

Skylab



Delco Electronics

*General Motors Corporation
- Santa Barbara Operations
Santa Barbara, California*

SATELLITE ORBIT (SL-1)	234 x 234 nmi
SATELLITE ORBIT DURATION	1 h 33 min 12 s
SATELLITE ORBIT RATE	3.86 deg/min
V_C (SURFACE)	7,905.4 m/s
I.E. $V_C = \sqrt{\frac{\mu}{R}}$	25,936.0 ft/s
	15,356.7 nmi/h
ESCAPE VELOCITY (SURFACE)	11,027 m/s
	36,178 ft/s
	21,421 nmi/h
ONE DEGREE ON SURFACE	60 nmi
μ	$0.3986032 \times 10^{15} \text{ m}^3/\text{s}^2$
RADIUS	6,378,165 m
	20,925,738 ft
	3,444 nmi
MASS	$5.975 \times 10^{24} \text{ kg}$
SURFACE GRAVITY	32.14 ft/s^2
ORBIT CHARACTERISTICS	EARTH ABOUT SUN
SEMI MAJOR AXIS	$1.496 \times 10^{11} \text{ m}$
	$4.908 \times 10^{11} \text{ ft}$
	$8.073 \times 10^7 \text{ nmi}$
ECCENTRICITY	0.0167
MEAN VELOCITY	29,770 m/s
	97,702 ft/s
	57,888 nmi/h
PERIOD	365.24 days
INCLINATION	23.44 deg
μ_{SUN}	$= 0.132715445 \times 10^{21} \text{ m}^3/\text{s}^2$
1 METER	$= 3,2808 \text{ ft}$
	$= 5.3961 \times 10^{-4} \text{ nmi}$
	$= 6.2137 \times 10^{-4} \text{ m}$
1 ARC-SEC	$= 4.8481 \times 10^{-6} \text{ rad}$
	$= 2.7778 \times 10^{-4} \text{ deg}$
1 meru	$= 7.292115 \times 10^{-8} \text{ rad/s}$
	$= 4.178 \times 10^{-6} \text{ deg/s}$
	$= 2.507 \times 10^{-4} \text{ arc-min/s}$
	$= 0.01504 \text{ arc-sec/s}$
1 cm/sec ²	$= 3.281 \times 10^{-2} \text{ ft/s}^2$
	$= 1.0197 \times 10^{-3} \text{ g}$

GUIDANCE AND NAVIGATION SUMMARY

CM SOFTWARE

ASPO 45 CRT DISPLAYS

LAUNCH AND BURN SCHEDULES

BURN PERTURBATIONS

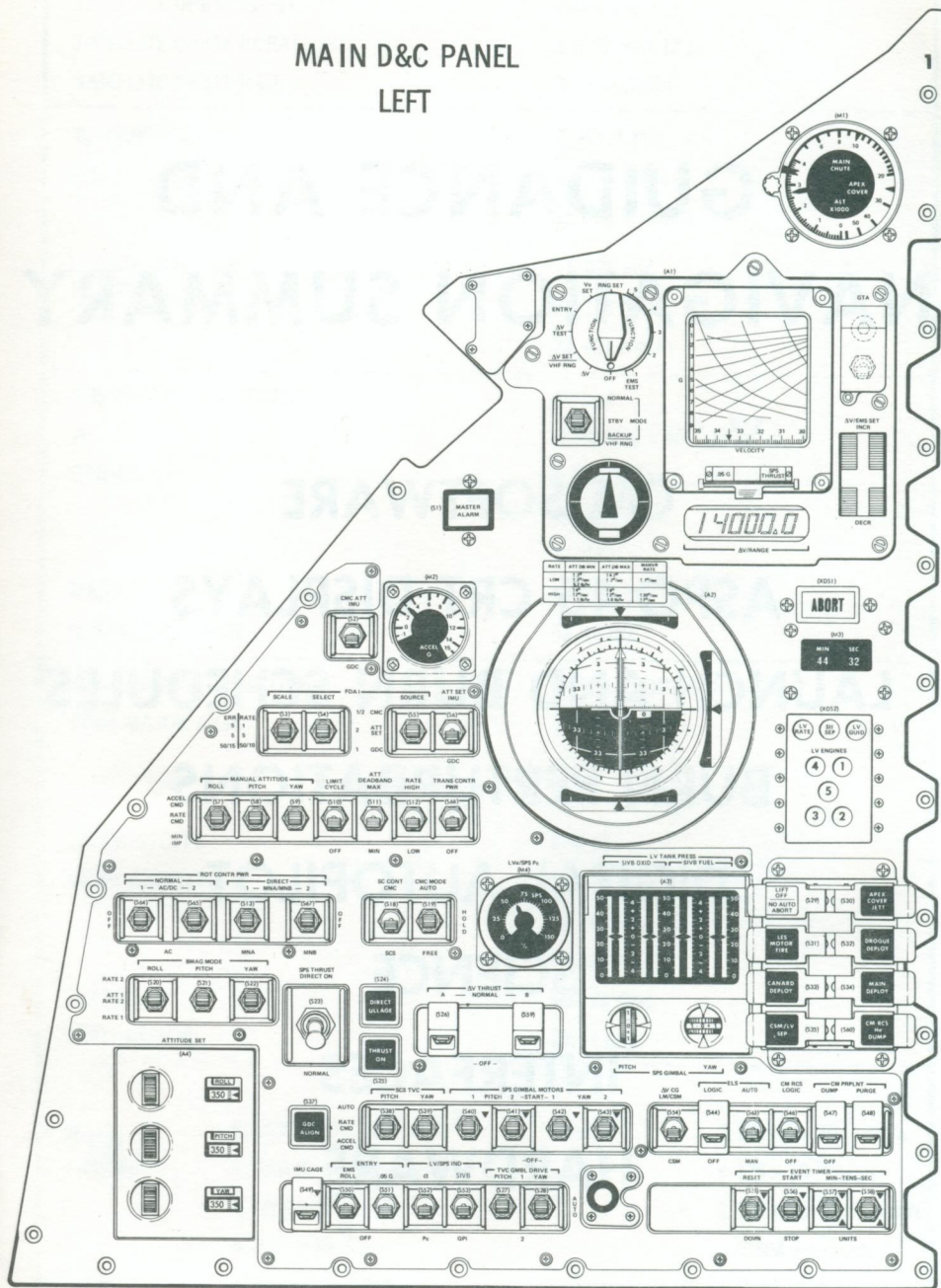
DIGITAL AUTOPILOT

SCIENCE

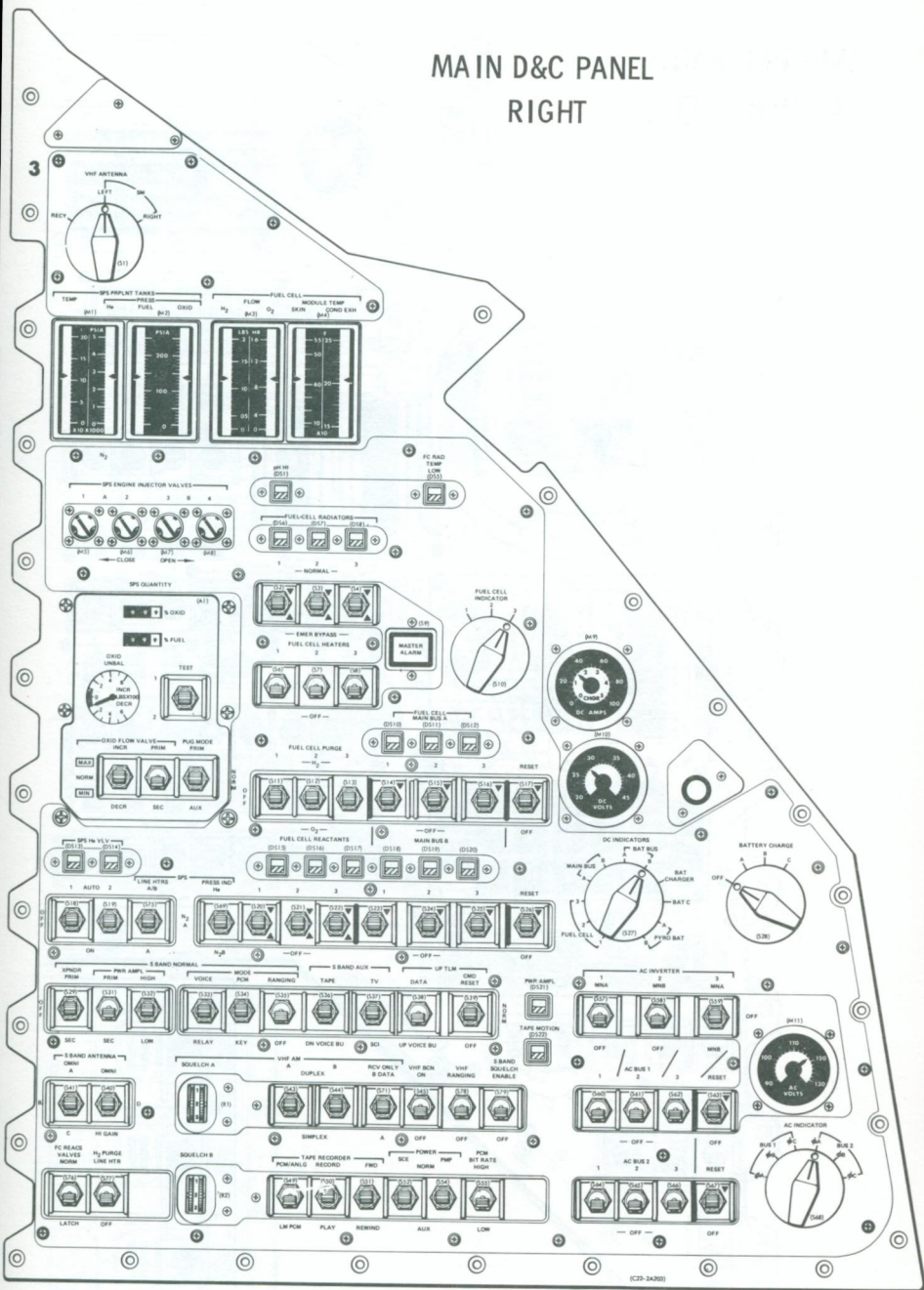
INTERFACES

HARDWARE

MAIN D&C PANEL LEFT



MAIN D&C PANEL
RIGHT



MAIN D&C PANEL CENTER (LEFT)

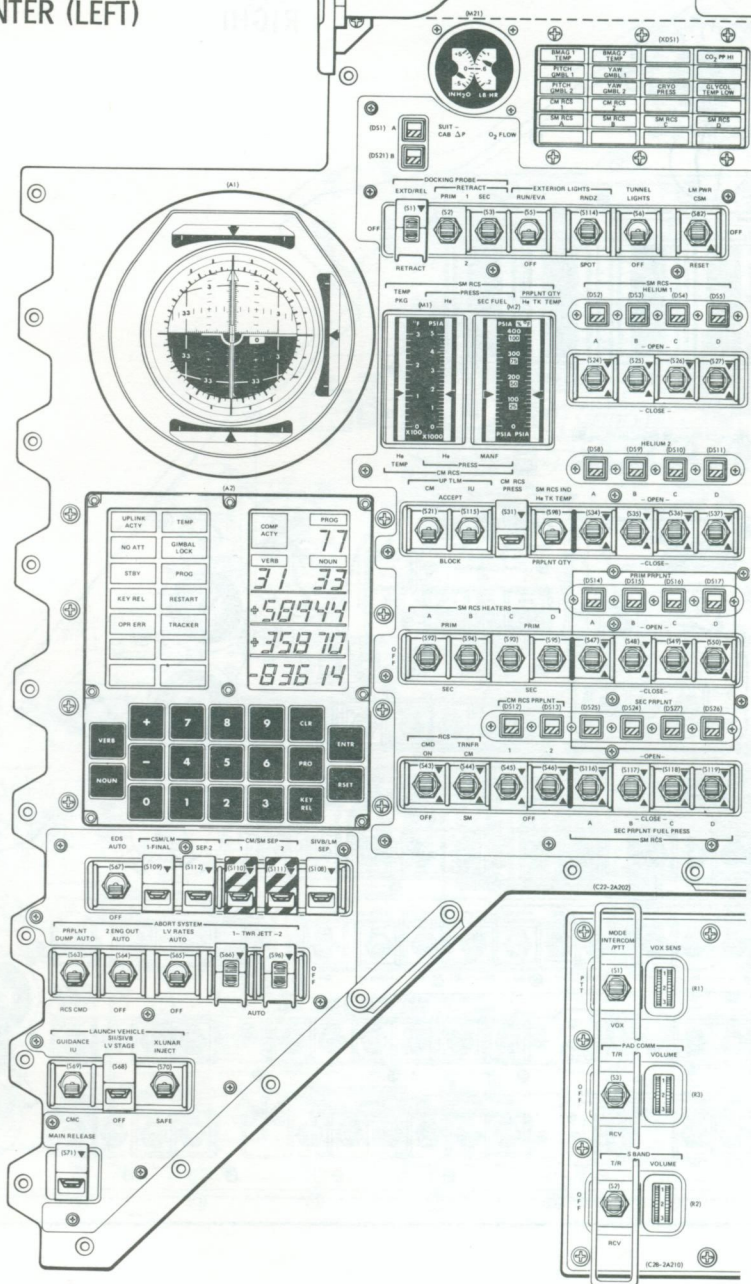
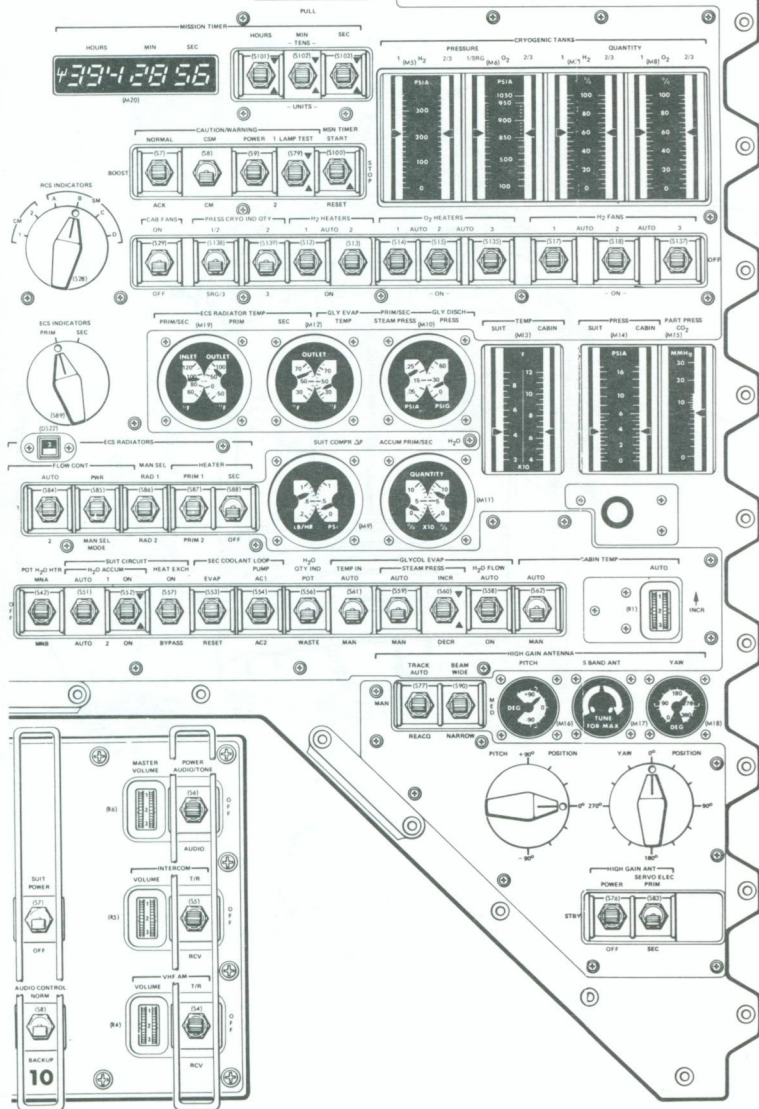
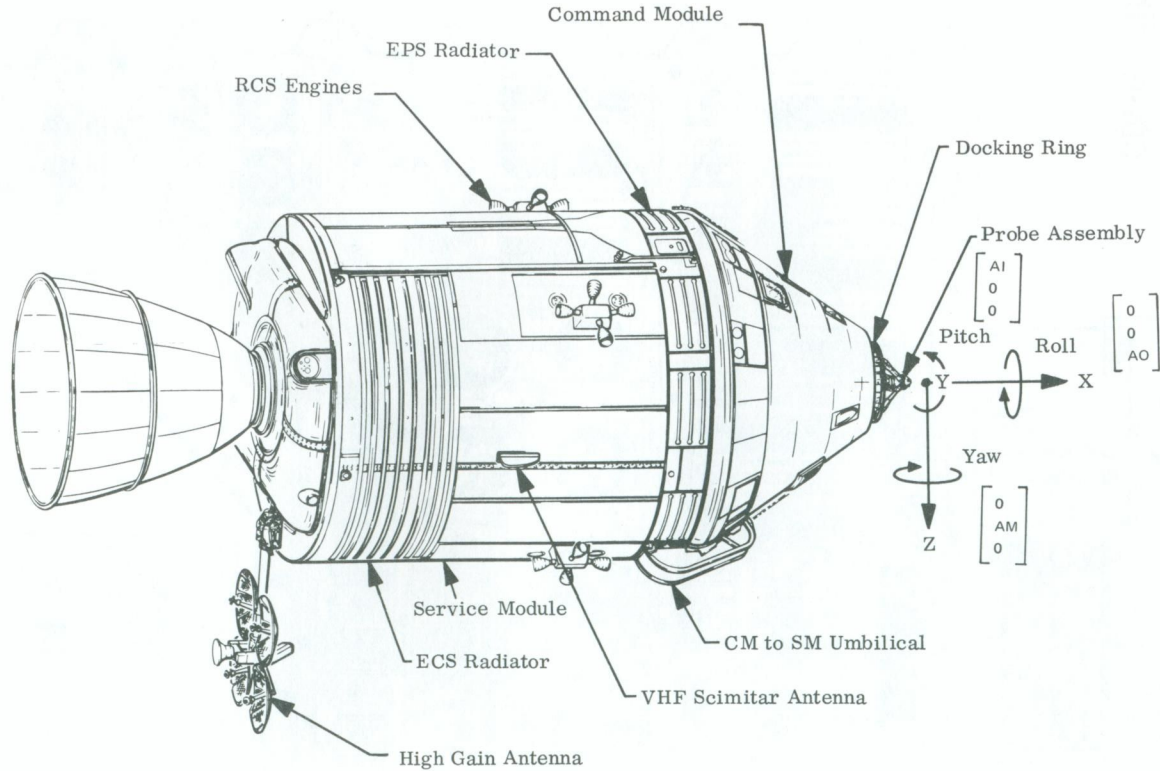


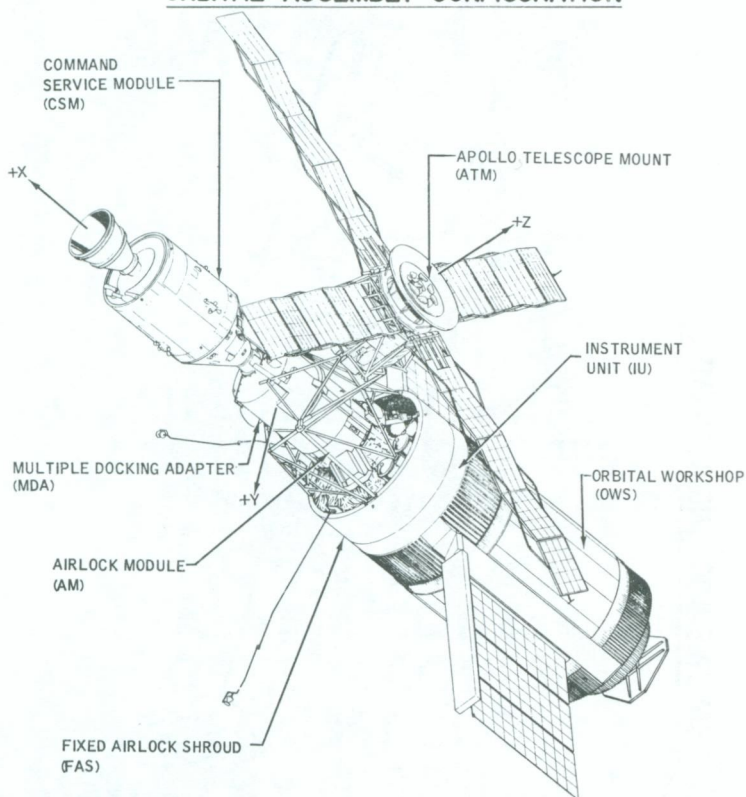
Diagram of the rear panel of the 1000 Series Rack Mountable Power Supply. The diagram shows a top-down view of the power supply unit with various ports and connectors labeled. On the left, there is a 'DC IN' port with a 'DC IN 1' label. Below it are 'SPS PWR SW', 'DC BUS DISCONNECT', 'GND', and 'VSS' ports. In the center, there are three 'DC BUS' ports labeled 'DC BUS 1', 'DC BUS 2', and 'DC BUS 3'. To the right of these are 'AC BUS 1' and 'AC BUS 2' ports. On the far right, there is a 'POST LOG VENT' port. The diagram also shows a 'DC IN 1' port with a 'DC IN 1' label. The unit is shown with a 'DC IN 1' port and a 'DC IN 1' label. The diagram is labeled '1000 Series Rack Mountable Power Supply' and 'Rear Panel View'.



CM/SM CONFIGURATION



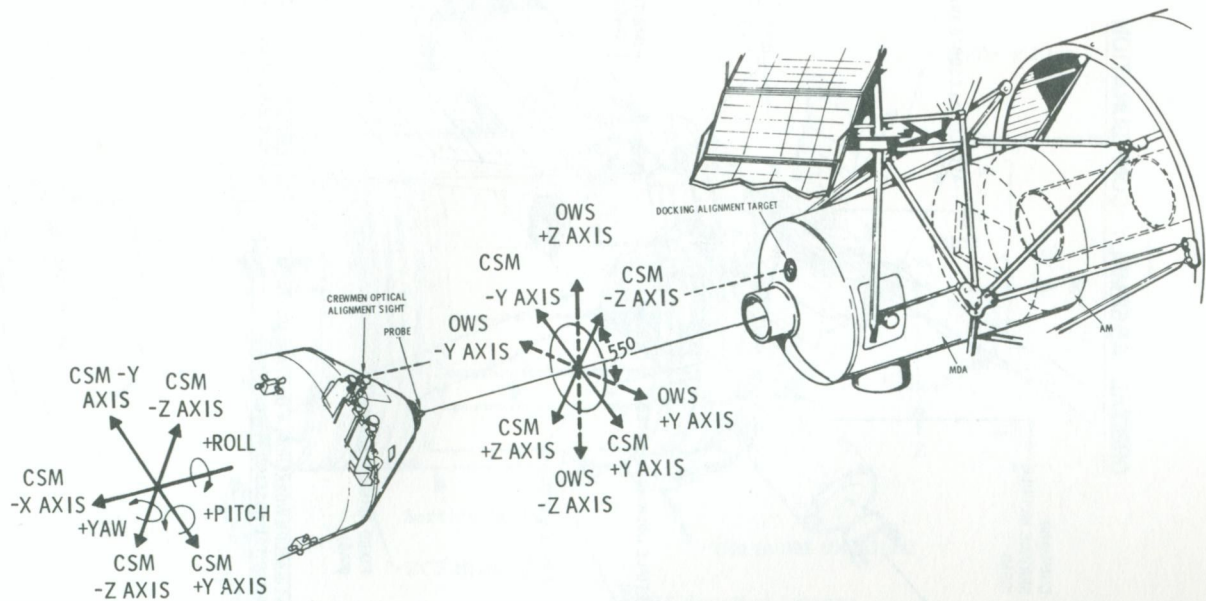
ORBITAL ASSEMBLY CONFIGURATION



SWS (SATURN WORKSHOP) = OWS/AM/MDA/ATM
 OA (ORBITAL ASSEMBLY) = CSM/SWS

OA LENGTH	-	116.2 FT
OWS SAS WING SPAN	-	93 FT
ATM SAS WING SPAN	-	98 FT

CSM/SWS DOCKING ALIGNMENT



CM SOFTWARE

SKYLARK

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

ERASABLE MEMORY PROGRAMS

CM DSKY

UPLINK ACTY Light

1. Is energized by the first character of a digital UPLINK message received by the AGC. If the light is not extinguished by the UPLINK transmission it should be extinguished by the crew use of RSET or KEY REL buttons when the UPLINK transmission is complete.
2. Is energized during the Rendezvous Navigation program (P20) when the Tracking Attitude routine (R61) detects that a gimbal angle or pointing 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. (Note four exceptions: PRO (Proceed), RSET (reset), ENTR (enter), and if ENTR is pushed as a single button response to a flashing display.)
 - c. The astronaut makes a keystroke on top of (his own) Monitor Verb Display.
2. Deenergized when:
 - a. Astronaut relinquishes DSKY by hitting KEY REL button.
 - b. Astronaut terminates his current sequence normally, for example,
 - (1) With final ENTR of a load sequence.
 - (2) The ENTR of a response to a flashing display.
 - (3) The ENTR of an extended verb request.
3. Some special DSKY cases that may not be universally appreciated are:
 - a. The astronaut may select a non-Monitor Verb display on top of his own previously selected Monitor Verb. This will cause KEY REL light to flash (See 1 (c) above). Hitting the KEY REL button will bring back (unsuspend) the monitor and extinguish the light. However, if these sequences are selected on top of an internal display, the KEY REL light will not go out as the monitor is unsuspended. It requires one more KEY REL button operation to extinguish the light and bring back the internal display.
 - b. Suppose the astronaut selects another verb-noun combination (e.g. a V16 monitor) on top of an internal flashing display. That internal display can still be answered with a PRO or VERB 34 ENTR (terminate), which wipes everything from the DSKY till the next internal display. Therefore, an astronaut selected monitor should, as a rule, never be terminated with VERB 34 ENTR, because that may not be the desired response to the flashing display. The KEY REL button should be used instead.

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.

CM DSKY (CONTINUED)

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).
4. It is deenergized when the conditions of 1 above no longer exist.

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.

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. 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.
 - b. 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 light contains 21, 22, or 23, the action is rejected and the OPR ERR light is energized.
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 SKYLARK

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 (EOI)
Coast	20	Universal Tracking
	21	Ground Track Determination
	25	Contingency Range Rate
	27	AGC Update
	29	Time-of-Longitude
Pre-thrusting	30	External Delta V
	31	NC1 Targeting
	32	NC2 Targeting
	33	NCC Targeting
	34	NSR Targeting
	35	Transfer Phase Initiation (TPI) Targeting
	36	Transfer Phase Midcourse Correction (TPM) Targeting
	37	Rendezvous Final Phase
	38	Plane Change
Thrusting	40	SPS
	41	RCS
	47	Thrust Monitor
	48	Rendezvous Thrust Monitor
Alignment	50	ATM Orientation Determination
	51	IMU Orientation Determination
	52	IMU Realign
	53	Backup IMU Orientation Determination
	54	Backup IMU Realign
	55	ATM Star Tracker Gimbal Angle
Entry	61	Entry - Preparation
	62	Entry - CM/SM Separation and Preentry Maneuver
	63	Entry - Initialization
	64	Entry - Post 0.05G
	65	Entry - Upcontrol
	66	Entry - Ballistic
	67	Entry - Final Phase
Post-thrusting	77	CSM Velocity Vector Update

LIST OF ROUTINES FOR PROGRAM SKYLARK

ROUTINE	ROUTINE TITLE
00	Final Automatic Request Terminate
01	Erasable and Channel Modification Routine
02	IMU Status Check
03	Digital Autopilot Data Load
04	Docked DAP Data Load
07	MINKEY Controller
21	Rendezvous Tracking Sighting Mark
22	Rendezvous Tracking Data Processing
23	Backup Rendezvous Tracking Sighting Mark
27	VHF Range Rate Mark Processing
30	Orbit Parameter Display
31	Rendezvous Parameter Display Routine No. 1
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
60	Attitude Maneuver
61	Tracking Attitude
62	Crew-Defined Maneuver
63	Rendezvous Final Attitude
64	Optics Angle Transformation
67	Universal Tracking Rotation

LIST OF VERBS USED IN PROGRAM SKYLARK

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 ICDU
 41 Coarse align CDU's (specify N20 or N91)
 42 Pulse torque gyros
 43 Load IMU attitude error needles (test only)
 44 Request Docked DAP Data Load Routine (R04)
 45 Activate Docked DAP
 46 Activate CSM DAP
 47 Move OWS state vector into CM state vector
 48 Request DAP Data Load routine (R03)
 49 Request crew defined maneuver Routine (R62)

LIST OF VERBS USED IN PROGRAM SKYLARK

50 Please perform
 51 Please mark
 52 Spare
 53 Please perform alternate LOS mark
 54 Request Rendezvous Backup Sighting Mark routine (R23)
 55 Increment AGC time (decimal)
 56 Terminate tracking (P20)
 57 Request display of full track flag (FULTKFLG)
 58 Enable auto maneuver in P20
 59 Enable jets disabled in R04 Docked DAP Data Load routine
 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 Transform optics angles to tracking angles (R64)
 65 Optical verification of prelaunch alignment
 66 Vehicles are attached. Move this vehicle state vector to other vehicle
 67 Start W-matrix RSS error display
 68 Spare
 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) (Octal)
 74 Initialize erasable dump via DOWNLINK
 75 Backup liftoff
 76 Start R27 VHF range rate mark processing in P20
 77 Stop R27 VHF range rate mark processing in P20
 78 Update prelaunch azimuth
 79 Spare
 80 Enable OWS 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 Spare
 93 Enable W-matrix initialization
 94 Spare
 95 Spare
 96 Terminate integration and go to P00
 97 Please perform engine-fail (R40)
 98 Spare
 99 Please Enable Engine Ignition.

LIST OF NOUNS USED IN PROGRAM SKYLARK

00	Not in use	
01	Specify address (fractional)	.XXXXX fractional .XXXXX fractional .XXXXX fractional
02	Specify address (whole)	XXXXXX, integer XXXXXX, integer XXXXXX, integer
03	Specify address (degree)	XXX, XX deg XXX, XX deg XXX, XX deg
04	Attitude Errors (AK's)	XXX, XX deg XXX, XX deg XXX, XX deg
05	Angular error/difference Celestial angle	XXX, XX deg XXX, XX deg
06	Option code ID Option code	Octal Octal
07	CHANNEL/FLAGWORD/ERASABLE OPERATOR (Loading Noun 07 will set or reset selected bits in any erasable register)	
	ECADR	Octal
	BIT ID	Octal
	Action	Octal
08	Alarm data	
	ADRES	Octal
	BBANK	Octal
	ERCOUNT	Octal
09	Alarm codes	
	First	Octal
	Second	Octal
	Last	Octal
10	Channel to be specified	Octal
11	TIG of NCC	00XXX, h 000XX, min 0XX, XX s
12	Option code (extended verbs only)	Octal Octal
13	TIG of NSR	00XXX, h 000XX, min 0XX, XX s
14	Star Tracker Azimuth Elevation	XXXXXX, arc-min XXXXXX, arc-min
15	Increment address	Octal
16	Time of event (used by extended verbs only)	00XXX, h 000XX, min 0XX, XX s
17	Astronaut total attitude	R XXX, XX deg P XXX, XX deg Y XXX, XX deg

LIST OF NOUNS USED IN PROGRAM SKYLARK

18	Desired automaneuver FDAI ball angles	R	XXX, XX deg
		P	XXX, XX deg
		Y	XXX, XX deg
19	Star Tracker Azimuth (use verb 04 to display)		XXXXXX Octal XXXXXX Octal
20	Present ICDU angles	R (OG)	XXX, XX deg
		P (IG)	XXX, XX deg
		Y (MG)	XXX, XX deg
21	PIPA's	X	XXXXXX, pulses
		Y	XXXXXX, pulses
		Z	XXXXXX, pulses
22	Desired ICDU angles	R (OG)	XXX, XX deg
		P (IG)	XXX, XX deg
		Y (MG)	XXX, XX deg
23	Nav Base to ATM Euler angles		XXX, XX deg XXX, XX deg XXX, XX deg
24	Delta time for AGC clock		00XXX, h 000XX, min 0XX, XX s
25	CHECKLIST (used with V50)		XXXXXX.
26	PRIO/DELAY, ADRES, BBCON		Octal Octal Octal
27	Self-test on/off switch		XXXXXX.
28	TIG of NC2		00XXX, h 000XX, min 0XX, XX s
29	XSM launch azimuth		XXX, XX deg
30	Target codes		XXXXXX. XXXXXX. XXXXXX.
31	Time of rendezvous W matrix initialization		00XXX, h 000XX, min 0XX, XX s
32	Time from perigee		00XXX, h 000XX, min 0XX, XX s
33	Time of ignition (GETI)		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 SKYLARK

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	TIG of Last Maneuver	00XXX. h 000XX. min 0XX. XX s
40 *	Time from ignition/cutoff (TFI/TFC) VG Delta V (accumulated)	XXbXX 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 Other vehicle weight	XXXXXX. lbs XXXXXX. lbs
48	Gimbal pitch trim Gimbal yaw trim	XXX. XX deg XXX. XX deg
49	Delta R Delta V VHF or optics code	XXX. XX nmi XXXX. X ft/s 0000X.
50 *	Splash error Perigee TFF	XXXX. X nmi XXXX. X nmi XX b XX min/s
51	Spare	
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 SKYLARK

54	Range		XXXX, XX nmi
	Range rate		XXXXX, X ft/s
	Theta		XXXX, XX deg
55	Perigee code		0000X,
	Elevation angle		XXXX, XX deg
56	Vehicle Rate	R	X, XXXXX deg/s
		P	X, XXXXX deg/s
		Y	X, XXXXX deg/s
57	No. of half revs.		XXXXX,
	Delta alt NCC		XXXXX, X nmi
	Delta alt NSR		XXXXX, X nmi
58	Delta V (TPI)		XXXXX, X ft/s
	Delta V (TPF)		XXXXX, X ft/s
	Delta time (TPI - NOMTPI)		XX b XX min/s
59	Delta V LOS 1		XXXXX, X ft/s
	Delta V LOS 2		XXXXX, X ft/s
	Delta V LOS 3		XXXXX, X ft/s
60	GMAX		XXXX, XX g
	VPRED		XXXXXX, ft/s
	GAMMA EI		XXXX, XX deg (+ above)
61	Splash Target		
	Latitude		XXXX, XX deg (+north)
	Longitude		XXXX, XX deg (+east)
	Heads up/down		+/-00001
62	Inertial velocity magnitude		XXXXXX, ft/s
	Altitude rate		XXXXXX, ft/s
	Altitude above pad radius		XXXXX, X nmi
63 *	Range from EI altitude to splash		XXXXX, X nmi
	Predicted inertial velocity		XXXXXX, ft/s
	Time from EI altitude		XX b XX min/s
64	Drag acceleration		XXXX, XX g
	Inertial velocity		XXXXXX, ft/s
	Range to splash		XXXXX, X nmi (+ is overshoot)
65	Sampled AGC time		00XXXX, h
	(fetched in interrupt)		000XX, min
			0XX, XX s
66	Commanded bank angle		XXXX, XX deg
	Crossrange error		XXXXX, X nmi (+south)
	Downrange error		XXXXX, X nmi (+ overshoot)
67	Range to target		XXXXX, X nmi (+ overshoot)
	Present latitude		XXXX, XX deg (+ north)
	Present longitude		XXXX, XX deg (+ east)
68	Commanded bank angle		XXXX, XX deg
	Inertial velocity		XXXXXX, ft/s
	Altitude rate		XXXXXX, ft/s
69	Commanded bank angle		XXXX, XX deg
	Drag level		XXXX, XX g
	Exit velocity		XXXXXX, ft/s

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

LIST OF NOUNS USED IN PROGRAM SKYLARK

70	Sighting Source/Celestial Body Code (Before mark)	Octal
71	Sighting Source/Celestial Body Code (After mark)	Octal
72	Time of R27-VHR Range	00XXX h
	Rate mark processing optimization	00XX. min 0XX. XX s
73	Altitude	XXXXXXb. nmi
	Velocity	XXXXXX. ft/s
	Flight path angle	XXX. XX deg
74	Commanded bank angle	XXX. XX deg
	Inertial velocity	XXXXXX. ft/s
	Drag acceleration	XXX. XX g
75*	Delta altitude (NSR)	XXXX. X nmi
	Delta time (TPI-NSR)	XXbXX min/s
	Delta time (TPI-NOMTPI)	XXbXX min/s
76	Current R27 range	XXX. XX nmi
	Current R27 range rate	XXXX. X ft/s
	Time from R27 optimization	XXbXX min/s
77	R27 Range	XXX. XX nmi
	R27 Range rate	XXXX. X ft/s
	R27 Theta/Phi/Code	XXX. XX deg/
78	P20 Yaw Angle (UTYAW)	XXX. XX deg
	P20 Pitch Angle (UTPIT)	XXX. XX deg
	OMICRON	XXX. XX deg
79	P20 rotation rate	X. XXXX deg/s
	P20 deadband	XXX. XX deg
80*	Time from ignition/cutoff	XXbXX min/s
	Velocity to be gained	XXXXXX. ft/s
	Delta V (accumulated)	XXXXXX. 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	NSR Delta VX (LV)	XXXX. X ft/s
	NSR Delta VY (LV)	XXXX. X ft/s
	NSR 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 V next maneuver	XXXX. X ft/s
	Delta H next maneuver	XXXX. X nmi
	Delta V 3rd maneuver	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	Docked DAP Flag Specification	Octal
	Channel 5 jets inhibited by Docked DAP	Octal
	Channel 6 jets inhibited by Docked DAP	Octal
88	Celestial body 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 SKYLARK

89	Docked DAP Maneuver rate Docked DAP Deadband		X. XXXX deg/s XXXX, XX deg
90	Rendezvous out of plane parameters Y (CSM) YDOT (CSM) YDOT (OWS)		XXX. XX nmi XXXX. X ft/s XXXX. X ft/s
91	Present optics angles Shaft Trunnion		XXX. XX deg XX. XXX deg
92	New optics angles Shaft Trunnion		XXX. XX deg XX. XXX deg
93	Delta gyro angles	X Y Z	XX. XXX deg XX. XXX deg XX. XXX deg
94	Alternate LOS Shaft angle Trunnion angle		XXX. XX deg XX. XXX deg
95	TIG of NC1		00XXX h 000XX. m 0XX. XX s
96	Y (CSM) YDOT (CSM) YDOT (OWS)		XXX. XX nmi XXXX. X ft/s XXXX. X ft/s
97	System test inputs		XXXXX. XXXXX. XXXXX.
98	System test results and input		XXXXX. . XXXXX XXXXX.
99	RSS of position error RSS of velocity error RSS option code		XXXXX. ft XXXX. X ft/s XXXXX.

