hat{X}' = \begin{bmatrix} \underline{r}_P \\ \underline{v}_P \end{bmatrix} = \begin{bmatrix} \underline{r}_{n-1} + (t_n - t_{n-1}) \left(\underline{v}_{n-1} + \dfrac{\Delta \underline{\tilde{v}}_P}{2} + \dfrac{g_{n-1} \Delta t}{2} \right) \\ \underline{v}_{n-1} + \Delta \underline{\tilde{v}}_P + (g_P + g_{n-1}) \dfrac{\Delta t}{2} \end{bmatrix}$$

P = PLATFORM FRAME

- STATE VECTOR UPDATE

$$\underline{\hat{x}} = \begin{bmatrix} \underline{r}_P \\ \underline{v}_P \end{bmatrix} + \begin{bmatrix} \delta \tilde{q}_h \, \omega \underline{u}_{hP} \\ \delta q_u \, \omega_u \, \underline{u}_{APu} \end{bmatrix}$$

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 $|\delta q| \leq$ 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 $|\delta q_u| \leq 7.5 + 0.125 \, (\underline{V}_u' - \underline{\omega}_P \times \underline{r}_P)$.
- ASTRONAUT APPROVAL FOR UPDATING HAS BEEN GIVEN (V57).

*DELQFIX = 500 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 acceleration over the 2-second interval

$$r = r_0 + v_0 \Delta t + \frac{1}{2} a \Delta t^2$$

$$\underline{r}_p = \underline{r}_{n-1} + \underline{v}_{n-1}(t_n - t_{n-1}) + \frac{\Delta \underline{\tilde{v}}_p}{2} \Delta t + \frac{\underline{g}_{n-1}}{2} \Delta t^2$$

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

$\Delta \underline{\tilde{v}}_p$ = 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

$$v = v_0 + a\Delta t$$

$$\underline{v}_p = \underline{v}_{n-1} + \Delta \underline{\tilde{v}}_p + \left[\frac{\underline{g}_{n-1} + \underline{g}_p}{2}\right] \Delta t$$

where

$\underline{v}_{n-1}$ = velocity ($\underline{v}_p$) at end of previous interval

$\Delta \underline{\tilde{v}}_p$ = 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 $\quad h' = r_p - r_{Ls}$

where

r_p = magnitude of position, $\underline{r}_p$

r_{LS} = magnitude of landing site, $\underline{r}_{LS}$

Velocity $\quad v' = |\underline{v}_p|$

Mass $\quad m_n = m_{n-1} - |\Delta \underline{\tilde{v}}_p| \, m_{n-1} / V_e$ (V_e = Exhaust Velocity Constant)

Velocity Increment $\quad \Delta V = \Delta V + |\Delta \underline{\tilde{v}}_p|$

UPDATE THE STATE VECTOR USING LR RANGE DATA

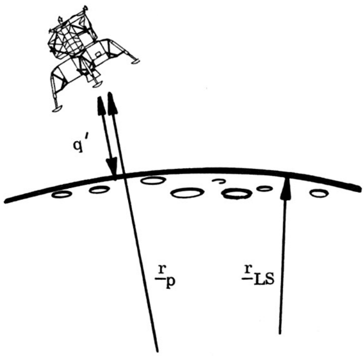
- Compute the measurement residual

$$\delta q = \tilde{q}^* - q'$$

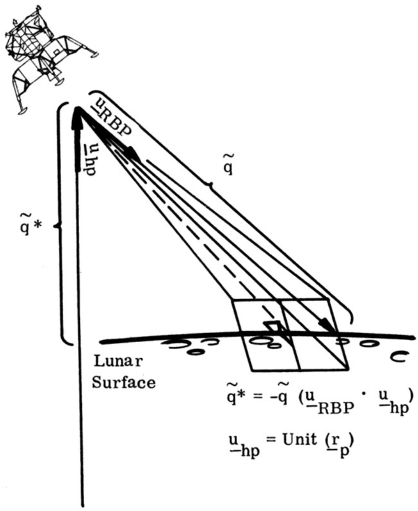
where

$\tilde{q}^*$ = altitude derived from LR slant range (corrected for doppler effect)

q' = estimated altitude



$$q' = r_p - r_{LS}$$

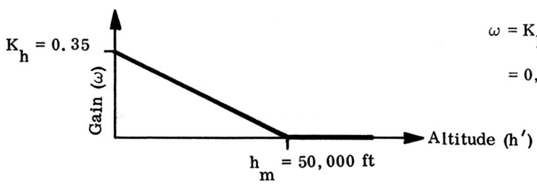


$$\tilde{q}^* = -\tilde{q}\,(\underline{u}_{RBP} \cdot \underline{u}_{hp})$$

$$\underline{u}_{hp} = \text{Unit}\,(\underline{r}_p)$$

- Update the position vector using the precomputed gain and measurement residual

$$\underline{r}_p = \underline{r}_p + \omega\,\delta q\,\underline{u}_{hp}$$

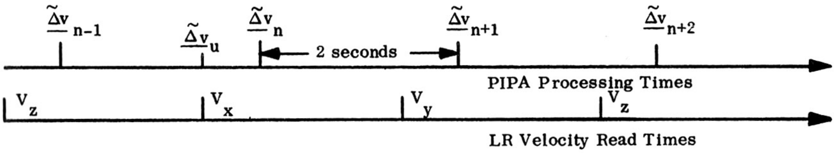


$$\omega = K_h\left(1 - \frac{h'}{h_m}\right),\ h' \le h_m$$

$$= 0,\ h' > h_m$$

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.



$\tilde{q}_u = V_x$ $\quad\quad$ $\tilde{q}_u = V_y$ $\quad\quad$ $\tilde{q}_u = V_z$

$\underline{u}_{AP_u} = [C_{PB_u}]\,\underline{u}_x$ $\quad\quad$ $\underline{u}_{AP_u} = [C_{PB_u}]\,\underline{u}_y$ $\quad\quad$ $\underline{u}_{AP_u} = [C_{PB_u}]\,\underline{u}_z$

- Compute the measurement residual corresponding to the time that the velocity data is read (t_u).

  $\delta q = \tilde{q}_u - q'_u$

  $\tilde{q}_u$ = LR velocity component read at time t_u

  q'_u = 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

  $\underline{\omega}_p \times \underline{r}_p$ = velocity of lunar surface

  $\underline{u}_{AP_u}$ = unit vector in direction of LM velocity data

  $\underline{v}'_u - \underline{\omega}_p \times \underline{r}_p$ = velocity of LM relative to lunar surface

  $\underline{v}'_u$ = 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

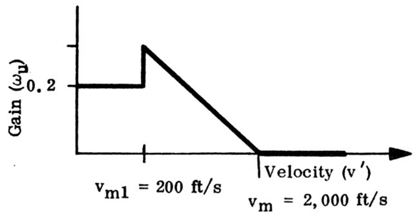
  $\underline{v}_{n-1}$ = LM velocity at end of previous update cycle

  $\Delta\tilde{\underline{v}}_u$ = PIPA ΔV read at time of LR velocity data t_u

  $\underline{g}_{n-1}$ = lunar gravitational acceleration at end of previous cycle

- Update the LM velocity vector at time t_n using measurement residual and extrapolate velocity ($\underline{v}_p$)

  $\underline{v}_p = \underline{v}_p + \omega_u\, \delta q\, \underline{u}_{AP_u}$



$\omega_u = 0, \; v' > v_m$

$\omega_u = 0.3\,(1 - v'/v_m), \; v_{m1} \le v' \le v_m$

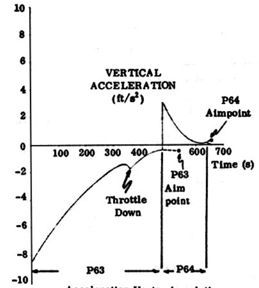
$\omega = 0.2, \; v' < v_{m1}$

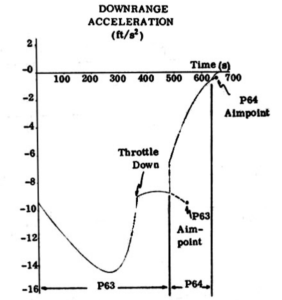
LUNAR LANDING GUIDANCE FRAME PARAMETERS (TYPICAL)

VERTICAL IS ALONG GUIDANCE FRAME X-AXIS

CROSS RANGE PARAMETERS ARE NOMINALLY ZERO

DOWN RANGE IS ALONG GUIDANCE FRAME Z-AXIS



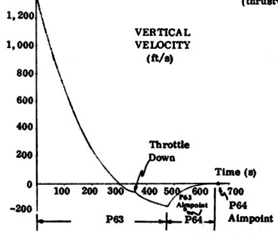


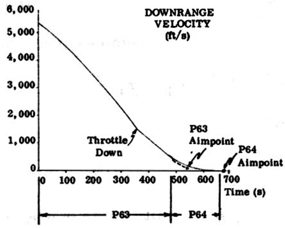
Acceleration Vector is solution of equation

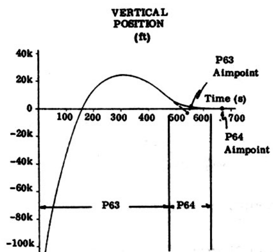
$$\underline{A}_G = \frac{6}{T_{go}}(\underline{v}_o + \underline{v}_f) + \frac{12}{T_{go}}(\underline{r}_f - \underline{r}_o) + \underline{A}_f$$

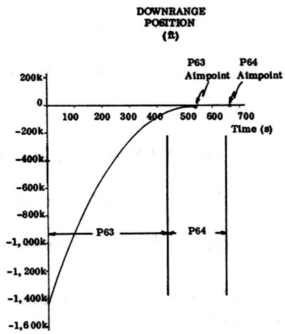
($\underline{v}_o$ and $\underline{r}_o$ are plotted below)

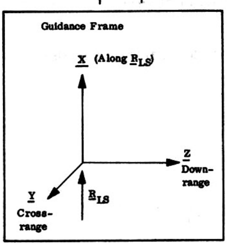
Velocity is determined by integrating applied acceleration (thrust+gravity).



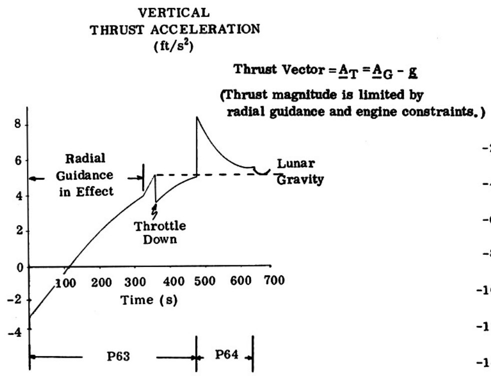


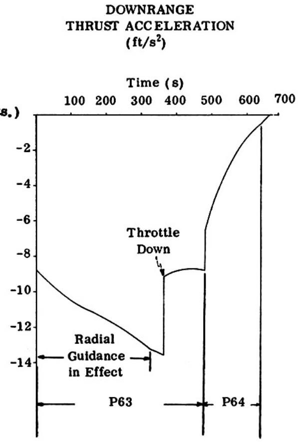


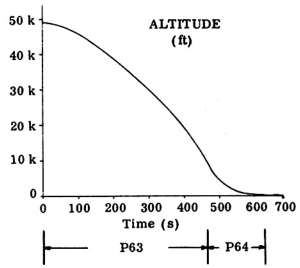


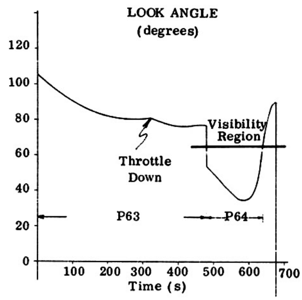


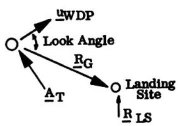
LUNAR LANDING GUIDANCE FRAME PARAMETERS (TYPICAL) (Continued)

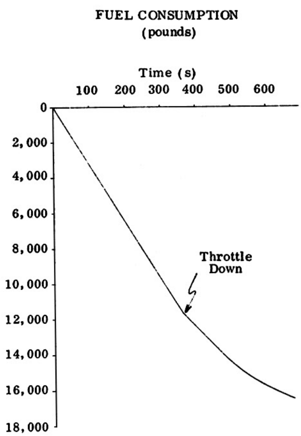


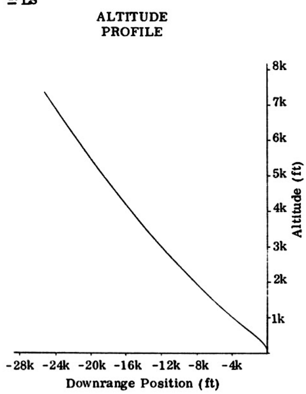




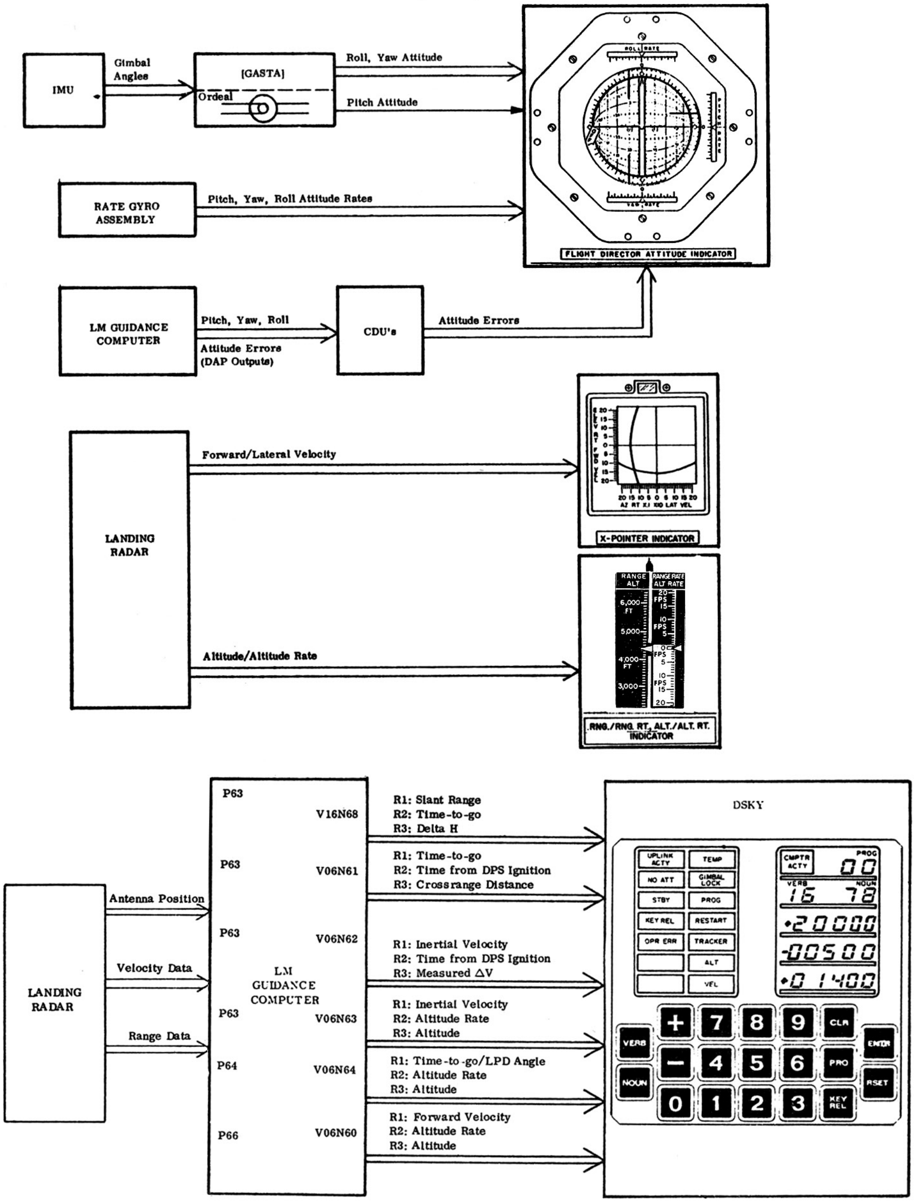




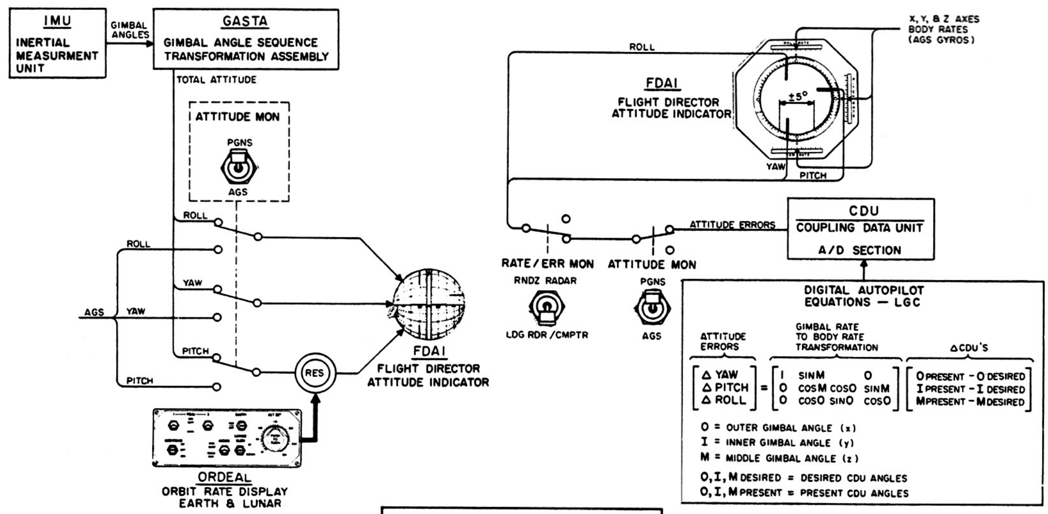




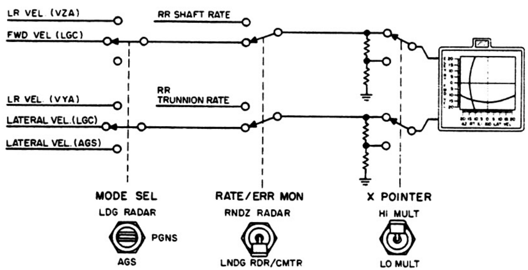
LM LANDING DISPLAYS
P63, P64, P66



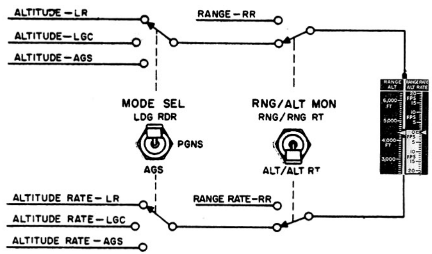
DESCENT DISPLAYS



FLIGHT DIRECTOR ATTITUDE INDICATOR

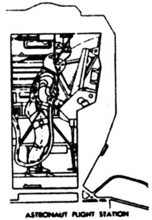


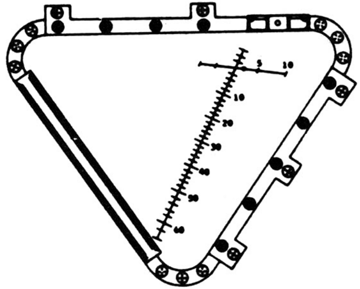
X POINTER INDICATOR



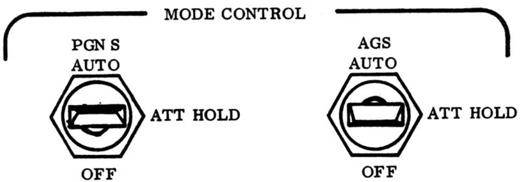
RANGE/RANGE RATE, ALTITUDE/ALTITUDE RATE INDICATOR

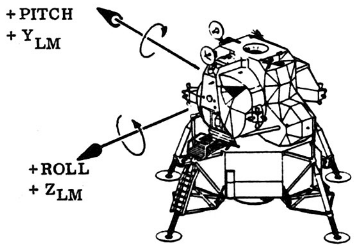
LANDING SITE REDESIGNATION
P64 ONLY

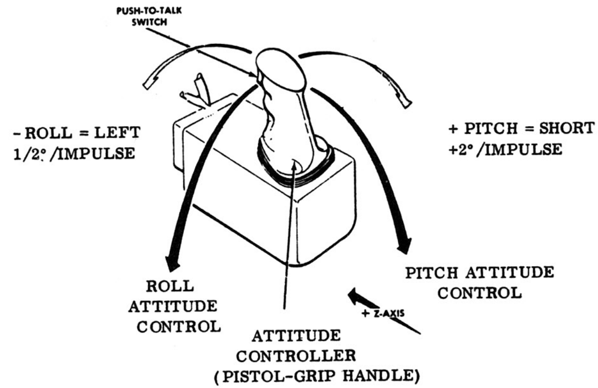




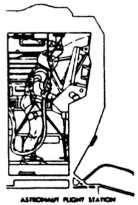
COMMANDER'S WINDOW
(LANDING POINT DESIGNATOR ON
COMMANDER'S WINDOW ONLY)



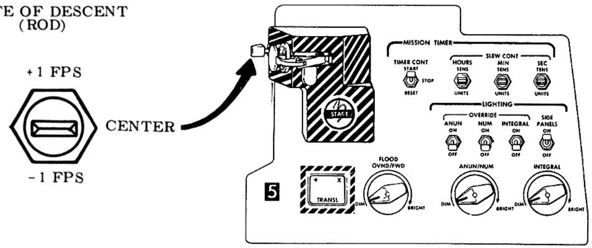


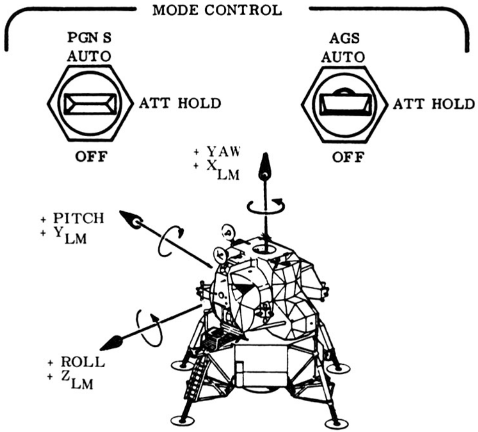


LANDING PHASE MODE CONTROL
P66

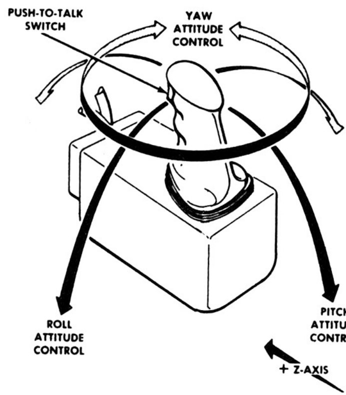


RATE OF DESCENT
(ROD)

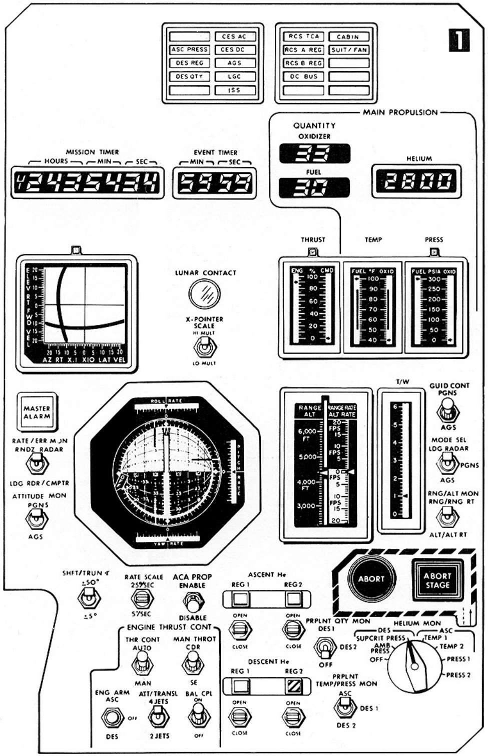


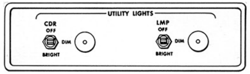


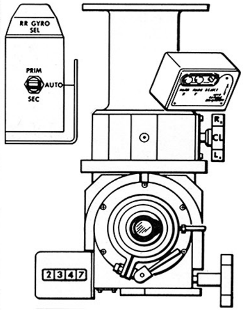
MANUAL LM ATTITUDE CONTROLLER



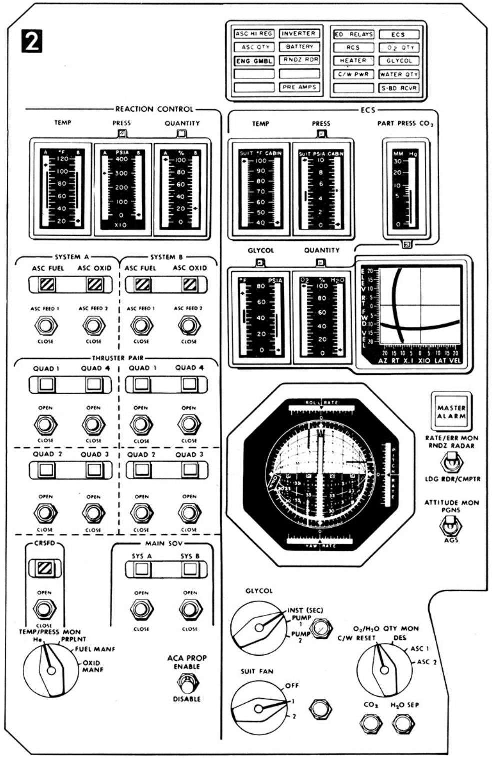
LM CONTROLS AND DISPLAYS



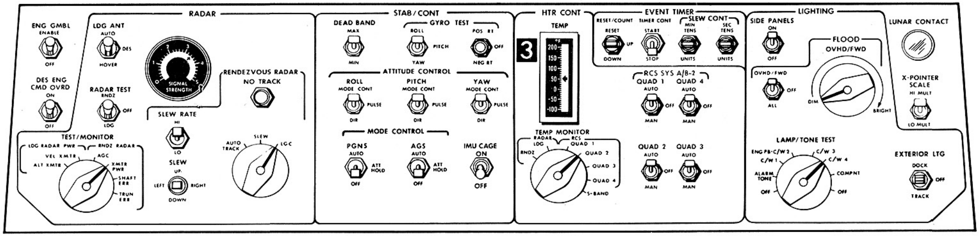




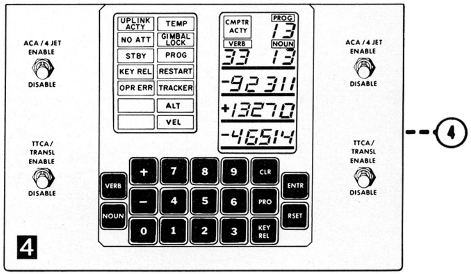
Alignment Optical Telescope (AOT)

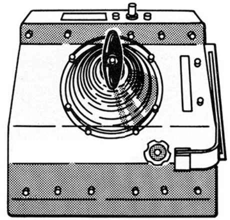


LM CONTROLS AND DISPLAYS



Display Keyboard Assembly (DSKY)





Attitude Controller Assembly (ACA)

Thrust/Translation Controller Assembly (TTCA)

Cabin Controls and Displays

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				GET: Hours		+	0	0			
+	0	0	0			GET: Minutes		+	0	0	0		
+	0					GET: 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						
						Gyro Torquing Angles (degrees): X	N93						
						Gyro Torquing Angles (degrees): Y							
						Gyro Torquing Angles (degrees): Z							
						Calculated Gyro Drift (meru): X							
						Calculated Gyro Drift (meru): Y							
						Calculated Gyro Drift (meru): Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				GET: Hours		+	0	0			
+	0	0	0			GET: Minutes		+	0	0	0		
+	0					GET: 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						
						Gyro Torquing Angles (degrees): X	N93						
						Gyro Torquing Angles (degrees): Y							
						Gyro Torquing Angles (degrees): Z							
						Calculated Gyro Drift (meru): X							
						Calculated Gyro Drift (meru): Y							
						Calculated Gyro Drift (meru): Z							

NOTES:

PDI + 20 (103:53)

LANDING ALIGNMENT OPTION

P57, R2 00003 (REFSMMAT alignment option)

N06, 00010, 00001, 00110 — REFSMMAT + gravity alignment technique, REFSMMAT defined, stored attitude available

(N0 ATT LT - on/off twice) (Gravity measured)

N04 + __________ (Gravity tilt vs vehicle X axis) (0.01°)

V32E (Recycle)

N04 + __________ (Spacecraft X axis stability)
PRO

N22 ICDU angles
PRO (N0 ATT LT - on/off twice)

N05 ____________ Angle difference (0.01°)

N93 ____________ X Torquing angles (0.001°)
____________ Y
____________ Z

V34E, P00E ____________ (Terminate, do not torque platform)

PDI + 45 (104:18)

TWO-STAR PLATFORM ALIGNMENT-Landing Site Location Check

P57, R2 00003 (REFSMMAT alignment option)
PRO

N06, 00010, 00002, 00110 — Two-celestial body alignment technique, REFSMMAT defined, stored attitude available
PRO

First Star Marks:

First Star ____________ (Atria 134)
Cursor ____________
Spiral ____________

N79 Load then V32E
Cursor ____________
Spiral ____________

N79 Load then V32E
Cursor ____________
Spiral ____________

N79 Load then PRO

Second Star (Rasalhague 335)
Cursor ___________
Spiral ___________

N79 Load then V32E
Cursor ___________
Spiral ___________

N79 Load then V32E
Cursor ___________
Spiral ___________

N79 Load then PRO

Second Star Marks

N05 ___________ Star Angle Difference (0.01°)
PRO

N93 ___________ X Torquing angle (.001°)
___________ Y
___________ Z
PRO (gyro torquing)

N25 00014 ENTR

N89 ___________ Lat (0.001°)
___________ Long/2 (0.001°)
___________ Alt (0.01 nmi)

PDI + 1:00 (104:33)

TWO-STAR PLATFORM ALIGNMENT - Landing Site Location Check

P57, R2 00003 (REFSMMAT alignment option)
PRO

N06 00010
00002
00110

(Two-celestial body alignment technique, REFSMMAT defined, stored attitude available)

First Star ___________ (Antares 233)
Cursor ___________
Spiral ___________

N79 Load then V32E
Cursor ___________
Spiral ___________

N79 Load then V32E
Cursor ___________
Spiral ___________

N79 Load then PRO

First Star Marks

Second Star ____________ (Formalhaut 645)
Cursor ____________
Spiral ____________

N79 Load then V32E
Cursor ____________
Spiral ____________

N79 Load then V32E
Cursor ____________
Spiral ____________

N79 Load then PRO

$\}$ Second Star Marks

N05 ____________ Star Angle Difference (0.01°))
PRO (gyro torquing)

N93 ____________ X Torquing angle (.001°)
____________ Y
____________ Z

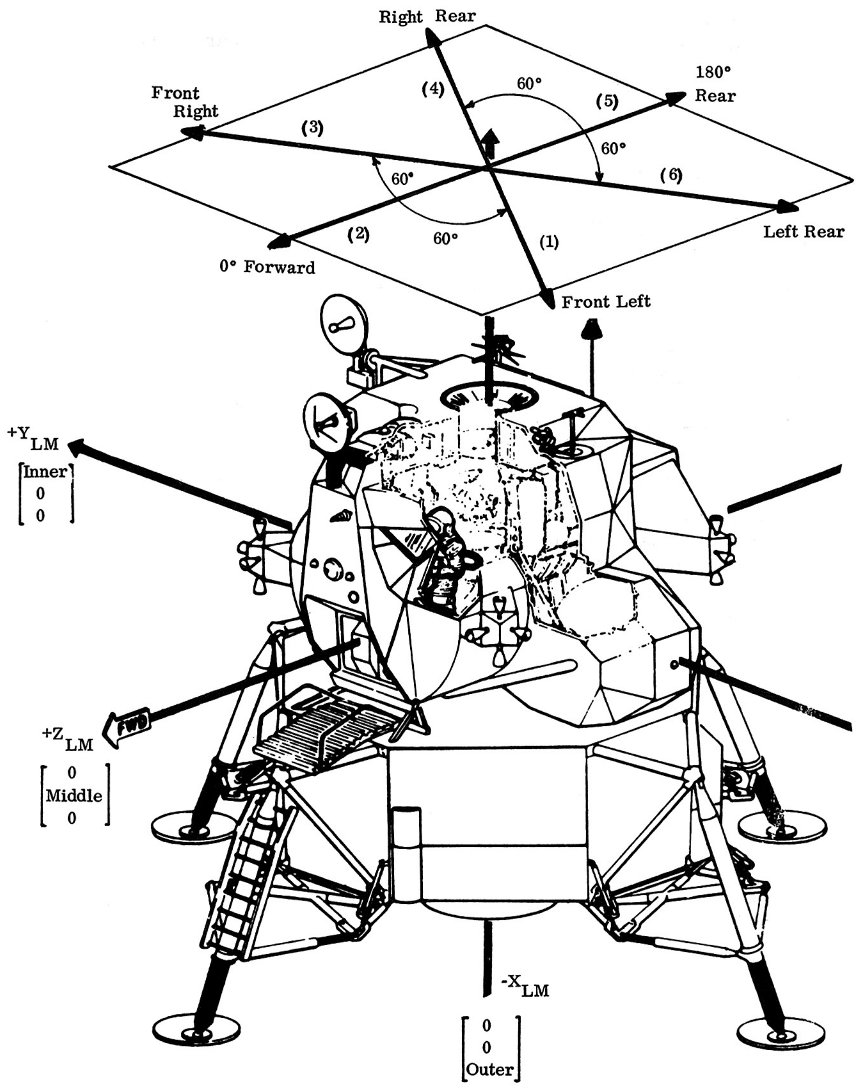
N25 00014 ENTR

N89 ____________ Lat (0.001°)
____________ Long/2 (0.001°)
____________ Alt (0.01 nmi)

Consult MSFN
PRO - (Update RLS)
V34E-(Terminate)
CB AOT - Open, CL/0.0°
P00E

LUNAR SURFACE ALIGNMENT

AOT DETENT POSITIONS



LUNAR SURFACE ALIGNMENT - P57

VERB 37 ENTR,
57 ENTR

VERB 04 NOUN 06 (FLASHING)
SPECIFY IMU ORIENTATION
a. PREFERRED (00001)
b. REFSMMAT (00003)
c. LANDING SITE (00004)

PREFERRED: VERB 22 ENTR, 00001 ENTR

REFSMMAT: VERB 22 ENTR, 00003 ENTR

LANDING SITE: VERB 22 ENTR, 00004 ENTR

VERB 06 NOUN 34 (FLASHING)
TIME OF ALIGNMENT

TIME OF ALIGNMENT CAN BE MODIFIED WITH A VERB 25 DATA LOAD

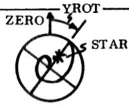
VERB 05 NOUN 06 (FLASHING)
SPECIFY ALIGNMENT TECHNIQUE
a. STORED ATTITUDE (00000)
b. STORED ATTITUDE + GRAVITY (00001)
c. TWO CELESTIAL BODIES (00002)
d. ONE CELESTIAL BODY + GRAVITY (00003)

VERB 22 ENTR, 0000X ENTR

TECHNIQUE 1 OR 3: EXECUTE THE GRAVITY DETERMINATION ROUTINE
VERB 06 NOUN 04 (FLASHING)
± XXX.XX° (ANGULAR DIFFERENCE BETWEEN PRESENT AND PREVIOUSLY STORED GRAVITY VECTOR)

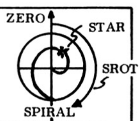
TECHNIQUE 0 OR 2: GRAVITY DETERMINATION NOT RELEVANT TO THESE TECHNIQUES

TECHNIQUE 2 OR 3:



CURSOR
MEASUREMENT

PERFORM AOT SIGHTINGS ON CELESTIAL BODIES AS REQUIRED BY TECHNIQUE



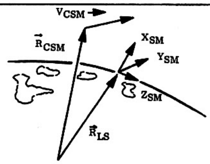
SPIRAL
MEASUREMENT

TECHNIQUE 0 OR 1: AOT NOT USED FOR THESE TECHNIQUES

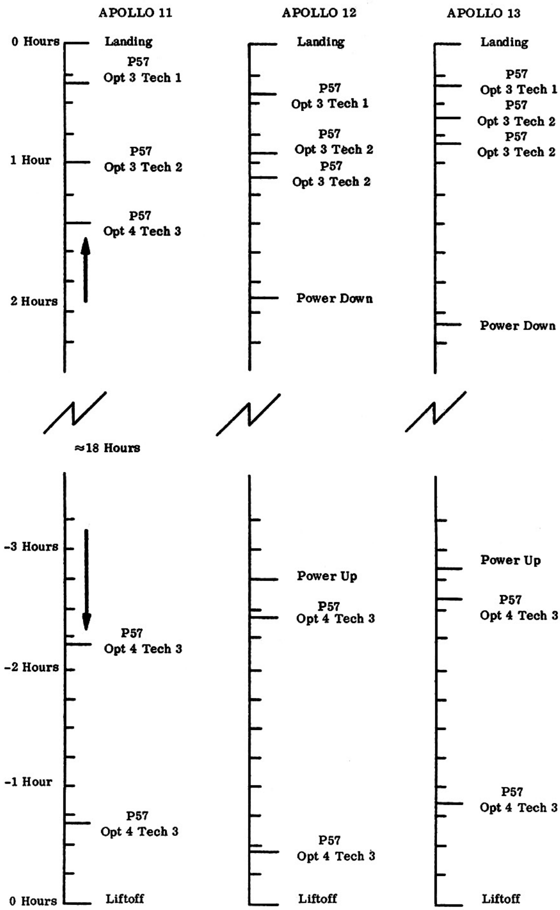
VERB 06 NOUN 05 (FLASHING)
± XXX.XX° (ALIGNMENT ANGLE DIFFERENCE)

COMPUTE AND STORE NEW REFSMMAT AND ALIGN IMU TO DESIRED ORIENTATION

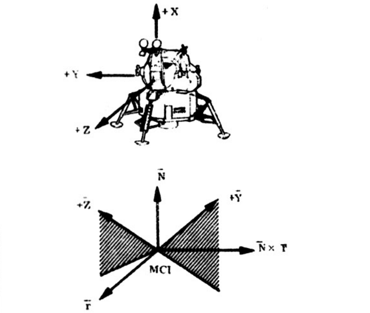
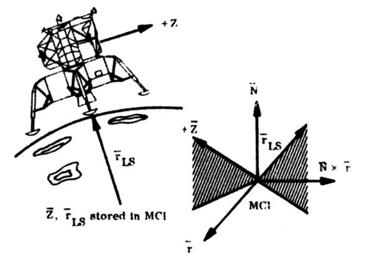
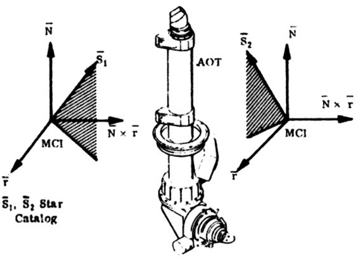
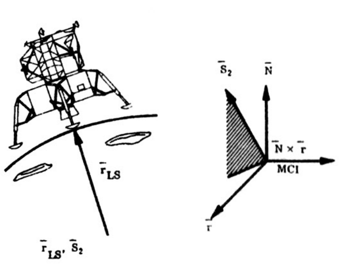
LUNAR SURFACE ALIGNMENT — P57

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.	$[\text{REFSMMAT}] = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{CURRENTLY MAINTAINED} \\ \text{LGC SM ORIENTATION} \end{bmatrix}$
00004 (LANDING SITE)	 THIS OPTION ALIGNS THE X_{SM} ALONG $\vec{R}_{LS}$ AND Z_{SM} DOWNRANGE.	$\begin{bmatrix} \text{LANDING SITE} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{UNIT}(\vec{R}_{LS}) \\ \text{UNIT}(\vec{Z}_{SM} \times \vec{X}_{SM}) \\ \text{UNIT}[(\vec{R}_{CSM} \times \vec{V}_{CSM}) \times \vec{X}_{SM}] \end{bmatrix}$ WHERE $\vec{R}_{LS}$ IS THE LANDING SITE POSITION VECTOR; $\vec{R}_{CSM}$, $\vec{V}_{CSM}$ ARE THE POSITION AND VELOCITY VECTORS FOR THE CSM AT TIME OF ALIGNMENT

P57 SEQUENCES



LUNAR SURFACE ALIGNMENT – P57

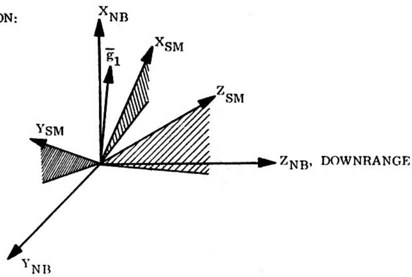
TECHNIQUE	LOS DIRECTION IN BASIC REFERENCE COORDINATES	CALCULATE REFSMMAT
0	 LM + $\bar{Y}$ and + $\bar{Z}$ stored from previous alignment (P57, P68)	$\bar{S}_A$ (specified) $= \begin{bmatrix} \bar{Y} \\ (\bar{Y} \times \bar{Z}) \times \bar{Y} \\ \bar{Y} \times \bar{Z} \end{bmatrix} \bar{1}_{MCI} \triangleq [A]\ \bar{1}_{MCI}$ $\bar{S}_B$ (measured) $= \begin{bmatrix} \bar{Y}_M \\ (\bar{Y}_M \times \bar{Z}_M) \times \bar{Y}_M \\ \bar{Y}_M \times \bar{Z}_M \end{bmatrix} \bar{1}_{SMCS} \triangleq [B]\ \bar{1}_{SMCS}$ $\bar{S}_A = [A]\ \bar{1}_{MCI} = \bar{S}_B = [B]\ \bar{1}_{SMCS}$ $\bar{1}_{SMCS} = [REFSMMAT]\ \bar{1}_{MCI} = [B]^{-1}\ [A]\ \bar{1}_{MCI}$
1		$\bar{S}_A$ (specified) $= \begin{bmatrix} \bar{r}_{LS} \\ (\bar{r}_{LS} \times \bar{Z}) \times \bar{r}_{LS} \\ \bar{r}_{LS} \times \bar{Z} \end{bmatrix} \bar{1}_{MCI} \triangleq [A]\ \bar{1}_{MCI}$ $\bar{S}_B$ (measured) $= \begin{bmatrix} \bar{g}_{LS} \\ (\bar{g}_{LS} \times \bar{Z}_M) \times \bar{g}_{LS} \\ \bar{g}_{LS} \times \bar{Z}_M \end{bmatrix} \bar{1}_{SMCS} \triangleq [B]\ \bar{1}_{SMCS}$ $\bar{1}_{SMCS} = [REFSMMAT]\ \bar{1}_{MCI} = [B]^{-1}\ [A]\ \bar{1}_{MCI}$
2		$\bar{S}_A$ (specified) $= \begin{bmatrix} \bar{S}_1 \\ (\bar{S}_1 \times \bar{S}_2) \times \bar{S}_1 \\ \bar{S}_1 \times \bar{S}_2 \end{bmatrix} \bar{1}_{MCI} = [A]\ \bar{1}_{MCI}$ $\bar{S}_B$ (measured) $= \begin{bmatrix} \bar{S}_{1M} \\ (\bar{S}_{1M} \times \bar{S}_{2M}) \times \bar{S}_{1M} \\ \bar{S}_{1M} \times \bar{S}_{2M} \end{bmatrix} \bar{1}_{SMCS} = [B]\ \bar{1}_{SMCS}$ $\bar{1}_{SMCS} = [REFSMMAT]\ \bar{1}_{MCI} = [B]^{-1}\ [A]\ \bar{1}_{MCI}$
3		$\bar{S}_A$ (specified) $= \begin{bmatrix} \bar{r}_{LS} \\ (\bar{r}_{LS} \times \bar{S}_2) \times \bar{r}_{LS} \\ \bar{r}_{LS} \times \bar{S}_2 \end{bmatrix} \bar{1}_{MCI} = [A]\ \bar{1}_{MCI}$ $\bar{S}_B$ (measured) $= \begin{bmatrix} \bar{g}_{LS} \\ (\bar{g}_{LS} \times \bar{S}_{2M}) \times \bar{g}_{LS} \\ \bar{g}_{LS} \times \bar{S}_{2M} \end{bmatrix} \bar{1}_{SMCS} = [B]\ \bar{1}_{SMCS}$ $\bar{1}_{SMCS} = [REFSMMAT]\ \bar{1}_{MCI} = [B]^{-1}\ [A]\ \bar{1}_{MCI}$

MCI = Moon Centered Inertial; SMCS = Stable Member Coordinate System

LUNAR SURFACE ALIGNMENT
GRAVITY DETERMINATION ROUTINE

1. COARSE ALIGN THE IMU TO THE FIRST ORIENTATION:

OGA $\simeq$ +42°
MGA $\simeq$ +35.25°
IGA $\simeq$ -42°



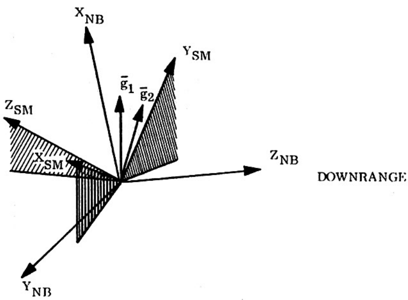
2. PLACE THE IMU IN AN INERTIAL MODE AND SAMPLE THE OUTPUT OF THE PIPA's OVER A PERIOD OF 40 SECONDS. ($PIPA_X$, $PIPA_Y$, $PIPA_Z$). FORM A UNIT VECTOR $\vec{g}_1$

$$\vec{g}_1 = \frac{PIPA_X \hat{X}_{SM} + PIPA_Y \hat{Y}_{SM} + PIPA_Z \hat{Z}_{SM}}{\sqrt{PIPA_X{}^2 + PIPA_Y{}^2 + PIPA_Z{}^2}}$$

WHERE $\vec{g}_1$ 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.

OGA $\simeq$ -138°
MGA $\simeq$ +35.25°
IGA $\simeq$ -42°



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 $\vec{g}_2$

$$\vec{g}_2 = \frac{PIPA_X \hat{X}_{SM} + PIPA_Y \hat{Y}_{SM} + PIPA_Z \hat{Z}_{SM}}{\sqrt{PIPA_X{}^2 + PIPA_Y{}^2 + PIPA_Z{}^2}}$$

where $\vec{g}_2$ 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 $\vec{g}_1$ AND $\vec{g}_2$ WHICH REPRESENTS THE DIRECTION OF THE LUNAR GRAVITY VECTOR.

$$\vec{U}_G = \text{UNIT } (\vec{g}_1 + \vec{g}_2)$$

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

1–Preferred, 2–Invalid
3–REFSMMAT, 4–Landing Site

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 — Time of Alignment		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0	0		Alignment Mode		X	0	0	0	0	
						Gravity Error Angle (deg)							
						OG — Alignment Final ICDU Angles	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 — Gyro Torquing Angles (deg)	N93						
						Y							
						Z							
						X — Calculated Gyro Drifts (meru)							
						Y							
						Z							
						Latitude (deg)	N89						
						Longitude/2 (deg) — Landing Site							
						Altitude (nmi)							

APOLLO 13 P57's

1st P57	Done to option 3 (REFSMMAT) with technique 1 (gravity and Z Nav base). Normally two gravity measurements. First gravity error angle indicates angle between X-nav base and local vertical. Second gravity measurement indicates stability of spacecraft.* The N93 GTA's are the relationship between the SM and local horizontal. The latter gravity measurement will be used in the next P57 for co-ordinates of landing site. No gyro drifts can be calculated from N93. The GTA's are not normally torqued.
2nd P57	Done to option 3 (REFSMMAT) with technique 2 (two body). No gravity measurements are made. The N93 GTA's will put SM on the pre descent defined REFSMMAT in preparation for display of the landing site co-ordinates. Latitude, longitude and altitude of the landing site are displayed based on the previous gravity vector. If the co-ordinates are accepted (via proceed) they are converted and stored as R_{ls}. The N93 may be used to calculate gyro drift over the interval from the last P52. The drift terms will include acceleration sensitive terms due to descent and 1/6G.
3rd P57	Same as the second P57 except gyro drift cannot be calculated due to the short interval of time. This P57 is mainly used to verify the results of the second P57.
4th P57	Done to option 4 (landing site, time to be specified) with technique 3 (gravity and one star). First P57 after power up on the lunar surface. Normally two gravity measurements are made. The first measurement indicates any change in the nav base since the last gravity measurement. Second gravity measurement indicates stability of spacecraft. The N93 GTA's will align the SM to the REFSMMAT defined by option 4. No gyro drift calculation from N93 since this is first alignment since power up.
5th P57	Same as fourth P57. Normally done to same time of liftoff as fourth P57. Normally only one gravity measurement made. Gyro drift may be calculated from N93 if above is true. Final alignment before liftoff. The drift terms will include 1/6G acceleration sensitive terms.

*Gravity error angle of .01° is within accuracy of system.

P22–ORBITAL NAVIGATION

REV 15

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)							

+	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	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)							

NOTES:

P22–ORBITAL NAVIGATION
MARK DATA
REV 15

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

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	Time	N33	+	0	0			
+	0	0	0			Minutes	of		+	0	0	0		
+	0					Seconds	Ascent		+	0				
X	0	0	0	0		Option Code		N06	X	0	0	0	0	
+	0	0				Hours	Time	N33	+	0	0			
+	0	0	0			Minutes	of		+	0	0	0		
+	0					Seconds	Ascent		+	0				
X	0	0	0	0		Option Code		N06	X	0	0	0	0	
+	0	0				Hours	Time	N33	+	0	0			
+	0	0	0			Minutes	of		+	0	0	0		
+	0					Seconds	Ascent		+	0				

NOTES:

P22–ORBITAL NAVIGATION

REV 17

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)								

+	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	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)								

NOTES.

P22–ORBITAL NAVIGATION
MARK DATA
REV 17

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

NOTES:

P22–ORBITAL NAVIGATION
REV 18

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)							

+	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	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)							

P22–ORBITAL NAVIGATION
MARK DATA
REV 18

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles (degree)	+					
+						Trunnion		+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles (degree)	+					
+						Trunnion		+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P							
						Y	IMU Gimbal Angles (degree)						
						R							
+						Shaft	SXT Angles (degree)	+					
+						Trunnion		+					

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				P_{Trim}	N48		0	0			
	0	0				Y_{Trim} (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			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				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 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	GET		+	0	0	0		
+	0					Seconds	GET		+	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	Gyro Torquing Angles (degrees)							
						Z	Gyro Torquing Angles (degrees)							
						X	Calculated Gyro Drift (meru)							
						Y	Calculated Gyro Drift (meru)							
						Z	Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option			X	0	0	0	0	
+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes	GET		+	0	0	0		
+	0					Seconds	GET		+	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	Gyro Torquing Angles (degrees)							
						Z	Gyro Torquing Angles (degrees)							
						X	Calculated Gyro Drift (meru)							
						Y	Calculated Gyro Drift (meru)							
						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)

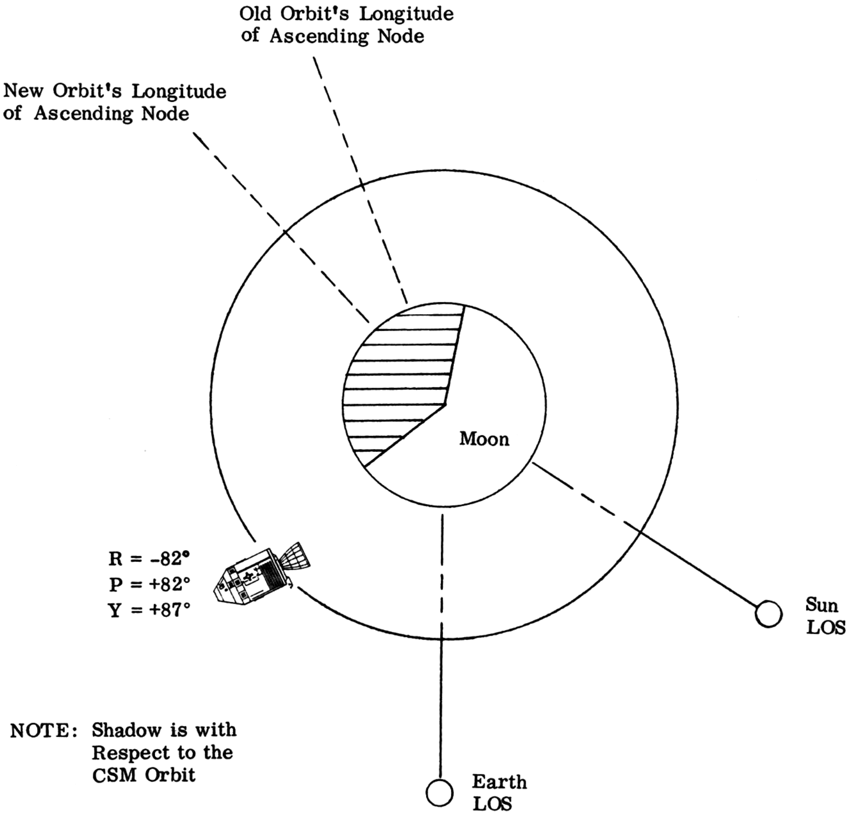
V37 Flashing, V82 Enter

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)	

LUNAR ORBIT PLANE CHANGE - 1

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
LOPC-1	10.0/183.6	113:42:02.7	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
$V_{x_{TRIM}}$		$V_{y_{TRIM}}$		$V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P22–ORBITAL NAVIGATION

REV 29

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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 Elevation	+	0	0	0		
+	0					Seconds	+	0				
+	0	0				Hours T2 GET at	+	0	0			
+	0	0	0			Minutes 35 degrees Elevation	+	0	0	0		
+	0					Seconds	+	0				
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)						

+	0	0				Hours TI GET at	+	0	0			
+	0	0	0			Minutes 0 degree Elevation	+	0	0	0		
+	0					Seconds	+	0				
+	0	0				Hours T2 GET at	+	0	0			
+	0	0	0			Minutes 35 degrees Elevation	+	0	0	0		
+	0					Seconds	+	0				
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)						

NOTES:

P22–ORBITAL NAVIGATION
MARK DATA
REV 29

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P						
						Y IMU Gimbal Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

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		+	0	0			
+	0	0	0			Minutes GET		+	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		+	0	0			
+	0	0	0			Minutes GET		+	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:

P22–ORBITAL NAVIGATION

REV 30

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)							

+	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	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)							

NOTES:

P57–LUNAR SURFACE ALIGNMENT

V37 Enter, 57 Enter

V04 N06 Flashing

R1: 00001
R2: 0000X Alignment option

1–Preferred, 2–Invalid
3–REFSMMAT, 4–Landing Site

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 (Time of Alignment)	N34	+	0	0			
+	0	0	0			Minutes (Time of Alignment)		+	0	0	0		
+	0					Seconds (Time of Alignment)		+	0				
X	0	0	0	0		Alignment Mode		X	0	0	0	0	
						Gravity Error Angle (deg)							
						OG (Alignment Final ICDU Angles)	N22						
						IG (Alignment Final ICDU Angles)							
						MG (Alignment Final ICDU Angles)							
X	0	0				Star Code 1	N71	X	0	0			
						Cursor Angle (deg) (Star No. 1)	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) (Star No. 2)	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 (Gyro Torquing Angles (deg))	N93						
						Y (Gyro Torquing Angles (deg))							
						Z (Gyro Torquing Angles (deg))							
						X (Calculated Gyro Drifts (meru))							
						Y (Calculated Gyro Drifts (meru))							
						Z (Calculated Gyro Drifts (meru))							
						Latitude (deg) (Landing Site)	N89						
						Longitude/2 (deg) (Landing Site)							
						Altitude (nmi) (Landing Site)							

P22–ORBITAL NAVIGATION
MARK DATA
REV 30

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P	IMU Gimbal						
						Y	Angles (degree)						
						R							
+						Shaft	SXT Angles	+					
+						Trunnion	(degree)	+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P	IMU Gimbal						
						Y	Angles (degree)						
						R							
+						Shaft	SXT Angles	+					
+						Trunnion	(degree)	+					

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
						P	IMU Gimbal						
						Y	Angles (degree)						
						R							
+						Shaft	SXT Angles	+					
+						Trunnion	(degree)	+					

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	Time of Ascent		+	0	0	0		
+	0					Seconds			+	0				
X	0	0	0	0		Option Code		N06	X	0	0	0	0	
+	0	0				Hours		N33	+	0	0			
+	0	0	0			Minutes	Time of Ascent		+	0	0	0		
+	0					Seconds			+	0				
X	0	0	0	0		Option Code		N06	X	0	0	0	0	
+	0	0				Hours		N33	+	0	0			
+	0	0	0			Minutes	Time of Ascent		+	0	0	0		
+	0					Seconds			+	0				

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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

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)

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 Insertion (AGS)							
						231 Landing Site Radius (AGS)							

*Load 8 nmi if crossrange is greater than 8 nmi.

NOTES:

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 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	N11	+	0	0			
+	0	0	0			Minutes TIG for CSI (LGC)		+	0	0	0		
+	0					Seconds		+	0				
N55 (+00001) No. of Apsidal Crossings (+026.60) Elevation Angle (+130.00) Central Angle													
+	0	0				Hours	N37	+	0	0			
+	0	0	0			Minutes TIG for TPI (LGC)		+	0	0	0		
+	0					Seconds		+	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 ½ 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:

P57–LUNAR SURFACE ALIGNMENT

V37 Enter, 57 Enter

V04 N06 Flashing

R1: 00001
R2: 0000X Alignment option

1–Preferred, 2–Invalid
3–REFSMMAT, 4–Landing Site

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

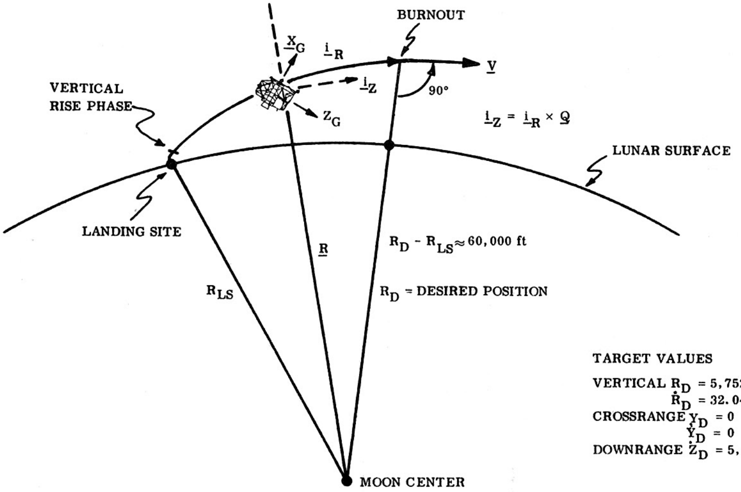
R1: 00014 Fine Align Option

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 — Time of Alignment		+	0	0	0		
+	0					Seconds		+	0				
X	0	0	0	0		Alignment Mode		X	0	0	0	0	
						Gravity Error Angle (deg)							
						OG — Alignment Final ICDU Angles	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 — Gyro Torquing Angles (deg)	N93						
						Y							
						Z							
						X — Calculated Gyro Drifts (meru)							
						Y							
						Z							
						Latitude (deg) — Landing Site	N89						
						Longitude/2 (deg)							
						Altitude (nmi)							

LUNAR ASCENT GUIDANCE (P12)



TARGET VALUES

VERTICAL R_D = 5,752,316.9 ft
$\dot{R}_D$ = 32.04 ft/s
CROSSRANGE Y_D = 0
$\dot{Y}_D$ = 0
DOWNRANGE $\dot{Z}_D$ = 5,535.62 ft/s

VERTICAL RISE: PHASE LASTS UNTIL $\dot{R} > 40$ ft/s or $h \geq 25,000$ ft

$a_{TR} = 1/\tau\,(A + [t - to]\;B) - g_{eff}$ COMMAND SPECIFIC FORCE (VERTICAL)

$a_{TY} = 1/\tau\,(C + [t - to]\;D)$ COMMAND SPECIFIC FORCE (CROSSRANGE)

$a_{TZ} = (a_T{}^2 - a_h{}^2)^{1/2}\ \mathrm{SGN}\ (\dot{Z}_D - Z)$ COMMAND SPECIFIC FORCE (DOWNRANGE)

A = PITCH ATTITUDE CONSTANT = $(-K_1 B - (\dot{R}_D - \dot{R})/L)$

B = PITCH RATE CONSTANT = $[K_2\ (\dot{R}_D - \dot{R}) - (R_D - R - \dot{R}T_{GO})]/T_{GO}E$

C = YAW ATTITUDE CONSTANT = $[-K_1 D - (\dot{Y}_D - \dot{Y})/L]$

D = YAW RATE CONSTANT = $[K_2\ (\dot{Y}_D - Y) - (Y_D - Y - \dot{Y}T_{GO})]\ /T_{GO}E$

g_{eff} = EFFECTIVE GRAVITY = $|\underline{r} \times \underline{v}|^2/r^3 - \mu_m/r^2$

WHERE

(t - to) = DELAY TERMS = 1 SECOND

Q = TARGET COORDINATE VECTOR = $(\underline{V}_C \times R_C)$ OF COMMAND MODULE

a_h = SPECIFIC FORCE IN RY PLANE

τ = MASS/MASS FLOW RATE f (THE AVERAGE OF THE LAST FOUR PIP READINGS, EXHAUST VELOCITY, PREVIOUS τ)

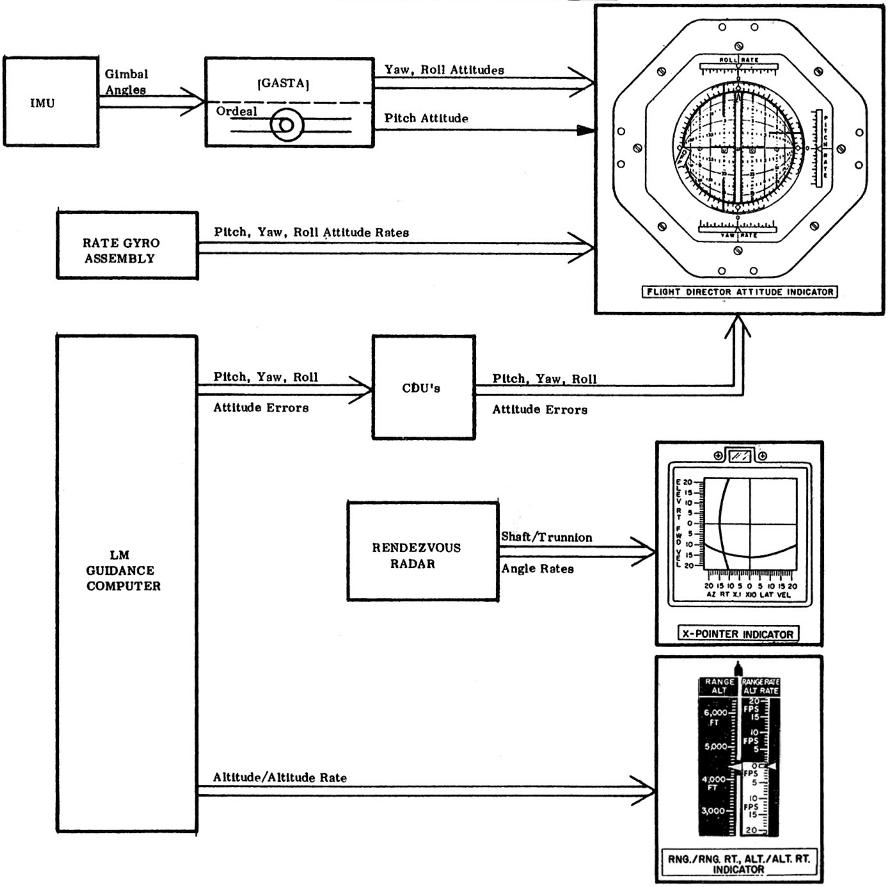
$T_{GO} \approx$ f(APS TAIL OFF, MASS/MASS FLOW RATE, EXHAUST VELOCITY, VELOCITY TO BE GAINED)

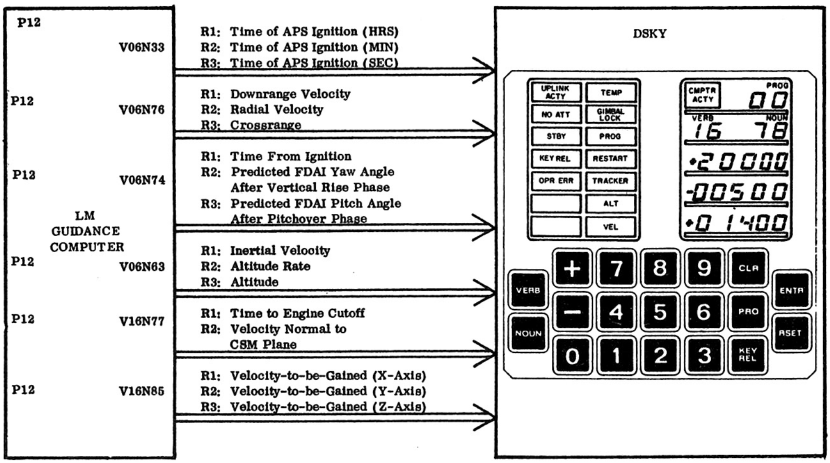
L, E, K_1, $K_2 \approx$ f (MASS/MASS FLOW RATE, EXHAUST VELOCITY, TIME TO GO)

a_T = AVAILABLE SPECIFIC FORCE

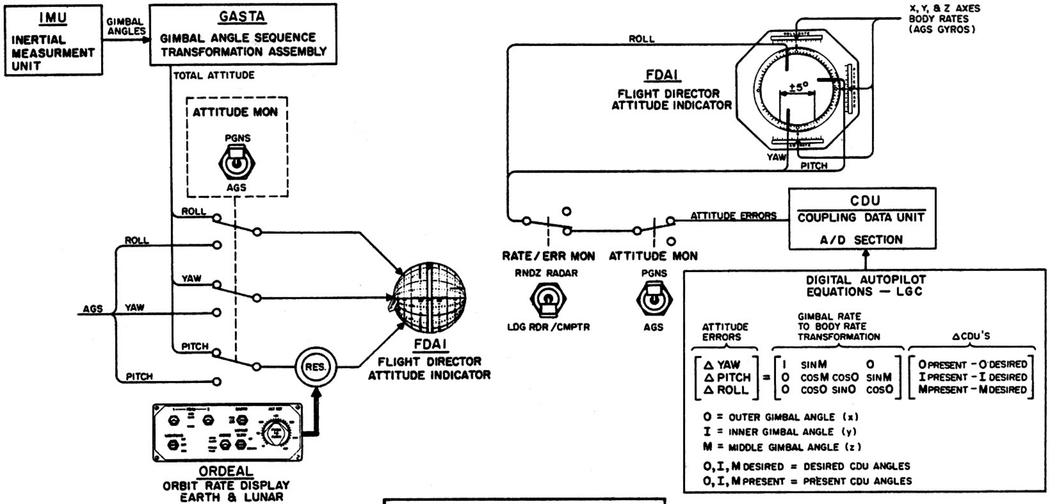
μ_m LUNAR GRAVITATIONAL CONSTANT

ASCENT DISPLAYS (P12)

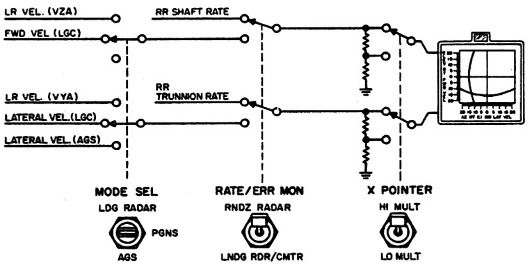




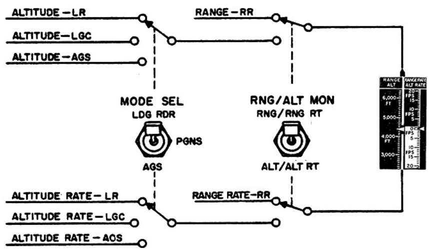
ASCENT DISPLAYS



FLIGHT DIRECTOR ATTITUDE INDICATOR

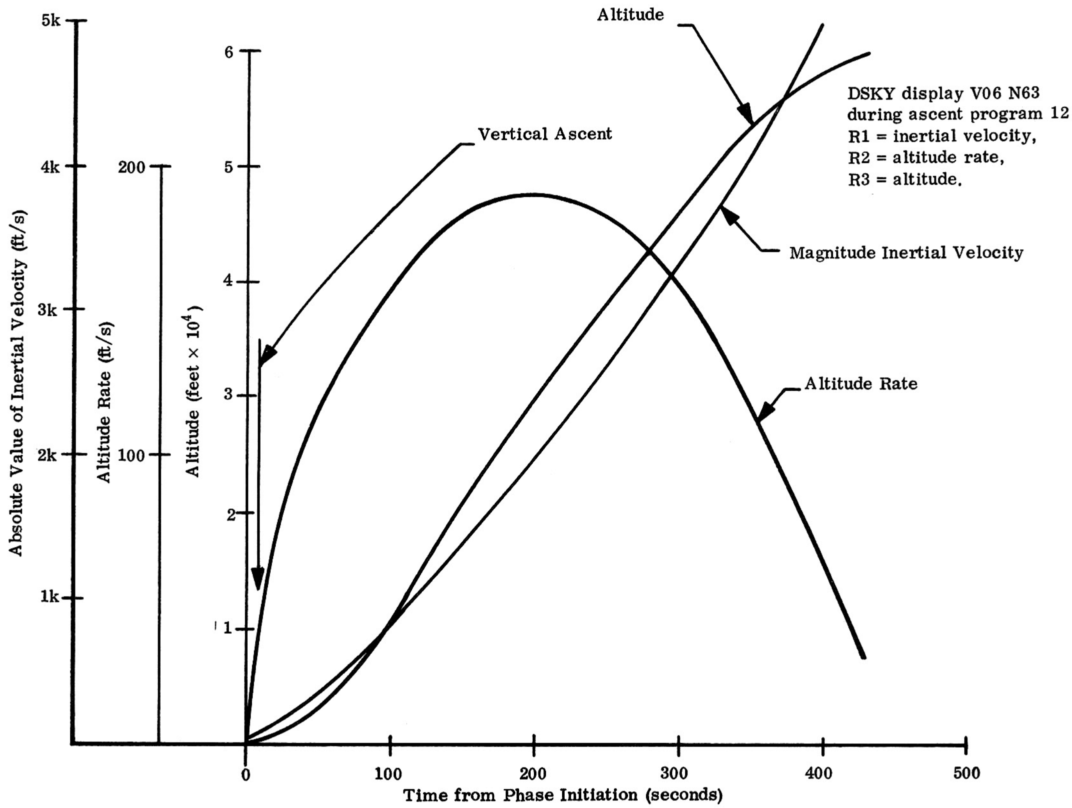


X POINTER INDICATOR



RANGE/RANGE RATE, ALTITUDE/ALTITUDE RATE INDICATOR

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 Insertion (AGS)							
						231 Landing Site Radius (AGS)							

*Load 8 nmi if crossrange is greater than 8 nmi.

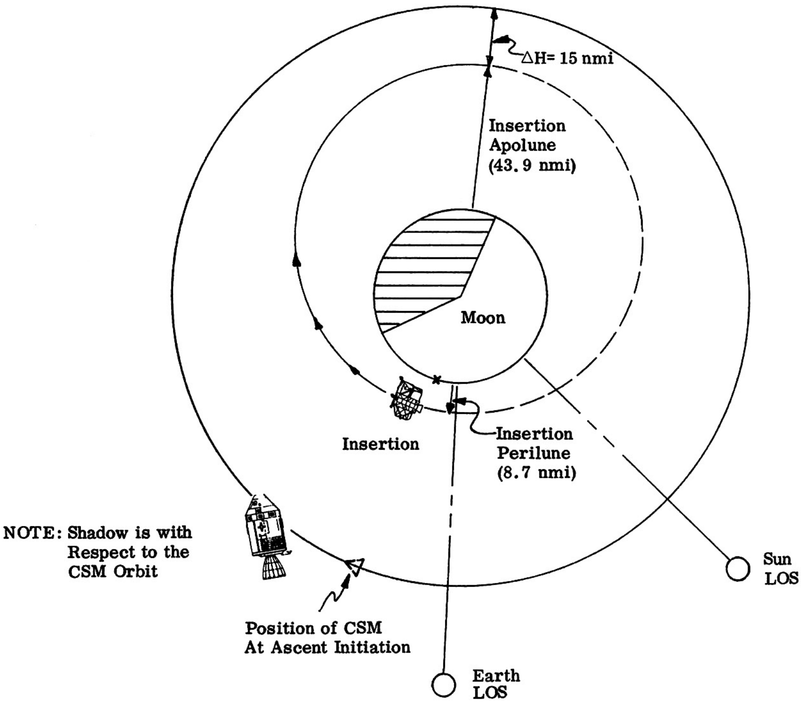
NOTES:

LM INSERTION

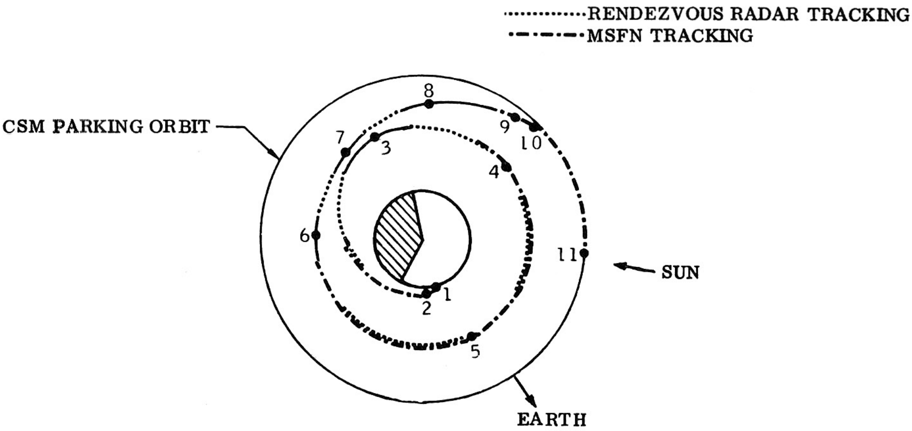
EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
INSERTION	427.3/6044.4	137:09:15.8	LM-APS/PGNS	P-12

RESIDUALS (ft/s)					+ x x	h
ΔV_x	N85		AGS	500	+ x x x	min GET
ΔV_y	PGNS			501		
ΔV_z				502	+ x	s

$V_{x_{TRIM}}$ $V_{y_{TRIM}}$ $V_{z_{TRIM}}$ (ft/s)



ORBITAL SCHEMATIC OF ASCENT THROUGH DOCKING



1. LIFT-OFF
2. LM INSERTION
3. CSI
4. PC
5. CDH
6. TPI
7. MC-1
8. MC-2
9. BEGIN BRAKING
10. BEGIN STATION-KEEPING
11. DOCKING

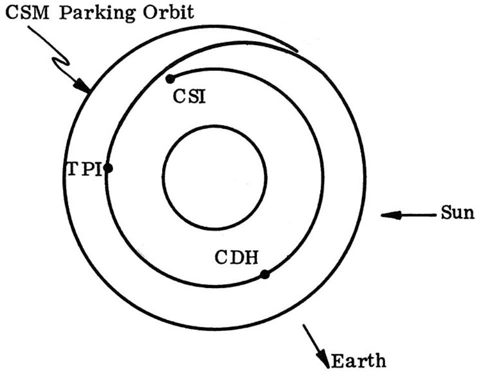
RENDEZVOUS

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),

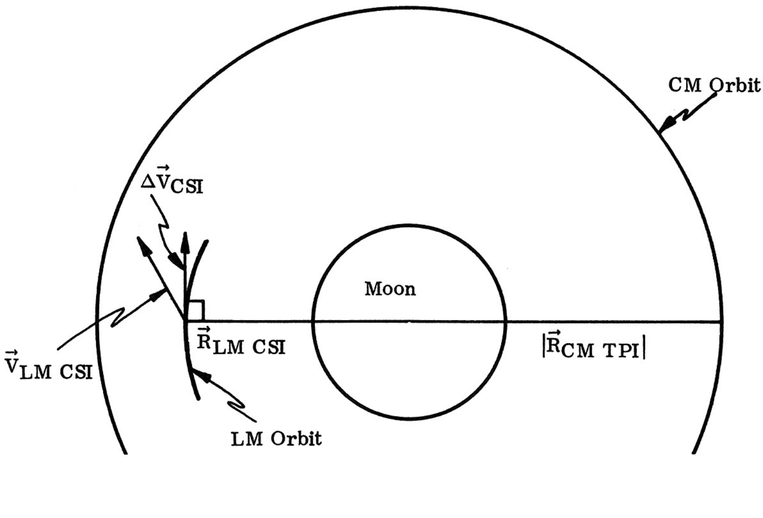
b. Constant Delta Height (CDH),

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)

$$\Delta\vec{V}_{CSI} = \left[\left(\frac{2\mu}{|\vec{R}_{LM\ CSI}| \left(\frac{|\vec{R}_{LM\ CSI}|}{|\vec{R}_{CM\ TPI}|} + 1 \right)} \right)^{1/2} - \vec{V}_{LM\ CSI} \cdot \vec{h} \right] \vec{h} \quad \text{ft/s} \qquad (1)$$

where

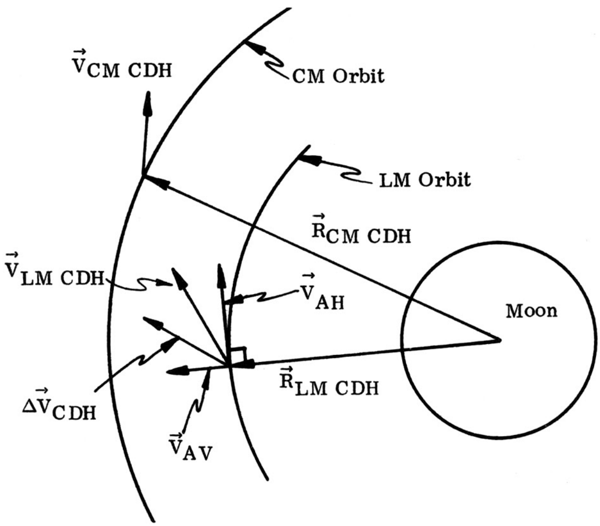
$\vec{R}_{LM\ CSI}$, $\vec{V}_{LM\ CSI}$ — position and velocity vectors for the LM at the time of the CSI maneuver (ft, ft/s).

$\vec{R}_{CM\ TPI}$ — position vector of the CM at the time of the TPI maneuver (ft).

$\vec{h}$ — unit vector normal to $\vec{R}_{LM\ CSI}$ and in the orbital plane.

$\Delta\vec{V}_{CSI}$ — impulsive ΔV required to perform the CSI maneuver (ft/s).

The initial value for $\Delta\vec{V}_{CSI}$ 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)

$$\vec{V}_{AV} = \left\{ \vec{V}_{CM\ CDH} \cdot \text{Unit}\,[\vec{R}_{CM\ CDH}] \left(\frac{a_{CM\ CDH}}{a_{LM\ CDH}} \right)^{3/2} \right\} \text{Unit}[\vec{R}_{LM\ CDH}] \quad \text{ft/s} \tag{2}$$

$$\vec{V}_{AH} = \left[\mu \left(\frac{2}{|\vec{R}_{LM\ CDH}|} - \frac{1}{a_{LM\ CDH}} \right) - |\vec{V}_{AV}|^2 \right]^{1/2} \text{Unit}\,[\vec{U} \times \vec{R}_{LM\ CDH}] \quad \text{ft/s} \tag{3}$$

$$\Delta\vec{V}_{CDH} = \vec{V}_{AH} + \vec{V}_{AV} - \vec{V}_{LM\ CDH} \quad \text{ft/s} \tag{4}$$

where

$\vec{R}_{LM\ CDH}$, $\vec{V}_{LM\ CDH}$ — position and velocity vectors of the LM at the time of CDH (ft, ft/s).

$\vec{R}_{CM\ CDH}$, $\vec{V}_{CM\ CDH}$ — position and velocity vectors of the CM at the time of CDH (ft, ft/s).

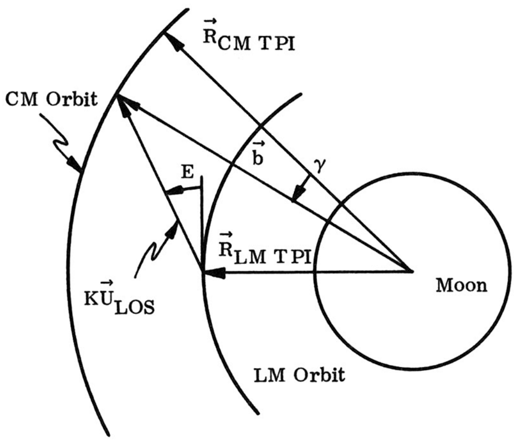
$a_{LM\ CDH}$, $a_{CM\ CDH}$ — semi-major axis of the LM and CM orbits, respectively, at the time of CDH (ft).

$\vec{V}_{AV}$, $\vec{V}_{AH}$ — 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)

$$\vec{b} = \vec{R}_{LM\ TPI} + K\vec{U}_{LOS} \quad \text{ft} \qquad (5)$$

$$\gamma = \cos^{-1} \left[\text{Unit } (\vec{b} \cdot \vec{R}_{CM\ TPI})\right] \text{Sign } \left[\vec{U} \cdot (\vec{b} \times \vec{R}_{CM\ TPI})\right] \quad \text{radians} \qquad (6)$$

where

$\vec{R}_{LM\ TPI}$, $\vec{R}_{CM\ TPI}$ — 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

$$K^2 + 2K\, \vec{R}_{LM\ TPI} \cdot \vec{U}_{LOS} + (|\vec{R}_{LM\ TPI}|^2 - |\vec{R}_{CM\ TPI}|^2) = 0$$

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).

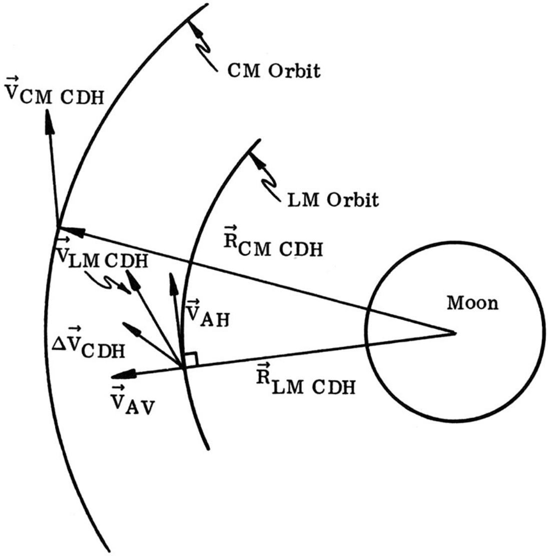
The angle γ indicates the adequacy of the CSI and CDH solutions. If γ is not near zero, a perturbation of $\Delta\vec{V}_{CSI}$ is made and Equations 2 - 6 are executed again. This procedure will continue until γ is sufficiently small.

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)



$$\vec{V}_{AV} = \left\{ \vec{V}_{CM\ CDH} \cdot \text{Unit}\ [\vec{R}_{CM\ CDH}] \left(\frac{a_{CM\ CDH}}{a_{LM\ CDH}} \right)^{3/2} \right\} \text{Unit}\ [\vec{R}_{LM\ CDH}] \quad \text{ft/s}$$

$$\vec{V}_{AH} = \left[\mu \left(\frac{2}{|\vec{R}_{LM\ CDH}|} - \frac{1}{a_{LM\ CDH}} \right) - |\vec{V}_{AV}|^2 \right]^{1/2} \text{Unit}\ [\vec{U} \times \vec{R}_{LM\ CDH}] \quad \text{ft/s}$$

$$\Delta\vec{V}_{CDH} = \vec{V}_{AH} + \vec{V}_{AV} - \vec{V}_{LM\ CDH} \quad \text{ft/s}$$

where

$\vec{R}_{LM\ CDH}$, $\vec{V}_{LM\ CDH}$ — position and velocity vectors of the LM at the time of CDH (ft, ft/s).

$\vec{R}_{CM\ CDH}$, $\vec{V}_{CM\ CDH}$ — position and velocity vectors of the CM at the time of CDH (ft, ft/s).

$a_{LM\ CDH}$, $a_{CM\ CDH}$ — semi-major axis of the LM and CM orbits, respectively, at the time of CDH (ft).

RENDEZVOUS (CONTINUED)

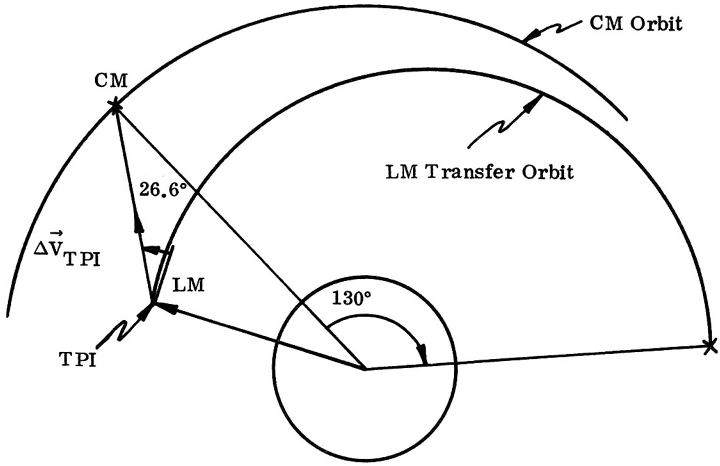
$\vec{V}_{AV}$, $\vec{V}_{AH}$ — desired vertical and horizontal velocities, respectively, of the LM after completion of the CDH maneuver (ft/s).

$\vec{U}$ — unit vector normal to the orbital plane and in the direction of the angular momentum vector of the CM.

$\Delta\vec{V}_{CDH}$ — impulsive ΔV required to perform the CDH maneuvers (ft/s).

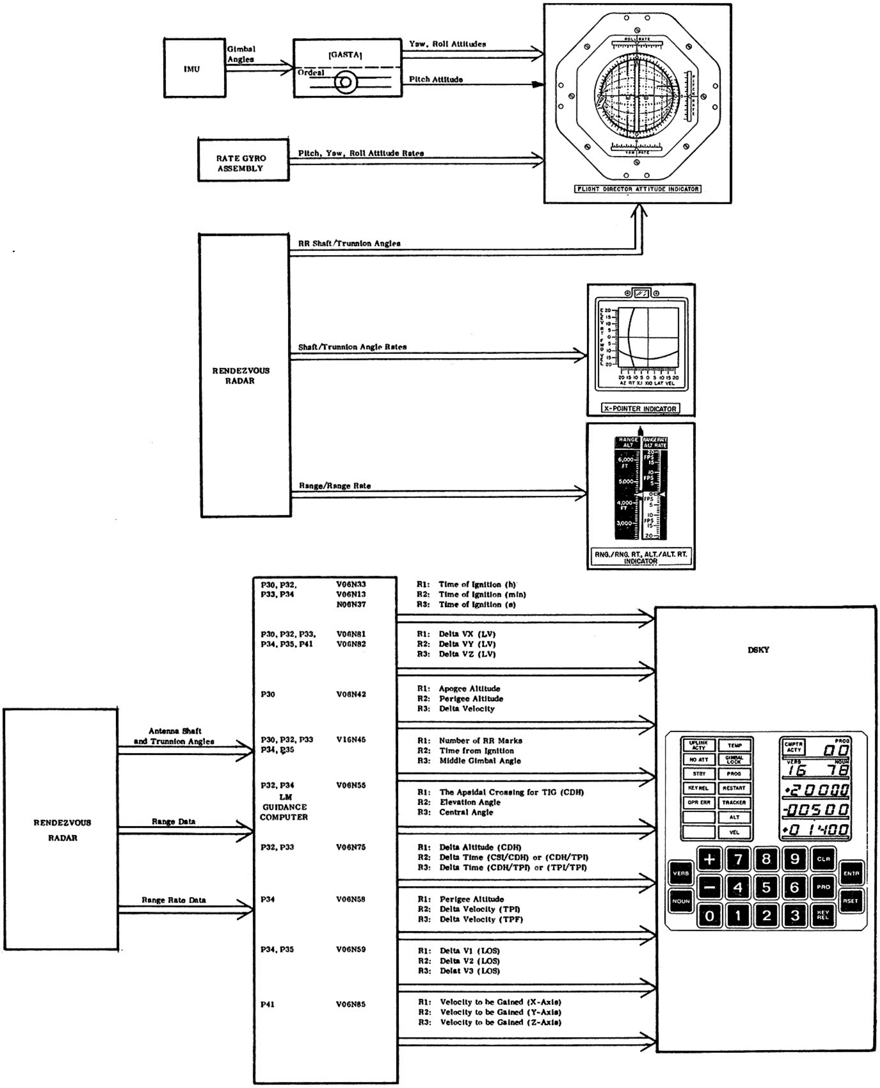
The $\Delta\vec{V}_{CDH}$ is added impulsively to the LM velocity vector. The CDH targeting program then advances the state of both the LM and CM until a time is found at which the geometry requirements of the TPI maneuver are satisfied. This time is stored as TIG_{TPI} and the CDH targeting program 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 $\Delta\vec{V}_{TPI}$ is calculated and the program is terminated.

RENDEZVOUS DISPLAYS



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			+	0	0			
+	0	0	0			Minutes	GET		+	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			+	0	0			
+	0	0	0			Minutes	GET		+	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								

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				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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:

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 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	CSI (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	TPI (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 ½ 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

N75		
ΔH	CSI/CDH	CDH/TPI
•	••	••
•	••	••
•	••	••

N81		
Δ VX CSI		YDOT N90 / CSI
•		
•	(-)	•
•	(-)	•

N82		
Δ VX CDH	ΔVY CDH	ΔVZ CDH
•	•	•
•	•	•
•	•	•

AGS

402	372	267/450
ΔH	CSI-CDH	ΔVG (CSI)

263	371
Y DOT CSI	Δ V 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

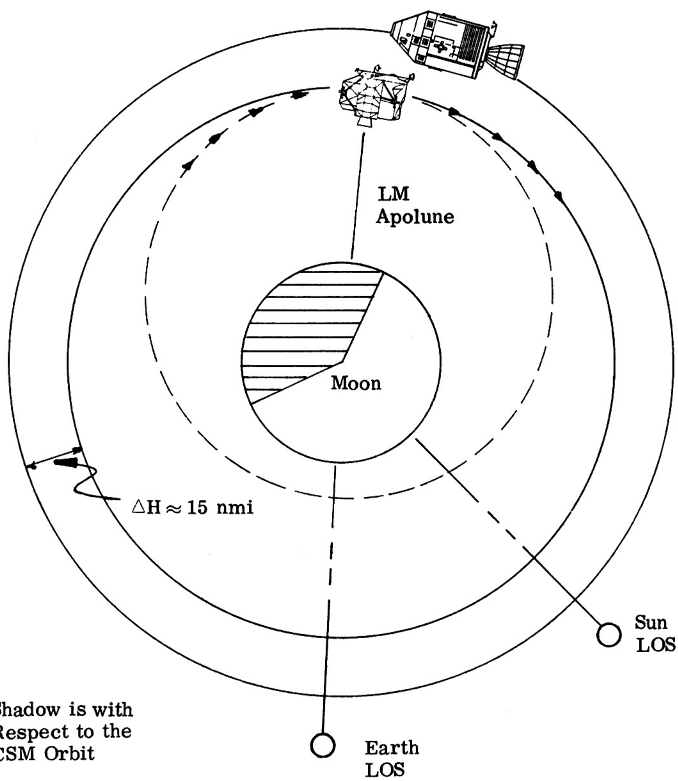
COMPARE:
1. PGNS vs CMC
2. PGNS vs AGS
3. CMC vs AGS
4. CMC vs Charts
5. V90 < 2 ft/s – no burn

COELLIPTIC SEQUENCE INITIATION

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
CSI (POSIGRADE)	44.4/49.6	138:06:00.9	LM-RCS/PGNS EXT ΔV (P-41)	P-32

RESIDUALS (ft/s)							
ΔV_x	N85	_ _ _ . _	AGS	500	_ _ _ . _	+ x x _ _ _ .	h
ΔV_y	PGNS	_ _ _ . _		501	_ _ _ . _	+ x x x _ .	min GET
ΔV_z		_ _ _ . _		502	_ _ _ . _	+ x _ _ . _	s

— — —.— $V_{x_{TRIM}}$ — — —.— $V_{y_{TRIM}}$ — — —.— $V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

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)							
+						H_{Apogee}	N42	+					
						$H_{Perigee}$ (nmi)							
+						ΔVR (ft/s)		+					
X	X	X				BT (min:s)		X	X	X			
X	X	X				R FDAI Inertial Angles		X	X	X			
X	X	X				P (degrees)		X	X	X			
						ΔV_X AGS	N86						
						ΔV_Y Targeting (ft/s)							
						ΔV_Z							
X	X	X				COAS Star		X	X	X			
X	X					COAS Az (degrees)		X	X				
X	X	X				COAS EL (degrees)		X	X	X			

NOTES:

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								

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

ΔH(CDH), ΔT(TPI-CDH), ΔT(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 compuation)

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

ΔH	ΔT TPI/CDH	TPI SLIP
•	:	:
•	:	:
•	:	:

N81

ΔVX	YDOT N90 CDH	ΔVZ
•		•
•	(-) •	•
•	(-) •	•

CSM SOLUTION (change sign)

ΔVX	ΔVY	ΔVZ
•	•	•

N86 (AGS)

ΔVX	ΔVY	ΔVZ
•	•	•

AGS

402 ΔH	450 ΔVX	452 ΔVZ

263 ΔVY (CDH)	270 ΔVY (NOW)

BURN RULES

CRITERIA: $\dot{X}$ = 2 ft/s and $\dot{Z}$ = 6 ft/s

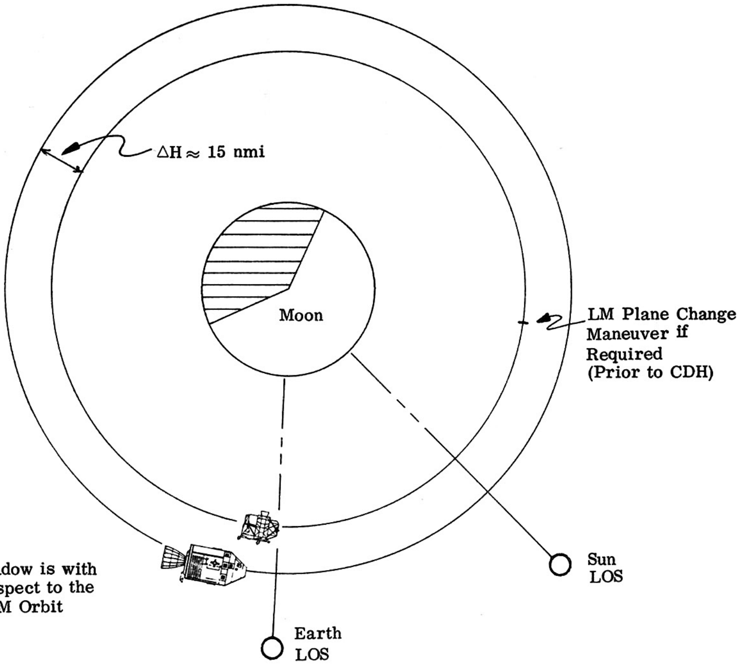
COMPARE:
1. PGNS vs CMC
2. PGNS vs AGS
3. CMC vs AGS
4. CMC vs Charts
5. If all above fail, burn CMC solution.
6. V90 < 2 ft/s – no burn.

CONSTANT DELTA HEIGHT

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
CDH	NOMINALLY ZERO	139:04:14.1	LM-RCS/PGNS EXT ΔV (P-41)	P-33

RESIDUALS (ft/s)								
ΔV_x	N85	_ _ _ . _	AGS	500	_ _ _ . _	+ x x _ _ _ .	h	GET
ΔV_y	PGNS	_ _ _ . _		501	_ _ _ . _	+ x x x _ _ .	min	
ΔV_z		_ _ _ . _		502	_ _ _ . _	+ x _ _ . _	s	

— — —•— $V_{x_{TRIM}}$ — — —•— $V_{y_{TRIM}}$ — — —•— $V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

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			

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 — TIG of TPI	N37	+	0	0			
+	0	0	0			Minutes — TIG of TPI		+	0	0	0		
+	0					Seconds — TIG of TPI		+	0				
N55 (+00000) Conic Integration, (+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

N58

HP	ΔV TPI	ΔV TPF

N81

ΔVX	ΔVY	ΔVZ
	N90	

N59

ΔVF +/A-	ΔVR +/L-	ΔVD +/U-

AGS

373
TIG TPI

267 ΔV TPI	ΔV	371 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 AGS
3. CMC vs AGS
4. CMC vs Charts
5. If all above fail, burn CMC solution

If TIG TPI $\geq$8 minutes early, recycle P32 with TIG equal to nominal TIG - 8 minutes.

TRANSFER PHASE INITIATION

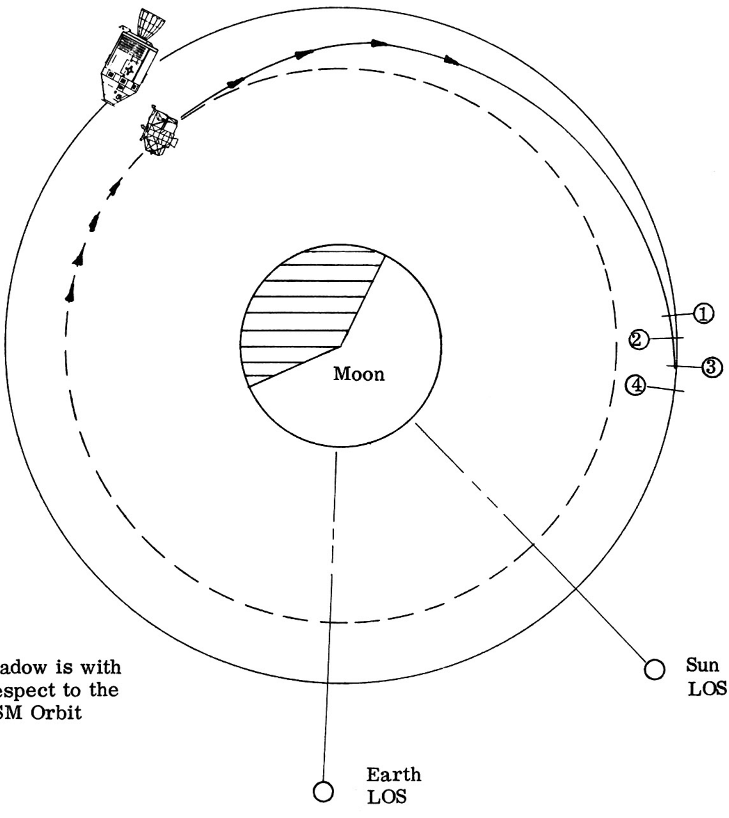
EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
TPI (ALONG 26.6° LOS)	$22.1/_{24.8}$	139:45:13.8	LM-RCS/PGNS LAMBERT (P-41)	P-34

RESIDUALS (ft/s)					
ΔV_x	N85 PGNS		AGS	500	
ΔV_y				501	
ΔV_z				502	

+ x x	h	
+ x x x	min	GET
+ x	s	

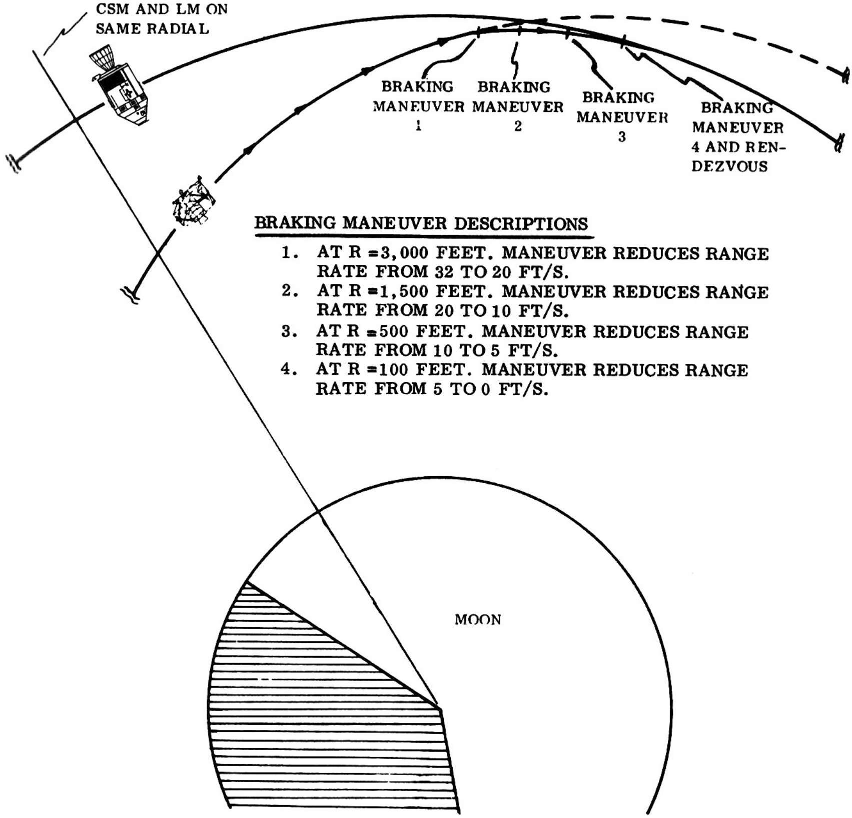
— — — •— $V_{x_{TRIM}}$ — — — •— $V_{y_{TRIM}}$ — — — •— $V_{z_{TRIM}}$ (ft/s)

1. First Braking Maneuver
2. Second Braking Maneuver
3. Third Braking Maneuver
4. Fourth Braking Maneuver



NOTE: Shadow is with Respect to the CSM Orbit

LM RENDEZVOUS FINAL PHASE



BRAKING MANEUVER DESCRIPTIONS

1. AT R =3,000 FEET. MANEUVER REDUCES RANGE RATE FROM 32 TO 20 FT/S.
2. AT R =1,500 FEET. MANEUVER REDUCES RANGE RATE FROM 20 TO 10 FT/S.
3. AT R =500 FEET. MANEUVER REDUCES RANGE RATE FROM 10 TO 5 FT/S.
4. AT R =100 FEET. MANEUVER REDUCES RANGE RATE FROM 5 TO 0 FT/S.

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	X	X				R		X	X	X			
X	X	X				P IMU Gimbal Angles (degrees)		X	X	X			
X	X	X				Y		X	X	X			
X	X	X				BT (min:s)		X	X	X			
						VI (ft/s)							
						X	N83						
						Y ΔV ft/s							
						Z							
						V ft/s	N62						
						HDOT ft/s							
						H nmi							

NOTES:

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)							
+						H_{Apogee}	N42	+					
						$H_{Perigee}$ (nmi)							
+						ΔVR (ft/s)		+					
X	X	X				BT (min:s)		X	X	X			
X	X	X				R FDAI Inertial Angles		X	X	X			
X	X	X				P (degrees)		X	X	X			
						ΔV_X AGS	N86						
						ΔV_Y Targeting (ft/s)							
						ΔV_Z							
X	X	X				COAS Star		X	X	X			
X	X					COAS Az (degrees)		X	X				
X	X	X				COAS EL (degrees)		X	X	X			

NOTES:

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	X	X				R		X	X	X			
X	X	X				P IMU Gimbal Angles (degrees)		X	X	X			
X	X	X				Y		X	X	X			
X	X	X				BT (min:s)		X	X	X			
						VI (ft/s)							
						X	N83						
						Y ΔV ft/s							
						Z							
						V ft/s	N62						
						HDOT ft/s							
						H nmi							

NOTES:

P30–EXTERNAL ΔV

TEI 40

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				Y_{Trim} (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			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		X	X	X			
						ULLAGE							

P42—APS THRUSTING LM

V37 Enter, 42 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 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 Residuals (ft/s)	
		Y	
		Z	
	85	X TRIM (ft/s)	
		Y	
		Z	
	44	HA (nmi)	
		HP (nmi)	
		TFF (min:s)	

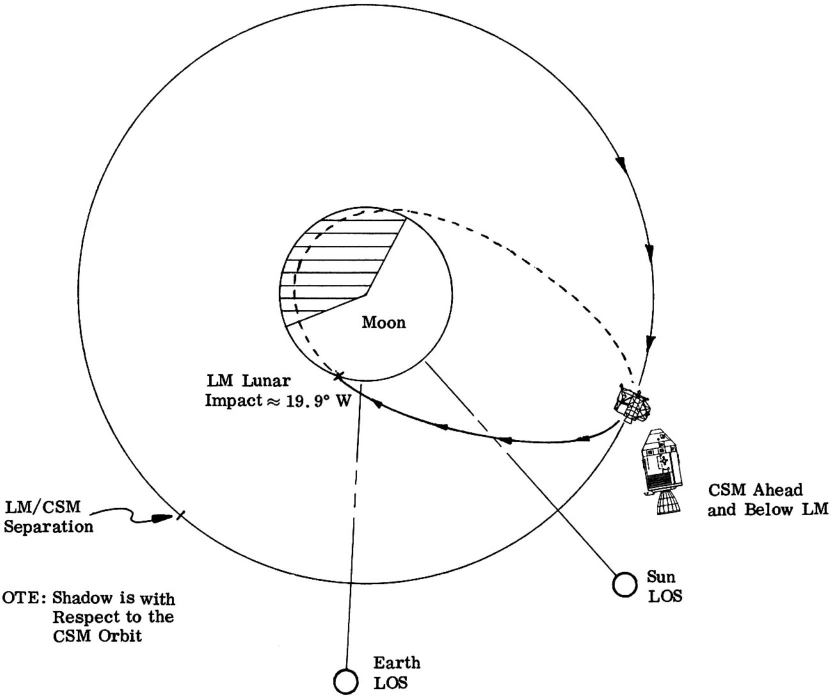
LM LUNAR IMPACT

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
LM LUNAR IMPACT MANEUVER (RETROGRADE)	75.2/185.5	144:32:20.2	LM-RCS/PGNS EXT ΔV (P-42)	P-30

RESIDUALS (ft/s)					
ΔV_x	N85 PGNS	.	AGS	500	.
ΔV_y		.		501	.
ΔV_z		.		502	.

+	x	x			.	h	GET
+	x	x	x		.	min	
+	x		.			s	

— — —•— $V_{x_{TRIM}}$ — — —•— $V_{y_{TRIM}}$ — — —•— $V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

P30–EXTERNAL ΔV

PLANE CHANGE & TEI 42

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} (degrees)	N48		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 IMU Gimbal Angles (deg)		X	X	X			
X	X	X				P		X	X	X			
X	X	X				Y		X	X	X			
+						H_{Apogee} nmi	N44	+					
						$H_{Perigee}$							
+						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		
+					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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		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	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:

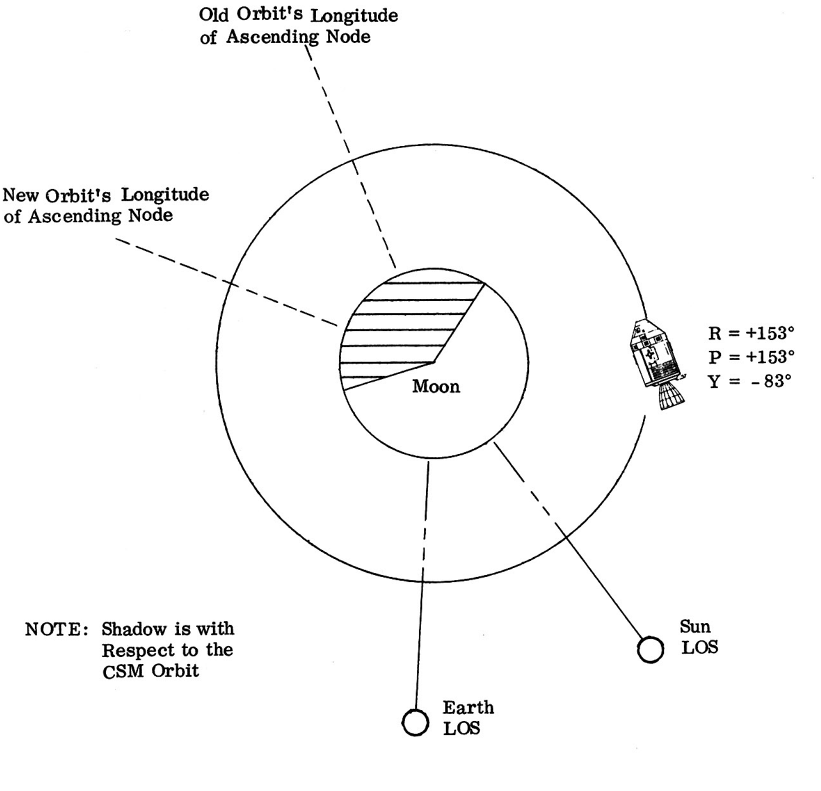
P40 – SPS THRUSTING CSM

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	Residuals (ft/s)	
		Y		
		Z		
	85	X	TRIM (ft/s)	
		Y		
		Z		
	44	HA (nmi)		
		HP (nmi)		
		TFF (min:s)		

LUNAR ORBIT PLANE CHANGE - 2

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
LOPC-2	43.0/824.6	154:13:10.8	SPS/G & N EXT ΔV (P-40)	P-32
	ΔV_x N85		+ x x	h
	ΔV_y RESIDUALS (ft/s)		+ x x x	min GET
	ΔV_z (BODY AXIS)		+ x	s
— — — . — $V_{x_{TRIM}}$		— — — . — $V_{y_{TRIM}}$		— — — . — $V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

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 GET		+	0	0	0		
+	0					Seconds GET		+	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 GET		+	0	0	0		
+	0					Seconds GET		+	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:

P30–EXTERNAL ΔV
TEI 44 & 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				P_{Trim}	N48		0	0			
	0	0				Y_{Trim} (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			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		X	X	X			
						ULLAGE							

NOTES:

P22–ORBITAL NAVIGATION

REV 44

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)							

+	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	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)							

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 GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours GET		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P22–ORBITAL NAVIGATION
MARK DATA
REV 44

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

NOTES:

P22–ORBITAL NAVIGATION

REV 45

V32 Enter, 22 Enter

V06 N45 Flashing, R3: Middle Gimbal Angle

V05 N70 Flashing, R2: A B 0 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	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)									

+	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	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)									

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				GET Hours		+	0	0			
+	0	0	0			GET Minutes		+	0	0	0		
+	0					GET 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						
						Gyro Torquing Angles (degrees) X	N93						
						Gyro Torquing Angles (degrees) Y							
						Gyro Torquing Angles (degrees) Z							
						Calculated Gyro Drift (meru) X							
						Calculated Gyro Drift (meru) Y							
						Calculated Gyro Drift (meru) Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				GET Hours		+	0	0			
+	0	0	0			GET Minutes		+	0	0	0		
+	0					GET 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						
						Gyro Torquing Angles (degrees) X	N93						
						Gyro Torquing Angles (degrees) Y							
						Gyro Torquing Angles (degrees) Z							
						Calculated Gyro Drift (meru) X							
						Calculated Gyro Drift (meru) Y							
						Calculated Gyro Drift (meru) Z							

NOTES:

P22–ORBITAL NAVIGATION
MARK DATA
REV 45

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

+	0	0				Hours	+	0	0			
+	0	0	0			Minutes GET	+	0	0	0		
+	0					Seconds	+	0				
						P IMU Gimbal						
						Y Angles (degree)						
						R						
+						Shaft SXT Angles	+					
+						Trunnion (degree)	+					

NOTES:

P30–EXTERNAL ΔV
TEI 46 (PRELIMINARY) & TEI 46 (NOMINAL)

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} (degrees) N48		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 IMU Gimbal Angles (deg)	X	X	X			
X	X	X				P	X	X	X			
X	X	X				Y	X	X	X			
+						H_{Apogee} nmi N44	+					
						$H_{Perigee}$						
+						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		
+					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				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 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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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:

P30–EXTERNAL ΔV
TEI 47

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GETI

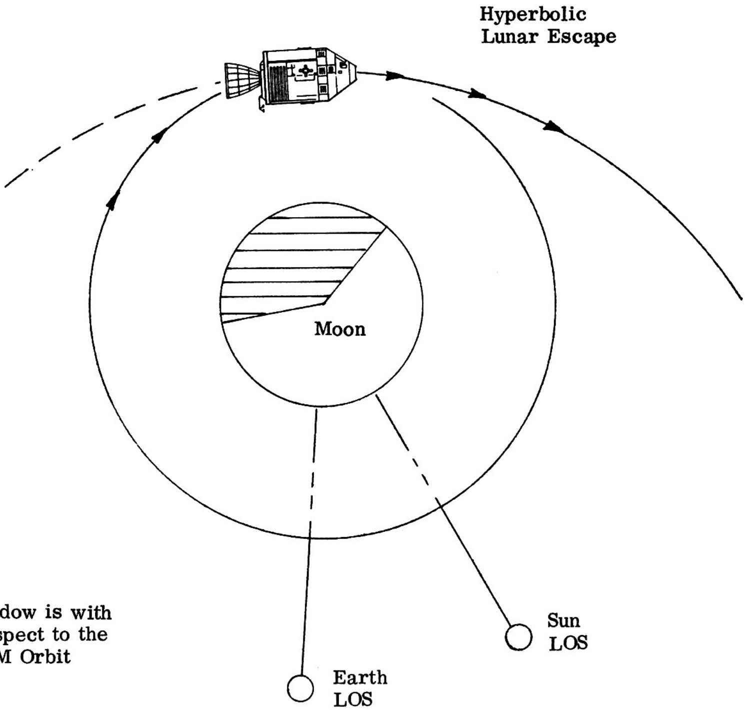
V06 N81 Flashing, Load Desired ΔV

						Purpose								
		/				Prop/Guidance				/				
+						Weight (lb)	N47	+						
	0	0				P_{Trim} (degrees)	N48		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} nmi	N44	+						
						$H_{Perigee}$								
+						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			
+					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				R_{Align}		X	X	X				
X	X	X				P_{Align}		X	X	X				
X	X	X				Y_{Align}		X	X	X				
						ULLAGE								

NOTES:

TRANSEARTH INJECTION

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
TEI (POSIGRADE)	135.0/3147.7	167:28:58.3	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
$V_{x_{TRIM}}$		$V_{y_{TRIM}}$		$V_{z_{TRIM}}$ (ft/s)



NOTE: Shadow is with Respect to the CSM Orbit

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		+	0	0			
+	0	0	0			Minutes	GET	+	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	N93						
						Y Gyro Torquing Angles (degrees)							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	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	N93						
						Y Gyro Torquing Angles (degrees)							
						Z							
						X							
						Y Calculated Gyro Drift (meru)							
						Z							

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
X	X					R IMU		X	X				
X	X					P Gimbal Angles		X	X				
X	X					Y (degree)		X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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			+	0	0			
+	0	0	0			Minutes	GET		+	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			+	0	0			
+	0	0	0			Minutes	GET		+	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:

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				P_{Trim} N48		0	0			
	0	0				Y_{Trim} (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			
+						H_{Apogee} N44	+					
						$H_{Perigee}$ 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				R_{Align}	X	X	X			
X	X	X				P_{Align}	X	X	X			
X	X	X				Y_{Align}	X	X	X			
						ULLAGE						

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

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
						06-40	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)

						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

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes			+	0	0	0		
+	0					Seconds			+	0				
X	X					R	IMU Gimbal Angles (degree)		X	X				
X	X					P			X	X				
X	X					Y			X	X				
+						Pos Err (ft) W Matrix		V67	+					
+						Vel Err (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
						Celestial		N88						
						Body								
						Vector								
+						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

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes			+	0	0	0		
+	0					Seconds			+	0				
X	X					R	IMU Gimbal Angles (degree)		X	X				
X	X					P			X	X				
X	X					Y			X	X				
+						Pos Err (ft)	W Matrix	V67	+					
+						Vel Err (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
						Celestial		N88						
						Body								
						Vector								
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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
- 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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
X	X					R IMU		X	X				
X	X					P Gimbal Angles		X	X				
X	X					Y (degree)		X	X				
+						Pos Err (ft)	V67	+					
+						W Matrix Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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**

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU	X	X				
X	X					P	Gimbal Angles	X	X				
X	X					Y	(degree)	X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft)	V67	+					
						W Matrix							
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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
V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0				
+	0	0	0			Minutes	GET	+	0	0	0			
+	0					Seconds		+	0					
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	+						

MIDCOURSE NAVIGATION

+	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		X	X					
X	X					Y	(degree)		X	X					
+						Pos Err (ft)	W Matrix	V67	+						
+						Vel Err (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
						Celestial		N88							
						Body									
						Vector									
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours } GET		+	0	0			
+	0	0	0			Minutes } GET		+	0	0	0		
+	0					Seconds } GET		+	0				
X	X					R IMU Gimbal Angles (degree)		X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft)	V67	+					
						W Matrix							
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P23—CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter
V06 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

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
X	X					R IMU		X	X				
X	X					P Gimbal Angles		X	X				
X	X					Y (degree)		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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 (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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 (GET)		+	0	0	0		
+	0					Seconds (GET)		+	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:

P23—CISLUNAR MIDCOURSE NAVIGATION

V37 Enter, 23 Enter
V06 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**

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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
- 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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0				
+	0	0	0			Minutes	GET	+	0	0	0			
+	0					Seconds		+	0					
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	+						

MIDCOURSE NAVIGATION

+	0	0				Hours	GET		+	0	0				
+	0	0	0			Minutes	GET		+	0	0	0			
+	0					Seconds	GET		+	0					
X	X					R	IMU Gimbal Angles (degree)		X	X					
X	X					P	IMU Gimbal Angles (degree)		X	X					
X	X					Y	IMU Gimbal Angles (degree)		X	X					
+						Pos Err (ft)	W Matrix	V67	+						
+						Vel Err (ft/s)	W Matrix		+						
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	
						Celestial		N88							
						Body									
						Vector									
+						Trun Angle Degrees		N92 R2	+						
						ΔR nmi		N49							
						ΔV ft/s									

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours } GET		+	0	0			
+	0	0	0			Minutes } GET		+	0	0	0		
+	0					Seconds } GET		+	0				
X	X					R IMU Gimbal Angles (degree)		X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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
- **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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours } GET		+	0	0			
+	0	0	0			Minutes } GET		+	0	0	0		
+	0					Seconds } GET		+	0				
X	X					R IMU Gimbal Angles (degree)		X	X				
X	X					P IMU Gimbal Angles (degree)		X	X				
X	X					Y IMU Gimbal Angles (degree)		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (ft/s) W Matrix		+					
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
						Celestial Body Vector	N88						
						Celestial Body Vector							
						Celestial Body Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0				
+	0	0	0			Minutes	GET	+	0	0	0			
+	0					Seconds		+	0					
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	+						

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0					Seconds		+	0					
X	X					R	IMU Gimbal Angles (degree)	X	X					
X	X					P		X	X					
X	X					Y		X	X					
+						Pos Err (ft)	V67	+						
+						W Matrix Vel Err (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	
						Celestial	N88							
						Body								
						Vector								
+						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

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R IMU Gimbal Angles (degree)		X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						Trun Angle Degrees	N92 R2	+					
						ΔR nmi	N49						
						ΔV ft/s							

NOTES:

P30–EXTERNAL ΔV

MCC 6

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} (degrees)	N48		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 IMU Gimbal Angles (deg)		X	X	X				
X	X	X				P		X	X	X				
X	X	X				Y		X	X	X				
+						H_{Apogee} nmi	N44	+						
						$H_{Perigee}$								
+						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			
+					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				R_{Align}		X	X	X				
X	X	X				P_{Align}		X	X	X				
X	X	X				Y_{Align}		X	X	X				
						ULLAGE								

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			
	+						V_{400K} N60	+					
	-	0	0				γ_{400K}	—	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		

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			+	0	0				
+	0	0	0			Minutes	GET		+	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		N93							
						Y	Gyro Torquing Angles (degrees)								
						Z									
						X									
						Y	Calculated Gyro Drift (meru)								
						Z									

X	0	0	0	0		P52 Option			X	0	0	0	0		
+	0	0				Hours			+	0	0				
+	0	0	0			Minutes	GET		+	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		N93							
						Y	Gyro Torquing Angles (degrees)								
						Z									
						X									
						Y	Calculated Gyro Drift (meru)								
						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
			X			06-40	TFI (min:s)
							VG (ft/s)
							ΔVM (ft/s)
			X			06-40	TFC (min:s)
							VG (ft/s)
							ΔVM (ft/s)
			X			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)
			X				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	

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes			+	0	0	0		
+	0					Seconds			+	0				
X	X					R	IMU Gimbal Angles (degree)		X	X				
X	X					P			X	X				
X	X					Y			X	X				
+						Pos Err (ft) W Matrix		V67	+					
+						Vel Err (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
						Celestial		N88						
						Body								
						Vector								
+						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

V59 Flashing, Perform Optics Calibration
V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU	X	X				
X	X					P	Gimbal Angles	X	X				
X	X					Y	(degree)	X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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 } GET		+	0	0			
+	0	0	0			Minutes } GET		+	0	0	0		
+	0					Seconds } GET		+	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 } Gyro Torquing Angles (degrees)							
						Z } Gyro Torquing Angles (degrees)							
						X } Calculated Gyro Drift (meru)							
						Y } Calculated Gyro Drift (meru)							
						Z } Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours } GET		+	0	0			
+	0	0	0			Minutes } GET		+	0	0	0		
+	0					Seconds } GET		+	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 } Gyro Torquing Angles (degrees)							
						Z } Gyro Torquing Angles (degrees)							
						X } Calculated Gyro Drift (meru)							
						Y } Calculated Gyro Drift (meru)							
						Z } Calculated Gyro Drift (meru)							

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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0					Seconds		+	0				
X	X					R	IMU Gimbal Angles (degree)	X	X				
X	X					P		X	X				
X	X					Y		X	X				
+						Pos Err (ft) W Matrix	V67	+					
+						Vel Err (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
						Celestial	N88						
						Body							
						Vector							
+						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

V59 Flashing, Perform Optics Calibration

V51 Flashing - Please Mark

OPTICS CALIBRATION

+	0	0				Hours		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds		+	0				
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	+					

MIDCOURSE NAVIGATION

+	0	0				Hours	GET		+	0	0			
+	0	0	0			Minutes			+	0	0	0		
+	0					Seconds			+	0				
X	X					R	IMU Gimbal Angles (degree)		X	X				
X	X					P			X	X				
X	X					Y			X	X				
+						Pos Err (ft)	W Matrix	V67	+					
+						Vel Err (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
						Celestial		N88						
						Body								
						Vector								
+						Trun Angle Degrees		N92 R2	+					
						ΔR nmi		N49						
						ΔV ft/s								

NOTES:

P30–EXTERNAL ΔV
MCC 7

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				Y_{Trim} (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			
+						H_{Apogee}	N44	+					
						$H_{Perigee}$ 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				R_{Align}		X	X	X			
X	X	X				P_{Align}		X	X	X			
X	X	X				Y_{Align}		X	X	X			
						ULLAGE							

NOTES:

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 El-17		X	X	X			
		0					Lat	N61		0				
							Long							
	X	X	X				Max g		X	X	X			
	+						V_{400K}	N60	+					
	-	0	0				γ_{400K}		—	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 El-2		+					0
	+				0	0	TRN		+				0	0
	X	X	X				BSS		X	X	X			
	X	X					SPA El-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 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 GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours GET		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						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

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	
			X			06-40	TFI (min:s)	
							VG (ft/s)	
							ΔVM (ft/s)	
			X			06-40	TFC (min:s)	
							VG (ft/s)	
							ΔVM (ft/s)	
			X			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)	
			X				TFF (min:s)	

						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 GET		+	0	0	0		
+	0					Seconds GET		+	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 Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

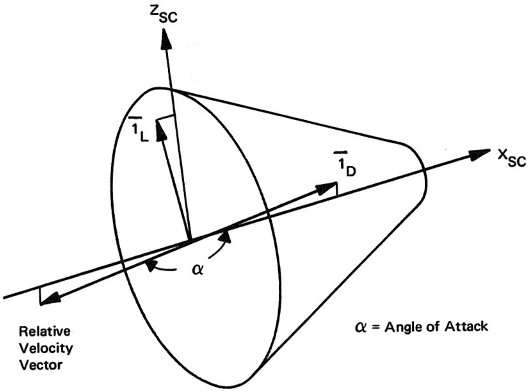
X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours GET		+	0	0			
+	0	0	0			Minutes GET		+	0	0	0		
+	0					Seconds GET		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						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:

$$\overline{D} = \tfrac{1}{2} \frac{SC_D}{M} \rho v^2 \, \overline{1}_D (\text{ft/s}^2)$$

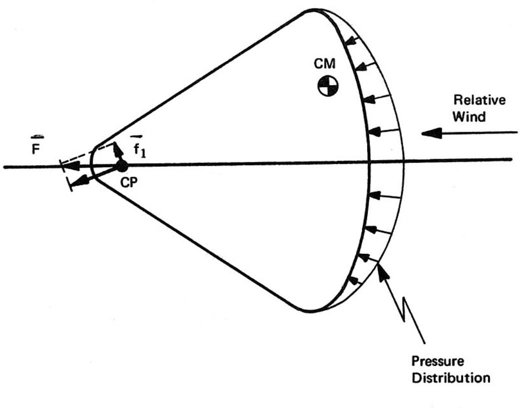
Lift is a force perpendicular to the relative velocity vector and equal to;

$$\overline{L} = \tfrac{1}{2} \frac{SC_L}{M} \rho v^2 \, \overline{1}_L (\text{ft/s}^2)$$

where,

ρ = Atmospheric density (slugs/ft^3)[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 (ft^2)

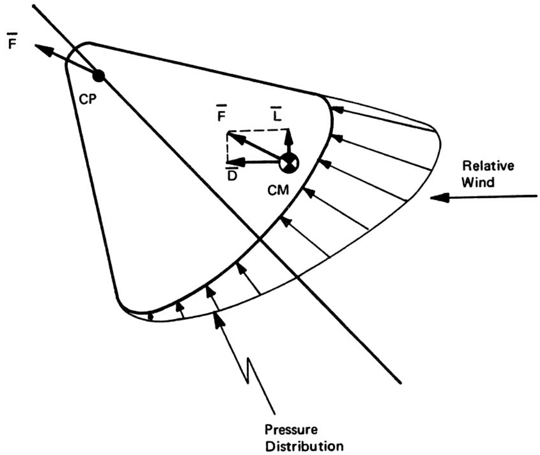
Aerodynamic lift (or C_L) is a consequence of the vehicle center-of-mass (CM)[2] being offset from its axis of symmetry. With the relative velocity vector along the axis of symmetry, the resulting symmetrical pressure distribution produces a resultant force ($\overline{F}$) through the center-of-pressure (CP)[3]. The component of this force ($\overline{f}_1$) 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 $\overline{F}$ is fully along the line joining the CM and CP.