LIST OF ALARM CODES USED WITH V05 N09
FOR PROGRAM SKYLARK

CODE	PURPOSE	SET BY
00107	Star tracker angles out of limits	P55
00110	No mark since last mark reject	SXTMARK
00113	No inbits (Channel 16)	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
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	P51, P53
00220	IMU not aligned (No REFSMMAT)	R02
00401	Desired gimbal angles yield Gimbal Lock	Fine Align, IMU-2, R61
00402	Second MINKEY pulse torque must be done	P52
00404	*Target out of view (trunnion angle > 90 degrees)	R52
00405	*Two stars not available	P52, P54
00406	Rendezvous navigation not operating	R23
00421	W-Matrix overflow	INTEGRV
00500	Not enough pitch or yaw jets	Docked DAP
00501	Not enough roll jets	Docked DAP
00600	*Failure in Phase Match iteration	P31, P32
00601	*Failure in Height Maneuver iteration	P31, P32
00602	*Failure in Outer Loop iteration	P31, P32
00603	*Failure in iteration	P31, P32, P33
00611	*No TIG for Given Elevation Angle	P34, P35
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
01703	Insufficient time for integration, TIG was slipped	R41

LIST OF ALARM CODES USED WITH V05 N09
FOR PROGRAM SKYLARK

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
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 illegally selected	P01
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
31211	Illegal interrupt of Extended Verb	SXTMARK,
32000	Jask interrupting the preceding jask	DKJSLECT
2XXXX -	Indicates a go-to-routine 00 type abort.	
3XXXX -	Indicates a bailout type abort.	

Note: For V05 N09 Displays:

- R1 - XXXXXX (first alarm to occur after last reset).
- R2 - XXXXXX (second alarm to occur after last reset)
- R3 - XXXXXX (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 SKYLARK

(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 desired.)

CODE	PURPOSE	INPUT FOR R2	PROGRAMS
0001	Specify IMU orientation	1 = preferred, 2 = nominal 3 = REFSMMAT	P52, P54
0002	Specify vehicle	1 = this vehicle 2 = other vehicle	P21, R30, P29
0004	Specify FULTKFLG setting	0 = Full, VHF and optics	P20
00012	Specify P50 option	1 = Partial, VHF or optics 1 = ATM sun sensor 2 = ATM sun sensor and star tracker 3 = ATM angles from separate source	P50
00013	Specify P55 option	1 = Celestial body and IMU orientation 2 = Celestial body, optics mark and solar inertial	P55
00024	Specify P20 mode	0 = Rendezvous, (Vecpoint) 1 = Celestial body, (Vecpoint) 2 = Rotate 4 = Rendezvous, (3-axis) 5 = Celestial body, (3-axis)	P20

LIST OF CHECKLIST REFERENCE CODES USED WITH V50N25
FOR PROGRAM SKYLARK

CODE	ACTION TO BE EFFECTED
00013	Key in coarse align option
00014	Key in fine alignment option
00015	Perform celestial body acquisition
00016	Key in Terminate Mark sequence
00017	Perform MINKEY rendezvous sequence
00020	Perform MINKEY PC pulse torquing
00041	Switch CM/SM separation to UP
00062	Key in AGC power down
00204	Key in SPS gimbal trim test option

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 SKYLARK

APSESW	FW8	B5	NCINTFLG	FW0	B2
ASTNFLAG	FW7	B12	NCLPFLG	FW1	B9
ATMFLAG	FW0	B11	NC12FLG	FW0	B5
ATTCHFLG	FW7	B2	NEEDLFLG	FW0	B9
AUTOSEQ	FW10	B7	NEWIFLG	FW8	B13
AVEGFLAG	FW1	B1	NEWTFLAG	FW5	B10
AVEMIDSW	FW9	B1	NJETSFLG	FW1	B15
AZIMFLAG	FW11	B8	NODOFLAG	FW2	B1
CALCMAN2	FW2	B2	NODOP01	FW1	B12
CMDAPARM	FW6	B12	NORMSW	FW7	B10
CM/DSTBY	FW6	B2	NOSWITCH	FW6	B7
COGAFLAG	FW8	B4	NOUNFLG	FW11	B10
CULTFLAG	FW3	B7	NRMIDFLG	FW4	B13
CYCLFLAG	FW11	B11	NRMNVFLG	FW4	B8
CYC61FLG	FW0	B4	NRUPTFLG	FW4	B4
DAPBIT1	FW6	B15	NWAITFLG	FW4	B10
DAPBIT2	FW6	B14	N22ORN17	FW9	B6
DIM0FLAG	FW3	B1	N77FLAG	FW11	B9
DRIFTFLG	FW2	B15	ORDERSW	FW8	B6
DSKYFLAG	FW5	B15	PCFLAG	FW10	B1
EGSW	FW6	B8	PCMANFLG	FW10	B15
ENG2FLAG	FW1	B11	PDSPFLAG	FW4	B12
ENGONFLG	FW5	B7	PFRATFLG	FW2	B4
ENTRYDSP	FW6	B13	PINBRFLG	FW4	B6
ERADFLAG	FW1	B13	POOFLAG	FW3	B9
ETPIFLAG	FW2	B7	PRECIFLG	FW3	B8
EXTRANGE	FW10	B9	PRIODFLG	FW4	B14
FINALFLG	FW2	B6	PRONVFLG	FW4	B7
FIRSTFLG	FW2	B7	PTV93FLG	FW10	B4
FIXFLAG	FW11	B7	P21FLAG	FW2	B12
FREEFLAG	FW0	B3	P25FLAG	FW11	B4
FULTKFLG	FW10	B2	P29FLAG	FW0	B1
GAMDIFSW	FW6	B11	P35FLAG	FW10	B8
GLOKFAIL	FW3	B14	P48FLAG	FW11	B5
GONEBY	FW7	B8	P50FLAG	FW0	B10
GONEPAST	FW6	B10	P50.1FLG	FW0	B12
GRRBKFLG	FW5	B5	P55.1FLG	FW0	B13
GUESSW	FW1	B2	QUITFLAG	FW9	B5
GYMDIFSW	FW6	B1	REFSMFLG	FW3	B13
HDSUPFLG	FW10	B11	REINTFLG	FW10	B13
HIND	FW6	B6	REJCTFLG	FW10	B12
IDLEFAIL	FW1	B6	RELVELSW	FW6	B9
IGNFLAG	FW7	B13	RENDWFLG	FW5	B1
IMPULSW	FW2	B9	REVFLAG	FW2	B5
IMUSE	FW0	B8	RNDVZFLG	FW0	B7
INCORFLG	FW5	B11	RVSW	FW7	B9
INFINFLG	FW8	B7	R21MARK	FW2	B14
INRLSW	FW6	B5	R22CAFLG	FW9	B7
INTFLAG	FW10	B14	R27FLAG	FW11	B12
INTYPFLG	FW3	B4	R27UP1	FW11	B1
ITERFLG	FW2	B13	R27UP2	FW11	B2
ITSWICH	FW7	B14	R31FLAG	FW9	B4
JSWITCH	FW0	B14	R53FLAG	FW0	B6
LATSW	FW6	B4	R67FLAG	FW8	B2
MANEUFLG	FW10	B5	SBFLAG	FW2	B3
MARKFLG	FW1	B4	SKIPVHF	FW2	B10
MAXDBFLG	FW9	B12	SLOPESW	FW1	B3
MID1FLAG	FW9	B3	SNAPFLAG	FW11	B6
MIDAVFLG	FW9	B2	SOLNSW	FW5	B3
MKOVFLAG	FW4	B3	SOURCFLG	FW9	B8
MRKIDFLG	FW4	B15	STATEFLG	FW3	B5
MRKNVFLG	FW4	B9	STERSW	FW2	B11
MRUPTFLG	FW4	B5	STIKFLAG	FW1	B14
MWAITFLG	FW4	B11			

FLAGWORD BIT ASSIGNMENTS(ALPHABETICAL)
FOR SKYLARK

STRULLSW	FW6	B13	VHFRFLAG	FW9	B9
SWTOVER	FW9	B15	VINTFLAG	FW3	B3
TARGIFLG	FW1	B10	VNFLAG	FW4	B2
TCOMPFLG	FW10	B6	V37FLAG	FW7	B6
TDFLAG	FW11	B3	V50N18FL	FW3	B15
TERMIFLG	FW7	B15	V96ONFLG	FW8	B3
TFFSW	FW7	B1	XDELVFLG	FW2	B8
TIMRFLAG	FW7	B11	XDSPFLAG	FW4	B1
TPIMNFLG	FW10	B3	.05GSW	FW6	B3
TRACKFLG	FW1	B5	360SW	FW8	B1
UPDATFLG	FW1	B7	3AXISFLG	FW5	B6
UPLOCKFL	FW7	B4	45/46FLG	FW3	B6
UTFLAG	FW8	B9	500**FLG	FW3	B12
VEHUPFLG	FW1	B8	501**FLG	FW3	B11
VERIFLAG	FW7	B3			
VFLAG	FW3	B10			

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

(FLAGWORD 0) E Address 74

Bit	Name	1	0
1	P29FLAG	First pass through P29.	Subsequent pass through P29.
2	NCINTFLG	Conic integration.	Precision integration.
3	FREEFLAG	(Temporary flag used in many routines.)	
4	CYC61FLG	KALCMANU computes maneuver time.	KALCMANU executes maneuver.
5	NC12FLG	P32 (NC2) active.	P31 (NC1) active.
6	R53FLAG	V51 initiated	V51 not initiated.
7	RNDVZFLG	P20 rendezvous option running.	P20 rendezvous option not running.
8	IMUSE	IMU in use.	IMU not in use.
9	NEEDLFLG	Total attitude error displayed.	A/P following error displayed.
10	P50FLAG	Bypass 401 alarm check in CALCGA	Perform 401 alarm check
11	ATMFLAG	ATM mark sighting enabled.	ATM mark sighting not enabled.
12	P50.1FLG	Option = 1 in P50.	Option not = 1 in P50
13	P55.1FLG	Option = 1 in P55.	Option not = 1 in P55.
14	JSWITCH	Integration of W matrix.	Integration of state vector.
15	Not used.		

(FLAGWORD 1) E Address 75

Bit	Name	1	0
1	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	MARKFLG	Mark accepted. Mark rejected is allowed.	No mark reject allowed.
5	TRACKFLG	Tracking allowed.	Tracking not allowed.
6	IDLEFAIL	Inhibit R40.	Enable R40 (engine fail).
7	UPDATFLG	Updating by marks allowed.	Updating by marks not allowed.
8	VEHUPFLG	CSM state vector being updated.	OWS state vector being updated.
9	NCLPFLG	Computing NSR altitude difference in P31/P32.	Computing NCC altitude difference in P31.
10	TARG1FLG	Sighting OWS	Not sighting OWS
11	ENG2FLAG	RCS burn.	SPS burn.
12	NODOP01	P01 not allowed.	P01 allowed.
13	ERADFLAG	EARTH—compute Fischer ellipsoid radius.	EARTH—use Launch site radius
14	STIKFLAG	RHC control or MGA $>75^{\circ}$ and P20 track inhibited.	AGC control or MGA $<75^{\circ}$.
15	NJETSFLG	Two-jet RCS burn.	Four-jet RCS burn.

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

(FLAGWORD 2) E Address 76

Bit	Name	1	0
1	NODOFLAG	V37 not permitted.	V37 permitted.
2	CALCMAN2	Perform maneuver starting procedure.	Bypass starting procedure.
3	SBFLAG	Perform complex short burn logic.	Perform simple short burn logic if burn <1 sec.
4	PFRATFLG	Preferred attitude computed.	Preferred attitude not computed.
5	REVFLAG	Compute matrix in GET. LVC.	Compute matrix and vector in GET. LVC.
6	FINALFLG	Last pass through rendezvous program computations.	Interim pass through rendezvous program computations.
7	FIRSTFLG	First pass through S40.9	Succeeding pass through S40.9
	ETPIFLAG	Elevation angle supplied for P35.	TPI time supplied for P35.
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	SKIPVHF	Disregard radar read because of software or hardware RESTART.	Radar read to proceed normally.
11	STEERSW	Steering to be done (P40).	Steering omitted (P40).
12	P21FLAG	Succeeding pass through P21, use base vector for calculation.	First pass through P21, calculate base vector.
13	ITERFLG	15 iterations have occurred in ITER.	15 iterations have not occurred in ITER.
14	R21MARK	Rendezvous optics marking enabled.	Rendezvous optics marking disabled.
15	DRIFTFLG	T3RUPT calls gyro compensation.	T3RUPT does no gyro compensation.

(FLAGWORD 3) E Address 77

Bit	Name	1	0
1	DIMOFLAG	W matrix is to be used.	W matrix is not to be used.
2	Not used		
3	VINTFLAG	CSM state vector being integrated.	OWS state vector being integrated.
4	INTYPFLG	Conic integration.	Encke integration.
5	STATEFLG	Permanent state vector being updated.	Permanent state vector not being updated.
6	45/46FLG	V45 was last DAP turn on extended verb.	V46 was last DAP turn on extended verb.
7	CULTFLAG	Star occulted.	Star not occulted.
8	PRECIFLG	Precision Integration being done.	Periodic integration enabled.
9	POOFLAG	Periodic Integration is being done.	Periodic integration is not being done.
10	VFLAG	Less than two stars in the field of view.	Two stars in the field of view.

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

(FLAGWORD 3) (Continued)

Bit	Name	1	0
11	501**FLG	The 501 alarm has been set to indicate not enough jets uninhibited for some roll rotation wanted by the DAP.	The 501 alarm has not yet been set. 501**FLG is reset in R04.
12	500**FLG	The 500 alarm has been set to indicate not enough jets uninhibited for some pitch or yaw rotation wanted by the DAP.	The 500 alarm has not yet been set. 500**FLG is reset in R04.
13	REFSMFLG	REFSMMAT good.	REFSMMAT no good.
14	GLOKFAIL	Desired middle gimbal angle exceeds 60°.	Desired middle gimbal angle is less than 60°.
15	V50N18FL	Enable R60 attitude maneuver.	Inhibit R60 attitude maneuver.

(FLAGWORD 4) E Address 100

Bit	Name	1	0
1	XDSPFLAG	Mark display not to be interrupted.	No special mark information.
2	VNFLAG	VNFLASH display.	GOFLASH display.
3	MKOVFLAG	Mark display over normal display.	No mark display over normal display.
4	NRUPTFLG	Normal display interrupted by priority or mark display.	Normal display not interrupted by priority or mark display.
5	MRUPTFLG	Mark display interrupted by priority display.	Mark display not interrupted by priority display.
6	PINBRFLG	Astronaut has interfered with existing display.	Astronaut has not interfered with existing display.
7	PRONVFLG	Astronaut using keyboard when priority display initiated.	Astronaut not using keyboard when priority display initiated.
8	NRMNVFLG	Astronaut using keyboard when normal display initiated.	Astronaut not using keyboard when normal display initiated.
9	MRKNVFLG	Astronaut using keyboard when mark display initiated.	Astronaut not using keyboard when mark display initiated.
10	NWAITFLG	Higher priority display operating when normal display initiated.	No higher priority display operating when normal display initiated.
11	MWAITFLG	Higher priority display operating when mark display initiated.	No higher priority display operating when mark display initiated.
12	PDSPFLAG	Priority display status exists	Priority display status does not exist
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) E address 101

Bit	Name	1	0
1	RENDWFLG	W matrix valid for rendezvous navigation.	W matrix invalid for rendezvous navigation.
2	Not used		
3	SOLNSW	Lambert does not converge, or time-radius nearly circular.	Lambert converges or time-radius noncircular.
4	Not used		
5	GRRBKFLG	Backup liftoff received.	Backup liftoff not received.

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

(FLAGWORD 5) (Continued)

Bit	Name	1	0
6	3AXISFLG	Maneuver specified by three axes.	Maneuver specified by one axis (VECPPOINT).
7	ENGONFLG	Engine turn on.	Engine turned off.
8	Not used		
9	Not used		
10	NEWTFLG	New longitude iteration. Skip display.	Display normal.
11	INCORFLG	First incorporation.	Second incorporation.
12	Not used		
13	Not used		
14	Not used		
15	DSKYFLAG	Displays sent to DSKY.	No displays to DSKY.

(FLAGWORD 6) E Address 102

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	EGSW	In final entry phase.	Not in final entry phase.
9	RELVELSW	Targeting uses earth-relative velocity.	Targeting uses inertial velocity.
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 Steering burn.	Do impulse burn.
14	DAPBIT2	B14 0 1 0 1	
15	DAPBIT1	B15 0 0 1 1	
		A/P None RCS TVC Saturn	DAP selection indicator.

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

(FLAGWORD 7) E Address 103

Bit	Name	1	0
1	TFFSW	Calculate TPERIGEE.	Calculate TFF.
2	ATTCHFLG	Two vehicles attached. Bit not tested by program	Two vehicles not attached.
3	VERIFLAG	Changed when V33E occurs at end of P27.	
4	UPLOCKFL	K-K-K fail.	No K-K-K fail.
5	Not Assigned		
6	V37FLAG	AVERAGEG (SERVICER) running.	AVERAGEG (SERVICER) off.
7	Not Assigned		
8	GONEBY	Passed target.	Approaching target.
9	RVSF	Do not compute final state vector in time-theta.	Compute final state vector in time-theta.
10	NORMSW	Unit normal input to Lambert.	Lambert computes its own 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.

(FLAGWORD 8) E Address 104

Bit	Name	1	0
1	360SW	Transfer angle near 360 degrees.	Transfer angle not near 360 degrees.
2	R67FLAG	R67 rotation active.	R67 rotation inactive.
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	APSESF	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. (Never set to 1)	Iterator uses first order standard mode.
7	INFINFLG	No conic solution (closure through infinity required).	Conic solution exists.
8	Not used		
9	UTFLAG	P20 option 1, 2, or 5 selected.	P20 option 0 or 4 selected.
10	Not used		
11	Not used		
12	Not used		
13	NEWIFLG	First pass through integration.	Succeeding iteration of integration.
14	Not used		
15	Not used		

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

(FLAGWORD 9) E Address 105

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).
7	R22CAFLG	R22 is processing an optics mark.	R22 is not processing an optics mark.
8	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, (V87)	Stop acceptance of range data, (V88)
10	Not used		
11	Not used		
12	MAXDBFLG	Maximum A/P deadband selected.	Minimum A/P deadband selected.
13	Not used		
14	Not used		
15	SWTOVER	Switchover to Low bandwidth filter has occurred.	No switchover has occurred

(FLAGWORD 10) E Address 106

Bit	Name	1	0
1	PCFLAG	Plane change maneuver being targeted.	Not plane change targeting.
2	FULTKFLG	Optics or VHF marks being taken.	Optics and VHF marks being taken.
3	TPIMNFLG	TPI targeting complete.	TPI targeting not complete.
4	PTV93FLG	W matrix to be initialized after maneuver.	W matrix initialized.
5	MANEUFLG	No mark incorporation since targeting completed.	Mark incorporated.
6	TCOMPFLG	- Then + torque.	+ then - torque.
7	AUTOSEQ	MINKEY auto-rendezvous.	Manual rendezvous.
8	P35FLAG	MCC targeting completed.	MCC targeting not completed.
9	EXTRANGE	R63 range valid	R63 range meaningless
10	Not used		
11	HDSUPFLG	Heads-up tracking attitude.	Heads-down tracking attitude.
12	REJCTFLG	Reject mark data being processed by R22.	No mark rejected.
13	REINTFLG	Restartable integration in process.	No restartable integration in process.
14	INTFLAG	Integration in process.	Integration not in process.
15	PCMANFLG	P20 exits after maneuver to plane change attitude	P20 operates normally.

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

(FLAGWORD 11) E address 107

Bit	Name	1	0
1	R27UP1	1st pass in R27 complete.	1st pass in R27 not complete.
2	R27UP2	2nd pass in R27 complete.	2nd pass in R27 not complete.
3	TDFLAG	TD angle in R27 has been computed.	TD angle in R27 has not been computed
4	P25FLAG	Program is P25	Program is not P25.
5	P48FLAG	Program is P48	Program is not P48.
6	SNAPFLAG	Inhibit R22 mark processing.	Allow R22 mark processing
7	FIXFLAG	R27 in optimizing mode.	R27 not in optimizing mode.
8	AZIMFLAG	Three-axis tracking maneuver	VECPPOINT tracking maneuver
9	N77FLAG	Noun 77 update inhibited	Allow current state to be stored in N77.
10	NOUNFLG	Display Noun 77 in P25 and P48	Display N76 in P25 and P48
11	CYCLFLAG	R27 is still processing mark.	R27 ready for a new mark.
12	R27FLAG	Allow R27 call from P20 (V76)	Inhibit R27 in P20 (V77)
13	Not used		
14	Not used		
15	Not used		

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).

E Address 1323

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 _g is generated.
5	Bit is set to 1 to inhibit the generation of program alarm 0212 _g 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 _g 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 SKYLARK

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

E Address 1324

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 8.22 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.

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

E Address 1327.

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 _g is generated (but computation proceeds).
9	Not assigned.
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 the 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). Also may be value of C31FLWRD, Bit 5 if backup indicator is used.
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. Also may be value of C31FLWRD, Bit 4 if backup indicator is used.
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, then a switch out of Zero Optics mode will cause alarm 0116 _g 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 Bit 2 of this word is 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	Not assigned.

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

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

E Address 3130.

Bit	Meaning
15	Bit is set to 1 to indicate that a high rate (2 deg/s) automanuever is in progress. Bit is reset to 0 to indicate that a high rate automanuever is not in progress.
14	Bit is set to 1 if rate estimates are not good and a repeat of the rate filter initialization is required. Bit is reset to 0 if the G&N is in control and the IMU data is usable. Approximately 1 second after the bit is reset to 0 the rate filter initialization is complete.
13	Bit is set to 1 if the rate damping has not been completed on the roll axis. Bit is reset to 0 if the rate damping on the roll axis has been completed.
12	Bit is set to 1 if the rate damping has not been completed on the pitch axis. Bit is reset to 0 if the rate damping has been completed on the pitch axis.
11	Bit is set to 1 if the rate damping has not been completed on the yaw axis. Bit is reset to 0 if the rate damping has been completed on the yaw axis.
10, 9	If either or both bits have been set to 1, there has been a change in the RHC roll command since the last DAP cycle. Bit 9 set to 1 to indicate beginning and end of docked DAP automanuever.
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. Bit 7 set to 1 to indicate beginning and end of docked DAP automanuever.
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. Bit 5 set to 1 to indicate beginning and end of docked DAP automanuever.
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.

C31FLWRD, a flag used to determine if the channel representations of the CMC Mode switch, SC CONTROL switch and OPTICS ZERO switch are to be used or if backup indicators are to be used. Octal representation is AXXDX where:

E Address 00373

A VALUE

0 or 4	Bits 13, 14, 15 of Channel 31 are valid
1	CMC Control FREE
2	CMC Control HOLD
3	CMC Control AUTO
5	SCS Control FREE
6	SCS Control HOLD
7	SCS Control AUTO

D VALUE

0 or 4	Bits 4, 5 of Channel 33 are valid
1 or 5	Optics Mode CMC
2 or 6	Optics Mode ZERO
3 or 7	Optics Mode Manual

C31FLWRD Switch override can be activated by:

V21N01E
373E
AXXDXE

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

DAPDATR1, a flagword for RCS-CSM DAP interface. E Address 03114

R1 of Noun 46.

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	± 0.5 degree
	1	± 5.0 degrees
3-1	RATE:	Response to RHC, automatic maneuvers
	0	0.05 degree/second
	1	0.2 degree/second
	2	0.5 degree/second
	3	2.0 degrees/second

* Not to be used for Skylark

DAPDATR2, a flagword for RCS-CSM DAP interface. E Address 03115.

R2 of Noun 46.

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	A, B, C, D Quad fails	
9-7, 6-4,	0	Quad Failed
3-1	1	Quad OK

FLAGWORD BIT ASSIGNMENTS FOR SKYLARK

DAPDATR3, a flagword for Docked DAP interfaces. E Address 03070.

R1 of Noun 87

Bits	15-13	12-10	9-7	6-4	3-1
	AC-Roll	XTAC	XTBD	PCTRL	YCTRL
AC - Roll	Roll control jet selection quad preference for phase plane roll command. If an inhibited jet is encountered in a preferred quad DAP automatically uses other two quads for roll				
	0 BD preferred				
	1 AC preferred				
XTAC	X Translation using Quads AC				
	0 Do not use AC				
	1 Use AC				
XTBD	X translation using Quads BD				
	0 Do not use BD				
	1 Use BD				
PCTRL	Pitch Control				
	Preferred use of pitch torque couple or Z translation force jets for pitch control.				
	0 Use torque couple control for pitch				
	1 Use Z force control for pitch				
YCTRL	Yaw Control				
	Preferred use of yaw torque couple or Y translation force jets for yaw control				
	0 Use torque couple control for yaw				
	1 Use Y force control for yaw.				

CH5FAIL, a flag specifying channel 5 jets to be inhibited. E Address 3071

R2 of Noun 87

Bits	8	7	6	5	4	3	2	1
octal	B-4	B-3	D-4	D-3	A-4	A-3	C-4	C-3
value	00200	00100	00040	00020	00010	00004	00002	00001

0 = use specified jet

1 = inhibit specified jet

CH6FAIL, a flag specifying channel 6 jets to be inhibited. E Address 3072

R3 of Noun 87

Bits	8	7	6	5	4	3	2	1
octal	C-2	C-1	A-2	A-1	D-2	D-1	B-2	B-1
value	00200	00100	00040	00020	00010	00004	00002	00001

0 = use specified jet

1 = inhibit specified jet.

CHANNEL BIT ASSIGNMENTS

INPUT CHANNEL 3

Bits 1-14 Contains the HIGH ORDER SCALER: 23.3 hours = maximum capacity in increments of 5.12 seconds.

INPUT CHANNEL 4

Bits 1-14 Contains the LOW ORDER SCALER: 5.12 seconds = maximum capacity in increments of 1/3,200 second.

OUTPUT CHANNEL 5

BIT	JET DESIGNATION SM QUAD NO. /CM RING NO.	SM COMMAND TRANS/ROT (RCS DAP)	DOCKED DAP (Torque Couples Only)	CM COMMAND
1	C-3/1-3	+X/+P	+X/+P	+P
2	C-4/2-4	-X/-P	-X/-P	-P
3	A-3/2-3	-X/+P	-X/+P	+P
4	A-4/1-4	+X/-P	+X/-P	-P
5	D-3/2-5	+X/+Y _W	+X/+Y _W	+Y _W
6	D-4/1-6	-X/-Y _W	-X/-Y _W	-Y _W
7	B-3/1-5	-X/+Y _W	-X/+Y _W	+Y _W
8	B-4/2-6	+X/-Y _W	+X/-Y _W	-Y _W

OUTPUT CHANNEL 6

BIT	JET DESIGNATION SM QUAD NO./CM RING NO.	SM COMMAND TRANS/ROT (RCS DAP)	DOCKED DAP Force Control	CM COMMAND
1	B-1/1-1	+Z/+R	+P/+R	+R
2	B-2/1-2	-Z/-R	-P/-R	-R
3	D-1/2-1	-Z/+R	-P/+R	+R
4	D-2/2-2	+Z/-R	+P/-R	-R
5	A-1	+Y/+R	-Y _W /+R	
6	A-2	-Y/-R	+Y _W /-R	
7	C-1	-Y/+R	+Y _W /+R	
8	C-2	+Y/-R	-Y _W /-R	

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

CHANNEL BIT ASSIGNMENTS

OUTPUT CHANNEL 12

BIT

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	Not Used
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 1001₂ in order to obtain control.

OUTPUT CHANNEL 14

BIT

1	Not Used
2	Spare
3	Spare
4	Spare
5	Not Used
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

CHANNEL BIT ASSIGNMENTS

INPUT 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
6-15	Spares

INPUT 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
8-15	Spares

DSKY KEYINPUT KEYCODE

0	10000
1	00001
2	00010
3	00011
4	00100
5	00101
6	00110
7	00111
8	01000
9	01001
VERB	10001
NOUN	11111
ENTER	11100
ERROR RESET	10010
CLEAR	11110
KEY RELEASE	11001
+	11010
-	11011

INPUT CHANNEL 30

BIT

1	Not Used
2	Not Used
3	Not Used
4	Not Used
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.

CHANNEL BIT ASSIGNMENTS

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	Not Used
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.

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.

CHANNEL BIT ASSIGNMENTS

INPUT CHANNEL 77 - (RESTART MONITOR)

BIT

- 1 Parity Fail (E or F)
- 2 Parity Fail (E memory)
- 3 TC Trap
- 4 RUPT Lock
- 5 Nightwatchman
- 6 Voltage Fail
- 7 Counter Fail
- 8 Scalar Fail
- 9 Scalar Double Frequency Alarm

P00-CMC IDLING PROGRAM

Purpose:

1. To maintain the CMC in a condition of readiness for entry into other programs.
2. To update the CSM and OWS state vectors every four time steps.

Assumptions:

1. 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.
2. Program changes are inhibited during integration periods and program alarm 1520₈ will occur if a change is attempted when inhibited.

Sequence of Events:

V37E00E

V06N38E

Optional Display

V06N38	Time of State Vector Being Integrated	00XXXX 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. Erasable locations have been properly initialized. (Azimuth, +1; Latitude, +1; LAUNCHAZ, +1; IMU compensation parameters).

Sequence of Events:

V37E01E

No Att Light - ON, then OFF. Initializes the system and coarse aligns the platform to the desired orientation.

AGC advances to P02.

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.

Sequence of Events:

P02 entered automatically from P01.

Vertical erect for 640 seconds, then gyrocompass.

V78E Optional entry if launch azimuth change is desired.

Flashing	XSM Launch Azimuth
V06N29	

XXX.XX deg

P02 (continued)

V21E. Enter new launch azimuth.

PRO Vertical erect for 320 seconds, then gyrocompass.

V75E Optional at Liftoff if automatic Liftoff discrete is not received.

AGC advances to P11 at liftoff.

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

Sequence of Events:

Zero Optics for 15 seconds.

V65E

P03 displayed.

Flashing	Target Azimuth	XXX.XX deg
V06N41	Target Elevation	XX.XXX deg
	Target ID	00001

Target 1 coordinates.

V24E. Change azimuth and elevation if desired.

PRO

Flashing	Target Azimuth	XXX.XX deg
V06N41	Target Elevation	XX.XXX deg
	Target ID	00002

Target 2 coordinates.

V24E. Change azimuth and elevation if desired.

Optics Mode — CMC.

PRO

CMC drives optics LOS to Target 1.

Flashing
V51

Optics to Manual — Mark on Target 1.

Flashing	Checklist Code	00016
V50N25		

Request terminate Mark sequence.

MARK REJECT

(If mark was unsatisfactory), and recycle to Flashing V51.

PRO (If mark was satisfactory), and continue.

CMC drives optics LOS to Target 2.

Flashing
V51

P03 (continued)

Optics to Manual - Mark on Target 2.

Flashing	
V50N25	Checklist Code

00016

Terminate mark sequence.

MARK REJECT

(If mark was unsatisfactory), and recycle to previous Flashing V51.

PRO (If mark was satisfactory), and continue.

Flashing	Alignment Error
V06N93	In Delta Gyro Angles

X	XX.XXX deg
Y	XX.XXX deg
Z	XX.XXX deg

Displays Y_{SM} and X_{SM} leveling error and X_{SM} azimuth error.
V24E to zero Y and X leveling errors.

PRO Torques Z gyro to eliminate azimuth error.

V34E Terminates optical verification and returns to P02.

P06-CMC POWER DOWN PROGRAM

Purpose:

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

Assumptions:

1. If the computer power is switched off, the AGC Update program (P27) would have to be done to update the state vector and computer clock time.
2. The AGC is capable of maintaining an accurate value of ground elapsed time (GET) for only 23 hours when in the Standby mode. If the AGC is not brought out of the standby condition to the running condition at least once within 23 hours, the AGC value of GET must be updated.

Sequence of Events:

V37E06E

Flashing	Checklist Code
V50N25	

00062

Power down AGC.

If IMU power off desired - (CB). IMU Operate - open.

PRO Until Standby light on.

TURN-ON

Standby light on.

PRO Until Standby light off.

Flashing
V37

00E Select P00

If IMU power up desired - (CB). IMU Operate - close.

No Att light on for 90 seconds.

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-First Stage Only: should the saturn platform fail the astronaut may set the LV Guidance Switch to the CMC 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-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.

Sequence of Events:

V75 Enter is not keyed unless the liftoff discrete fails and P11 does not start automatically.

P11 displayed - Average G on.

V06N62	Inertial Velocity Magnitude	XXXXXX, ft/s
	Altitude Rate	XXXXXX, ft/s
	Altitude	XXXX, X nmi

Pitch/roll polynomial start at liftoff + 10.60 seconds.

Terminate polynomial at liftoff + 156.60 seconds.

V82E Orbital parameter display.

Flashing	Apogee Altitude	XXXX, X nmi
V16N44	Perigee Altitude	XXXX, X nmi
	TFF	XX b XX min/s

PRO

V37E00E

Average G off, P00 is selected.

V46E While in P11 will terminate polynomial computations and enable the RHC to steer the Saturn vehicle through the AGC interface.

P20 - UNIVERSAL TRACKING

Purpose:

1. Control CSM attitude/optics or attitude rates depending on which of the following five options is selected.
 - Option 0 - Point a specified S/C vector along the LOS to the OWS without constraining rotation about the vector (VECPPOINT). This option is used to acquire the OWS in the SXT field of view.
 - Option 1 - Point a specified S/C vector at a specified celestial body without constraining rotation about the vector (VECPPOINT). This option does not employ optics drive.
 - Option 2 - Perform rotation about a specified S/C vector at a specified rate and beginning at a specified time. This option is normally used to effect PTC. This option does not employ optics drive.
 - Option 4 - Point a specified S/C vector along the LOS to the OWS while constraining rotation about the vector (three-axis). This option is used to acquire the OWS in the SXT field of view and is automatically enabled by the MINKEY controller.
 - Option 5 - Point a specified S/C vector at a specified celestial body while constraining rotation about the vector (three-axis). This option does not employ optics drive.
2. Update the OWS or CSM State vector on the basis of optical tracking data and/or VHF range data (Options 0 and 4 only). Update the CSM and OWS State vectors every four time steps (Options 1, 2, and 5 only).

Assumptions:

1. The GNCS is normally in control of the vehicle in the Auto mode. If the astronaut assumes control of the vehicle with the RHC, the CSM will remain at the attitude it is driven to. Regardless of mode selection the CMS will calculate the desired tracking attitude.
2. The OWS optical beacon is visible to the CSM. (Options 0 or 4).
3. During rendezvous, W-matrix initialization is enabled by keying V93E, a fresh start (V36E), uplinked state vector update, and automatically during MINKEY.
4. The optics and VHF ranging mark counters are used to count the number of marks, by source, which are used to update either state vector. The counters are zeroed by W-matrix initialization and by a fresh start.
5. Range, Range rate estimation and display (N76, N77), based on raw VHF ranging data, may be enabled during options 0 and 4 by V76E. Disabled by V77E.
6. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

Option 4 may be initiated automatically by the MINKEY controller.
The sequence will start at MANEUVER below if automatic initiation.

V37E20E

Flashing	Option ID Code	00024
V04N06	Tracking Option Code	0000X

V22E to Load desired option:

0 = Rendezvous (VECPPOINT)
 1 = Celestial body (VECPPOINT)
 2 = Rotation (PTC/ORB rate)
 4 = Rendezvous (Three-axis)
 5 = Celestial body (Three-axis)
 (Option 4 assumed for MINKEY rendezvous)

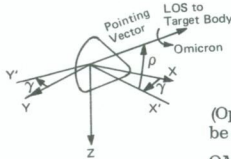
PRO

Flashing	Yaw Angle (γ)	XXX, XX deg
V06N78	Pitch Angle (ρ)	XXX, XX deg
	Azimuth Constraint (OMICRON)	XXX, XX deg

V25E to Load the desired coordinates.