Notes:

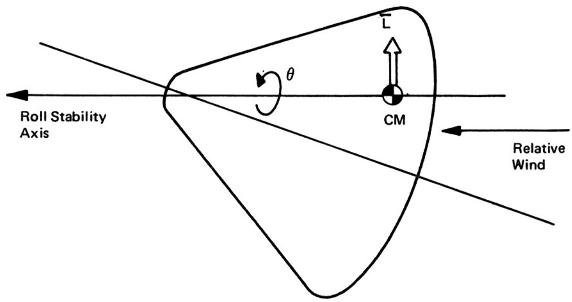
1. A slug is a constant, relating units in the equation
   F(pound-force) = M(slugs) x a(ft/s^2)
2. Center-of-mass: The point where the mass of a body may be regarded as being concentrated, insofar as motion of translation is concerned.
3. Center-of-pressure: The point where the resultant of all aerodynamic forces apparently operates.

In this stable attitude, the component of $\overline{F}$ 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.

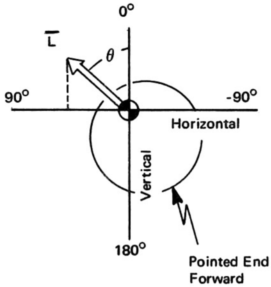


Lift Modulated Entry

During earth entry, steering is accomplished by orienting the lift vector ($\overline{L}$) 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.

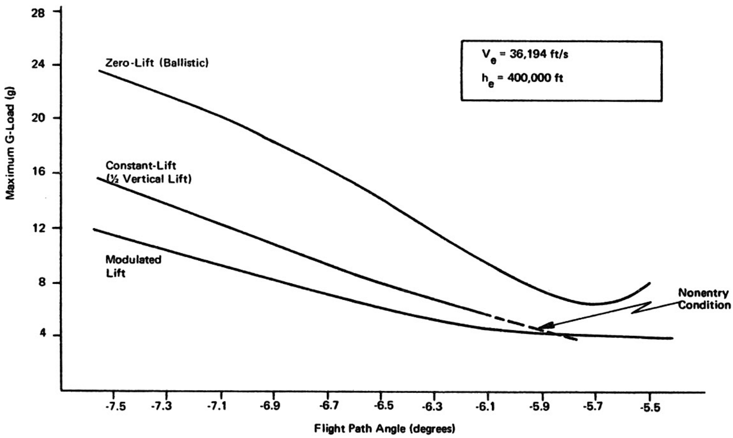


A roll angle (θ) of 0 degrees causes the lift vector to be up along the vertical and produces maximum downrange flight. A roll angle of ±90 degrees puts the lift vector in the local horizontal plane, producing maximum crossrange (or lateral) flight.

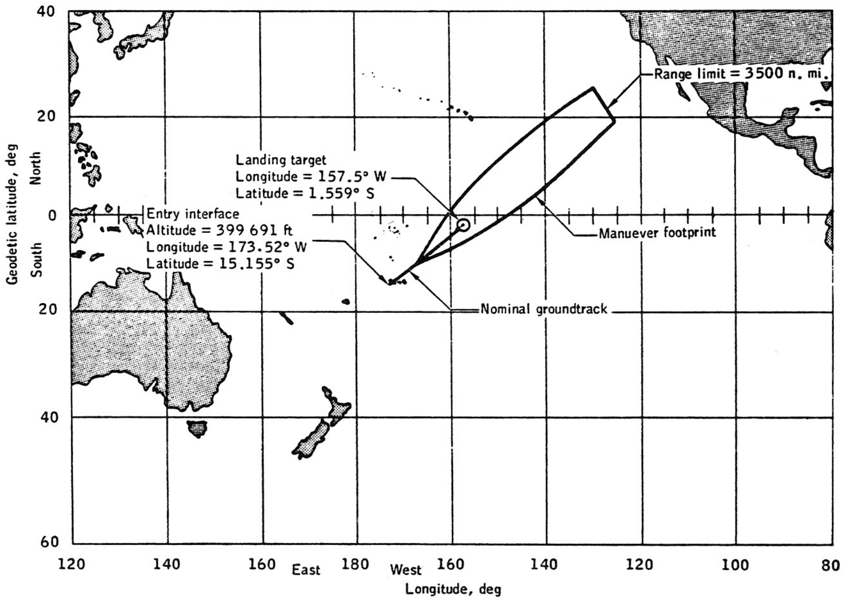


The entry control programs are designed to calculate the roll angle (θ) which will produce the vertical component of lift necessary to satisfy a guidance objective (constant drag flight, downrange target acquisition, and so forth). Crossrange control is maintained by choosing the proper sign of roll angle in order to reduce lateral errors.

Lift modulated flight can significantly reduce the peak accelerations experienced during entry, as shown below.



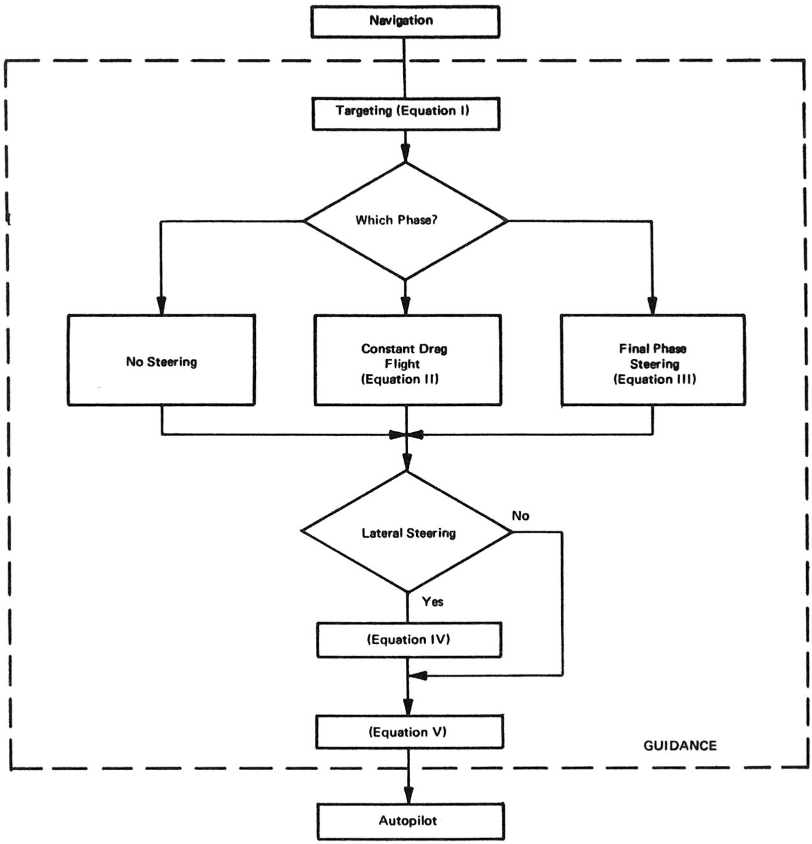
The maneuver footprint for the Apollo Command Module utilizing modulated lift is approximately 2,500 nautical miles in downrange and 250 nautical miles in crossrange. A typical entry footprint for a lunar return mission is shown below.



Entry Control Equations

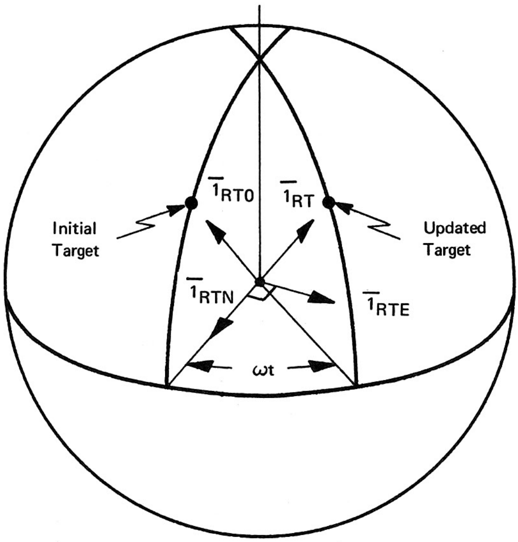
The entry guidance equations are solved every 2 seconds in the AGC. Navigation and autopilot functions are also performed during this computation cycle.

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 ($\overline{1}_{RT0}$), together with unit vectors in the equatorial plane directed easterly ($\overline{1}_{RTE}$) and in the target meridian ($\overline{1}_{RTN}$), is used as a reference from which a new target vector ($\overline{1}_{RT}$) is calculated based on an updated estimate of time-to-splash.



$$\overline{1}_{RT} = \overline{1}_{RTO} + \overline{1}_{RTN}\,[\cos(\omega t) - 1] + \overline{1}_{RTE}\sin(\omega t)$$

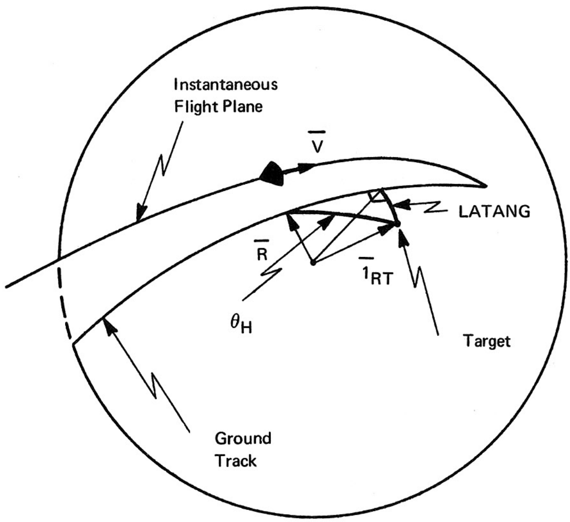
where (ωt) is the amount of earth's rotation for the difference between the old and new estimate of time-to-splash.

Based upon the new target vector $(\overline{1}_{RT})$, the downrange angle from the spacecraft to the splash point is computed using:

$$\theta_H = \arccos\left\{\overline{1}_{RT} \cdot \text{Unit } \overline{R}\right\} \text{(radians)}$$

The crossrange error from the present flight plane is calculated as follows:

$$\text{LATANG} = \overline{1}_{RT} \cdot \text{Unit } (\overline{V} \times \overline{R}) \quad \text{(radians)}$$



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 refrence parameters are computed using the following constant drag relationships.

$$(L/D)_{Ref} = -\left(\frac{V^2}{R} - g\right)\frac{1}{D_0} \text{ (unitless)}$$

$$\dot{R}_{Ref} = \frac{2D_0}{\beta V} \text{ (ft/s)}$$

$$D_{Ref} = D_0 \text{ (ft/s}^2\text{)}$$

where

V = velocity (ft/s)

R = radial distance (ft)

g = gravity (ft/s^2)

D_0 = desired drag level (ft/s^2)

β = constant associated with atmosphere $\left(\frac{1}{ft}\right)$

Gain factors were chosen which relate perturbations in drag and altitude rate to the reference L/D.

$$(L/D)_{control} = (L/D)_{Ref} + 0.01\,(D - D_{Ref}) - 0.002\,(\dot{R} - \dot{R}_{Ref})$$

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:

$$(L/D)_{control} = (L/D)_{Ref} + K_1\left\{(R - R_{Ref}) + K_2\,(D - D_{Ref}) + K_3\,(\dot{R} - \dot{R}_{Ref})\right\}$$

where

$(L/D)_{Ref}$ = constant value ($\approx$0.27)

R_{Ref} = reference range-to-go (radians)

D_{Ref} = reference drag (ft/s^2)

$\dot{R}_{Ref}$ = 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 (radians/ft/s^2)

K_3 = sensitivity of range to deviations in altitude rate (radians/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

$$\text{ROLLC} = (\text{K2ROLL}) \text{ arc-cos} \left[\frac{L/D_{control}}{L/D_{Ref}} \right] \quad \text{(degrees)}$$

where

$$L/D_{Ref} \simeq 0.3 \text{ (unitless)}$$

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

V06N60

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 R2 — AIG R3 — AMG	Desired final gimbal angles at EI

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 ($\approx$ 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 1,250 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

a. Purpose: Steer through the dense portion of atmosphere and achieve the planned splash point.

b. Initiation: P67 is entered automatically from P64 for the nominal lunar return entry.

c. 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:

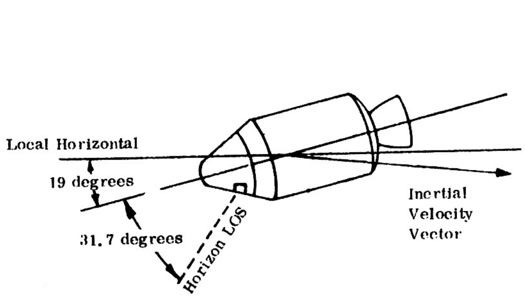
V06N66

R1 – BETA	Commanded roll angle
R2 – XRNGERR	Crossrange error
R3 – DWNRGER	Downrange error

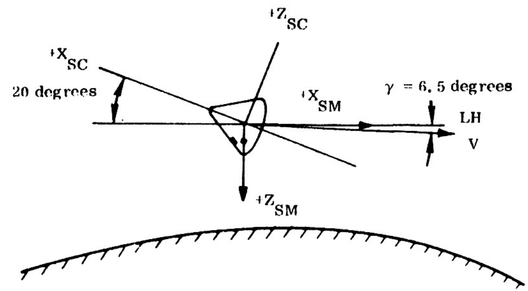
V16N67

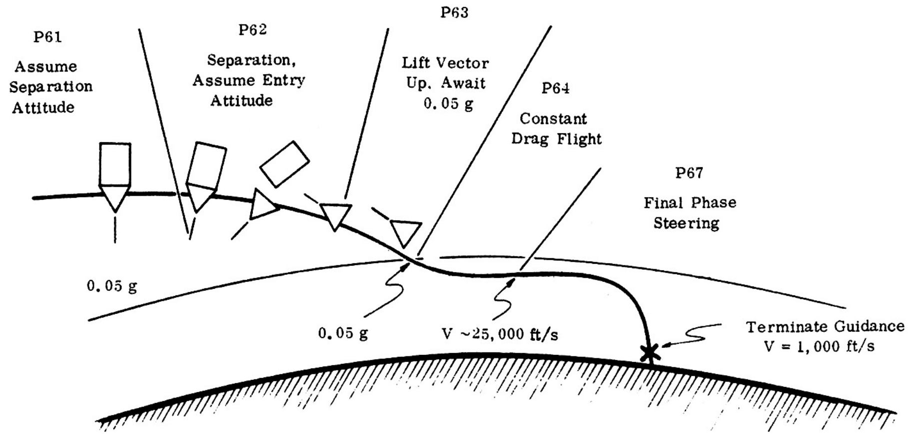
R1 – RTOGO	Range to target
R2 – LAT	Present latitude
R3 – LONG	Present longitude

TYPICAL CM/SM SEPARATION ATTITUDE



TYPICAL ATTITUDE AT ALTITUDE OF 400,000 FEET





TYPICAL ENTRY PROGRAM SEQUENCE OF EVENTS

APOLLO MISSION SPLASH POINT SUMMARY

Mission	Planned Target		Final DSKY Reading		Total DSKY Δ Error Nmi	Ship Splash Report		Total Recovery Ship Reported Error Nmi	Best-Estimate Trajectory (BET) Report		Total (official) Error Nmi	Remarks
	North Lat	West Long	North Lat	West Long		North Lat	West Long		North Lat	West Long		
Apollo 7	27.61	64.17	27.63	64.18	1.3	27.54	64.07	7.3	27.64	64.15	2.1	Earth Orbital
Apollo 8	8.13	165.03	8.10	165.01	2.1	8.12	165.02	0.9	8.1	165.01	2.3	Lunar Return
Apollo 9	23.25	68.00	23.26	68.01	0.8	23.21	67.94	4.3	23.22	67.98	2.1	Earth Orbital
Apollo 10	15.07	164.67	15.07	164.65	1.2	15.03	164.65	2.7	15.06	164.65	1.3	Lunar Return
Apollo 11	13.25	169.15	13.30	169.15	1.2	13.25	169.15	4.2	*	*	1.0*	Lunar Return
Apollo 12	15.81	165.17	15.87	165.16	3.6	15.78	165.15	2.2	15.83	165.17	1.1	Lunar Return

*Onboard data lost during entry - miss distance is best estimate

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

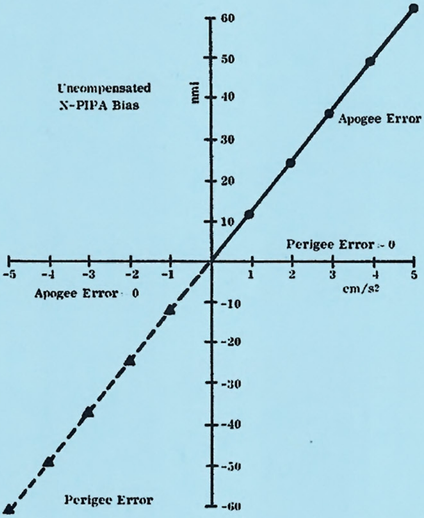
							Area							
	X	X	X				R 0.05 g		X	X	X			
	X	X	X				P 0.05 g		X	X	X			
	X	X	X				Y 0.05 g		X	X	X			
							GET Hor Ck							
	X	X	X				P EI-17		X	X	X			
		0					Lat	N61		0				
							Long							
	X	X	X				Max g		X	X	X			
	+						V_{400K}	N60	+					
	-	0	0				γ_{400K}		−	0	0			
	+						RTGO EMS		+					
	+						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		

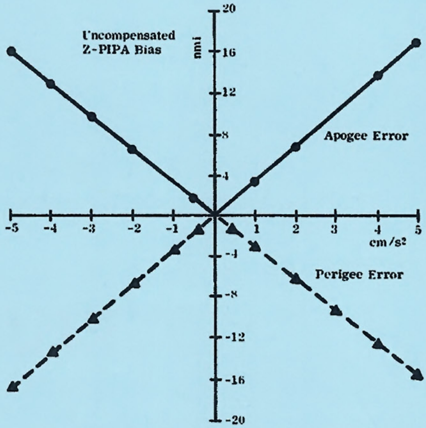
AREA	XXX	Splashdown Area Defined by Target Line.
R .05G P .05G Y .05G	XXX (deg) XXX (deg) XXX (deg)	Spacecraft IMU Gimbal Angles Required for Aerodynamic Trim at 0.05 g
GET (HOR CK)	XX:XX:XX (h:min:s)	Time of Entry Attitude Horizon Check at EI -17 Minutes.
P (HOR CK)	XXX (deg)	Pitch Attitude for Horizon Check at EI -17 Minutes.
LAT	±XX.XX (deg)	Latitude of Target Point.
LONG	±XXX.XX (deg)	Longitude of Target Point.
MAX G	XX.X (g)	Predicted Maximum Reentry Acceleration.
V_{400K}	XXXXX (ft/s)	Inertial Velocity at Entry Interface.
γ_{400K}	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 Corroidor.

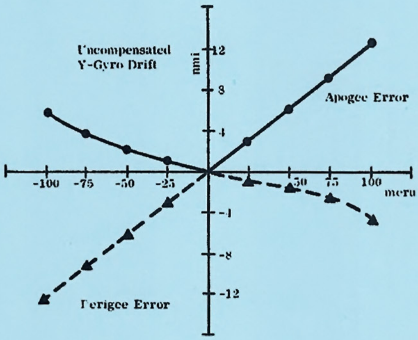
PERTURBATIONS

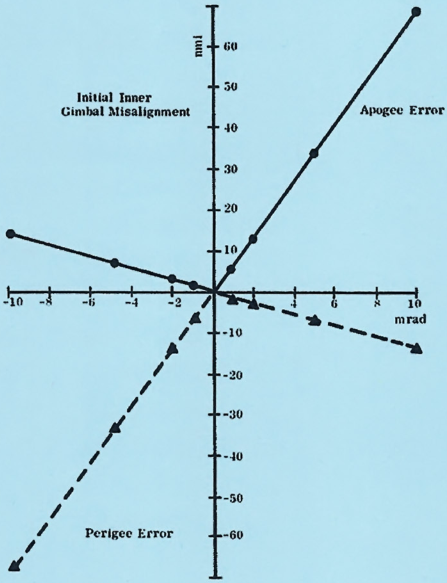
BOOST MONITOR
TLI
LUNAR ORBIT
LM DESCENT
LM ASCENT
TEI
ENTRY

BOOST MONITOR ERRORS
(Significant IMU Errors Only)





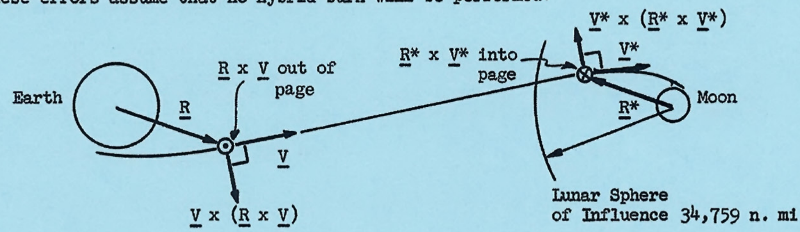




ERRORS IN PERICYNTHION
DUE TO VELOCITY ERRORS DURING TRANSLUNAR COAST

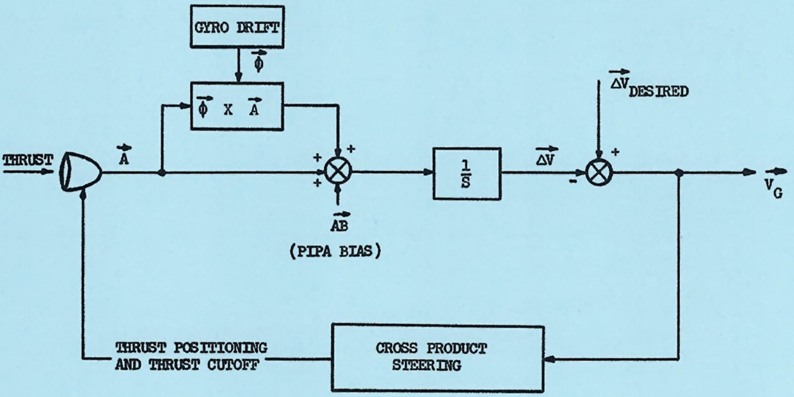
DIRECTION OF VELOCITY ERROR	ERROR IN PERICYNTHION (nmi/ft/s)
ERROR EXISTING AT TLI CUTOFF**	(02:40:49 GET)
Along V	109.77
Along R x V	0.11
Along V x (R x V)	-5.99
ERROR EXISTING AT MCC-1 (TLI + 9 hours)**	(11:40:49 GET)
Along V	32.94
Along R x V	1.54
Along V x (R x V)	-14.23
ERROR EXISTING AT HYBRID CUTOFF (TLI + 28 hours)	(30:40:51.2 GET)
Along V	18.86
Along R x V	1.22
Along V x (R x V)	-10.92
ERROR EXISTING AT MCC-3 (LOI - 22 hours)	(55:24:52.9 GET)
Along V	9.03
Along R x V	0.68
Along V x (R x V)	-5.21
ERROR EXISTING AT MCC-4 (LOI - 5 hours)	(72:24:52.9 GET)
Along V*	0.34
Along R* x V*	0
Along V* x (R* x V*)	2.75

* R and V are with respect to moon centered inertial system.
** These errors assume that no hybrid burn will be performed.



EFFECT OF INSTRUMENT ERRORS ON THRUST GUIDANCE

The thrust guidance used on Apollo, in simplified form, is as follows



The above steering loop attemps 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 ($V_{Residuals}$ = 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

$$\Delta V_X = \frac{5.0 \text{ n mi}}{-.68 \text{ n mi/ft/sec}} = -7.35 \text{ ft/sec}$$

3. The weighting factors relating instrument errors to velocity errors yield

$$-0.73 \times 10^{-2}\ AB_X \times 52.8 - 3.20 \times 10^{-2}\ AB_Z \times 52.8 = -7.35 \text{ ft/sec}$$

$$-0.38\ AB_X - 1.69\ AB_Z = -7.35 \text{ ft/sec}$$

Therefore:

Uncompensated AB_X = +19.3 cm/sec^2 assuming AB_Z = 0

Uncompensated AB_Z = +4.3 cm/sec^2 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:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S/C\ CSM} = \left[R_X\,(-7.25°)\right]\left[SM\text{-}NB\right]\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}$$

where:

$\left[SM\text{-}NB\right]$ = Transformation from stable member to the nav base using gimbal angles

$\left[R_X\,(-7.25°)\right]$ = 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

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S/C\ LM} = \left[SM\text{-}NB\right]\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}$$

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	0	272	357
DOI	0	283	0
CIRCULARIZATION	0	111	0
LOPC-1	0	0	0
LM CSI	0	270	0
LM TPI	0	269	0
LOPC-2	0	0	0
TEI	180	0	0

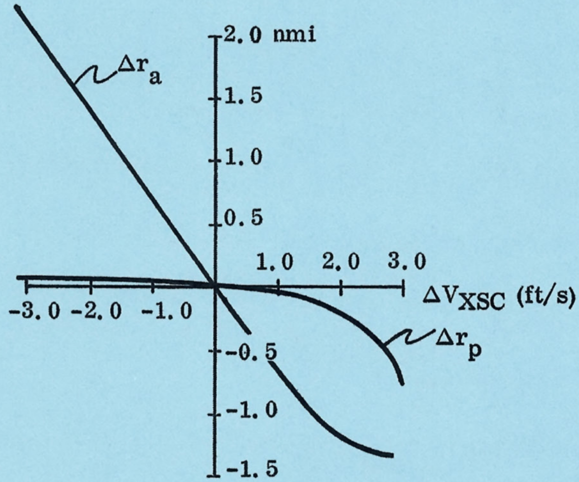
For all maneuvers thrust is assumed along $+X_{S/C}$ axis with the exceptions of the CSI and TPI maneuvers where thrust was assumed along the $+Z_{S/C}$ axis.

APOLLO 13 LUNAR ORBIT MANEUVER PERTURBATIONS

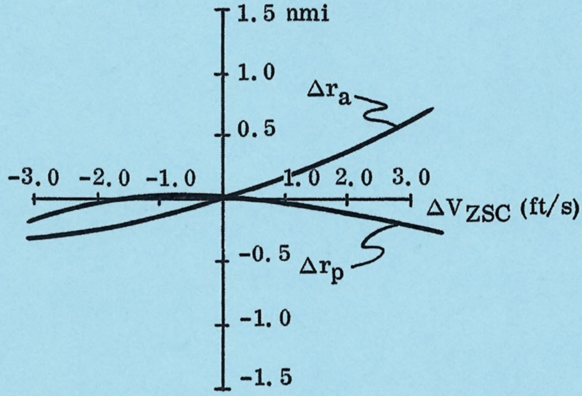
MANEUVER	BODY AXES VELOCITY ERRORS	ERROR IN PERIGEE (nmi/ft/s)	ERROR IN APOGEE (nmi/ft/s)	STABLE MEMBER TO SPACECRAFT CONTROL AXES TRANSFORMATION [SC] = [M] [SM]			[SM] = [REFSMMAT] [BRS], REFSMMAT; BRS = BASIC REFERENCE SYSTEM				
LOI	ΔV_X	—	-0.84	0.038	-0.049	0.998	0.580	-0.727	-0.367		Lunar
	ΔV_Y	—	—	0.133	0.990	0.043	-0.010	-0.457	0.889	=	Landing
	ΔV_Z	—	-0.08	-0.990	0.131	0.044	-0.815	-0.512	-0.272		Site
DOI	ΔV_X	-0.68	—	0.223	-0.007	0.975					
	ΔV_Y	—	—	0.123	0.992	-0.021	Same as Above				
	ΔV_Z	-0.11	—	-0.967	0.124	0.222					
CSM Circularization	ΔV_X	0.32	0.41	-0.358	-0.024	-0.933					
	ΔV_Y	—	—	-0.127	0.992	0.023	Same as Above				
	ΔV_Z	0.13	-0.24	0.925	0.126	-0.358					
LOPC-1	ΔV_X	—	—	1	0	0	-0.006	-0.503	0.864		
	ΔV_Y	-0.07	-0.67	0	1	0	0.980	0.169	0.105	=	Preferred
	ΔV_Z	-0.12	—	0	0	1	-0.199	0.848	0.492		
CSI*	ΔV_X	Graph A	Graph A	0	0	1	0.806	-0.519	-0.285		
	ΔV_Y	—	—	0	1	0	0.026	-0.450	0.892	=	Lunar Liftoff
	ΔV_Z	Graph B	Graph B	1	0	0	-0.591	-0.727	-0.349		
TPI*	ΔV_X	—	-0.30	-0.023	0	0.999					
	ΔV_Y	—	—	0	1	0	Same as Above				
	ΔV_Z	—	0.67	-0.999	0	-0.023					
LOPC-2	ΔV_X	—	—	1	0	0	-0.123	0.502	-0.856		
	ΔV_Y	—	0.74	0	0.992	-0.126	0.985	-0.042	-0.166	=	Preferred
	ΔV_Z	—	0.08	0	0.126	0.992	-0.119	-0.864	-0.489		
TEI	ΔV_X	—	—	1	0	0	0.085	0.586	0.806		
	ΔV_Y	—	—	0	-0.992	0.126	0.159	-0.807	0.569	=	Preferred
	ΔV_Z	—	—	0	-0.126	-0.992	0.984	0.080	-0.162		

*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 13 CSI Maneuver Apogee and Perigee Perturbations



Graph B. Apollo 13 CSI Maneuver Apogee and Perigee Perturbations



ΔV_{SC} ERRORS CAUSED BY GYRO DRIFTS $\left[\vec{\phi} \times \vec{A}\right]$ AND PIPA BIASES

GYRO DRIFTS - MERU

PIPA BIASES - CM/SEC^2

ΔV_{SC} - FT/SEC

ΔT_P - SEC (LENGTH OF BURN + 30 SECONDS FOR STARTUP OF AVERAGEG ROUTINF)

ΔT_G - SEC (TIME FROM LAST ALIGNMENT TO BURN)

WEIGHT FACTORS RELATE PIPA BIAS AND GYRO DRIFTS TO VELOCITY ERROR.

LOI

$\Delta V_{X_{SC}} = -0.13 \times 10^{-2}\ AB_X\ \Delta T_P + 0.16 \times 10^{-2}\ AB_Y\ \Delta T_P - 3.27 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Y_{SC}} = -2.03 \times 10^{-4}\ NBDX\ \Delta T_G + 2.69 \times 10^{-5}\ NBDY\ \Delta T_G - 0.91 \times 10^{-5}\ NBDZ\ \Delta T_G - 0.44 \times 10^{-2}\ AB_X\ \Delta T_P - 3.25 \times 10^{-2}\ AB_Y\ \Delta T_P - 0.14 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Z_{SC}} = -2.73 \times 10^{-5}\ NBDX\ \Delta T_G - 2.03 \times 10^{-4}\ NBDY\ \Delta T_G + 0.89 \times 10^{-5}\ NBDZ\ \Delta T_G + 3.25 \times 10^{-2}\ AB_X\ \Delta T_P - 0.43 \times 10^{-2}\ AB_Y\ \Delta T_P - 0.15 \times 10^{-2}\ AB_Z\ \Delta T_P$

DOI

$\Delta V_{X_{SC}} = -0.73 \times 10^{-2}\ AB_X\ \Delta T_P - 3.20 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Y_{SC}} = -1.50 \times 10^{-5}\ NBDX\ \Delta T_G + 0.19 \times 10^{-5}\ NBDY\ \Delta T_G - 0.34 \times 10^{-5}\ NBDZ\ \Delta T_G - 0.40 \times 10^{-2}\ AB_X\ \Delta T_P - 3.26 \times 10^{-2}\ AB_Y\ \Delta T_P$

$\Delta V_{Z_{SC}} = -0.19 \times 10^{-5}\ NBDX\ \Delta T_G - 1.54 \times 10^{-5}\ NBDY\ \Delta T_G + 3.17 \times 10^{-2}\ AB_X\ \Delta T_P - 0.41 \times 10^{-2}\ AB_X\ \Delta T_P - 0.73 \times 10^{-2}\ AB_Z\ \Delta T_P$

CIRCULARIZATION

$\Delta V_{X_{SC}} = 1.18 \times 10^{-2}\ AB_X\ \Delta T_P + 3.06 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Y_{SC}} = 4.75 \times 10^{-6}\ NBDX\ \Delta T_G + 0.65 \times 10^{-6}\ NBDY\ \Delta T_G + 1.84 \times 10^{-6}\ NBDZ\ \Delta T_G + 0.41 \times 10^{-2}\ AB_X\ \Delta T_P - 3.25 \times 10^{-2}\ AB_Y\ \Delta T_P$

$\Delta V_{Z_{SC}} = 0.65 \times 10^{-6}\ NBDX\ \Delta T_G - 5.09 \times 10^{-6}\ NBDY\ \Delta T_G + 0.12 \times 10^{-6}\ NBDZ\ \Delta T_G - 3.03 \times 10^{-2}\ AB_X\ \Delta T_P - 0.41 \times 10^{-2}\ AB_Y\ \Delta T_P + 1.18 \times 10^{-2}\ AB_Z\ \Delta T_P$

PLANE CHANGE 1

$\Delta V_{X_{SC}} = -3.28 \times 10^{-2}\ AB_X\ \Delta T_P$

$\Delta V_{Y_{SC}} = 0.17 \times 10^{-5}\ NBDY\ \Delta T_G - 1.33 \times 10^{-5}\ NBDZ\ \Delta T_G - 3.25 \times 10^{-2}\ AB_Y\ \Delta T_P + 0.41 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Z_{SC}} = -1.33 \times 10^{-5}\ NBDY\ \Delta T_G - 0.17 \times 10^{-5}\ NBDZ\ \Delta T_G - 0.41 \times 10^{-3}\ AB_Y\ \Delta T_P - 3.25 \times 10^{-2}\ AB_Z\ \Delta T_P$

LM CSI

$\Delta V_{X_{SC}} = 3.62 \times 10^{-6}\ NBDY\ \Delta T_G - 3.28 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Y_{SC}} = +3.62 \times 10^{-6}\ NBDZ\ \Delta T_G - 3.28 \times 10^{-2}\ AB_Y\ \Delta T_P$

$\Delta V_{Z_{SC}} = 3.28 \times 10^{-2}\ AB_X\ \Delta T_P$

LM TPI

$\Delta V_{X_{SC}} = +1.79 \times 10^{-6}\ NBDY\ \Delta T_G - 3.28 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Y_{SC}} = +1.79 \times 10^{-6}\ NBDZ\ \Delta T_G - 3.28 \times 10^{-2}\ AB_Y\ \Delta T_P$

$\Delta V_{Z_{SC}} = 3.28 \times 10^{-2}\ AB_X\ \Delta T_P$

PLANE CHANGE 2

$\Delta V_{X_{SC}} = -3.28 \times 10^{-2}\ AB_X\ \Delta T_P$

$\Delta V_{Y_{SC}} = 0.76 \times 10^{-5}\ NBDY\ \Delta T_G - 5.97 \times 10^{-5}\ NBDZ\ \Delta T_G - 3.25 \times 10^{-2}\ AB_Y\ \Delta T_P + 0.41 \times 10^{-2}\ AB_Z\ \Delta T_P$

$\Delta V_{Z_{SC}} = -5.97 \times 10^{-5}\ NBDY\ \Delta T_G - 0.76 \times 10^{-5}\ NBDZ\ \Delta T_G - 0.41 \times 10^{-2}\ AB_Y\ \Delta T_P - 3.25 \times 10^{-2}\ AB_Z\ \Delta T_P$

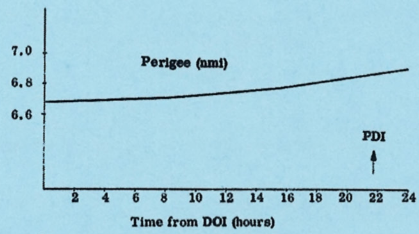
TEI

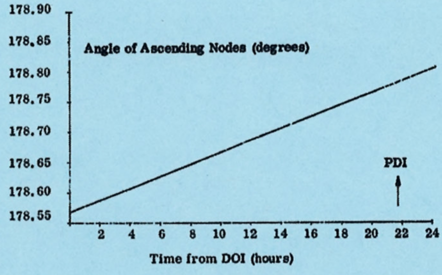
$\Delta V_{X_{SC}} = -3.28 \times 10^{-2}\ AB_X\ \Delta T_P$

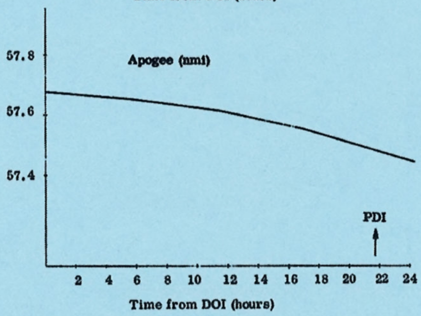
$\Delta V_{Y_{SC}} = -0.29 \times 10^{-4}\ NBDY\ \Delta T_G + 2.28 \times 10^{-4}\ NBDZ\ \Delta T_G + 3.25 \times 10^{-2}\ AB_Y\ \Delta T_P - 0.41 \times 10^{-2}\ AB_Z\ \Delta T_P$

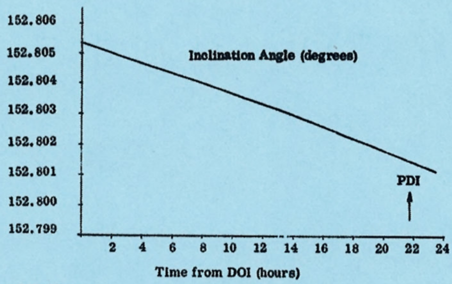
$\Delta V_{Z_{SC}} = 2.28 \times 10^{-4}\ NBDY\ \Delta T_G + 0.29 \times 10^{-4}\ NBDZ\ \Delta T_G + 0.41 \times 10^{-2}\ AB_Y\ \Delta T_P + 3.25 \times 10^{-2}\ AB_Z\ \Delta T_P$

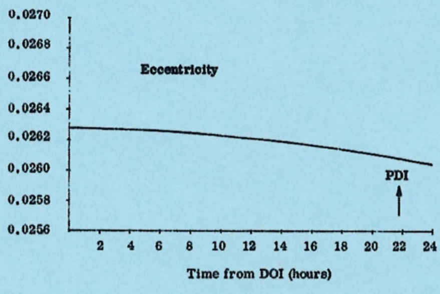
APOLLO 13 LUNAR ORBIT PARAMETERS (TYPICAL)

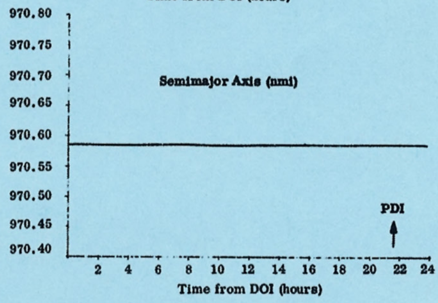


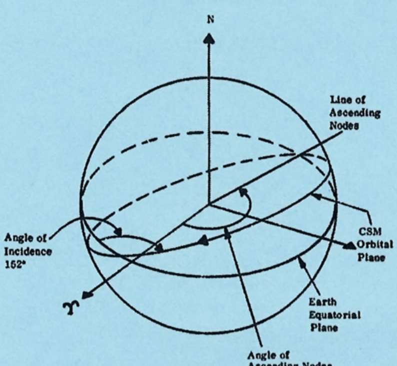




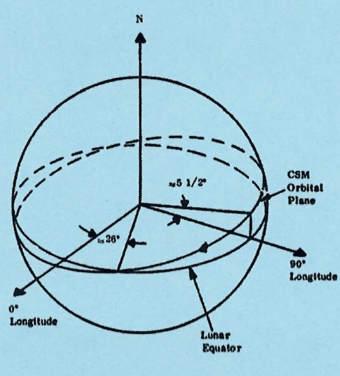






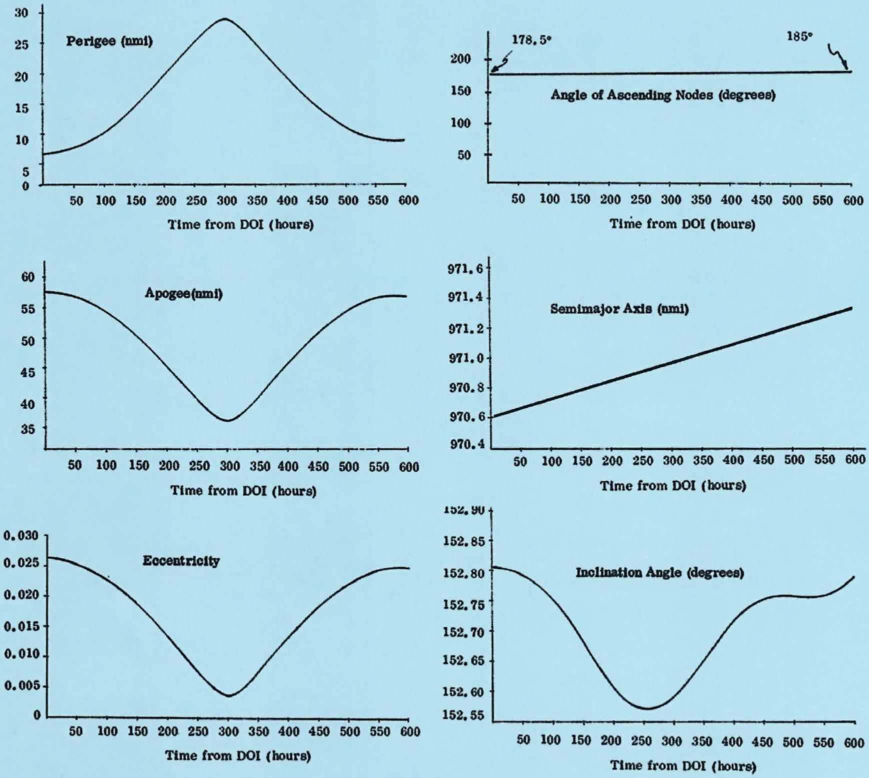


CSM LUNAR ORBIT IN INERTIAL SPACE



CSM LUNAR ORBIT IN LUNAR SPACE

EFFECT OF LUNAR DISTURBANCE ACCELERATION ON LUNAR ORBITAL PARAMETERS (TYPICAL)



$$
\begin{aligned}
\underline{a}_{dM} = \frac{\mu_M}{r^2}\Bigg\{ & \sum_{i=2}^{4} J_{iM}\left(\frac{r_M}{r}\right)^{i}\left[P'_{i+1}(\cos\phi)\,\underline{u}_r - P'_i(\cos\phi)\,\underline{u}_Z\right] \\
& + 3J_{22}\left(\frac{r_M}{r}\right)^{2}\left[\frac{-5(X_M^{2}-Y_M^{2})}{r^2}\,\underline{u}_r + \frac{2X_M}{r}\,\underline{i}_M - \frac{2Y_M}{r}\,\underline{j}_M\right] \\
& + \frac{3}{2}C_{31}\left(\frac{r_M}{r}\right)^{3}\Bigg[\frac{5X_M}{r}(1-7\cos^2\phi)\,\underline{u}_r + (5\cos^2\phi-1)\,\underline{i}_M \\
& + \frac{10X_M Z_M}{r^2}\,\underline{k}_M\Bigg]\Bigg\}
\end{aligned}
$$

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} = 2.07108×10^{-4}

J_{3M} = -2.1×10^{-5}

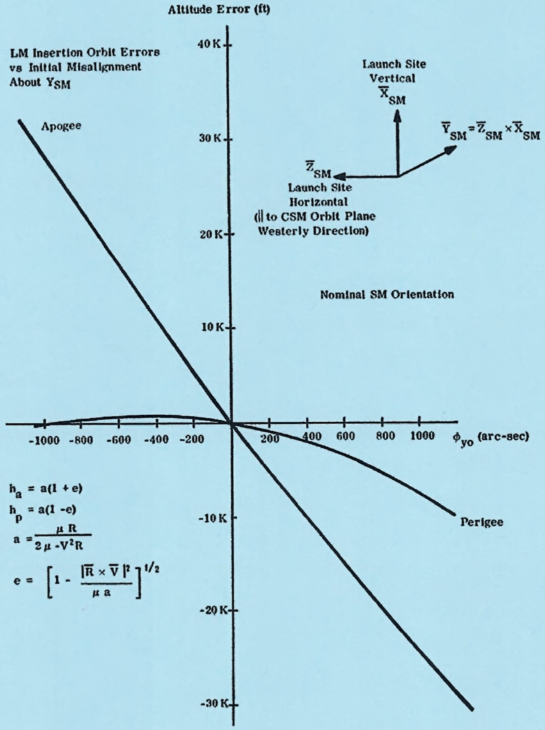
J_{4M} = 0

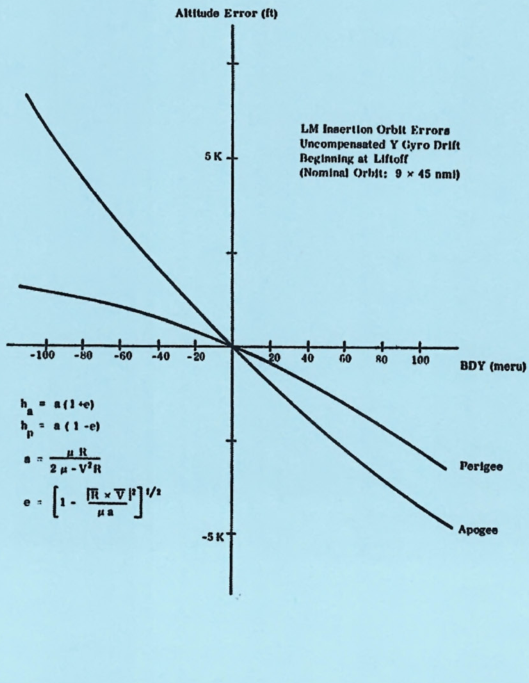
J_{22} = 2.0716×10^{-5}

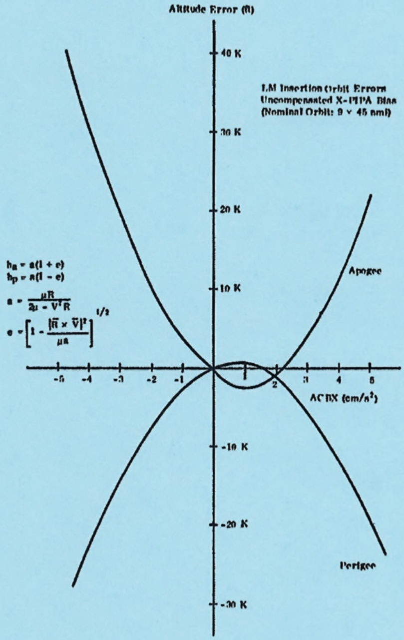
C_{31} = 3.82×10^{-5}

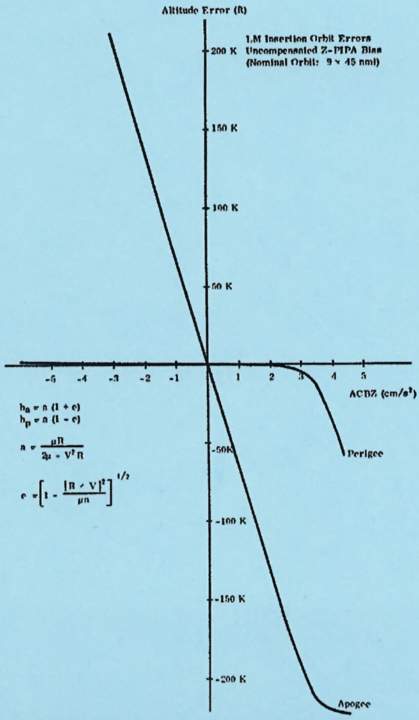
EFFECT OF INSTRUMENT ERRORS ON
LUNAR LANDING POSITION
APOLLO 13

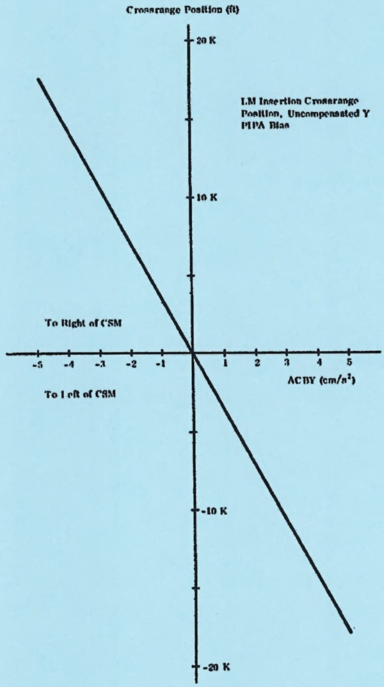
INSTRUMENT ERROR	CROSS-RANGE ERROR (ft)	DOWN RANGE ERROR (ft)
PIPA BIAS (cm/sec^2)		
X	0	-173
Y	-3100	0
Z	0	-3066
IMU MISALIGNMENTS (mrad.)		
About X_{SM}	880	0
About Y_{SM}	0	-100
About Z_{SM}	54	0
GYRO DRIFT (meru)		
NBDX	11.5	0
NBDY	0	-3.5
NBDZ	3	0

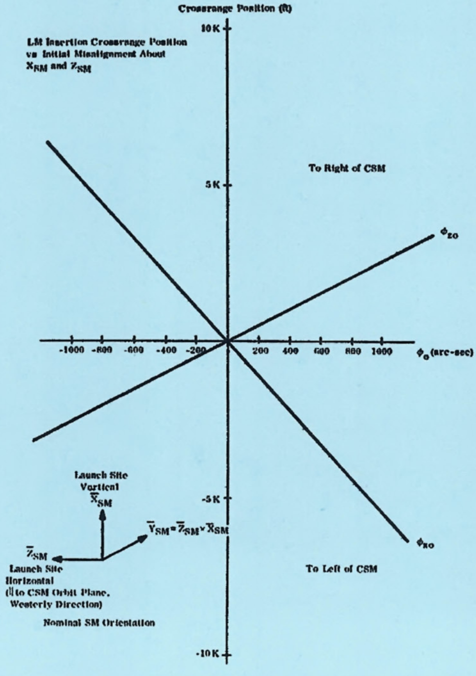

Altitude Error (ft)
LM Insertion Orbit Errors
vs Initial Misalignment
About Y_{SM}
Launch Site
Vertical
$\overline{X}_{SM}$
$\overline{Y}_{SM} = \overline{Z}_{SM} \times \overline{X}_{SM}$
$\overline{Z}_{SM}$
Launch Site
Horizontal
(∥ to CSM Orbit Plane
Westerly Direction)
Nominal SM Orientation
40 K
30 K
20 K
10 K
-10 K
-20 K
-30 K
Apogee
Perigee
-1000 -800 -600 -400 -200
200 400 600 800 1000
ϕ_{yo} (arc-sec)
$h_a = a(1 + e)$
$h_p = a(1 - e)$
$a = \frac{\mu R}{2\mu - V^2 R}$
$e = \left[1 - \frac{|\overline{R} \times \overline{V}|^2}{\mu a}\right]^{1/2}$

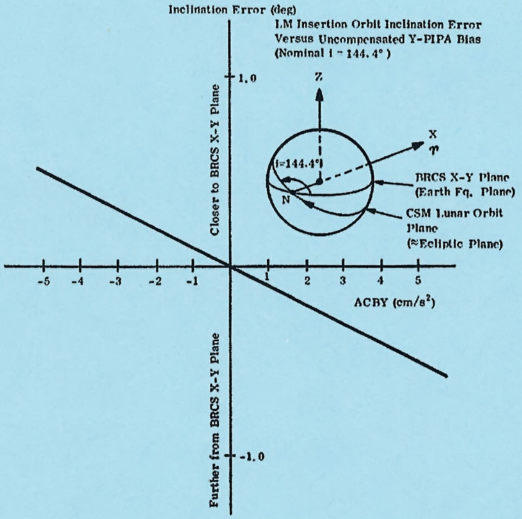

Altitude Error (ft)
LM Insertion Orbit Errors
Uncompensated Y Gyro Drift
Beginning at Liftoff
(Nominal Orbit: 9 × 45 nmi)
5 K
-5 K
-100 -80 -60 -40 -20
20 40 60 80 100
BDY (meru)
Perigee
Apogee
$h_a = a(1 + e)$
$h_p = a(1 - e)$
$a = \frac{\mu R}{2\mu - V^2 R}$
$e = \left[1 - \frac{|\overline{R} \times \overline{V}|^2}{\mu a}\right]^{1/2}$

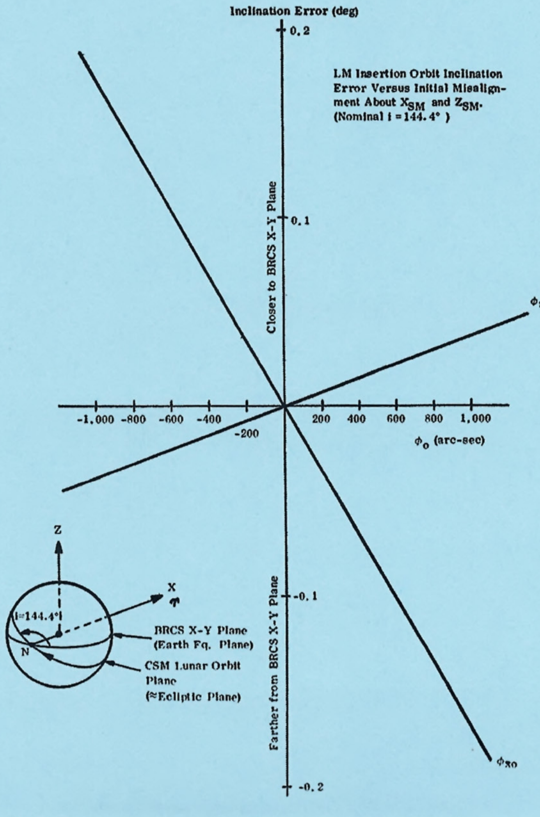

Altitude Error (ft)
40 K
30 K
20 K
10 K
-10 K
-20 K
-30 K
LM Insertion Orbit Errors
Uncompensated X-PIPA Bias
(Nominal Orbit: 9 × 45 nmi)
Apogee
Perigee
-5
-4
-3
-2
-1
1
2
3
4
5
ACBX (cm/s²)
$h_a = a(1 + e)$
$h_p = a(1 - e)$
$a = \frac{\mu R}{2\mu - V^2 R}$
$e = \left[1 - \frac{|\bar{R} \times \bar{V}|^2}{\mu a}\right]^{1/2}$


Altitude Error (ft)
200 K
150 K
100 K
50 K
-50K
-100 K
-150 K
-200 K
LM Insertion Orbit Errors
Uncompensated Z-PIPA Bias
(Nominal Orbit: 9 × 45 nmi)
-5
-4
-3
-2
-1
1
2
3
4
5
ACBZ (cm/s²)
Perigee
Apogee
$h_a = a\,(1 + e)$
$h_p = a\,(1 - e)$
$a = \frac{\mu R}{2\mu - V^2 R}$
$e = \left[1 - \frac{|R \times V|^2}{\mu a}\right]^{1/2}$

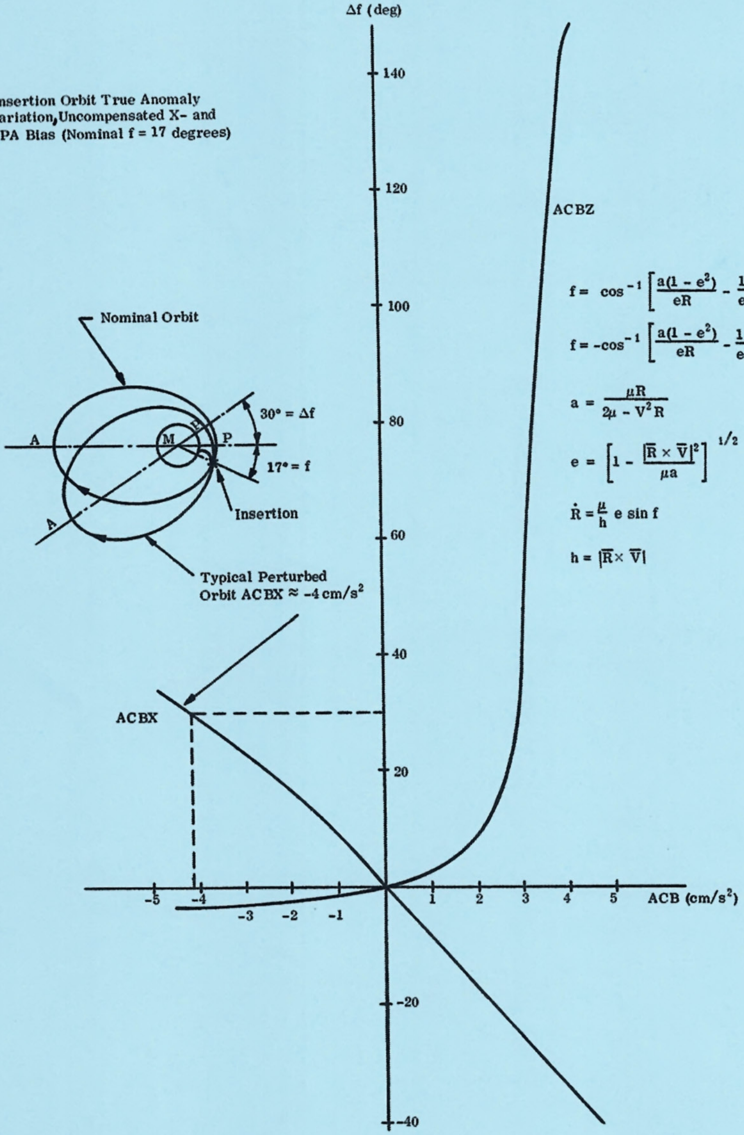

Crossrange Position (ft)
20 K
10 K
-10 K
-20 K
LM Insertion Crossrange Position, Uncompensated Y PIPA Bias
To Right of CSM
To Left of CSM
-5
-4
-3
-2
-1
1
2
3
4
5
ACBY (cm/s²)


Crossrange Position (ft)
10 K
5 K
-5 K
-10 K
LM Insertion Crossrange Position vs Initial Misalignment About X_{SM} and Z_{SM}
To Right of CSM
To Left of CSM
ϕ_{ZO}
ϕ_{XO}
-1000
-800
-600
-400
-200
200
400
600
800
1000
ϕ_0 (arc-sec)
Launch Site Vertical
$\overline{X}_{SM}$
$\overline{Y}_{SM} = \overline{Z}_{SM} \times \overline{X}_{SM}$
$\overline{Z}_{SM}$
Launch Site Horizontal
(‖ to CSM Orbit Plane, Westerly Direction)
Nominal SM Orientation


Inclination Error (deg)
LM Insertion Orbit Inclination Error
Versus Uncompensated Y-PIPA Bias
(Nominal i = 144.4°)
1.0
Z
X
♈
i=144.4°
N
BRCS X-Y Plane
(Earth Eq. Plane)
CSM Lunar Orbit
Plane
(≈Ecliptic Plane)
Closer to BRCS X-Y Plane
-5
-4
-3
-2
-1
1
2
3
4
5
ACBY (cm/s²)
Farther from BRCS X-Y Plane
-1.0


Inclination Error (deg)
0.2
LM Insertion Orbit Inclination
Error Versus Initial Misalignment About X_{SM} and Z_{SM}.
(Nominal i = 144.4°)
Closer to BRCS X-Y Plane
0.1
ϕ_{zo}
-1,000
-800
-600
-400
-200
200
400
600
800
1,000
ϕ_o (arc-sec)
Z
X
♈
i=144.4°
N
BRCS X-Y Plane
(Earth Eq. Plane)
CSM Lunar Orbit
Plane
(≈Ecliptic Plane)
Farther from BRCS X-Y Plane
-0.1
ϕ_{xo}
-0.2

LM Insertion Orbit True Anomaly (f) Variation, Uncompensated X- and Z-PIPA Bias (Nominal f = 17 degrees)



$$f = \cos^{-1}\left[\frac{a(1-e^2)}{eR} - \frac{1}{e}\right] \quad (\dot{R}\ \text{Pos})$$

$$f = -\cos^{-1}\left[\frac{a(1-e^2)}{eR} - \frac{1}{e}\right] \quad (\dot{R}\ \text{Neg})$$

$$a = \frac{\mu R}{2\mu - V^2 R}$$

$$e = \left[1 - \frac{|\overline{R} \times \overline{V}|^2}{\mu a}\right]^{1/2}$$

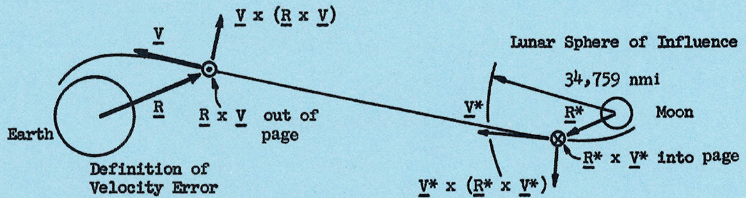
$$\dot{R} = \frac{\mu}{h}\, e \sin f$$

$$h = |\overline{R} \times \overline{V}|$$

ERRORS AT THE ENTRY INTERFACE (400,000 FT. ALT.)
DUE TO VELOCITY ERRORS DURING TRANSEARTH COAST

DIRECTION OF VELOCITY ERROR	ERROR IN VACUUM PERIGEE (nmi/ft/s)	ERROR IN TIME OF ARRIVAL (s/ft/s)	ERROR IN VELOCITY AT EI (ft/s/ft/s)	ERROR IN FLIGHT PATH ANGLE AT EI (degrees/ft/s)
ERROR EXISTING AT TEI CUTOFF		(167:31:13.2 GET)		
Along V*	-30.75	-116.4	8.13	-2.62
Along R* x V*	0.29	4.4	0.15	0.02
Along V* x (R* x V*)	- 5.39	10.0	0.30	-0.35
ERROR EXISTING AT MCC-5 (TEI + 15 hours)		(182:31:13.2 GET)		
Along V	-7.79	-43.25	-0.14	-0.51
Along R x V	0.92	8.30	0	0.06
Along V x (R x V)	-7.11	4.55	0.08	-0.47
ERROR EXISTING AT MCC-6 (EI - 22 hours)		(218:49:37.6 GET)		
Along V	1.21	-4.15	-0.01	0.08
Along R x V	0.01	0.05	0.15	0
Along V x (R x V)	5.30	12.60	0.19	0.35
ERROR EXISTING AT MCC-7 (EI - 3 hours)		(237:49:37.6 GET)		
Along V	0.01	0	1.00	0
Along R x V	0	0	0	0
Along V x (R x V)	0.02	0	0.02	0

* R and V are with respect to moon centered inertial system



Definition of Velocity Error Direction

TYPICAL LUNAR RETURN ENTRY POSITION ERROR SENSITIVITIES AT GUIDANCE TERMINATION

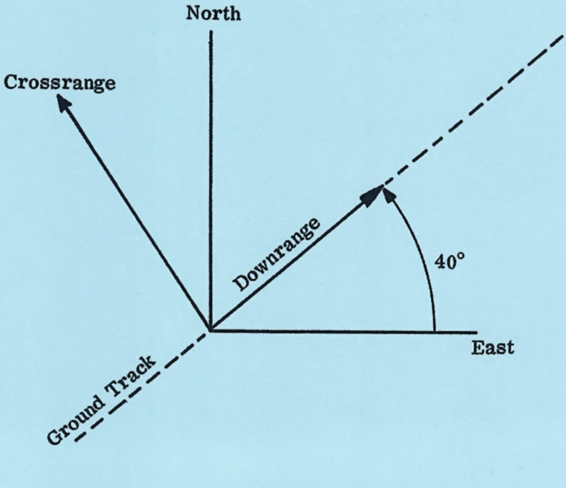
ERROR SOURCE (ϵ)		NOMINAL 1,250 NMI ENTRY	
		Downrange Error (nmi/ϵ)	Crossrange Error (nmi/ϵ)
GYRO BIAS DRIFT (meru)	NBDX	0.0	-0.16
	NBDY	-0.15	0.0
	NBDZ	0.0	-0.41
ACCELEROMETER BIAS (cm/sec^2)	ACBX	-4.48	0.0
	ACBY	0.0	4.66
	ACBZ	-1.50	0.0

NOTES:

1. Assumed accelerometer operation 15 minutes prior to EI (altitude of 400,000 feet).
2. Assumed IMU drift from 1.5 hours prior to EI.
3. Assumed IMU orientation such that at EI:

$$\bar{Z}_{SM} = -\text{Unit}(\bar{R})$$
$$\bar{Y}_{SM} = -\text{Unit}(\bar{R} \times \bar{V})$$
$$\bar{X}_{SM} = \bar{Y}_{SM} \times \bar{Z}_{SM}$$

4. Crossrange-downrange definition:



Nominal 1,250 Nautical Miles Entry

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.

$$\text{State Vector} = \underline{x}(t) = \begin{bmatrix} \delta r \\ \hline \delta v \end{bmatrix} = \begin{bmatrix} \delta r_x \\ \delta r_y \\ \delta r_z \\ \delta v_x \\ \delta v_y \\ \delta v_z \end{bmatrix} = \begin{bmatrix} \text{Deviations from conic position} \\ \\ \text{Deviations from conic velocity} \end{bmatrix}$$

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.

1. Extrapolate the state vector ahead to time t_n, using the best estimate of the state at time t_{n-1}.

$$\underline{\hat{X}}'_n = [\phi_{n-1}]\underline{\hat{X}}_{n-1}$$

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.

$$\underline{\hat{Y}}'_n = [H_n]\,\underline{\hat{X}}'_n$$

5. Update the estimate of the state vector, using the extrapolated state $\underline{\hat{X}}'_n$, the optimal gain $[K^*_n]$, the extrapolated measurement $\underline{\hat{Y}}'_n$, and the actual measurement at time t_n, $\underline{Y}_n$.

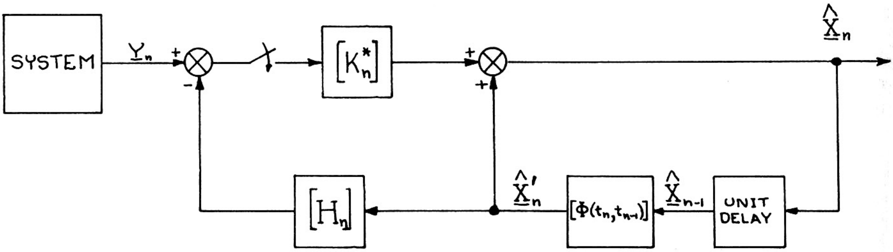
$$\underline{\hat{X}}_n = \underline{\hat{X}}'_n + [K^*_n]\,(\underline{Y}_n - \underline{\hat{Y}}'_n)$$

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.

$$\hat{\underline{X}}_n = \hat{\underline{X}}'_n + [K_n^*](\underline{Y}_n - [H_n]\,\hat{\underline{X}}'_n)$$

$$[E_n] = [E'_n] - [K_n^*][H_n][E'_n]$$

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.

TABLE 1

Celestial Navigation Terminology	Kalman Filter Terminology	Correlation
$\underline{b}$ = geometry vector of dimension "D"	$[H]$ = measurement matrix	$\underline{b}^T \Rightarrow [H]$
$\underline{\omega}$ = weighting vector of dimension "D"	$[K_n^*]$ = optimal gain matrix	$\underline{\omega} \Rightarrow [K_n^*]$
$[W]$ = error transition matrix of dimension "D x D"	$[E]$ = error covariance matrix	$[E] \Rightarrow [WW^T]$
$\underline{x}$ = 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	$\bar{\alpha}^2 \Rightarrow [V]$
δQ = measurement deviation (scalar)	$(\hat{\underline{Y}}'_n - \underline{Y}_n)$ = measurement residual	$\delta Q \Rightarrow (\hat{\underline{Y}}'_n - \underline{Y}_n)$

The basic Kalman filter described above was modified (Reference 9 and Table 1) for celestial navigation in the following basic aspects.

- The state vector ($\underline{x}$) is not extrapolated utilizing the "state transition" matrix concept developed by Kalman. Rather, extrapolation of the deviation state vector is achieved by numerical integration of the differential equations

$$\delta \dot{\underline{r}} = \delta \underline{v}$$
$$\delta \dot{\underline{v}} = G(\underline{r}_c)\, \delta \underline{r} + \underline{a}_d$$

where

$G(\underline{r}_c)$ is the gravity gradient matrix
$$\frac{\mu}{r_c^5}\left(3\underline{r}_c\underline{r}_c^T - r_c^2 I\right)$$

$\underline{r}_c$ is the osculating conic position vector. ($\underline{r}_c$ is extrapolated from $\underline{r}_o$ and v_o which define an osculating conic orbit at t_o the time of the last rectification or trajectory redefinition)

$\underline{a}_d$ is a disturbance acceleration which characterizes the gravitational anomalies of a central force field.

$\delta \underline{r}$, $\delta \underline{v}$ are vector deviations from the osculating orbital elements $\underline{r}_c$ and $\underline{v}_c$. $\delta \underline{r}\,(t_o) = \delta \underline{v}\,(t_o) = \underline{0}$

$\delta \underline{r}$ and $\delta \underline{v}$ are extrapolated from (t_o) to the time of the present measurement using Encke's method of differential accelerations.

$\underline{r}_c$ and $\underline{v}_c$ are extrapolated from (t_o) to the time of the present measurement using Kepler's subroutine.

Thus, for small deviations from the reference trajectory, the state vector differential equation characterizing linear perturbations is

$$\dot{\underline{x}} = \begin{bmatrix} 0 & I \\ G(r_c) & 0 \end{bmatrix} \underline{x} + \begin{bmatrix} \underline{0} \\ \underline{a}_d \end{bmatrix}$$

where $\underline{x}$ equals the deviation state vector

$$\begin{bmatrix} \delta \underline{r} \\ \delta \underline{v} \end{bmatrix}$$

- The "error covariance" matrix concept (E) developed by Kalman is replaced by the "error transition" matrix concept (W) for incorporation of celestial observations.

Generally, errors in the estimation of the state vector are characterized by the elements of the error covariance matrix E. For position and velocity state vectors, the error covariance matrix is as shown below.

$$E_{6x6} = \begin{bmatrix} \overline{\underline{e}_r \underline{e}_r^T} & \overline{\underline{e}_r \underline{e}_v^T} \\ \overline{\underline{e}_v \underline{e}_r^T} & \overline{\underline{e}_v \underline{e}_v^T} \end{bmatrix}$$

where

$$\begin{bmatrix} \underline{e}_r \\ \underline{e}_v \end{bmatrix} = \begin{bmatrix} \hat{\delta \underline{r}} - \delta \underline{r} \\ \hat{\delta \underline{v}} - \delta \underline{v} \end{bmatrix} = (\hat{\underline{x}} - \underline{x})$$

and

$\hat{\underline{x}}$ is the estimate of state which arises as a result of a measurement incorporation.

$\underline{x}$ is the actual state vector

$\overline{\underline{e}_r \underline{e}_r^T}$, $\overline{\underline{e}_r \underline{e}_v^T}$, etc is a vector averaging process which yields a 3/3 matrix of mean square errors.

Error covariance matricies (E) are usually extrapolated using a state transition procedure which follows naturally from the differential equation of the state vector. Thus for classic Kalman Filtering

TIME DOMAIN DYNAMICS	EXTRAPOLATION PROCEDURE
if $\dot{\underline{x}} = F\underline{x}$	$\hat{\underline{x}}' = \Phi \hat{\underline{x}}$
then $\dot{E} = FE + EF^T$	$E' = \Phi E \Phi^T + U$

where U is the covariance matrix of the process noise

Instead of extrapolating the error covariance matrix by implementing the above equation, the square root of the error covariance is extrapolated. Thus if

$$E \triangleq WW^T$$

extrapolating W instead of E always assures that E' will remain positive definite.

For celestial navigation, the differential equations and their corresponding extrapolation procedures are as shown below.

TIME DOMAIN DYNAMICS	EXTRAPOLATION PROCEDURE USING NYSTROMS METHOD
$\dot{\underline{x}} = \begin{bmatrix} 0 & I \\ G(r_c) & 0 \end{bmatrix} \underline{x}$	$\hat{\underline{x}}' = \hat{\underline{x}}(t_1) + \int_{t_1}^{t_2} \begin{bmatrix} 0 & I \\ G(r_c) & 0 \end{bmatrix} \hat{\underline{x}}\, dt$
$\dot{w} = \begin{bmatrix} 0 & I \\ G(r_c) & 0 \end{bmatrix} w$	$w' = w(t_1) + \int_{t_1}^{t_2} \begin{bmatrix} 0 & I \\ G(r_c) & 0 \end{bmatrix} w\, dt$

Since process noise is neglected in the extrapolation procedure for the error transition matrix, elements of W will degrade until a point is reached where all measurement data is ignored. To preclude this, the W matrix is periodically reinitialized.

With E replaced by W for celestial navigation, the optimal gain computation part of the Kalman Filter recursive cycle changes accordingly.

The optimal gain matrix utilized in Kalman filtering is computed during each iteration cycle using the equation

$$K = E'H^T\,(HE'H^T + V)^{-1}$$

where

K is a matrix of weight factors which, when used to premultiply the measurement residual vector, yields the optimum linear estimate of the state vector.

E' is the extrapolated error covariance matrix.

H is a matrix relating the state vector to the measurement vector.

V is the covariance matrix of the measurement noise.

The optimum weight factor used for incorporation of celestial observations into the deviation state vector is obtained by direct substitution of a geometry vector $\underline{b}$ and the error transition matrix W into the Kalman equation for K. Thus

$$E = WW^T$$

then $\underline{w} = [W'W'^T]\,\underline{b}\,[\underline{b}^T W' W'^T \underline{b} + \bar{\alpha}^2]^{-1}$

The implications of the above substitutions are as follows:

a. Measurement data from several sources (SXT, RR, LR, VHF, and so on) is processed using a geometry vector $\underline{b}$ for each source which relates the deviation state vector variables $\delta\underline{r}$ and $\delta\underline{v}$ to the sensor output. In this manner, measurements are incorporated sequentially as they are taken using the same computational procedure. The geometry vector $\underline{b}$ is such that it establishes a component of the state vector in the direction of $\underline{b}$ in state space.

b. The product $\underline{b}^T W' W'^T \underline{b}$ is a scalar; thus by definition of the geometry vector $\underline{b}$, the covariance of the measurement process is a scalar (the same reduction in dimension occurs when a single element of state is measured).

c. Inversion of a matrix is avoided and replaced with division by a scalar. The gain matrix is reduced to a gain vector equal to

$$\underline{w} = \frac{\underline{W'Z}}{Z^2 + \bar{\alpha}^2}$$

where $Z \triangleq W'^T \underline{b}$

and $Z^2 = Z^T Z$

- With the measurement matrix H replaced by the geometry vector $\underline{b}$, the celestial navigation measurement process becomes equivalent to one of measuring a single element of state.

  When Kalman filtering is used, the expected or predicted value of the forthcoming measurement is computed using the relation

$$\hat{Y}' = H\hat{\underline{X}}'$$

where

$\hat{\underline{X}}'$ is the estimate of state (available after incorporation of the last measurement) extrapolated to the time of this measurement.

H is a matrix relating measurements to state variables.

$\hat{Y}'$ is the extrapolated estimate of the forthcoming measurement.

For celestial observations, deviations from the reference trajectory are couched in terms of deviations from a reference angle which characterizes the geometry of the observation made. A geometry vector $\underline{b}$ is defined for each observation such that

$$\delta\hat{A}' = \underline{b}^T\hat{\underline{X}}' = \left[\underline{h}^T, \underline{0}^T\right] \begin{bmatrix} \delta\hat{\underline{r}}' \\ \hline \delta\hat{\underline{v}}' \end{bmatrix} = \text{a scalar}$$

where

$\hat{X}' = \begin{bmatrix} \delta\hat{\underline{r}}' \\ \hline \delta\hat{\underline{v}}' \end{bmatrix}$ is the extrapolated estimate of state integrated forward to the measurement time using Encke's method of differential accelerations.

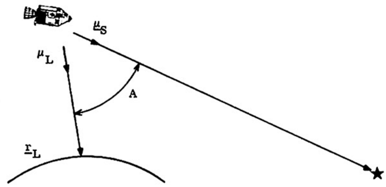
The components of $\underline{h}$ are the partial derivatives of the geometry angle A with respect to $\underline{\hat{X}}'$. Thus

$$\underline{h} = \begin{bmatrix} h_x \\ h_y \\ h_z \end{bmatrix} = \begin{bmatrix} \alpha A/\alpha(\delta \hat{r}_x') \\ \alpha A/\alpha(\delta \hat{r}_y') \\ \alpha A/\alpha(\delta \hat{r}_z') \end{bmatrix}$$

where

$\delta\hat{r}_x'$, $\delta\hat{r}_y'$, $\delta\hat{r}_z'$ are position deviations from the osculating orbit extrapolated to the time of the forthcoming measurements.

As an example, the geometry vector for a star landmark measurement is derived as follows:



$$r_L \cos A \triangleq \underline{\mu}_S^T \underline{r}_L$$

Taking partials

$$\delta r_L \cos A - r_L \sin A\, \delta A = \underline{\mu}_S^T\ \delta \underline{r}_L$$

$$\delta A = (\delta r_L \cos A - \underline{\mu}_S^T \delta \underline{r}_L)/r_L \sin A$$

By definition

$$\delta r_L r_L \text{ a scalar} = \underline{r}_L^T \delta \underline{r}_L$$

therefore

$$\delta r_L = \frac{r_L^T}{r_L}\ \delta \underline{r}_L = \underline{\mu}_L^T \delta \underline{r}_L$$

and

$$\delta A = \frac{\underline{\mu}_L^T\ \delta \underline{r}_L \cos A - \underline{\mu}_S^T\ \delta r_L}{r_L \sin A}$$

$$\delta A = \frac{\left(\underline{\mu}_L^T \cos A - \underline{\mu}_S^T\right) \delta \underline{r}_L}{r_L \sin A} = \frac{\left(\underline{\mu}_L \cos A - \underline{\mu}_S^T\right)\left(-\delta \underline{r}'\right)}{r_L \sin A}$$

$$\underline{h} = \frac{\underline{\mu}_S - \underline{\mu}_L \cos A}{r_L \sin A} \qquad \frac{1}{r_L} \text{Unit} (\underline{\mu}_S - \underline{\mu}_L (\underline{\mu}_S \cdot \underline{\mu}_L))$$

- All other $\underline{b}$ vectors for various Apollo measurement procedures are derived hereafter by purely geometric means.
- After a measurement is taken a new estimate of state is computed using the equation

$$\underline{\hat{X}}(t_2) = \underline{\hat{X}}'(t_2) + \underline{w}\ (\delta A - \delta \hat{A}')$$

where

$\underline{\hat{X}}(t_2)$ is the new estimate of the deviation state vector $\begin{pmatrix} \delta \hat{\underline{r}} \\ \delta \hat{\underline{v}} \end{pmatrix}$

$\underline{\hat{X}}'(t_2)$ is the extrapolate estimate of state which is computed from integrating the differential equation

$$\underline{\hat{X}}'(t_2) = \hat{X}(t_1) + \int_{t_1}^{t_2} \begin{bmatrix} G\ {}^0(r_c) & {}^I_0 \end{bmatrix} \underline{\hat{X}}\, dt$$

$\underline{w}$ is an optimum weight factor vector

δA is the actual measurement.

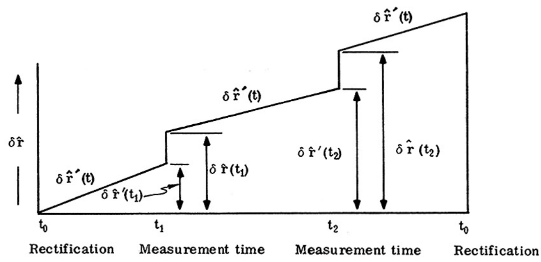
$\delta \hat{A}'$ is the predicted measurement.

t_1 is the time of the last measurement incorporation.

t_2 is the present measurement time.

A measurement incorporation produces a step change in $\underline{\hat{X}}$.

At incorporation, $\delta\hat{\underline{r}}'$ and $\delta\hat{\underline{v}}'$ are replaced with $\delta\hat{\underline{r}}$ and $\delta\hat{\underline{v}}$. Thereafter, $\delta\hat{\underline{r}}'$ and $\delta\hat{\underline{v}}'$ are again extrapolated from $\delta\hat{\underline{r}}$ and $\delta\hat{\underline{v}}$ using the differential equation shown above. The figure below illustrates this measurement incorporation process.



Whenever the elements of $\hat{X}$ exceed preselected values, the reference trajectory is redefined; that is, rectified using the relation

$$\begin{bmatrix} \underline{r}_o \\ \hline \underline{v}_o \end{bmatrix} = \begin{bmatrix} \underline{r}_c \\ \hline \underline{v}_c \end{bmatrix} + \begin{bmatrix} \delta\hat{\underline{r}} \\ \hline \delta\hat{\underline{v}} \end{bmatrix}$$

where

$\underline{r}_o$ and $\underline{v}_o$ are osculating orbit elements of the new epoch.

$\underline{r}_c$ and $\underline{v}_c$ have been extrapolated from the last rectification using Kepler's equation.

$\delta\hat{r}$, $\delta\hat{v}$ are the vector deviations from $\underline{r}_c$ and $\underline{v}_c$.

- With E replaced by W for celestial navigation, the update equation for the error transition matrix W is obtained from simple substitution.

  The final step in the Kalman filter recursive process is the computation of the estimator's error covariance matrix. Updates of error covariance for Kalman filtering are achieved using the relation

  $$E = E' - KHE'$$

  where

  E is the matrix of mean square errors characterizing the accuracy of the estimation process.

  E' is the error covariance matrix extrapolated forward from the last measurement of the time of the present measurement.

  K is the optimal gain matrix.

  H is the matrix relation between measurement and state variables.

The equation used for updating the error transition matrix is obtained by direct substitution as shown below

$$WW^T = W'W'^T - \underline{w}\,\underline{b}^T W' W'^T$$

that is

$$W = W' - \frac{\underline{w}\,\underline{Z}^T}{1 + \sqrt{\dfrac{\bar{\alpha}^2}{Z^2 + \bar{\alpha}^2}}}$$

here

W arises from the definition $E = WW^T$

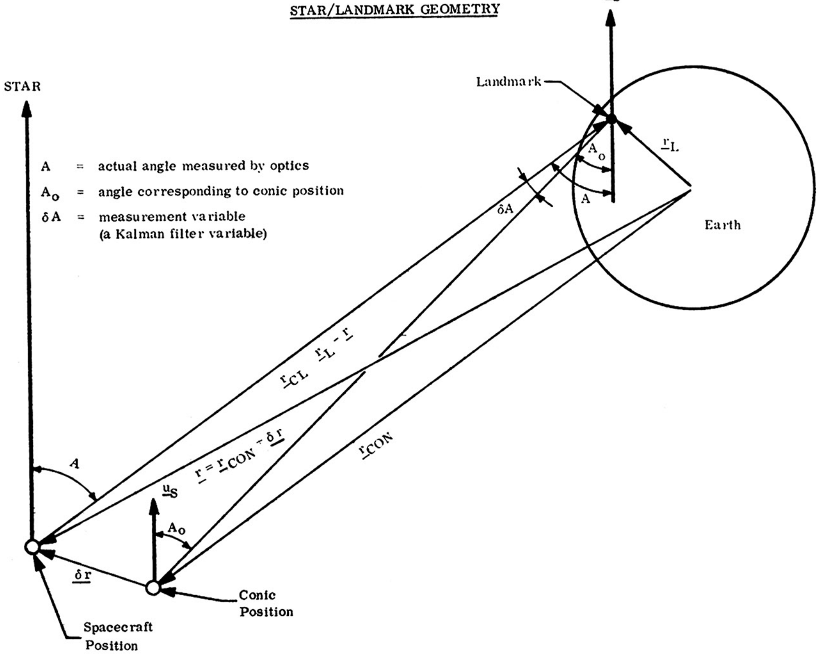
W' is the error transition matrix extrapolated forward from the last measurement to the time of the present measurement.

$\underline{w}$ is the optimum weight vector used to incorporate measurement data in an optimum manner.

$\underline{Z}^T$ is the vector $\underline{b}^T W'$ used to simplify the W equation.

$\bar{\alpha}^2$ is the mean square error of the measurement process.

STAR/LANDMARK GEOMETRY



The relationship between the state vector and measurement variable can be determined by redrawing part of the preceding figure.

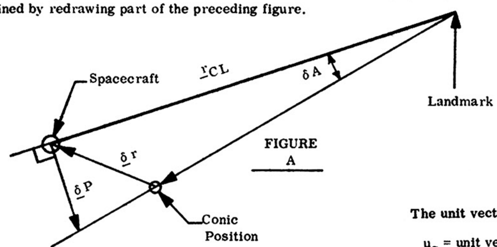
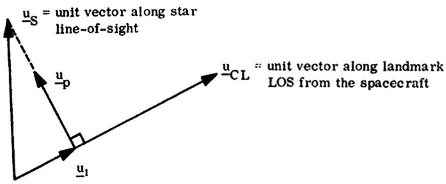


FIGURE A

$$\delta A = \frac{|\underline{\delta P}|}{|\underline{r}_{CL}|} = \frac{\underline{u}_p^T\,\underline{\delta r}}{|\underline{r}_{CL}|} = \frac{\underline{u}_p^T}{|\underline{r}_{CL}|}\quad \underline{\delta r} = \underline{b}^T\,\underline{\delta x}$$

where $\underline{u}_p$ is a unit vector prependicular to $\underline{r}_{CL}$

The unit vector, $\underline{u}_p$, can be determined from Figure A



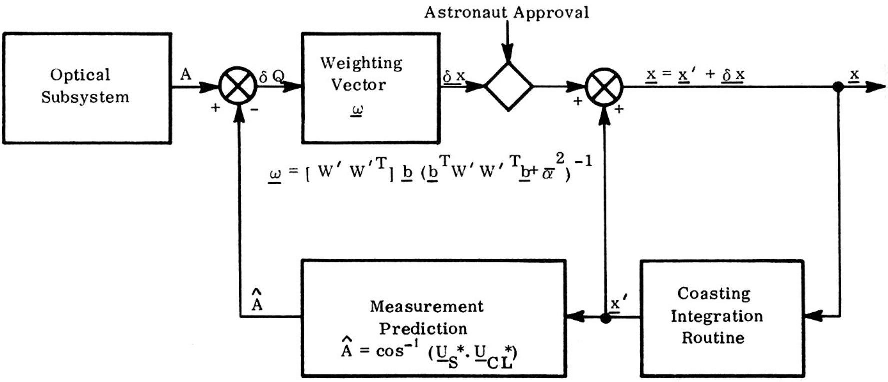
$\underline{u}_p$ = Unit $(\underline{u}_S - \underline{u}_1)$

$\underline{u}_1$ = Component of $\underline{u}_S$ along $\underline{u}_{CL} = (\underline{u}_S \cdot \underline{u}_{CL})\,\underline{u}_{CL}$

$\underline{u}_p$ = Unit $(\underline{u}_S - (\underline{u}_S \cdot \underline{u}_{CL})\,\underline{u}_{CL})$

$$\therefore\quad b = \frac{1}{|\underline{r}_{CL}|}\begin{bmatrix} \text{Unit}\,(\underline{u}_S - (\underline{u}_S \cdot \underline{u}_{CL})\,\underline{u}_{CL} \\ \underline{0} \end{bmatrix}$$

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:

$$\underline{x} = \underline{x}' + \underline{\delta x} = \underline{x}' + \underline{\omega}\ \delta Q$$

$$[W] = [W'] - \frac{\underline{\omega} \underline{Z}^T}{1 + \sqrt{\dfrac{\overline{\alpha}^2}{Z^2 + \overline{\alpha}^2}}}$$

CISLUNAR MIDCOURSE NAVIGATION ROUTINE
P-23

MEASUREMENT VARIANCE

$$\overline{\alpha}^2 = Var_{Trun} + Var_L / r_{CL}^2$$

$$= (0.05\ mr)^2 + \frac{1\ nmi^2}{r_{CL}^2}$$

INITIAL "W" MATRIX

$$[W] = \left[\begin{array}{c|c} w_{mr} I & 0 \\ \hline 0 & w_{mv} I \end{array}\right]$$

$$w^*_{mr} = 1,005.84\ m = 3,300\ ft$$

$$w^*_{mv} = 1.00584\ m/s = 3.3\ ft/s$$

*These values are stored in erasable memory.

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

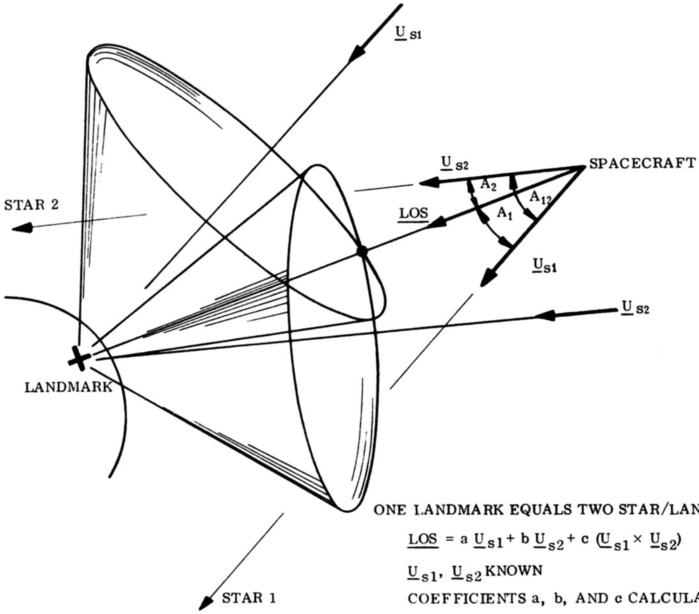
$= \underline{r}_{con} + \underline{\delta r}$

$\underline{v}_c$ = SPACECRAFT VELOCITY VECTOR

$= \underline{v}_{con} + \underline{\delta v}$

$\underline{r}_L$ = LANDMARK POSITION VECTOR

ORBITAL NAVIGATION — LANDMARK TRACK

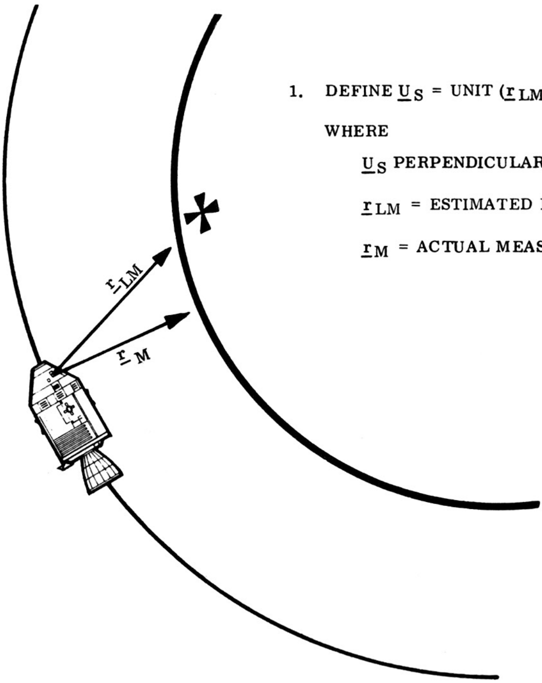


ONE LANDMARK EQUALS TWO STAR/LANDMARK SIGHTINGS.

$\underline{LOS} = a\,\underline{U}_{s1} + b\,\underline{U}_{s2} + c\,(\underline{U}_{s1} \times \underline{U}_{s2})$

$\underline{U}_{s1}$, $\underline{U}_{s2}$ KNOWN

COEFFICIENTS a, b, AND c CALCULATED



1. DEFINE $\underline{U}_S$ = UNIT $(\underline{r}_{LM} \times \underline{r}_M)$

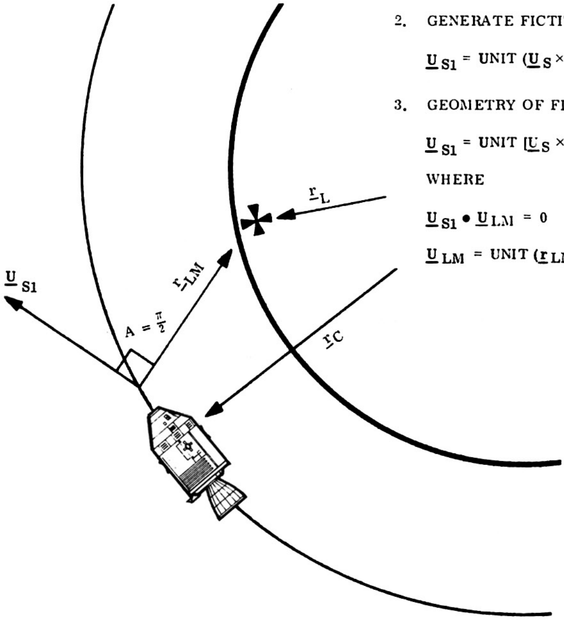
   WHERE

   $\underline{U}_S$ PERPENDICULAR TO MEASUREMENT PLANE

   $\underline{r}_{LM}$ = ESTIMATED LOS FROM SPACECRAFT TO LANDMARK

   $\underline{r}_M$ = ACTUAL MEASURED LOS FROM SPACECRAFT TO LANDMARK

ORBITAL NAVIGATION — LANDMARK TRACK (CONTINUED)



2. GENERATE FICTITIOUS STAR

$$\underline{U}_{S1} = \text{UNIT}\,(\underline{U}_S \times \underline{r}_{LM}) \quad \begin{cases} \underline{U}_{S1} \text{ PERPENDICULAR TO } \underline{r}_{LM} \\ \underline{U}_{S1} \text{ IN MEASUREMENT PLANE} \end{cases}$$

3. GEOMETRY OF FICTITIOUS STAR AND STATE VECTOR

$$\underline{U}_{S1} = \text{UNIT}\,[\underline{U}_S \times (\underline{r}_L - \underline{r}_C)]$$

WHERE

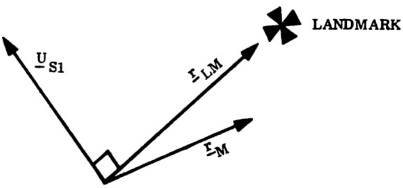
$$\underline{U}_{S1} \bullet \underline{U}_{LM} = 0$$

$$\underline{U}_{LM} = \text{UNIT}\,(\underline{r}_{LM})$$

4. IN TERMS OF STATE VECTOR

$$\underline{U}_{S1} \bullet \underline{U}_{LM} = 0 = \frac{1}{|r_{LM}|} \begin{bmatrix} -\underline{U}_{S1} \\ 0 \\ +\underline{U}_{S1} \end{bmatrix} \bullet \begin{bmatrix} \underline{r}_C \\ \underline{V}_C \\ \underline{r}_L \end{bmatrix}$$

5. CONSIDERING ACTUAL MEASUREMENT $\underline{r}_M$



6. MEASUREMENT RESIDUAL IN TERMS OF STATE VECTOR

$$\underline{U}_{S1M} = \text{UNIT}\,(\underline{U}_S \times \underline{r}_M)$$

$$\delta Q = 0 - \frac{1}{|r_M|} \begin{bmatrix} -\underline{U}_{S1M} \\ 0 \\ \underline{U}_{S1M} \end{bmatrix} \bullet \begin{bmatrix} \underline{r}_C \\ \underline{V}_C \\ \underline{r}_L \end{bmatrix} \qquad \text{A SCALAR DEVIATION FROM ZERO.}$$

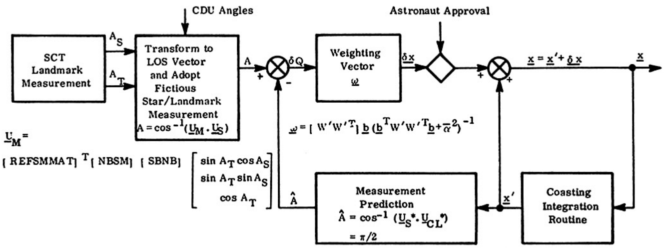
UPDATE STATE

$$\underline{X} = \underline{X}' + \underline{\omega}\,\delta Q$$

$\underline{X}'$ = EXTRAPOLATED ESTIMATE OF STATE

$\underline{\omega}$ = 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.

$$\underline{x} = \underline{x}' + \underline{\delta x} = \underline{x}' + \underline{\omega}\,\delta Q$$

$$[W] = [W'] - \frac{\underline{\omega} Z^T}{1 + \sqrt{\dfrac{\bar{\alpha}^2}{Z^2 + \bar{\alpha}^2}}}$$

ORBITAL NAVIGATION ROUTINE
P-22

MEASUREMENT VARIANCE

$$\bar{\alpha}^2 = Var_{SCT} + Var_{IMU} = (1\,mr)^2 + (0.2\,mr)^2$$

INITIAL "W" MATRIX

$$[W] = \left[\begin{array}{c|c|c} w_{\ell r} I & 0 & 0 \\ \hline 0 & w_{\ell v} I & 0 \\ \hline 0 & 0 & w_{\ell} I \end{array}\right]$$

$w^*_{\ell r} = 0.0$

$w^*_{\ell v} = 0.0$

$w^*_{\ell} = 10,000$ meters

***These values are stored in erasable memory.**

RENDEZVOUS NAVIGATION PROGRAM (LEM)
P-20

MEASUREMENT VARIANCE

RANGE MEASUREMENT

$$\overline{\alpha}^2 = \text{Max}\left\{ \text{Var}_R^*, \ \frac{\text{Var}^*_{R\,min}}{r_{CL}^{\ 2}} \right\} = \text{Max}\left\{ 0.111111 \times 10^{-4}, \ \frac{66\,m^2}{r_{CL}^{\ 2}} \right\}$$

RANGE RATE MEASUREMENT

$$\overline{\alpha}^2 = \text{Max}\left\{ \dot{r}^2 \ \text{Var}_V^*, \ \text{Var}^*_{V\,min} \right\} = \text{Max}\left\{ \dot{r}^2 \ 1.8777 \times 10^{-5}, \ 0.017445 \ m^2/s^2 \right\}$$

SHAFT ANGLE MEASUREMENT

$$\overline{\alpha}^2 = \text{Var}_\beta^* + \text{Var}_{IMU} = (1\,mr)^2 + (0.2\ mr)^2$$

TRUNNION ANGLE MEASUREMENT

$$\overline{\alpha}^2 = \text{Var}_\theta^* + \text{Var}_{IMU} = (1\,mr)^2 + (0.2\,mr)^2$$

INITIAL "W" MATRICES

FOR RENDEZVOUS

$$[W] = \left[\begin{array}{c|c|ccc} w_{rr}I & 0 & & 0 & \\ \hline 0 & w_{rv}I & & 0 & \\ \hline & & w_\beta & 0 & 0 \\ 0 & 0 & 0 & w_\theta & 0 \\ & & 0 & 0 & 0 \end{array}\right]$$

$w_{rr}^* = 3,048\ m = 10^4\ ft$

$w_{rv}^* = 3.048\ m/s = 10\ ft/s$

$w_\beta^* = 15\ mrad$

$w_\theta^* = 15\ mrad$

FOR LUNAR SURFACE NAVIGATION

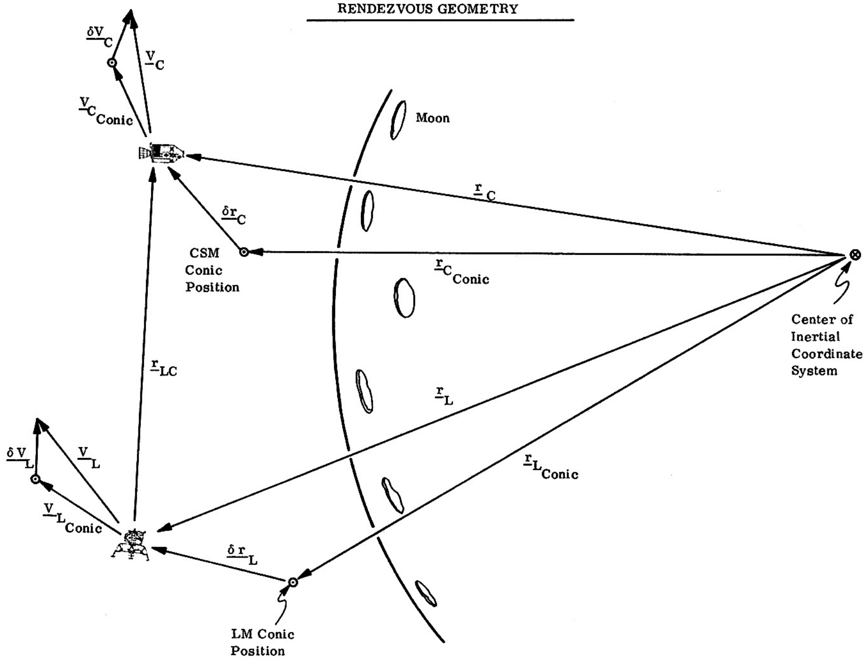
$$[W] = \left[\begin{array}{c|c} w_{\ell r}I & 0 \\ \hline 0 & w_{\ell v}I \end{array}\right]$$

$w_{\ell r}^* = 0.0$

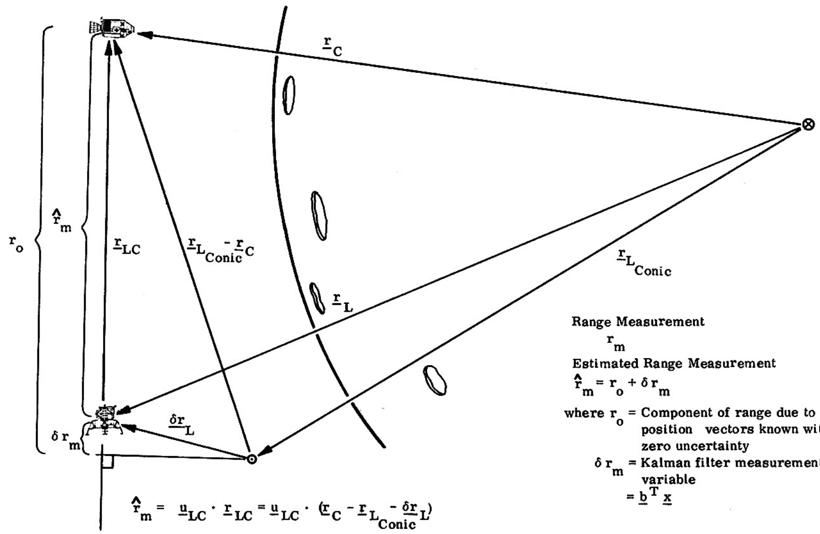
$w_{\ell v}^* = 0.0$

*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 $= \underline{b}^T \underline{x}$

$$\hat{r}_m = \underline{u}_{LC} \cdot \underline{r}_{LC} = \underline{u}_{LC} \cdot (\underline{r}_C - \underline{r}_{L_{Conic}} - \underline{\delta r}_L)$$

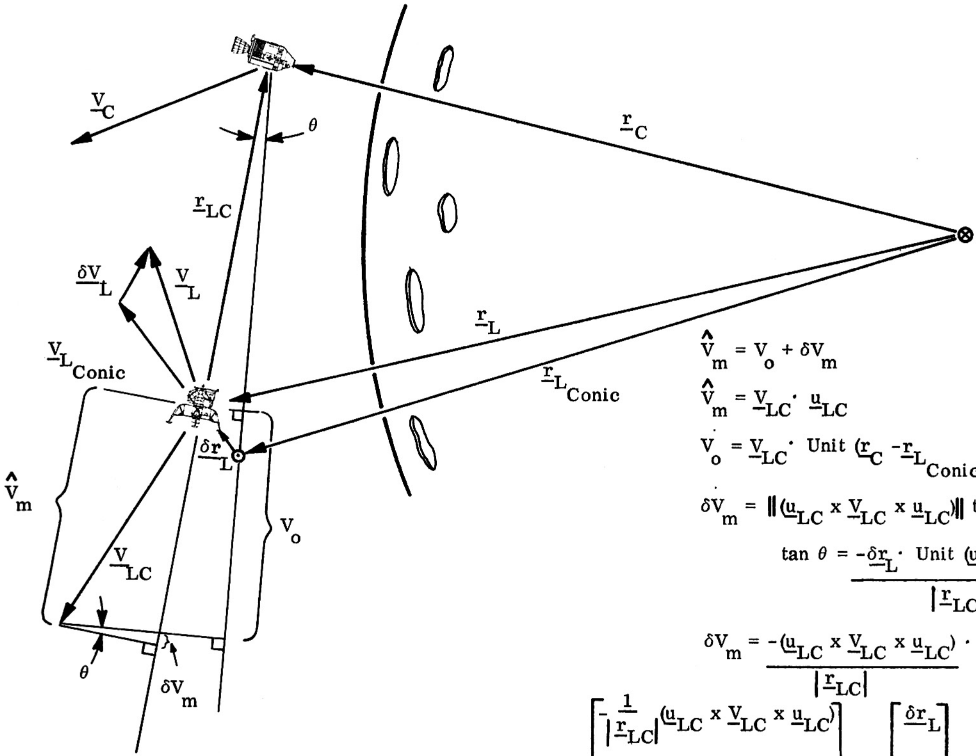
$$= \underline{u}_{LC} \cdot (\underline{r}_C - \underline{r}_{L_{Conic}}) - \underline{u}_{LC} \cdot \underline{\delta r}_L$$

$$= r_o - \underline{u}_{LC} \cdot \underline{\delta r}_L$$

$$\delta r_m = -\underline{u}_{LC} \cdot \underline{\delta r}_L = \underline{b}^T \underline{x}$$

$$\underline{b} = \begin{bmatrix} -\underline{u}_{LC} \\ \underline{0} \\ \underline{0} \end{bmatrix} \quad \underline{x} = \begin{bmatrix} \underline{\delta r}_L \\ \underline{\delta V}_L \\ \delta\beta \\ \delta\theta \\ 0 \end{bmatrix}$$

RENDEZVOUS RANGE RATE (V_m) MEASUREMENT continued



$$\hat{V}_m = V_o + \delta V_m$$

$$\hat{V}_m = \underline{V}_{LC} \cdot \underline{u}_{LC}$$

$$\dot{V}_o = \underline{V}_{LC} \cdot \text{Unit}\,(\underline{r}_C - \underline{r}_{L_{Conic}})$$

$$\delta \dot{V}_m = \|(\underline{u}_{LC} \times \underline{V}_{LC} \times \underline{u}_{LC})\| \tan\theta$$

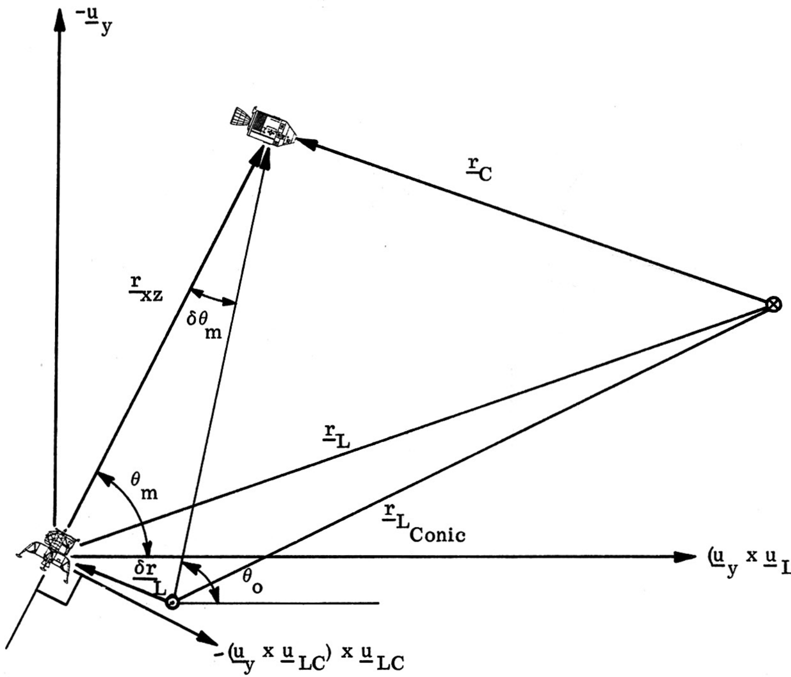
$$\tan\theta = \frac{-\delta\underline{r}_L \cdot \text{Unit}\,(\underline{u}_{LC} \times \underline{V}_{LC} \times \underline{u}_{LC})}{|\underline{r}_{LC}|}$$

$$\delta V_m = \frac{-(\underline{u}_{LC} \times \underline{V}_{LC} \times \underline{u}_{LC}) \cdot \delta\underline{r}_L}{|\underline{r}_{LC}|}$$

$$\delta V_m = \underline{b}^T \underline{x} = \begin{bmatrix} -\frac{1}{|\underline{r}_{LC}|}(\underline{u}_{LC} \times \underline{V}_{LC} \times \underline{u}_{LC}) \\ -\underline{u}_{LC} \\ \underline{0} \end{bmatrix} \begin{bmatrix} \delta\underline{r}_L \\ \delta\underline{V}_L \\ \delta\beta \\ \delta\theta \\ 0 \end{bmatrix}$$

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.



$$\hat{\theta}_m = \theta_m + \delta\theta$$
$$= \theta_o + \delta\theta_m + \delta\theta$$

where θ_o = component of θ_m due to $\underline{r}_C - \underline{r}_{L_{Conic}}$

$\delta\theta_m$ = component of θ_m due to $\delta\underline{r}_L$

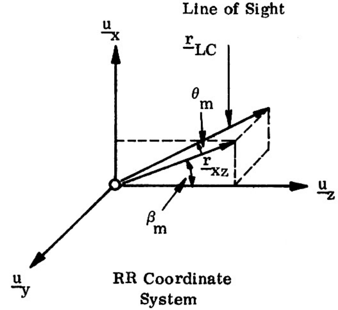
$$= \delta\underline{r}_L \cdot \frac{-1}{|\underline{r}_{xz}|} \text{Unit} \left[(\underline{u}_y \times \underline{u}_{LC}) \times u_{LC} \right]$$

Kalman filter measurement variable =

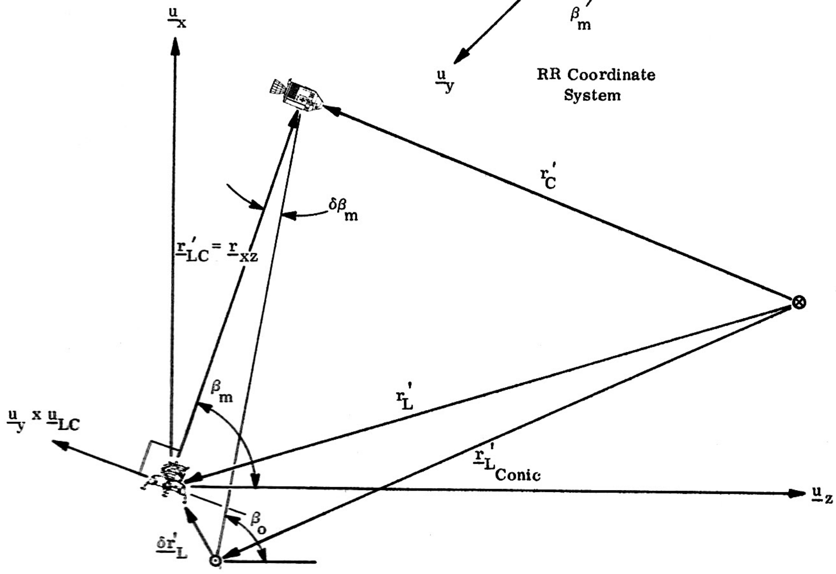
$$\delta\theta_m + \delta\theta = \underline{b}^T \underline{x}$$

$$\doteq \begin{bmatrix} -\frac{1}{|\underline{r}_{xz}|} \text{ Unit } [(\underline{u}_y \times \underline{u}_{LC}) \times \underline{u}_{LC} \\ \underline{0} \\ 0 \\ 1 \\ 0 \end{bmatrix} \cdot \begin{bmatrix} \delta\underline{r}_L \\ \delta\underline{V}_L \\ \delta\beta \\ \delta\theta \\ 0 \end{bmatrix}$$

RENDEZVOUS RADAR SHAFT ANGLE (β_m) MEASUREMENTS



RR Coordinate System



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 $\underline{r}_{LC}$

β_o = portion of RR shaft angle due to $\underline{r}_C$ and $\underline{r}_{L_{Conic}}$

$$\delta\beta_m = \frac{1}{\underline{r}_{xz}} \left[\text{Unit } (\underline{u}_y \times \underline{u}_{LC}) \quad \delta\underline{r}_L \right]$$

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. $= \delta\beta_m + \delta\beta_o = \underline{b}^T \underline{x}$

$$= \begin{bmatrix} \frac{1}{\underline{r}_{xz}} \left[\text{Unit } (\underline{u}_y \times \underline{u}_{LC}) \right] \\ \underline{0} \\ 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \delta\underline{r}_L \\ \delta\underline{V}_L \\ \delta\beta \\ \delta\theta \\ 0 \end{bmatrix}$$

RENDEZVOUS NAVIGATION PROGRAM (CSM)
P-20

MEASUREMENT VARIANCE

OPTICAL TRACKING

$$\overline{\alpha}^2 = Var_{SXT} + Var_{IMU} + \frac{Var^*_{INT}}{r_{CL}^2}$$

$$= (0.2\,mr)^2 + (0.2\,mr)^2 + \frac{(14\,m)^2}{r_{CL}^2}$$

VHF RANGING

$$\overline{\alpha}^2 = Max\left\{Var^*_R, \frac{Var^*_{R\,min}}{r_{CL}^2}\right\}$$

$$= Max\left\{0.0\%, \frac{-83.6127\,m^2}{r_{CL}^2}\right\}$$

ALTERNATE LOS

$$\overline{\alpha}^2 = Var^*_{ALT} + Var_{IMU}$$

$$= 12\,mr^2 + (0.2\,mr)^2$$

INITIAL "W" MATRIX

$$[W] = \left[\begin{array}{c|c} w_{rr}I & 0 \\ \hline 0 & w_{rv}I \end{array}\right]$$

$$w^*_{rr} = 3,048\,m = 10^4\,ft$$

$$w^*_{rv} = 3.048\,m/s = 10\,ft/s$$

*These values are stored in erasable memory.

RENDEZVOUS RANGE RATE (V_m) MEASUREMENT

Rendezvous range rate measurement has a term due to deviation from conic velocity ($\underline{\delta V}_L$) and a term due to devial RENDEZVOUS RA($\underline{\delta r}_L$). The term due to velocity deviation ($\underline{\delta V}_L$) is:

$$\hat{V}_m = \underline{V}_{LC} \cdot \underline{u}_{LC}$$

$$= \underline{u}_{LC} \cdot (\underline{V}_C - \underline{V}_{L_{Conic}} - \underline{\delta V}_L) = \underline{u}_{LC} \cdot (\underline{V}_C - \underline{V}_{L_{Conic}}) - \underline{u}_{LC} \cdot \underline{\delta V}_L$$

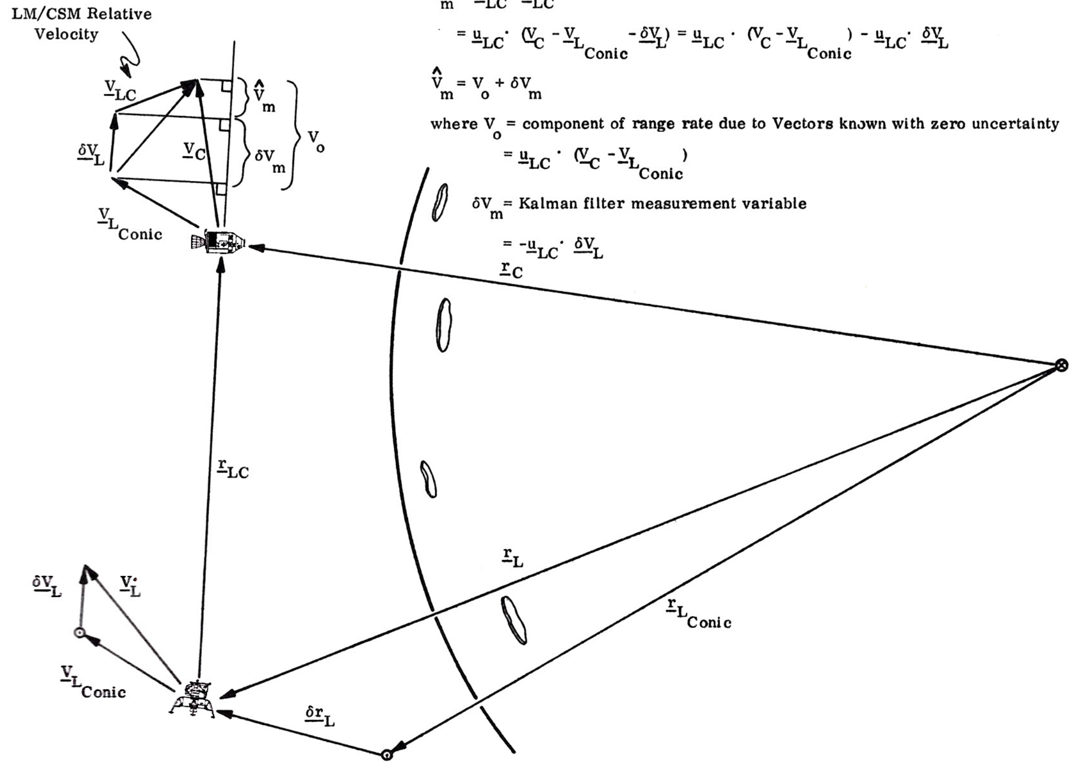
$$\hat{V}_m = V_o + \delta V_m$$

where V_o = component of range rate due to Vectors known with zero uncertainty

$$= \underline{u}_{LC} \cdot (\underline{V}_C - \underline{V}_{L_{Conic}})$$

δV_m = Kalman filter measurement variable

$$= -\underline{u}_{LC} \cdot \underline{\delta V}_L$$



A. ORBITAL RELATIONSHIPS

Assuming a spherical planet, the equation of motion for a satellite is given by

$$\frac{d^2 \vec{r}}{d\, t^2} = -\frac{\mu}{r^3}\ \vec{r} \qquad (1)$$

where

$\mu = (M_{\text{Planet}} + M_{\text{Satellite}})\ G$

G = gravitational constant

The solution of Equation 1 is:

$$r = \frac{h^2/\mu}{1 + e \cos f} \qquad (2)$$

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	$\vec{h} = \vec{r} \times \vec{v} = r^2 \dot{f}$ = 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	$P = 2\pi\ (a^{3/2}/\mu^{1/2})$
Mean Motion	$n = \mu^{1/2}/a^{3/2}$
Mean Anomaly	$M = n\ (t - \tau)$
	τ = time of perigee passage
Eccentric Anomaly	$E - e \sin E = M$ (Kepler's Equation)
	$\tan (E/2) = [(1 - e)/(1 + e)]^{1/2} \tan (f/2)$

Hyperbola Only

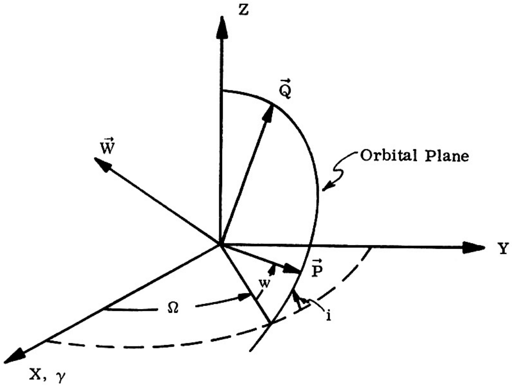
Mean Motion	$\gamma^2 = \mu/a^3$
Mean Anomaly	$M = \gamma\ (t - \tau)$
	τ = time of perigee passage
Eccentric Anomaly	$H - e \sinh H = M$
	$\tanh (H/2) = [(e - 1)/(e + 1)]^{1/2} \tan (f/2)$

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

$$\begin{bmatrix} P \\ Q \\ W \end{bmatrix}_{Orbit} = [R_Z(w)]\ [R_X(i)]\ [R_Z(\Omega)] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI} = [A] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI} \qquad (3)$$



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:

$$\begin{bmatrix} P \\ Q \\ W \end{bmatrix} = \begin{bmatrix} P_X & P_Y & P_Z \\ Q_X & Q_Y & Q_Z \\ W_X & W_Y & W_Z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI} = [B] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI} \qquad (4)$$

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:

$$\vec{P} = \frac{1}{\mu e} \left[\left(v^2 - \frac{\mu}{r}\right)\vec{r} - (\vec{r} \cdot \vec{v})\ \vec{v} \right] \qquad (5)$$

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:

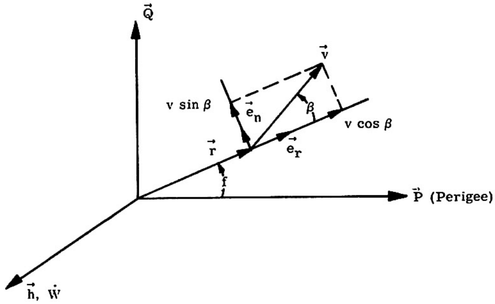


Figure 2

$$\vec{P} = \vec{e}_r \cos f - \vec{e}_n \sin f \tag{6}$$

(1) $\vec{e}_r = \frac{\vec{r}}{r}$; $\vec{e}_h = \frac{\vec{h}}{h}$; $\vec{e}_n = \frac{\vec{h}}{h} \times \frac{\vec{r}}{r}$

(2) $r = \frac{h^2/\mu}{1+e\cos f}$; $\cos f = \frac{h^2}{\mu e} r^{-1} - \frac{1}{e}$; $\sin f = \frac{h}{\mu e} \dot{r}$;

but $\dot{r} = v\vec{e}_r = v \cos\beta = \frac{\vec{r} \cdot \vec{v}}{r}$

(3) $\sin f = \frac{h}{\mu e} \frac{\vec{r} \cdot \vec{v}}{r}$

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

$$h = r v \sin\beta, \ \cos\beta = \frac{\vec{r} \cdot \vec{v}}{rv}$$

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 $\vec{h}$ = 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

$$\vec{W} = \frac{\vec{h}}{h} = \frac{\vec{r} \times \vec{v}}{rv \sin\beta} \tag{7}$$

Having determined $\vec{P}$ and $\vec{W}$, the remaining unit vector, $\vec{Q}$, is calculated as follows:

$$\vec{Q} = \vec{W} \times \vec{P} \tag{8}$$

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 $0° \leq i \leq 180°$, 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

$$\vec{r}(t_2) = \left[1 - \frac{X^2}{r_1} C(X^2 \alpha_1) \right] \vec{r}_1 + \left[\Delta t - \frac{X^3}{\sqrt{\mu}} S(X^2 \alpha_1) \right] \vec{v}_1 \qquad (9)$$

$$\vec{v}(t_2) = \frac{\sqrt{\mu}}{r_2 r_1} \left[\alpha_1 X^3 S(X^2 \alpha_1) - X \right] \vec{r}_1 + \left[1 - \frac{X^2}{r_2} C(X^2 \alpha_1) \right] \vec{v}_1 \qquad (10)$$

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

$$X = X_1 + S\left[1 - F_3 S(1 - 2F_3 S) - \frac{1}{6}\left(\frac{1}{r_1} - \alpha_1\right) S^2\right] \qquad (11)$$

where

$X_1 = 0$ for the first iteration and X 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-Rhapson iteration scheme as follows:

$$X_{n+1} = X_n - \frac{F(X_n)}{F'(X_n)} \qquad (12)$$

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 r_γ and v_γ in ECI space. 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.