P20 (continued)

γ, ρ are rotational coordinates of the desired pointing axis or axis of rotation. The coordinates represent Euler rotation of the S/C + X axis about the +Z axis and then about the new +Y axis.



COAS pointing	= $0^\circ, 0^\circ$	} Option 0, 4
Optics pointing	= $0^\circ, -35^\circ$	
Hds dn L. V.	= $0^\circ, 90^\circ$	} Option 1, 5
Hds up L. V	= $0^\circ, 270^\circ$	

(Optics coordinates are assumed for rendezvous but may be changed at anytime).

OMICRON is an attitude constraint about the pointing vector for the three-axis options. It is ignored in VECPOINT options.

0°	= Apex forward/heads up L. V
180°	= Apex forward/heads down L. V
180°	= OA Z L. V.
$180^\circ + \eta_z$	= Solar Inertial

η_z is the OA X axis out-of-plane angle

PRO

Flashing	Desired Rate (Option 2 only)	X. XXXX deg/s
V06N79	Desired Deadband	XXX.XX deg

V24E to Load desired rate and deadband.

PRO to appropriate option

CELESTIAL BODY TRACK (Option 1 or 5)

Flashing	Star ID Code	000XX
V01N70		

V21E to load desired Star Code.

PRO If Star Code \neq 00, Go to MANEUVER

Flashing	Unit position vector	X .XXXXX
V06N88	of desired planet	Y .XXXXX
		Z .XXXXX

V25E to load position vector.

PRO to MANEUVER

ROTATION (Option 2)

Flashing	GET at which rotation	00XXX h
V06N34	maneuver is to start	000XX min
		0XX.XX s

V25E to load desired GET (all 0's specify present time)

PRO to TERMINATE (rotation will commence at specified GET). Selection of P21, P27, P29, P30, P52, or P54 will not stop rotation.

RENDEZVOUS (Option 0 or 4)MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on.

If the tracking attitude error is less than 10 degrees, proceed to the appropriate marking sequence.

The attitude error is defined as:

P20 Option 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 (continued)

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG (R)	XXX.XX deg
V50N18	automaneuver	IG (P)	XXX.XX deg
		MG (Y)	XXX.XX deg

PRO

V06N18 Maneuver in progress

Flashing

V50N18 Maneuver Complete

ENTER Terminates automaneuver routine. If rendezvous option go to appropriate marking sequence, otherwise go to TERMINATE.

OPTICS MARKING (Option 0 or 4)

The rendezvous sighting mark routine is called automatically. Proceed with optics marking.

VHF RANGE MARKING (Option 0 or 4)

If MINKEY controller active, VHF marking is initiated automatically when the range is within 327.67 nmi.

V87E Sets VHF Range Flag manually.

Enables ranging marks for use by R22 at 1-minute intervals.

V88E Resets VHF Range Flag manually.

Disables ranging marks. Use V87E to reenable.

BACKUP COAS MARKING (Option 0 or 4)

V54E Calls the backup sighting mark routine.

Flashing	Optics angle coordinates	Shaft	XXX.XX deg
V06N94	for alternate LOS (COAS)	Trunnion	XX.XXX deg

V24E to load coordinates.

COAS LOS coordinates can be determined by sighting on a boresight star and using P52 to compute the desired optics angles to acquire the star in the SXT field.

PRO

Flashing	MARK Counter (VHF - Optics)	XXbXX
V53N45	TFI of Next Burn	XXbXX min/s
	MGA at TIG	XXX.XX deg

TFI and MGA are computed by targeting program, if running.

ENTER Used for marking with COAS. V86E is used to reject a backup mark.

Note: N78 may be modified to specify +X axis pointing for COAS marking at any time. The program will calculate a maneuver to +X axis tracking attitude.

UPDATE DISPLAY (Option 0 or 4)

If any mark produces a state vector position or velocity magnitude change greater than a preloaded value, the astronaut receives a display of the data for approval/disapproval.

Flashing	Delta R	XXX.XX nmi
V06N49	Delta V	XXX.X ft/s
	Source Code (1-OPT, 2-VHF)	0000X

PRO Uses data and updates the state vector.

V32E Rejects mark data and state vector update not done.

TERMINATE

V56E

Flashing
V37 Select New Program

P21-GROUND TRACK DETERMINATION PROGRAM

Purpose:

1. Provide astronaut with details of his ground track.

Assumptions:

1. Can be used while CSM is in earth orbit to determine ground track of either OWS or CSM.
2. Vehicle whose ground track parameters are calculated to remain in freefall from the present time until T Lat Long.

Sequence of Events:

V37E21E

Flashing V04N06	Option Code (specify vehicle)	00002
	Vehicle Code (1-CSM, 2-OWS)	00001

CSM is assumed; if OWS is desired, V22E2E

PRO

Flashing V06N34	Time Lat/Long	00XXX. h 000XX. min 0XX.XX s
--------------------	---------------	------------------------------------

V25E. Key in time at which vehicle position is desired.
Time = 0 specifies present time.

PRO

Flashing V06N43	Latitude of Vehicle	XXX.XX deg (+ north)
	Longitude of Vehicle	XXX.XX deg (+ east)
	Altitude Above Launch Pad	XXXX.X nmi

V32E recycles to Flashing V06N34 for new display.

V06N73E

Optional Display

Flashing V06N73	Altitude	XXXXXXb nmi
	Velocity	XXXXXX. ft/s
	Flight Path Angle	XXX.XX deg

KEY REL

Flashing V06N43	Same as N43 above
--------------------	-------------------

PRO

Flashing V37	Select New Program.
-----------------	---------------------

P25-CONTINGENCY VHF RANGE RATE PROGRAM

Purpose:

1. To display to the astronaut, range and range rate from a source independent of the vehicle state vectors.
2. To allow the astronaut to select a sequence of times for which range rate will be optimized.

Assumptions:

1. VHF range generator is ON and has acquisition.
2. If the astronaut loads N72 with a time in the future, optimizations will occur automatically every 4 minutes beginning with that time.

Sequence of Events:

V37E25E

Flashing	Time at which range	00XXX h
V06N72	Rate will be optimized	000XX min
		0XX. XX s

V25E to load desired GET (all 0's specify no optimization desired)

PRO if 0's entered go to V16N77 display.

Flashing	VHF Range	XXX. XX nmi
V16N76	Range Rate	XXXX. X ft/s
	Time to optimization	XXbXX min/s

PRO

Flashing	VHF Range	XXX. XX nmi
V16N77	Range Rate	XXXX. X ft/s
	Theta/PHI/Code	-00001

PRO

V32E Recycle to N72 display

Flashing	Select new program
V37	

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. 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).
2. Update is allowed in the CSM when the AGC is in P00, P02 or P20 (Options 1, 2 or 5), and if the DSKY is available.
3. The UPTTEL Accept/Block switch must be in Accept for telemetry update.
4. 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.

Sequence of Events:

Select P00 if P00, P02, P20 (Options 1, 2, or 5) not selected.

Up Telemetry switch - Accept Enable Uplink.

Uplink Acty light - ON Program selected via Uplink. Mode window displays 27.

Returns to program selected prior to P27 update

Up Telemetry switch - Block Disable uplink.

P29-TIME OF LONGITUDE

Purpose:

1. To provide the astronaut with an estimated time of passage over a selected longitude.

Assumptions:

1. This program may be selected while the CSM is in earth orbit to find the time of longitude of either the CSM or the OWS.
2. This program assumes the vehicle whose ground track parameters are calculated remains in freefall from the selected start time until the time of longitude crossing.

Sequence of Events:

V37E29E

Flashing	Option ID Code	00002
V04N06	Vehicle Option (1-CSM, 2-OWS)	0000X

V22E to load desired vehicle code.

PRO

Flashing	GET at which CMC	00XXX h
V06N34	begins search (all 0's	000XX min
	for present time)	0XX.XX s

V25E to load desired time.

PRO

Flashing	Desired Longitude (R2)	XXX.XX deg
V06N43		

V22E to load desired longitude.

PRO

Flashing	Time of longitude crossing	00XXX h
V06N34	by specified vehicle	000XX min
		0XX.XX s

PRO

V32E to previous flashing V06N43 to change longitude.

Flashing	Latitude at Longitude Crossing	XXX.XX deg
V06N43	Longitude Specified	XXX.XX deg
	Altitude of Vehicle at Longitude Crossing	XXXX.X nmi

PRO V32E to Flashing V04N06 to recycle.

Flashing	
V37	Select New Program

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.

Assumptions:

1. Target parameters (TIG and ΔV (LV)) may have been loaded from the ground during a prior execution of P27.
2. External Delta V flag is set during the program to designate to the thrusting program that external Delta V steering is to be used.

Sequence of Events:

V37E30E

Flashing	Ground Elapsed Time of Ignition (TIG)	00XXX, h
V06N33		000XX, min
		0XX, XX s

V25E to load desired TIG.

PRO

Flashing	Impulsive Delta V at TIG	X XXXX, X ft/s
V06N81	in Local Vertical Coordinates	Y XXXX, X ft/s
		Z XXXX, X ft/s

V25E to load desired Delta V.

PRO

Flashing	Apogee Altitude	XXXX, X nmi
V06N42	Perigee Altitude	XXXX, X nmi
	Magnitude of Delta V at TIG	XXXX, X ft/s

PRO

Flashing	Mark Counter (VHF - Optics)	XXbXX marks
V16N45	Time from Ignition (TFI)	XXbXX min/s
	Middle Gimbal Angle at TIG with	XXX, XX deg
	Vehicle +X Axis in Direction of Thrust	

If the REFSMMAT flag is reset (that is, the IMU is not aligned) MGA will equal -00002.

PRO

Flashing	Select New Program
V37	

P31-NC1 TARGETING

Purpose:

1. To calculate the parameters associated with the NC1 for Delta V burns.
2. To store the NC1 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 OWS is selected to be a prescribed angle (E) from the horizontal plane defined at the active position.
2. The NC1, NC2, NCC maneuvers are constrained to be horizontal maneuvers.
3. The NSR maneuver is constrained to result in coelliptic orbits following the maneuver.
4. The following time constraints apply
 - a. The TPI time and the time between the NCC and NSR maneuvers are specified.
 - b. The times between NC1 and NC2 maneuvers and the NC2 and NCC maneuvers are indirectly specified by specifying the number of 1/2 revolutions involved in the transfers between the maneuvers.
5. The altitudes between the OWS orbit and the CSM at both NCC and NSR time are specified.
6. 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, take optics marks and/or allow VHF ranging marks to accumulate.
7. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).
8. 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.
9. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E31E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If the tracking attitude error is less than 10 degrees, proceed to TARGETING.

The attitude error is defined as:

P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG (R)	XXX.XX deg
V50N18	automaneuver	IG (P)	XXX.XX deg
		MG (Y)	XXX.XX deg

P31 (continued)

PRO

V06N18 Maneuver in progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing Maneuver Complete (manual sequence)
V50N18

ENTER Terminates automaneuver routine, go to TARGETING

TARGETING

Flashing GET of NC1 Ignition TIG (NC1)
V06N95

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

V25E to load desired TIG.

PRO

Flashing	No. of 1/2 Revs (NC1/NC2)
V06N57	Δ Altitude (NCC)
	Δ Altitude (NSR)

```
0000X
XXXX, X nmi
XXXX, X nmi
```

PRO

Flashing GET of TPI Ignition TIG (TPI)
V06N37

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

V25E to modify TIG.

PRO

Flashing Mark Counter (VHF-Optics)
V16N45 Time from Ignition TFI (NC1)
MGA

XX b XX
XX b XX min/s
-00001

Mark counter updated by P20 which is running in the background. MGA is displayed on the final pass through the program.

PRO Sets Final flag to execute final pass through program

V32E Continues but Final flag not set. Used when another pass is desired.

Alarm Codes 00600 through 00603 may occur. If an alarm occurs, V32E recycles to V06N95 where the input parameters may be adjusted for a new solution.

Flashing	Delta V (NC2)
V06N84	Delta altitude (NC2)
	Delta V (NCC)

XXXX.X ft/s
XXXX.X nmi
XXXX.X ft/s

PRO

Flashing Delta V at TIG (NC1)
V06N81 In Local Vertical Coordinates

X	XXXX.X ft/s
Y	XXXX.X ft/s
Z	XXXX.X ft/s

V25E to modify Delta V.

PRO If Final flag not set go to previous flashing V16N45

Flashing Mark Counter (VHF-Optics)
V16N45 TFI (NC1)
MGA

XX b XX
XX b XX min/s
XXX, XX deg

MGA will be the MGA at TIG (NC1). If the IMU is not aligned, MGA will be -00002.

PRO

If MINKEY controller is active, W matrix reinitialization is performed and the appropriate burn program is initiated.

If Delta V solution < 10 ft/s, P41 is initiated.

If Delta V solution ≥ 10 ft/s, P40 is initiated.

Flashing

V37 Select New Program (manual sequence)

P32 - NC2 TARGETING

Purpose:

1. To calculate parameters associated with the NC2 maneuver for Delta V burns.
2. To store the NC2 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 OWS is selected to be a prescribed angle (E) from the horizontal plane defined at the active position.
2. The NC2 and NCC maneuvers are constrained to horizontal maneuvers.
3. The NSR maneuver is constrained to result in coelliptic orbits following the maneuver.
4. The following time constraints apply:
 - a. The TPI time and the time between NCC and NSR maneuvers are specified.
 - b. The time between NC2 and NCC maneuvers is indirectly specified by specifying the number of 1/2 revolutions involved in the transfer between maneuvers.
5. The altitude between the OWS orbit and the CSM at NSR is specified.
6. If P20 is in operation while the program is operating, the astronaut may hold at any flashing display and take optics marks and/or allow VHF ranging marks to accumulate.
7. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).
8. 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.
9. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E32E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If the tracking attitude error is less than 10 degrees, proceed to TARGETING.

The attitude error is defined as:

P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG(R)	XXX.XX deg
V50N18	automaneuver	IG (P)	XXX.XX deg
		MG(Y)	XXX.XX deg

P32 (continued)

PRO

V06N18 Maneuver in progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing Maneuver Complete (manual sequence)
V50N18

ENTER Terminates automaneuver routine, go to TARGETING

TARGETINGFlashing GET of NC2 Ignition TIG (NC2) 00XXX h
V06N28 000XX min
0XX.XX s

V25E to load desired TIG.

PRO

Flashing Blank
V06N57 Delta altitude (NCC) XXXX.X nmi
Delta altitude (NSR) XXXX.X nmi

V25E to load desired data.

PRO

Flashing GET of TPI Ignition TIG (TPI) 00XXX h
V06N37 000XX min
0XX.XX s

V25E to load desired TIG.

PRO

Flashing Mark Counter (VHF - Optics) XX b XX
V16N45 Time from Ignition TFI (NC2) XX b XX min/s
MGA -00001Mark Counter updated by P20 which may be running in the background.
MGA is only displayed on the final pass through the program.

PRO Set Final flag to execute final pass through program.

V32E continues in program but Final flag is not set. Used when another pass is desired.

Alarm Codes 00600 through 00603 may occur. If an alarm occurs, V32E recycles to V06N28 where the input parameters may be adjusted for a new solution.

Flashing Delta velocity (NCC) XXXX.X ft/s
V06N84 Delta altitude (NCC) XXXX.X nmi
Delta velocity (NSR) XXXX.X ft/s

PRO

Flashing Delta V at TIG (NC2) X XXXX.X ft/s
V06N81 In Local Vertical Coordinates Y XXXX.X ft/s
Z XXXX.X ft/s

V25E to modify Delta V

PRO

If Final flag is reset, go to previous Flashing V16N45.

Flashing Mark Counter (VHF - Optics) XX b XX
V16N45 TFI (NC2) XX b XX min/s
MGA XXX.XX deg

MGA will be the MGA at TIG (NC2). If the IMU is not aligned, MGA will be -00002.

PRO

If MINKEY controller is active, W-matrix reinitialization is performed and the appropriate burn program is initiated.

If Delta V solution < 10 ft/s, P41 is initiated.
If Delta V solution \geq 10 ft/s, P40 is initiated.Flashing
V37 Select New Program (manual sequence)

P33 - NCC TARGETING

Purpose:

1. To calculate parameters associated with the NCC maneuver for Lambert steering Delta V burns.
2. To store the NCC target parameters for use by the desired thrusting program.

Assumptions:

1. This program is based upon previous completion of the NC2 Targeting program (P32). Therefore:
 - a. At a selected TPI time the line of sight between the CSM and the OWS was selected to be a prescribed angle (E) from the horizontal plane defined at the active vehicle position.
 - b. The NCC and NSR maneuvers were assumed to be parallel to the plane of the OWS orbit. However, the N81 display is modified to establish an antinode at NSR.
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display 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 Universal Tracking program (P20).
4. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E33E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If tracking attitude error is less than 10 degrees, proceed to TARGETING.

The attitude error is defined as:

P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG(R)	XXX, XX deg
V50N18	automaneuver	IG (P)	XXX, XX deg
		MG (Y)	XXX, XX deg

PRO

V06N18 Maneuver in progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing	Maneuver Complete (manual sequence)
V50N18	

ENTER Terminate automaneuver routine, go to TARGETING

P33 (continued)

TARGETING

Flashing	GET of NCC Ignition TIG (NCC)	00XXX h
V06N11		000XX min
		0XX, XX s

V25E to correct desired TIG.

PRO

Flashing	GET of NSR Ignition TIG (NSR)	00XXX h
V06N13		000XX min
		0XX, XX s

V25E to correct desired TIG.

PRO

Flashing	GET of TPI Ignition TIG (TPI)	00XXX h
V06N37		000XX min
		0XX, XX s

V25E to correct desired TIG.

PRO

Flashing	Mark Counter (VHF - Optics)	XXbXX
V16N45	Time from Ignition TFI (NCC)	XXbXX min/s
	MGA	-00001

Mark counter is updated by P20 which may be running in the background.
MGA is only displayed on the final pass.

PRO Sets Final flag to execute final pass through program

V32E continues in program but Final flag is not set. Used when another pass is desired.
If an Alarm occurs, a V32E may be used to recycle to V06N11 and readjust TIG.

PRO

Flashing	Delta V at TIG (NSR)	X	XXXX.X ft/s
V06N82	In Local Vertical Coordinates	Y	XXXX.X ft/s
		Z	XXXX.X ft/s

PRO

Flashing	Delta V at TIG (NCC)	X	XXXX.X ft/s
V06N81	in Local Vertical Coordinates	Y	XXXX.X ft/s
		Z	XXXX.X ft/s

PRO If Final flag is reset go to previous Flashing V16N45.

Flashing	Mark Counter (VHF - Optics)	XXbXX
V16N45	TFI (NCC)	XXbXX min/s
	MGA (NCC)	XXX, XX deg

MGA will be the MGA at TIG (NCC). If the IMU is not aligned, MGA will be -00002.

PRO

If MINKEY controller is active, W-matrix reinitialization is performed and the appropriate burn program is initiated.

If Delta V solution < 10 ft/s, P41 is initiated
If Delta V solution \geq 10 ft/s, P40 is initiated

Flashing	
V37	Select New Program (manual sequence)

P34 - NSR TARGETING PROGRAM

Purpose:

1. To calculate parameters associated with NSR maneuver Delta V burns.
2. To store the NSR target parameters for use by the desired thrust program.

Assumptions:

1. This program is based upon previous completion of the NCI (P31), NC2 (P32), and NCC (P33) targeting programs.
Therefore:
 - a. At a preselected TPI time the line of sight between the CSM and OWS was selected to be a prescribed angle (E) from the horizontal plane defined at the active vehicle position.
 - b. The NSR maneuver is assumed to be parallel to the plane of the OWS orbit. However out-of-plane parameters are computed for TIG (NSR) and are available by keying V06N90E at flashing V16N45 after a computation cycle. In addition N81 display is modified to establish an antinode at NSR.
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display 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 Universal Tracking Program (P20).
4. This program may be selected manually or automatically by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E34E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If tracking attitude error is less than 10 degrees, proceed to TARGETING.

The attitude error is defined as:

P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG(R)	XXX.XX deg
V50N18	automaneuver	IG (P)	XXX.XX deg
		MG (Y)	XXX.XX deg

PRO

V06N18 Maneuver in progress

P34 (continued)

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing Maneuver Complete (manual sequence)
V50N18

ENTER Terminate automaneuver routine, go to TARGETING

TARGETING

Flashing GET of NSR Ignition TIG (NSR) 00XXX h
V06N13 000XX min
0XX.XX s

V25E to correct desired TIG.

PRO

Flashing Mark Counter (VHF - Optics) XX b XX
V16N45 TFI (NSR) XX b XX min/s
MGA at TIG (NSR) -00001

Mark counter is updated by P20 which may be running in the background.

MGA is -1 until the final pass of the program.

PRO Sets Final flag to execute final pass through program.

V32E continues in program but Final flag is not set. Used when another pass is desired.

If an alarm 611 occurs, a V32E may be used to recycle to V06N13 and readjust TIG.

Flashing Delta altitude (NSR) XXXX.X nmi
V06N75 Delta Time (TPI-NSR) XX b XX min/s
Delta Time (TPI-NOMTPI) XX b XX min/s

PRO

Flashing Delta V at TIG (NSR) in X XXXX.X ft/s
V06N81 Local Vertical Coordinates Y XXXX.X ft/s
Z XXXX.X ft/s

V25E to modify Delta V.

PRO If Final flag is reset, go to previous Flashing V16N45.

Flashing Mark Counter (VHF - Optics) XX b XX
V16N45 TFI (TPI) XXbXX min/s
MGA XXX.XX deg

MGA will be the expected MGA at TIG (NSR). If the IMU is not aligned, MGA will be -00002.

PRO

If MINKEY controller is active, W-matrix reinitialization is performed and the appropriate burn program is initiated.

If Delta V solution < 10 ft/s, P41 is initiated.

If Delta V solution ≥ 10 ft/s, P40 is initiated.

Flashing
V37 Select New Program (manual sequence)

P35--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/OWS 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 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 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 Universal Tracking program.
6. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.
7. The Delta V in LOS coordinates is available in N59.
8. This program may be selected manually or internally by the MINKEY controller.

P35 (continued)

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E35E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If tracking attitude error is less than 10 degrees, proceed to TARGETING

The attitude error is defined as:

P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG(R) XXX.XX deg
V50N18	automaneuver	IG (P) XXX.XX deg
		MG (Y) XXX.XX deg

PRO

V06N18 Maneuver in progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing	Maneuver Complete (manual sequence)
V50N18	

ENTER Terminate automaneuver routine, go to TARGETING.

TARGETING

Flashing	GET of TPI Ignition TIG (TPI)	00XXX h
V06N37		000XX min
		0XX.XX s

V25E to correct desired TIG.

PRO

Flashing	Number of Precision Offsets	0000X
V06N55	Elevation Angle	XXX.XX deg

V24E to load desired data.

Number of precision offsets is an integration code where X = 0 specifies integration of a conic trajectory to generate the target vector and X ≠ 0 specifies precision integration to generate the target vector.

Elevation angle is the angle between the CSM/OWS LOS and the CSM local horizontal at TIG (TPI). E should = +00000 if E is to be computed at TIG specified.

P35 (continued)

PRO

Flashing	Mark Counter (VHF - Optics)	XXbXX
V16N45	TFI (TPI)	XXbXX min/s
	MGA at TIG (TPI)	-00001

Mark counter is updated by P20 which may be running in the background.

MGA is -1 until the final pass of the program.

PRO Set Final flag.

V32E continues in program but Final flag is not set. Used when another pass is desired.

COMPUTE ELEVATION ANGLE FOR GIVEN TIG

If elevation angle above was = 0.

Flashing	Same as N55 above, except elevation angle has
V06N55	been computed.

PRO Sets Final flag to execute final pass through program

V32E continues in program but Final flag is not set. Used when another pass is desired.

COMPUTE TIG FOR GIVEN ELEVATION ANGLE. If elevation angle above was $\neq 0$.

Flashing	Time of Ignition for Specified	00XXX h
V06N37	Elevation Angle TIG (TPI)	000XX min
		0XX.XX s

If MINKEY FINAL PASS, set E = 0 and go to COMPUTE ELEVATION ANGLE FOR GIVEN TIG above.

Note: If alarm 00611 occurs, PRO to TARGETING at start of program.

PRO

Flashing	Delta V Required for TPI	XXXX.X ft/s
V06N58	Delta V Required for TPF	XXXX.X ft/s
	Delta time (TPI-NOMTPI)	XXbXX min/s

PRO

Flashing	Delta V at TIG (TPI) in	X	XXXX.X ft/s
V06N81	Local Vertical Coordinates	Y	XXXX.X ft/s
		Z	XXXX.X ft/s

Optional Display N59E

V16N59	Delta Velocity X (LOS)	XXXX.X ft/s
	Delta Velocity Y (LOS)	XXXX.X ft/s
	Delta Velocity Z (LOS)	XXXX.X ft/s

KEY REL to Flashing V06N81

PRO If Final flag is reset, go to previous Flashing V16N45.

Flashing	Mark Counter (VHF - Optics)	XXbXX
V16N45	TFI (TPI)	XXbXX min/s
	MGA	XXX.XX deg

MGA will be the expected MGA at TIG (TPI). If the IMU is not aligned, MGA will be -00002.

PRO

If MINKEY controller active, W-matrix reinitialization is performed and the appropriate burn program is initiated.

If Delta V solution < 10 ft/s, P41 is initiated.
If Delta V solution \geq 10 ft/s, P40 is initiated.

Flashing	
V37	Select New Program (manual sequence)

P36-CSM TRANSFER PHASE MIDCOURSE (TPM)
TARGETING PROGRAM

Purpose:

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

Assumptions:

1. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display 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 the expected maneuver time.
3. The time of intercept (T INT) was defined by previous completion of the Transfer Phase Initiation (TPI) program (P-35) 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 Universal Tracking program.
5. The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.
6. The Delta V in LV coordinates is available in N81.
7. The program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E36E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If the tracking attitude error is less than 10 degrees, proceed to TARGETING.

The attitude error is defined as:

- P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.
- P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG(R) XXX, XX deg
V50N18	automaneuver	IG(P) XXX, XX deg
		MG(Y) XXX, XX deg

P36 (continued)

PRO

V06N18 Maneuver in progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing Maneuver Complete (manual sequence)
V50N18

ENTER Terminates automaneuver routine, go to TARGETING.

TARGETING

Flashing	Mark Counters (VHF-Optics)	XX b XX
V16N45	TFI (TPM)	XX b XX min/s
	MGA	-00001

Mark counter is updated by P20, which may be running in the background.
MGA is -1 until the final pass through program.

PRO Sets Final Flag to execute final pass through program

V32E continues but Final flag is not set. Used when another pass is desired.

Flashing	Delta V at TIG (TPM)	X	XXXX. X ft/s
V06N59	in LOS Coordinates	Y	XXXX. X ft/s
		Z	XXXX. X ft/s

V25E to modify Delta V

PRO If Final flag is reset, go to previous Flashing V16N45.

Flashing	Mark Counter (VHF - Optics)	XX b XX
V16N45	TFI (TPM)	XX b XX min/s
	MGA	XXX. XX deg

MGA will be expected MGA at TIG (TPM). If the IMU is not aligned, MGA will be -00002.

PRO

If MINKEY controller is active, W-matrix reinitialization is performed and the
appropriate burn program is initiated.

If Delta V solution < 10 ft/s, P41 is initiated.
If Delta V solution ≥ 10 ft/s, P40 is initiated.

Flashing
V37 Select New Program (manual sequence)

P37- RENDEZVOUS FINAL PHASE PROGRAM

Purpose:

1. To establish X-axis tracking (P20, with UTPIT and UTYAW = 0 deg.)
2. To select R31 internally to provide range and range rate information prior to the braking phase of rendezvous.

Assumptions:

1. This program is selected by the astronaut by DSKY entry or by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E37E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If the tracking attitude error is less than 10 degrees, proceed to TARGETING.

The attitude error is defined as:

P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG(R) XXX.XX deg
V50N18	automaneuver	IG(P) XXX.XX deg
		MG(Y) XXX.XX deg

PRO

V06N18 Maneuver in progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing	Maneuver Complete (manual sequence)
V50N18	

ENTER Terminates automaneuver routine, go to TARGETING.

TARGETING

Flashing	Range	XXX.XX nmi
V16N54	Range Rate	XXXX.X ft/s
	Theta	XXX.XX deg

PRO If manual sequence, go to Flashing V37.

If MINKEY controller is active, MINKEY initiates P48 Rendezvous thrust monitor.

Flashing	
V37	Select New Program (manual sequence).

P38-PLANE CHANGE TARGETING (PC) PROGRAM

Purpose:

1. To calculate parameters associated with the plane change (PC) maneuver for Delta V burns.
2. To store the PC target parameters for use by the desired thrusting program.

Assumptions:

1. This program assumes a stored TIG from the last maneuver, an uplinked TIG or crew loaded TIG in N39.
2. If P20 is in operation while this program is in operation, the astronaut may hold at any flashing display 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 Universal Tracking program (P20).
4. This program is normally used to target a plane change burn at the midpoint (90 degrees central angle) after the last maneuver.
5. The external Delta V flag is used during this program to designate to the thrusting program that Lambert steering is to be used.
6. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E38E

Note: If P20 rendezvous option is not running, P20 Option 4 is activated now.

Flashing	MINKEY Rendezvous Option	
V50N25	Checklist Code	00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

If the tracking attitude error is less than 10 degrees, proceed to TARGETING.

The attitude error is defined as:

P20 Options 0 & 1 - Angular error between the vehicle pointing axis and the LOS to the target with no angular constraint about the pointing vector.

P20 Options 4 & 5 - Angular errors between the actual and desired gimbal angles required to align the vehicle pointing axis along the LOS to the target and constrain the rotation about the pointing vector.

V58E

Request automaneuver execution.

Flashing	Desired FDAI angles for	OG(R) XXX.XX deg
V50N18	automaneuver	IG(P) XXX.XX deg
		MG(Y) XXX.XX deg

PRO

V06N18 Maneuver in progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing Maneuver Complete (manual sequence)
V50N18

ENTER Terminates automaneuver routine, go to TARGETING.

P38 (continued)

TARGETING

Flashing	Time of Ignition (last maneuver)	00XXXX. h
V06N39		000XX. min
		0XX. XX s

V25E to modify TIG.

PRO

Flashing	GET of PC Ignition TIG (PC)	00XXX h
V06N33		000XX min
		0XX. XX s

V25E to modify TIG.

PRO

Flashing	Mark Counter (VHF-Optics)	XX b XX
V16N45	Time from Ignition TFI (PC)	XX b XX min/s
	MGA	-00001

Mark Counter is updated by P20 which may be running in the background.
MGA is -1 until the final pass through program.

PRO Sets Final flag to execute the final pass through program.

V32E Continues in program but Final flag is not set. Used when another pass is desired.

PRO

Flashing	Delta V at TIG (PC)	X	XXXX. X ft/s
V06N81	In Local Vertical Coordinates	Y	XXXX. X ft/s
		Z	XXXX. X ft/s

V25E to modify Delta V.

PRO If Final flag is reset, go to previous Flashing V16N45.

Flashing	Mark Counter (VHF-Optics)	XX b XX
V16N45	TFI (PC)	XX b XX min/s
	MGA	XXX. XX deg

MGA will be the MGA at TIG (PC). If the IMU is not aligned, MGA will be -00002.

PRO If Manual Sequence, go to Flashing V37.

If MINKEY controller is active, W-matrix reinitialization is performed and Delta V (N81) magnitude is tested:

If DV magnitude = 0, MINKEY initiates Flashing V37.

If DV magnitude > 0, MINKEY initiates P52 for possible realignment to new orientation to avoid gimbal lock for +X-axis burn. Go to P52. (PC Realign).

Note: Crew may elect to perform a Y-axis RCS burn, if the Delta V is small, to bypass realigning the IMU. This option is available in P52 (PC Realign). If the IMU is reoriented for a PC maneuver, it is returned to its original orientation by P52 as controlled by the MINKEY sequencer.

Flashing	
V37	Select New Program (manual sequence).

P40-SPS PROGRAM

Purpose:

1. To compute a preferred IMU orientation and a preferred vehicle attitude for an SPS thrusting maneuver and to maneuver the vehicle to the thrusting attitude.
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 control the GNCS during countdown, ignition, thrusting, and thrust termination of a GNCS controlled SPS 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.

3. The TTE clock is set to count to zero at TIG.
4. Engine ignition may be slipped beyond the established TIG if desired by the crew or if integration can not be completed on time.
5. The SPS thrusting program does not monitor the SC control discrete (Channel 31, Bit 15) during thrusting. This means that the AGC will continue to generate engine actuator commands, SPS Engine On discrete, and FDAI attitude error needle commands until the AGC solution indicates Engine Off at which time these commands and the Engine On discrete are terminated. However, this program is not written to take into account the situation where control may be taken away from the GNCS and then given back, and it is not recommended. In event control is taken away from the GNCS, the AGC will only be responsible for computation of position and velocity.
6. 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 V06N81E.
7. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
8. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to Flashing V50N18.

Maneuver to pad burn attitude and check SXT and boresight stars using optics angles on pad.

V37E40E

Flashing	Desired FDAI Angles for	OG(R)	XXX.XX deg
V50N18	Automaneuver	IG(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

Request maneuver to computed burn attitude.

P40 (continued)

PRO

V06N18 Same as N18 above.

Maneuver is in process; final FDAI angles displayed.

Flashing Same as N18 above.

V50N18 Automaneuver is completed.

SCS-GDC aligned to IMU for backup attitude reference.

SPS gimbal drive motors energized.

S/C Control to SCS; SPS servo check and manual drive check performed.

S/C Control to CMC.

PRO

Flashing Same as N18 above.

V50N18 Vehicle is trimmed to burn attitude.

ENTER

Flashing Gimbal Slew Test Option

V50N25 Checklist Code

00204

PRO SLEWS SPS gimbal ± 2 degrees; ENTER - Bypasses gimbal slew test.

SPS gimbals commanded to trim angles (P, Y)

V06N40 Time from Ignition/Cutoff (TFI)

XX b XX min/s

Velocity to be Gained (Vg)

XXXX, X ft/s

Accumulated Velocity (ΔV)

XXXX, X ft/s

DSKY blanks at TIG -35 seconds, and V06N40 resumes at TIG -30 seconds.

Average G on.

Ullage initiated with THC if required.

Flashing Same as N40 above at TIG -5 seconds.

V99N40 Astronaut approval of ignition requested.

PRO Ignition approved.

V06N40 Same as N40 above.

Ignition at TIG.

TVC DAP activated.

SPS engine cutoff; burn complete.

TVC DAP off.

Flashing Same as N40 above.

V16N40

PRO

Flashing Vg Residuals in Control

X XXXX, X ft/s

V16N85 System (body) Coordinates

Y XXXX, X ft/s

Z XXXX, X ft/s

TRIM Vg residuals with THC if required.

PRO If MINKEY controller is active, P3X is entered except P38 at P20 entry.

Flashing Apocenter Altitude, Ha

XXXX, X nmi

V16N44 Pericenter Altitude, Hp

XXXX, X nmi

TFF

XX b XX min/s

PRO

Flashing Select New Program

V37

Average G off.

P41-RCS PROGRAM

Purpose:

1. Compute a preferred IMU orientation and preferred vehicle attitude for an RCS thrusting maneuver and to maneuver the vehicle to the thrusting attitude.
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, re-alignment is desirable.
 - b. A new orientation achieved by selection of P52.
3. 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.

3. The TTE clock is set to count to zero at TIG.
4. Translation initiation may be slipped beyond the established TIG if desired by the crew or if integration cannot be completed on time.
5. 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 V06N81E.
6. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
7. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to Flashing V50N18.

Maneuver to pad burn attitude and check SXT and boresight stars using optics angles on pad.

V37E41E

Flashing	Desired FDAI Angles	OG(R)	XXX.XX deg
V50N18		IG(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

Request maneuver to computed burn attitude.

PRO

V06N18 Same as N18 above.

Automaneuver in process; final FDAI angles displayed.

Flashing	Same as N18 above. Maneuver is complete.
V50N18	

ENTER

V16N85	Velocity to be Gained in Control	X	XXXX.X ft/s
	System (body) Coordinates (Vg)	Y	XXXX.X ft/s
		Z	XXXX.X ft/s

DSKY blanks at TIG -35 seconds and resumes display at TIG -30 seconds.
Average G on at TIG -30 seconds.

Flashing	Flash signifies TIG has arrived.
V16N85	Same as N85 above.

Null Vg with THC at TIG.

P41 (continued)

PRO If MINKEY controller is active, P3X, is entered except P38 at P20 entry.

Flashing
V37 (Manual Sequence)

V82E Request Orbital Parameter display.

Flashing	Apocenter Altitude	XXXX, X ft/s
V16N44	Pericenter Altitude	XXXX, X ft/s
	TFF	XX b XX min/s

PRO

Flashing
V37 Select New Program.

Average G off.

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.

Assumptions:

1. This program can be 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 (P35) and then the SPS Thrusting program (P40) or the RCS Thrusting program (P41).
2. Range, Range Rate, and Theta may be displayed during this program by calling the Rendezvous Parameter Display routine No. 1 (R31) with V83E.
3. Range, Range Rate and PHI may be displayed during this program by calling the Rendezvous Parameter Display routine No. 2 (R34) with V85E.
4. VI, H-DOT and H may be called by keying in V16N62E.
5. The Orbit Parameter Display routine may be called during this program by keying in V82E.
6. 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.

Sequence of Events:

V37E47E

Average G On

Flashing	Delta V Accumulated in Control	X	XXXX, X ft/s
V16N83	Coordinate System	Y	XXXX, X ft/s
		Z	XXXX, X ft/s

Display of integrated acceleration during thrusting.

OPTIONAL DISPLAYS

V16N62E

V16N62	Magnitude of Inertial Velocity (VI)	XXXXX, ft/s
	Rate of Change of Altitude (HDOT)	XXXXX, ft/s
	Altitude Above Pad Radius (H)	XXXX, X nmi

P47 (continued)

KEY REL

Flashing Same as N83 above.
V16N83

V83E Rendezvous parameter display at crew option.

Flashing	Range of CSM to OWS	XXX.XX nmi
V16N54	Range Rate	XXXX.X ft/s
	Angle Between CSM +X Axis and	XXX.XX deg
	Local Horizontal (Theta)	

PRO

V85E Rendezvous parameter display at crew option.

Flashing	Range of CSM to OWS	XXX.XX nmi
V16N53	Range Rate	XXXX.X ft/s
	Angle Between Optics SLOS and the	XXX.XX deg
	Local Horizontal (PHI)	

PRO

V82E Orbital parameter display.

Flashing	Apocenter Altitude	XXXX.X nmi
V16N44	Pericenter Altitude	XXXX.X nmi
	TFF	XX b XX min/s

PRO

Flashing Same as N83 above.
V16N83

PRO

Flashing Select New Program.
V37.

Average G off.

P48 RENDEZVOUS THRUST MONITOR PROGRAM

Purpose:

1. To display to the astronaut range and range rate from a source independent of vehicle state vectors.
2. To display CMC calculated values of theta.
3. To allow the astronaut to select a time at which the rendezvous range rate will be optimized. Optimization is then repeated at four minute intervals.
4. To monitor vehicle acceleration during a non-GNCS controlled thrusting maneuver.

Assumptions:

1. VHF is operating.
2. The responsibility of avoiding gimbal lock is on the astronaut.
3. Range, range rate and PHI (computed from state vectors) may be displayed by keying in V82E
5. This program is normally used during rendezvous final phase.
6. This program should be turned on a few minutes prior to the planned thrusting maneuver to allow for range rate convergence, and terminated as soon as possible after the maneuver in order to keep IMU compensation and average G computation errors at a minimum.

P48 (continued)

Sequence of Events:

V37E48E

Average G on.

Flashing	Current R27 Range	XXX. XX nmi
V16N77	Current R27 Range Rate	XXXX. X ft/s
	R27 Theta	XXX. XX deg.

Theta - Angle between CSM +X axis and the local horizontal plane.

V25N72E Load desired optimization time for R27.

V32E

Flashing	Optimized Range	XXX. XX nmi
V16N76	Optimized Range Rate	XXXX. X ft/s
	Time to Optimization (TFO)	XXbXX min/s

PRO

Flashing		
V16N83	Delta Vx (body)	XXXX. X ft/s
	Delta Vy (body)	XXXX. X ft/s
	Delta Vz (body)	XXXX. X ft/s

V32E. To reinitialize: If the optimization time is loaded to non-zero recycle to flashing V16N70 otherwise the recycle is to the flashing V16N77 display.

PRO To terminate

Flashing	
V37	Select new program.

P50 - ATM ORIENTATION DETERMINATION PROGRAM

Purpose:

1. To compute and store the orientation of the Apollo Telescope Mount (ATM) sensor coordinate system with respect to the Navigation Base coordinate system.
2. To compute and display the docking angles corresponding to this orientation.

Assumptions:

1. The CSM must be docked to the orbital assembly.
2. The +Z axis of the ATM sensor system points in the same direction as the sun sensor. The -Y axis of the ATM sensor coordinate system points in the same direction as the star tracker when star tracker gimbal angles are zero.
3. Three options are available
 - a. Option 1 - ATM sun sensor and IMU orientation are used to determine ATM sensor orientation.
 - b. Option 2 - ATM sun sensor, ATM star tracker, and IMU orientation are used to determine ATM sensor orientation.
 - c. Option 3 - Independent source is used to determine ATM orientation.
4. ATM must be in solar inertial attitude for Options 1 and 2.
5. Astronaut must record star tracker gimbal angles at time of mark in Option 2. These are used as input (N14) later in the program.
6. The IMU must be aligned for Options 1 and 2.

P50 (continued)

7. Star tracker must be locked on to celestial body for Option 2.
8. The astronaut identifies the celestial body acquired by the star tracker. Sun and earth are not valid celestial bodies for the star tracker.
9. Any proportional set of components may be loaded into N88. However, unit vectors are recommended.
10. The astronaut has the option to update or not update the currently stored ATM sensor orientation. Option 3 may be used to display current ATM sensor orientation.

Sequence of Events:

V37E50E

Flashing	Option ID code	00012
V04N06	Marking option	0000X
	X=1, ATM sun sensor	
	2, ATM sun sensor and Star Tracker	
	3, Docking angles from independent source	

PRO Option 3 Go to Flashing V06N23 display

Flashing	Request mark
V51	
	Verify OA in solar inertial attitude and if option 2, verify star acquisition by star tracker.

MARK If option 2 record star tracker gimbal angles at time of mark

Flashing	Checklist code	00016
V50N25		

PRO Option 1 Go to Flashing V06N23 display.

Flashing	Sensor/celestial body code	00CDE
V01N71		
	C=0, optics sighting	
	1, ATM sun sensor sighting	
	2, ATM star tracker sighting	
	DE=Celestial body code. 04, 14, or 25 are expected for star tracker sightings.	

PRO

Flashing	Star tracker azimuth (outer gimbal)	0XXXX arc min
V06N14	Star tracker elevation (inner gimbal)	0XXXX arc min

V24E Load S. T. gimbal angles recorded at mark.

PRO

Flashing	Docking angles	α	XXX.XX deg
V06N23	(Euler angles of ATM system with respect to NB)	β	XXX.XX deg
		γ	XXX.XX deg

V25E Load docking angles if Option 3.

PRO

Flashing	
V37	Select new program.

Purpose:

P51 - IMU ORIENTATION DETERMINATION PROGRAM

1. To determine the inertial orientation of the IMU using sightings on two celestial bodies using the scanning telescope or the sextant, the ATM sun sensor, or the ATM star tracker.

Assumptions:

1. 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.
2. There are no restraints on the CSM attitude control mode in this program.
3. If the ATM sun sensor is used as a source of sighting data, CSM must be docked to orbital assembly, ATM must be in solar inertial attitude, and ATM orientation with respect to nav base must be known.
4. Any proportional set of components may be loaded into N88. However, unit vectors are recommended.

Sequence of Events:

V37E51E

Flashing	Checklist Code	00015
V50N25	Perform Celestial Body Acquisition	

ENTER To Bypass Coarse Align PRO to Flashing V51

V41N22	Desired Gimbal Angles to	OG	000.00 deg
	Coarse Align to	IG	000.00 deg
		MG	000.00 deg

No Att light on.

No Att light off when coarse align complete.

Flashing	
V51	Request mark.

Orbital assembly in solar attitude. Star tracker and sun sensor locked on

ZERO OPTICS for 15 seconds,

OPTICS Mode - Manual

MARK If Star Tracker, Record star tracker gimbal angles

Flashing	Checklist Code	00016
V50N25	Request terminate mark sequence.	

MARK REJECT and recycle to Flashing V51 if not satisfactory.

PRO

Flashing	Sensor / Celestial body code	00CDE
V01N71		

C=0, Optics sighting
 1, ATM Sun Sensor sighting
 2, ATM Star Tracker sighting

DE=Celestial body code. 04, 14 or 25
 are expected for Star Tracker sighting.

PRO

If C \neq 2 and DE =0, go to Flashing V06N88If C \neq 2 and first mark, recycle to Flashing V51If C \neq 2 and second mark, go to Flashing V06N05

Flashing	Star Tracker Azimuth (outer gimbal)	0XXXX arc-min.
V06N14	Star Tracker Elevation (inner gimbal)	0XXXX arc-min

PRO

If DE \neq 0 and first mark, recycle to Flashing V51If DE \neq 0 and second mark, go to Flashing V06N05

Flashing	Unit Vector Specifies Planet	X	.XXXXX
V06N88	Position	Y	.XXXXX
		Z	.XXXXX

V25E to Load Planet vector.

PRO If first mark, recycle to Flashing V51

Flashing	Star Angle difference*	XXX.XX deg
V06N05	Star Angle (Measured)	XXX.XX deg

PRO V32E to recycle to start of program.

REFSMMAT flag set.

Flashing Select New Program.
V37

* Acceptable N05 Limits

STAR/STAR	SXT 0.03°	
	SCT 0.11°	
STAR/PLANET	SXT 0.18°	CSM IMU alignment only.
	SCT 0.21°	

P52 - IMU REALIGN PROGRAM

Purpose:

1. To align the IMU from a "known" orientation to one of three orientations selected by the astronaut using sightings on two celestial bodies with the scanning telescope, the sextant, the ATM sun sensor, or the ATM star tracker.

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. Nominal Orientation (00002)

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

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

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

where

R = The geocentric radius vector at time T (align) selected by the astronaut.

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

c. REFSMMAT (00003)

The present IMU orientation differs from that to which it was last aligned due to gyro drift. This option realigns the IMU to its previous alignment orientation (REFSMMAT).

2. To align the IMU to a predetermined orientation suitable for a plane change (PC) maneuver and to realign the IMU after the maneuver to the pre-PC orientation.

$$X_{SM} = \text{Unit } (X_{SMO} \cos 45^\circ + Y_{SMO} \sin 45^\circ) \text{ for first maneuver}$$

$$X_{SM} = \text{Unit } (X_{SMO} \cos 45^\circ - Y_{SMO} \cos 45^\circ) \text{ for second maneuver}$$

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

$$Z_{SM} = Z_{SMO}$$

where subscript 'O' refers to the orientation existing before the alignment.

P52 (continued)

Assumptions:

1. The configuration may be SIVB/CSM, SKYLAB/CSM, or CSM. The present configuration should have been into the CMC by completion of either R03 or R04 and either V45 or V46 (depending on configuration).
2. If the CMC Mode switch is in CMC-Attitude Hold during the Gyro Torquing routine (R55), the DAP will maneuver the vehicle to follow the platform.
3. An option is provided to point the sextant LOS at astronaut selected or AGC selected starts either manually by crew input or automatically under AGC control.
4. This program may be selected manually or internally by the MINKEY controller in conjunction with the plane change maneuver.

Sequence of Events:

If entered automatically by MINKEY controller, go to PC REALIGN.

V37E52E

Flashing	Option ID Code	00001
V04N06	Alignment Option	0000X
	1 - preferred, 2 - nominal	
	3 - REFSMMAT.	

V22E to key in desired alignment option.

PRO To appropriate option.

PC REALIGN

Flashing	Gimbal angles which will	OG	XXX.XX deg
V06N22	result from pulse torque to	IG	XXX.XX deg
	PC orientation	MG	XXX.XX deg

If MGA is not satisfactory, maneuver vehicle and V32E to recompute N22 angles.

PRO If N22 angles are satisfactory.

Flashing	MINKEY Pulse Torque Option	
V50N25	Checklist Code	00020

ENTER If this is first reorientation maneuver, the pulse torque to PC orientation is bypassed and MINKEY enters the RCS Burn program (P41). If this is the second reorientation maneuver, alarm 00402 is generated. The platform must be torqued to its original orientation.

PRO Commence with pulse torquing.

V16N20	Present ICDU Angles	OG	XXX.XX deg
		IG	XXX.XX deg
		MG	XXX.XX deg

Upon completion of pulse torquing to new orientation, the MINKEY controller will initiate:

1. P41 if pre-plane change burn and if $\Delta V < 10$ ft/s
2. P40 if pre-plane change burn and if $\Delta V \geq 10$ ft/s
3. P33 if plane-change maneuver completed (second pulse torque)

NOMINAL OPTION (00002)

Flashing	GET of Position and Velocity	00XXX h
V06N34	Vectors defining nominal coordinate system. T(Align).	000XX min
		0XX.XX s

V25E to Load T(Align). All 0's specify present time.

PRO To Preferred Option.

PREFERRED OPTION (00001)

Flashing	Desired Gimbal Angles for New	OG	XXX.XX deg
V06N22	Orientation at Present Vehicle	IG	XXX.XX deg
	Attitude	MG	XXX.XX deg

If the new orientation yields gimbal lock, maneuver vehicle and V32E to recompute (N22) desired gimbal angles.

P52 (continued)

PRO

Flashing	Coarse Align Option	
V50N25	Checklist Code	00013

CMC Mode Switch - FREE

(Avoids maneuvering vehicle) - Key in ENTER or PRO.

Gyro Torque Only

ENTER

Torques gyros to achieve new orientation (maintains attitude reference).

V16N20	Monitor Gimbal Angles	OG	XXX.XX deg
		IG	XXX.XX deg
		MG	XXX.XX deg

Go to RECHECK when torquing is complete.

Coarse Align Only

PRO Coarse aligns gimbals to achieve new orientation (lose attitude reference).

No Att light ON until coarse align complete.

Go to REFMMAT option when No Att light out.

REFMMAT OPTION (00003)

Flashing	Checklist Code	00015
V50N25		

Request Celestial Body acquisition.

PRO AGC will select two available stars. Use ENTER to specify crew selection of stars.

MARK SEQUENCE

Flashing	Sensor/Celestial body	00CDE
V01N70		

C=0, Optics sighting
 1, ATM Sun Sensor sighting
 2, ATM Star Tracker sighting

DE=Celestialbody code. 04, 14 or 25
 expected for Star Tracker sighting

V21E to Load Sensor and star code.

ZERO OPTICS for 15 seconds

OPTICS Mode - CMC

PRO If C = 0 and DE \neq 0, go to V06N92 display.If C \neq 0 and DE \neq 0, go to Flashing V51.

Flashing	Unit vector specifies	X	.XXXXXX
V06N88	Planet Position	Y	.XXXXXX
		Z	.XXXXXX

V25E to specify desired planet vector.

PRO If C \neq 0, go to Flashing V51

V06N92	Desired Optics Angles	Shaft	XXX.XX deg
		Trunnion	XXX.XX deg

CMC drives optics LOS to target.

OPTICS Mode - Manual

Flashing	Request MARK
V51	

P52 (continued)

Verify OA in Solar-Inertial attitude and/or Star Tracker star is acquired if ATM marking.
 MARK If Star Tracker sighting record Star Tracker gimbal angles.

Flashing	Checklist code	00016
V50N25	Request terminate mark sequence	

MARK REJECT and recycle to Flashing V51 if not satisfactory

PRO

Flashing	Same as N70 above	00CDE
V01N71		

V21E if sensor/celestial body code incorrect.

PRO

If C \neq 2 and DE = 0, go to Flashing V06N88
 If C \neq 2 and first mark, recycle to MARK SEQUENCE
 If C \neq 2 and second mark, go to Flashing V06N05

Flashing	Star Tracker Azimuth (Outer gimbal)	0XXXX arc min
V06N14	Star Tracker Elevation (Inner gimbal)	0XXXX arc min

V24E to Load recorded gimbal angles

PRO

If DE \neq 0 and first mark, recycle to MARK SEQUENCE
 If DE \neq 0 and second mark, go to Flashing V06N05

Flashing	Same as N88 above.
V06N88	

V25E to correct planet vector.

PRO

If first MARK recycle to MARK SEQUENCE.

Flashing	Star Angle Difference*	XXX.XX deg
V06N05	Star Angle (Measured)	XXX.XX deg

If N05 not satisfactory, V32E, and go to RECHECK.

PRO

Flashing	Gyro Torque Angles to Fine Align	X	XX.XXX deg
V06N93	The stable member	Y	XX.XXX deg
		Z	XX.XXX deg

CMC Mode Switch - Free (Avoids maneuvering vehicle when torquing gyros).

PRO Torque gyros. V32E to bypass gyro torquing.

RECHECK

Flashing	Checklist Code	00014
V50N25	Fine Alignment Option	

PRO Recycles to REFSMMAT option for check on alignment.

ENTER

Flashing	Select New Program
V37	

*Acceptable N05 Limits

STAR/STAR	SXT 0.03°	CSM OPTICS Only.
	SCT 0.11°	
STAR/PLANET	SXT 0.18°	
	SCT 0.21°	

P53 - BACKUP IMU ORIENTATION DETERMINATION PROGRAM

Purpose:

1. To determine the inertial orientation of the IMU using a backup optical device, the ATM sun sensor, or the ATM Star Tracker.

Assumptions:

1. This program is identical to P51 except that R56 is called in place of R53.
2. 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.

Sequence of Events:

V37E53E

Flashing	Checklist Code	00015
V50N25	Perform Celestial Body Acquisition.	

ENTER To bypass coarse align, PRO to Flashing V06N94.

V41N22	Desired Gimbal Angles	OG	XXX, XX
	to Coarse Align to	IG	XXX, XX
		MG	XXX, XX

No Att light on

No Att light off when coarse align complete.

Flashing	Optics Angle Coordinates	Shaft	XXX, XX deg
V06N94	for Alternate LOS	Trunnion	XX, XXX deg

V24E to load LOS coordinates.	COAS Nominal Shaft	+00000
	Trunnion	+57470

PRO

Flashing	Request MARK
V53	

Orbital Assembly in solar attitude and Star Tracker locked on if ATM sighting.

ENTER Does alternate LOS mark. If Star Tracker Sighting, record Gimbal Angles

Flashing	Checklist Code	00016
V50N25	Terminate Mark Sequence	

PRO Key ENTER to reject mark and recycle to Flashing V53.

Flashing	Sensor/Celestial body code	00CDE
V01N71		
	C=0, COAS sighting	
	1, ATM Sun Sensor sighting	
	2, ATM Star Tracker sighting	
	DE=Celestial body code. 04, 14 or 25	
	expected for Star Tracker sighting.	

PRO If C \neq 2 and DE = 0, go to Flashing V06N88If C \neq 2 and first mark, recycle to Flashing V06N94If C \neq 2 and second mark, go to Flashing V06N05

Flashing	Star Tracker Azimuth (Outer gimbal)	0XXXX arc min
V06N14	Star Tracker Elevation (Inner gimbal)	0XXXX arc min

V25E to Load recorded gimbal angles

PRO If DE \neq 0 and first mark, recycle to Flashing V06N94If DE \neq 0 and second mark, go to Flashing V06N05

Flashing	Unit Vector Specifies	X	.XXXXXX
V06N88	Planet Position	Y	.XXXXXX
		Z	.XXXXXX

P53 (continued)

PRO If first mark, recycle to Flashing V06N94.

Flashing	Star Angle Difference*	XXX.XX deg
V06N05	Star Angle (measured)	XXX.XX deg

PRO V32E to recycle to start of program.

Set REFSMMAT flag.

Flashing	Select New Program.
V37	

* Acceptable N05 Limits

STAR/STAR	COAS	0.70°	CSM Optics Only.
STAR/PLANET	COAS	0.72°	

P54 - BACKUP IMU REALIGN PROGRAM

Purpose:

1. To align the IMU from a "known" orientation to one of three orientations selected by the astronaut using sightings on two celestial bodies with a backup optical device; the ATM sun sensor, or the ATM star tracker.
 - 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. Nominal Orientation (00002)

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

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

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

where

R = The geocentric radius vector at Time T(aligned) selected by the astronaut.

V = The inertial velocity vector at time T (aligned) selected by the astronaut.
 - c. REFSMMAT (00003)

The present IMU orientation differs from that to which it was last aligned due to gyro drift. This option realigns the IMU to its previous alignment orientation (REFSMMAT).

Assumptions:

1. The docked configuration may be SIVB/GSM, SKYLAB/CSM, or CSM. The present configuration should have been entered into the CMC by completion of either routine R03 or R04 and either V45 or V46.
2. If the CMC Mode switch is in CMC-Attitude Hold during the Gyro Torquing routine (R55), the DAP will maneuver the vehicle to follow the platform.
3. If the ATM sun sensor is used as a source of sighting data, CSM must be docked to orbital assembly, ATM must be solar inertial attitude, and ATM orientation with respect to the Nav Base must be known.
4. If ATM star tracker is used as source of sighting data, CSM must be docked to orbital assembly, and ATM orientation with respect to the Nav Base must be known.

Sequence of Events:

V37E54E

Flashing	Option ID Code	00001
V04N06	Alignment Option	0000X
	1 - preferred, 2 - nominal,	
	3 - REFSMMAT.	

V22E to load desired option

PRO To appropriate option.

NOMINAL OPTION (00002)

Flashing	GET of position and velocity	00XXX h
V06N34	vectors defining nominal	000XX min
	coordinate system. T(Align)	0XX.XX s

V25E to Load T(Align). All 0's specify present time

PRO To Preferred Option.

PREFERRED OPTION (00001)

Flashing	Desired Gimbal Angles for New	OG	XXX.XX deg
V06N22	Orientation at Present Vehicle	IG	XXX.XX deg
	Attitude	MG	XXX.XX deg

If the new orientation yields gimbal lock, maneuver vehicle and V32E to recompute (N22) desired gimbal angles.

P54 (continued)

PRO

Flashing	Checklist Code	00013
V50N25	Coarse Align Option	

CMC Mode switch - Free (avoids maneuvering vehicle). Key in ENTER or PRO.

ENTER

Torques gyros to achieve new orientation (maintains attitude reference).

V16N20	Monitor Gimbal Angles	OG	XXX.XX deg
		IG	XXX.XX deg
		MG	XXX.XX deg

Go to RECHECK when torquing is complete.

PRO Coarse aligns gimbal to achieve new orientation (loses attitude reference).

No Att light - on.

No Att light - off when coarse align is complete, go to REFSMMAT option.

REFSMMAT OPTION (00003)

Flashing	Checklist Code	00015
V50N25		

Request Celestial Body acquisition.

PRO AGC will select two available stars. Use ENTER to specify crew selection of stars.

MARK SEQUENCE

Flashing	Sensor/Celestial body code	00CDE
V01N70		

C=0, COAS sighting

1, ATM Sun Sensor sighting

2, ATM Star Tracker sighting

DE=Celestial body code. 04, 14 or 25
expected for Star Tracker sighting.

V21E to Load Sensor and Star code

PRO If DE \neq 0, go to Flashing V06N94

Flashing	Unit Vector Specifies	X	.XXXXXX
V06N88	Planet Position	Y	.XXXXXX
		Z	.XXXXXX

V25E to Load desired planet vector.

PRO

Flashing	Optics Angles for Alternate LOS	Shaft	XXX.XX deg
V06N94		Trunnion	XX.XXX deg
	COAS Nominal:	Shaft	+00000
		Trunnion	+57470

V24E to Load LOS coordinates.

PRO

Flashing	Request Mark
V53	

Verify OA in Solar-Inertial attitude and/or Star Tracker star is acquired for ATM marking.

ENTER Does alternate LOS mark

If Star Tracker Sighting record Star Tracker gimbal angles.

Flashing	Checklist Code	00016
V50N25	Terminate Mark Sequence	

PRO Key ENTER to reject MARK and recycle to Flashing V53.

Flashing	Same as N70 above	00CDE
V01N71		

V21E to correct Sensor/Celestial body code.

P54 (continued)

PRO If C \neq 2 and DE=0, go to Flashing V06N88
 If C \neq 2 and first mark, recycle to MARK SEQUENCE
 If C \neq 2 and second mark, go to Flashing V06N05

Flashing	Star Tracker Azimuth (Outer gimbal)	0XXXX arc min
V06N14	Star Tracker Elevation (Inner gimbal)	0XXXX arc min

V24E to Load recorded gimbal angles

PRO If DE \neq 0 and first mark, recycle to MARK SEQUENCE
 If DE \neq 0 and second mark, go to Flashing V06N05

Flashing	Same as N88 above
V06N88	

V25E to correct planet vector

PRO If first mark, recycle to MARK SEQUENCE

Flashing	Star Angle Difference*	XXX. XX deg
V06N05	Star Angle (Measured)	XXX. XX deg

PRO If N05 unsatisfactory, V32E and go to RECHECK.

Flashing	Gyro Torque Angles to Fine Align	X XX.XXX deg
V06N93	Stable Member	Y XX.XXX deg
		Z XX.XXX deg

CMC Mode Switch - Free
 (Avoids maneuvering vehicle when torquing gyros.)

PRO Torques gyros. (V32E to bypass gyro torquing.)

RECHECK

Flashing	Checklist Code	00014
V50N25	Fine Alignment Option	

PRO Recycles to REFSMMAT option for check on alignment.

ENTER

Terminate Program

Flashing	Select New Program
V37	

*Acceptable N05 Limits

STAR/STAR COAS 0.70°
 STAR/PLANET COAS 0.72°

P55-ATM STAR TRACKER GIMBAL ANGLE PROGRAM

Purpose:

1. To compute and display the gimbal angles required by the ATM Star Tracker in order to point at a desired celestial body.

Assumptions:

1. The ATM orientation determination program (P50) has been done prior to the selection of this program to determine the ATM sensor attitude (Y_{ATM} and Z_{ATM})
2. Two options are available
 - a. Option 1 - Use IMU orientation to determine ATM Star Tracker gimbal angles.
 - b. Option 2 - Uses CSM optics mark and LOS to Sun to determine ATM Star Tracker gimbal angles.
3. The astronaut identifies the celestial body to be acquired by the star tracker. Sun or earth are not to be selected as celestial bodies for the star tracker.
4. ATM must be in solar inertial attitude in order to use Option 2.
5. The CSM must be docked to the orbital assembly.
6. The format of N19 (OCTAL Azimuth Angles) is suitable for loading directly in to the ATM computer.
7. Any proportional set of components may be loaded into Noun 88. However, unit vectors are recommended.

Sequence of Events:

V37E55E

Flashing
V04N06Specify P55 Option
Option Code00013
0000X

- 1 - Celestial Body and IMU orientation
- 2 - Celestial Body, Optics Mark, and ATM Solar-Inertial attitude

PRO To appropriate Option.

OPTION 2 Celestial Body, optics mark, and ATM Solar-inertial attitudeFlashing
V51

Please Mark

OPTICS Zero - to OFF

MARK

Flashing
V50N25Checklist Code
Terminate Marking

00016

PRO

Flashing
V01N71Sensor/Celestial body code
C=0, Optics used for sighting
DE=Celestial body code

00CDE

V21E to Load Sensor/Celestial body code marked on

PRO If DE \neq 0, go to Flashing V01N70Flashing
V06N88Unit Vector specifies
Planet positionX .XXXXX
Y .XXXXX
Z .XXXXX

P55 (continued)

OPTION 1

Flashing V01N70	Sensor/Celestial body code	00CDE
--------------------	----------------------------	-------

C=0, Optics sighting
 1, ATM Sun Sensor sighting
 2, ATM Star Tracker sighting

} C need not
 be specified

DE=Celestial body code for which
 Star Tracker angles are desired.

V21E to Load desired celestial body code

PRO If DE ≠ 0, go to Flashing V06N14

Flashing V06N88	Unit Vector specifies Planet position (Star Tracker target)	X .XXXXXX Y .XXXXXX Z .XXXXXX
--------------------	--	-------------------------------------

PRO

Flashing V06N14	Star Tracker Azimuth (Outer gimbal) Star Tracker Elevation (Inner gimbal)	0XXXXX arc min 0XXXXX arc min
--------------------	--	----------------------------------

For alternate star recycle V32E to OPTION 1

PRO For outer gimbal angle in octal

Flashing V04N19	Star Tracker Azimuth (octal)	0SABC 00DE0
--------------------	------------------------------	----------------

ABCDE = Absolute value of Azimuth (octal)
 S = Sign bit, 0 = "+"
 1 = "-"

PRO V32E to recycle to OPTION 1

Flashing V37	Select new Program
-----------------	--------------------

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.

Sequence of Events:

V37E61E

Average G On

Flashing	Impact Latitude	XXX, XX deg
V06N61	Impact Longitude	XXX, XX deg
	Roll Attitude Code	±0000X
	X = +1 - heads up/lift vector down	
	X = -1 - heads down/lift vector up (normal)	

V25E to load entry data.

PRO

Flashing	G Max	XXX, XX g
V06N60	VPRED	XXXXX, ft/s
	GAMMA EI	XXX, XX deg

GMAX is the maximum predicted acceleration for ENTRY at nominal bank angle (L/D ratio = 0.18). VPRED is the predicted inertial velocity at Entry Interface (EI) altitude of 400 k ft. GAMMA EI is the flight path angle between the inertial velocity vector and the local horizontal at EI altitude of 400 k ft.

PRO

Flashing	RTOGO	XXXX, X nmi
V16N63	VIO	XXXXX, ft/s
	TFE	XXbXX min/s

RTOGO is the range to go from a preselected altitude (0.05 g altitude) to splash. VIO is the predicted velocity at the preselected altitude. TFE is the time until the preselected altitude is reached.

RTOGO and VIO may be used for EMS initialization if pad values not available.

PRO

AGC advanced to P62.

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

Purpose:

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

Assumptions:

1. The program is entered with adequate freefall time to accomplish CM/SM separation and complete the maneuver from a worst case starting attitude.
2. The IMU is satisfactorily aligned for entry.
3. The program is automatically selected by the Entry-Preparation program (P61) or it may be selected manually.
4. The astronaut may monitor N63 (RTOGO, VIO, TFE) by keying in V16 N63E.

Sequence of Events:

V37E62E

If entered manually; normally entered automatically from P61.

Average G on. Normally on from P61.

Flashing	Checklist Code	00041
V50N25		

Perform CM/SM separation.

Maneuver to Separation Attitude.

SC Control to SCS.

CM/SM Separation - On.

Maneuver to Horizon Track Attitude.

PRO

Entry DAP Activated

Flashing	Impact Latitude	XXX.XX deg
V06N61	Impact Longitude	XXX.XX deg
	Roll Attitude	±0000X
	X = +1 - heads up/lift vector down	
	X = -1 - heads down/lift vector up (normal)	

V25E to load desired data.

PRO If angle of attack of CM is within 45 degrees of desired, go to P63.

V06N22	Desired Gimbal Angles	OG(R)	XXX.XX deg
		IG(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

Roll angle depends on heads up/down option. Pitch depends on the desired angle of attack into the atmosphere. When CM is within 45 degrees of desired advance to P63.

AGC Advances to P63.

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).

Sequence of Events:

P63 entered automatically from P62.

V06N64	Drag Acceleration	XXX.XX g
	Inertial Velocity	XXXXX. ft/s
	Range to Splash	XXXXX.X nmi
		(+ is overshoot)

OPTIONAL DISPLAYS

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate of Change (HDOT)	XXXXX. ft/s

V16N63E

V16N63	Range from EMS Altitude (RTOGO)	XXXXX.X nmi
	Inertial Velocity at EMS Altitude	XXXXX. ft/s
	Time to go Until EMS Altitude	XX b XX min/s

V16N74E

V16N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

Manual track of horizon reduces pitch error needle as pitch attitude approaches the desired angle of attack.

SC Control Switch - CMC/Auto.

Entry DAP now controlling vehicle attitude.

G&N System senses 0.05g drag acceleration.

AGC advanced to P64.

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 continue entry DSKY displays.

Assumptions:

1. The program is automatically selected by the Entry-Initialization program (P63).

Sequence of Events:

P64 entered automatically from P63 at 0.05 g.

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

OPTIONAL DISPLAYS

V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HDOT)	XXXXX. ft/s

AGC advances to P65 or P67.

If $VI < 27$ k ft/s at 0.05 g, go to P67 when 0.2 g drag is sensed.
 If $VI \geq 27$ k ft/s, a constant drag trajectory is flown until HDOT becomes more positive than -700 ft/s. A range-to-go check will determine if a controlled skip (P65) phase should be entered.
 The entry is targeted nominally for a RTOGO at EI which will be too small to satisfy P65 requirements and P67 is entered at this point.

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 $Q7 \text{ ft/s}^2$) and thereupon to select the Entry-Ballistic Phase program (P66).
4. Where HDOT 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.

Sequence of Events:

P65 entered automatically from P64.

Flashing	Commanded Bank Angle (Beta)	XXX.XX deg
V16N69	Drag Level at Skipout (DL)	XXX.XX g
	Skipout Velocity (VL)	XXXXX. ft/s

PRO Manual response to N69 is not necessary to terminate P65. Selection of P66 or P67 by entry guidance provides automatic termination.

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

OPTIONAL DISPLAYS

V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXX. ft/s
	Range-to-Splash (RTOTARG)	XXXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HDOT)	XXXXX. ft/s

AGC advanced to P66 or P67.

P67 will be entered when HDOT is negative and the velocity is sufficiently low.

P66 will be entered when exit is sensed.

P66-ENTRY - BALLISTIC PROGRAM

Purpose:

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

Assumptions:

1. This program is automatically selected by the Entry-Upcontrol program (P65) when drag acceleration becomes less than $Q7 \text{ ft/s}^2$.

Sequence of Events:

P66 is entered automatically from P65.

V06N22	Desired Gimbal Angles	OG	XXX.XX deg
	to Orient the Vehicle to	IG	XXX.XX deg
	Correct Angle of Attack	MG	XXX.XX deg

Three-axis control of S/C is regained when acceleration falls below 0.05 g and is relinquished when the drag increases above this value.

OPTIONAL DISPLAYS

V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HDOT)	XXXXX. ft/s

V16N74E

V16N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

AGC advances to P67.

P67 is entered at reentry or when approximately 0.2 g is sensed.

P67-ENTRY - FINAL PHASE PROGRAM

Purpose:

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

Assumptions:

1. The program is automatically selected by:
 - a. P65 when HDOT is negative and the V is sufficiently low ($V-VL-C18 \text{ neg}$).
 - b. P66 when drag acceleration builds up to $Q7F + 0.5 \text{ ft/s}^2$ (or approximately 0.2 g).
 - c. P64 if no upcontrol solution exists with $VL > 18,000 \text{ ft/s}$.

Sequence of Events:

P67 is entered automatically from P64, P65, or P66.

V06N66	Commanded Bank Angle (Beta)	XXX.XX deg
	Crossrange Error	XXXXX.X nmi (+ south)
	Downrange Error	XXXXX.X nmi (+ overshoot)

OPTIONAL DISPLAYS

V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXXX. ft/s
	Range to Splash (RTOTARG)	XXXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXXX. ft/s
	Altitude Rate (HDOT)	XXXXXX. ft/s

V16N74E

V16N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

Relative velocity reaches $1,000 \text{ ft/s}$

Flashing	Range-to-Splash (RTOTARG)	XXXXX.X nmi (+ overshoot)
V16N67	Present Latitude	XXX.XX deg (+ north)
	Present Longitude	XXX.XX deg (+ east)

SC Control - SCS

Prevent jet firings when Drogue chutes deploy.

PRO

Flashing	Select New Program.
V37	

Average G off.

P77—CSM VELOCITY VECTOR UPDATE

Purpose:

1. To provide a means of notifying the CMC that CSM has changed (or will change) its orbital parameters by the execution of a thrusting maneuver when Average G is not running.
2. To provide to the CMC the Delta V applied to the CSM to enable an updating of the CSM state vector.

Assumptions:

1. The crew has the Delta V applied to the CSM in local vertical coordinates at a specified TIG.
2. R03 should be performed after P77 to update CSM mass.
3. The contents of N81 is the same as the previous value at entrance to P77.

Sequence of Events:

V37E77E

Flashing	TIG at which Delta V	00XXX h
V06N33	maneuver was executed	000XX min
		0XX.XX s

V25E to Load TIG

PRO

Flashing	Delta V executed in	X XXXX.X ft/s
V06N81	Local Vertical Coordinates	Y XXXX.X ft/s
		Z XXXX.X ft/s

V25E to load Delta V

PRO

Flashing	
V37	Select New Program

R07-MINKEY CONTROLLER ROUTINE

Purpose:

1. To perform automatic sequencing of rendezvous programs.
2. To establish Universal Tracking program (P20) Option 4, with present values for P20 displays.

Assumptions:

1. The initialization values for the W matrix must be loaded prior to selection of a rendezvous targeting program.
2. This routine is initiated by astronaut selection of a rendezvous targeting program.

P31 (NC1 Targeting)

1. Start rendezvous navigation (P20) Option 4, with optics tracking assumed; maneuver to track attitude and enable VHF ranging and state vector updating.
2. Perform NC1 targeting computations.
3. Inhibit rendezvous navigation.
4. Select a burn program.*
5. Select NC2 targeting (P32).

P32 (NC2 Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF ranging and state vector updating.
2. Perform NC2 targeting computations.
3. Inhibit rendezvous navigation.
4. Select a burn program*.
5. Select NCC Targeting P33.

P33 (NCC Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF ranging and state vector updating.
2. Perform NCC targeting computations.
3. Inhibit rendezvous navigation.
4. Select a burn program*.
5. Select NSR targeting (P34)

P34 (NSR Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF tracking and state vector updating.
2. Perform NSR targeting computations.
3. Inhibit rendezvous navigation.
4. Select a burn program*.
5. Select TPI targeting (P35).

P35 (TPI Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF tracking and state vector updating.
2. Perform TPI targeting computations and reinitialize W matrix.
3. Inhibit rendezvous navigation.
4. Select a burn program*.
5. Select TPM Targeting (P36).

R07 (continued)

P36 (TPM Targeting)

1. Start Rendezvous Navigation Tracking (P20), maneuver to tracking attitude and enable VHF tracking and state vector updating.
2. Perform TPM targeting computations and reinitialize W matrix.
3. Inhibit rendezvous navigation
4. Select a burn program*
5. Reinitiate TPM Targeting (P36) or Rendezvous Final Phase (P37).

P37 (Rendezvous Final Phase)

1. Start rendezvous navigation (P20), maneuver to X-axis tracking attitude and enable VHF tracking and state vector updating.
2. Activate rendezvous parameters display (R31) of range, range rate, and theta.
3. Exit MINKEY auto sequencing and manually select new program.