The conic section concept utilized for navigation requires the computation of trajectory segments under a wide variety of constraints. Depending on the constraints involved, the set of universal equations will solve

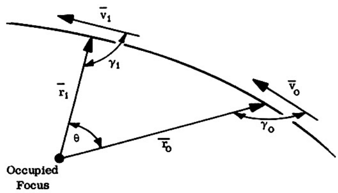
1 - Kepler's Problem given r_o, v_o, and Δt, solve for r_1, v_1.

2 - Lambert's Problem given r_o, r_1, and Δt, solve for conic parameters.

3 - Time - Theta Problem given r_o, v_o, and θ, solve for Δt.

4 - Time - Radius Problem given r_o, v_o, and r_1, solve for Δt.

where:



f = true anomaly measured from pericenter

Δt = flight time from r_o to r_1

p = semilatus rectum

$\alpha = 1/a$, a = semimajor axis

γ = flight path angle

θ = true anomaly difference $(f_1 - f_o)$

The equation set used for solution of the above problem is

13. $$\sqrt{\mu}\,\Delta t = \sqrt{p}\,\cot\gamma_o\, x^2\, C(\alpha x^2) + (1 - r_o\alpha)\, x^3\, S(\alpha x^2) + r_o x$$

14. $$\cot\frac{\theta}{2} = \frac{r_o\,[1 - \alpha x^2\, S(\alpha x^2)]}{\sqrt{p}\, x\, C(\alpha x^2)} + \cot\gamma_o$$

15. $$\frac{p}{r_o} = \frac{1 - \cos\theta}{\frac{r_o}{r_1} - \cos\theta + \sin\theta\,\cot\gamma_o}$$

16. $$\frac{r}{\mu} v^2 = 2 - r\alpha$$

17. $$r\alpha = 2 - \frac{p}{r}(1 + \cot^2\gamma)$$

18. $$\cot\frac{\theta}{2} = \frac{\cot\gamma_o + \frac{r_o}{r_1}\cot\gamma_1}{\left(1 - \frac{r_o}{r_1}\right)}, \quad r_o \neq r_1$$

19. $$\frac{p}{r_o} = \frac{2\left(\frac{r_o}{r_1} - 1\right)}{\left(\frac{r_o}{r_1}\right)^2\left(1 + \cot^2\gamma_1\right) - \left(1 + \cot^2\gamma_o\right)}$$

20. $$r_1 = \left[1 - \frac{x^2}{r_o} C(\alpha x^2)\right] r_o + \left[\Delta t - \frac{x^3}{\sqrt{\mu}} S(\alpha x^2)\right] v_o$$

21. $$v_1 = \frac{\sqrt{\mu}}{r_o r_1}\left[\alpha x^3 S(\alpha x^2) - x\right] r_o + \left[1 - \frac{x^2}{r_1} C(\alpha x^2)\right] v_o$$

22. $$\cot\gamma = \frac{r \cdot v}{|r \times v|}$$

Therefore:

1 Kepler's Solution. Compute $r_o\alpha$ using Equation 16; compute x using Equation 13 and $\sqrt{p}\ \cot\gamma_o = \frac{r_o \cdot v_o}{\sqrt{\mu}}$; compute r_1 and v_1 using Equations 20 and 21.

2 Lambert's Solution. Guess a $\cot\gamma_o$; compute p/r_o and $r_o\alpha$ using Equations 15 and 17; compute x using Equation 14 iteratively; compute Δt using Equation 13. If Δt disagrees with the desired Δt, adjust $\cot\gamma_o$ and repeat.

3 Time - Theta Solution. Compute $\cot\gamma_o$, $r_o\alpha$, and p/r_o using Equations 22, 16, and 17; solve for x using Equation 14 iteratively; compute Δt using Equation 13.

4 Time - Radius Solution. Compute $\cot\gamma_o$, $r_o\alpha$, p/r_o, and $\cot\gamma_1$ using Equations 22, 16, 17, and 17; compute $\cot\frac{\theta}{2}$ using Equation 18; compute x using Equation 14 iteratively: compute Δt using Equation 13.

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

$$\frac{d^2 \vec{r}}{dt^2} + \frac{\mu}{r^3} \vec{r} = \vec{a}_d \tag{23}$$

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 $\frac{\mu}{r^2}$, 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

$$\begin{aligned} \vec{r} &= \vec{r}_c + \vec{\delta} \\ \vec{v} &= \vec{v}_c + \vec{\sigma} \end{aligned} \tag{24}$$

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 24 and substituting into Equation 23 gives the following expression for the differential acceleration

$$\frac{d^2 \vec{\delta}}{dt^2} = \frac{\mu}{r_c^3} \left[\left[1 - \frac{r_c^3}{r^3} \right] \vec{r} - \vec{\delta} \right] + \vec{a}_d \tag{25}$$

subject to the initial conditions

$$\vec{\delta}(t_o) = 0, \quad \frac{d\vec{\delta}}{dt}(t_o) = \vec{\sigma}(t_o) = 0$$

This method (Equation 25) is known as Encke's method of differential accelerations.

Since the coefficient of $\vec{r}$ in Equation 25 requires the subtraction of nearly equal quantities, prohibitive errors are introduced by solving Equation 25 in its present form. This difficulty can be overcome by making the substitution

$$\left(1 - \frac{r_c^3}{r^3} \right) = \frac{\vec{r}}{r^2} \left(1 + \frac{\rho^2}{1+\rho} \right) \left[(\vec{r}_c + \vec{r}) \cdot \vec{\delta} \right] \quad \text{where} \quad \rho = r_c/r$$

Equation 25, therefore, becomes

$$\frac{d^2 \vec{\delta}}{dt^2} = \frac{\mu}{r_c^3} \left\{ \frac{\vec{r}}{r^2} \left(1 + \frac{\rho^2}{1+\rho} \right) \left[(\vec{r}_c + \vec{r}) \cdot \vec{\delta} \right] - \vec{\delta} \right\} + \vec{a}_d \tag{26}$$

Equation 26 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, $\vec{\delta}\ (t)$ 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 $\vec{\delta}\ (t)$ reaches a predetermined limit. 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 26.
3. A new conic from which to calculate deviations is defined each time the deviations ($\vec{\delta}\ (t)$) 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.

R_{Earth} = 3,441 nmi

R_1 = 3,660 nmi

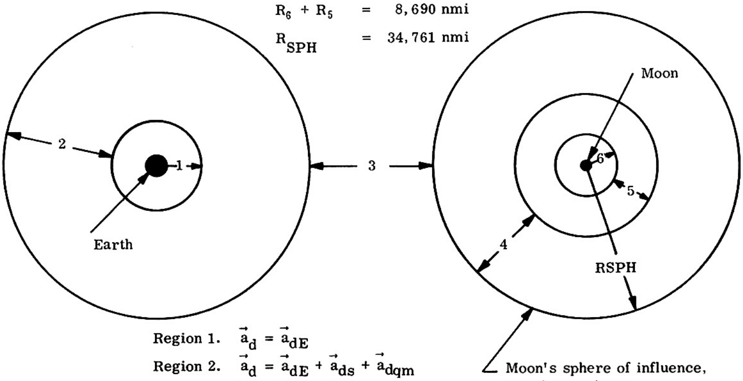
$R_1 + R_2$ = 43,452 nmi

R_{Moon} = 938 nmi

R_6 = 1,154 nmi

$R_6 + R_5$ = 8,690 nmi

R_{SPH} = 34,761 nmi



Region 1. $\vec{a}_d = \vec{a}_{dE}$

Region 2. $\vec{a}_d = \vec{a}_{dE} + \vec{a}_{ds} + \vec{a}_{dqm}$

Region 3. $\vec{a}_d = \vec{a}_{ds} + \vec{a}_{dqm}$

Region 4. $\vec{a}_d = \vec{a}_{ds} + \vec{a}_{dqE}$

Region 5. $\vec{a}_d = \vec{a}_{dm} + \vec{a}_{ds} + \vec{a}_{dqE}$

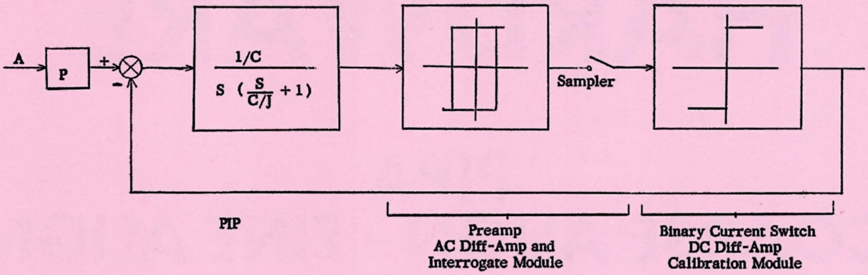
Region 6. $\vec{a}_d = \vec{a}_{dm}$

Figure 3. Apollo Disturbance Acceleration Regions

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.	Scale factor		5.85	cm/sec/pulse	1.00	cm/sec/pulse
3.	Pendulosity	P	0.25	$\frac{\text{dyne cm}}{\text{cm/sec}^2}$	0.25	$\frac{\text{dyne cm}}{\text{cm/sec}^2}$
4.	Torque to balance	T	4680	dyne cm	800	dyne cm
5.	PIP float inertia	J	14.0	$\frac{\text{dyne cm}}{\text{rad/sec}^2}$	14.0	$\frac{\text{dyne cm}}{\text{rad/sec}^2}$
6.	PIP viscous damping	C	12×10^4	$\frac{\text{dyne cm}}{\text{rad/sec}}$	12×10^4	$\frac{\text{dyne cm}}{\text{rad/sec}}$
7.	PIP break point	C/J	8550	rad/sec	8550	rad/sec
8.	PIP time constant	J/C	.117	ms	.117	ms
9.	Total torque constant		.42	dyne cm/ma^2	.42	dyne cm/ma^2
10.	Nominal torque current		105	ma	44	ma

SUSPENSION CHARACTERISTICS

1.	Radial Force	2.3 grams per .0001" min
2.	Suspension current	65 ± 6 ma
		the two ends (SG & TG) matched with 3 ma
3.	Phase angle of current	lags 45° ± 2.8°
4.	Suspension stiffness	30×10^{-3} grams/micro-inch

TYPICAL TEMPERATURE CHARACTERISTICS

1.	Scale Factor	150 ppm/°F	CM
		300 ppm/°F	LM
2.	Bias	.05 cm/sec^2/°F	LM/CM

°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/sec^2 of that evaluated in a zero gravity (a_b) 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

PIPA Bias CM = (.0005569) (Reg Contents in Decimal) cm/sec^2
PIPA Bias LM = (.0007628) (Reg Contents in Decimal) cm/sec^2

The correction to the PIPA's is

$$PIPA_C = (1 + SFE_I)\ PIPA_I - BIAS_I \Delta t$$

where

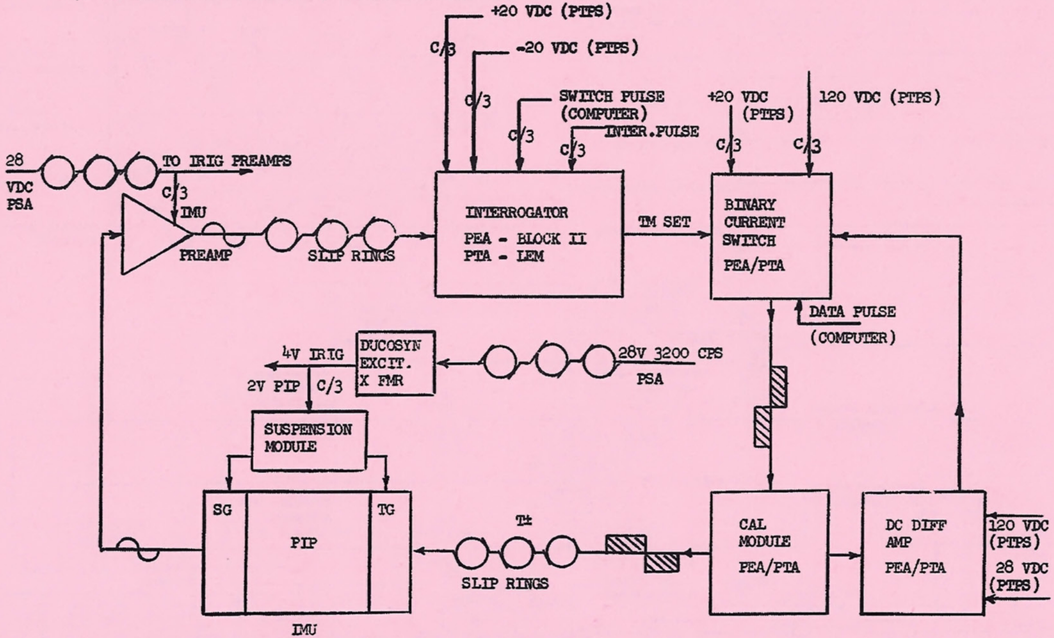
$PIPA_C$ is the compensated data for the I^{th} PIPA denoted $PIPAX_C$, $PIPAY_C$, $PIPAZ_C$

$$SFE = \frac{SF - SF_{nom}}{SF_{nom}} \quad \text{(erasable load)}$$

$$SF = \text{Scale-factor} \ \frac{CM/Sec}{Pulse}$$

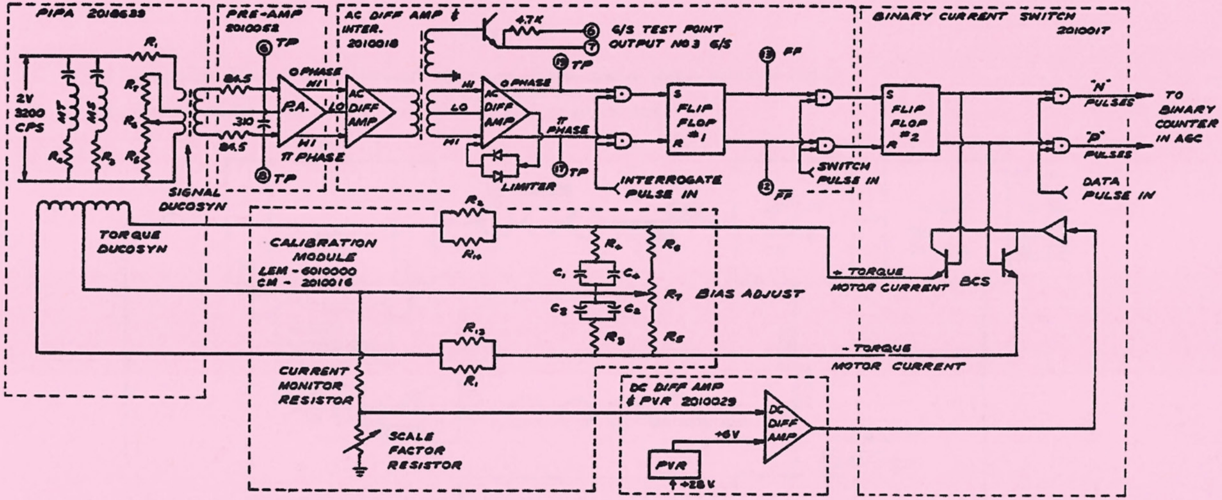
$BIAS_I$ is the bias for the I^{th} PIPA (an erasable load)

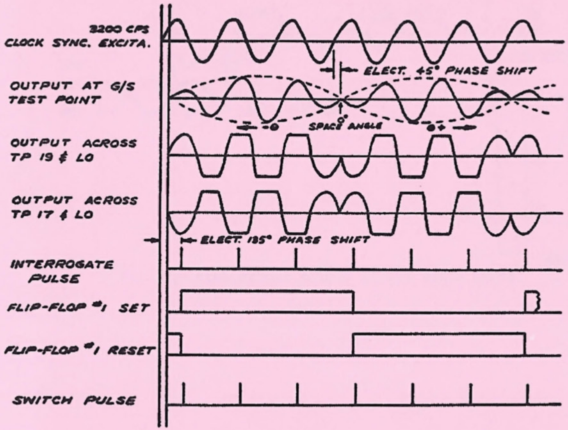
C/3 indicates assets common to all three loops.

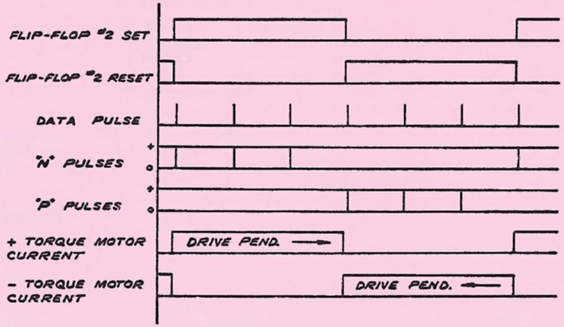


PTPS = Pulse Torque Power Supply. For Block II PTPS is in the PSA
For LEM PTPS is in the PTA
PEA = PIPA Electronics Header Assembly (CM); PTA = Pulse Torque Header Assembly (LEM).

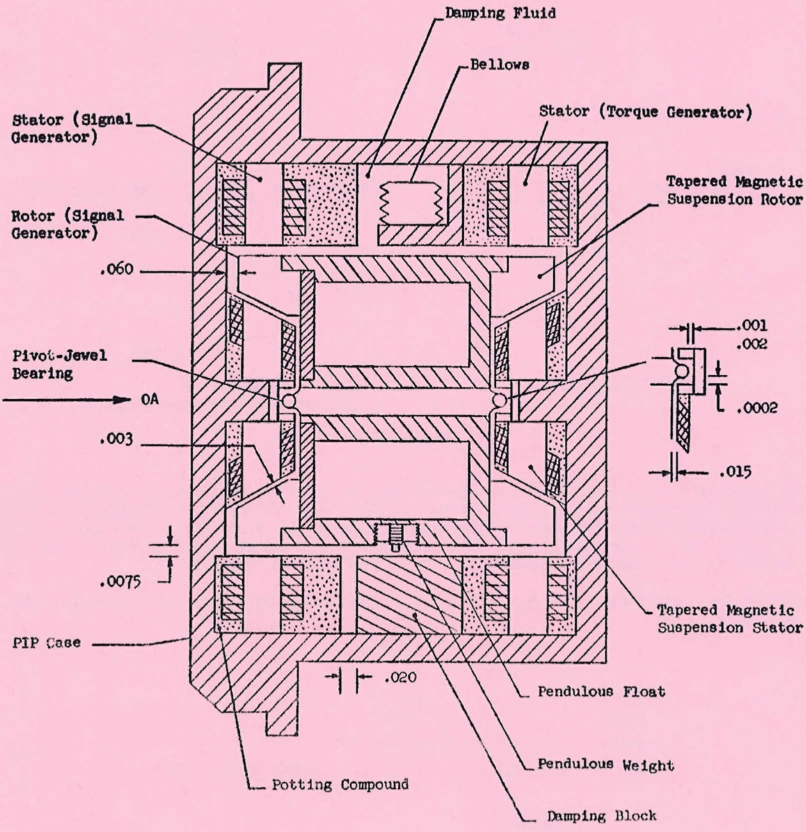
PIPA LOOP







PIPA LOOP TIME LINE FOR A 3:3 MODING CYCLE


Damping Fluid
Bellows
Stator (Signal Generator)
Stator (Torque Generator)
Tapered Magnetic Suspension Rotor
Rotor (Signal Generator)
.060
.001
.002
Pivot-Jewel Bearing
OA
.0002
.003
.015
.0075
Tapered Magnetic Suspension Stator
PIP Case
.020
Pendulous Float
Pendulous Weight
Potting Compound
Damping Block

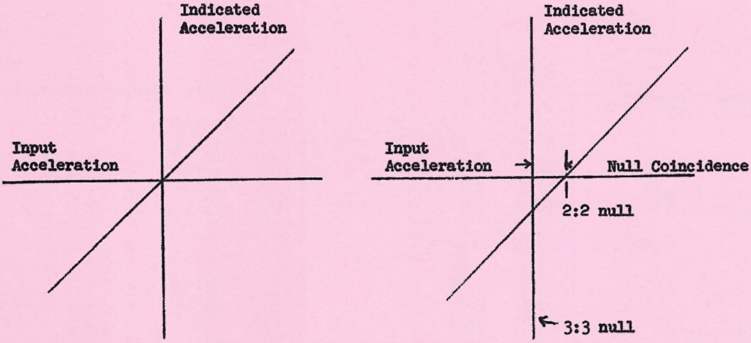
APOLLO PIP

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 unbalance 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.



Solid 3:3 moding PIPA

Solid 2:2 moding PIPA
(2:2 mode artificially achieved)

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 Δ V's and mode 3:3.

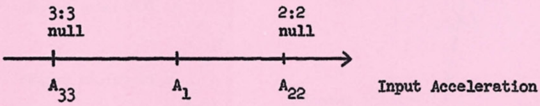


Figure 2

For an input acceleration of A_{22}, a dual moding PIPA will also issue zero Δ V's and mode 2:2. For an input acceleration between the A_{33} and A_{22} limits, the PIPA will issue zero Δ V'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.

HISTORY OF IN-FLIGHT PIPA PERFORMANCE

		AVG IN-FLIGHT ERROR*	CHANGE FROM (PREFLIGHT) COMP	LUNAR ORBITAL DEVIATIONS MINIMUM	LUNAR ORBITAL DEVIATIONS MAXIMUM
Apollo 8	X	-0.01	-	No Lunar Orbital Variations Available	
	Y	+0.03	-		
	Z	+0.00	-		
Apollo 9 CM	X	+0.02	+1.17	-0.39	-0.58
	Y	-0.04	+0.28	-0.32	-0.42
	Z	-0.08	-	+0.32	+0.42
LM	X	+0.01	-		
	Y	-0.15	-		
	Z	+0.01	-		
Apollo 10 CM	X	0.0	-0.27	0.0	-0.36
	Y	0.0	-	0.0	-0.29
	Z	0.0	-	0.0	+0.03
LM	X	-0.06	-		
	Y	-0.12	-		
	Z	0.03	-		
Apollo 11 CM	X	-	-	-0.07	-0.31
	Y	-0.02	-0.21	-0.25	+0.34
	Z	+0.03	+0.12	-0.01	+0.11
LM	X	-0.01	-		
	Y	+0.02	+0.06		
	Z	-0.03	+0.17		
Apollo 12 CM	X	+0.09	-	0.0	+0.27
	Y	-0.05	-	-0.08	-0.20
	Z	0.0	-	-0.04	-0.25
* LM	X	-0.05	-0.05 Pre-DOI		
		0.0	-0.15 Post-Ascent		
	Y	0.0	0.0 Pre-DOI		
		0.0	-0.18 Post-Ascent		
	Z	0.0	-0.06 Pre-DOI		
		0.0	+0.29 Post-Ascent		

*Deviations from compensation updates when made, or from preflight loads when no update was made. All units cm/s^2

**This IMU was turned off for ~27 hours on the lunar surface.

NOTE: Variations of CM bias in lunar orbit caused by variations in coolant temperature.

IMU COARSE ALIGN LOOP

The coarse align loop drives the IMU gimbals to the angles commanded by the computer with an accuracy of ± 1.5°. 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 ± 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

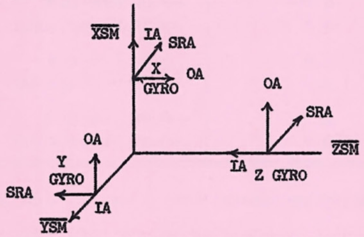
The elements of the inertial mode are the gyro, stabilization amplifier, and gimbal torque motor. The gyro senses inertial rotation about its input axis and supplies torquing to the gimbal via the stabilization amplifier to compensate for the motion.

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}	+NBDY	+ADIAY (a_{YSM})	-ADSRAY (a_{ZSM})
W_{ZSM}	-NBDZ	+ADIAZ (a_{ZSM})	+ADSRAZ (a_{YSM})

a_{XSM}, a_{YSM}, a_{ZSM} is positive along positive stable member axes.

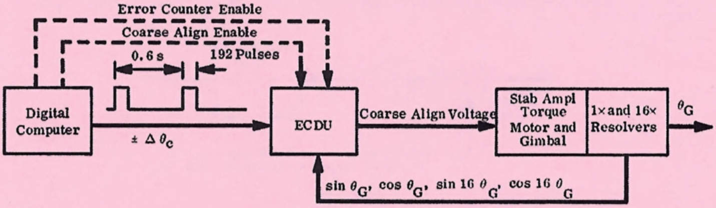


Gyro	IA Along	SRA Along	OA Along
X	$+\overline{XSM}$	$-\overline{YSM}$	$+\overline{ZSM}$
Y	$+\overline{YSM}$	$-\overline{ZSM}$	$+\overline{XSM}$
Z	$-\overline{ZSM}$	$-\overline{YSM}$	$+\overline{XSM}$

Input axes of the X, Y, Z accelerometers lie respectively along positive XSM, YSM, ZSM axes.

IMU COARSE ALIGN LOOP

The servomechanism used to achieve coarse align of the Block II IMU is shown below.



IMU Coarse Align Loop

Computer Operation

The following sequence of events is performed by the computer each time the Coarse Align program is entered.

1. Issue Coarse Align Enable. The computer sets Bit 4 of Channel 12 which issues the Coarse Align Enable discrete to the ECDU.
2. Issue Error Counter Enable. The computer sets Bit 6 of Channel 12 which issues the Error Counter Enable discrete to all three IMU axes of the ECDU.
3. Determine Command Angle. The contents of the computer gimbal angle counters are read and differenced with the desired gimbal angle to determine the command angle.
4. Issue Command Angle. Gimbal angle commands are issued in bursts of 192 pulses (8.4 degrees) at a rate of 3,200 pulses/second. Each burst requires 60 milliseconds. The delav between bursts is 540 milliseconds. If the command is not an integral multiple of 192 pulses, the remainder is issued as the last command. Gimbal commands are gated out of the computer by setting Bits 13, 14, and 15 of Channel 14. All three bits are set simultaneously, thereby allowing all three gimbals to be slewed simultaneously.
5. Determine If Command Angle Is Achieved. After gimbal commands have been issued, the computer reads gimbal position and compares the position achieved with the desired angle. If the difference is greater than 2.0 degrees, an alarm is issued.

Steps 1 through 5 constitute a computer control process which positions gimbals in an open loop sense. The computer does not check final gimbal position such that corrective commands can be issued if the desired position has not been reached. The check on final gimbal position is used to determine if an alarm condition exists.

ECDU Response to Coarse Align Enable

When addressed by the Coarse Align Enable discrete from the computer, the ECDU:

1. Provides a ground to the PSA coarse align input relays, thereby switching the stabilization amplifier inputs from IRIG outputs to the ECDU DAC output.
2. Supplies a ground for the PSA stabilization amplifier demodulator relay, thereby changing the reference excitation of the stabilization amplifier ring demodulators from 3,200 Hz to 800 Hz.
3. Provides grounds for the coarse align relay in each of the stabilization amplifiers, thereby changing stabilization amplifier servo compensation.
4. Generates an internal moding signal which enables gimbal feedback pulses ($\Delta 2^2$) to increment the error counter. This signal also changes the read counter high speed pulse rate (P_I pulses) from 12.8 kpps to 6.4 kpps.

ECDU Response to Error Counter Enable

When addressed by the Error Counter Enable discrete from the computer, the ECDU:

1. Generates an internal moding signal which allows error counter pulses ($P_E = \Delta 2^2$ or $\Delta\theta_c$) to increment the error counter. Absence of this discrete zeros the error counter and holds it there.
2. The Error Counter Enable command (E) is combined with the Coarse Align discrete (C_A) and the CDU Zero command (CDUZ) to mode the read counter in accordance with the following logic equation.

$$Y = \overline{E} \cdot C_A + CDUZ$$

where

a. The presence of Y inhibits P_I pulses from incrementing the read counter
b. $\overline{E}$ = Error Counter Enable "not"
c. C_A = Coarse Align Enable
d. CDUZ = CDU Zero Discrete
e. $E \cdot C_A$ is an "and" operation
f. + is an "or" operation

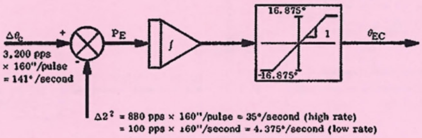
Inhibiting the read counter in this fashion will prevent gimbal drift due to residual voltages within the loop. The fine error will accumulate to a value such that the effect of residual voltages is cancelled.

ECDU Servo Control

Servoing the IMU to the correct position as commanded by the computer is achieved by a multiple loop system consisting of the error counter, a DAC, the coarse align mixing amplifier, a system of rate and switch selection logic, the read counter, and the stabilization loop.

Error Counter

The error counter provides digital differencing between gimbal commands and gimbal positions. Input pulses to the error counter are either position command pulses ($\Delta\theta_c$) from the computer or gimbal position feedback pulses ($\Delta 2^2$) from the read counter loop. Computer command pulses ($+\Delta\theta_c$) cause the error counter to count up. Read counter ($\Delta 2^2$) pulses will, in turn, count the error counter down, thereby, producing negative feedback. The error counter is also mechanized to inhibit (P_E) pulses when Bits 7 and 8 of the error counter are "1." The result is a limiting of the output at 11.25° + 5.625° or 16.875°. The total functional characteristic is shown below.



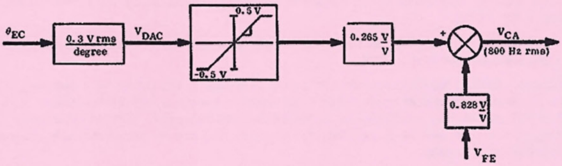
Error Counter

DAC (Digital to Analog Converter)

The DAC consists of logic switches driven by the error counter, a divide down resistive ladder network, and a scaling amplifier. The function of the DAC is to provide an 800 Hz signal whose amplitude is proportional to the angle content of the error counter. DAC sensitivity is adjusted to 0.3 Vrms/degree.

Coarse Align Mixing Amplifier

The coarse align mixing amplifier adds the fine error voltage and the DAC output with a mixing ratio of 3 to 1 in favor of the fine error input. DAC outputs to the coarse align mixing amplifier are diode-limited to 0.5 volt as shown below.



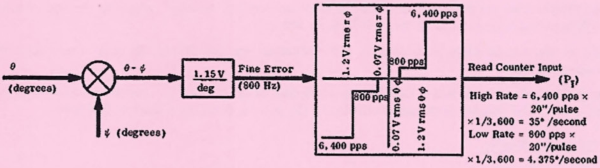
Coarse Align Mixing Amplifier

Fine System Switch Selection Logic

The fine system switch selection logic is a network of weighting resistors, summing amplifiers, and switches used to implement the trigonometric identity $-\sin(\theta - \psi) = -\sin\theta\cos\psi + \cos\theta\sin\psi$. Functionally, this network compares the gimbal angle (θ) as represented by the 16-speed resolver signals to the read counter angle (ψ) and generates an error signal used to drive the read counter loop.

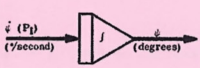
Rate Select and Up/Down Logic

Rate select and up/down logic is generated from the fine error signal (an analog measure of the error between resolver angle and read counter angle) by Schmitt trigger type level detectors. The rate select and up/down logic processes the sampled output of the Schmitt triggers to determine at which rate the read counter should be incremented. If the output of the high speed Schmitt is high (1.7-volt trigger threshold), the read counter is incremented at 6,400 pps; if the output of the fine Schmitt is high (0.1-volt trigger threshold), the rate is 800 pps. Thus, in one sample time the read counter will be incremented 1 bit at low speed or 8 bits at high speed. The functional equivalent of System Rate and Switch Selection is shown below.



Read Counter

The read counter is a 16-stage digital counter with an IMU angle granularity of 20 seconds/bit. Inputs to the read counter are controlled by rate select and up/down logic. The output is used by the fine system switch selection logic to produce the fine error signal. Access by the computer is to the low order bit ($\Delta 2^0$). Access by the error counter is to the third order bit ($\Delta 2^2$). Functionally, the read counter is represented as an integrator with a count rate in degrees/second and an output in degrees.

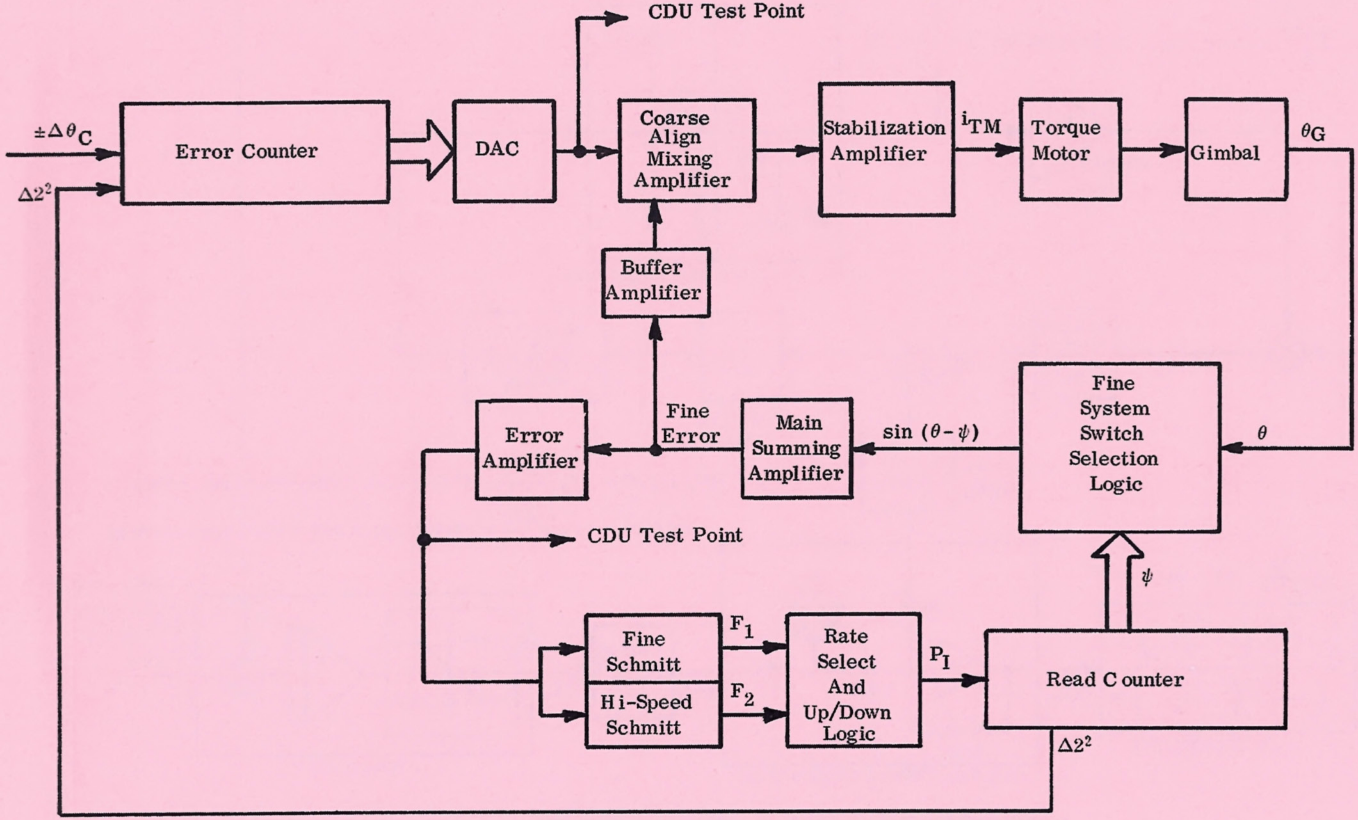


Stabilization Loop

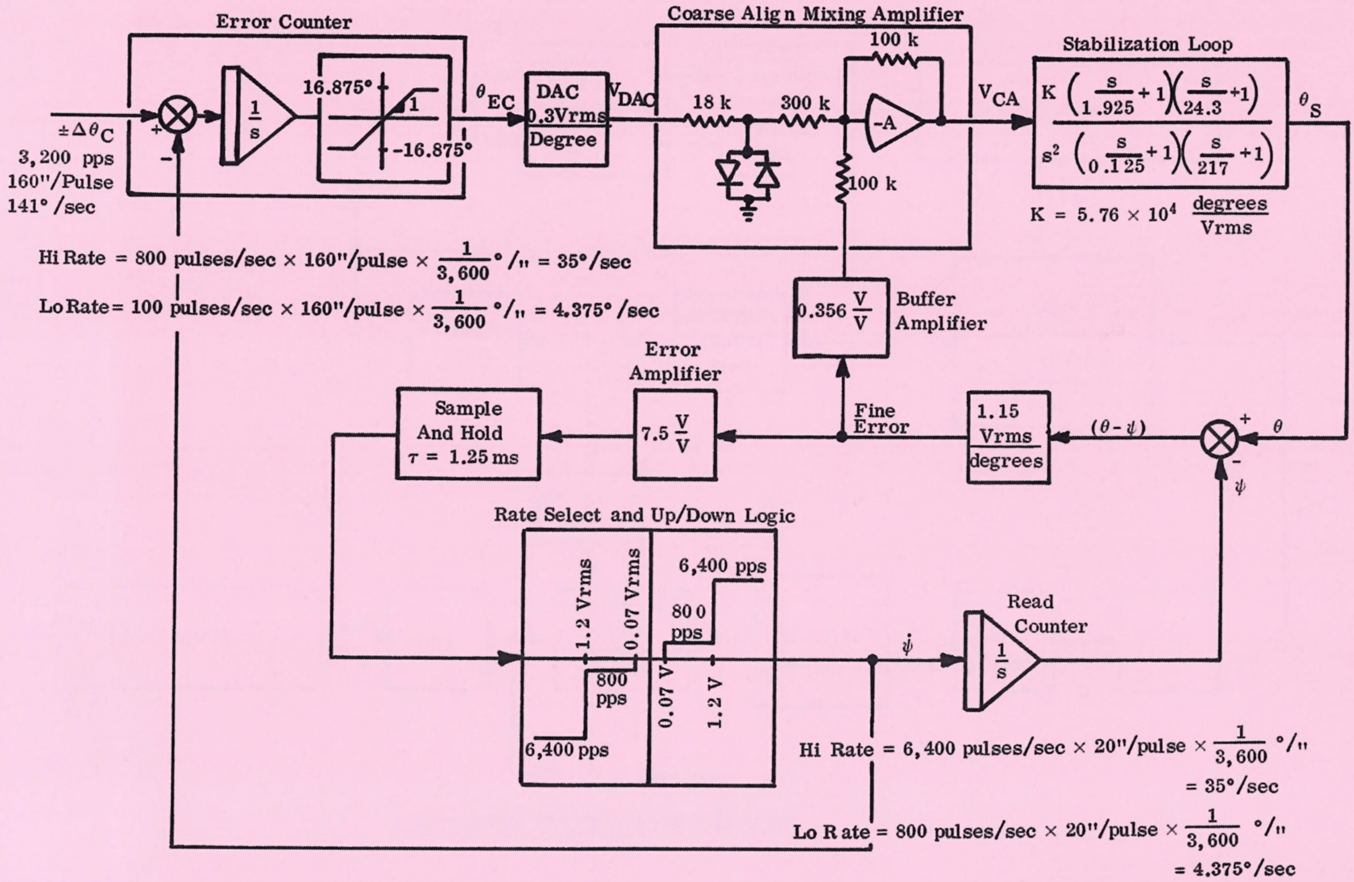
The analog part of the coarse align servomechanism consists of the stabilization amplifier, torque motor, and gimbal. The overall transfer function of the above three elements is as shown below.

$$\underset{(800\ \text{Hz rms})}{V_{CA}} \longrightarrow \boxed{\frac{57.750\left(\frac{s}{1.925}+1\right)\left(\frac{s}{24.3}+1\right)}{\left(\frac{s}{0.125}+1\right)\left(\frac{s}{217}+1\right)s^2}} \longrightarrow \underset{(\text{degrees})}{\theta_G}$$

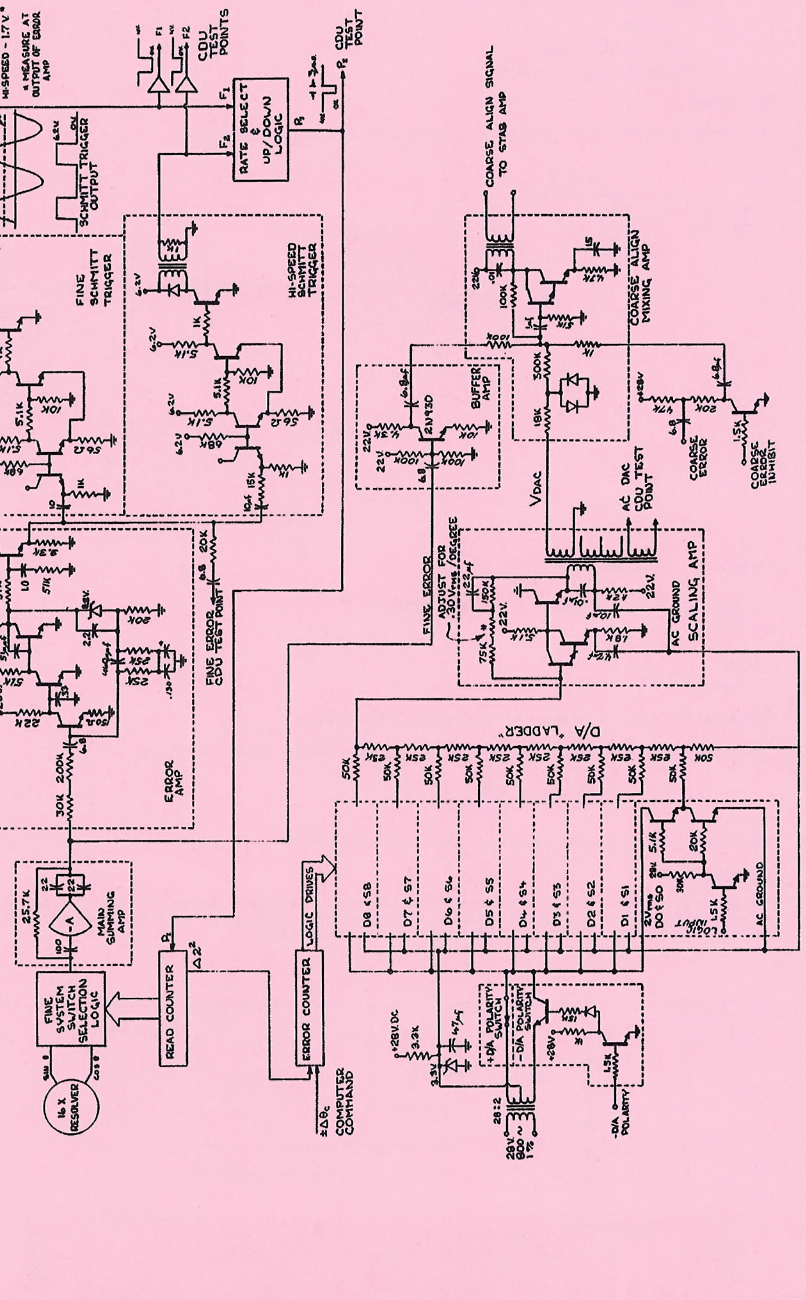
IMU COARSE ALIGN BLOCK DIAGRAM



IMU COARSE ALIGN FUNCTIONAL BLOCK DIAGRAM



ECDU COARSE ALIGN NETWORK



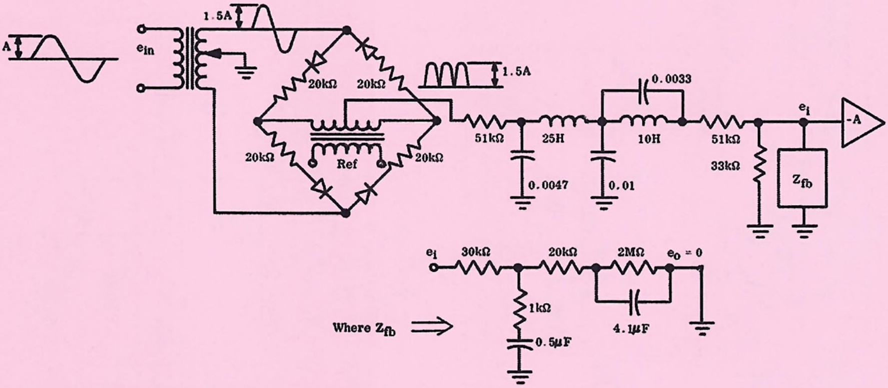
IMU INERTIAL MODE

The circuitry employed by the Block II stabilization amplifier operates on IRIG error signals in the following sequence:

1. Input network
   a. Full wave phase sensitive ring demodulator
   b. AC ripple filter
2. High gain amplifier and torque motor current driver
3. Feedback network
   a. Armature current sampler
   b. R-C servo compensation network

<u>Input Network</u>

The input gain characteristic of the stabilization amplifier originates from the circuit shown below.



The gain factor relating demodulator output to IRIG input is:

$$\frac{V_{dc}}{V_{rms}} = 1.5 \text{ (XFMR scale factor) } \times 1.414 \left(\frac{\text{ac peak-to-peak}}{\text{ac V rms}}\right) \times \frac{2^*}{\pi}$$

$$\frac{V_{dc}}{V_{rms}} = 1.35 \text{ V/V}$$

$^*\frac{2}{\pi}$ is the dc component of the Fourier series of a full wave rectified signal.

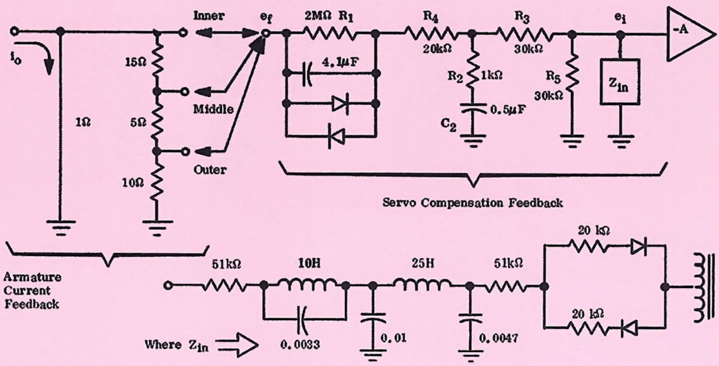
The total input gain relating IRIG error signals (3,200 Hz) to dc volts at the High Gain Amplifier input is

$$\frac{e_o}{e_{in}} = 1.35 \frac{V_{dc}}{V_{rms}} \times \frac{33\text{ k}\Omega}{145\text{ k}\Omega} = 0.307 \frac{V_{dc}}{V_{rms}} \text{(IRIG)}$$

Where 33 kΩ/145 kΩ is the effective "divide down" resistance of the input network.

<u>Feedback Network</u>

The feedback gain characteristic of the stabilization amplifier originates from armature current feedback of the gimbal drive motors. A 1-ohm resistor is inserted in series with the armature winding of each motor to detect armature current. The appropriate feedback gain unique to each gimbal loop is obtained with the divide-down networks shown below



where

$$e_{fb} \text{ (inner loop)} = (i_{TM}) \left(\frac{1 \times 30}{1 + 30}\right) = \frac{30}{31}\, i_{TM}$$

$$e_{fb} \text{ (middle loop)} = (i_{TM}) \left(\frac{15}{30}\right)\left(\frac{30}{31}\right) = \frac{15}{31}\, i_{TM}$$

$$e_{fb} \text{ (outer loop)} = (i_{TM}) \left(\frac{10}{30}\right) \left(\frac{30}{31}\right) = \frac{10}{31}\, i_{TM}$$

Frequency shaping of torque motor current is achieved with the passive "T" network shown above. The frequency response characteristic of the feedback compensation network is:

$$\frac{e_o}{e_{fb}} = 0.020 \frac{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)}{\left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)} \quad \text{volts/volt}$$

with the feedback diodes not conducting.

$$\frac{e_o}{i_{TM}} = \left(\frac{30}{31} \text{ or } \frac{15}{31} \text{ or } \frac{10}{31}\right) 0.020 \frac{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)}{\left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)}$$

Assuming an ideal High Gain Amplifier, the input and feedback networks can be combined as if each were working into an operational amplifier thus:

$$\frac{i_{TM}}{V_{rms\ (IRIG)}} = \frac{\text{Input Network}}{\text{Feedback Network}} = \frac{0.307}{0.020} \frac{\left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)}{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)}$$

$$\frac{i_{TM\ (Adc)}}{V_{IRIG}\ (\text{Vrms ac})} = \frac{15\left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)}{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)} \quad \text{A/V (inner axis)}$$

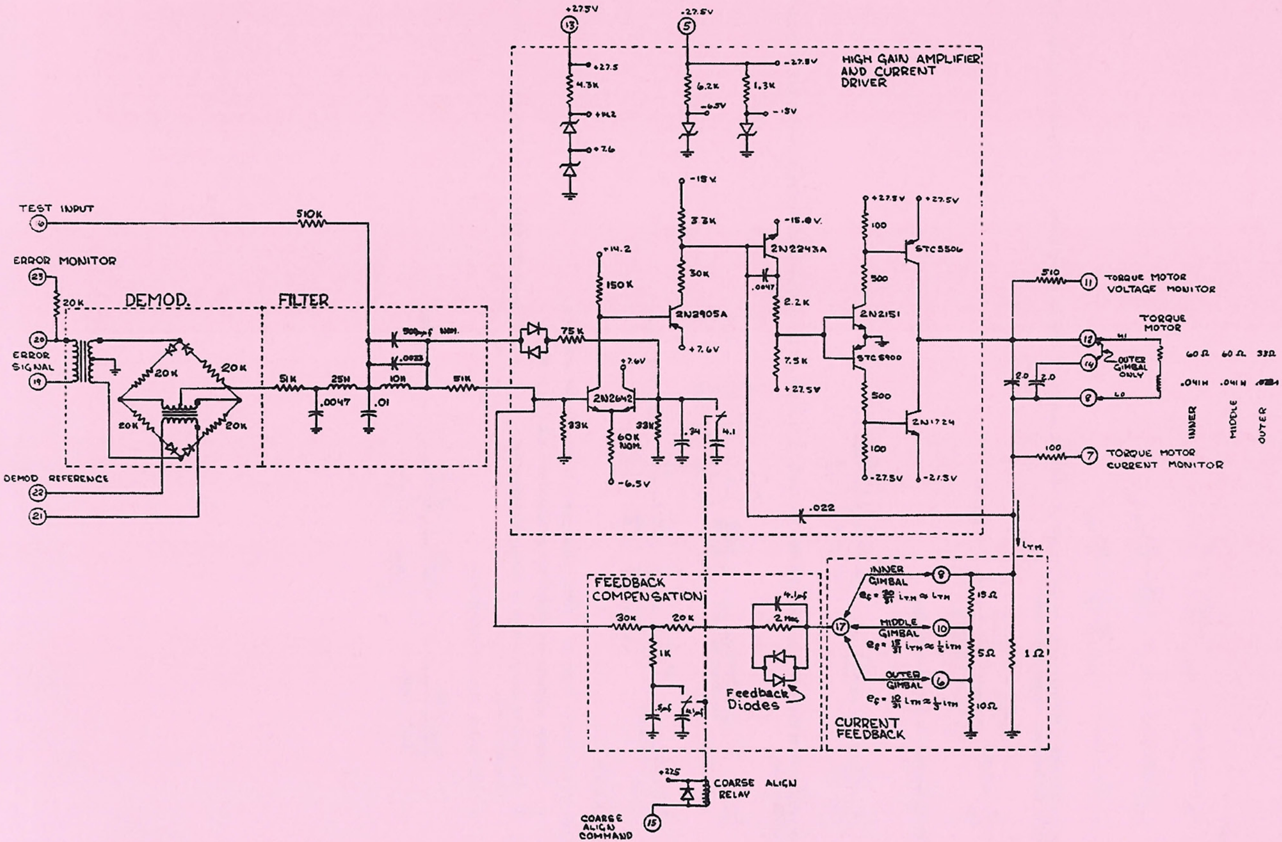
<u>Course Align</u>

When used for coarse align, the stabilization amplifier is reconfigured as follows:

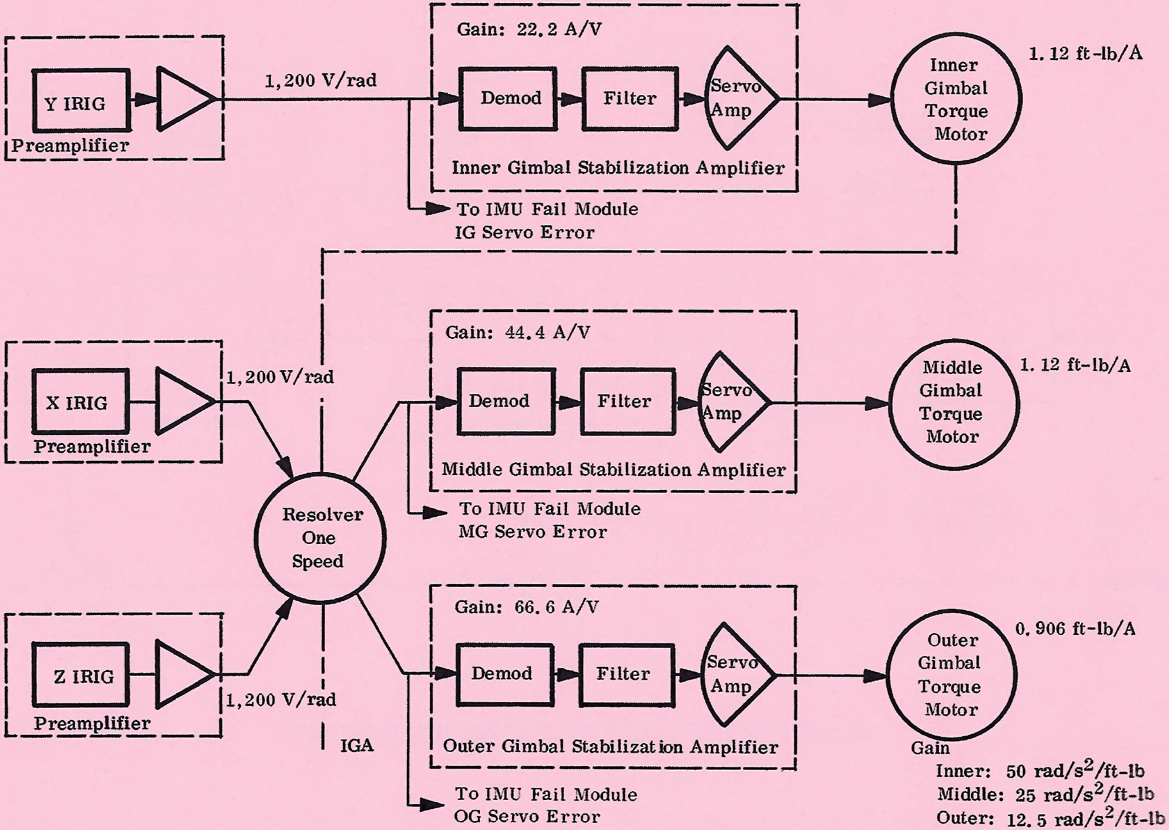
1. The input and reference signals are switched from 3,200 Hz to 800 Hz.
2. The feedback compensation is changed by connecting a 4.1 μF capacitor in parallel with the 0.5 μF capacitor used for the inertial mode.
3. The coarse align compensation is:

$$\frac{i_{TM}\ (\text{Adc})}{V_{DAC}\ (\text{Vrms ac})} = 15 \frac{\left(\frac{s}{1.925} + 1\right)\left(\frac{s}{24.3} + 1\right)}{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{217} + 1\right)} \quad \text{inner loop}$$

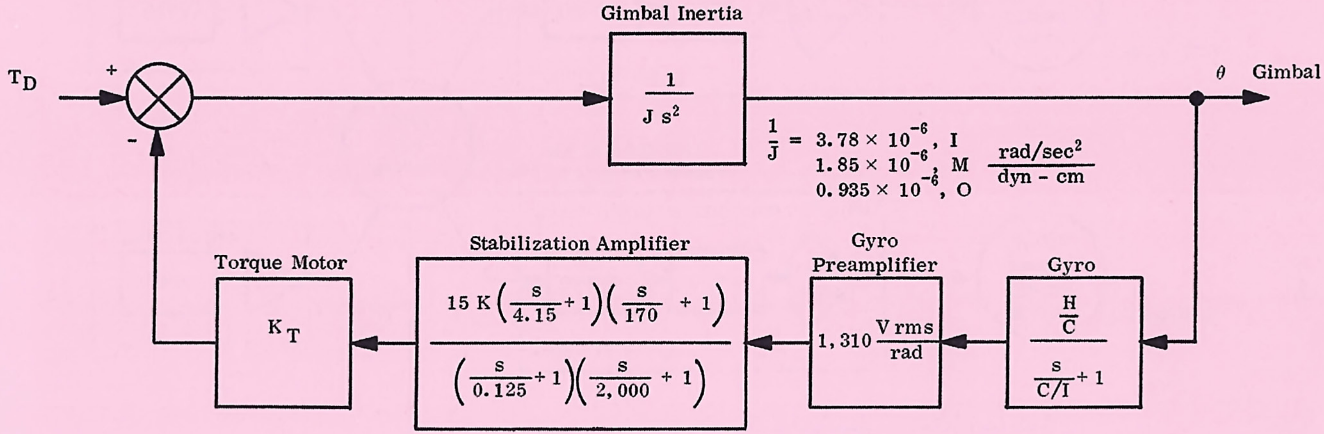
IMU STABILIZATION AMPLIFIER



IMU "INERTIAL MODE" BLOCK DIAGRAM



IMU "INERTIAL MODE" FUNCTIONAL BLOCK DIAGRAM

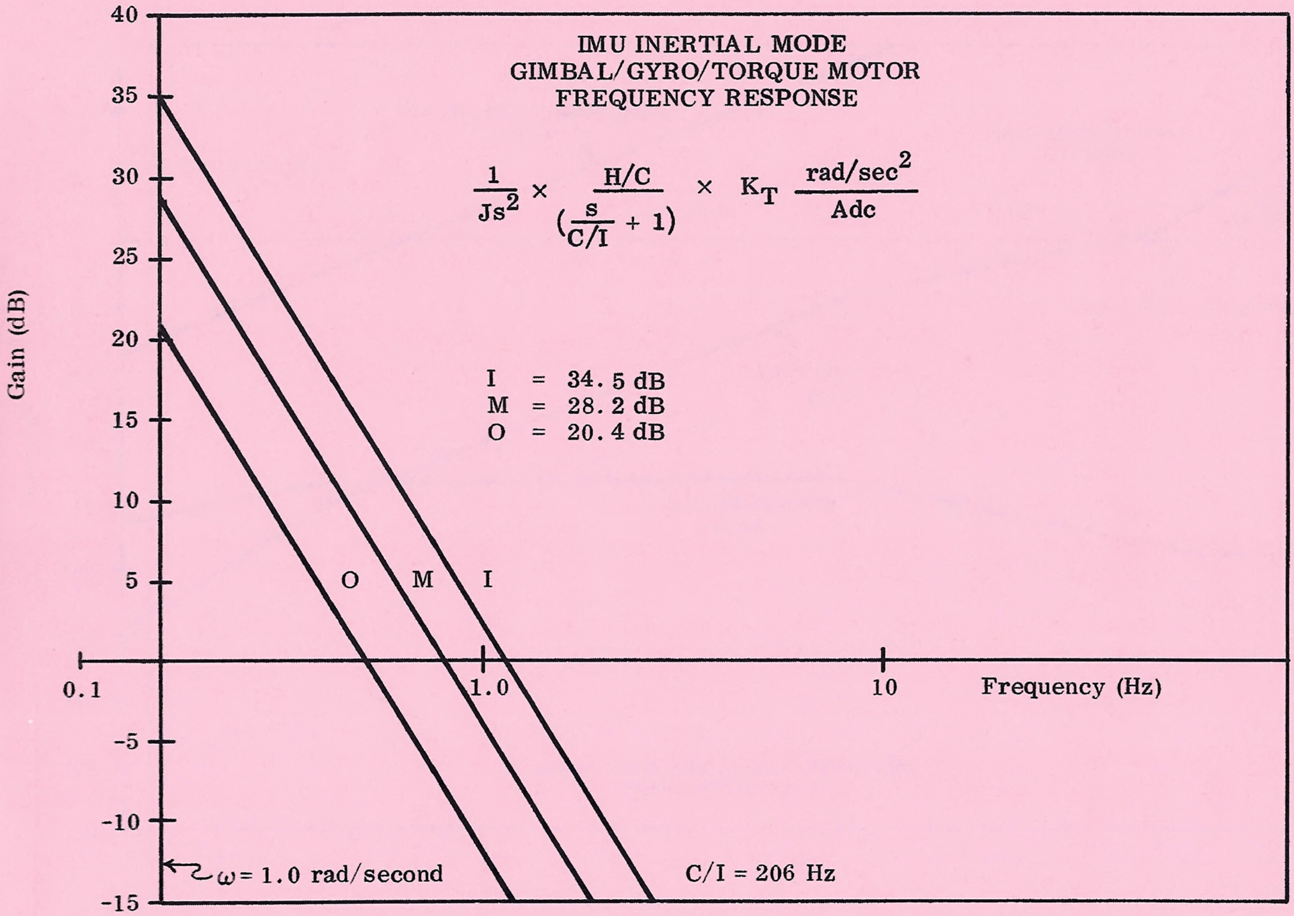


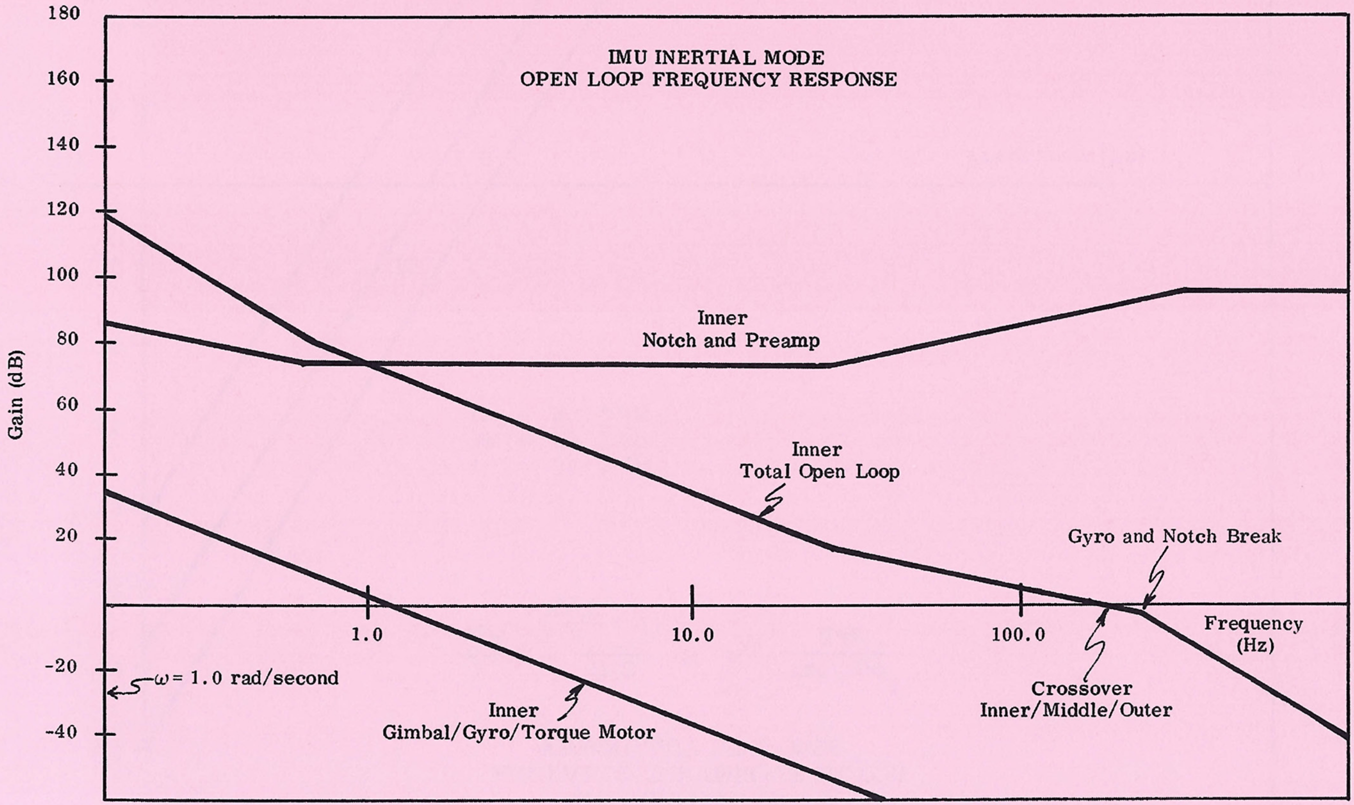
$$\frac{1}{J} = \begin{array}{l} 3.78 \times 10^{-6},\ I \\ 1.85 \times 10^{-6},\ M \\ 0.935 \times 10^{-6},\ O \end{array} \quad \frac{rad/sec^2}{dyn - cm}$$