P38 (NPC Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF ranging and state vector updating.
2. Perform PC targeting computations.
3. Inhibit rendezvous navigation.
4. Plane change realignment option:
 - a. If PC Delta V = 0, go to exit program.
 - b. If PC Delta V \neq 0, select IMU Realignment (P52) program.
 - (1) If X-axis thrusting desired, realign IMU to PC orientation to avoid gimbal lock and go to selection of burn program, Step 5.
 - (2) If Y-axis thrusting desired, IMU realignment is bypassed and RCS burn program (P41) is selected.
5. Select a burn program. * (P41 Selected if Y axis RCS used)
6. Reorient IMU to original orientation prior to PC realign and maneuver to OWS tracking attitude (only if IMU reorientation was performed).

*Automatic selection of a burn program (P40/P41) is based on the Delta V solution computed in the targeting program.

1. If Delta V < 10 ft/s, the RCS burn (P41) program is selected.
2. If Delta V \geq 10 ft/s, the SPS burn (P40) program is selected.

CMC ERASABLE MEMORY PROGRAMS

The following erasable program and procedures have been developed to extend the capability of the Skylark software and to provide workarounds in the event that hardware malfunctions limit normal use of the G&N system.

SL-1 RECOVER ANGLE PHI AT T_D

Assumptions/Limitations:

1. R27 is operating in optimization mode
2. Execution is constrained to occur in the interval $T_D + 10$ seconds to $T_D + 85$ sec.
3. The procedure should not be executed during a targeting comp cycle.
4. A restart occurring after execution could result in an erroneous PHI.

DESCRIPTION: Due to a routine phasing discrepancy a possibility exists that PHI, the angle between optics LOS and Local horizontal, might not be updated at R27 optimization time T_D . This procedure calls the job which performs the computation of PHI for the designated optimization time.

SL-2 SOFTWARE RESTART.

Assumptions/limitations: None.

DESCRIPTION: In preference to the hardware restart of V69 a software restart (bail-out alarm 31211) can be initiated by executing a waitlist call to the MKABORT routine.

SL-3 GDC REFSMMAT DETERMINATION.

Assumptions/limitations

1. GDC is inertial.
2. The established inertial reference is valid only for the orientation at which the star sightings are made.

DESCRIPTION: Loading of N20 with GDC angles and proper initiation of P51 logic enables onboard computation of GDC REFSMMAT for GDC orientation. Refer to CSM G&C checklist G3-20.

SL-4 BACKUP OPTICS VARIANCE.

Assumptions/limitations

1. SXT or SCT usable - may be immobile (if IMU good).
2. GDC inertially referenced if IMU failed (complements SL-3).

DESCRIPTION: Increased uncertainty in mark data due to a degraded IMU or optics, or when GDC inertial reference is used, can be compensated for by using the COAS variance (ALTVAR) rather than the SXT variance (SXTVAR).

SL-5 MARK TAKING WITH MARK BUTTON FAILURE.

Assumption/limitations

1. A MARK switch short precludes use of the NAV DSKY keyboard for other than performing optical marking.

DESCRIPTION: Interrupt processing of the NAV DSKY key inputs also results in storage of MARK data. Normal MARK logic can be activated by a waitlist call to routine MARKDIF in the event of an open MARK switch failure. A shorted MARK switch failure merely requires depression of a NAV DSKY key which is interpreted as a MARK. Refer to CSM G&C checklist G4-15.

CMC ERASABLE MEMORY PROGRAMS (con't)

SL-6 DSKY DISPLAY OF VHF RANGE DURING P37

Assumptions/limitations

1. This procedure complements SL-3 and 4 for performing rendezvous navigation with a failed IMU.
2. P20 (Option 0 or 4) is running, and VHF ranging is enabled.
3. State vector updates are enabled, but N49 display is blocked.

DESCRIPTION: In the event that the EMS range counter should fail during rendezvous final phase, a means is available for backup range display on the DSKY. By enabling state vector updates during P37 the range marks can be monitored as they are interrogated. A possible waiting N49 display will terminate state vector updating and hence VHF range marking until the N49 display is responded to.

SL-9 INHIBIT GIMBAL LOCK MONITOR DOWNMODING.

Assumptions/limitations

1. Any V37 major mode change will disable SL-9.
2. TVC DAP does not operate normally.
3. Entry programs do not operate normally.
4. Maneuver to actual gimbal lock will cause an IMU dump.

DESCRIPTION: In the event that a ZCDU failure causes an apparent gimbal lock condition, the automatic coarse align moding can be inhibited by setting AVEGFLAG and loading the Saturn vehicle configuration in R1 of N46. This procedure preserves the use of the IMU as an inertial reference, but precludes use of the TVC digital autopilot.

SL-15 MANUAL RANGE INPUT.

Assumptions/limitations

1. Automatic acquisition of range marks cannot be accomplished.
2. Cannot be activated while a MARK is being processed.
3. This program is overwritten in P27/40/41/52/54.

DESCRIPTION: Should the automatic VHF range marking become disabled, a method is available for manually inserting range marks. The range mark address is loaded with a future value of range. When the loaded value of range is encountered, as determined from the EMS range counter, the erasable program is activated and the range mark is processed.

SL-21 ENTER P51/P53 WITH IMU OPERATE BIT FAILED OFF.

Assumptions/limitations

1. IMU is operating and inertial.

DESCRIPTION: In the event that the IMU-operate input discrete should fail off, IMU orientation determination can be performed by bypassing the first portion of the program.

SL-22 SPS GIMBAL DRIVE TEST.

Assumptions/limitations

1. Valid gimbal trims have been loaded via DAP data load routine.
2. Not to be performed while in P40.

DESCRIPTION: In order to avoid executing P30/P40 to perform an SPS gimbal drive test, this procedure performs a waitlist call to that portion of P40 (S40.6) which executes the gimbal drive test.

Refer to CSM G&C Checklist - G2-10

CMC ERASABLE MEMORY PROGRAMS (con't)

SL-23 MONITOR JET-ON FAILURE.

Assumption/limitations

1. RCS DAP is active and Auto or Hold mode is selected.

DESCRIPTION: DAP attitude errors are sampled once per second to determine if the DAP deadband has been exceeded by an amount specified in the erasable program. If that amount is exceeded, presumably due to a thruster failed on or off, ISS warning is energized, which in turn activates the Master Alarm.

SL-26 IMU CDU TRANSIENT MONITOR.

Assumptions/limitations

1. Downlink interrupts are received every 20 ms (high bit rate) or every 100 ms (low bit rate).
2. W matrix is invalid and will not be integrated.
3. P20 options 0 and 4, rendezvous targeting programs and self check are not operating.

DESCRIPTION: As a protection against undesirable effects of CDU transients, particularly ZCDU transients which result in apparent gimbal lock, a once per 0.1 second CDU monitor is performed to detect unreasonable CDU drive rates. If a CDU change of greater than a specified value (⁴ recommended) over one sample period occurs the ISS WARNING is energized, which, in turn, activates MASTER ALARM to alert the crew. To distinguish a CDU transient from a detected jet on/off fail (SL-28) OPR ERR light is also illuminated. In addition, the N20 angle that is detected in error is replaced by the previous sampled value. The axis in which the transient occurred is flagged by setting Channel 11, Bit 11, 12, or 15, for X, Y, or Z axis, respectively.

SL-27 MONITOR SINGLE IMU CDU.

Assumptions/limitations

1. Pre-TPI rendezvous targeting programs and self-check are not operating.
2. Effective CDU rate detection limit is $16.8^\circ/\text{second}$ during high bit rate and $20^\circ/\text{second}$ low bit rate.
3. Bit rate selection must be loaded into program for proper rate detection.

DESCRIPTION: Since rendezvous navigation and TPI targeting programs preclude the use of SL-26 (CDU transient detection), a single axis CDU transient detector is available in this procedure which samples at a once per 0.24-second sample rate for CDU changes of greater than ⁴. The crew is alerted by ISS WARNING, MASTER ALARM, and OPR ERR should a transient occur same as in SL-26. Availability of erasable memory during rendezvous precipitated the need for an abbreviated version of SL-26.

SL-28 MONITOR JET-ON FAILURE AND DO SL-26

Assumptions/limitations

1. For use during P00 and P20 Options 2 and 5.
2. W matrix is invalid and should not be integrated.
3. Same as for SL-26
4. SL-26 must be uplinked.

DESCRIPTION: This EMP provides the jet on/off monitor as described in SL-23 and operates SL-26, which must be uplinked in addition to this EMP. Both CDU transients and jet on/off failures will trigger the ISS WARNING and MASTER ALARM indications with the OPR ERR indication being triggered by CDU transients only.

CMC ERASABLE MEMORY PROGRAMS (con't)

SL-50 CONVERT GYRO TORQUE ANGLES (N93) TO CDU ANGLES FOR FAILED IMU.

Assumptions/limitations

1. IMU is unusable
2. GDC is aligned using SL-3.

DESCRIPTION: P52 realignment of the GDC using optics can be accomplished using this procedure to convert N93 torquing angles to final N20 Euler angles. The present N20 Euler angles of the GDC at which attitude marking was performed are inputted, as well as the N93 torque angles required to realign the GDC to the present GDC REFSSMMAT. Since such torquing of the GDC is impossible, this procedure uses the N93 angles to compute a final set of N20 Euler angles which would result from gyro torquing of the IMU stable member. The GDC can then be aligned to the resulting N20 angles thus accomplishing a GDC REFSSMMAT REALIGN.

SL-51 COMBINED RATE PROGRAM FOR ORBITAL ASSEMBLY MANEUVER.

Assumptions/limitations

1. IMU is powered down.
2. OA attitude controlled by Control Moment Gyros

DESCRIPTION: This program is designed to provide vehicle torques according to external commanded rate inputs using the SM RCS jets. The purpose of executing such torquing commands is twofold.

1. Due to the offset C. G. of the OA, performing X translation maneuvers to trim the vehicle orbit produces a rotational torque on the vehicle. This torquing has an adverse effect on the total momentum vector of the control moment gyros (CMG) which are controlling vehicle attitude. To counteract the undesired torque, this program produces jet firings according to precomputed rate commands which have been loaded.
2. Ground computed rate commands can be executed to produce torques about all three vehicle axes using the SM RCS. The purpose of applying these torques is for management of the CMG momentum vector in either a momentum dump or momentum desaturation maneuver. This capability provides a backup to the thruster attitude control system (TACS) of the OWS.

This program will be loaded prior to power down to standby to make it readily available for use.

SL-52 CHECKSUM ON VAC AREA STORAGE

Assumptions/limitations: None

DESCRIPTION: This program does an erasable sum check on the VAC AREA storage cells. It is designed to be used with SL-51 which uses VAC AREA storage for the program. Since SL-51 is loaded prior to power down its integrity can be checked after power up using this program.

ASPO 45 CRT DISPLAYS

MSK-671

MSK-672

CSM GNC PRIMARY

0671

GMTA _____		SITE _____				
GMTC _____		QUADA	QUADB	QUADC	QUADD	PSM
CTE _____	WPU LBS	_____	_____	_____	_____	_____
CMCB _____	P/T PCT	_____	_____	_____	_____	_____
CMC _____	HE TK P	_____	_____	_____	_____	_____
	HE TK T	_____	_____	_____	_____	_____
OPT _____	HE MN P	_____	_____	_____	_____	_____
CMC _____	FU MN P	_____	_____	_____	_____	_____
ID _____ FL _____	OX MN P	_____	_____	_____	_____	_____
VERB NOUN PRGM	CM RCS	SYS 1	SYS 2		FU TK P	_____
_____	HE TK P	_____	_____		OX TK P	_____
REG 1 _____	HE TK T	_____	_____		SPS	_____
REG 2 _____	HE MN P	_____	_____		HE TK P	_____
REG 3 _____		PITCH	YAW	ROLL	HE TK T	_____
MAN ATT SW	ISS	_____	_____	_____	FU TK P	_____
P Y R	ACDU	_____	_____	_____	FU IN P	_____
DAP ATT	ΔATT	_____	_____	_____	OX TK P	_____
RATE DB	FCDU	_____	_____	_____	OX IN P	_____
	ERR	CMC	_____	_____	CHMBR P	_____
ADB	SCS	_____	_____	_____	N2 A P	_____
DAPDTR1 RATE	CMC	_____	_____	_____	N2 B P	_____
DAPDTR2	SCS	_____	_____	_____		_____
DAPDTR3	OPT POS	_____	_____	_____	REDO	_____
DKRATE	GMB CMD	_____	_____	_____	FALRG	_____
DKDB	OCDU DC	_____	_____	_____	CHNL77	_____
SLOPE	SPS GMB	_____	_____	_____	DSTB11	_____
WCHDAP	AT TVC	_____	_____	_____		_____
CHAN31	MN TVC	_____	_____	_____	VEH ACC	_____
	DIF CUR	_____	_____	_____		_____

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ACDU	Actual CDU Angles (N 20)	XXX. deg	FL	Verb/Noun Flasher Status	
ADB	DAP Attitude Deadband Presently in Use	X. X deg	GMB CMD	TVC DAP Issued SPS Engine Actuator Commands (Pitch, Yaw)	X. XX deg
AT- TVC	SCS Auto- TVC Servo Loop Commands	X. XX deg			D H M S
CHAN 31	Computer Input Channel Containing RHC, THC and Vehicle Control Mode Command Inputs.	XXXXX ₈	GMTA	Greenwich Mean Time at Receipt of S/C Analog Data	XXX: XX: XX: XX
CHNL 77	Channel 77 Restart Monitor	XXXXX ₈	GMTC	Greenwich Mean Time at Receipt of CMC Downlist	D H M S
CMC	CSM Computer Clock	H M S XXX:XX:XX	ID	Identification of CMC Downlist being Transmitted	XXX: XX: XX: XX
CMC	S/C Control and Mode Switch Status (SCS or CMC Auto, Hold or Free)	H M S	ISS	Inner, Middle, Outer 1X Resolver Angles	XXX deg
CMCB	CMC Clock Time Minus a ΔT Specified, Usually Equal to a ΔT Clock Update, to sync CMC and CTE Times.	XXX:XX:XX	MAN ATT SW	SCS Vehicle Control Mode Switch Status in P, Y, and R Axes (Rate Command, Accel Command or Min Impulse)	
CTE	Central Timing Equipment Clock	H M S XXX:XX:XX	MN TVC	SCS Manual TVC Servo Loop Commands	X. XX deg
ΔATT	Difference of 1x Resolvers and ACDU angles	XXX deg	NO'N	Noun Displayed on DSKY	XX.
DAP	Functional DAP Mode status (No DAP, SAT DAP, RCS DAP, or TVC DAP)		OCUDUC	OCDU DAC Output Scaled to Optics or TVC Gimbal Commands	X. XX deg
DAPDTR1	RCS DAP Data Flags Indicating Crew Selection of Vehicle Configuration, X Translation QUAD Preference, Maneuver Rate, and Attitude Deadband (N46).	XXXXX ₈	OPT	Optics Mode Switch Status (Zero, CMC, or Manual)	
DAPDTR2	RCS DAP Data Flags Indicating Crew Selection of Roll Quad Preference and RCS Quad Fail Status (N46).	XXXXX ₈	OPT POS	Optics CDU Angles (Shaft, Trum)	XXX. XX deg
DAPDTR3	Docked DAP Data Flags Indicating Crew Selection of Roll and X Translation Quad Preference, and Force/Couple Mode for Pitch and Yaw Control (N87).	XXXXX ₈	PRGM	Computer Program Displayed on DSKY	XX
DB	RCS DAP Attitude Deadband Selected by Crew in DAPDTR1 (N46).	X. X deg	REDO	Counter Indicating Number of Hardware Restarts Since Last Fresh Start (V36)	XXXXX
DIFCUR	SPS Gimbal Motor Differential Clutch Current (Pitch, Yaw)	XXX. MA	RATE	RCS DAP Maneuver Rate Selected by Crew in DAPDTR1 (N46).	X. XX deg/sec
DKDB	Docked DAP Attitude Deadband Selected by Crew (N89)	X. X deg	RATE CMC	RCS/Docked DAP Computed Control Axis Rates (ADOT) or TVC DAP Computed Body Rates (OMEGAB)	X. XXX deg/sec
DKRATE	Docked DAP Maneuver Rate Selected by Crew (N89)	X. XX deg/sec	RATE SCS	SCS Body Rates, P, Y, R, Derived from BMAG Rate Gyros	X. XXX deg/sec
DSTB11	Display Table of DSKY Status Lights X0400g Program Caution X0200g Tracker Warning X0020g No Attitude X0040g Gimbal Lock	XXXXX ₈	REG 1, REG 2 REG 3	Row 1, Row 2 and Row 3 Displayed on DSKY	XXXXX
ERR CMC	RCS/Docked/TVC DAP computed Attitude Error Needle Commands	X. XXX deg	SITE	STDN Remote Site from which Data is being Received	
ERR SCS	Errors Displayed on FDAI Error Needles (FDAI No. 1 or Selected FDAI)	X. XXX deg	SLOPE	Specifies the Slope of the Phase Plane Boundaries	X. XXXX deg/sec/deg
FALRG	Most Recent Program Alarm Code	XXXXX ₈	SPS GMB	SPC Gimbal Trim Angles from Gimbal Position Transducers	X. XX deg
FCDU	Final Desired CDU Angles (N22)	XXX deg	VEH ACC	Computation of Vehicle Acceleration During Thrusting from RSS of PIPA Measurements	XX. XXXX ft/sec/sec
			VERB	Verb Displayed on DSKY	XX.
			WCHDAP	DAP Mode Flag. 1 Signifies Docked DAP is Active, 0 Signifies Undocked RCS DAP is Active.	XXXXX ₈

CMC MONITOR I

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ID _____	SITE _____	X/ROLL _____	Y/PITCH _____	Z/YAW _____
FGWD 0 _____	GMTC _____	PIPA _____	_____	_____
FGWD 1 _____	CTE _____	DELV _____	_____	_____
FGWD 2 _____	CMCB _____	VGIMU _____	_____	_____
FGWD 3 _____	CMC _____	FCDU _____	_____	_____
FGWD 4 _____	CMCAT _____	DCDU _____	_____	_____
FGWD 5 _____	TCMSV _____	ACDU _____	_____	_____
FGWD 6 _____	TOWSV _____	ISS _____	_____	_____
FGWD 7 _____	TGO _____	ERROR _____	_____	_____
FGWD 8 _____	TIG _____	AK _____	_____	_____
FGWD 9 _____	TEVNT _____	ADOT _____	_____	_____
FGWD 10 _____	_____	OMGAC _____	_____	_____
FGWD 11 _____	PG _____ FL _____ WARN _____	ENT _____	_____	_____
_____	VB _____ NN _____ PRG _____	P ERR _____	_____	_____
CHNL11 _____	_____ KKK _____	I BIAS _____	_____	_____
CHNL12 _____	R1 _____ UPFST _____	P OCTL _____	_____	_____
CHNL13 _____	R2 _____ UPSW _____	DLTA T _____	_____	_____
CHNL14 _____	R3 _____ CMD _____	OWS _____ ACTOFF _____	_____	_____
CHNL30 _____	_____	CSM _____	GMBCMD _____	_____
CHNL31 _____	REDO _____ DSTB11 _____	UTYAW _____	DPDTR1 _____	_____
CHNL32 _____	_____ FALRG CHNL 77 _____	UTPIT _____	DPDTR2 _____	_____
CHNL33 _____	RSBBQ _____	ADB _____	DOCK _____	DAP _____
_____	_____ C31FW _____	_____	DPDTR3 _____	_____
IMDE30 _____	_____	INTEG TIME _____	VHF _____	C5FAIL _____
IMDE33 _____	HLDFG _____ RCSFG _____	_____	_____	C6FAIL _____
OPTMDE _____	_____ N06 _____	OPT _____	_____	DKRTE _____
WCHDAP _____	STARID1 _____ R1 _____	OGC _____	_____	DKDB _____
_____	STARID2 _____ R2 _____	IGC _____	_____	SLOPE _____
_____	CDU SHFT _____	MGC _____	_____	_____
_____	CDU TRUN _____	ΔVLV X _____	Y _____	Z _____

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ACDU	Actual CDU Angles (N20)	XXX.XX deg	DELV	Values of X, Y and Z PIPA Counters at Last Reading, Compensated for Scale Factor and Bias Errors.	XXXX.X ft/sec
ACTOFF	SPS Gimbal Trims in CMC (PACTOFF, YACTOFF)	X.XXX deg			
ADB	DAP Attitude Deadband Presently in Use	X.XX deg	DKDB	Attitude Deadband Selected for Docked DAP Control (N89).	X.XX deg
ADOT	RCS/Docked DAP Computed Control Axis Rates (ADOT) or TVC DAP Computed Body Rates (OMEGAB).	XX.XX deg/sec	DKRTE	Maneuver Rate Selected for Docked DAP Control (N89).	X.XXXX deg. sec
AK	RCS/Docked/TVC DAP computed Attitude Error Needle Commands	XX.XX deg	DLTAT	Elapsed Time Since Last PIPA Bias Computation was Initialized (ΔT over which Bias is Computed)	XXXXX sec
BIAS	Measured Accelerometer Bias Computed Every 10 sec. over Time Interval in "DLTAT"	X.XXXX ft/sec/sec	DPDTR1	RCS DAP Data Flags Indicating Crew Selection of Vehicle Configuration, X Translation Quad Preference, Maneuver Rate, and Attitude Deadband (N46).	XXXXX ₈
C5FAIL	Docked DAP Jet Inhibit Buffers; Bits are Respectively Dedicated to Output Channels 5 and 6 Jet Command Bits.	XXXXX ₈	DPDTR2	RCS DAP Data Flags Indicating Crew Selection of Roll Quad Preference and RCS Quad Fail Status (N46).	XXXXX ₈
C6FAIL					
C31FW	Switch Override Buffer for S/C Control, CMC Mode and Optics Mode and Zero Switches.	XXXXX ₈	DPDTR3	Docked DAP Data Flags Indicating Crew Selection of Roll and X Translation Quad Preference, and Force/Couple Mode for Pitch and Yaw Control (N87).	XXXXX ₈
CDU SHAFT	Optics Shaft CDU Angle (N91)	XXX.XX deg			
CDU TRUNNION	Optics Trunnion CDU Angle (N91)	XX.XXX deg			
CHNL 11 - CHNL 14	Computer Output Channels	XXXXX ₈	DSTB11	Display Table of DSKY Status Lights X0400g Program Caution X0200g Tracker Warning X0020g No Attitude X0040g Gimbal Lock	XXXXX ₈
CHNL 30 - CHNL 33	Computer Input Channels	XXXXX ₈			
CHNL 77	Channel 77 Restart Monitor	XXXXX ₈			
		H M			
CMC	CSM Computer Clock	XXX:XX:XX.XX	ENT	Vehicle Rates, p, q, r Relative to the Entry Coordinate System	X.XX deg/sec
		H M S			
CMCB	CMC Clock Time Minus ΔT Specified, Usually Equal to a ΔT Clock Update, to Sync CMCB and CTE Times.	XXX:XX:XX.XX	ERR	Uncompensated PIPA Bias (Measured Minus Loaded Values)	X.XXXX ft/sec/sec
		H M S			
CMC ΔT	Difference of GETC and CMC Times	XXX:XX:XX.XX	ERROR	RCS/Docked DAP Phase Plane Attitude Errors (R, P, Y)	XXX.XX deg
CMD	Uplink Too Fast Status		FALRG	First, Second and Most Recent Program Alarm Codes Since Last Error Reset	XXXXX ₈ XXXXX ₈ XXXXX ₈
CSM	CMC Loaded CSM Mass	XXXXX lbs	FCDU	Final Desired CDU Angles (N22)	XXX.XX deg
		H M S			
CTE	Central Timing Equipment Clock	XXX:XX:XX.XX	FGWD0 - FGWD11	Computer Flagwords 0 Through 11	XXXXX ₈
DCDU	DAP Desired CDU Angles (Phase Plane Reference)	XXX.XX deg	FL	Verb/Noun Flasher Status	
$\Delta VLVX, Y, Z$	X, Y and Z Components of Delta V in Local Vertical Coordinates (N81)	XXXX.X ft/sec	GMBCMD	TVC DAP Issued SPS Engine Actuator Commands (Pitch, Yaw)	X.XXX deg
			GMTC	Greenwich Mean Time at Receipt of CMC Downlist	D H M S XXX:XX:XX:XX

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HLDFLG	CMC Flag used to Control Nature of Attitude Hold Performed by RCS/ Docked DAP.	XXXXX ₈	RCSFG	Status Register for Control of RCS/ Docked DAP Functions, RCS Flags	XXXXX ₈
ID	Identification of Downlist Being Transmitted		REDO	Counter Indicating Number of Hardware Restarts since Last Fresh Start (V36).	XXXXX
IGC	During Gyro Torquing, The "Y" Gyro Torquing Angle, or During P50 the Inner Gimbal Docking Angle δ .	X.XXX deg	RSBBQ	Value of BBANK and Q Registers at the Point of Restart	XXXXX ₈ XXXXX ₈
IMDE 30	IMU Status and Input Channel 30 Buffer Register, Imodes 30	XXXXX ₈	SITE	STDN Remote Site From which Data is being Received	
IMDE 33	IMU Status and Input Channel 33 Buffer Register, Imodes 33	XXXXX ₈	SLOPE	Specifies the Slope of the Phase Plane Boundaries.	X.XXX deg/sec/deg
INTEG TIME	Time to which state vector is Presently Integrated	H M S XXX:XX:XX.XX	STARID1 STARID2	Octal Equivalent of the First and Second CMC STAR I.D. Number	XXXXX ₈ XXXXX ₈
ISS	Outer, Inner and Middle 1 X Resolver Angles	XXX.XX deg	TCMSV	Time Tag of CSM State Vector	H M S XXX:XX:XX.XX
KKK	Uplink Data Status		TEVNT	CMC Time of Last Event; SPS Ignition, Cutoff or Liftoff	H M S XXX:XX:XX.XX
MGC	During Gyro Torquing the "Z" Gyro Torquing Angle or During P50, The Middle Gimbal Angle γ .	X.XXX deg	TIG	CMC Time of Ignition or Time of Cutoff After Ignition Occurs	H M S XXX:XX:XX.XX
N06	R1, Option Code Specifies Option Category	XX ₈	TGO	Time to SPS Cutoff	H M S XXX:XX:XX.XX
NN	R2, Option Specifies which Option Elected	XX ₈	TOWSV	Time Tag of Orbital Workshop State Vector	H M S XXX:XX:XX.XX
OCTL	Noun Displayed on DSKY	XX	UPFST	Block Inlink Discrete Status	
OGC	Octal Equivalent of Loaded PIPA Bias Compensation	XXXXX ₈	UPSW	Uplink Accept/Block Switch Status	
OMGAC	During Gyro Torquing the X Gyro Torquing Angle, or During P50 the Outer Gimbal Docking Angle α .	X.XXX deg	UTPTT	P20 Pitch Coordinate Defining S/C Pointing Vector (SCAXIS). (New X Rotation About Rotated S/C Y axis, Rotation Ordered Yaw, Pitch).	XXX.XX deg
OMGAC	RCS/Docked DAP Control Axis Rate Command (W Body) or TVC DAP Body Rate Commands (OMEGAC) from Cross Product Steering.	XX.XX deg/sec	UTYAW	P20 Yaw Coordinate Defining S/C Pointing Vector (SCAXIS). (X Rotation about S/C Z Axis, Rotation Ordered Yaw, Pitch).	XXX.XX deg
OPT	Number of Optics Marks Incorporated in State Vector (P20).	XX.	VB	Verb Displayed on DSKY	XX.
OPTMDE	Optics Status Register, OPTMODES	XXXXX ₈	VGIMU	X, Y, Z Velocity to be Gained in SM Coordinates	XXXX.X ft/sec
OWS	Other Vehicle Mass Loaded in CMC	XXXXX lbs	VHF	Number of VHF Range Marks Incorporated in State Vector (P20).	XX.
PG	Computer Program Displayed on DSKY	XX.	WARN	CMC Warning Lamp Status	
PIPA	Contents of X, Y and Z PIPA Counters in ΔV Counts.	XXXXX	WCHDAP	DAP Mode Flag. 1 signifies Docked DAP is Active. 0 Signifies Undocked RCS DAP is Active.	XXXXX ₈
PRG	Program Caution Lamp Status				
R1, R2, R3	Row 1, Row, 2, and Row 3 Displayed on DSKY.	XXXXX			

LAUNCH & BURN SCHEDULE

**GYROCOMPASSING & LAUNCH
BOOST & EARTH ORBIT INSERTION
RENDEZVOUS
DEORBIT & ENTRY**

PRELAUNCH IMU COMPENSATION

POSITION	GYRO DRIFTS			PIPA	
	NBD (meru)	ADIA (meru/g)	ADSRA (meru/g)	BIAS ₂ (ft/s ²)	SCALE FACTOR (ppm)
X					
Y					
Z					

IMU COMPENSATION UPDATES

POSITION	GYRO NBD (meru)	PIPA BIAS (ft/s ²)	TIME OF UPDATE GET		
			h	min	s
X					
Y					
Z					
X					
Y					
Z					
X					
Y					
Z					

SKYLAB 2 POWERED MANEUVER SUMMARY

Event	Date	Calendar day ^a	Time of burn initiation			SWS rev	ΔV , fps	Burn duration sec	Lighting	Altitude n. mi. ^b	Geocentric latitude, deg	Longitude, deg	Resultant perigee/apogee ^b , n. mi.
			G. m. t., hr:min:sec	CSM g. e. t., d:hr:min:sec	SWS g. e. t., d:hr:min:sec								
SL-1 lift-off	May 14	134	17:30:00.0	-00:23:29:36.0	00:00:00:00.0	--	--	--	Day	--	28.45	- 80.60	--
Insertion	May 14	135	17:39:47.8	-00:23:19:48.2	00:00:09:47.8	1	--	--	Day	233.9	39.47	- 66.18	232.0/234.8
SL 2 lift-off	May 15	135	16:59:36.0	00:00:00:00.0	00:23:29:36.0	15	--	--	Day	--	28.47	- 80.62	--
Insertion	May 15	135	17:09:25.8	00:00:09:49.8	00:23:39:25.8	15	--	--	Day	81.0	39.01	- 65.32	81.0/120.1
CSM/S-IVB separation ^c	May 15	135	17:15:36.0	00:00:16:00.0	00:23:45:36.0	15	3.0	7.4	Day	83.0	49.10	- 33.98	81.0/121.6
Phasing 1 (NC1)	May 15	135	19:19:47.9	00:02:20:11.9	01:01:49:47.9	16	218.9	9.6	Night	121.4	-34.37	73.68	121.4/204.7
Phasing 2 (NC2)	May 15	135	21:35:39.3	00:04:36:03.3	01:04:05:39.3	17	160.6	6.9	Day	204.6	34.36	-140.61	203.8/213.5
Corrective combination (NCC)	May 15	135	22:21:48.5	00:05:22:12.5	01:04:51:48.5	18	30.5	1.2	Night	213.3	-34.73	27.92	213.2/223.1
Coelliptic (NSR)	May 15	135	22:58:48.5	00:05:59:12.5	01:05:28:48.5	18	19.1	0.7	Day	223.4	9.09	170.64	222.3/223.6
Terminal phase initialization (TPI)	May 15	135	23:49:14.7	00:06:49:38.7	01:06:19:14.7	19	20.6	0.7	Night	224.2	-18.98	- 12.97	224.1/234.2
Terminal phase finalization (TPF) ^c	May 16	136	00:22:52.1	00:07:23:16.1	01:06:52:52.1	19	d27.9	65.4	Day	232.8	-18.59	125.31	232.0/235.2
Docking	May 16	136	00:39:36.0	00:07:40:00.0	01:07:09:36.0	19	--	--	Day	233.6	31.16	167.80	232.0/235.2
Orbit trim 1-PM ^c	May 16	136	15:22:59.7	00:22:23:23.7	01:21:52:59.7	28	0	0	Night	234.1	-26.70	117.69	232.0/235.2
Orbit trim 1-RN ^c	May 16	136	16:09:35.7	00:23:09:59.7	01:22:39:35.7	29	0	0	Day	233.4	26.80	- 74.03	232.0/235.2
Orbit trim 2-PM ^c	May 23	143	12:08:42.4	07:19:09:06.4	08:18:38:42.4	127	0.4	6.4	Night	233.8	-47.92	167.94	231.2/237.0
Orbit trim 2-RN ^c	May 23	143	12:55:20.2	07:19:55:44.2	08:19:25:20.2	128	0	0	Day	232.4	48.01	- 23.41	231.2/237.0
Orbit trim 3-PM ^c	June 8	159	12:02:00.6	23:19:02:24.6	24:18:32:00.6	358	3.1	49.8	Night	231.5	-14.95	171.08	227.8/240.6
Undocking	June 12	164	12:46:55.0	27:19:47:19.0	28:19:16:55.0	416	--	--	Dawn	227.0	42.30	-160.35	227.0/241.1
Separation	June 12	164	13:33:37.0	27:20:34:01.0	28:20:03:37.0	417	5.0	11.5	Dusk	237.6	-46.06	74.19	224.5/240.4
Shaping (SPS-1)	June 12	164	14:01:22.4	27:21:01:46.4	28:20:31:22.4	417	264.1	11.0	Night	227.9	9.02	137.05	90.4/229.6
Deorbit (SPS-2)	June 12	164	17:03:01.0	28:00:03:25.0	28:23:33:01.0	419	193.8	7.8	Night	226.8	11.71	93.19	-12.7/229.6
Landing	June 12	164	17:44:07.0	28:00:44:31.0	29:00:14:07.0	419	--	--	Day	--	26.78	-130.09	--

LB-3

^a Time base convention - G. m. t. with days beginning 0^h0^m0^s January 1 (day 120 is April 30)

^b Above a spherical earth of radius 3443.93-n. mi. radius.

^c RCS.

^d Theoretical cost, actual cost for line-of-sight control, stationkeeping, flyaround, and docking is an additional 26 fps.

PM = Posigrade Maneuver at Orbital Midnight

RN = Retrograde Maneuver at Orbital Noon

SKYLAB I-II

EVENT	DATE	TIME (H:MIN:S) C.D.T.	TIME (H:MIN:S) G.E.T.
SL-1 LIFT OFF	MAY 14, 1973	12:30: 0.	+23:29:36.
SL-1 INSERTION	MAY 14, 1973	12:39:47.8	+23:19:48.
DAY 1 ACTIVITIES			
LIFTOFF -P02 TO P11	MAY 15, 1973	11:59:36.	0: 0: 0.
ENABLE TOWER CLEARANCE YAW MANEUVER	MAY 15, 1973	11:59:37.	0: 0: 1.
INITIATE PITCH AND ROLL PROGRAM	MAY 15, 1973	11:59:46.	0: 0:10.
MAXIMUM DYNAMIC PRESSURE	MAY 15, 1973	12: 0:50.	0: 1:14.
INITIATE ATTITUDE ARREST	MAY 15, 1973	12: 1:46.	0: 2:11.
INITIATE TB2	MAY 15, 1973	12: 1:51.	0: 2:15.
S-1B INBOARD ENGINE CUTOFF	MAY 15, 1973	12: 1:54.	0: 2:18.
S-1B OUTBOARD ENGINE CUTOFF/INITIATE TB6	MAY 15, 1973	12: 1:57.	0: 2:21.
PHYSICAL S-1B/S-1VB SEPARATION	MAY 15, 1973	12: 1:58.	0: 2:22.
S-1VB IGNITION SIGNAL	MAY 15, 1973	12: 1:59.	0: 2:23.
S-1VB 90 ° THRUST	MAY 15, 1973	12: 2: 3.	0: 2:27.
ULLAGE ROCKET CASER JETTISON	MAY 15, 1973	12: 2:10.	0: 2:34.
LAUNCH ESCAPE SYSTEM JETTISON	MAY 15, 1973	12: 2:22.	0: 2:46.
STOP ATTITUDE ARREST/INITIATE GUIDANCE	MAY 15, 1973	12: 2:27.	0: 2:51.
MIXTURE RATIO SHIFT SIGNAL	MAY 15, 1973	12: 7:23.	0: 7:47.
S-1VB GUIDANCE CUTOFF SIGNAL	MAY 15, 1973	12: 9:16.	0: 9:40.
INITIATE TB4	MAY 15, 1973	12: 9:16.	0: 9:40.
ORBITAL INSERTION (LB-16)	MAY 15, 1973	12: 9:26.	0: 9:50.
CSM S-1VP SEPARATION (LB-16)	MAY 15, 1973	12:15:36.	0:16: 0.
P52 IMU REALIGN (OPT 3: LAUNCH REFSMMAT)	MAY 15, 1973	12:29:36.	0:30: 0.
P52 IMU REALIGN (OPT 2: RENDEZ. ORIENT)	MAY 15, 1973	12:39:36.	0:40: 0.
CBAS LOS CALIBRATION (STAR 45,F0MALHAUT)	MAY 15, 1973	12:54:36.	0:55: 0.
P31 NC1 TARGETING COMPLETE	MAY 15, 1973	13: 3:36.	1: 4: 0.
P20 OPTION 5 (TRACK EARTH)	MAY 15, 1973	13: 7:36.	1: 8: 0.
NC1 PRELIMINARY PAD (LB-43)	MAY 15, 1973	13:31:36.	1:32: 0.
STAR ACQUISITION PAD	MAY 15, 1973	13:31:37.	1:32: 1.
GYRO TORQUE ANGLES REPORT (LB-30)	MAY 15, 1973	13:31:38.	1:32: 2.
NC1 FINAL PAD (LB-43)	MAY 15, 1973	13:49:36.	1:50: 0.
ENTER PAD-SPS THRUST	MAY 15, 1973	14:15:36.	2:16: 0.
NC1 BURN IGNITION	MAY 15, 1973	14:19:48.	2:20:12.
P52 IMU REALIGN (OPT 3: REND. REFSMMAT)	MAY 15, 1973	14:24:36.	2:25: 0.