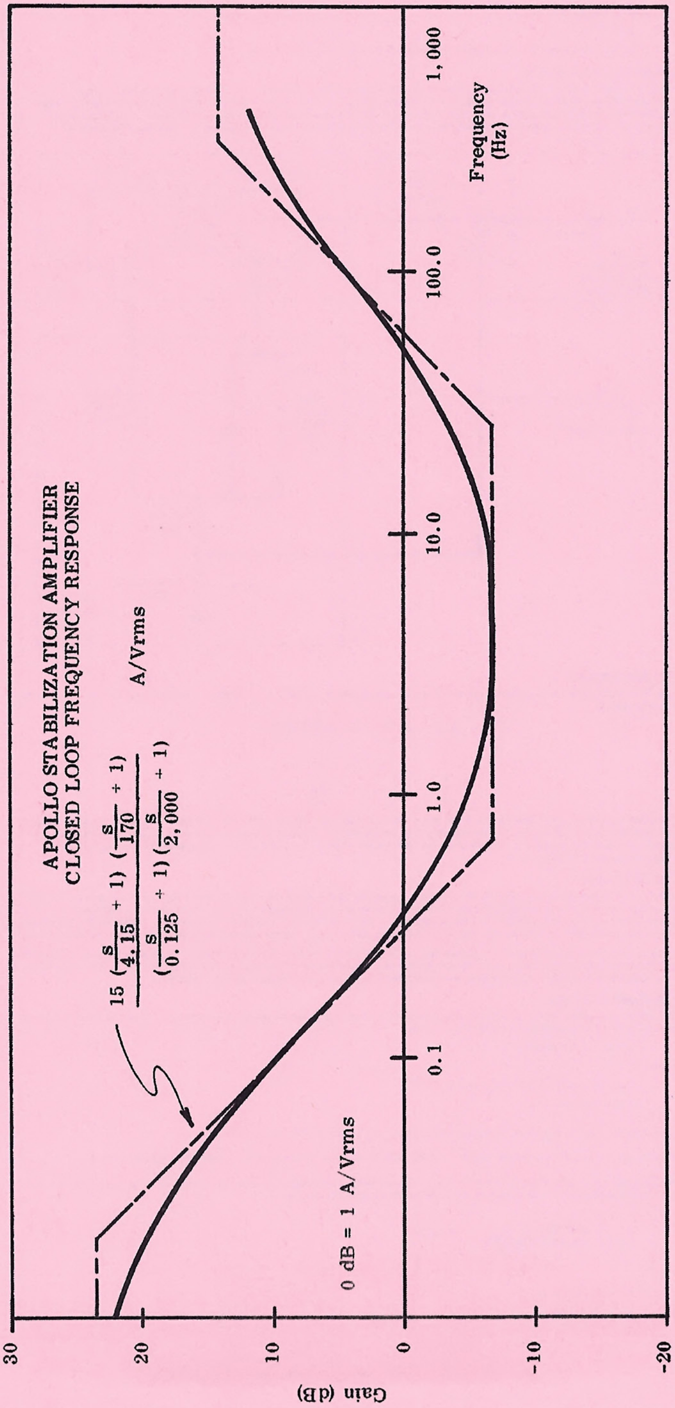
$$K_T = 1.52 \times 10^7 \frac{dyn - cm}{A},\ I$$
$$1.52 \times 10^7 \frac{dyn - cm}{A},\ M$$
$$1.23 \times 10^7 \frac{dyn - cm}{A},\ O$$

$$K = 1 \frac{A}{V\ rms},\ I$$
$$2 \frac{A}{V\ rms},\ M$$
$$3 \frac{A}{V\ rms},\ O$$

$$H = 0.434 \times 10^6 \frac{dyn - cm}{rad/sec}$$
$$C = 0.475 \times 10^6 \frac{dyn - cm}{rad/sec}$$
$$I = 367\ gm - cm^2$$
$$H/C = 0.915$$
$$C/I = 1,290\ rad/sec$$


IMU INERTIAL MODE
GIMBAL/GYRO/TORQUE MOTOR
FREQUENCY RESPONSE
$\frac{1}{Js^2} \times \frac{H/C}{\left(\frac{s}{C/I} + 1\right)} \times K_T \frac{rad/sec^2}{Adc}$
I = 34.5 dB
M = 28.2 dB
O = 20.4 dB
O
M
I
Gain (dB)
40
35
30
25
20
15
10
5
-5
-10
-15
0.1
1.0
10
Frequency (Hz)
ω = 1.0 rad/second
C/I = 206 Hz


IMU INERTIAL MODE
OPEN LOOP FREQUENCY RESPONSE
Gain (dB)
180
160
140
120
100
80
60
40
20
-20
-40
1.0
10.0
100.0
Frequency
(Hz)
Inner
Notch and Preamp
Inner
Total Open Loop
Gyro and Notch Break
Crossover
Inner/Middle/Outer
Inner
Gimbal/Gyro/Torque Motor
ω = 1.0 rad/second


APOLLO STABILIZATION AMPLIFIER
CLOSED LOOP FREQUENCY RESPONSE
$\dfrac{15\left(\frac{s}{4.15}+1\right)\left(\frac{s}{170}+1\right)}{\left(\frac{s}{0.125}+1\right)\left(\frac{s}{2,000}+1\right)}$ A/Vrms
0 dB = 1 A/Vrms
Gain (dB)
30
20
10
0
-10
-20
0.1
1.0
10.0
100.0
1,000
Frequency
(Hz)

GYRO PULSE TORQUING

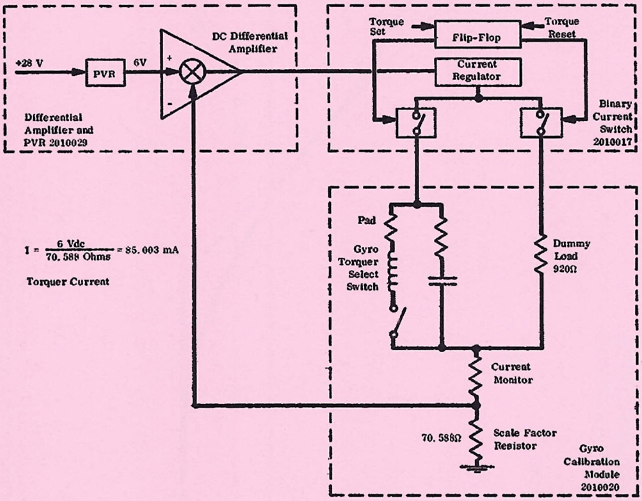
Gyro torque, its corresponding precession rate, and hence gimbal position are controlled by regulating the pulse width of gyro torquer current. In the Fine Align mode, the length of the torquer current pulse is precisely controlled by the computer to achieve a desired gimbal position.

To torque a particular gyro, the following sequence of commands is issued by the computer:

1. Gyro Torque Enable
2. Gyro Select
3. Gyro Set (the Gyro Reset command is issued at all times when Gyro Set is off)

Gyro Torque Enable Command

The Gyro Torque Enable command is issued by the computer through Bit 6 of Channel 14. The Bit 6 gates a 102.4 kHz pulse train out of the computer to a relay driver in the Gyro Calibration Module. When actuated, 28 Vdc is applied to the Precision Voltage Reference (PVR) supply and 120 Vdc is applied to the Binary Current Switch and DC Differential Amplifier. The Gyro Torque Enable command must be issued 20 milliseconds prior to the Gyro Select Command to assure ample time for relay closure.



Gyro Select Command

The Gyro Select command is controlled by the computer through Bits 7, 8, and 9 of Channel 14. The selection logic is shown in the following table:

BIT 7	BIT 8	BIT 9	TORQUER WINDING
0	1	0	+Y
0	1	1	-Y
1	0	0	+X
1	0	1	-X
1	1	0	+Z
1	1	1	-Z

The mode logic shown above gates a 102.4 kHz pulse train out of the computer to one of six transistor switches in the Gyro Calibration Module. This pulse train will close the transistor switch, thereby enabling torquer current when the Gyro Set command is issued. If more than one gyro is to be torqued, the order of selection is Y, Z, and X with each gyro being completely torqued before the next one is selected.

Gyro Set Command

The Gyro Set command is controlled by the computer through Bit 10 of Channel 14. This bit sets a flip-flop which gates a 3.2 kHz pulse train out of the computer to the Binary Current Switch via the Gyro Calibration Module. When actuated in this manner, gyro torque current is switched from the 920-ohm dummy load to the torque winding selected by the computer. When the desired number of set pulses has been issued, the flip-flop is reset causing current to be transferred from the torquer winding to the dummy load.

If the number of set pulses to be issued is less than 16,384, they are all issued in a single burst at a rate of 3,200 pps. If the number is greater than 16,384, they are divided into groups of 8,192 pulses plus a remainder. Gimbal positioning is then achieved by issuing successive bursts of 8,192 pulses, each separated by a 30-millisecond delay, plus the remainder.

Pulse Torque Scale Factor

The pulse torque scale factor, in arc-seconds of gimbal travel per computer set pulse, is 0.617981±1,750 ppm at the G & N level of test. The torque produced by each gyro torquer is:

$$T = Ki = 4,335 \text{ dyne-cm}$$

where

K is microsyn sensitivity in dyne-cm/amp^2

i is microsyn current

Each torquer is padded to provide 4,335 dyne-cm of torque for a current of 85.003 mA.

Torquer current is precisely set and regulated by the PVR and the scale factor resistor in the Gyro Calibration Module.

The gyro pulse torque loop operates to achieve gimbal positioning under computer control by controlling the gyro precession rate and, hence, gimbal rate. The maximum slew rate capability of this system is:

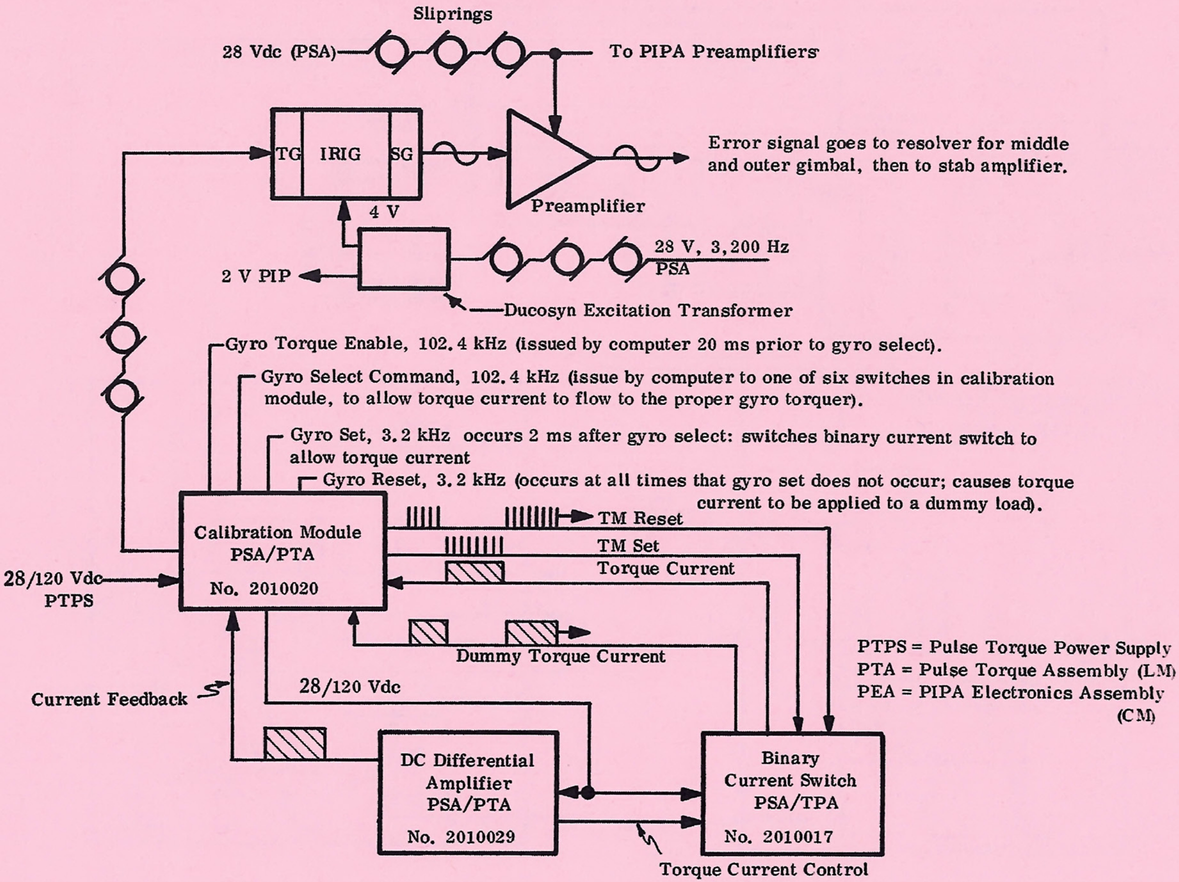
$$\dot{\theta} = \frac{T}{H} = \frac{4335 \text{ dyne-cm}}{0.434 \times 10^6 \, \frac{\text{dyne-cm}}{\text{rad/s}}} = 10 \text{ mrad/s}$$

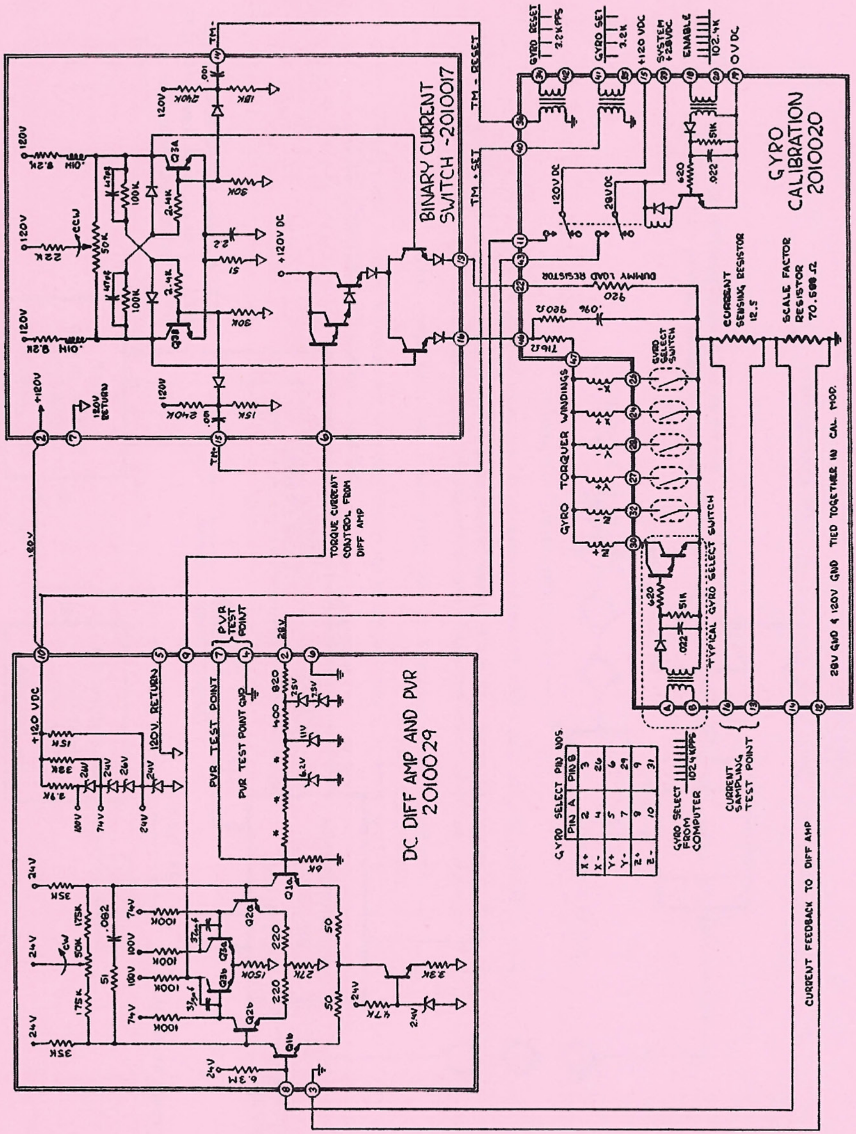
where

T = microsyn torque

H = gyro angular momentum

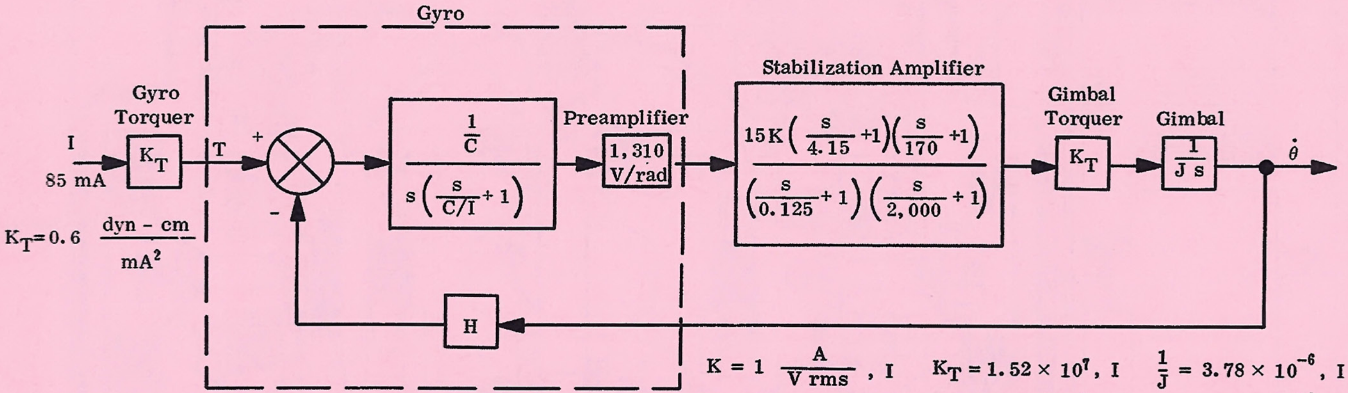
GYRO PULSE TORQUING LOOP





GYRO PULSE TORQUING LOOP

IMU FINE ALIGN FUNCTIONAL BLOCK DIAGRAM



$H = 0.434 \times 10^6 \ \frac{\text{dyn - cm}}{\text{rad/sec}}$

$C = 0.475 \times 10^6 \ \frac{\text{dyn - cm}}{\text{rad/sec}}$

$I = 367 \text{ gm - cm}^2$

$K = 1 \ \frac{\text{A}}{\text{V rms}}$, I

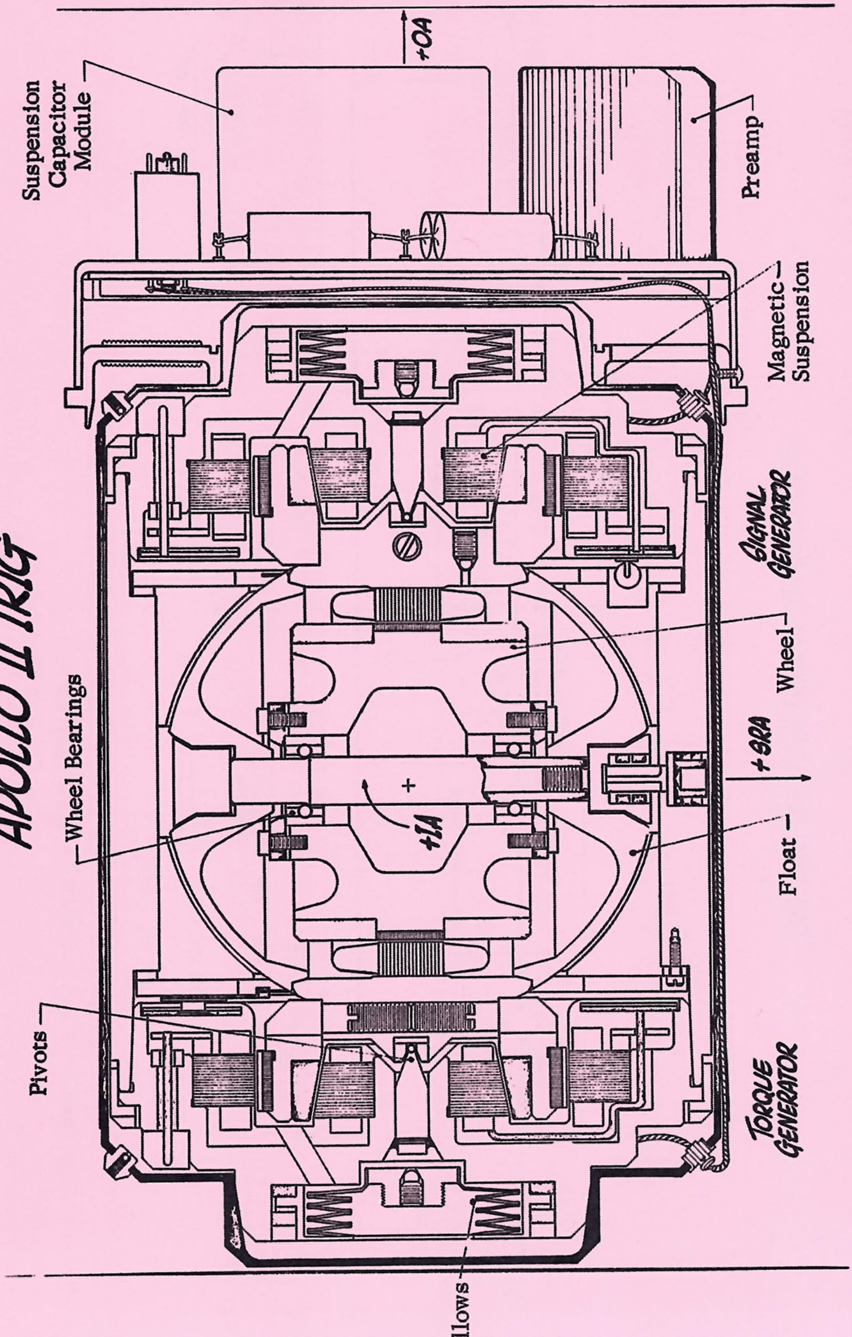
$K = 2$, M

$K = 3$, O

$K_T = 1.52 \times 10^7$, I
$= 1.52 \times 10^7$, M
$= 1.23 \times 10^7$, O
$\frac{\text{dyn - cm}}{\text{A}}$

$\frac{1}{J} = 3.78 \times 10^{-6}$, I
$= 1.85 \times 10^{-6}$, M
$= 0.935 \times 10^{-6}$, O
$\frac{\text{rad/sec}^2}{\text{dyn - cm}}$

Gyro Torque $= K_T I^2 = 0.6(85)^2 = 4,335$ dyn - cm


APOLLO II IRIG
+OA
Suspension Capacitor Module
Preamp
Magnetic Suspension
SIGNAL GENERATOR
Wheel
+SRA
Float
+IA
Wheel Bearings
Pivots
TORQUE GENERATOR
Bellows

APOLLO 25 IRIG

Moments of Inertia:

about OA:	367.3 gram-cm^2
about IA:	650.8 gram-cm^2
about SRA:	724.9 gram-cm^2

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-cm^2 sec

Signal Generator:

Input: 4 volts, 3200 cps
Sensitivity: 10 mv/mrad

Torque Generator Sensitivity: 0.6 dyne-cm/ma^2

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/$^\circ$ F
Drift:	0.2 meru/$^\circ$ F

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/LM
ADIA	meru/g	862 /630
ADSRA	meru/g	862 /630
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

$$XIRIG = -ADIAX\ PIPAX_C + ADSRAX\ PIPAY_C - NBDX\ \Delta t$$

$$YIRIG = -ADIAY\ PIPAY_C + ADSRAY\ PIPAZ_C - NBDY\ \Delta t$$

$$ZIRIG = -ADIAZ\ PIPAZ_C - ADSRAZ\ PIPAY_C + NBDZ\ \Delta t$$

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)

ADIAX, ADIAY, ADIAZ are gyro drifts due to acceleration in the input axis (an erasable load)

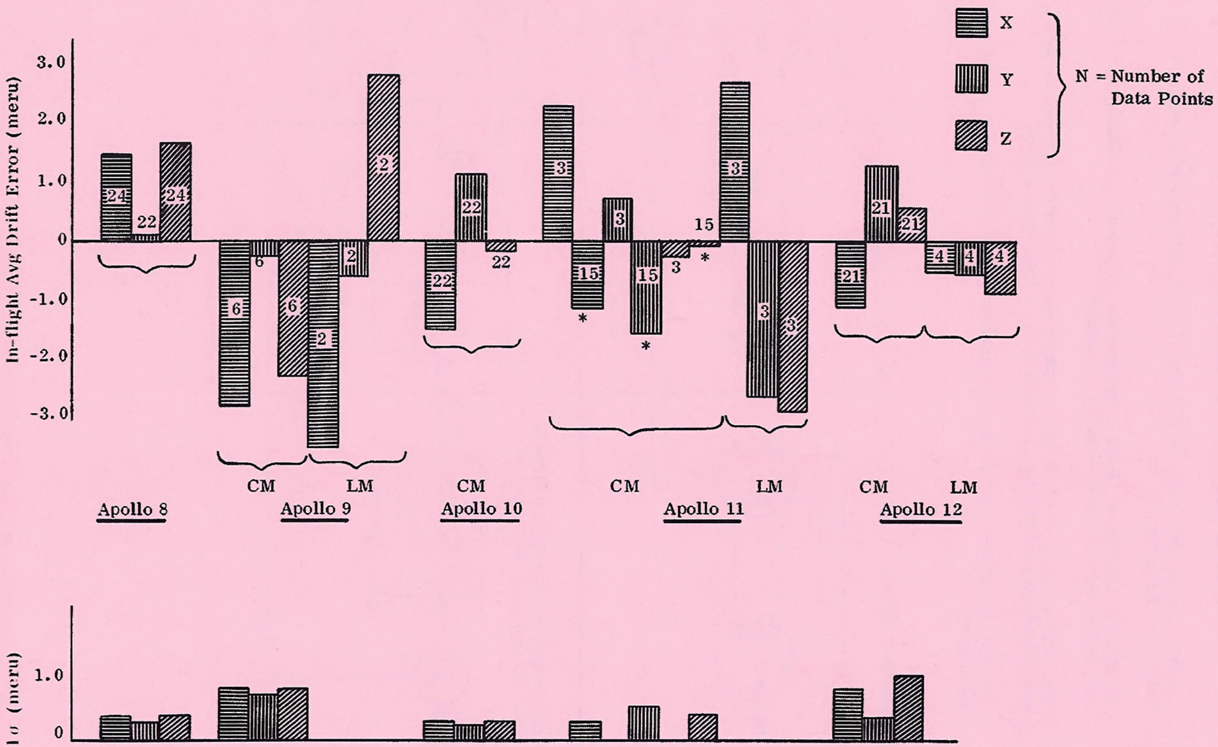
When the magnitude of any IRIG command exceeds two pulses, the commands are sent to the gyros.

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 DRIFT NBD = (.007835) (Reg Contents in Decimal) MERU

HISTORY OF IN-FLIGHT GYRO DRIFT ERRORS



*After in-flight compensation change

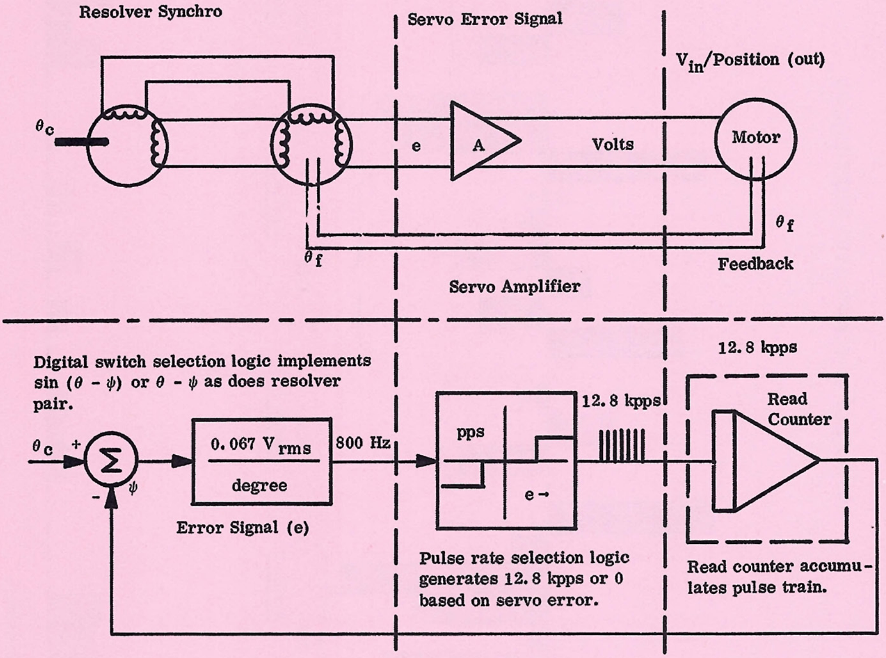
ELECTRONICS COUPLING DISPLAY UNIT (ECDU)

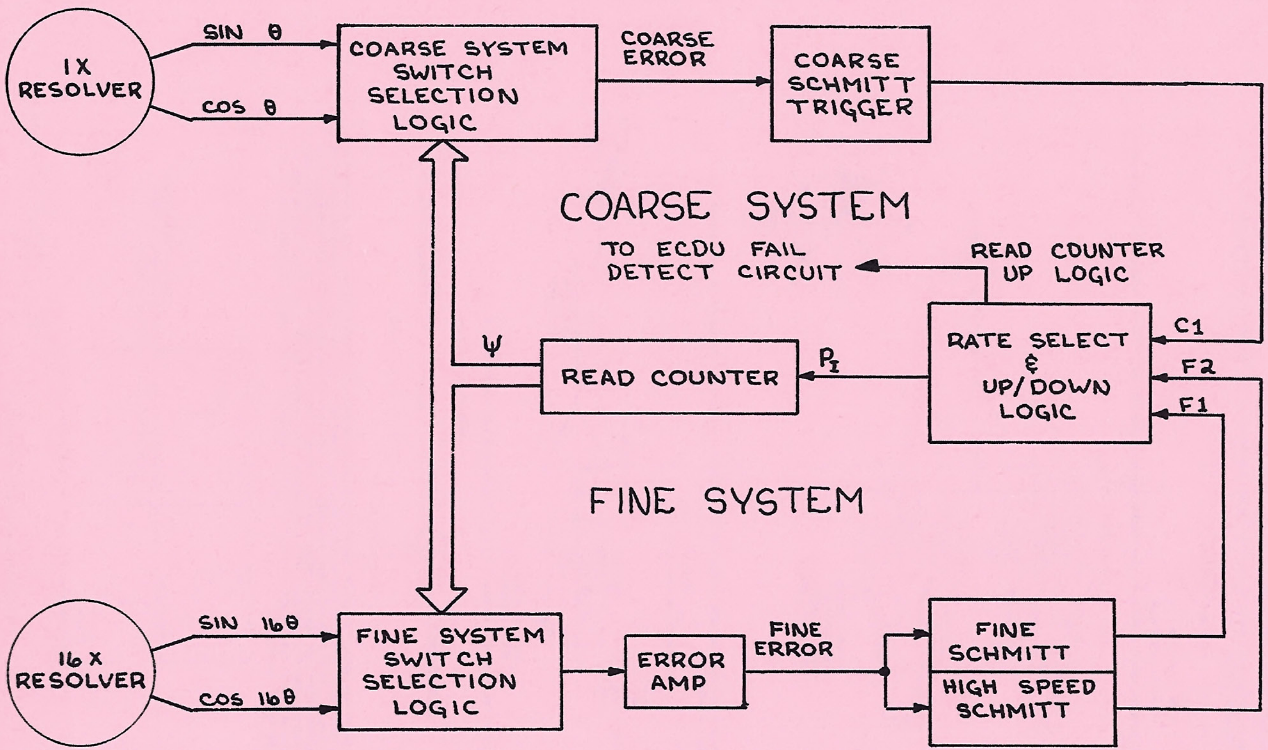
The ECDU encodes and scales the IMU gimbal angles and transfers the angles to the computer in the proper format.

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 × gimbal resolver (the fine system); the other encoding loop is used with the 1 × 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

ELECTRONICS COUPLING DISPLAY UNIT ECDU (CONTINUED)

The ECDU is an analog-to-digital converter which utilizes two encoding loops and one read counter to which the computer has access. One loop designated the "fine system" is used to encode 16× gimbal resolver angles. The other, a "coarse system," encodes 1× gimbal resolver angles.

When the difference between a gimbal resolver angle and the ECDU read counter exceeds 8.4 degrees, the "coarse system" has exclusive control of the read counter. For errors smaller than 8.4 degrees, the "fine system" has exclusive control of the read counter.

Coarse System

The coarse system utilizes a system of switch selection logic, weighting resistors, and summing amplifiers to generate a trigonometric identity of the form:

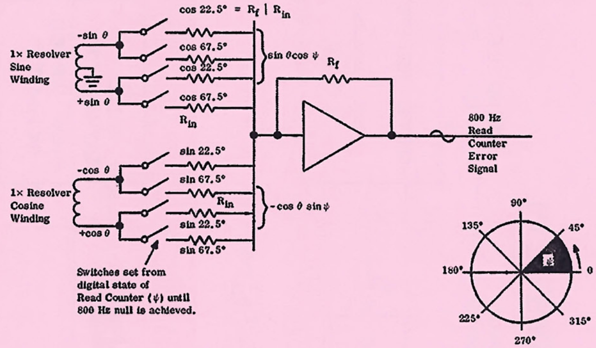
$$-\sin(\theta - \psi) = -\sin\theta\cos\psi + \cos\theta\sin\psi$$

where

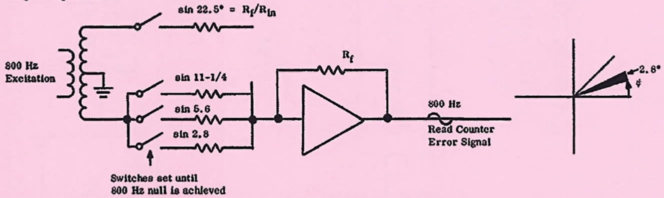
θ = the gimbal angle

ψ = the read counter angle

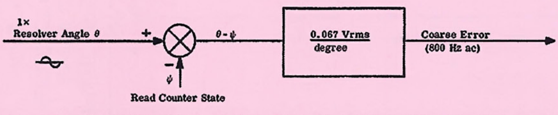
This trigonometric identity is used as an error signal to drive the read counter until ψ has been isolated to one of eight 45-degree segments.



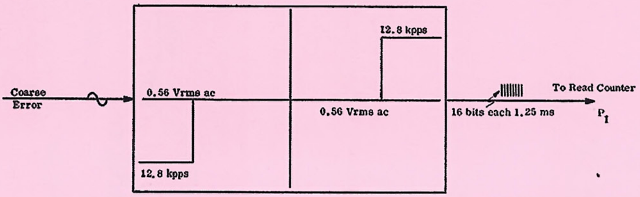
A ladder network provides an additional signal which drives the read counter until ψ has been further isolated to one of 16, 2.8-degree segments.



The functional equivalent of the entire coarse system error detecting logic is as shown below.



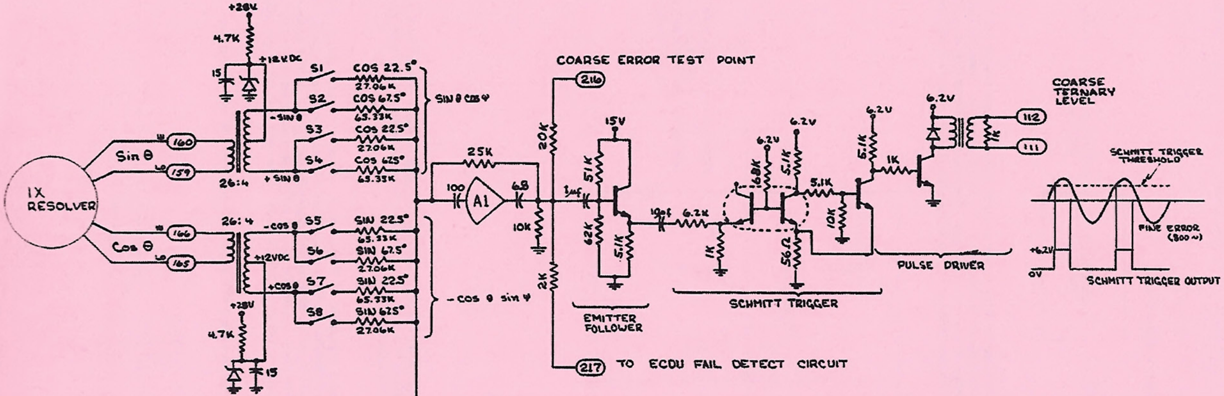
In the manner shown above, the error between the 1× resolver position and the digital state of the read counter is converted to an 800 Hz analog signal. This is converted back into a digital drive signal for the read counter by the "coarse Schmitt trigger and rate selection logic." The coarse Schmitt trigger threshold is set at 0.56 Vrms (8.4 degrees) thereby deactivating the coarse read counter loop when the error between 1× resolver position and the read counter is less than 8.4 degrees. The pulse train output of the Schmitt trigger is interrogated by a 1,600 pps impulse train. When the coarse Schmitt is detected high, the read counter is incremented at a rate of 12.8 kpps, thus reading 16 bits into the read counter in 1/800 of a second. The functional equivalent of this signal processing is shown below.

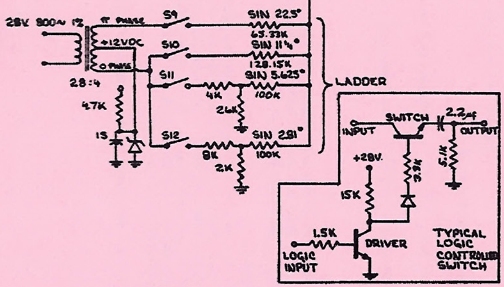


$$\frac{16\ \text{bits}}{\text{burst}} \times \frac{800\ \text{bursts}}{\text{second}} \times \frac{20\ \text{arc-sec}}{\text{bit}} = 70°/\text{second}$$

Coarse Schmitt Trigger and Rate Selection Logic

(The CM optics CDU's do not contain a coarse system.)





COARSE SYSTEM READ COUNTER WEIGHT FACTOR	
2^0	
2^1	
2^2	
2^3	
2^4	
2^5	
2^6	
2^7	
2^8	
2^9	2.8125°
2^{10}	5.625°
2^{11}	11.25°
2^{12}	22.5°
2^{13}	45°
2^{14}	90°
2^{15}	180°

COARSE SYSTEM SWITCH CONTROL LOGIC *
$S1 = 13 \cdot 14 \cdot \overline{15} + \overline{13} \cdot \overline{14} \cdot 15$
$S2 = 13 \cdot \overline{14} \cdot 15 + \overline{13} \cdot 14 \cdot \overline{15}$
$S3 = 13 \cdot 14 \cdot 15 + \overline{13} \cdot \overline{14} \cdot \overline{15}$
$S4 = \overline{13} \cdot 14 \cdot 15 + 13 \cdot \overline{14} \cdot \overline{15}$
$S5 = 13 \cdot 14 \cdot \overline{15} + \overline{13} \cdot \overline{14} \cdot \overline{15}$
$S6 = \overline{13} \cdot 14 \cdot \overline{15} + 13 \cdot \overline{14} \cdot 15$
$S7 = 13 \cdot 14 \cdot 15 + \overline{13} \cdot \overline{14} \cdot 15$
$S8 = \overline{13} \cdot 14 \cdot 15 + 13 \cdot \overline{14} \cdot 15$
$S9 = \overline{12}$
$S10 = 11$
$S11 = 10$
$S12 = 9$

* NUMBERS IN LOGIC EQUATIONS REFER TO READ COUNTER POSITIONS I.E. 13 = LOGIC "1" WHEN THERE IS A BIT IN THE 2^{13} POSITION

ECDU
COARSE SYSTEM
SWITCHING NETWORK

ELECTRONICS COUPLING DISPLAY UNIT ECDU (CONTINUED)

Fine System

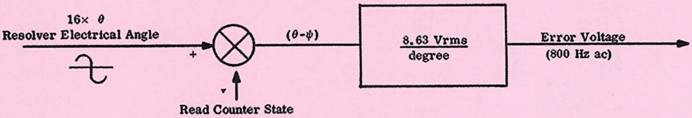
The fine system utilizes a system of switch selection logic, weighting resistors, and summing amplifiers to generate the trigonometric identity.

$$-\sin(\theta-\psi) = \sin\theta\cos\psi + \cos\theta\sin\psi$$

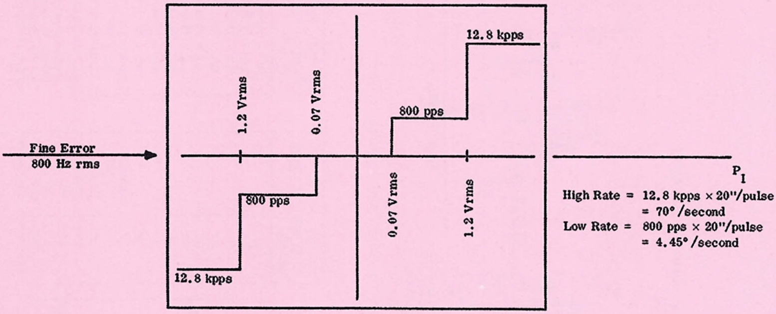
This identity is used as an error signal to drive the read counter until ψ is isolated to one of 256, 0.088-degree segments. Mechanization of this identity is similar to that of the coarse system except for the following significant differences.

1. The fine system generates an internal reference $\cos(\theta-\psi)$ to excite ladder switches.
2. The 16× resolver angle is divided into 16 segments of 22.5 degrees resolver electrical.
3. The ladder divides each 22.5-degree segment into 256 segments of 0.088 degree resolver electrical. The 1× mechanical equivalent is 0.088 degree/16 or 0.0056 degree (20 seconds of arc).
4. A quadrature reject network is employed to achieve a true loop null.

The functional equivalent of the fine system error detection logic is shown below.



Fine systems error signals are converted back into digital read counter drive signals by a fine Schmitt trigger system and a high speed Schmitt trigger system operating in tandum. Each is interrogated by the same 1,600 pps impulse train. When the high speed Schmitt trigger is detected high, the read counter is incremented at a rate of 12,800 pps. When the fine Schmitt trigger is detected high, the read counter is incremented at a rate of 800 pps. The threshold level of the fine system Schmitt triggers is set such that the rate selection logic shown below is achieved.



Schmitt Trigger Threshold

$$1.2\ \text{Vrms} \times \frac{1\ \text{degree}}{8.63\ \text{V}/°} = 2.2\ \text{degrees read counter}$$

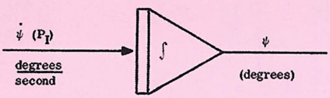
$$0.07\ \text{Vrms} \times \frac{1\ \text{degree}}{8.63\ \text{V}/°} = 0.131\ \text{degree read counter}$$

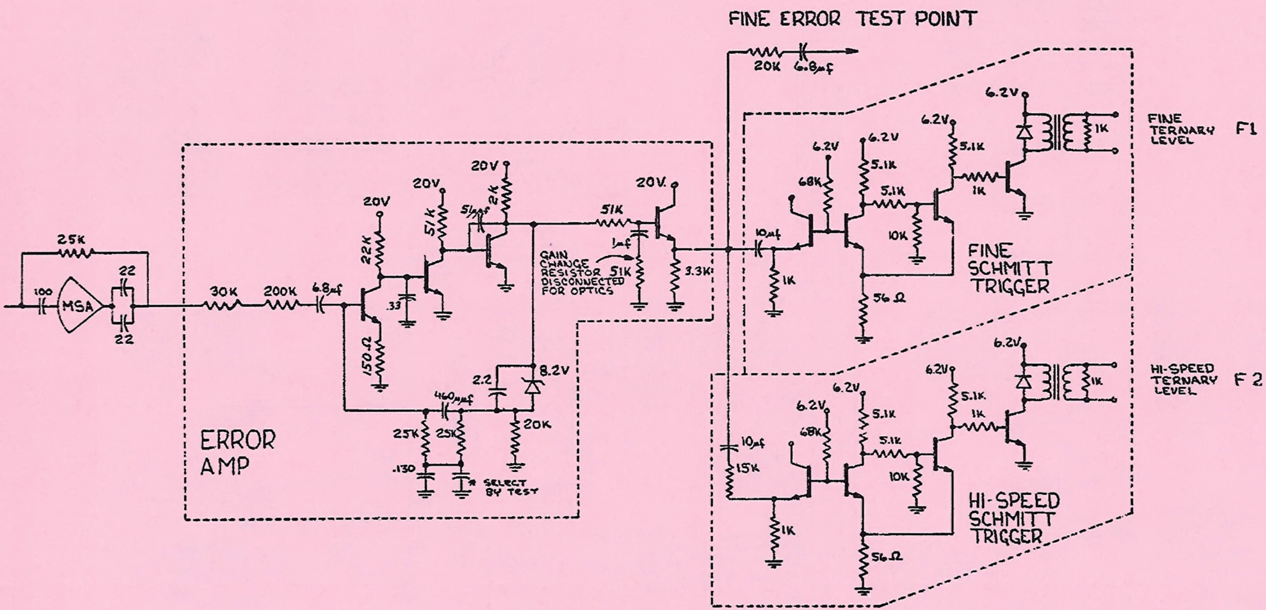
The rate select and up/down logic processes the sampled output of the Schmitt triggers to determine at which rate the read counter is incremented. If the high speed Schmitt is "on," the increment rate is 12,800 pps or 16 bits in one sample time. If the fine Schmitt is "on," the increment rate is 800 pps or 1 bit in one sample time.

Read Counter

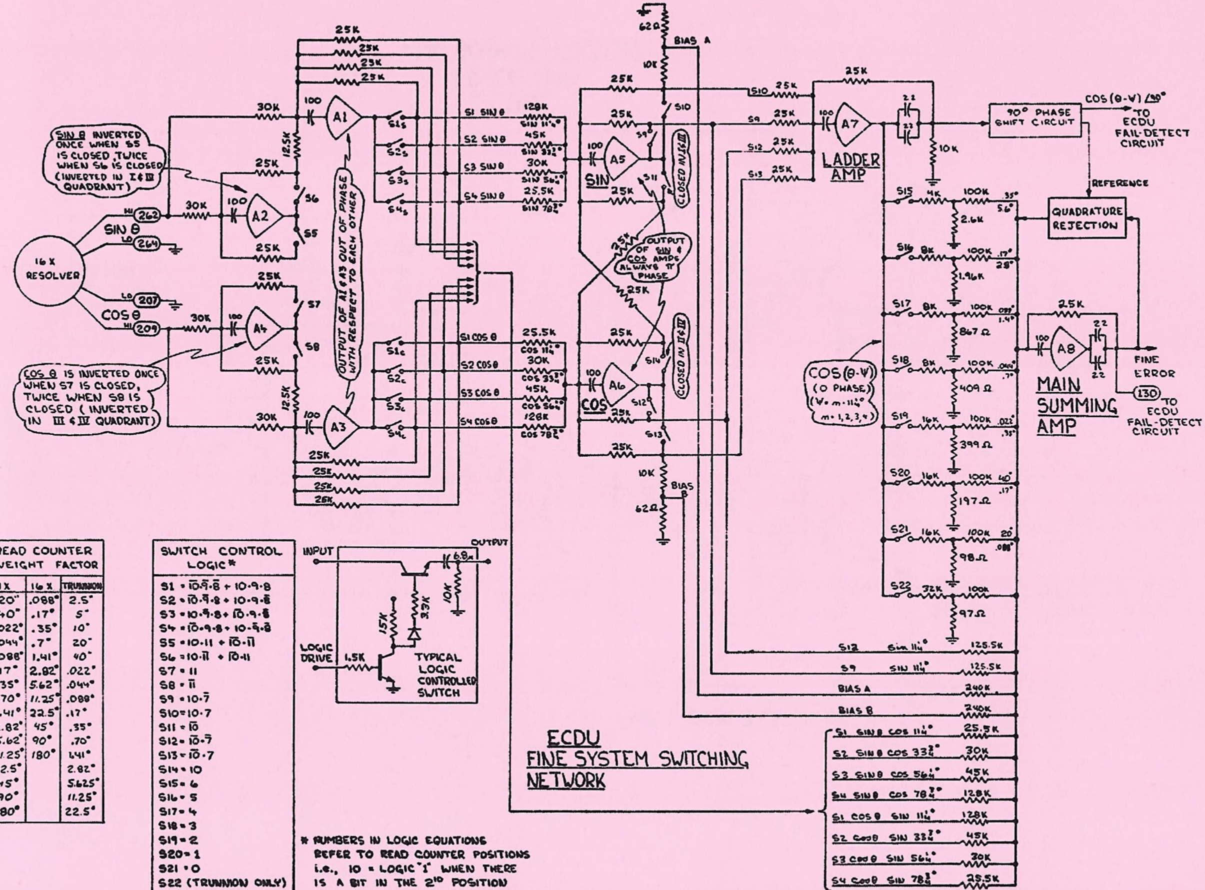
The read counter is a 16-stage digital counter with an IMU angle granularity of 20 seconds/bit. Inputs to the read counter are controlled by rate select and up/down logic. The output is used by the fine system switch selection logic to produce the fine error signal. Access to the contents of the read counter by both the computer and the error counter is serial only. Access by the computer is to the first order bit ($\Delta 2^0$). Access by the error counter is to the third order bit ($\Delta 2^2$). Because of the above, the count rate to the computer is four times faster than to the error counter. Computer bits, however, have one-fourth the weight factor of those transferred to the error counter.

Functionally, the read counter is represented as an integrator with a count rate in degrees/second and an output in degrees.





ECDU
ERROR AMP
AND SCHMITT TRIGGERS

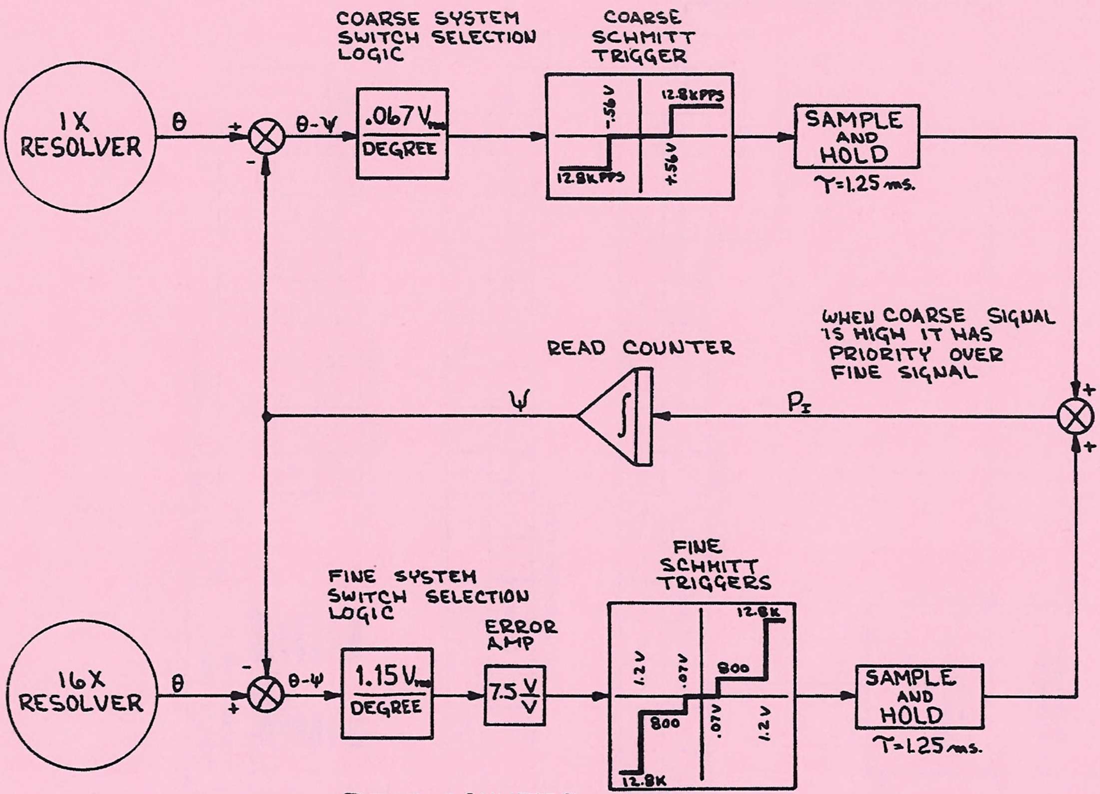


ECDU FINE SYSTEM SWITCHING NETWORK

READ COUNTER WEIGHT FACTOR	1X	16 X	TRUNNION
2^0	20"	.088°	2.5"
2^1	40"	.17°	5"
2^2	.022°	.35°	10"
2^3	.044°	.7°	20"
2^4	.088°	1.41°	40"
2^5	.17°	2.82°	.022°
2^6	.35°	5.62°	.044°
2^7	.70°	11.25°	.088°
2^8	1.41°	22.5°	.17°
2^9	2.82°	45°	.35°
2^{10}	5.62°	90°	.70°
2^{11}	11.25°	180°	1.41°
2^{12}	22.5°		2.82°
2^{13}	45°		5.625°
2^{14}	90°		11.25°
2^{15}	180°		22.5°

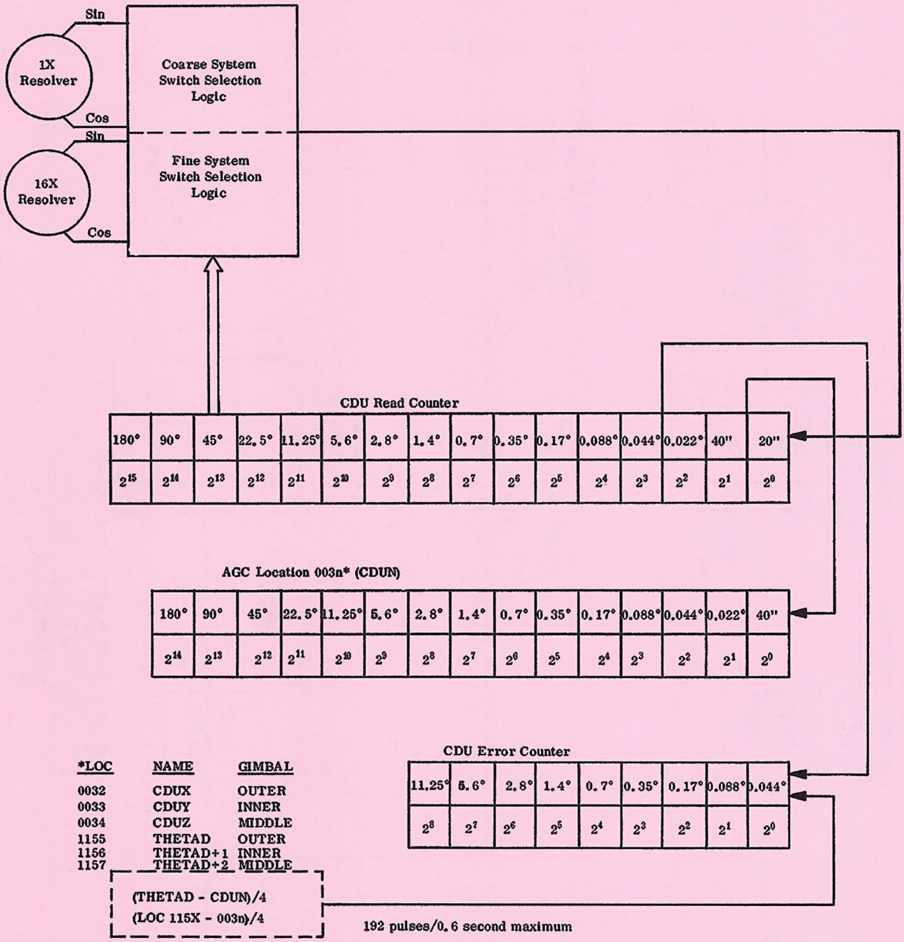
SWITCH CONTROL LOGIC*
S1 = $\overline{10}\cdot\overline{9}\cdot\overline{8} + 10\cdot 9\cdot 8$
S2 = $\overline{10}\cdot\overline{9}\cdot 8 + 10\cdot 9\cdot\overline{8}$
S3 = $10\cdot\overline{9}\cdot 8 + \overline{10}\cdot 9\cdot\overline{8}$
S4 = $\overline{10}\cdot 9\cdot 8 + 10\cdot\overline{9}\cdot\overline{8}$
S5 = $10\cdot 11 + \overline{10}\cdot\overline{11}$
S6 = $10\cdot\overline{11} + \overline{10}\cdot 11$
S7 = 11
S8 = $\overline{11}$
S9 = $10\cdot\overline{7}$
S10 = $10\cdot 7$
S11 = $\overline{10}$
S12 = $\overline{10}\cdot\overline{7}$
S13 = $\overline{10}\cdot 7$
S14 = 10
S15 = 6
S16 = 5
S17 = 4
S18 = 3
S19 = 2
S20 = 1
S21 = 0
S22 (TRUNNION ONLY)

* NUMBERS IN LOGIC EQUATIONS REFER TO READ COUNTER POSITIONS i.e., 10 = LOGIC "1" WHEN THERE IS A BIT IN THE 2^{10} POSITION (IMU & OPTICS SHAFT ONLY)



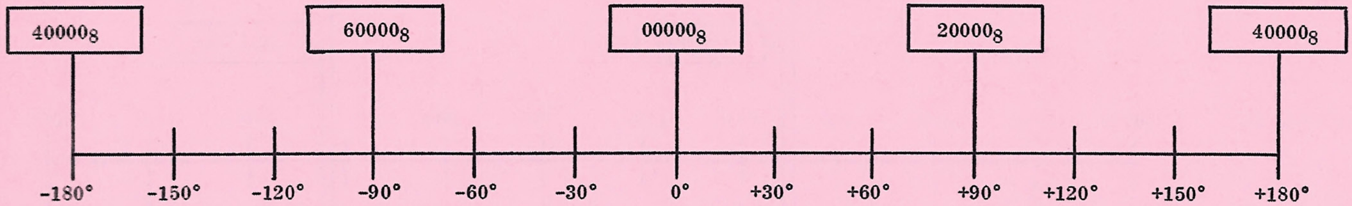
READ COUNTER LOOP
FUNCTIONAL BLOCK
DIAGRAM

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

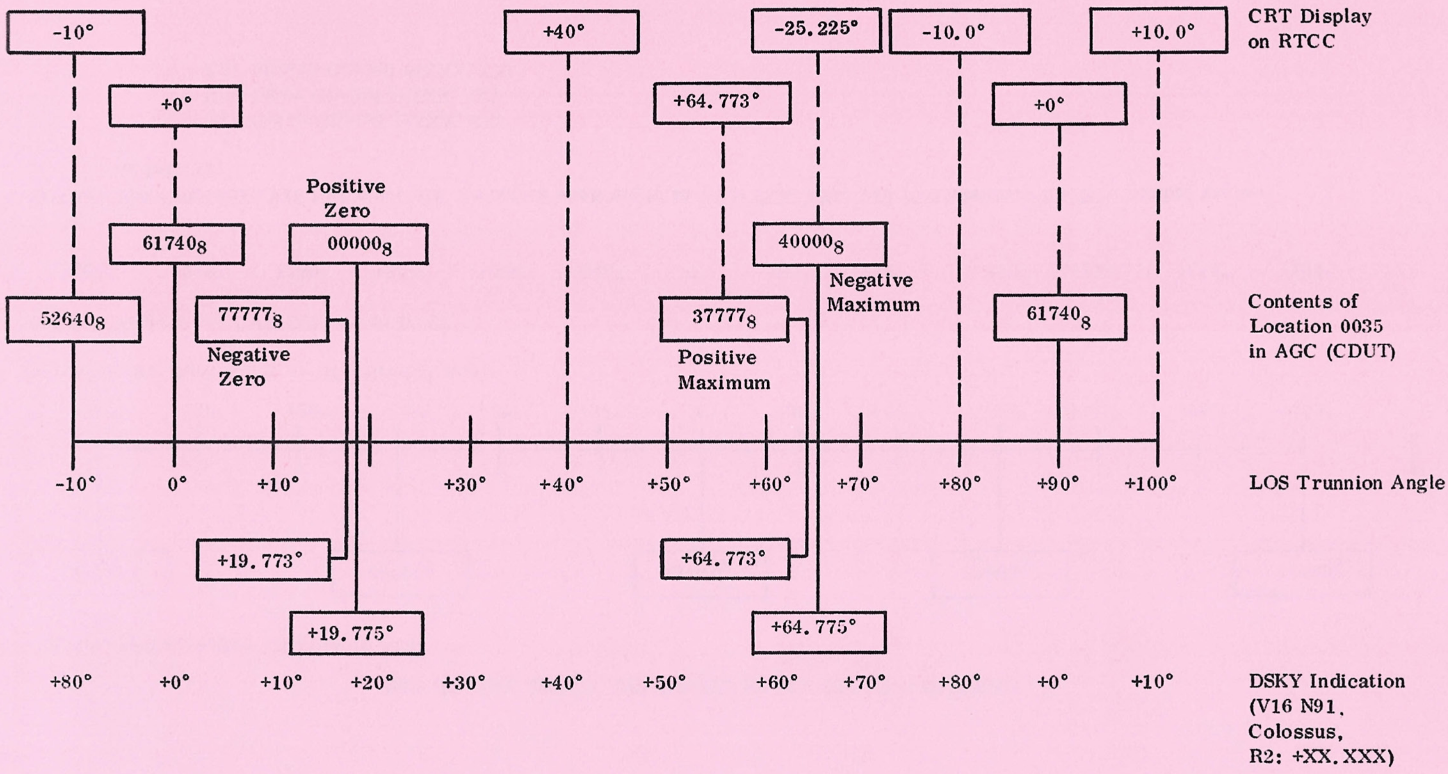
DSKY Indication and CRT Display on RTCC

+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:

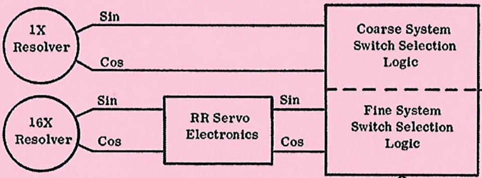
R1: Outer Gimbal (+XXX.XX)
R2: Inner Gimbal (+XXX.XX)
R3: Middle Gimbal (+XXX.XX)

OPTICS TRUNNION SCALING DIAGRAM



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



CDU Read Counter

180°	90°	45°	22. 5°	11.25°	5. 6°	2. 8°	1. 4°	0. 7°	0. 35°	0. 17°	0.088°	0.044°	0.022°	40"	20"
2^{15}	2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^{9}	2^{8}	2^{7}	2^{6}	2^{5}	2^{4}	2^{3}	2^{2}	2^{1}	2^{0}

LGC Location 0035 (CDUT) for Trunnion and 0036 (CDUS) for Shaft

180°	90°	45°	22. 5°	11.25°	5. 6°	2. 8°	1. 4°	0. 7°	0. 35°	0. 17°	0.088°	0.044°	0.022°	40"
2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^{9}	2^{8}	2^{7}	2^{6}	2^{5}	2^{4}	2^{3}	2^{2}	2^{1}	2^{0}

CDU Error Counter

11.25°	5. 6°	2. 8°	1. 4°	0. 7°	0. 35°	0. 17°	0.088°	0.044°
2^{8}	2^{7}	2^{6}	2^{5}	2^{4}	2^{3}	2^{2}	2^{1}	2^{0}

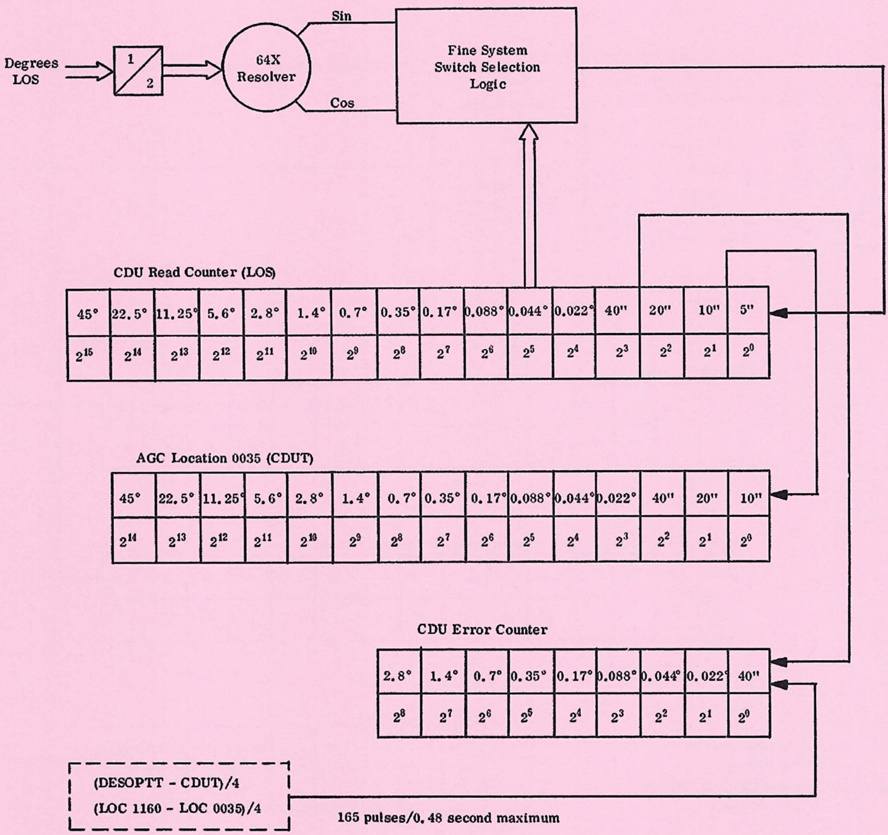
Note: RR scaling is the same as
IMU gimbal scaling.