SKYLAB I-II

EVENT		DATE	TIME (H:MINS) C.D.T.	TIME (H:MINS) G.E.T.
DAY 1 ACTIVITIES CANTO				
NPC PAD (IF REQ'D)	(LB-48)	MAY 15, 1973	14:59:36.	3: 0: 0.
NC1 BURN STATUS REPORT	(LB-45)			
NC2 PRELIMINARY PAD	(LB-53)			
GYR0 TORQUE ANGLES REPORT	(LB-46)			
ENTER P40 OR P41	(LB-49)	MAY 15, 1973	15: 3: 5.	3: 3:29.
NPC BURN IGNITION		MAY 15, 1973	15: 5: 5.	3: 5:29.
NPC BURN STATUS REPORT	(LB-50)	MAY 15, 1973	15: 7:36.	3: 8: 0.
P52 IMU REALIGN (OPT 3: REND. REFMMAT)		MAY 15, 1973	15:34:36.	3:35: 0.
P32 NC2 TARGETING	(LB-53)	MAY 15, 1973	15:44:36.	3:45: 0.
NC2 FINAL PAD	(LB-53)	MAY 15, 1973	16: 9:36.	4:10: 0.
NCC PRELIMINARY PAD	(LB-57)			
NSR PRELIMINARY PAD	(LB-61)			
GYR0 TORQUE ANGLES REPORT	(LB-51)			
P32 NC2 TARGETING COMPLETE	(LB-53)	MAY 15, 1973	16:21:36.	4:22: 0.
ENTER P40 SPS THRUST	(LB-54)	MAY 15, 1973	16:29:36.	4:30: 0.
NC2 BURN IGNITION		MAY 15, 1973	16:35:39.	4:36: 3.
NC2 BURN STATUS REPORT	(LB-55)	MAY 15, 1973	16:37:36.	4:38: 0.
P33 NCC TARGETING	(LB-57)	MAY 15, 1973	16:41:36.	4:42: 0.
NCC FINAL PAD	(LB-57)	MAY 15, 1973	17: 7:36.	5: 8: 0.
NSR FINAL PAD	(LB-61)	MAY 15, 1973	17: 7:36.	5: 8: 0.
P33 NCC TARGETING COMPLETE		MAY 15, 1973	17: 9:36.	5:10: 0.
ENTER P40 SPS THRUST		MAY 15, 1973	17:13:36.	5:14: 0.
NCC IGNITION		MAY 15, 1973	17:21:48.	5:22:12.
P34 NSR TARGETING	(LB-61)	MAY 15, 1973	17:27:36.	5:28: 0.
NCC BURN STATUS REPORT	(LB-59)	MAY 15, 1973	17:41:36.	5:42: 0.
NSR TARGETING COMPLETE		MAY 15, 1973	17:47:36.	5:48: 0.
ENTER P40 SPS THRUST		MAY 15, 1973	17:53:36.	5:54: 0.
NSR BURN IGNITION		MAY 15, 1973	17:58:48.	5:59:12.
NSR BURN STATUS REPORT	(LB-63)	MAY 15, 1973	18: 2:36.	6: 3: 0.
MANEUVER TO ACQUIRE SWS		MAY 15, 1973	18: 5:36.	6: 6: 0.
TPI PRELIMINARY PAD	(LB-66)			
DOCKING ATTITUDE PAD		MAY 15, 1973	18: 9:36.	6:10: 0.

SKYLAB I-II

EVENT	DATE	TIME (H:MIN:SS) C.D.T.	TIME (H:MIN:SS) G.E.T.
DAY 1 ACTIVITIES CONTD			
FINAL TPI PAD (LB-66)	MAY 15, 1973	18:24:36.	6:25: 0.
P35 TPI TARGETING COMPLETE	MAY 15, 1973	18:36:36.	6:37: 0.
ENTER P40 SPS THRUST	MAY 15, 1973	18:44:36.	6:45: 0.
TPI BURN IGNITION	MAY 15, 1973	18:49:15.	6:49:39.
P36 TPM1 TARGETING (LB-70)	MAY 15, 1973	18:51:36.	6:52: 0.
ENTER P41 RCS THRUST	MAY 15, 1973	19: 0:36.	7: 1: 0.
TPM1 IGNITION	MAY 15, 1973	19: 2:36.	7: 3: 0.
P36 TPM2 TARGETING (LB-72)	MAY 15, 1973	19: 5:36.	7: 6: 0.
ENTER P41 RCS THRUST	MAY 15, 1973	19: 9:36.	7:10: 0.
TPM2 IGNITION	MAY 15, 1973	19:11:36.	7:12: 0.
P37 RENDEZVOUS FINAL PHASE (LB-75)	MAY 15, 1973	19:13:36.	7:14: 0.
P48 BRAKING (LB-76)	MAY 15, 1973	19:22:52.	7:23:16.
STATIONKEEPING, FLYAROUND	MAY 15, 1973	19:28:36.	7:29: 0.
8WS PICTURES & TV DACKING	MAY 15, 1973	19:39:36.	7:40: 0.
RECORD P50 START TIME	MAY 15, 1973	19:52:36.	7:53: 0.
P52 IMU REALIGN (RPT 3: STARS 25 ACRUX, 33 ANTARES, REND, REFSMMAT) (LB-77)	MAY 15, 1973	20: 7:36.	8: 8: 0.
P50 ATM ORIENTATION DETERMINATION (OPTION 1) (LB-78)	MAY 15, 1973	20:43:36.	8:44: 0.
DACKED ALIGN P52 TORQUE ANGLES REPORT, P50 NGUN 23 REPORT (LB-78)	MAY 15, 1973	20:52:36.	8:53: 0.
CREW 8 HOUR SLEEP PERIOD	MAY 15, 1973	21:59:36.	10: 0: 0.
BEGIN JVT 19 MULT. DACKING ADAPTER	MAY 16, 1973	7:29:36.	19:30: 0.
TRIM BURN PAD	MAY 16, 1973	8:42:36.	20:43: 0.
P52 IMU REALIGN (RPT 3: REND, REFSMMAT) (LB-79)	MAY 16, 1973	10: 7:36.	22: 8: 0.
ARRIT TRIM BURN (RCS, MANUAL)	MAY 16, 1973	10:22:60.	22:23:24.
REGRADE MIDNIGHT	MAY 16, 1973	10:41:36.	22:42: 0.
P50 ATM ORIENTATION DETERMINATION (RPT 2) SUN SENSOR & STAR TRACKER MARKS (LB-80)	MAY 16, 1973		

SKYLAB I-II

EVENT	DATE	TIME (H:MIN: S) C.D.T.	TIME (H:MIN: S) G.E.T.
DAY 1 ACTIVITIES CONTD			
P52 IMU REALIGN (BRT 3: REND* REFSMMAT)	MAY 16, 1973	10:53:36.	22:54: 0.
SUN SENSOR/STAR TRACKER MARKS (LB-81)			
P50 NAUN 23 REPORT (LB-80)	MAY 16, 1973	11: 3:36.	23: 4: 0.
GYRO TORQUE ANGLES REPORT (LB-81)	MAY 16, 1973	11: 3:36.	23: 4: 0.
ORBIT TRIM BURN (RCS MANUAL)	MAY 16, 1973	11: 9:35.	23: 9:59.
RETROGRADE NAUN			
POWER DOWN CSM GEN	MAY 16, 1973	11:13:36.	23:14: 0.
DAY 2 ACTIVITIES			
SPECIMEN MASS MEASUREMENT EXPERIMENT CAL	MAY 16, 1973	16:36:36.	28:37: 0.
DAY 3 ACTIVITIES			
BODY MASS MEASUREMENT EXPERIMENT CAL	MAY 17, 1973	13:30:36.	49:31: 0.
DAY 4 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 1 REV 58	MAY 18, 1973	12:50:36.	72:51: 0.
DAY 5 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 2 REV 72	MAY 19, 1973	12: 4:36.	96: 5: 0.
DAY 6 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 3 REV 87	MAY 20, 1973	12:54:36.	120:55: 0.
DAY 7 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 4 REV 114	MAY 22, 1973	9:36:36.	165:37: 0.
DAY 9 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 5 REV 132	MAY 23, 1973	15:37:36.	195:38: 0.
TV TOUR OF ORBITAL WORKSHOP (ONE HOUR)	MAY 24, 1973	9:15:36.	213:16: 0.

SKYLAB I & II

EVENT	DATE	TIME (H:MIN:S) C.D.T.	TIME (H:MIN:S) G.E.T.
DAY 10 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 6 REV 157	MAY 25, 1973	9:24:36.	237:25: 0.
DAY 11 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 7 REV 171	MAY 26, 1973	8:40:36.	260:41: 0.
Z-LV ATTITUDE MNVR,EREP PASS # 8 REV 172	MAY 26, 1973	10:13:36.	262:14: 0.
DAY 14 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS # 9 REV 205	MAY 28, 1973	16:35:36.	316:36: 0.
ASTRONAUT MANEUVERING UNIT TEST RUN	MAY 29, 1973	8: 0:36.	332: 1: 0.
DAY 17 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS #10 REV 247	MAY 31, 1973	14:46:36.	386:47: 0.
DAY 18 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS #11 REV 261	JUNE 1, 1973	14: 2:36.	410: 3: 0.
DAY 19 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS #12 REV 275	JUNE 2, 1973	13: 7:36.	433: 8: 0.
DAY 20 ACTIVITIES			
Z-LV ATTITUDE MNVR,EREP PASS #13 REV 303	JUNE 4, 1973	11:53:36.	479:54: 0.
DAY 21 ACTIVITIES			
CSM G&N POWER UP	JUNE 5, 1973	7:59:36.	500: 0: 0.
E MEMORY DUMP	JUNE 5, 1973	8:14:36.	500:15: 0.
P51 IMU ORIENTATION DETERMINATION (LB-82)	JUNE 5, 1973	8:39:36.	500:40: 0.
P52 IMU REALIGN (SPT 1: ENTRY REFSMMAT) (LB-83)	JUNE 5, 1973	8:51:36.	500:52: 0.

SKYLAB I & II

EVENT	DATE	TIME (H:MIN: S) C.D.T.	TIME (H:MIN: S) G.E.T.
DAY 21 ACTIVITIES CONTD			
P50 ATM ORIENTATION DETERMINATION (BPT 2:) RECAL. OF ATM TO NB TRANSFORM (LB-84)	JUNE 5, 1973	9:31:36.	501:32: 0.
P30 EXT. DELTA V , SIMULATED PHASING	JUNE 5, 1973	9:43:36.	501:44: 0.
P40 SPS THRUST, SIMULATED PHASING	JUNE 5, 1973	9:47:36.	501:48: 0.
P52 IMU REALIGN (BPT 3: ENTRY REFSMMAT) (LB-85)	JUNE 5, 1973	10:49:36.	502:50: 0.
POWER DOWN CSM G&N	JUNE 5, 1973	10:59:36.	503: 0: 0.
DAY 22 ACTIVITIES			
DEORBIT/ENTRY SIM (POWER OFF DRY RUN)	JUNE 6, 1973	9:14:36.	525:15: 0.
DAY 23 ACTIVITIES			
TV PRESS CONFERENCE (ONE HALF HOUR)	JUNE 7, 1973	11:24:36.	551:25: 0.
DAY 25 ACTIVITIES			
Z-LV ATTITUDE MNVR, EREP PASS #14 REV 361	JUNE 8, 1973	12:10:36.	576:11: 0.
DAY 26 ACTIVITIES			
EXTRAVEHICULAR ACTIVITY (CDR & SPT)	JUNE 9, 1973	11:59:36.	600: 0: 0.
DAY 28 ACTIVITIES			
CSM G&N POWER UP	JUNE 12, 1973	0:59:36.	661: 0: 0.
E MEMORY DUMP	JUNE 12, 1973	1:19:36.	661:20: 0.
TRANSFER POWER FROM SWS TO DESCENT BATTERIES	JUNE 12, 1973	1:44:36.	661:45: 0.
P51 IMU ORIENTATION DETERMINATION SUN SENSOR ; STAR TRACKER MARKS (LB-86)	JUNE 12, 1973	2:21:36.	662:22: 0.
P52 IMU REALIGN (BPT 1: ENTRY REFSMMAT)	JUNE 12, 1973	2:39:36.	662:40: 0.

SKYLAB I-II

EVENT		DATE	TIME (H:MIN:SS) C.D.T.	TIME (H:MIN:SS) G.E.T.
DAY 28 ACTIVITIES CONTD				
CSM-SWS SEPARATION PAD	(LB-92)	JUNE 12, 1973	5:59:36.	666: 0: 0.
SPS1 SHAPING PAD	(LB-95)			
SPS2 DEBRIT PAD	(LB-100)			
ENTRY PAD	(LB-90)	JUNE 12, 1973	5:59:36.	666: 0: 0.
P52 IMU REALIGN (APT 3: ENTRY REFSMMAT)	(LB-89)	JUNE 12, 1973	7: 4:36.	667: 5: 0.
CSM-SWS UNDOCKING	(LB-91)	JUNE 12, 1973	7:46:55.	667:47:19.
FLYAROUND SWS:PHOTO'S & TV		JUNE 12, 1973	7:46:56.	667:47:20.
ENTER P41 RCS THRUST	(LB-93)	JUNE 12, 1973	8:25:36.	668:26: 0.
CSM-SWS SEPARATION	(LB-94)	JUNE 12, 1973	8:33:38.	668:34: 2.
ENTER P40 SPS THRUST	(LB-96)	JUNE 12, 1973	8:45:36.	668:46: 0.
SPS1 SHAPING BURN IGNITION	(LB-97)	JUNE 12, 1973	9: 1:22.	669: 1:46.
P52 IMU REALIGN (APT 3: ENTRY REFSMMAT)	(LB-98)	JUNE 12, 1973	10:10:36.	670:11: 0.
GYRO TORQUE ANGLES REPORT	(LB-98)	JUNE 12, 1973	10:59:36.	671: 0: 0.
SPS2 PAD UPDATE	(LB-100)	JUNE 12, 1973	11: 0:36.	671: 1: 0.
ENTRY PAD UPDATE	(LB-99)			
ENTER P40 SPS THRUST.	(LB-101)	JUNE 12, 1973	11:52:36.	671:53: 0.
DAY 29 ACTIVITIES				
SPS2 DEBRIT BURN IGNITION	(LB-102)	JUNE 12, 1973	12: 3: 1.	672: 3:25.
P62 ENTRY-CSM/SW SEPARATION & PRE-ENTRY MANEUVER		JUNE 12, 1973	12: 7:36.	672: 8: 0.
CSM-SW SEPARATION		JUNE 12, 1973	12:12:36.	672:13: 0.
ENTRY INTERFACE		JUNE 12, 1973	12:28:16.	672:28:40.
SPLASHDOWN PACIFIC OCEAN		JUNE 12, 1973	12:44: 7.	672:44:31.

GYRO COMPASSING

The purpose of gyro compassing is to provide for a Launch alignment so that the crew can monitor the boost phase performance, a back up control for orbit insertion, and an inertial reference frame for incorporating the velocity gained during boost and thus maintaining the state vector.

The earth pre-launch alignment orientation is a local vertical alignment pointing along a launch azimuth. For Skylab missions, this corresponds to approximately 45° east of north for the 50° inclined orbit of the Skylab workshop (SWS).

In vector notation

$$\begin{aligned}\underline{U}_{zsm} &= \text{unit } (-r) \\ \underline{U}_{xsm} &= \text{unit } (A)\end{aligned}$$

$$\underline{U}_{ysm} = \underline{U}_{zsm} \times \underline{U}_{xsm}$$

$$\underline{U}_{xsm} = \text{Stable x axis}$$

$$\underline{U}_{zsm} = \text{stable member z axis}$$

A is a horizontal vector at the desired launch azimuth angle.

U_{ysm} completes the set.

The alignment by the computer is a two step process. The first step is to level the platform for a specific time of 320 seconds after a coarse aligning to the initial computed alignment direction.

After the leveling and a settling period is accomplished, the computer automatically switches to the gyro compassing mode where gyro's are torqued both for level and azimuth.

The basic loop diagram's for vertical erection and azimuth alignment are shown in Figures A & B.

Both loops are similar. During the vertical erection period, no attempt to align the platform in a specific azimuth is made.

The three accelerometer outputs are processed by the IMU compensation program every .5 seconds, compensated for bias and scale factor error and used to compute the gyro compensation for ADIA and ADSRA drifts which are then added to the normal bias drift (NBD).

After rotation by the xsm matrix to the local vertical and azimuth direction system, the x and y accelerometer outputs are filtered and used as an indication of the amount of "off-level" of the inertial platform.

Proportional control is then applied for the theoretical east and vertical gyros. The theoretical south gyro uses proportional plus integral control.

After rotation by the xsm matrix again, the outputs are ready to be applied to the actual gyros. Earth rate compensation for 5 seconds at the local latitude is added and the actual gyros torqued at the end of the 5 second cycle.

The gyro compensation routine inserts a "dead zone" of two to three gyro pulses before torquing the gyros.

In the process of torquing the gyros, the routine rounds off to the nearest integral pulse and saves the fractional remainder for the next sampling time.

In addition, to maintain the same magnetic condition of the gyros, an additional two pulses positive and two pulses negative are performed after every command.

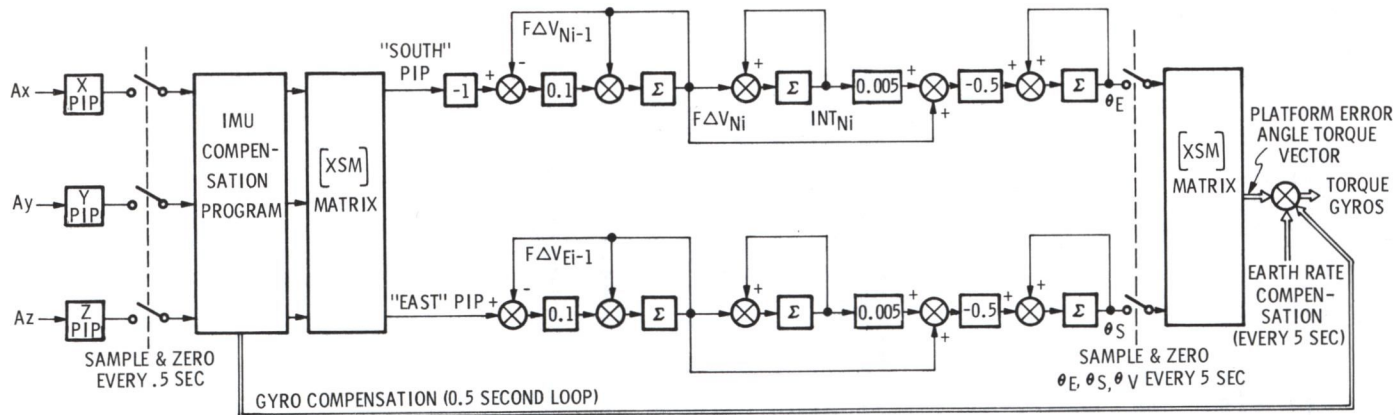


FIGURE A VERTICAL ERECTION LOOP FOR PRE-LAUNCH ALIGNMENT

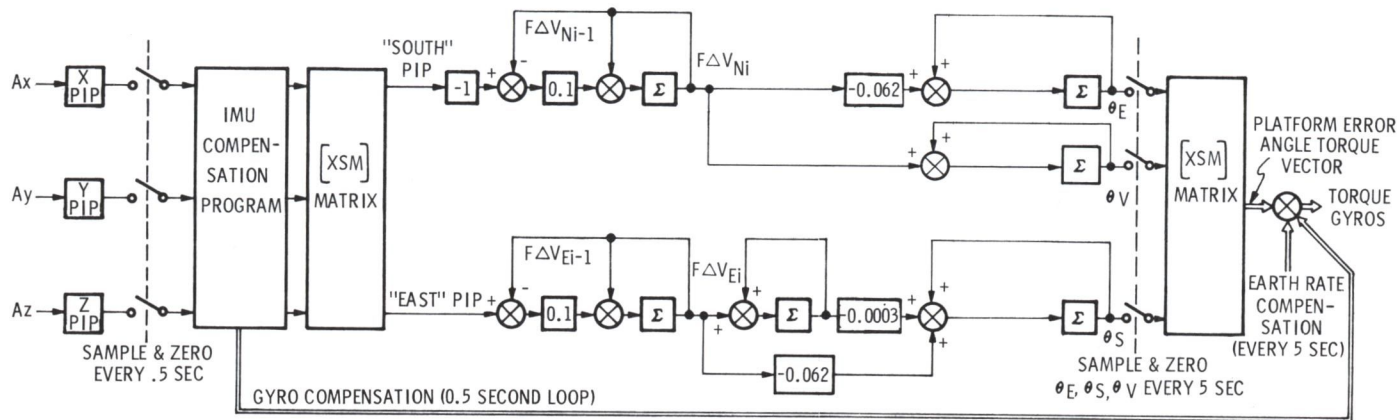


FIGURE B. AZIMUTH ALIGNMENT LOOP FOR PRE-LAUNCH ALIGNMENT

LAUNCH AZIMUTH CHANGE

V78E Optional entry if Launch azimuth change is desired.

Flashing xsm Launch Azimuth
V06N29

XXX. XX deg.

V21E Load new Launch Azimuth

--	--	--	--	--	--

deg

PRO

Copy GMT of Launch Azimuth
entry

_____ . hr
 _____ . min
 _____ . sec
 _____ date

Wait 320 seconds for vertical erect,
then gyrocompass.

V78E Optional entry if Launch azimuth change is desired.

Flashing xsm Launch Azimuth
V06N29

XXX. XX deg.

V21E Load new Launch Azimuth

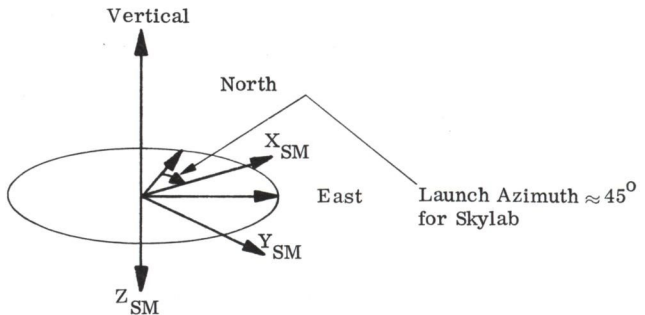
deg

PRO

Copy GMT of Launch Azimuth
entry

_____ . hr
 _____ . min
 _____ . sec
 _____ date

Wait 320 seconds for vertical erect,
then gyrocompass.



BOOST MONITOR

Liftoff GMT _____ .hrs
 _____ .min
 _____ .sec
 _____ (date)

SATURN BOOST

TYPICAL TRAJ SKYLAB

DET	Θ	VI	H	H
0+30	83	1420	370	0.8
1+00	67	1927	966	4.0
1+30	48	3095	1700	10.5
2+00	32	5288	2549	21.0
2+30	26	7454	2899	35.3
3+00	33	7851	2382	48.3
3+30	31	8349	1983	59.1
4+00	29	8947	1610	67.9
4+30	26	9641	1265	75.0
5+00	24	10432	950	80.5
5+30	21	11323	664	84.4
6+00	18	12324	411	87.1
6+30	14	13449	194	88.6
7+00	11	14710	19	89.1
7+30	7	16133	-109	88.8
8+00	3	17669	-200	88.1
8+30	0	19236	-277	86.9
9+00	356	21028	-283	85.5
9+30	352	23101	-204	84.2
10+00	349	25553	-20	83.6
10+01	349	25682	-4	83.6

BOOST POLYNOMIALS (154.6 sec)

$$\Delta \text{ Pitch Angle (S/C)} = -.14318735 - .441615526 - .00749417016^2 + .00022391274t^3 \\ - .00000217666786^4 + 7.5715679 \times 10^{-9}t^5 - 5.9732834 \times 10^{-12}t^6$$

Where t = Δ time from deduced time of liftoff when the roll and pitch computed attitude errors should start. (Nominally 10.6 sec after liftoff). The stop time is nominally 154.6 sec after liftoff. The attitude errors are biased by the actual vehicle angle if Saturn takeover is accomplished.

$$RA = \text{Roll angle} = \text{Saturn Roll Rate} \cdot t - 180^\circ + \text{Launch Azimuth} - (-90^\circ)$$

*Loaded in Prelaunch Erasable as SATRLRT ($1^\circ/\text{sec}$) and AZIMUTH (-90°)

PA = Pitch Angle

$$\begin{bmatrix} \underline{X}_{DC} \\ \underline{Y}_{DC} \\ \underline{Z}_{DC} \end{bmatrix} = \begin{bmatrix} \sin PA & 0 & -\cos PA \\ -\sin RA \cos PA & -\cos RA & -\sin RA \sin PA \\ -\cos RA \cos PA & -\sin RA & -\cos RA \sin PA \end{bmatrix}$$

\underline{X}_{DC} = desired X S/C vector

\underline{Y}_{DC} = desired Y S/C vector

\underline{Z}_{DC} = desired Z S/C vector

INSERTION MONITOR

GET _____ .hrs
 _____ .min
 _____ .sec

N62

VI Inertial Velocity _____ .ft/s
 H Attitude rate _____ .ft/s
 H Altitude _____ nmi

N44

ha Altitude of Apogee _____ nmi
 hp Altitude of Perigee _____ nmi
 TFF Time from
 Free Fall
 (300,000 ft) _____ min-sec

CSM/LV SEPARATION

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	X	X	X							
X	X	X				Y		X	X	X							
X	X	X				BT		X	X	X							
						VI	(ft/s)										
						X	ΔV ft/s	N83									
						Y											
						Z											
						V	ft/s	N62									
						HDOT	ft/s										
						H	nmi										

NOTES:

BASIC REFERENCE COORDINATES AND REFSMMAT

The Basic Reference Coordinate system (BRC) is an orthogonal inertial coordinate system whose origin is located at the earth center of mass (Figure 1). The orientation of this coordinate system is defined by the line of intersection of the mean earth equatorial plane and the mean ecliptic at the beginning of the Besselain year which starts January .9233573, 1950, E. T. The X axis (\underline{u}_{XI}) is defined by the intersection of the earth's equatorial plane and the ecliptic in the direction of the ascending node. The Z axis (\underline{u}_{ZI}) is along the mean earth north pole, and Y axis (\underline{u}_{YI}) completes the right-handed triad.

REFSMMAT. The matrix used to transform the elements of a vector given in BRC space to IMU space is known as REFSMMAT.

Three REFSMMAT's or IMU alignments are utilized during this mission. Each is a unique matrix which locates a stable member axis (\underline{u}_{XSM} , \underline{u}_{YSM} , or \underline{u}_{ZSM}) in BRC space (Figure 2).

IMU REALIGNMENT. Any desired IMU orientation with respect to the BRC system and its associated REFSMMAT can be obtained from star sightings (Program P52) or star/solar tracking.

The procedure generally used to change the alignment of the IMU from one of the three primary attitudes to another is as follows:

- The astronaut executes Program P52, Option 3. This realigns the IMU to the present inertial attitude thereby eliminating the effects of gyro drift.
- The astronaut executes Program P52, Option 1. The REFSMMAT for Option 1 is generally uplinked prior to entering P52. When executed, the program computes and displays the IMU gimbal angles for the desired IMU attitude using the present vehicle attitude.

A total of three options are available to the crew when executing P52 (Figure 3). The basic difference between options is the manner in which REFSMMAT is obtained. The basic orthogonalization procedure used to compute REFSMMAT is shown in Figure 4. Navigation stars, the solar ephemeris and the vehicle state vectors are referenced to this system.

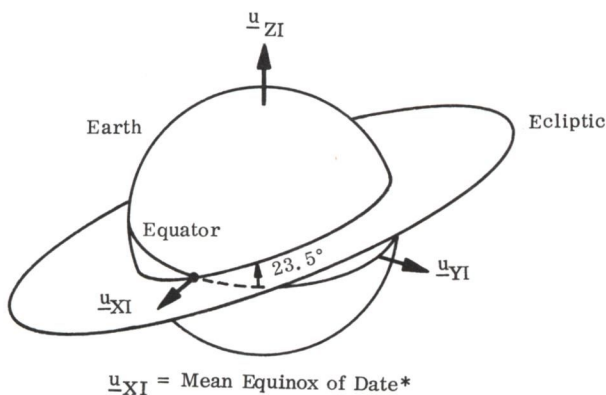


Figure 1. Basic Reference Coordinate System

LAUNCH PAD REFSMMAT

1. Launch
2. Insertion
3. Separation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{Spacecraft Platform Stable Members} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{ECI}$$

XIX = -0.76035378	XIY = 0.25293247	XIZ = 0.59823679
YIX = -0.26629318	YIY = 0.71869139	YIZ = -0.64231659
ZIX = -0.59241037	ZIY = -0.64769424	ZIZ = -0.47910554

RENDEZVOUS

1. NC1
2. NC2
3. NPC
4. NCC
5. NSR
6. TPI
7. TPM
8. TPF

XIX = 0.63632872	XIY = -0.36665178	XIZ = -0.67871364
YIX = -0.27147419	YIY = 0.71711006	YIZ = -0.64191505
ZIX = 0.72207168	ZIY = 0.59272221	ZIZ = 0.35678123

DEORBIT REFSMMAT

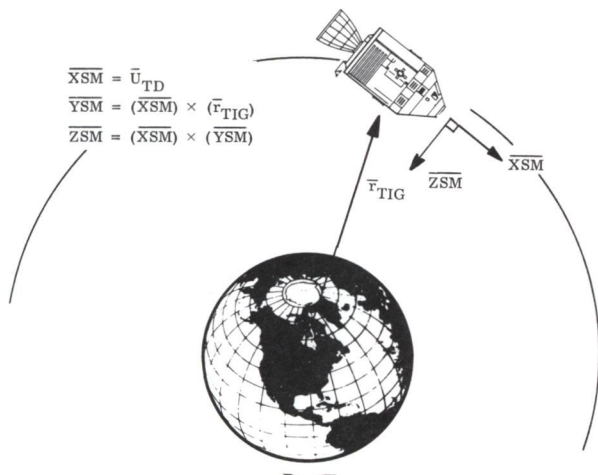
1. Shaping
2. Deorbit
3. Entry

XIX = 0.54516294	XIY = -0.34309210	XIZ = 0.76490859
YIX = 0.65889438	YIY = -0.38877073	YIZ = -0.64398409
ZIX = 0.51831993	ZIY = 0.85507024	ZIZ = 0.014118064

Figure 2. Mission REFSMMAT'S

OPTION: 00001 (PREFERRED)

DESCRIPTION: Preferred Thrusting Illustrated



The PREFERRED option refers to one of two possibilities:

- The PREFERRED thrusting orientation which is calculated and stored by P40 and P41.
- 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. The PREFERRED ATTITUDE flag is reset by P40 and P41 at TIG - 30 seconds.

CALCULATION OF ORIENTATION:

$$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} \bar{X}_{SM} \\ \bar{Y}_{SM} \\ \bar{Z}_{SM} \end{bmatrix} = \begin{bmatrix} \bar{U}_{TD} \\ \text{Unit } (\bar{U}_{TD} \times \bar{r}_{TIG}) \\ \text{Unit } (\bar{U}_{TD} \times (\bar{U}_{TD} \times \bar{r}_{TIG})) \end{bmatrix}$$

where

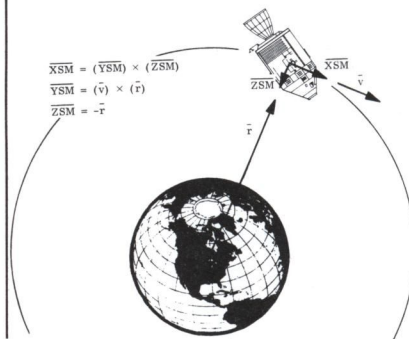
\bar{U}_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.

\bar{r}_{TIG} is the position vector of the vehicle at ignition expressed in the basic reference system.

Figure 3. (Sheet 1 of 2)

OPTION: 00002 (NOMINAL)

DESCRIPTION: LOCAL VERTICAL



The CMC requests the g, e, t, for which the vehicle \bar{r} and \bar{v} are to be selected to define the NOMINAL orientation.

CALCULATION OF ORIENTATION:

CSM

$$\begin{bmatrix} \text{Nominal} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} Y_{SM} \times Z_{SM} \\ \text{Unit} (\bar{v} \times \bar{r}) \\ \text{Unit} (-\bar{r}) \end{bmatrix}$$

where

$\left. \begin{array}{l} \bar{r} \\ \bar{v} \end{array} \right\}$ are position and velocity vectors of vehicle at the time specified.

OPTION: 00003 (REFSMMAT)

DESCRIPTION:

This option is used for gyro drift determination. This option realigns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.

$$\begin{bmatrix} \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{Orientation} \end{bmatrix}$$

Figure 3. (Sheet 2 of 2)

P50 ATM ORIENTATION DETERMINATION

Option 1 - ATM Vector Determination using ATM Sun Sensor

Assuming solar inertial mode (Z_{ATM} axis is pointing at the sun) the known sun vector in NB space is:

$$\underline{u}_{S1} = \underline{Z}_{ATM} = [AO]^T [AM]^T [AI]^T [REFSMMAT] \underline{u}_{ES}$$

AO, AM, AI are outer, middle, inner gimbal angles at mark time. \underline{u}_{ES} is sun unit vector in ECI space accessed from CMC star table.

The second known vector is the previously stored Y_{ATM} axis in NB space.

$$\underline{u}_{S2} = \underline{Y}_{ATM}$$

$$\underline{u}_{S1} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}_{NB} \quad \underline{u}_{S2} = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}_{NB}$$

Measured vectors \underline{u}_{S1M} and \underline{u}_{S2M} are the Z_{ATM} and Y_{ATM} axis vectors in ATM space.

$$\underline{u}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix}_{ATM} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \quad \underline{u}_{S2M} = \begin{bmatrix} X_{2M} \\ Y_{2M} \\ Z_{2M} \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

AXISGEN computations, below, generate a set of vectors describing ATM coordinate system axes in NB space using the known and measured celestial body vectors. Option 1 merely corrects the stored Y_{ATM} vector, in the Y, Z plane, to be perpendicular to the Z_{ATM} vector.

Option 2 - ATM Vector Determination Using ATM Sun Sensor and Star Tracker

Assuming solar inertial mode the known sun vector in NB space is:

$$\underline{u}_{S1} = \underline{Z}_{ATM} = [AO]^T [AM]^T [AI]^T [REFSMMAT] \underline{u}_{ES}$$

The second sighting is provided by the star tracker whose outer (ψ_3) and inner (ψ_1) gimbal angles (at mark time) and acquired star code are entered into the CMC.

$$\underline{u}_{S2} = [AO]^T [AM]^T [AI]^T [REFSMMAT] \underline{u}_{CB}$$

\underline{u}_{CB} is known celestial body unit vector in ECI space.

Measured vectors \underline{u}_{S1M} and \underline{u}_{S2M} are the Z_{ATM} axis and star tracker LOS in ATM coordinates, where the star tracker LOS is defined along the $-Y_{ATM}$ axis with zero outer and inner star tracker gimbal angles.

$$\underline{u}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix}_{ATM} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \quad \underline{u}_{S2M} = \begin{bmatrix} X_{2M} \\ Y_{2M} \\ Z_{2M} \end{bmatrix} = \begin{bmatrix} \cos \psi_1 \sin \psi_3 \\ -\cos \psi_1 \cos \psi_3 \\ -\sin \psi_1 \end{bmatrix}$$

AXISGEN computations below generate a set of vectors describing ATM coordinate system axes in NB space using the known and measured celestial body vectors.