LUMINARY RR Angle Readout (V16 N72)
R1 + XXX. XX Trunnion
R2 + XXX. XX Shaft

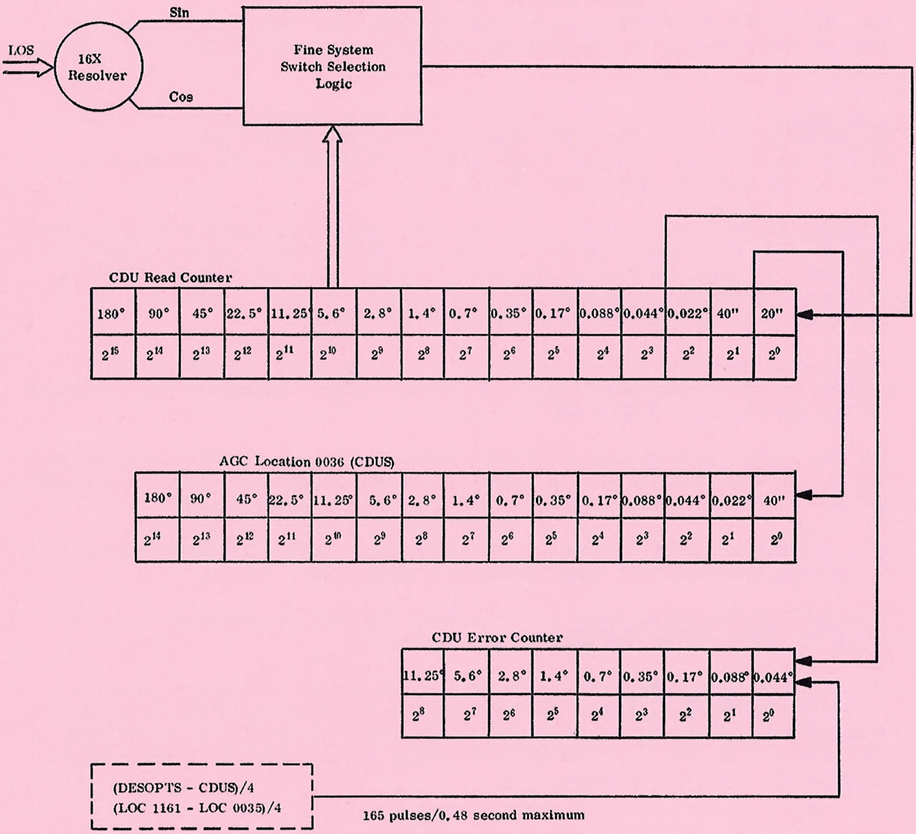
RR Gyro Torque Commands

384 pulses/0. 5 second maximum

OPTICS TRUNNION/CDU/AGC INTERFACE DIAGRAM



OPTICS SHAFT/CDU/AGC INTERFACE DIAGRAM



CM OPTICS

The Optical Subsystem has three major modes of Operation (MANUAL, COMPUTER and ZERO OPTICS).

The configuration of the Sextant Trunnion and shaft servos determines the mode of operation and is controlled by switches on the G&N Indicator Control Panel.

ZERO OPTICS is a Sextant velocity follow-up servo commanded to zero degrees by position measuring resolvers mounted in the SXT head. The actuating errors are the sine windings of the 64X and 1X resolvers for trunnion and the 16X and 1/2X resolvers for shaft.

COMPUTER operate optics uses the Sextant servos in a integrator configuration that accepts position commands from the CDU DAC's. The computer supplies the CDU error counter with pulses every 0.5 seconds. At each 0.5 seconds, the computer recalculates the number of pulses required to position the LCS using information obtained from the CDU read counter.

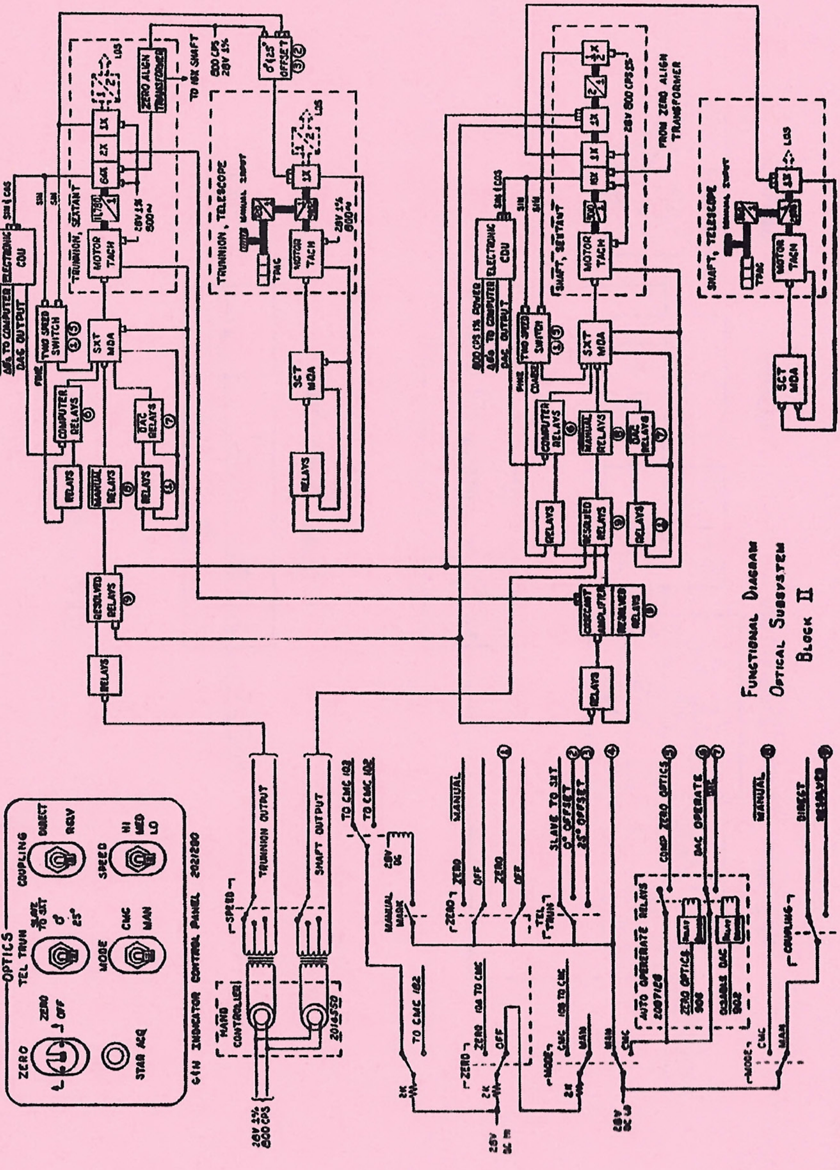
MANUAL mode uses the Sextant servos in a integrator configuration that accepts velocity commands from the Hand Controller. There are two sub-modes of the MANUAL mode, DIRECT and RESOLVED.

For the DIRECT MODE up and down Hand Controller motion results in increasing and decreasing trunnion angles respectively and right and left Hand Controller motion results in increasing and decreasing shaft angles respectively.

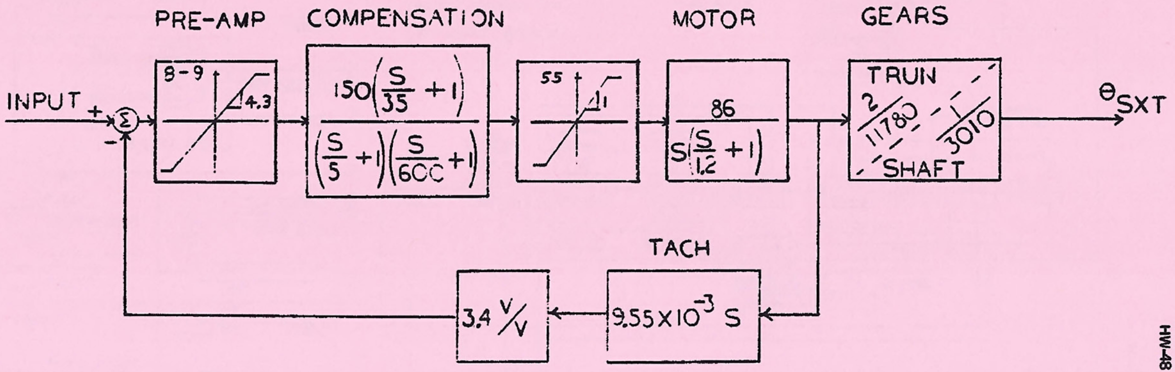
For the RESOLVED MODE up-down or left-right Hand Controller motion results in up-down or left-right image motion respectively.

The SCANNING TELESCOPE SHAFT servo follows the Sextant shaft servo in all modes of operation of the Optical Subsystem.

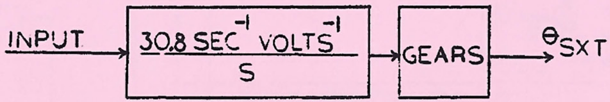
The SCANNING TELESCOPE TRUNNION servo follows the Sextant trunnion servo in all modes of operation of the Optical Subsystem except when the Optical Subsystem is in the MANUAL mode and the TEL TRUN is set to 0° offset and 25° offset. In the 0° offset and 25° offset modes, the SCT trunnion angle is held at 0° and 25° respectively.



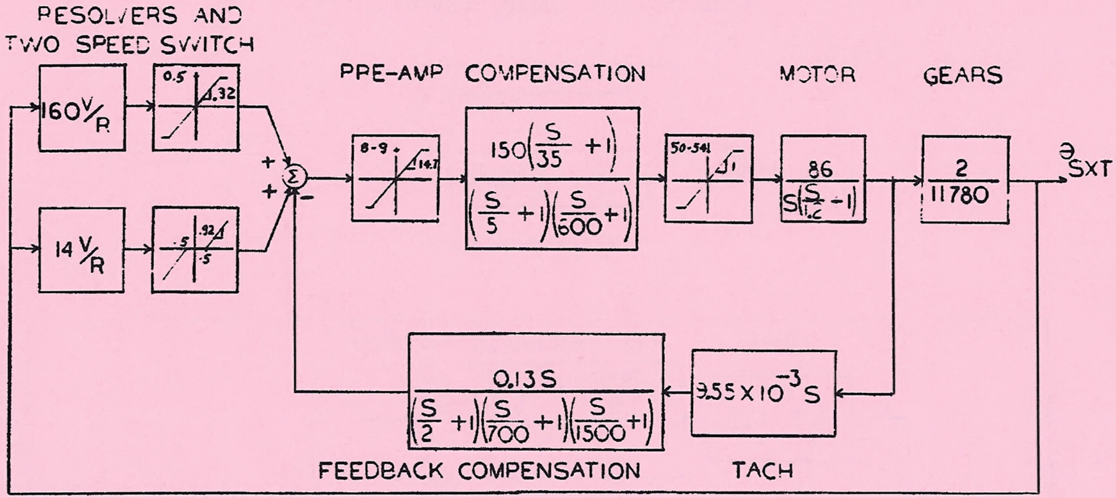
Functional Diagram
Optical Subsystem
Block II

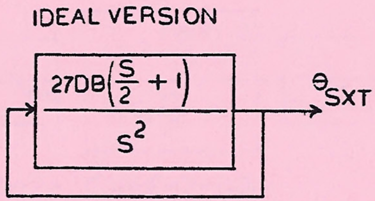


IDEAL VERSION

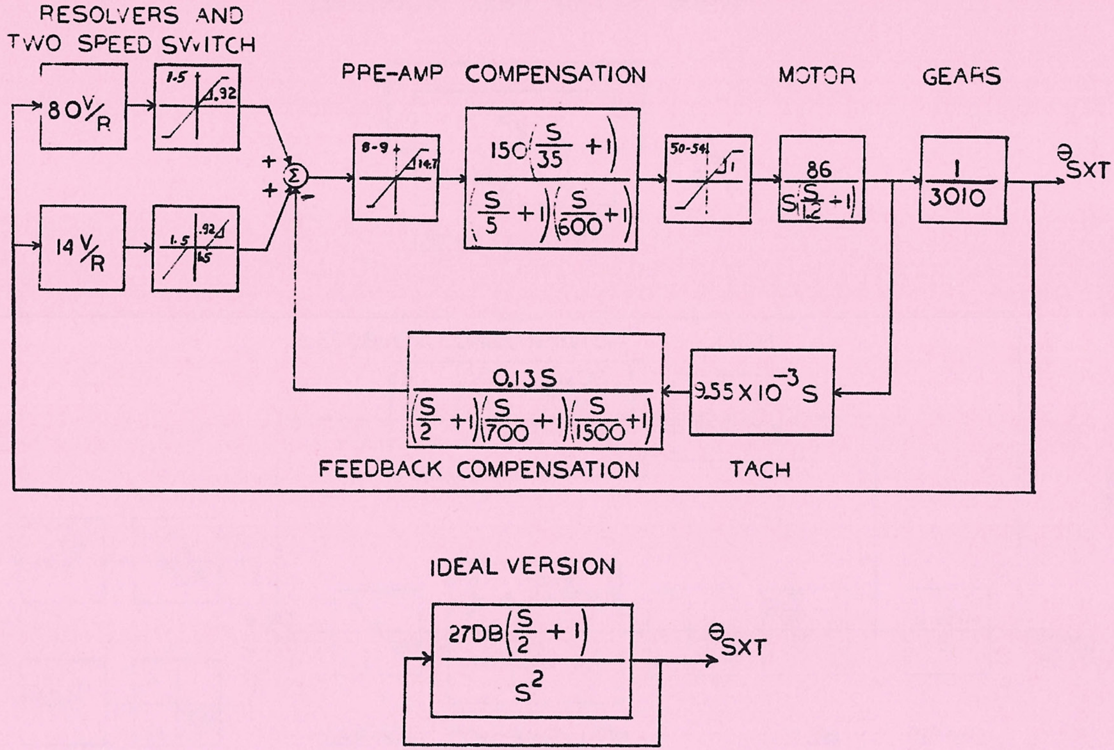


SXT INTEGRATORS



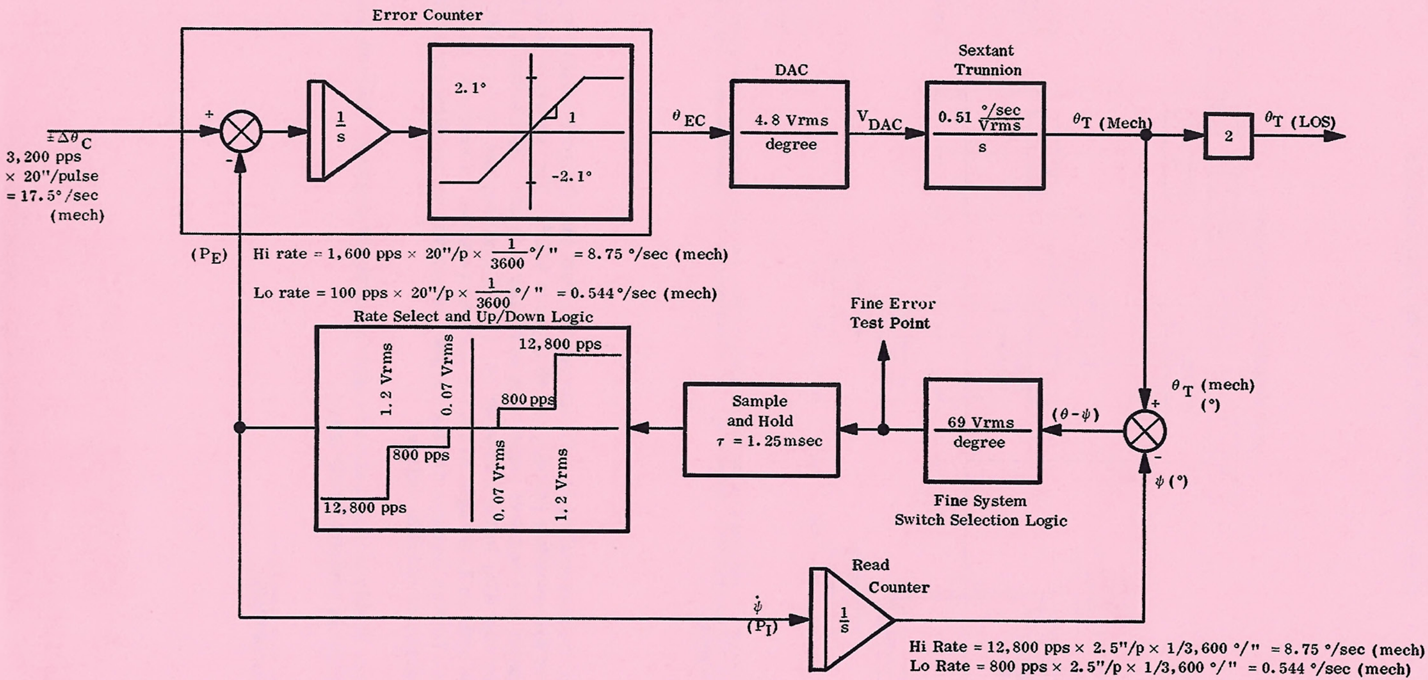


TRUNNION ZERO OPTICS SERVO



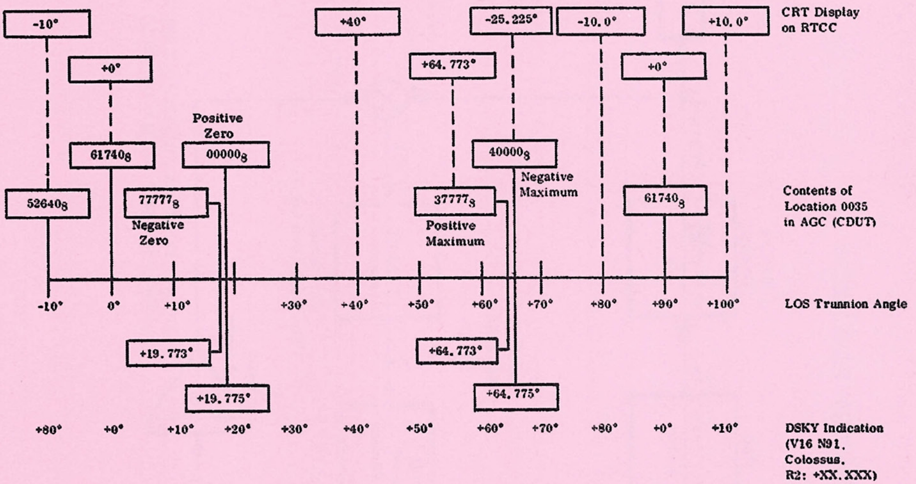
SHAFT ZERO OPTICS SERVO

TRUNNION COMPUTER OPERATE MODE FUNCTIONAL BLOCK DIAGRAM



OPTICS TRUNNION DRIVING LIMITATIONS

OPTICS TRUNNION SCALING DIAGRAM



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 (40000_8) 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 (40000_8) 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 vignetted.

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*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.

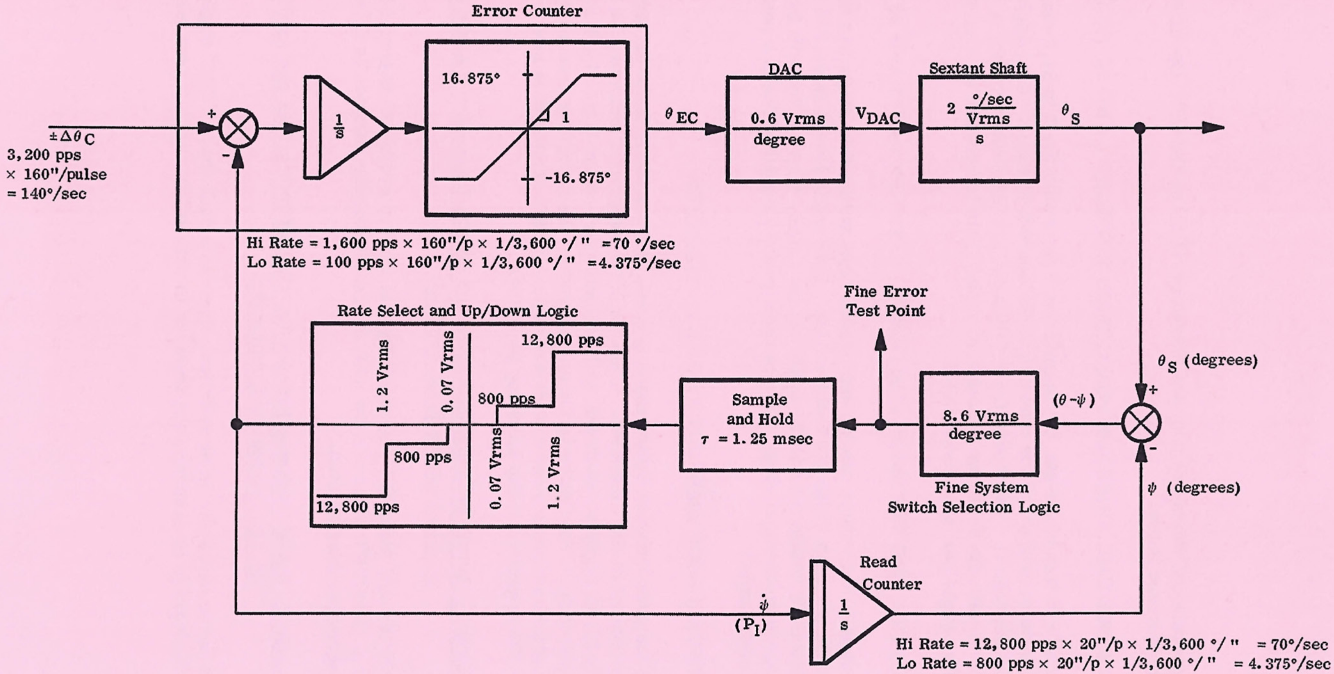
a. <u>Case 1: Initial Trunnion Between 0 and 64.773 Degrees and Angle Close to 64.773 Degrees is Commanded</u>

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.

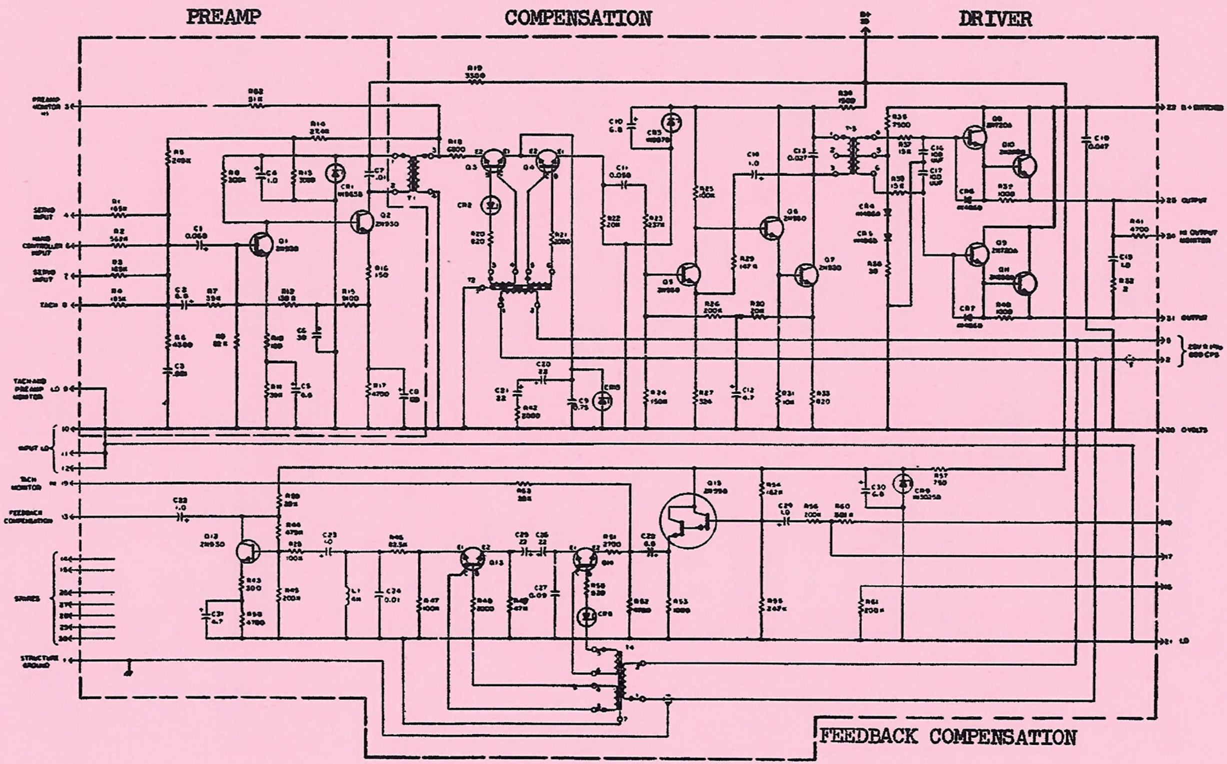
b. <u>Case 2: Initial Trunnion Between 64.775 and 90 Degrees and Angle Close to 64.775 Degrees is Commanded</u>

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			
		SXT		SCT	
TRUNNION	SHAFT	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 $\widehat{sec}$/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 $\widehat{sec}$/sec	7.0	0.73	6.9	0.72

SERVO SENSITIVITY

	CALCULATION	SENSITIVITY
SXT TRUNNION		
Hand Controller	$105\ \frac{mr}{mv} \times \frac{205}{3.4} \times \frac{2}{11,780}$	$1.08\ \frac{\widehat{sec}/sec}{mv}$
Tachometer	3.4 x 1.08	$3.68\ \frac{\widehat{sec}/sec}{mv}$
SXT SHAFT		
Hand Controller	$105\ \frac{mr}{mv} \times \frac{205}{3.4} \times \frac{1}{3010}$	$2.1\ \frac{\widehat{sec}/sec}{mv}$
Tachometer	3.4 x 2.1	$7.14\ \frac{\widehat{sec}/sec}{mv}$

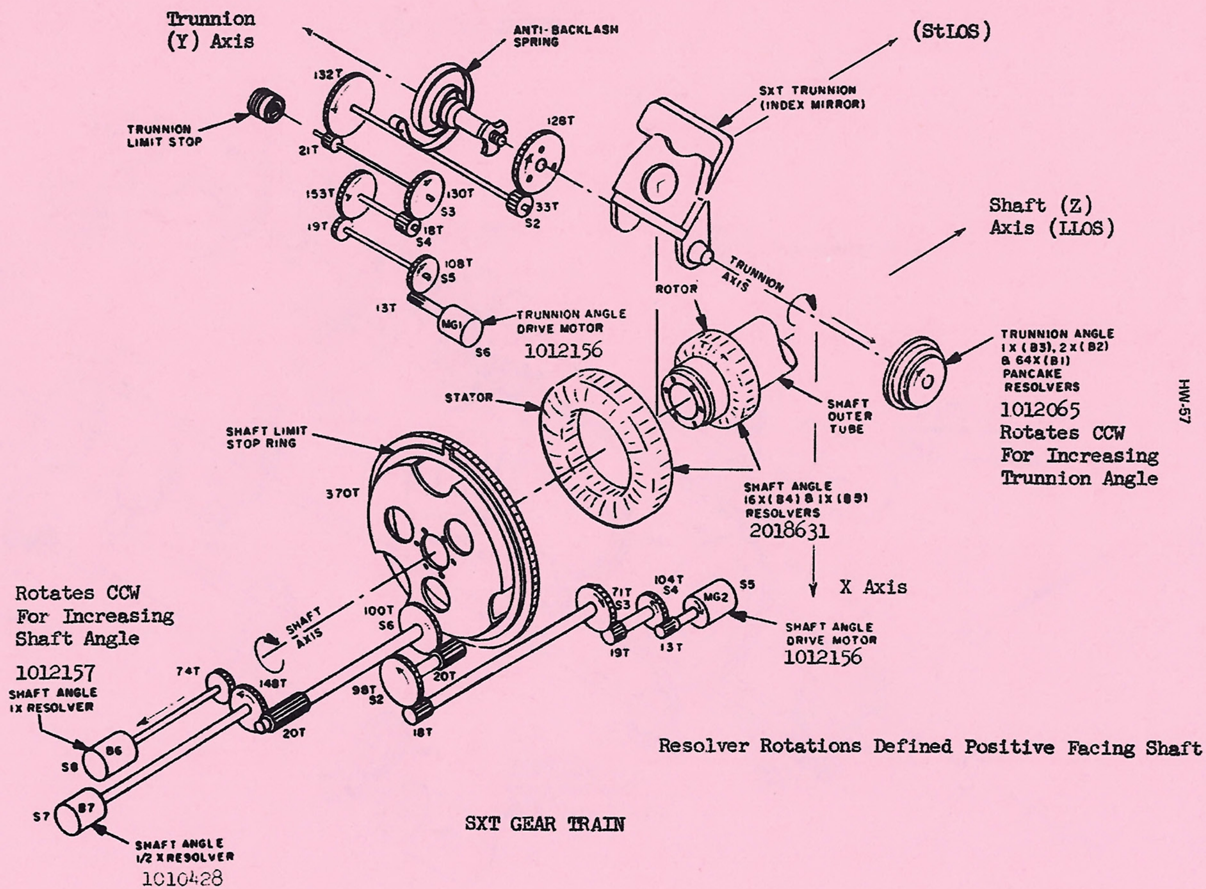
MAXIMUM CREEP RATES DUE TO RESIDUALS

	MAXIMUM RESIDUAL	SERVO SENSITIVITY	THEORETICAL MAXIMUM RATE
SXT TRUNNION			
Hand Controller	3 mv rms PS 2014550	$1.08\ \frac{\widehat{sec}/sec}{mv}$	3 $\widehat{sec}$/sec
Tachometer	15 mv rms PS 2016207	$3.70\ \frac{\widehat{sec}/sec}{mv}$	55 $\widehat{sec}$/sec
SXT SHAFT			
Hand Controller	3 mv rms PS 2014550	$2.1\ \frac{\widehat{sec}/sec}{mv}$	6 $\widehat{sec}$/sec
Tachometer	15 mv rms PS 2016207	$7.2\ \frac{\widehat{sec}/sec}{mv}$	108 $\widehat{sec}$/sec

OPTICAL SUBSYSTEM PHASING (ROTATIONS DEFINED FACING SHAFT)

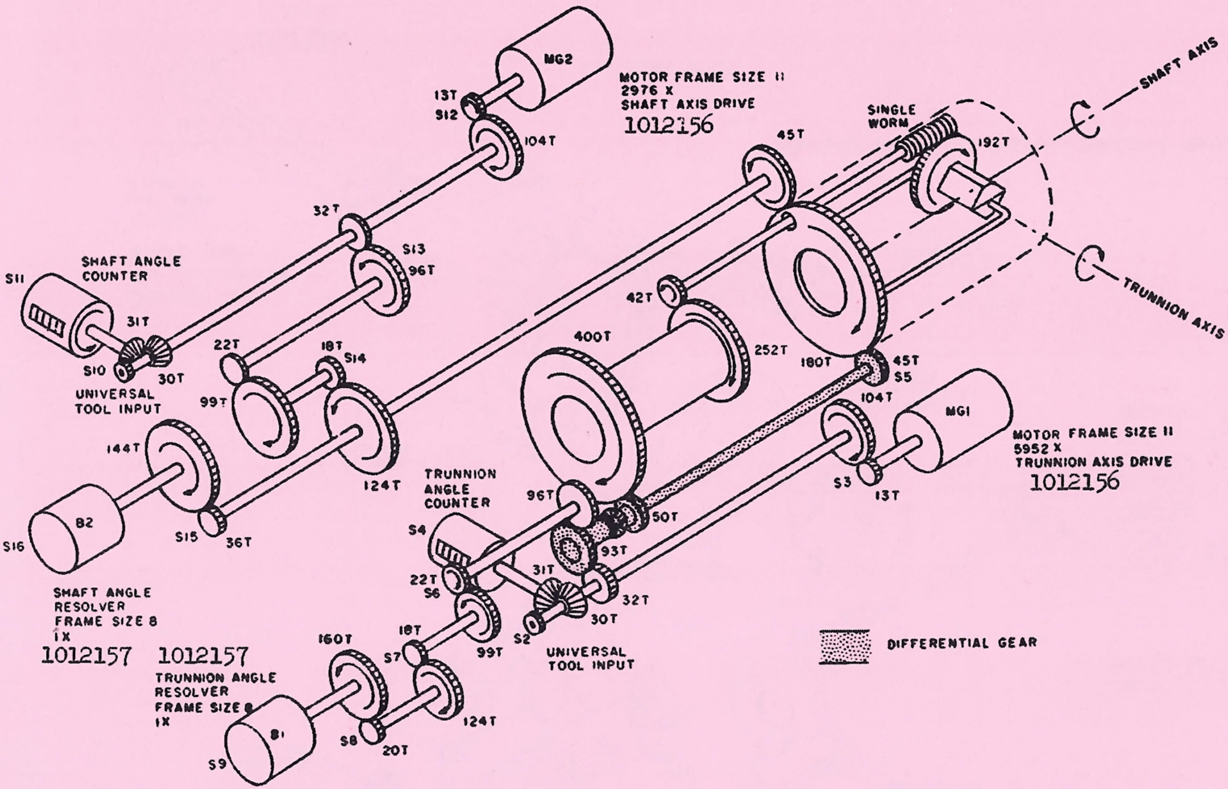
	Direct Mode		Resolved Mode*						
Integrator	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position	MDA Input	Motor Rotation	Tach Output	Resolver Rotation	LOS Angle
SXT TRUNNION	DOWN	$0\ \phi$	UP	$\pi\ \phi$	$0\ \phi$	CCW	$\pi\ \phi$	CW	Decreasing
	UP	$\pi\ \phi$	DOWN	$0\ \phi$	$\pi\ \phi$	CW	$0\ \phi$	CCW	Increasing
SCT TRUNNION (slaved to SXT TRUNNION)	DOWN	$0\ \phi$	UP	$\pi\ \phi$	$\pi\ \phi$	CW	$0\ \phi$	CCW	Decreasing
	UP	$\pi\ \phi$	DOWN	$0\ \phi$	$0\ \phi$	CCW	$\pi\ \phi$	CW	Increasing
SXT SHAFT	Left	$0\ \phi$	Right	$\pi\ \phi$	$0\ \phi$	CCW	$\pi\ \phi$	CW	Decreasing
	Right	$\pi\ \phi$	Left	$0\ \phi$	$\pi\ \phi$	CW	$0\ \phi$	CCW	Increasing
SCT SHAFT (slaved to SXT Shaft)	Left	$0\ \phi$	Right	$\pi\ \phi$	$\pi\ \phi$	CW	$0\ \phi$	CCW	Decreasing
	Right	$\pi\ \phi$	Left	$0\ \phi$	$0\ \phi$	CCW	$\pi\ \phi$	CW	Increasing

*1st quadrant only $0 < A_s < 90°$

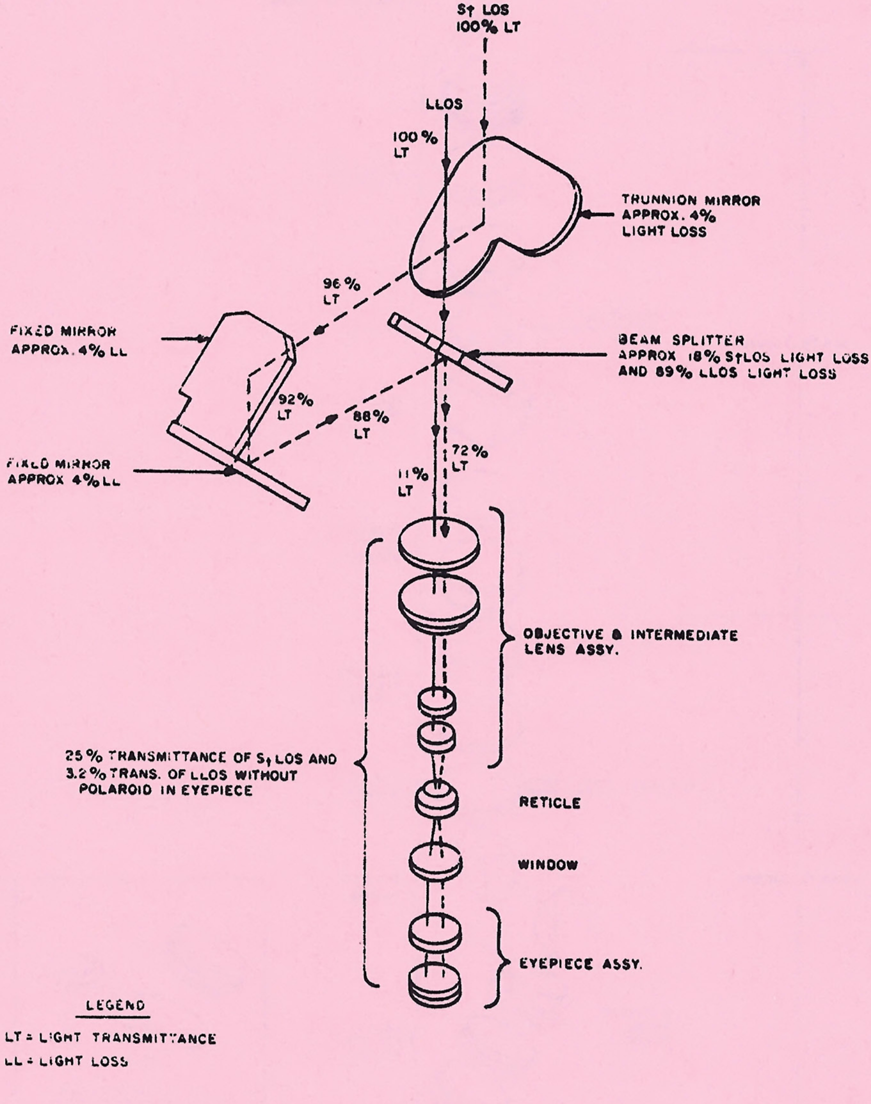


Resolver Rotations Defined Positive Facing Shaft

SXT GEAR TRAIN

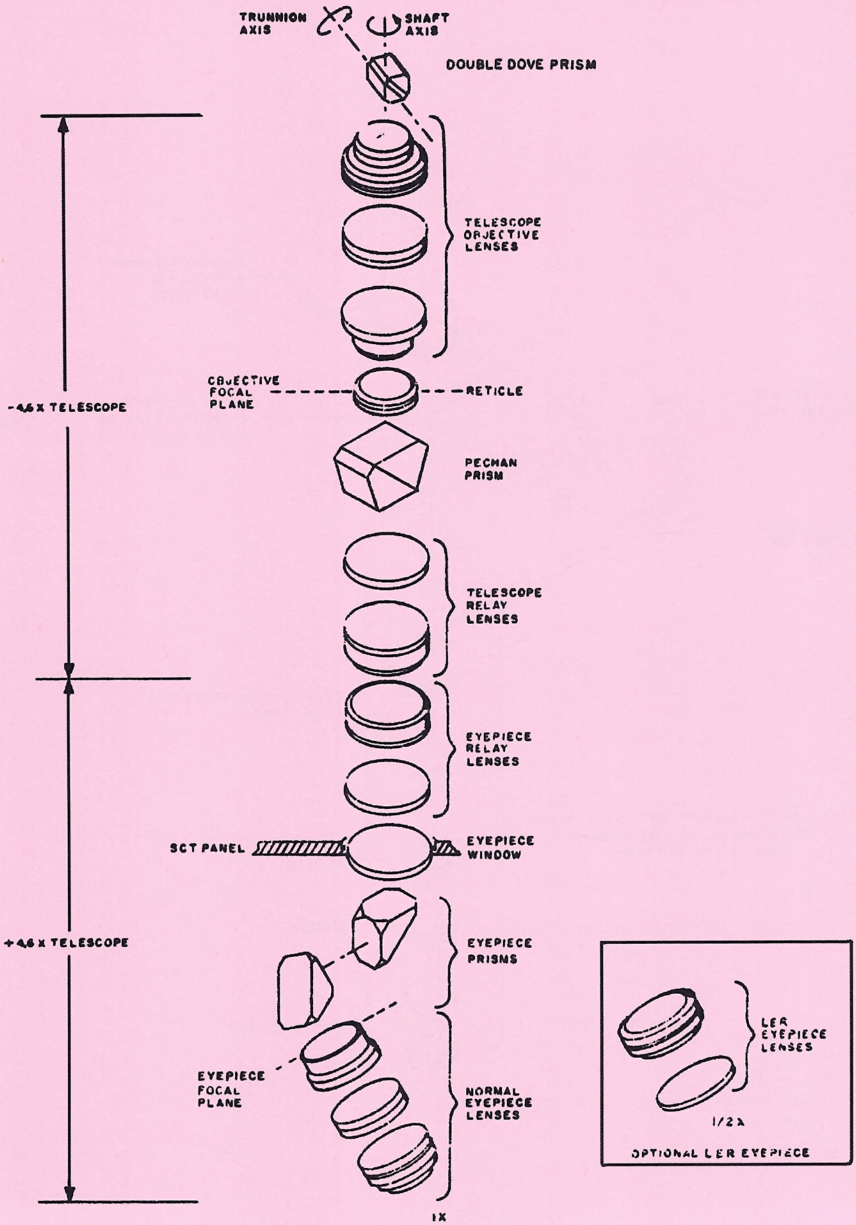


SCT GEAR TRAIN



S↑ LOS
100% LT
LLOS
100 % LT
TRUNNION MIRROR
APPROX. 4%
LIGHT LOSS
96 %
LT
FIXED MIRROR
APPROX. 4% LL
BEAM SPLITTER
APPROX 18% S↑LOS LIGHT LOSS
AND 89% LLOS LIGHT LOSS
92%
LT
88%
LT
FIXED MIRROR
APPROX 4% LL
72%
LT
11%
LT
OBJECTIVE & INTERMEDIATE
LENS ASSY.
25% TRANSMITTANCE OF S↑ LOS AND
3.2% TRANS. OF LLOS WITHOUT
POLAROID IN EYEPIECE
RETICLE
WINDOW
EYEPIECE ASSY.
LEGEND
LT = LIGHT TRANSMITTANCE
LL = LIGHT LOSS

SXT OPTICS


TRUNNION AXIS
SHAFT AXIS
DOUBLE DOVE PRISM
TELESCOPE OBJECTIVE LENSES
OBJECTIVE FOCAL PLANE
RETICLE
-4.6 X TELESCOPE
PECHAN PRISM
TELESCOPE RELAY LENSES
EYEPIECE RELAY LENSES
SCT PANEL
EYEPIECE WINDOW
+4.6 X TELESCOPE
EYEPIECE PRISMS
EYEPIECE FOCAL PLANE
NORMAL EYEPIECE LENSES
1X
LER EYEPIECE LENSES
1/2 X
OPTIONAL LER EYEPIECE

SCT OPTICS

APOLLO 13 NOUNS

05 ANG E.RR
10 CHANNEL
11 TIG CSI
13 TIG CDH
16 T EVENT (EXT VERB)
32 TF HP
33 TIG
34 T EVENT (PROGRAM)
35 TF EVENT
36 CMC TIME
37 TIG TPI
38 STATE VECTOR TIME
39 ΔT TRANSFER
42 H.A - H.P - Δ.V

43 L.AT - LO.NG - .H
44 H.A - H.P - TFF
49 ΔPO.S - ΔVE.L - CODE
51 HGA PIT.CH - HGA Y.AW
52 ACTUAL .ωT
53 RAN.GE - R.R - P.HI
54 RAN.GE - R.R - THE.TA
55 CODE - ELEV A.NG - .ωT
58 H.P - ΔVTP.I - ΔVTP.F
59 ΔVLOS.X - ΔVLOS.Y - ΔVLOS.Z
73 H(X10) - VEL. - GAM.MA
75 ΔH CD.H - ΔTI - ΔT2
79 .RATE - .DB - CODE
81 ΔV LOCAL VER.T

82 ΔVCDH LOCAL VER.T
83 ΔV CONTROL AXE.S
85 VG CONTROL AXE.S
87 CALIB SHA.FT - T.RUN
89 .LAT - LON.G/2 - A.LT
90 Y (.NM) - Y DO.T - P.SI
91 PRESENT SHA.FT - T.RUN
92 COMMAND SHA.FT - T.RUN
93 TORQUING .ANG
94 SHA.FT - T.RUN
99 POS ERR. - VEL ER.R - CODE

NOUN 70 CODES

R1: CELESTIAL BODY CODE 000DE

00	PLANET	27	ALKAID
01	ALPHERATZ	30	MENKENT
02	DIPHDA	31	ARCTURUS
03	NAVI	32	ALPHECCA
04	ACHERNAR	33	ANTARES
05	POLARIS	34	ATRIA
06	ACAMAR	35	RASALHAGUE
07	MENKAR	36	VEGA
10	MIRFAK	37	NUNKI
11	ALDEBARAN	40	ALTAIR
12	RIGEL		
13	CAPELLA		
14	CANOPUS		
15	SIRIUS		
16	PROCYON		
17	REGOR	41	DABIH
20	DNOCES	42	PEACOCK
21	ALPHARD	43	DENEB
22	REGULUS	44	ENIF
23	DENEBOLA	45	FOMALHAUT
24	GIENAH	46	SUN
25	ACRUX	47	EARTH
26	SPICA	50	MOON

P22 R2: LANDMARK DATA

LANDING SITE	10001
KNOWN SITE	10000
UNKNOWN SITE	20000

P23 R1: 000DE STAR ID

R2: 00C00
C=0 HORIZON
C=1 EARTH LDMK
C=2 LUNAR LDMK

R3: 00CD0 HORIZ ID
C=1 EARTH, 2 LUNAR
D=1 NEAR, 2 FAR

ALARM CODES (V05N09)

00110	MK REJECT ENTERED & IGNORED
00112	MK REJECT BEFORE MKS ACCEPTED
00113	NO INBITS (CH 16)
00114	MORE MKS THAN DESIRED
00115	V41N91 WITH OPTICS NOT IN CMC
00116	OPTICS SW MOVED BEFORE 15 SEC
00117	V41N91 BUT OPTICS NOT READY
00120	ZERO OPTICS FIRST
00121	CDUS BAD DURING MK-REPEAT
00122	MK NOT CALLED FOR
00124	TPI SEARCH UNSUCCESSFUL
00205	PIPA SATURATED
00206	CANNOT ZERO ICDU WITH ALARMS
00207	NEED 90 SEC FOR ISS TURN ON
00210	IMU NOT OPERATING
00211	COARSE ALIGN ERROR > 2 DEG
00212	PIPA FAIL BUT PIPA NOT IN USE
00213	IMU NOT ON-TURN ON IMU
00214	PROGRAM USING IMU BUT IMU OFF
00217	COARSE ALIGN/TORQUING PROBLEM
00220	IMU NOT ALIGNED/NO REFSMMAT
00401	DESIRED MGA TOO LARGE
00404 *	TGT OUT OF VIEW (TRUN > 90 DEG)
00405	STAR PAIR NOT AVAILABLE
00406	P20 NOT OPERATING
00421	W MATRIX OVERFLOW
00600	NO SOLUTION ON 1ST ITERATION
00601	HP < 5.8 NM AFTER CSI
00602	HP < 5.8 NM AFTER CDH
00603	CSI TIG TO CDH TIG $\Delta T < 10$ MIN
00604	CDH TIG TO TPI TIG $\Delta T < 10$ MIN
00605	TOO MANY ITERATIONS
00606	CSI $\Delta V > 1000$ LAST 2 ITERATIONS
00611	NO TIG FOR ELEV ANGLE GIVEN
00612	WRONG SPHERE OF INFL AT TIG
00613	REENTRY ANGLE OUT OF LIMITS
00777	ISS WARNING-PIPA FAIL
01102	CMC SELF TEST ERROR
01105	DOWNLINK TOO FAST
01106	UPLINK TOO FAST
01107	PHASE TABLE FAIL-ERASABLE BAD
01301	ARCSIN/ARCCOS INPUT > ONE
01407	VG INCREASING
01426	IMU UNSATISFACTORY
01427	IMU POLARITY REVERSED
01520	V37 NOT PERMITTED NOW
01600	OVERFLOW DURING DRIFT TEST
01601	BAD IMU TORQUE
01602	BAD OPTICS IN VERIFICATION
01703	INSUF TIME TO INTEG-TIG SLIP
03777	ISS WARNING-ICDU FAIL
04777	ISS WARNING-ICDU & PIPA FAIL
07777	ISS WARNING-IMU FAIL
10777	ISS WARNING-IMU & PIPA FAIL
13777	ISS WARNING-IMU & ICDU FAIL
14777	ISS WARN-IMU,ICDU & PIPA FAIL
20430	ORBITAL INTEGRATION STOPPED
20607	NO CONIC SOLUTION
20610	ALTITUDE 400K AT TIG (P37)
21103	UNUSED CCS BRANCH EXECUTED
21204	NEG OR ZERO WAITLIST CALL
21206	TWO DISPLAYS ATTEMPTED AT ONCE
21210	TWO PROGRAMS USING AT ONCE
21302	SQRT CALLED WITH NEG ARGUMENT
21501	DSKY ALARM DURING INTERNAL USE
21502	ILLEGAL FLASHING DISPLAY
21521	KEYED P01/V92 AFTER LIFTOFF
31104	DELAY ROUTINE IS BUSY
31201	EXEC OVERFLOW-NO VAC AREAS
31202	EXEC OVERFLOW-NO CORE SETS
31203	WAITLIST OVERFLOW-MANY TASKS
31207	NO VAC AREA FOR MKS
31211	CANNOT INTERUPT EXTENDED VERB

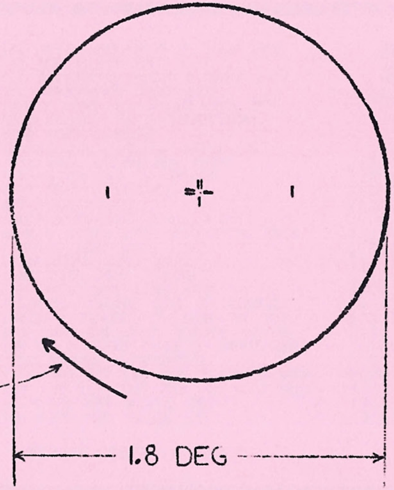
NOTE :

00404 * IS A PRIORITY ALARM
2XXXX INDICATES POODOO ALARM
3XXXX INDICATES BAILOUT ALARM

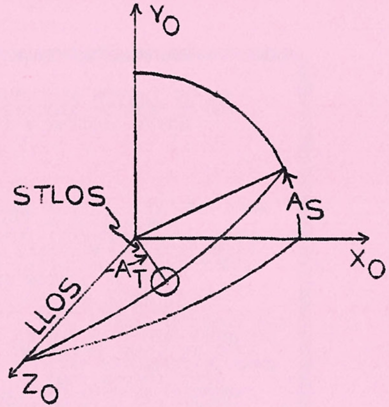
DRIVE RATES

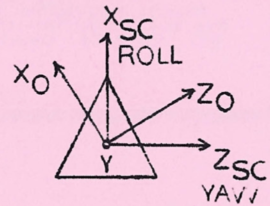
	TRUNNION	SHAFT
HI	10.0 DEG/S	19.5 DEG/S
MED	1.0 DEG/S	2.0 DEG/S
LO	0.1 DEG/S	0.2 DEG/S
MIN	25 SEC/S	50 SEC/S
CMC	3.8 DEG/S	15.1 DEG/S

SXT FIELD OF VIEW



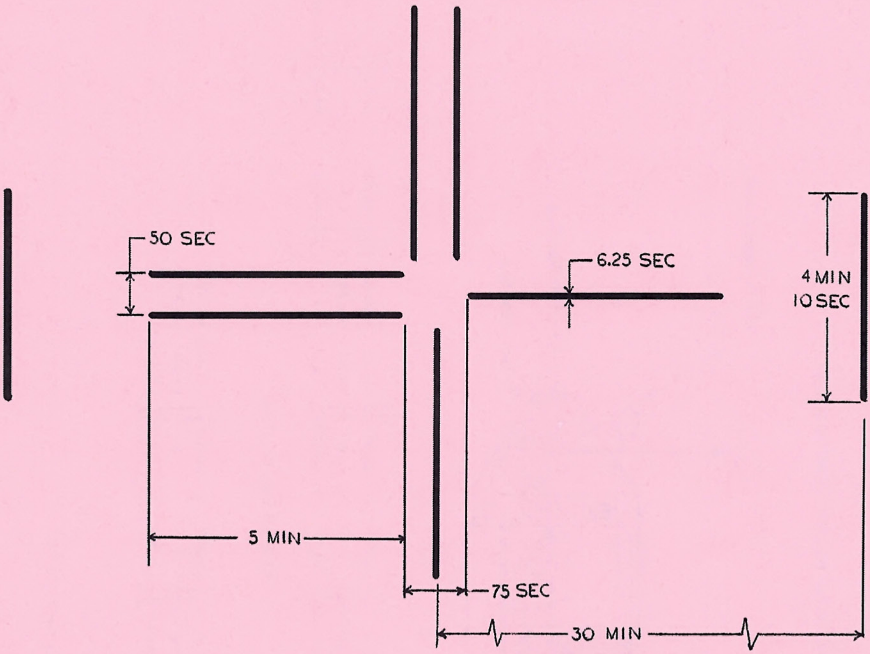
RETICLE ROTATION WITH OPTICS HAND CONTROLLER FULL RIGHT (MANUAL DIRECT MODE)



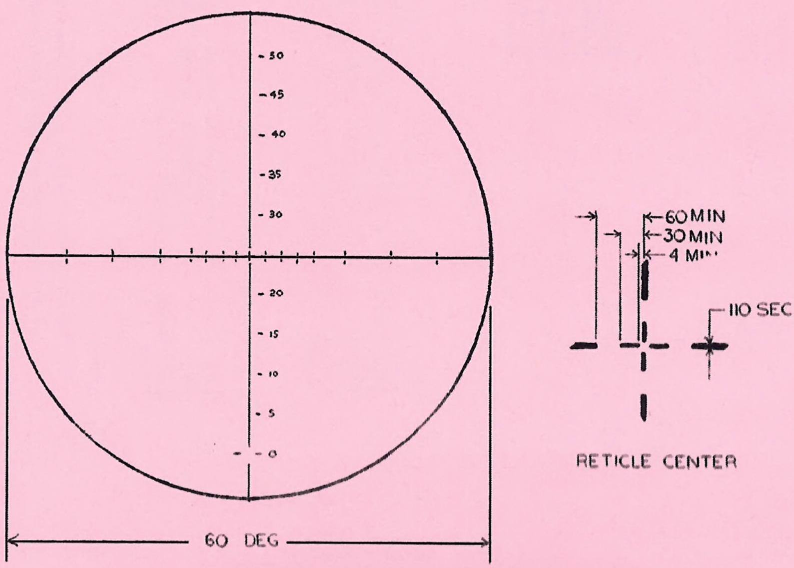


SXT LOS MECHANICAL LIMITS
TRUNNION 0(0,-10) TO 90(10,0) DEG
SHAFT 270(0,-10) TO -270(-10,0) DEG

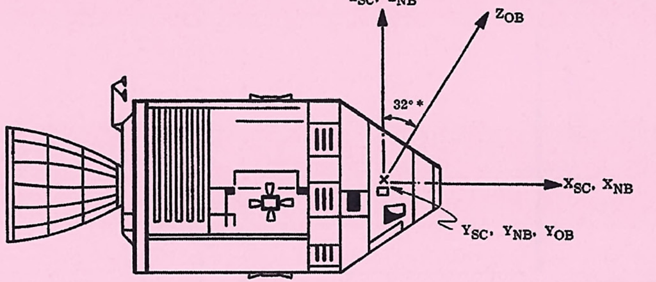
SXT VACUUM RETICLE



SCT RETICLE



OUA LINE OF SIGHT TO IMU STABLE MEMBER TRANSFORMATIONS



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} \cos 32^* & 0 & \sin 32^* \\ 0 & 1 & 0 \\ -\sin 32^* & 0 & \cos 32^* \end{bmatrix} \begin{bmatrix} \cos AS & -\sin AS & 0 \\ \sin AS & \cos AS & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos AT & 0 & \sin AT \\ 0 & 1 & 0 \\ -\sin AT & 0 & \cos AT \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ St\ LOS \end{bmatrix}$$

* Nominal Angle 32° 31' 23"

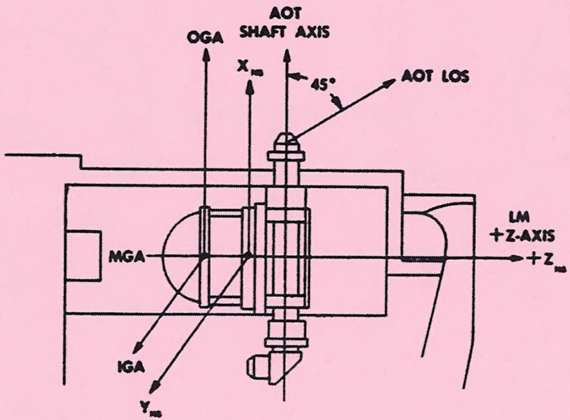
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} \cos 32^* & 0 & \sin 32^* \\ 0 & 1 & 0 \\ -\sin 32^* & 0 & \cos 32^* \end{bmatrix} \begin{bmatrix} \cos AS \sin AT \\ \sin AS \sin AT \\ \cos AT \end{bmatrix}$$

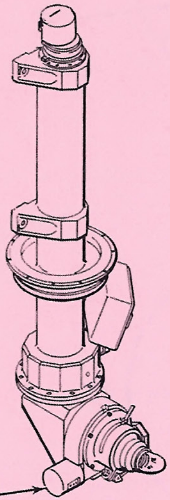
where

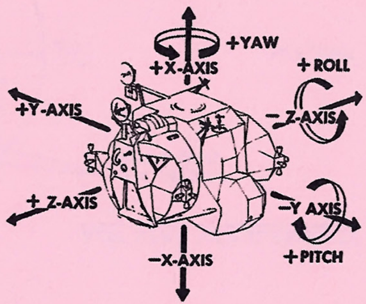
AI, AM and AO are the inner, middle, and outer gimbal angles as indicated by the CMC

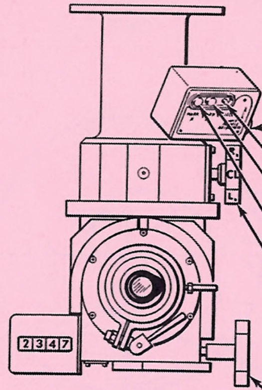
AS and AT are the SXT LOS shaft and trunnion angles

ALIGNMENT OPTICAL TELESCOPE

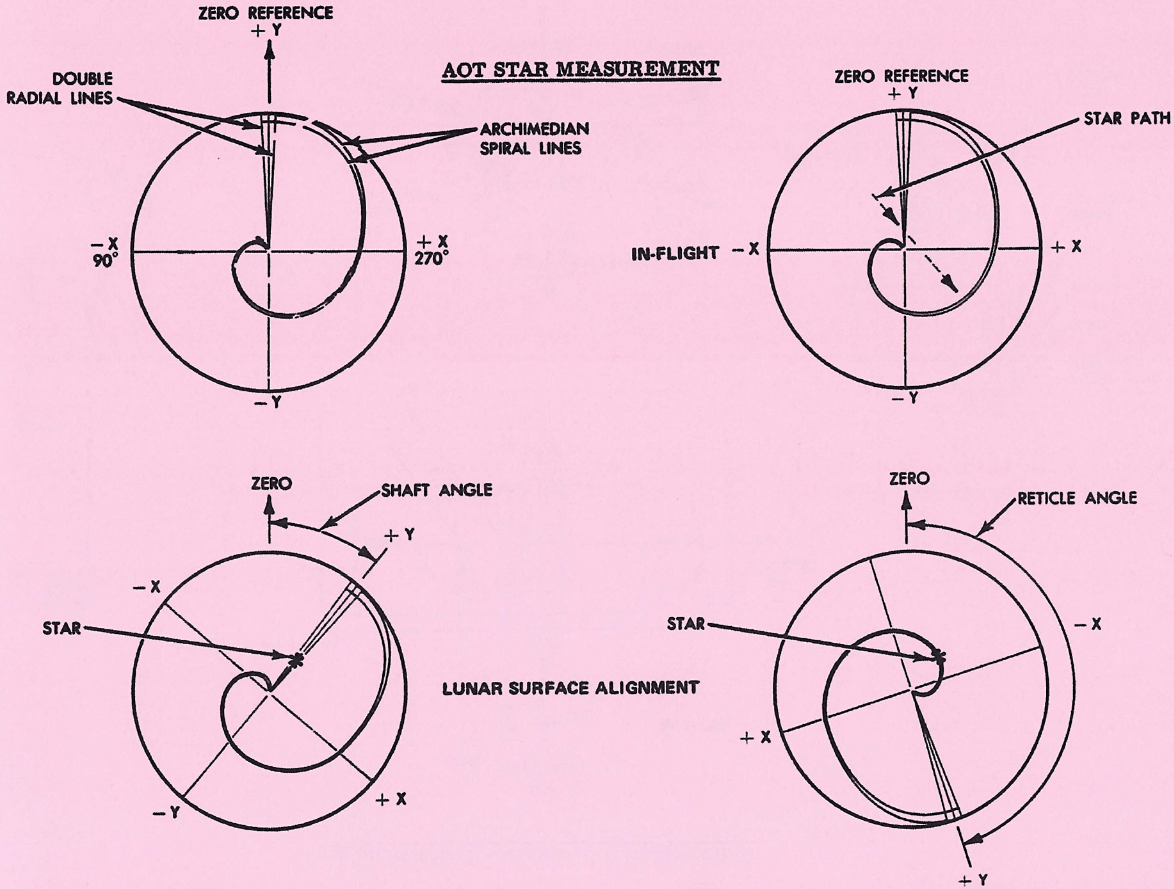


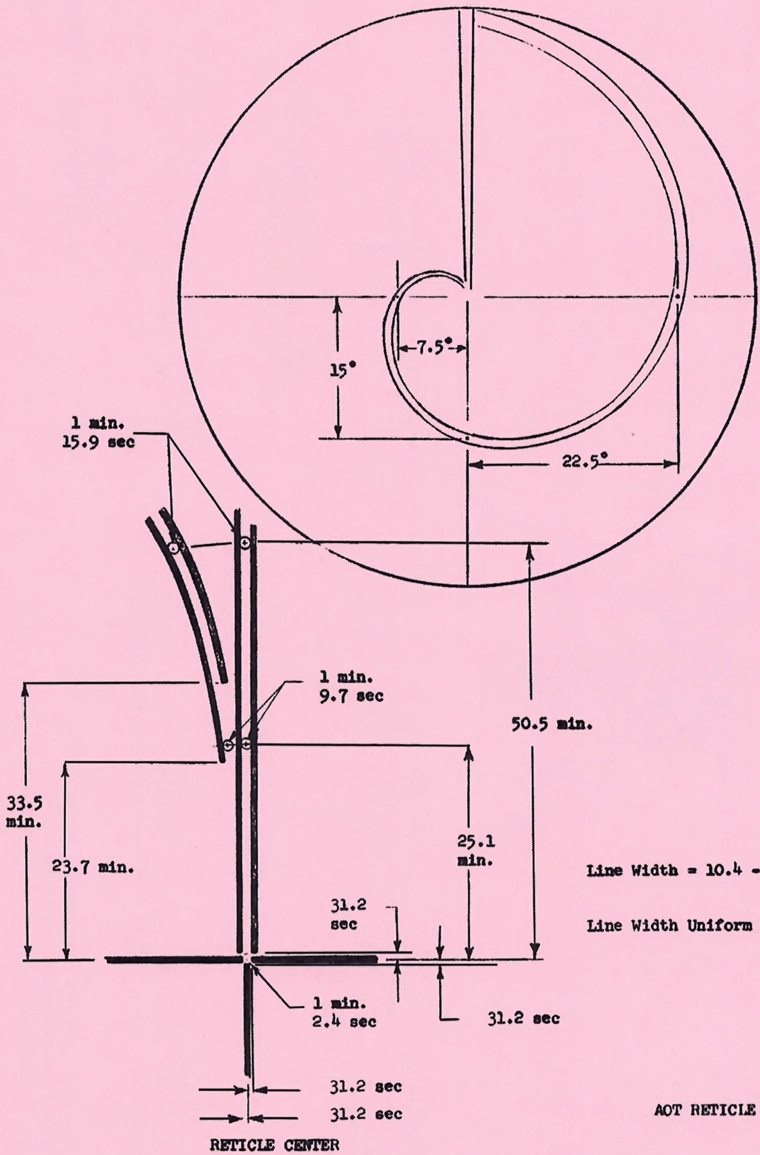






AOT STAR MEASUREMENT



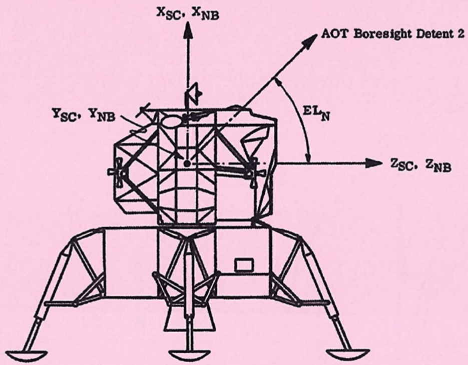


Line Width = 10.4 - 52 sec

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.