AXISGEN - A celestial body coordinate system with coordinate axes in NB space and ATM space is generated. The celestial body space axis vectors comprise the transformation matrices from NB and ATM space to celestial body space.

$$\underline{S}_A = \begin{bmatrix} \underline{u}_{S1} \\ \underline{u}_{S1} \times \underline{u}_{S2} \\ \underline{u}_{S1} \times (\underline{u}_{S1} \times \underline{u}_{S2}) \end{bmatrix} \underline{NB},$$

$$\underline{S}_A = \begin{bmatrix} \underline{X}_{CB} \\ \underline{Y}_{CB} \\ \underline{Z}_{CB} \end{bmatrix} \underline{NB},$$

$$\underline{S}_A = [A] \underline{NB}$$

$$\underline{S}_A = \underline{S}_B$$

$$\underline{S}_B = \begin{bmatrix} \underline{u}_{S1M} \\ \underline{u}_{S1M} \times \underline{u}_{S2M} \\ \underline{u}_{S1M} \times (\underline{u}_{S1M} \times \underline{u}_{S2M}) \end{bmatrix} \underline{ATM}$$

$$\underline{S}_B = \begin{bmatrix} \underline{X}'_{CB} \\ \underline{Y}'_{CB} \\ \underline{Z}'_{CB} \end{bmatrix} \underline{ATM}$$

$$\underline{S}_B = [B] \underline{ATM}$$

NB and ATM are the same vector expressed in NB space and ATM space and the celestial body coordinate system are identical since they are comprised of the same celestial body vectors

$$[A] \underline{NB} = [B] \underline{ATM}$$

$$\underline{ATM} = [B]^{-1} [A] \underline{NB}$$

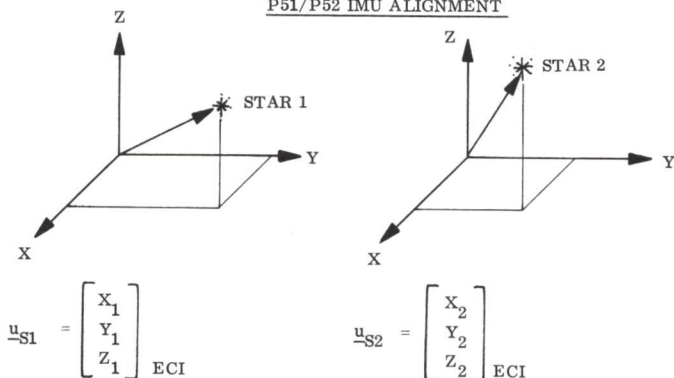
$$[NBATM] = [B]^{-1} [A]$$

$$[NBATM] = [\underline{X}'_{CB}, \underline{Y}'_{CB}, \underline{Z}'_{CB}]$$

$$\begin{bmatrix} \underline{X}_{CB} \\ \underline{Y}_{CB} \\ \underline{Z}_{CB} \end{bmatrix} = \begin{bmatrix} \underline{X}_{ATM} \\ \underline{Y}_{ATM} \\ \underline{Z}_{ATM} \end{bmatrix}$$

\underline{X}_{ATM} , \underline{Y}_{ATM} and \underline{Z}_{ATM} are the ATM coordinate system axes in NB space.

P51/P52 IMU ALIGNMENT



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

Optics Sighting Option

$$\underline{u}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix}_{SM}$$

$$\underline{u}_{S2M} = \begin{bmatrix} X_{2M} \\ Y_{2M} \\ Z_{2M} \end{bmatrix}_{SM}$$

$$\underline{u}_{SiM} = \begin{bmatrix} X_{iM} \\ Y_{iM} \\ Z_{iM} \end{bmatrix}_{i=1 \text{ or } 2} = [AI] [AM] [AO] [32^0] \begin{bmatrix} \cos AS \sin A_t \\ \sin AS \sin A_t \\ \cos A_t \end{bmatrix}$$

AI, AM, AO are inner, middle, and outer gimbal angles at i^{th} mark time. AS and A_t are SXT LOS shaft and trunnion angles at i^{th} mark time.

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

ATM Sun Sensor and Star Tracker Sighting Option

Assuming solar inertial mode with the Z_{ATM} axis pointing at the sun and the star tracker LOS pointing at a specified star the measured celestial body vectors in SM space are:

$$\underline{u}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix}_{SM} = [AI] [AM] [AO] \underline{Z}_{ATM}$$

$$\underline{u}_{S2M} = \begin{bmatrix} X_{2M} \\ Y_{2M} \\ Z_{2M} \end{bmatrix}_{SM} = [AI] [AM] [AO] [ATMNB] \begin{bmatrix} \cos \psi_1 \sin \psi_3 \\ -\cos \psi_1 \cos \psi_3 \\ -\sin \psi_1 \end{bmatrix}$$

$[ATMNB] = [NBATM]^T$ = ATM to NB coordinate transformation matrix computed in P50.

The ψ_1, ψ_3 vector is the star tracker LOS to target star vector in ATM coordinates, where ψ_1 and ψ_3 are tracker inner and outer gimbal angles at mark time. Known vectors \underline{u}_{S1} and \underline{u}_{S2} are the sun and star tracker target star unit vectors in reference system coordinates as stored in the CMC.

\underline{u}_{S1M} and \underline{u}_{S2M} are the measured unit vectors (sun sensor and star tracker mark) in stable member (SM) space of the sun and star.

AXISGEN - A celestial body coordinate system with coordinate axes in ECI space and SM space is generated. The celestial body space axis vectors comprise the transformation matrices from ECI and SM space to celestial body space.

$$\underline{S}_A = \begin{bmatrix} \underline{u}_{S1} \\ \underline{u}_{S1} \times \underline{u}_{S2} \\ \underline{u}_{S1} \times (\underline{u}_{S1} \times \underline{u}_{S2}) \end{bmatrix} \underline{ECI} \quad , \quad \underline{S}_B = \begin{bmatrix} \underline{u}_{S1M} \\ \underline{u}_{S1M} \times \underline{u}_{S2M} \\ \underline{u}_{S1M} \times (\underline{u}_{S1M} \times \underline{u}_{S2M}) \end{bmatrix} \underline{SM}$$

$$\underline{S}_A = [A] \underline{ECI}$$

$$\underline{S}_B = [B] \underline{SM}$$

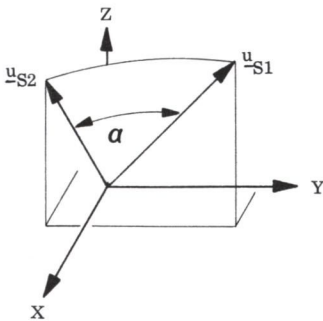
$$\underline{S}_A = \underline{S}_B$$

$$[A] \underline{ECI} = [B] \underline{SM}$$

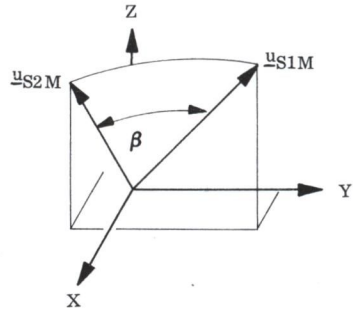
$$\underline{SM} = [B]^{-1} [A] \underline{ECI}$$

$$[REFSMMAT] = [B]^{-1} [A] = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} \underline{ECI}$$

X_{SM} Y_{SM} and Z_{SM} are the present stable member axes in reference coordinates.



$$\alpha = \cos^{-1} (\underline{u}_{S1} \cdot \underline{u}_{S2})$$



$$\beta = \cos^{-1} (\underline{u}_{S1M} \cdot \underline{u}_{S2M})$$

$$\text{Star Angle Difference} = \alpha - \beta$$

$$\text{Star Angle} = \beta$$

Figure 5. REFSMMAT Computations

DETERMINATION OF GYRO TORQUING ANGLES

The star sighting data obtained during P52 is used to calculate the gyro torquing angles required to align the stable member from its present orientation to the desired orientation as defined by the REF5MMAT presently stored in the computer.

Since the gyros in the IMU are always torqued in the sequence Y, Z, and X, the transformation from the present orientation to the desired orientation is defined by the permutation shown below:

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Desired}} = [\phi_X][\phi_Z][\phi_Y] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}}$$

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Desired}} = \begin{bmatrix} \cos\phi_Z \cos\phi_Y & \sin\phi_Z & -\cos\phi_Z \sin\phi_Y \\ (\sin\phi_X \sin\phi_Y - \cos\phi_X \sin\phi_Z \cos\phi_Y) & \cos\phi_X \cos\phi_Z & (\cos\phi_X \sin\phi_Z \sin\phi_Y + \sin\phi_X \cos\phi_Y) \\ (\sin\phi_X \sin\phi_Z \cos\phi_Y + \cos\phi_X \sin\phi_Y) & -\sin\phi_X \cos\phi_Z & (\cos\phi_X \cos\phi_Y - \sin\phi_X \sin\phi_Z \sin\phi_Y) \end{bmatrix} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}}$$

A transformation equivalent to the above transformation is obtainable from the star sighting data of the P52 program.

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Desired}} = [A]^{-1} [B] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}} = [C] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}} = \begin{bmatrix} C(1,1) & C(1,2) & C(1,3) \\ C(2,1) & C(2,2) & C(2,3) \\ C(3,1) & C(3,2) & C(3,3) \end{bmatrix} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}}$$

For P52

$$\underline{S}_A = [A] \underline{SM}_{\text{Desired}} \quad \underline{S}_B = [B] \underline{SM}_{\text{Present}}$$

$$[A] \underline{SM}_{\text{Desired}} = [B] \underline{SM}_{\text{Present}}$$

$$\underline{SM}_{\text{Desired}} = [A]^{-1} [B] \underline{SM}_{\text{Present}}$$

The gyro torquing angles can be computed from any convenient element for element assignment between the matrices [C] and $[\phi_X][\phi_Z][\phi_Y]$. Gyro torquing angles are computed using the relationship:

$$\phi_Y = \tan^{-1} \left(\frac{-C(1,3)}{C(1,1)} \right)$$

$$\phi_Z = \tan^{-1} \left(\frac{C(1,2) \cos\phi_Y}{C(1,1)} \right)$$

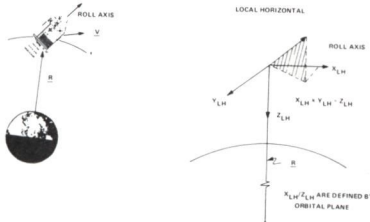
$$\phi_X = \tan^{-1} \left(\frac{-C(3,2)}{C(2,2)} \right)$$

SKYLAB SC-2 MISSION
REFSMMAT SUMMARY

APPLICABLE MANEUVER	REFSMMAT	ALIGNMENT CRITERIA (IMU AXIS)	REMARKS
Launch, Insertion, Separation	Launch Pad	X-axis along flight azimuth at Launch Z-axis along negative radius vector Y-axis completes the right-hand triad	At earth-launch the FDAI will display: Roll = 90° + flight azimuth Pitch = 90, Yaw = 0
NC1 TPI NC2 TPM NPC TPF NCC NSR	Rendezvous (Nominal)	Z-axis is aligned along the negative position vector defined at TPI igni- tion time. Y-axis is aligned along the negative momentum vector of the vehicle de- fined at TPI ignition time. X-axis completes the orthogonal sys- tem.	At TIG of TPI the FDAI will display Roll = 0° Pitch = E = elevation angle at TPI Yaw = 0°
Deorbit Entry	Deorbit (preferred)	X-axis aligned with the spacecraft X-body axis at the vehicle attitude for ignition with the thrust directed through the center of gravity. Z-axis in the plane formed by the X-axis and the position vector. Positive direction away from earth is a heads-down attitude. Positive direction towards earth for a heads- up attitude Y-axis completes the system.	During the two deorbit burns the FDAI will dis- play Roll = 0° Pitch = 180° Yaw = 0°

DETERMINATION OF S/C ROLL AXIS WITH RESPECT TO A LOCAL HORIZONTAL COORDINATE SYSTEM

The procedure outlined below provides a method for determining the direction cosines of the CSM roll axis with respect to the local horizontal coordinate system. This procedure requires knowing the IMU gimbal angles, the REFSMMAT to which the stable member is aligned, and the state vector (expressed in reference coordinates) of the CSM corresponding to the time of the gimbal angles.



The procedure is broken into two parts: the first defines the S/C axis with respect to the basic reference coordinate system; the second defines the S/C axis with respect to the local horizontal coordinate system.

The following transformations are used in the development of the procedure and are defined here for completeness.

[SMNB] - the transformation from the stable member to the navigation base of the G&N system. Since the navigation base axes are colinear with S/C axes for the CSM, this transformation also defines the transformation from the stable member to the S/C ([SMSC]).

$$\begin{bmatrix} X_{SC} \\ Y_{SC} \\ Z_{SC} \end{bmatrix} = [A_o]^{-1} [A_m]^{-1} [A_i]^{-1} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = [SMNB] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = [SMSC] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}$$

$$[SMSC] = \begin{bmatrix} \cos A_i \cos A_m & \sin A_m & -\sin A_i \cos A_m \\ (\sin A_i \sin A_o \cos A_i \sin A_m \cos A_o) & \cos A_m \cos A_o & (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o) \\ (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o) & -\cos A_m \sin A_o & (\cos A_i \cos A_o \sin A_i \sin A_m \sin A_o) \end{bmatrix}$$

where A_o , A_i , and A_m are the outer, inner, and middle gimbal angles as displayed on the DSKY.

[REFSMMAT] - the transformation from the basic reference coordinate system to the stable member. There are several different types of REFSMMAT and they are defined elsewhere in this section.

$$[REFSMMAT] = \begin{bmatrix} X_{IX} & X_{IY} & X_{IZ} \\ Y_{IX} & Y_{IY} & Y_{IZ} \\ Z_{IX} & Z_{IY} & Z_{IZ} \end{bmatrix}$$

[REFSC] - the transformation from the basic reference coordinate system to the S/C axes.

$$[REFSC] = [SMSC] [REFSMMAT] = \begin{bmatrix} X_{SC}/REF \\ Y_{SC}/REF \\ Z_{SC}/REF \end{bmatrix} = \begin{bmatrix} REFSC(1, 1) & REFSC(1, 2) & REFSC(1, 3) \\ REFSC(2, 1) & REFSC(2, 2) & REFSC(2, 3) \\ REFSC(3, 1) & REFSC(3, 2) & REFSC(3, 3) \end{bmatrix}$$

where X_{SC}/REF , Y_{SC}/REF , and Z_{SC}/REF define the X, Y, and Z axes of the CSM with respect to the basic reference coordinate system.

[LHREF] - the transformation from the local horizontal coordinate system to the basic reference coordinate system.

$$[LHREF] = [\text{unit}(\underline{V} \times \underline{R}) \times (-\underline{R})] \cdot \text{unit}(\underline{V} \times \underline{R}) \cdot \text{unit}(-\underline{R})$$

where \underline{R} and \underline{V} are the state vector of the CSM at the time of the gimbal angles.

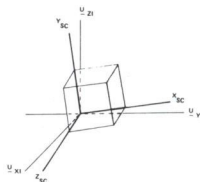
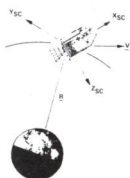
[LHSC] - the transformation from the local horizontal coordinate system to the CSM axes.

$$[LHSC] = [REFSC] [LHREF] = \begin{bmatrix} X_{SC}/LH \\ Y_{SC}/LH \\ Z_{SC}/LH \end{bmatrix}$$

where X_{SC}/LH , Y_{SC}/LH , and Z_{SC}/LH define the X, Y, and Z axes of the CSM with respect to the local horizontal coordinate system.

STEP 1. S/C AXES WRT BASIC REFERENCE COORDINATES

$$[\text{REFSC}] = [\text{SMSC}] [\text{REFSMMAT}]$$



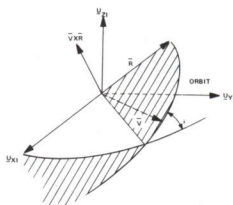
$$\left. \begin{aligned} \text{REFSC}(1, 1) &= \cos A_i \cos A_m X_{IX} + \sin A_m Y_{IX} - \sin A_i \cos A_m Z_{IX} \\ \text{REFSC}(1, 2) &= \cos A_i \cos A_m X_{IY} + \sin A_m Y_{IY} - \sin A_i \cos A_m Z_{IY} \\ \text{REFSC}(1, 3) &= \cos A_i \cos A_m X_{IZ} + \sin A_m Y_{IZ} - \sin A_i \cos A_m Z_{IZ} \end{aligned} \right\} = \underline{X}_{SC/REF}$$

$$\left. \begin{aligned} \text{REFSC}(2, 1) &= (\sin A_i \sin A_o - \cos A_i \sin A_m \cos A_o) X_{IX} + \cos A_m \cos A_o Y_{IX} + (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o) Z_{IX} \\ \text{REFSC}(2, 2) &= (\sin A_i \sin A_o - \cos A_i \sin A_m \cos A_o) X_{IY} + \cos A_m \cos A_o Y_{IY} + (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o) Z_{IY} \\ \text{REFSC}(2, 3) &= (\sin A_i \sin A_o - \cos A_i \sin A_m \cos A_o) X_{IZ} + \cos A_m \cos A_o Y_{IZ} + (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o) Z_{IZ} \end{aligned} \right\} = \underline{Y}_{SC/REF}$$

$$\left. \begin{aligned} \text{REFSC}(3, 1) &= (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o) X_{IX} - \cos A_m \sin A_o Y_{IX} + (\cos A_i \cos A_o - \sin A_i \sin A_m \sin A_o) Z_{IX} \\ \text{REFSC}(3, 2) &= (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o) X_{IY} - \cos A_m \sin A_o Y_{IY} + (\cos A_i \cos A_o - \sin A_i \sin A_m \sin A_o) Z_{IY} \\ \text{REFSC}(3, 3) &= (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o) X_{IZ} - \cos A_m \sin A_o Y_{IZ} + (\cos A_i \cos A_o - \sin A_i \sin A_m \sin A_o) Z_{IZ} \end{aligned} \right\} = \underline{Z}_{SC/REF}$$

STEP 2. S/C AXES WRT LOCAL HORIZONTAL COORDINATES

$$[\text{LHSC}] = [\text{REFSC}] [\text{LHREF}]$$



$$\left. \begin{aligned} \text{LHSC}(1, 1) &= \{ \text{REFSC}(1, 1), \text{REFSC}(1, 2), \text{REFSC}(1, 3) \} \circ \{ \text{unit} [(\underline{V} \times \underline{R}) \times (-\underline{R})] \} \\ \text{LHSC}(1, 2) &= \{ \text{REFSC}(1, 1), \text{REFSC}(1, 2), \text{REFSC}(1, 3) \} \circ \{ \text{unit} [\underline{V} \times \underline{R}] \} \\ \text{LHSC}(1, 3) &= \{ \text{REFSC}(1, 1), \text{REFSC}(1, 2), \text{REFSC}(1, 3) \} \circ \{ \text{unit} (-\underline{R}) \} \end{aligned} \right\} = \underline{X}_{SC/LH}$$

$$\left. \begin{aligned} \text{LHSC}(2, 1) &= \{ \text{REFSC}(2, 1), \text{REFSC}(2, 2), \text{REFSC}(2, 3) \} \circ \{ \text{unit} [(\underline{V} \times \underline{R}) \times (-\underline{R})] \} \\ \text{LHSC}(2, 2) &= \{ \text{REFSC}(2, 1), \text{REFSC}(2, 2), \text{REFSC}(2, 3) \} \circ \{ \text{unit} [\underline{V} \times \underline{R}] \} \\ \text{LHSC}(2, 3) &= \{ \text{REFSC}(2, 1), \text{REFSC}(2, 2), \text{REFSC}(2, 3) \} \circ \{ \text{unit} (-\underline{R}) \} \end{aligned} \right\} = \underline{Y}_{SC/LH}$$

$$\left. \begin{aligned} \text{LHSC}(3, 1) &= \{ \text{REFSC}(3, 1), \text{REFSC}(3, 2), \text{REFSC}(3, 3) \} \circ \{ \text{unit} [(\underline{V} \times \underline{R}) \times (-\underline{R})] \} \\ \text{LHSC}(3, 2) &= \{ \text{REFSC}(3, 1), \text{REFSC}(3, 2), \text{REFSC}(3, 3) \} \circ \{ \text{unit} [\underline{V} \times \underline{R}] \} \\ \text{LHSC}(3, 3) &= \{ \text{REFSC}(3, 1), \text{REFSC}(3, 2), \text{REFSC}(3, 3) \} \circ \{ \text{unit} (-\underline{R}) \} \end{aligned} \right\} = \underline{Z}_{SC/LH}$$

The \underline{X}_{SC} axis is the same as the roll axis and therefore the components of the roll axis of the S/C with respect to the local horizontal coordinate system are:

LHSC(1, 3) — component of \underline{X}_{SC} along \underline{R}

LHSC(1, 2) — component of \underline{X}_{SC} normal to orbital plane

LHSC(1, 1) — component of \underline{X}_{SC} normal to \underline{R} and in plane.

Data and Calculation Summary Sheet

A_O (X/Roll) . A_I (Y/Pitch) . A_m (Z/Yaw)

TIME _ _ _ : _ _ : _ _

[SMSC]

[REFSMMAT]

$$\mathbf{R}^*$$
 V^*

r_x	_____	v_x	_____
r_y	_____	v_y	_____
r_z	_____	v_z	_____

*The units of \underline{R} and \underline{V} are not important since they are used in unitized form.

[REFSC]

[L H R E F]

$$\text{Unit}[(\underline{V} \times \underline{R}) \times (-\underline{R})] = \text{Unit}(\underline{V} \times \underline{R}) \cdot \text{Unit}(-\underline{R})^{-1}$$

[LHSC]

$$\begin{aligned}\text{Roll} &= \tan^{-1} \left(\frac{-\text{LHSC}(3, 2)}{\text{LHSC}(2, 2)} \right) \\ \text{Yaw} &= \tan^{-1} \left(\frac{\text{LHSC}(1, 2) \cdot \cos \text{Roll}}{\text{LHSC}(2, 2)} \right) \\ \text{Pitch} &= \tan^{-1} \left(\frac{-\text{LHSC}(1, 3)}{\text{LHSC}(1, 1)} \right)\end{aligned}$$

LHSC (1, 1) = . _____ component of X_{SC} normal to $\underline{-R}$ and in plane
 LHSC (1, 2) = . _____ component of X_{SC} normal to orbital plane
 LHSC (1, 3) = . _____ component of X_{SC} along $\underline{-R}$

P52 - IMU REALIGN

(Post-Insertion REFSMMAT Realign)

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

V51 Flashing - Please Mark

x	0	0	0	0		P52 Option		x	0	0	0	0		
+	0	0				Hours	} GET of Gyro Torquing	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0			.		Seconds						.		
x	0	0				Sensor/Celestial Body Code 1		N71	x	0	0			
x	0	0				Sensor/Celestial Body Code 2		N71	x	0	0			
						Outer	} Star Tracker Gimbal Angles (arc-min)	N14						
						Inner								
				.		Star Angle Difference		N05				.		
				.		Star Angle Measured						.		
		.				X	} Gyro Torquing Angles (Degrees)	N93			.			
		.				Y					.			
		.				Z					.			
				.		X	} Calculated Gyro Drift (meru)					.		
				.		Y						.		
				.		Z						.		

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
 C = 1, Sun Sensor
 C = 2, Star Tracker

DE = 46, Sun
 DE = 04, Achernar
 DE = 14, Canopus
 DE = 25, Acrux

} Expected Codes for
 ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P52-IMU REALIGN
(Nominal)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000^x IMU Align Option

1-Preferred, 2 - Nominal,

3-REFSMMAT

V06N34 Flashing

V25E Load T(Align)

R1: 00 _____ Hours

R2: 000 _____ minutes

R3: 0 _____ seconds

V51 Flashing - Please Mark

x	0	0	0	0	0	P52 Option		x	0	0	0	0	0	0	
+	0	0				Hours Minutes Seconds	GET of Gyro Torquing	+	0	0					
+	0	0	0					+	0	0	0				
+	0			.									.		
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0					
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0					
						Outer	Star Tracker Gimbal	N14							
						Inner			Angles (arc-min)						
				.		Star Angle Difference	N05					.			
				.		Star Angle Measured						.			
		.				X	Gyro Torquing Angles (Degrees)	N93				.			
		.				Y							.		
		.				Z							.		
				.		X	Calculated Gyro Drift (meru)					.			
				.		Y						.			
				.		Z						.			

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Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P52-COAS LOS DETERMINATION

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1-Preferred, 2-Nominal

3-REFSMMAT

V22E Load Option 3

PRO

V50 N25 Flashing

R1 00015 Please Perform Star Acquisition

Enter

x	0	0	0	0	3	P52 Option	x	0	0	0	0	3
						PRO V50N25 Flashing Enter						
x	0	0	0			Celestial Body Code	N70	x	0	0	0	
						(45 - Fomalhaut) Mark with Verb Key						
						Shaft	N92					
						Trunnion						

Nominal: (+000.00) Shaft

(+57.470) Trunnion

RENDEZVOUS NAVIGATION PROGRAM (P20)

The Rendezvous Navigation Program, P20, is used during the Rendezvous phase of flight.

The navigation is performed using tracking of the orbital workshop by optical LOS of tracking with the SXT or COAS or the VHF ranging link.

The two processes are illustrated below.

RENDEZVOUS NAVIGATION VHF RANGING

The deviation state vectors for rendezvous navigation are

$$\underline{x}_c = \begin{bmatrix} \underline{\delta r} \\ \underline{\delta v} \end{bmatrix} \quad \underline{x}_w = \begin{bmatrix} \underline{\delta r} \\ \underline{\delta v} \end{bmatrix}$$

where

\underline{x}_c = deviation state of the CSM

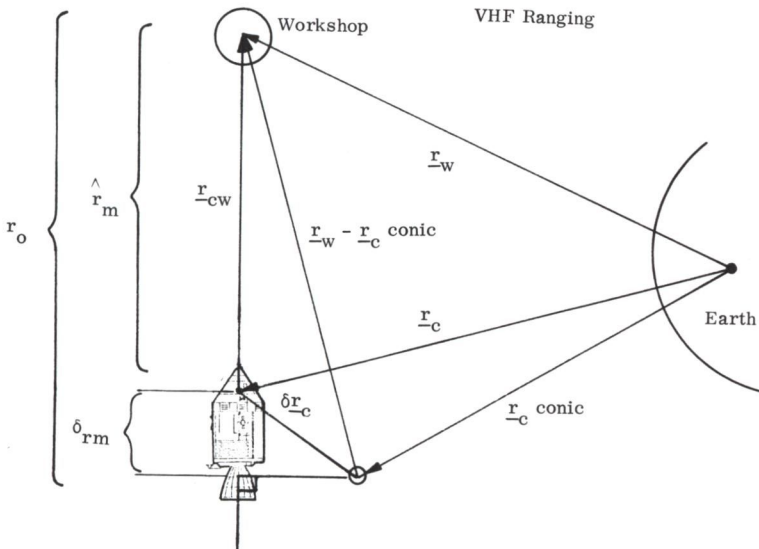
\underline{x}_w = deviation state of the Skylab workshop

$\underline{\delta r}$ = deviation from conic position

$\underline{\delta v}$ = deviation from the conic velocity

The Measurement Incorporation Routine is used to incorporate the rendezvous measurements.

The geometry vector \underline{b} is derived from the following figure.



RENDEZVOUS NAVIGATION PROGRAM
 (P20)

\hat{r}_m	=	$\underline{U}_{cw} \cdot \underline{r}_{cw}$	Estimated Range Measurement
\hat{r}_m	=	$\underline{U}_{cw} \cdot (\underline{r}_w - \underline{r}_c - \delta \underline{r}_c)$	$\hat{r}_m = r_o + \delta r_m$
\hat{r}_m	=	$\underline{U}_{cw} \cdot (\underline{r}_w - \underline{r}_c) - \underline{U}_{cw} \cdot (\delta \underline{r}_c)$	Where:
r_m	=	$r_o - \underline{U}_{cw} \cdot \delta \underline{r}_c$	r_o = Component of range due to position vectors known with zero uncertainty
$\hat{r}_m - r_o$	=	$\underline{U}_{cw} \cdot \delta \underline{r}_c$	δr_m = Kalman filter measurement variable where "-" is used for CSM state vector being updated and "+" for workshop = $\underline{b}^T \underline{x}$
δr_m	=	$-\underline{U}_{cw} \cdot \delta \underline{r}_c = [\underline{b}]^T \underline{x}$	
$\therefore \underline{b}$	=	$\begin{bmatrix} +\underline{U}_{cw} \\ 0 \end{bmatrix}$	

After computing the geometry vector \underline{b} , the measured deviation, δQ , and the measurement error variance α^2 are computed and used by the measurement incorporation routine to compute the changes in deviation state vector. The computations are:

$$\delta Q = r_m - |\underline{r}_{cw}|$$

$$\alpha^2 = \text{maximum value of } \left(\left\{ \text{Var}_R, \frac{\text{Var min}}{|\underline{r}_{cw}|^2} \right\} \right)^2$$

The values for Var_R and Var min are stored in erasable memory and are shown in the Science Section.

RENDEZVOUS NAVIGATION PROGRAM (P20)

RENDEZVOUS NAVIGATION OPTICS TRACKING

During rendezvous navigation, the inertial line of sight from the CSM to the orbital workshop is measured by recording optics shaft and trunnion angles, the IMU gimbal angles, and the time of the mark.

The optics angles are used to form a unit vector in Navigation Base coordinates.

$$\underline{U}_{NB} = [SB NB] \begin{bmatrix} \sin TA \sin SA \\ \sin TA \sin SA \\ \cos TA \end{bmatrix} \quad \begin{array}{l} \text{Where TA} = \text{trunnion angle} \\ \text{SA} = \text{shaft angle} \end{array}$$

[SB NB] = sextant base to Nav base transformation

$$= \begin{bmatrix} \cos \alpha & 0 & -\sin \alpha \\ 0 & 1 & 0 \\ \sin \alpha & 0 & \cos \alpha \end{bmatrix}$$

$$\alpha = -32^{\circ} 31' 23.19''$$

The navigation base unit vector is then transformed through stable member space to Basic Reference coordinates.

$$\underline{U}_n = [REFSMMAT]^T [NBSM] \underline{U}_{NB}$$

[REFSMMAT]^T = stable member to reference transformation

[NBSM] = Navigation base to stable member transformation using gimbal angles.

This navigation measurements of the line-of-sight vector is equivalent to the simultaneous measurement of the angles between lines of sight to the workshop and two stars. The computer uses two fictitious star directions to determine a geometry vector and the amount of the correction to the state vector. Depending on the particular state vector to be updated, a sign change on the b vector is required.

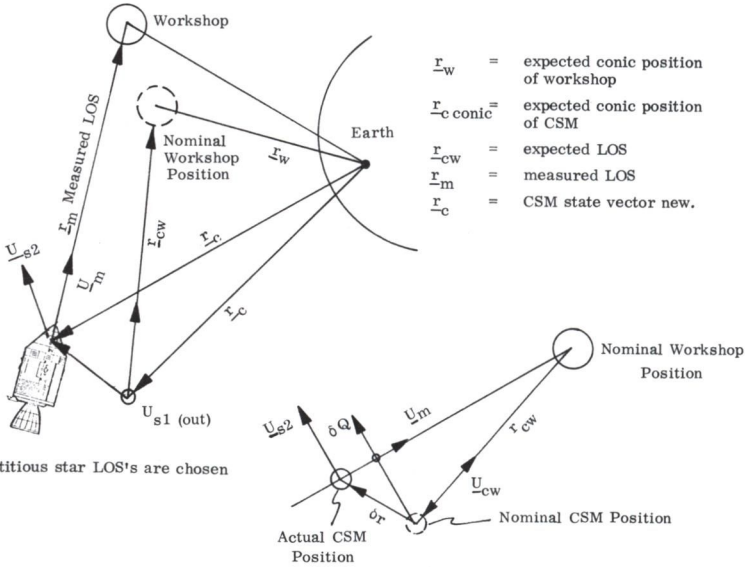
The dimension of the state vector is 6.

$$\underline{X} = \begin{bmatrix} \underline{\delta r} \\ \underline{\delta v} \end{bmatrix}$$

where \underline{X} = orbital navigation deviation state vector
 $\underline{\delta r}$ = deviation of spacecraft/workshop position from the reference conic position.
 $\underline{\delta v}$ = deviation of spacecraft/workshop velocity from the reference conic velocity

RENDEZVOUS NAVIGATION PROGRAM (P20)

The geometry vector \underline{b} is then computed from the following procedure.



The fictitious star LOS's are chosen

where

$$\begin{aligned} \underline{r}_{cw} &= \underline{r}_w - \underline{r}_c \\ \underline{U}_{cw} &= \text{Unit}(\underline{r}_{cw}) \\ \underline{U}_{s1} &= \text{Unit}(\underline{U}_{cw} + \underline{U}_m) \\ \underline{U}_{s2} &= \text{Unit}(\underline{U}_{s1} + \underline{U}_{cw}) \\ \delta Q &= \left| \underline{r}_{cw} \right| (\cos^{-1}(\underline{U}_{s2} \cdot \underline{U}_m) - \cos^{-1}(\underline{U}_{s2} \cdot \underline{U}_{cw})) \\ \delta Q &= \left| \underline{r}_{cw} \right| (\cos^{-1}(\underline{U}_{s2} \cdot \underline{U}_m) - \pi/2) \end{aligned}$$

Therefore the \underline{b} vector is $\pm \underline{U}_{s2}$

$$\therefore \underline{b} = \begin{bmatrix} \pm \underline{U}_{s2} \\ 0 \end{bmatrix}$$

where "+" is used for updating CSM state vector and "-" is used for updating orbital workshop state vector.

After computing the geometry vector \underline{b} , and the measured deviation, δQ , the measured error variance α^2 is computed and used by the measurement incorporation routine to compute the changes in deviation state vector. The computation is:

$$\alpha^2 = \left| \underline{r}_{cw} \right|^2 \left[\text{Var}_{\text{SXT}} + \text{Var}_{\text{IMU}} \right] + \text{Var}_{\text{INT}}$$

The values for Var_{SXT} , Var_{IMU} , and Var_{INT} are stored in erasable memory and are shown in the Science Section.

TARGETING CONSTRAINTS

The nature of the Skylab Rendezvous is dictated by constraints on the maneuvers, the maneuver times and the trajectory. NC1 and NC2 are constrained to be horizontal maneuvers and while targeting NC1 and NC2 the NCC maneuver is also constrained to be a horizontal maneuver. During the NCC program the NCC maneuver is limited by a fixed timed traverse between the two position vectors at NCC and NSR. The TPI maneuver is similarly limited.

The NSR maneuver is constrained to result in coelliptic orbits after the maneuver. Coelliptic orbits have an approximately constant radial distance between orbits.

Four of the maneuvers have time constraints. The TPI time and the time between NCC and NSR are specified. The times between NC1 and NC2 and between NC2 and NCC maneuvers are indirectly specified by specifying the number of revolutions (may be given by a fraction) involved in the transfers between the maneuvers. The time between the TPI and TPF maneuvers is also indirectly specified by specifying the central angle the workshop traverses between the TPI and TPI times.

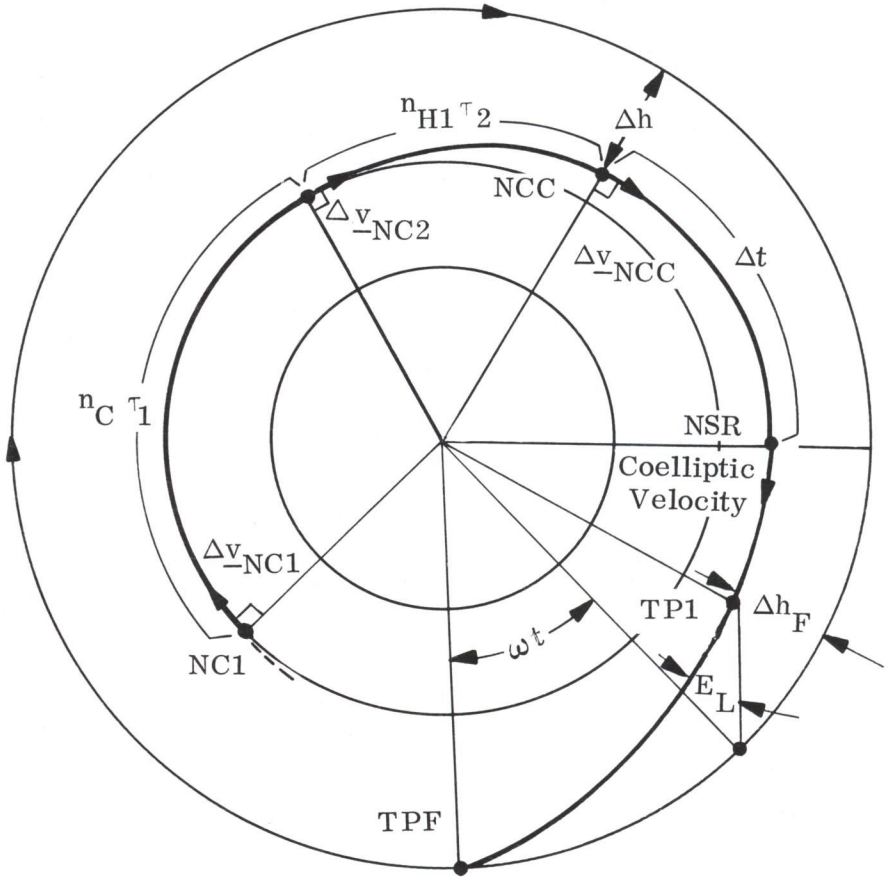
The rendezvous also has three trajectory constraints: two altitude and an elevation angle constraint.

The altitude differences between the OWS orbit and the CM are specified for the NCC and TPI times. Because the NCC altitude is specified only during the NC1 program, this constraint is not satisfied in the final trajectory if a navigation update occurs between NC1 and NC2.

The elevation angle specified is that angle (E) measured between the CM Local horizontal plane and the CM axis line of sight to the workshop at TPI time.

In addition to the three trajectory constraints, rendezvous also requires specification of the workshop central angle between TPI and TPF.

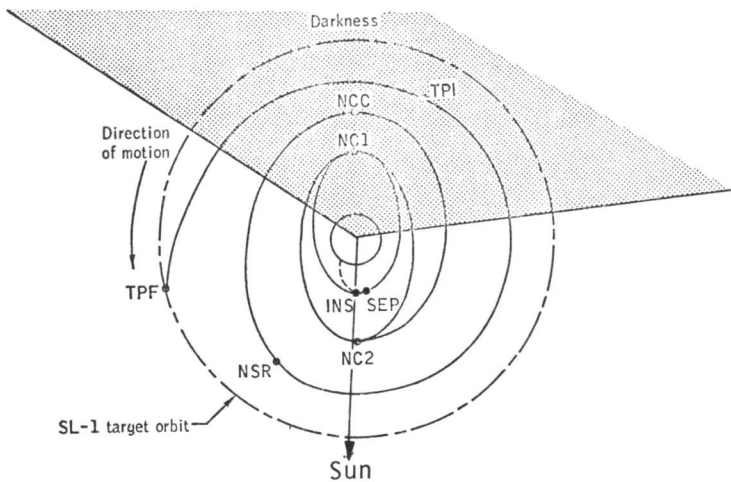
Orbit of WS Vehicle



- τ_1 = Period of post NC1 maneuver orbit
 τ_2 = Period of post NC2 maneuver orbit

Illustration of the Skylark Rendezvous Constraints

SL-1/SL-2 Rendezvous Orbital geometry.