$EL_N \approx 45°$, N = 1, 2, ---, 6; $AZ_1 \approx -60°$; $AZ_2 \approx 0°$; $AZ_3 \approx 60°$; $AZ_4 \approx 120°$; $AZ_5 \approx 180°$; $AZ_6 \approx -120°$

AS = Y Reticle Angle

$$AT = \frac{360 + \text{S Reticle Angle} - \text{Y Reticle Angle}}{12}$$

CSM DAP CONTROL

Flashing V04 N46

Register 1:

A	B	C	D	E
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 = 2.0 deg/s

Register 2:

AC Roll	Quad A	Quad B	Quad C	Quad D

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

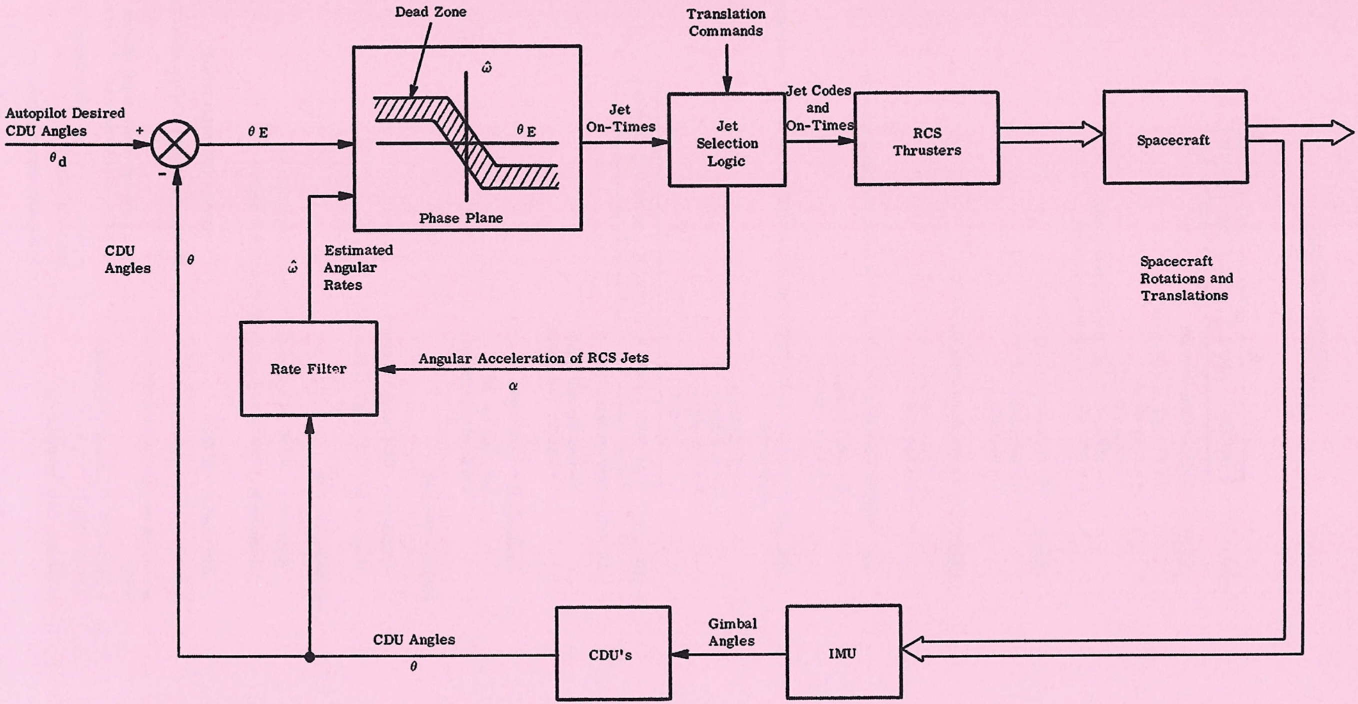
1. Automatic three-axis rotation.
2. Manual three-axis rotation and translation
3. Attitude hold to program or manual defined attitude.
4. Automatic rate damping.

ATTITUDE HOLD MODE

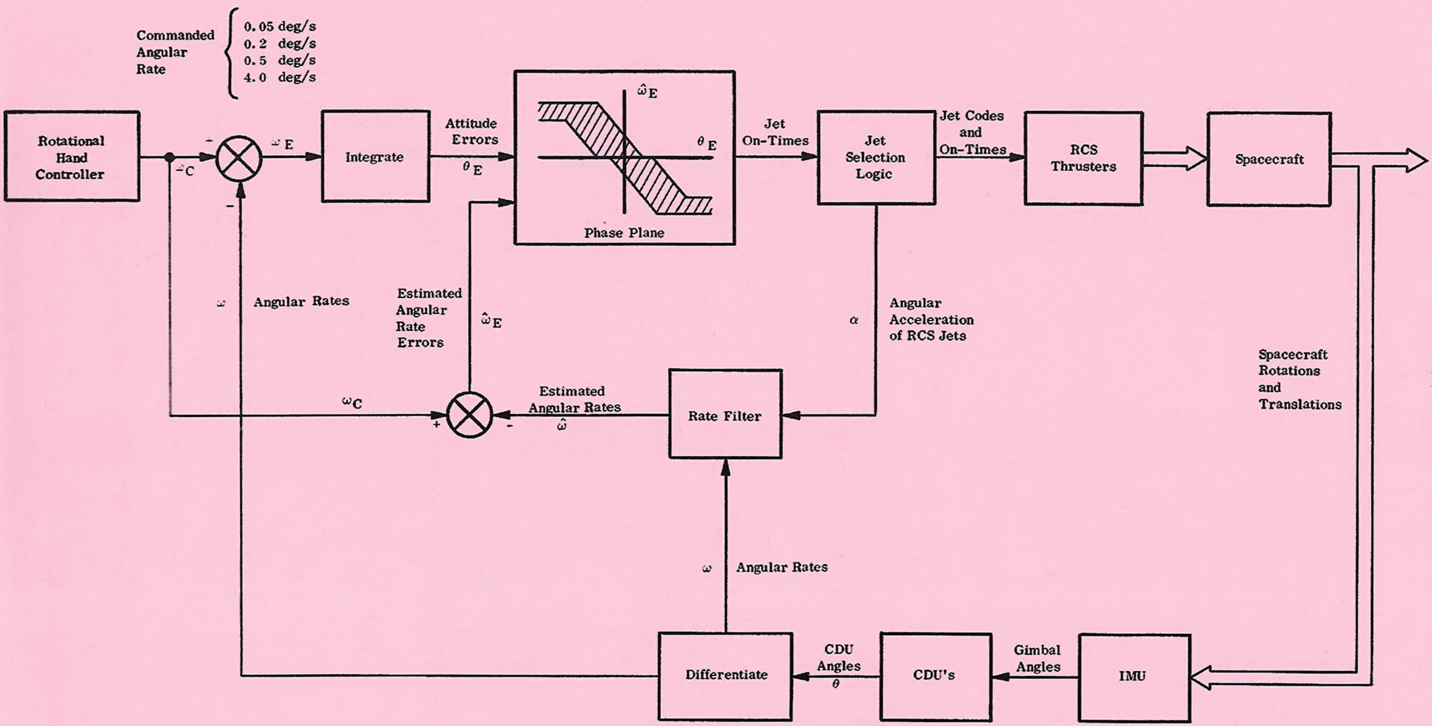
1. Manual three-axis rotation and translation.
2. RHC produces a rotational rate as specified by N46 while out of detent.
3. Attitude hold to attitude selected via hand controller.
4. Automatic rate damping.

CSM DIGITAL AUTOPILOT
COASTING FLIGHT

AUTOMATIC ATTITUDE HOLD MODE

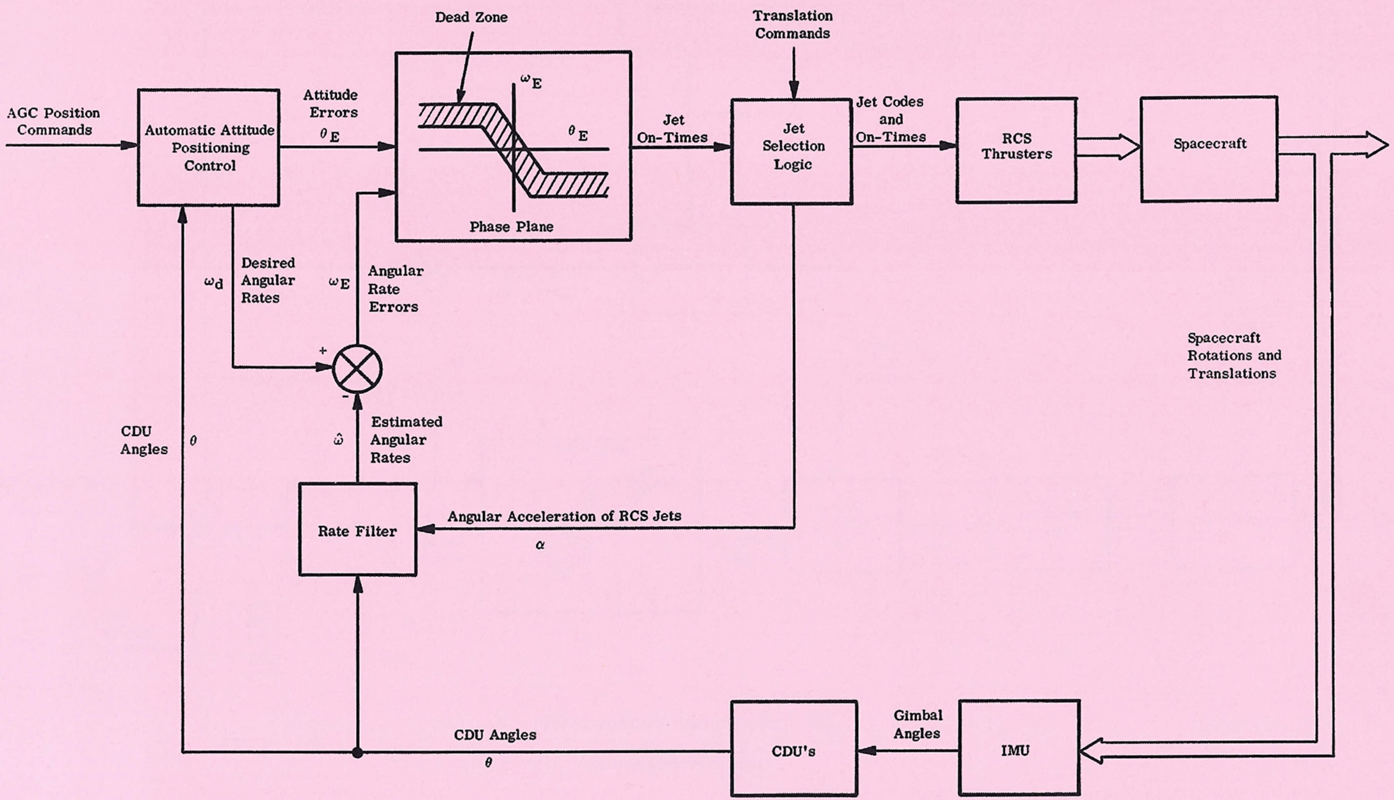


CSM DIGITAL AUTOPILOT
COASTING FLIGHT
MANUAL ANGULAR RATE CONTROL MODE

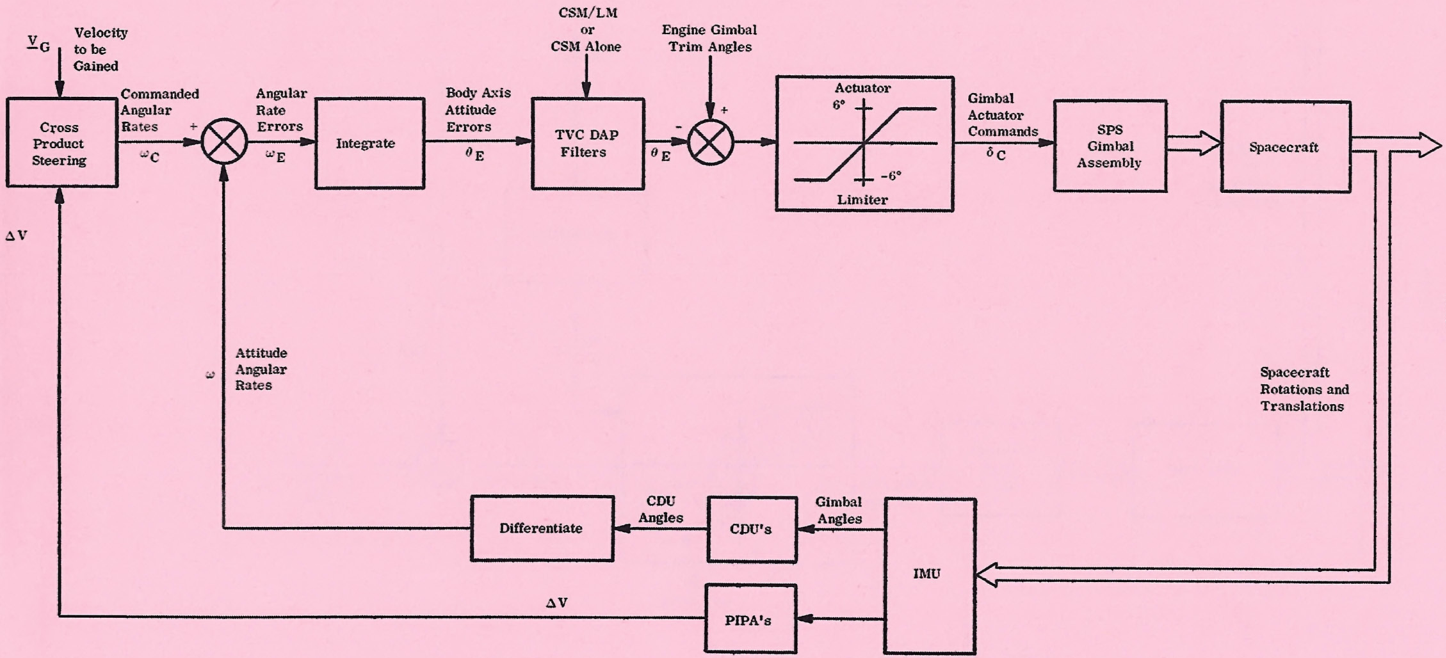


CSM DIGITAL AUTOPILOT
COASTING FLIGHT

AUTOMATIC ATTITUDE POSITIONING MODE

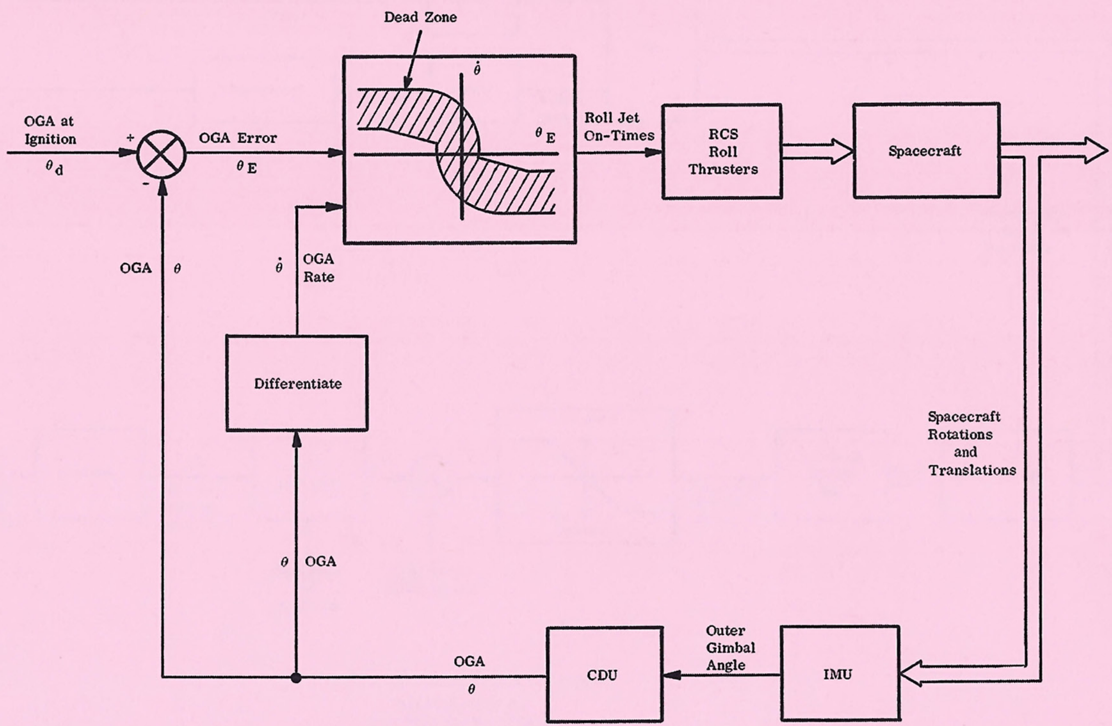


CSM DIGITAL AUTOPILOT
POWERED FLIGHT
THRUST VECTOR ATTITUDE CONTROL



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 - minimum impulse)
3 = Four-jet translation (RCS System B - minimum impulse)

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

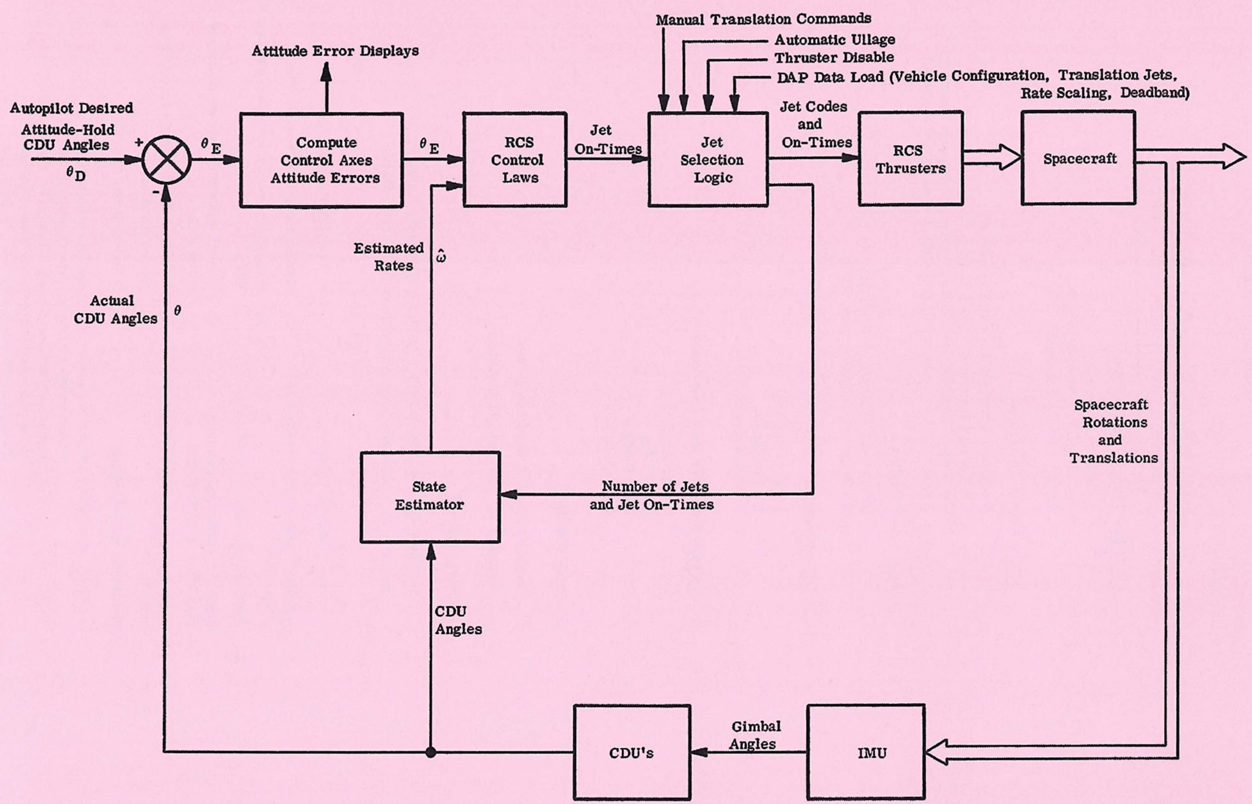
1. Manual three-axis translation.
2. Manual three-axis rate command using V77
3. Manual minimum impulse command using V76.
4. Attitude hold to attitude selected via hand controller
5. Automatic rate damping

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.

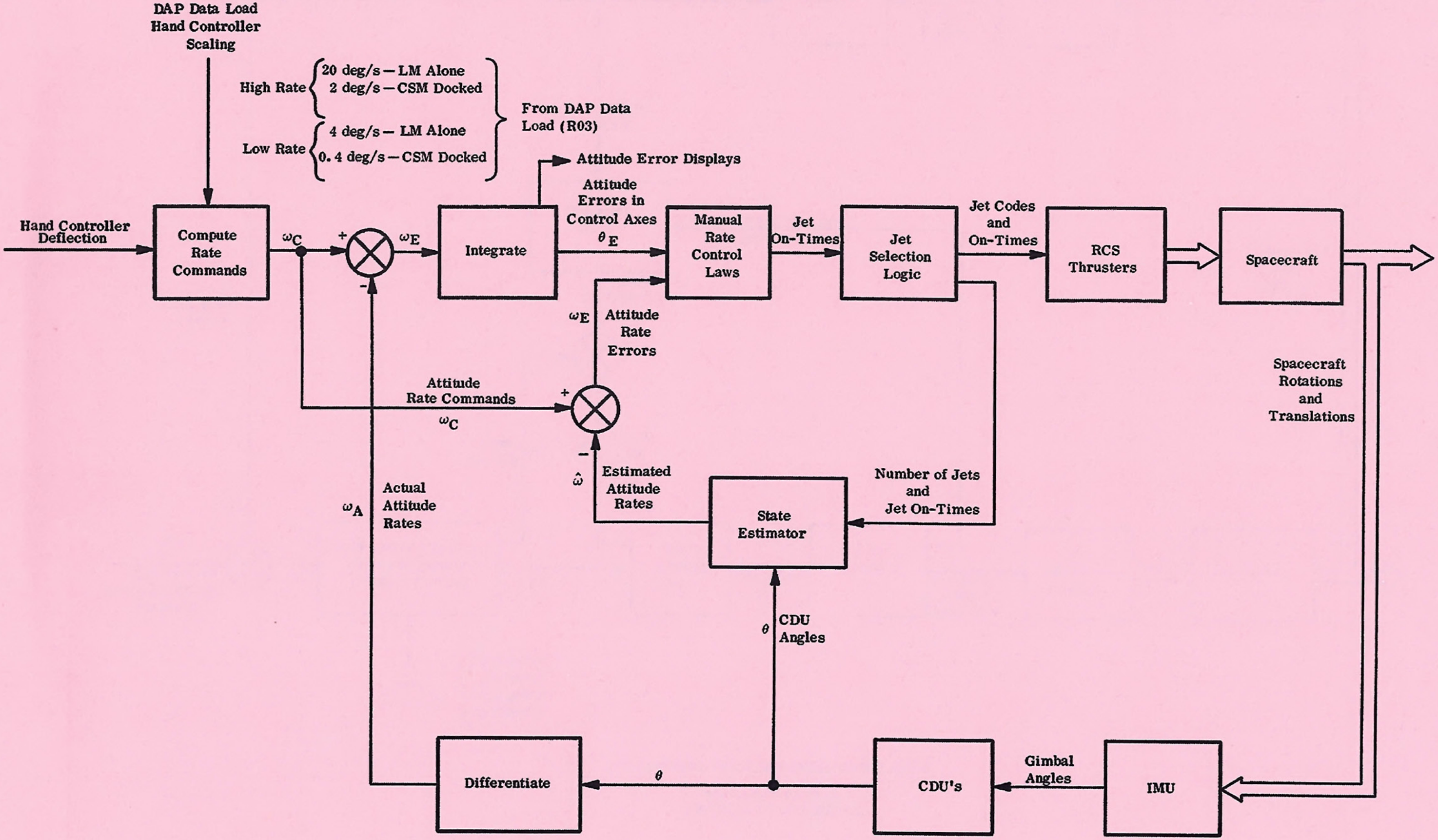
LM DIGITAL AUTOPILOT
COASTING FLIGHT

ATTITUDE-HOLD CONTROL MODE

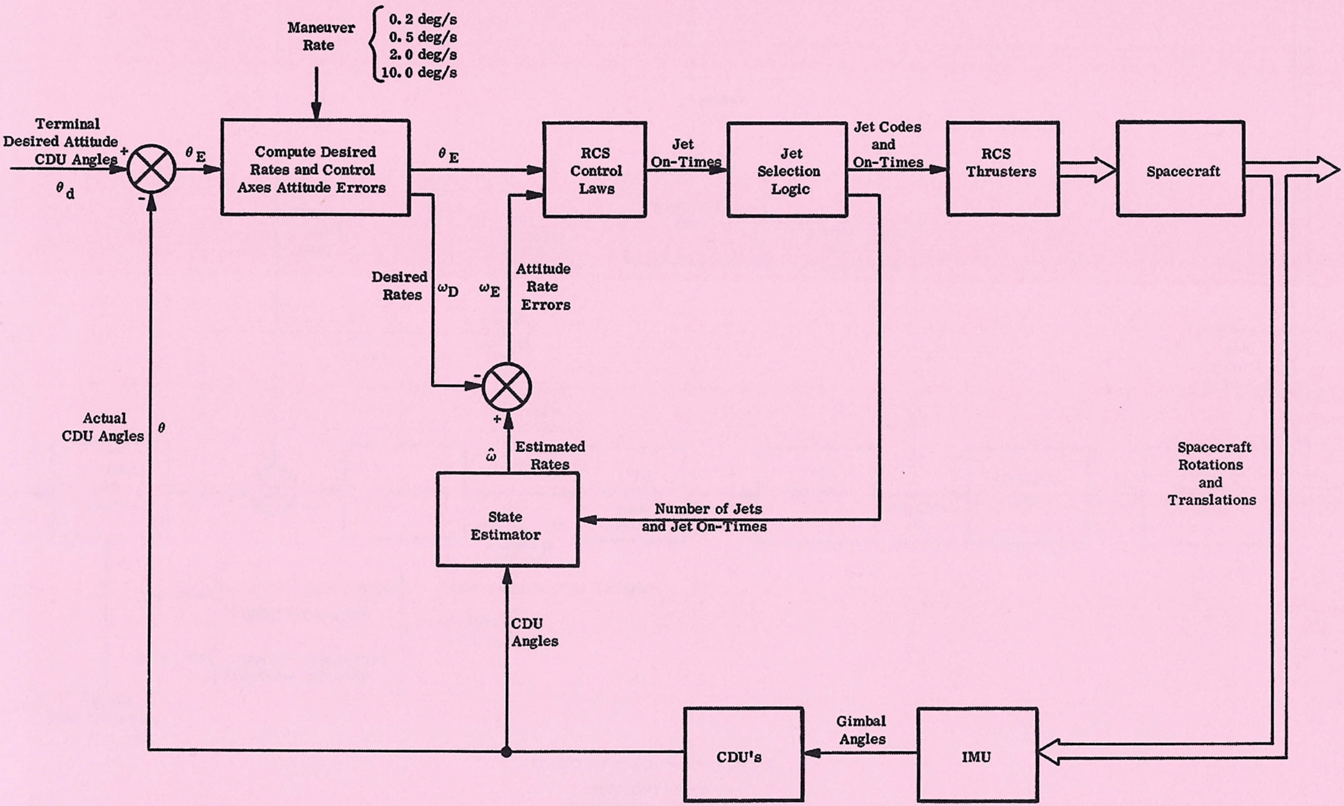


LM DIGITAL AUTOPILOT
COASTING FLIGHT

MANUAL ATTITUDE RATE MODE



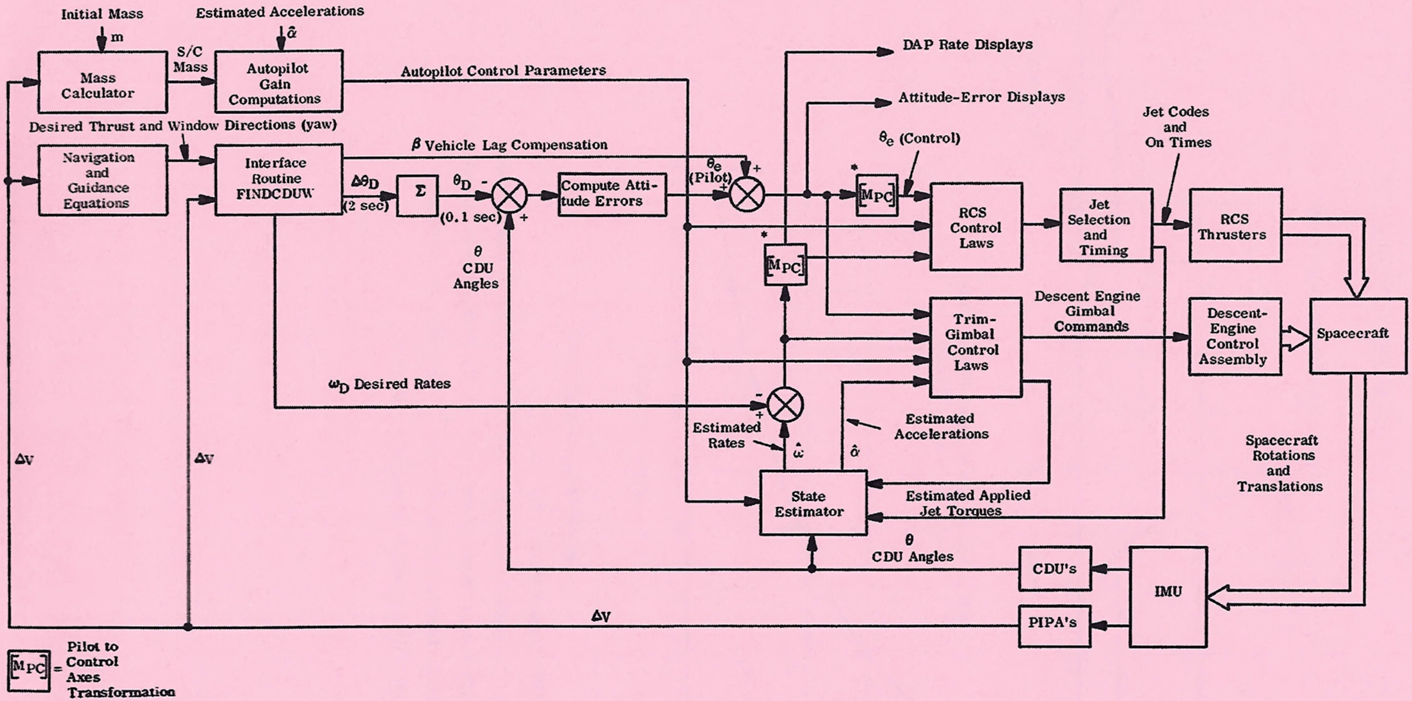
LM DIGITAL AUTOPILOT
COASTING FLIGHT
AUTOMATIC ATTITUDE POSITIONING MODE



HW-80

LM DIGITAL AUTOPILOT
POWERED FLIGHT

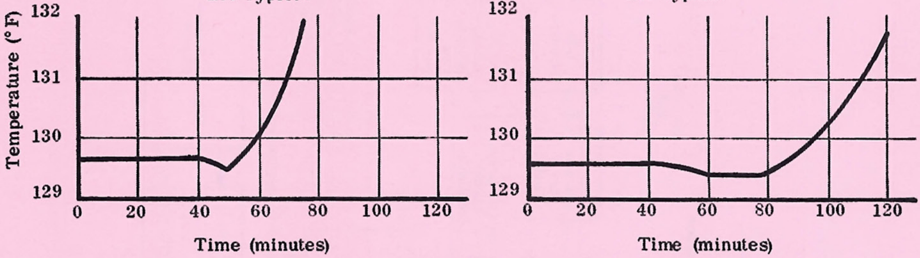
AUTOMATIC ATTITUDE AND STEERING CONTROL MODE



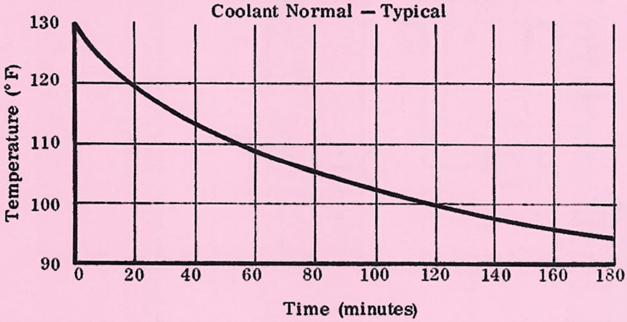
TYPICAL IMU TEMPERATURE

PIPA Temperature After Coolant Loss

LM Typical — CM Typical



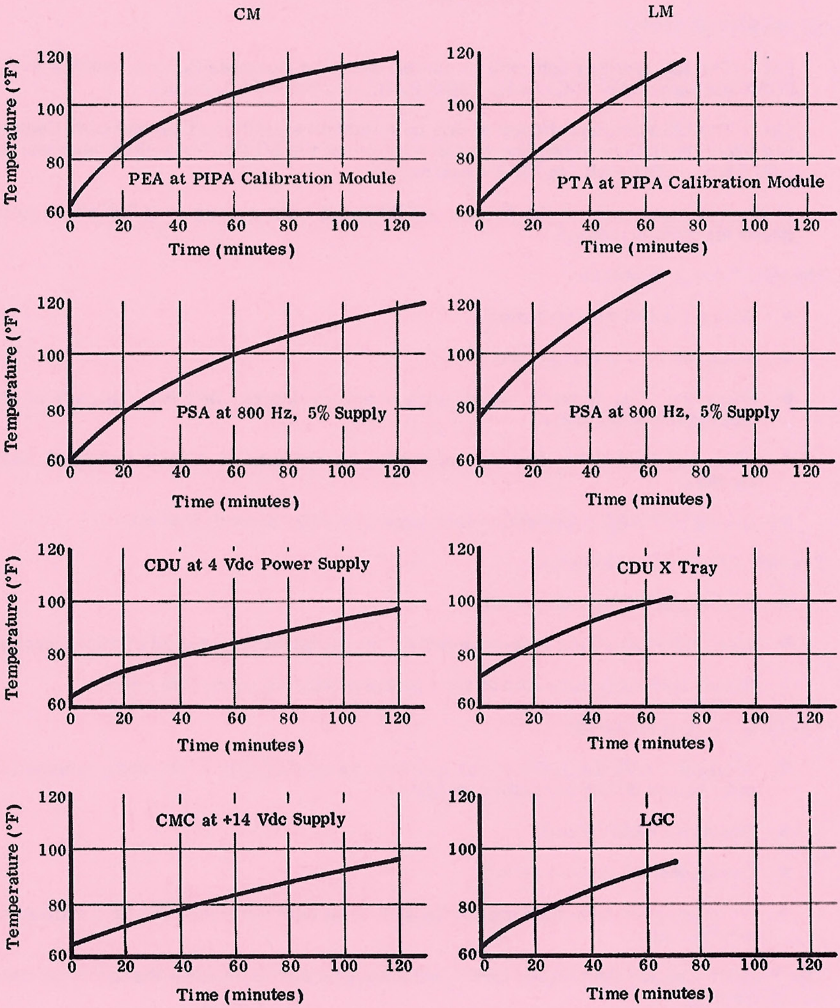
PIPA Temperature After Power Loss
Coolant Normal — Typical



NOMINAL PARAMETERS

- PIPA Temperature — 130 ± 1.5°F
- Low Temperature Alarm — 126 ± 2.5°F (PIPA Temperature)
- High Temperature Alarm — 135 ± 2.5°F (PIPA Temperature)
- Safety Thermostat Opens — 140 $^{+5}_{-2}$ °F (PIPA Temperature)
- Safety Thermostate Hysteresis — 2 - 5°F

TYPICAL HEADER TEMPERATURES AFTER
COOLANT LOSS



ISS WARNING LIGHT

LM – The ISS Warning light will be turned on if the Guidance Control switch is in the PGNS position and an IMU FAIL, ICDU FAIL, or a PIPA FAIL occurs.

CM – The ISS Warning light will always be turned on in both the LEB and CMP Caution and Warning stations regardless of the position of the SC Control switch whenever an IMU FAIL, ICDU FAIL, or PIPA FAIL occurs.

In both systems each of the failures are inhibited from causing an ISS Warning to be issued for specific reasons.

The IMU FAIL is inhibited:

- During the ISS turn-on period.
- When the IMU is being caged.
- When the IMU is being coarse aligned and during the first 5.12 seconds of the ensuing fine align mode.
- When the IMU CDU Zero is commanded by the astronaut for a period of 10.24 seconds.
- During R47 AGS Initialization for a period of 10.24 seconds (LM only).

The IMU CDU FAIL is inhibited:

- During the ISS turn-on period.
- When IMU CDU Zero is commanded by the astronaut for a period of 10.24 seconds.
- During R47 AGS Initialization for a period of 10.24 seconds (LM only).

The PIPA FAIL is inhibited:

- Anytime "AVERAGEG" is not running. "AVERAGEG" is normally running just prior to and during a thrusting maneuver.
- During a FRESH START.
- During the ISS turn-on period.
- At other times, only the Program Caution light with error code 00212 is allowed for a PIPA FAIL.

The Program Caution light on the DSKY will always be turned on when the computer issues an ISS Warning.

IMU FAIL

- IG or MG or OG servo error $>$ 3 Vrms (0.166°) for 2 seconds. This is a 3,200 Hz signal and is detected at the input to the respective servo amplifiers (see page HW-19).
- 28 Vac, 800 Hz, 5%, Phase B (to wheel supply) $<$ 14 V. This signal is detected at the output of the power supply and is such that if any 28 Vac, 800 Hz power supplies fail the failure will show up on this line.
- 28 Vac, 3,200 Hz, 1%, $<$14 V. This signal is detected on the feedback line in the regulation circuit.

Error codes for IMU FAIL.

IMU CDU FAIL

- IG or MG or OG coarse error $>$ 2 Vrms (θ - ψ $>$ 30°). This is an 800 Hz signal and is detected at the input to the emitter follower circuit preceding the coarse Schmitt trigger (see page HW-35).
- IG or MG or OG fine error $>$1 Vrms (θ - ψ $>$0.7°). This is an 800 Hz signal and is detected at the output of the main summing amplifier (see page HW-38).
- IG or MG or OG read counter limit cycle $>$160 Hz. This signal is detected from the upline output of the read counter up-down counter (see page HW-33).
- IG or MG or OG cos(θ - ψ) $<$2 Vrms. This is an 800 Hz signal and is detected at the output of the ladder amplifier (see page HW-38).
- +14 Vdc CDU power supply $<$+8 Vdc. This signal is detected at the output of the power supply.

  θ – gimbal resolver angle
  ψ – CDU read counter angle
  Error code for IMU CDU FAIL

PIPA FAIL

- No PIPA pulses for 312 microseconds.
- "+" and "-" PIPA pulses occurring simultaneously.
- No "+" and "-" pulses for 1.28 to 3.84 seconds.

OPTICS CDU FAIL

Same as IMU CDU FAIL with the exception that there is no coarse error signal.

RR CDU FAIL

Same as IMU CDU FAIL.

AGC/LGC Warning

The AGC/LGC Warning light will be turned on as a result of the following:

- Scalar Failure
- Scalar Double Failure
- AGC/LGC Power Failure
- AGC/LGC Counter Failure
- AGC/LGC V FAIL (STANDBY)
- AGC/LGC Restart (Hardware)

In addition, the Pulse Torque Power Supply Inhibit is generated every time a AGC/LGC Warning is generated. The effect is to open up the accelerometer loops and prevent any pulse torquing of gyros.

Scalar Failure

Occurs if Stage 17 of the scaler fails to produce pulses. This is the 1.28 second period scalar stage and thus a check of timing for all alarms. This failure causes immediate turn on of the AGC/LGC Warning light.

Scalar Double Failure

Occurs if the 100 pulse per second stage (.010 second period) operates at 200 pps. This provides a check on the scalar stability.

AGC/LGC Power Failure

Occurs when the prime +28 VDC power to the computer is lost. This failure causes an immediate turn on of the AGC/LGC Warning light.

Counter Failure

Occurs if counter increments happen too frequently or else fail to happen following an increment/decrement request. "Too frequently" means continuous counter requests and/or incrementing from .625 to 1.875 milliseconds.

Examples of counters are:

AGC/LGC input/output, (Time 1 and Time 2), ± CDU X, Y, Z, PIPA X, Y, Z, shaft and trunnion angles, Rate Hand Controllers R, P, Q, etc.

AGC/LGC Voltage FAIL (STANDBY)

The occurrence of a Voltage Failure while the computer is in the STANDBY mode will cause the AGC/LGC Warning light to be turned on. The causes of a Voltage Failure are given below in the RESTART section.

RESTARTS

A RESTART (hardware) and subsequent AGC/LGC Warning is generated for the following alarms:

- Oscillator Failure
- Transfer Control (TC) Trap
- Parity Alarm
- Nightwatchman Fail
- Interrupt (RUPT) Lock
- Voltage Fail

The RESTART inhibits access to memory temporarily, freezes the computer, stores in process information and then transfers control to address 4000. This address has the information address for the next instruction after a RESTART that the software programmer has provided.

In general, the programmer has chosen some particular point in a program to resume operation after a RESTART and operation continues with only small inconsequential loses of information of time and/or thrust.

Oscillator Fail

Occurs if loss of oscillator 1.024 milliseconds square wave happens. In addition a logic circuit insures a RESTART condition for a 250 millisecond interval upon transferring from STANDBY to OPERATE.

Transfer Control (TC) Trap

Occurs if too many or too few TC instructions are requested. The period for "too many" or "too few" is from 5 to 15 milliseconds in duration.

Parity Alarm

Occurs if any accessed word in fixed or erasable memory whose address is 10_8 or greater contains an even number of "ones." All locations of 10_8 or greater are stored in fixed or erasable memory with odd parity.

Nightwatchman Fail

Occurs if the computer should fail to access address 67 within a period whose duration varies from 0.64 to 1.92 seconds.

Nightwatchman assures that the computer is still operating during an extended idle period and is not tied up in some interrupt loop.

Interrupt (RUPT) Lock

Occurs if an interrupt is either "too long" or "too infrequent." The time period for "too long" or "too infrequent" varies from 140 milliseconds to 300 milliseconds.

Voltage Fail

Occurs if the AGC/LGC voltages (+28, +14, or +4 VDC) are out of limits for 157 to 470 microseconds.

These limits are:

- +28 VDC supply < 22.6 VDC or 20.3* VDC ±0.2 VDC
- +16 VDC < +14 VDC supply < +12.5 VDC
- +4.4 VDC < + 4 VDC supply < +3.65 VDC

*Two types of modules are in existence. Each computer has its own particular module.

When the computer is in the OPERATE mode a RESTART is generated for Voltage Fails. If the Computer is in the STANDBY mode, the Voltage Fail is processed through the warning filter to turn on the AGC/LGC Warning light.

All of the signals with the exception of Scalar failure or a prime power (+28 VDC) failure are processed through a buffer filter that prevents momentary transients from generating failures.

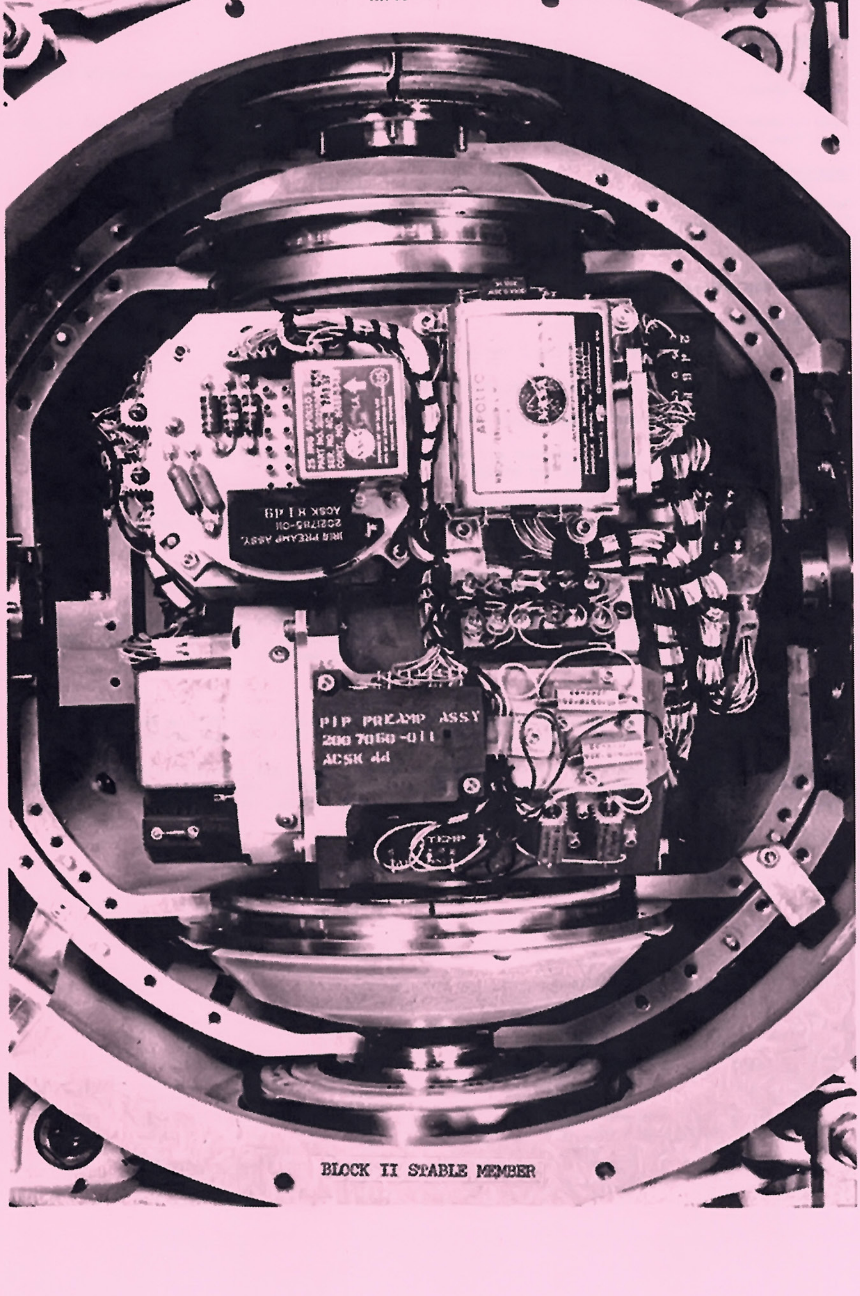
The filter operates such that an output will occur if input pulses occur at a rate of greater than 0.9 pps or 6 consecutive stretched (160 milliseconds) pulses occur or a single event longer than .960 seconds, then the AGC/LGC warning lasts for a minimum of 5 seconds.

V35E - Test Lights

The computer has a test light routine, called by V35E, that tests all the lights on the DSKY. All "8's" and "+" signs are displayed along with each light turned on for 5 seconds minimum.

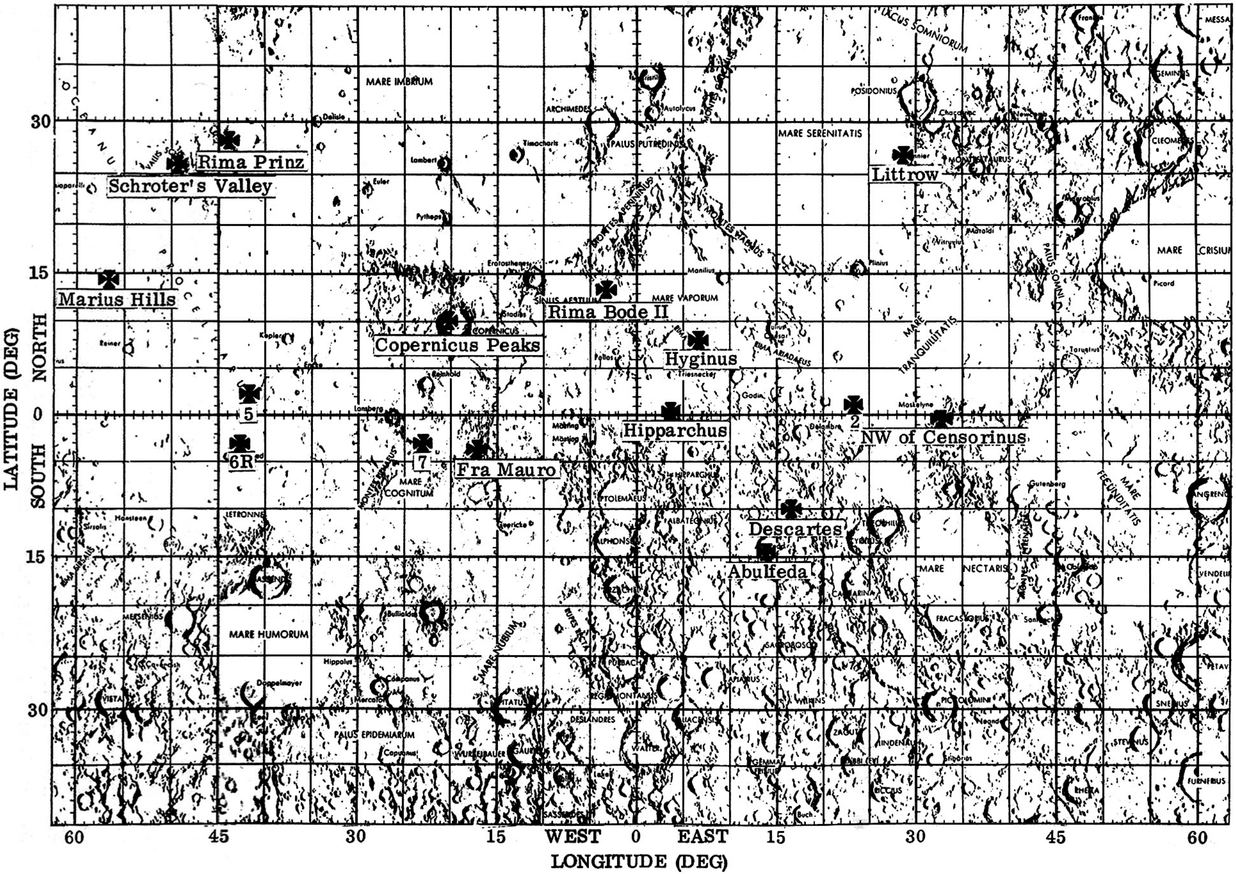
After the 5 seconds are completed, the lights are turned off. Note that this verb also turns off the Pulse Torque Power Supply which then causes the PIPA loops to open for approximately 5 seconds. This should be avoided if possible. The routine can be called when ISS operate is not on.

HW-88



BLOCK II STABLE MEMBER

LANDING SITE LOCATIONS



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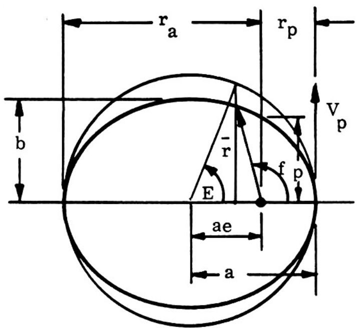
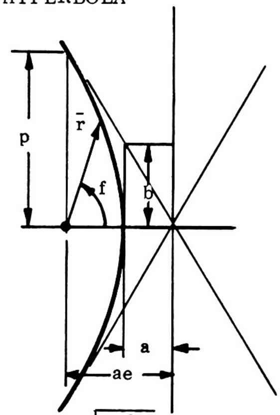
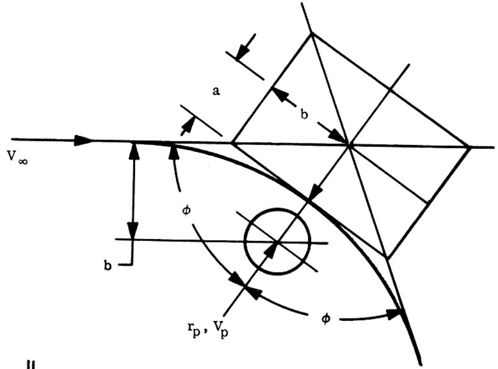
ELLIPSE	HYPERBOLA	HYPERBOLIC ENCOUNTER
		

		Ellipse	Hyperbola
Semiminor Axis	b =	$\sqrt{r_a r_p}$	$r_p \sqrt{1+\frac{2a}{r_p}}$
Semimajor Axis	a =	$\frac{r_a + r_p}{2}$	$\frac{\mu}{V_\infty^2}$
Eccentricity	e =	$\sqrt{1 - (\frac{b}{a})^2}$ <1	$\sqrt{1 + (\frac{b}{a})^2}$ >1
Position	r =	$\frac{a(1-e^2)}{1 + e \operatorname{Cos} f} = a\ (1 - e \operatorname{Cos} E)$	$\frac{a(e^2-1)}{1 + e \operatorname{Cos} f}$
Velocity	V =	$[\frac{\mu}{a}(\frac{1+2e \operatorname{Cos} f + e^2}{1-e^2})]^{1/2}$	$[\mu(\frac{2}{r}+\frac{1}{a})]^{1/2}$
Semilatus Rectum	p =	$a\ (1 - e^2)$	$a\ (e^2 - 1)$
			$V_\infty^2 = \frac{\mu}{a}$

$V_\infty^2 = V_p^2 - 2\,\mu/r_p = \mu/a$

$r_p V_p = b V_\infty$

$\operatorname{Tan} \phi = b/a = b V_\infty^2/\mu$

$\mu = GM_M$ $\quad ft^3/s^2$

M_M = Mass of the Moon