		Time, g. e. t., hr:min:sec	ΔV , fps	Resultant Perigee/apogee, n. mi.	Attitude (Roll, Pitch,) yaw deg.
INS	Insertion	0:09:50		81/120	181 342, -1
SEP	Separation	0:16:00	3.0	81/122	180, 317, -1
NC1	Phasing 1	2:20:12	218.9	121/205	180, 339, 2
NPC	Plane change	Plane change, if necessary, occurs at node between NC1 and NC2.			
NC2	Phasing 2	4:36:03	160.6	204/213	180, 159, 1
NCC	Corrective combination	5:22:12	30.5	213/223	180, 340, 1
NSR	Coelliptic	5:59:12	19.1	222/224	180, 198, 2
TPI	Terminal phase initiation	6:49:39	20.6	224/234	-1, 25, +1
TPF	Terminal phase finalization	7:23:16	27.9	223/235	181, 174, 1

NC1 Targeting

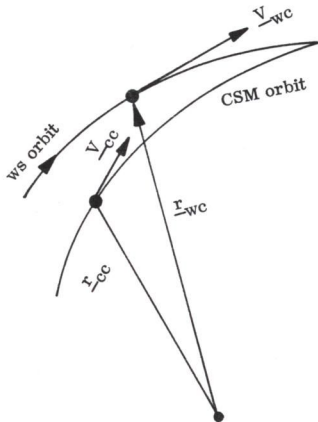
The NC1 Program (P31) computes the first phasing maneuver (NC1) parameters and the NC2, NCC, and NSR maneuver magnitudes for display.

The constraints are:

1. NC1, NC2, and NCC will be horizontal maneuvers.
2. The NC2 and NCC maneuvers will be considered height maneuvers.
3. The NC1 maneuver will be considered a phase maneuver.

The targeting starts with having the workshop and CM state vectors "phase matched" for the time of the NC1 maneuver. This procedure results in the same orbit central angle from NC1 to TPI for the workshop and the CM.

When the "phase match" is successfully completed, the CM state vector is rotated into the plane of the WS orbit.



$$\underline{Am} = \text{Unit}(\underline{r}_{wc} \times \underline{V}_{wc})$$

$$\underline{r}_{cc} = |\underline{V}_{cc}| \text{Unit} \left[\underline{r}_{cc} - \left(\underline{r}_{cc} \cdot \underline{Am} \right) \underline{Am} \right]$$

$$\underline{V}_{cc} = |\underline{V}_{cc}| \text{Unit} \left[\underline{V}_{cc} - \left(\underline{V}_{cc} \cdot \underline{Am} \right) \underline{Am} \right]$$

\underline{r}_{cc} = CSM position state vector updated to NC1 time using coasting integration

\underline{V}_{cc} = CSM velocity state vector updated to NC1 time using coasting integration.

\underline{r}_{wc} = Workshop position state vector updated to NC1 time using Kepler subroutine.

\underline{V}_{wc} = Workshop velocity state vector updated to NC1 time using Kepler subroutine.

The WS state vector is updated to the TPI time using Kepler subroutine obtaining \underline{r}_{WF} , \underline{v}_{WF} .

The desired CSM position vector \underline{r}_{CFD} at the TPI time is established using an iterative technique (QRO TPI routine) to determine the workshop position vector \underline{r}_{wJ} radially above \underline{r}_{CFD} .

Then

$$e_T = \pi/2 - E_L - \sin^{-1} [(r_J - \Delta h) \cos(E_L)/r] - \cos^{-1} [\text{Unit}(\underline{r}) \cdot \text{Unit}(\underline{r}_J)] \text{Sign} \\ [(\underline{r}_J \times \underline{r}) \cdot (\underline{r} \times \underline{v})]$$

where

e_T	=	Error in final transfer angle.
\underline{r}	=	Position state vector being updated.
\underline{v}	=	Velocity state vector being updated.
Δh	=	Delta altitude at final position
E_L	=	Elevation at final position
\underline{r}_J	=	Final position
\underline{v}_J	=	Final velocity
r_J	=	Magnitude of vector \underline{r}_J

When e_T is sufficiently small, the TPI geometry has been solved for the NC1 targeting and \underline{r} and \underline{v} are the desired \underline{r}_{wJ} and \underline{v}_{wJ} .

Then

$$\underline{r}_{CFD} = \underline{r}_{wJ} - \Delta h_F \text{Unit}(\underline{r}_{wJ})$$

$$\begin{aligned} \underline{r}_{CFD} &= \text{CM final desired position at TPI time} \\ \underline{r}_{wJ} &= \text{Workshop position at TPI time radially above CSM} \\ \Delta h_F &= \text{Delta height between CSM and Workshop at TPI time. (given)} \end{aligned}$$

$$\underline{v}_{CCF} = \underline{v}_{cc} + dVc \text{Unit}(\underline{A_m} \times \underline{r}_{cc})$$

$$\begin{aligned} \underline{v}_{CCF} &= \text{CSM final desired velocity at TPI time} \\ \underline{v}_{cc} &= \text{CSM velocity at NC1 time} \\ dVc &= \text{Added delta velocity at NC1 (given)} \end{aligned}$$

Using the same iterative technique values of state vector for the NC2 time and ΔV for NC2 are obtained. A repeat of the procedure yields their command module NCC maneuver which in turn yields the NSR state vector.

Upon advancing the workshop vector to be radially above the CSM at NSR the coelliptic velocity is computed in the following manner

$$a = \frac{1}{\frac{2}{|r|} - \frac{(\underline{v} \cdot \underline{v})}{\mu}} \quad \text{semi major axis (WS)}$$

$$a_D = a - h \quad \text{semi major axis of CSM}$$

$$V_v = \frac{\underline{v} \cdot \underline{r} \left(\frac{a}{a_D} \right)^{3/2}}{|\underline{r}|}$$

$$\underline{r}_c = \underline{r} - h \text{ Unit } (\underline{r})$$

$$\underline{v}_c = \sqrt{\mu \left[\frac{2}{|\underline{r}_c|} - \frac{1}{a_D} \right] - V_v^2} \text{ Unit } [(\underline{r} \times \underline{v}) \times \underline{r}] + V_v \frac{\underline{r}_c}{|\underline{r}_c|}$$

where \underline{r} = Workshop position vector

\underline{v} = Workshop velocity vector

h = Altitude between CSM and workshop.

μ = gravitational constant of earth

After updating the CSM state vector to the TPI time the altitude and phasing constraints are checked for being sufficiently small. If iteration failures occur the first or second height calculations of NC1 and NC2 are recomputed and repeated until the TPI geometry is satisfied.

Thus all the quantities necessary from NC1 to TPI have been satisfied by the NC1 targeting.

NC1 TARGETING

		NC1 PAD DATA											
		NGMINAL				PRELIMINARY				FINAL			
N95	HR	02											
TIG NC1	MIN	20											
	SEC	20.90											
N81	ΔV_X	219.0											
ΔV_{NC1}	ΔV_Y	0 0 0 0											
	ΔV_Z	0 0 0 0											
N22	R	180											
NC1	P	336											
	Y	002											
	ΔV_C	205.3											
	BT	0:10											

NC1 ONBOARD DATA

Verb 37 Enter, 31 Enter

V50N25 Flashing

R1: 00017 MINKEY Option

Enter Bypass MINKEY Option

V50N18 Flashing Request Maneuver to Roll, Pitch, Yaw Angles

Enter Reject Automatic Maneuver

+	0	0				Hours	} TIG of NC-1	N95	+	0	0			
+	0	0	0			Min			+	0	0	0		
+	0					Sec			+	0				
+	0	0	0	0		Half Revs (NC1/NC2)		N57	+	0	0	0	0	
						Δ Altitude (NCC) nmi								
						Δ Altitude (NSR) nmi								
+	0	0				Hours	} TIG of TPI	N37	+	0	0			
+	0	0	0			Min			+	0	0	0		
+	0					Sec			+	0				
		b				Marks		N45			b			
		b				Time From Ignition (min:sec)					b			
-	0	0	0	0	1	MGA			-	0	0	0	0	1
						ΔV (NC2) ft/s		N84						
						Δ Altitude (NC2) nmi								
						ΔV (NCC) ft/s								
						ΔV X } Local		N81						
						ΔV Y } Vertical								
						ΔV Z } ft/s								
		b				Marks		N45			b			
		b				Time From Ignition (min:sec)					b			
						MGA								

NOTES:

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 X N81 Comp Limits ± 0.5 FPS X
 X X X
 X CMC/MSFN Within Limits Go CMC X
 X No Agreement Go MSFN X
 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

P52-IMU REALIGN

(Post-NC1 REFSMMAT ALIGN)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT

V51 Flashing - Please Mark

x	0	0	0	0		P52 Option		x	0	0	0	0	
+	0	0				Hours	} GET of Gyro Torquing	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds					.		
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0			
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0			
						Outer	} Star Tracker Gimbal Angles (arc-min)	N14					
						Inner							
			.			Star Angle Difference	N05				.		
			.			Star Angle Measured					.		
		.				X	} Gyro Torquing Angles (Degrees)	N93			.		
		.				Y					.		
		.				Z					.		
		.				X	} Calculated Gyro Drift (meru)				.		
		.				Y					.		
		.				Z					.		

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 DE = 04, Achernar
 DE = 14, Canopus
 DE = 25, Acrux

} Expected Codes for
 ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

Normal Plane Change Targeting (NPC)

The plane change NPC targeting program computes the plane-change (PC) maneuver. The inputs are the state vectors of the CM and workshop at the time of the last maneuver. This last maneuver, made by the CM, is assumed to result in a nodal point after a 90-degree traverse from the maneuver position.

The targeting sequence:

1. The CM state vector \underline{r}_c , \underline{V}_c , is precision integrated to the time of the last maneuver.
2. The time of the nodal crossing is then computed by using the time-theta routine to update the CM state vector the rough 90 degrees.
3. The CM and WS state vectors are updated to the time of plane change, t_{pc} .
4. Compute the plane change parameters.

Normal Plane Change Targeting

$$\underline{U}_1 = \text{Unit} (\underline{V}_c \times \underline{r}_c) \sim$$

$$\underline{V}_c = \text{velocity vector CM at } t_{pc}$$

$$\underline{r}_c = \text{position vector CM at } t_{pc}$$

$$\underline{U}_2 = \text{Unit} (\underline{V}_w \times \underline{r}_w)$$

$$\underline{V}_w = \text{velocity vector WS at } t_{pc}$$

$$\underline{r}_w = \text{position vector WS at } t_{pc}$$

$$y_c = \underline{r}_c \cdot \underline{U}_2$$

$$\dot{y}_c = \underline{V}_c \cdot \underline{U}_2$$

$$y_w = \underline{V}_w \cdot \underline{U}_2$$

$$y_c = \text{out-of-plane position}$$

$$\dot{y}_c = \text{CM out-of-plane velocity}$$

$$\dot{y}_w = \text{i.e. WS out-of-plane velocity}$$

Normal Plane Change Targeting

$$\underline{\Delta V}_{LV} = (0, -\dot{y}_c, 0)$$

Define local vertical coordinate system axes in reference coordinates.

$$\underline{Z} = -\text{Unit } \underline{r}_c = \text{Unit } (-\underline{r}_c)$$

$$\underline{Y} = \underline{U}_1 = \text{Unit} (\underline{V}_c \times \underline{r}_c)$$

$$\underline{X} = \underline{Y} \times \underline{Z}$$

Compute $\underline{\Delta V}$ the CM out-of-plane velocity vector in reference coordinates

$$\underline{\Delta V}_{ECI} = \begin{bmatrix} \underline{X} & \underline{Y} & \underline{Z} \end{bmatrix} \underline{\Delta V}_{LV}$$

NPC ONBOARD DATA

NPC PAD DATA

N33	HR	+	X	X	X	X	X		
TIG NPC	MIN	+	X	X	X	X	X		
SEC	+	X	X	X	X	X	X		

N81	ΔV_X	+	X	0	0	0	0		
ΔV_{NPC}	ΔV_Y		X						
	ΔV_Z	+	X	0	0	0	0		

	ΔV_C		X	X	X	X	X		
BT			X	X	X	X	X		

Verb 37, Enter, 38 Enter

V50 N25 Flashing

R1: 00017 MINKEY Option

PRO Accept MINKEY Option

V50N18 Flashing Request Maneuver to Roll,
Pitch, and Yaw Angles

PRO

+	0	0			Hours		N39	+	0	0			
+	0	0	0		Min	TIG of		+	0	0	0		
+	0				Sec	Last Maneuver		+	0				
+	0	0			Hours		N33	+	0	0			
+	0	0	0		Min	TIG of		+	0	0	0		
+	0				Sec	Plane Change		+	0				
			b		Marks		N45			b			
			b		Time From Ignition (min:sec)					b			
-	0	0	0	0	MGA			-	0	0	0	0	1
					ΔV_x	Local	N81						
					ΔV_y	Vertical (PC)							
					ΔV_z	ft/s							
			b		Marks		N45			b			
			b		Time From Ignition (min:sec)					b			
					MGA								
					P52								
					OGA	New	N22						
					IGA	ICDU							
					MGA	ANGLES							
					MINKEY Pulse								
					Torque		N25						
					OGA	ICDU	N20						
					IGA	ANGLES							
					MGA								

If $\Delta V < 10$ FPS Automatic to P41If $\Delta V \geq 10$ FPS Automatic to P40

NOTES:

NORMAL PLANE CHANGE NPC

P40 - SPS Thrusting

Automatic MINKEY Entry

V50 N18 Flashing, Request Manœuver
to FDAI R, P, Y Angles

V06 N18, FDAI R, P, Y Angles After
Maneuver to Burn Attitude

V50 N25 Flashing, R1 = 00204, 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
300 K ft Earth Orbit

P41 - RCS Thrusting

Automatic MINKEY Entry

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

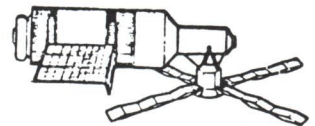
V16 N85 Flashing Body Axes Residuals (to be
Nulled

$\Delta V \geq 10$ FPS					
			50-18	Roll	
				Pitch (deg)	
				Yaw	
			06-18	Roll	
				Pitch (deg)	
				Yaw	
		X	06-40	TFI (min:s)	
				VG (ft/s)	
				$\Delta V M$ (ft/s)	
		X	06-40	TFC (min:s)	
				VG (ft/s)	
				$\Delta V M$ (ft/s)	
		X	16-40	TFC (min:s)	
				VG (ft/s)	
				$\Delta V M$ (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)	

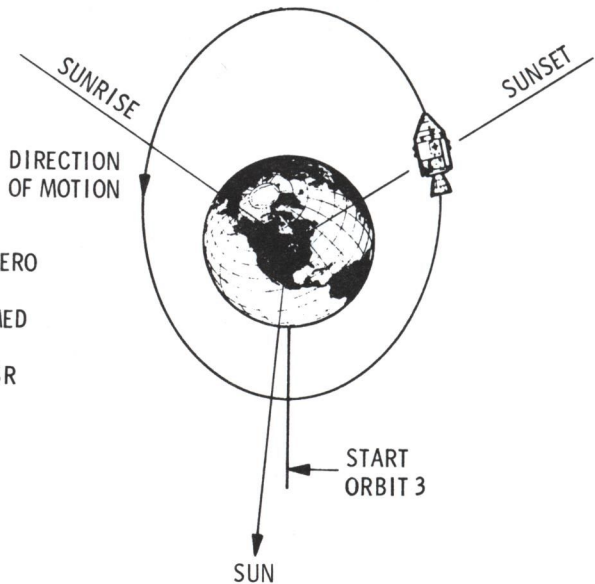
$\Delta V < 10$ FPS		
	50-18	Roll
		Pitch (deg)
		Yaw
	06-18	Roll
		Pitch (deg)
		Yaw
	06-85	X
		Y VG(ft/s)
		Z
	16-85	X
		Y VG(ft/s)
		Z
	16-85	X
		Y Residuals
		Z (ft/s)
	X	
	Y	Trim
	Z	(ft/s)

NPC - PLANE CHANGE

EVENT	BT / ΔV	G. E. T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
PLANE CHANGE NPC	0. 0/0. 0	03:05:29	SPS/G&N P40 EXT ΔV	P38
	ΔV_x N85		+ x x	h
	ΔV_y RESIDUALS (ft/s)		+ x x x	min GET
	ΔV_z (BODY AXIS)		+ x	s
$\text{---} \cdot \text{---} v_{x_{TRIM}}$ $\text{---} \cdot \text{---} v_{y_{TRIM}}$ $\text{---} \cdot \text{---} v_{z_{TRIM}}$ (ft/s)				



TIG: 3:05:29
 BURN TIME: NOM. ZERO
 ΔV : NOM. ZERO
 NOTE: NPC PERFORMED
 IF MGA $> 60^\circ$
 AT NCC OR NSR
 SPS OR RCS
 APOGEE: 204.7 nmi
 PERIGEE: 121.4 nmi



P52- IMU REALIGN

(Post-NPC REFSMMAT Realign)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT

V51 Flashing - Please Mark

x	0	0	0	0		P52 Option		x	0	0	0	0		
+	0	0				Hours	} GET of Gyro Torquing	+	0	0				
+	0	0	0			Minutes		+	0	0	0			
+	0			.		Seconds						.		
x	0	0				Sensor/Celestial Body Code 1		N71	x	0	0			
x	0	0				Sensor/Celestial Body Code 2		N71	x	0	0			
						Outer	} Star Tracker Gimbal Angles (arc-min)	N14						
						Inner								
				.		Star Angle Difference		N05				.		
				.		Star Angle Measured						.		
		.				X	} Gyro Torquing Angles (Degrees)	N93			.			
		.				Y					.			
		.				Z					.			
				.		X	} Calculated Gyro Drift (meru)					.		
				.		Y						.		
				.		Z						.		

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
 C = 1, Sun Sensor
 C = 2, Star Tracker

DE = 46, Sun
 DE = 04, Achernar
 DE = 14, Canopus
 DE = 25, Acrux

} Expected Codes for
 ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

NC2 Targeting

The NC2 targeting (P32) in addition to computing the second phasing maneuver (NC2) also computes and displays the NCC and NSR maneuver magnitudes. The NC2 targeting utilizes the same technique as the NC1 targeting except that the NC1 calculations are not made.

NC2 begins by phase matching the CM and WS state vectors as in the NC1 program. After rotating the CM state vector in the plane of the WS orbit, the initial estimate of the NC2 maneuver is added to the CM velocity vector. The CM state vector is then rotated the number of revolutions between NC2 and NCC to obtain the state at NCC. The NCC maneuver is next calculated with the same algorithm used in the NC1 program for the NCC maneuver.

Finally, the NC2 maneuver calculation is iterated to obtain the desired phasing at TPI (analogous to iterating NC1 maneuver in the NC1 targeting program).

NC2 TARGETING

NOMINAL			NC2 PAD DATA			PRELIMINARY			FINAL		
N28	HR	+	0	4		+			+		
TIG NC2	MIN	+	3	6		+			+		
	SEC	+	1	3	9	0			+		
N81	ΔV_x	+	1	6	0	8			+		
ΔV_{NC2}	ΔV_y	+	0	0	0	0			+	0	0
	ΔV_z	+	0	0	0	0			+	0	0
N22	R		1	8	0						
NC2	P		1	5	6						
	Y		0	0	1						
	ΔV_c	+	1	4	6	9			+		
	BT		0	0	7				+		

Verb 37 Enter, 32 Enter

V50 N25 Flashing

R1: 00017 MINKEY Option

Enter Bypass MINKEY Option

V50 N18 Flashing Request Maneuver to Roll,
Pitch, Yaw Angles

Enter Reject Automatic Maneuver

+	0	0				Hours		N28	+	0	0			
+	0	0	0			Min	TIG of		+	0	0	0		
+	0					Sec	NC-2		+	0				
						Blank		N57						
						Δ Altitude (NCC) nmi								
						Δ Altitude (NSC) nmi								
+	0	0				Hours		N37	+	0	0			
+	0	0	0			Min	TIG of		+	0	0	0		
+	0					Sec	TPI		+	0				
			b			Marks		N45			b			
			b			Time From Ignition (min:sec)				b				
-	0	0	0	0	1	MGA			-	0	0	0	0	1
						ΔV (NCC) ft/s		N84						
						Δ Altitude (NCC) nmi								
						ΔV (NSR) ft/s								
						ΔV X	Local	N81						
						ΔV Y	Vertical (NC2)							
						ΔV Z	ft/s							
			b			Marks		N45			b			
			b			Time From Ignition (min:sec)				b				
						MGA								

XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
X N81 COMP LIMITS \pm 0.5 FPS X
X X
X CMC/MFSN WITHIN LIMITS GO CMC X
X NO AGREEMENT GO MSFN X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXX

NC2- PHASING

P40 - SPS THRUSTING

Automatic MINKEY Entry

- 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 = 00204, 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 Free fall to 300 k ft Earth Orbit

$\Delta V \geq 10 \text{ FPS}$				
			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
				Z (ft/s)
			85	X
				Y TRIM
				Z (ft/s)
			44	HA (nmi)
				HP (nmi)
		X		TFF (min:s)

P41 - RCS THRUSTING

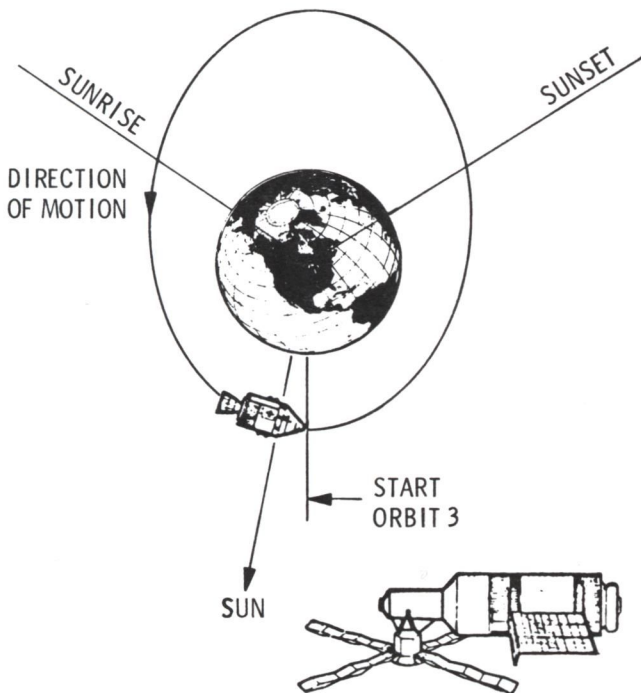
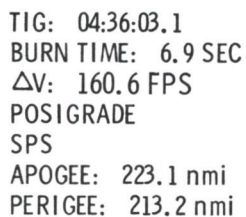
Automatic MINKEY Entry

- 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)

$\Delta V < 10 \text{ FPS}$				
			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
				Z (ft/s)
			X	
			Y	Trim
			Z	(ft/s)

NC2 - PHASING

EVENT					BT/ ΔV		G. E. T.		PROPULSION/ GUIDANCE					PRETHRUST TARGETING	
PHASING 2 NC2					6.9/160.6		04:36:03		SPS/G&N					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					— — — — • — V _y					— — — — • — V _z (ft/s)					
x _{TRIM}					y _{TRIM}					z _{TRIM}					



NCC Targeting

The NCC targeting requires the CM and WS state vectors, time of the NCC maneuver, time between NCC and NSR maneuver, time of the TPI maneuver altitude between the WS orbit and the CM at the TPI time, and elevation angle.

The workshop state vector is updated to TPI time and the CM state vector is updated to NCC time. Next the iterative scheme is used to find the workshop state vector radially above the desired CM position vector at TPI. Using the WS state vector and the altitude difference the coelliptic calculations are used to obtain the CM state vector prior to the TPI maneuver. This state vector is precision integrated backwards to NSR to find the target vector of the NCC maneuver.

Next the final velocity at NCC and NSR is calculated iteratively using the initial state vector, target state vector, time of transfer from initial position to target position. Then the velocities-to-be gained are calculated using the initial and final velocities at NCC and NSR.

NCC TARGETING

NOMINAL			NCC PAD DATA		
			PRELIMINARY	FINAL	
N11	HR	+	05		
TIG NCC	MIN	+	22		
	SEC	+	21.20		
N81	ΔV_x	+	030.4		
ΔV_{NCC}	ΔV_y	-	000.3		
	ΔV_z	-	001.8		
	ΔV_c	-	016.5		
N22	R		180		
NCC	P		340		
	Y		001		

NCC ONBOARD DATA

Verb 37 Enter, 33 Enter

V50 N25 Flashing

R1: 00017 MINKEY Option

Enter Bypass MINKEY Option

V50 N18 Flashing Request Maneuver to Roll,
Pitch, Yaw Angles

Enter Reject Automatic Maneuver

+	0	0			Hours	TIG of	N11	+	0	0		
+	0	0	0		Min	NCC		+	0	0	0	
+	0				Sec			+	0			
+	0	0			Hours	TIG of	N13	+	0	0		
+	0	0	0		Min	NSR		+	0	0	0	
+	0				Sec			+				
+	0	0			Hours	TIG of	N37	+	0	0		
+	0	0	0		Min	TPI		+	0	0	0	
+	0				Sec			+	0			
		b			Marks		N45			b		
		b			Time From Ignition (min:sec)					b		
-	0	0	0	0	MGA			-	0	0	0	0
					ΔV X	Local	N82					
					ΔV Y	Vertical (NSR)						
					ΔV Z	ft/s						
					ΔV X	Local	N81					
					ΔV Y	Vertical (NCC)						
					ΔV Z	ft/s						
		b			Marks		N45			b		
		b			Time From Ignition (min:sec)					b		
					MGA							

XX
X N81 COMP LIMITS +1.5, +5.0, +15.0 FPS X
X CMC/CHART WITHIN LIMITS GO CMC X
X IF NOT CMC/MSFN WITHIN LIMITS GO CMC X
X IF NOT CHART/MSFN WITHIN LIMITS GO CHART X
X NO AGREEMENT GO MSFN X
XX

NCC CORRECTIVE COMBINATION

P40-SPS Thrusting

Automatic MINKEY Entry

V50 N 18 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 = 00204, 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 Alti-
tude, Time to Freefall to 300 K ft Earth
orbit

 $\Delta V \geq 10$ FPS

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

P41-RCS Thrusting

Automatic MINKEY Entry

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

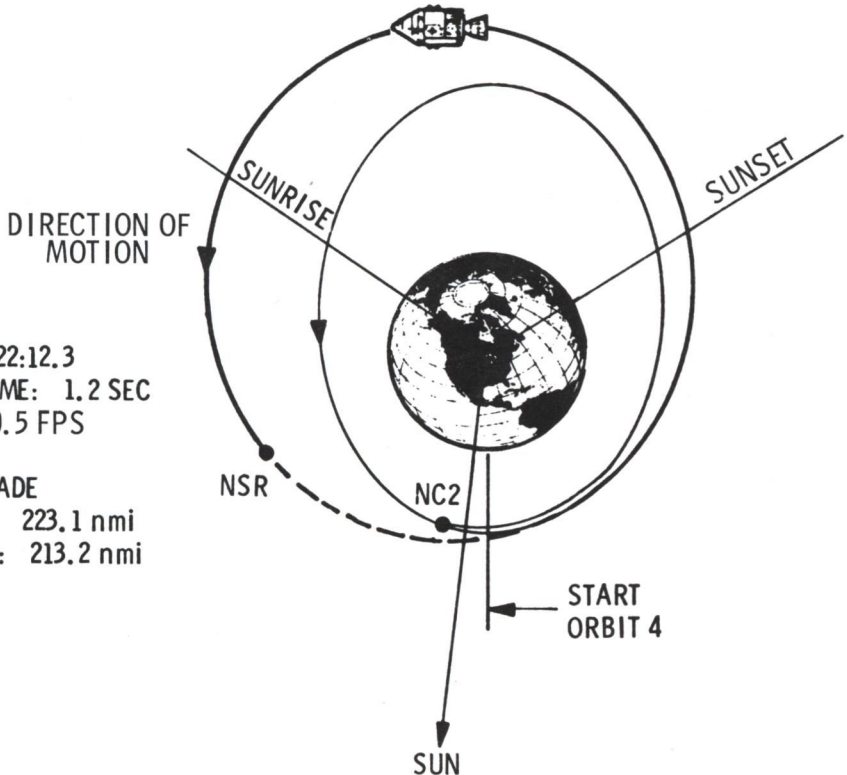
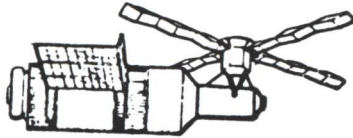
V16 N85 Flashing, Body Axes Residuals
(to be Nulled)

 $\Delta V < 10$ FPS

					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
						Z (ft/s)
					X	
					Y	Trim
					Z	(ft/s)

NCC - CORRECTIVE COMBINATION

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
CORRECTIVE COMBINATION -NCC	1.2/30.5	05:22:12	SPS/G&N	P33
	ΔV _x N85		+ x x	h
	ΔV _y RESIDUALS (ft/s)		+ x x x	min GET
	ΔV _z (BODY AXIS)		+ x	s
<div> <div>— — — • — V_xTRIM</div> <div>— — — • — V_yTRIM</div> <div>— — — • — V_zTRIM (ft/s)</div> </div>				



TIG: 5:22:12.3
 BURN TIME: 1.2 SEC
 ΔV: 30.5 FPS
 SPS
 POSIGRADE
 APOGEE: 223.1 nmi
 PERIGEE: 213.2 nmi

NSR Targeting

The NSR targeting program (P34) is the computation of the coelliptic maneuver.

The program inputs are:

1. CM and WS state vectors
2. Elevation angle
3. Time of NSR Maneuver
4. Time of TPI Maneuver

After precision updating of the CM and WS state vectors to the NSR maneuver time, the CM state vector is rotated into the WS orbit plane, and the WS state vector is updated to be colinear with the CM position vector using the time - theta routine.

The coelliptic maneuver constraint determines the semimajor axis A_c and vertical velocity. V_{cv} following the maneuver. After calculating the CM post-NSR velocity vector V_{c2} , both the CM and WS state vectors are conically updated to the time of the TPI maneuver. The TPI program is then used to calculate the time at which the specified elevation angle is attained.

NSR TARGETING

NSR PAD DATA

TIG NSR(N13) = TIG NCC(N11) + 00:37:00 = _____

		NOMINAL				PRELIMINARY				FINAL			
N81	ΔV_X	+	0	1	9	2							
ΔV_{NSR}	ΔV_Y	+	0	0	0	1							
	ΔV_Z	-	0	0	1	8							
	ΔV_C		0	0	5	3							
N22	R		1	8	0								
NSR	P		1	9	8								
	Y		0	0	2								

NSR ONBOARD DATA

Verb 37 Enter, 34 Enter

V50 N25 Flashing

R1: 00017 MINKEY Option

Enter Reject MINKEY Option

Request Maneuver to Roll, Pitch,
Yaw Angles

Enter Reject Automatic Maneuver

+	0	0				Hours	} TIG of NSR	N13	+	0	0			
+	0	0	0			Min			+	0	0	0		
+	0					Sec			+	0				
			b			Marks		N45			b			
			b			Time From Ignition (min:sec)					b			
-	0	0	0	0	1	MGA			-	0	0	0	0	1
						Δ Altitude (NSR) nmi		N75						
			b			Δ Time (TPI-NSR) (min:sec)					b			
			b			Δ Time (TPI-NOMTPI) (min:sec)					b			
						ΔV_X } Local		N81						
						ΔV_Y } Vertical NSR								
						ΔV_Z } ft/sec								
			b			Marks		N45			b			
			b			Time From Ignition (min:sec)					b			
						MGA								

```

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
X      N81 COMP LIMITS NA, NA, NA FPS X
X
X BURN P34 RECYCLE, CHART OR MSFN SOLN X
X      IF NCC WAS BURNED CMC, CHART X
X      OR MSFN, RESPECTIVELY         X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

```

NSR - COELLIPTIC

P40-SPS THRUSTING CSM

Automatic MINKEY Entry

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=00204, 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 300 K ft Earth
Orbit

$\Delta V \geq 10$ fps

					50-18	Roll	
						Pitch (deg)	
						Yaw	
					06-18	Roll	
						Pitch (deg)	
						Yaw	
				X	06-40	TFI (min:s)	
						VG (ft/s)	
						ΔVM (ft/s)	
					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)	
						TFF (min:s)	

P41-RCS THRUSTING

Automatic MINKEY Entry

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

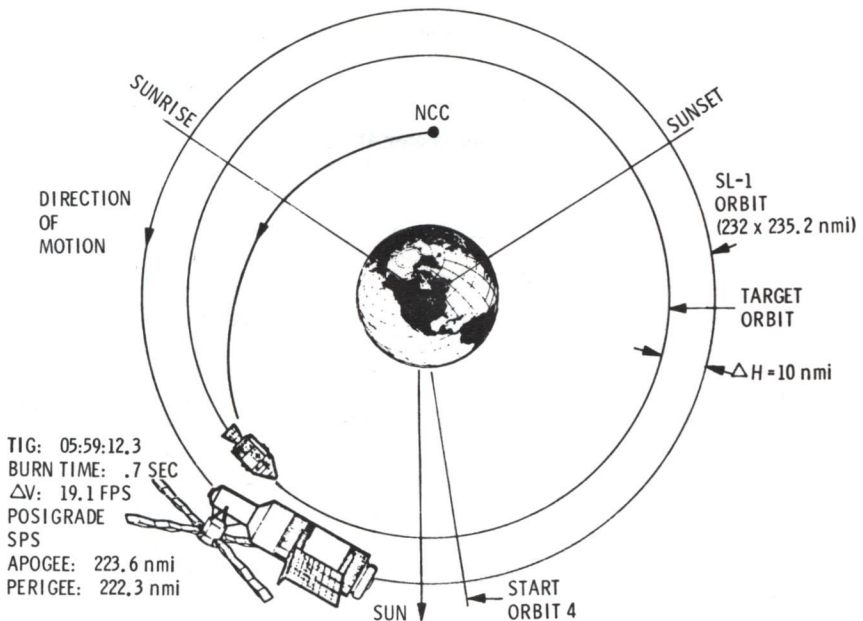
V16 N85 Flashing, Body Axes Residuals
(to be Nulled)

$\Delta V < 10$ fps

					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	

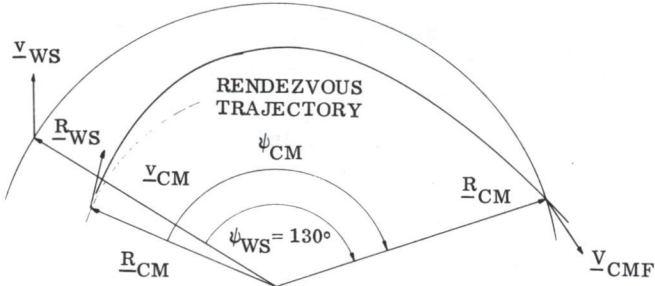
NSR - COELLIPTIC

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
COELLIPTIC NSR	0.7/19.1	05:59:12	SPS/G&N	P-34
	ΔV _x N85		+ x 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)				



TPI TARGETING

The TPI targeting for the Skylab mission is accomplished using the equations and techniques stated below utilizing the following information:



T_1 - time at which the TPI maneuver is to be performed

\underline{R}_{WS} - Workshop position vector at T_1

\underline{v}_{WS} - Workshop velocity vector at T_1

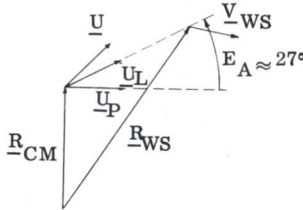
\underline{R}_{CM} - CSM position vector at T_1

\underline{v}_{CM} - CSM velocity vector at T_1

ψ_{WS} - Central angle CSM will traverse between TPI and rendezvous (130° nominally)

Targeting Procedure:

1. Compute the elevation angle of the CSM-WS LOS above the CSM horizontal plane at the specific time of TPI.



$$E_A = \cos^{-1} [\underline{U}_L \cdot \underline{U}_P \text{ SGN} (\underline{U}_P \cdot \underline{U} \times \underline{R}_{CM})]$$

where

$$\underline{U}_L = \text{unit} [\underline{R}_{WS} - \underline{R}_{CM}]$$

$$\underline{U} = \text{unit} [\underline{R}_{CM} \times \underline{v}_{CM}]$$

$$\underline{U}_P = \left[\underline{U}_L - \frac{(\underline{U}_L \cdot \underline{R}_{CM}) \underline{R}_{CM}}{|\underline{R}_{CM}|^2} \right]$$

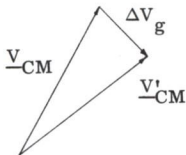
if $E_A < 0^\circ$ define $E_A = 2\pi - E_A$

2. Compute the time (t_{21}) required for the WS to travel through the central angle ψ_{WS} using the Time-Theta method described on page SC-15.
3. Update the state vector of the WS to the time of rendezvous ($\Delta T = t_{21}$) using Kepler's method as described on page SC-15 obtaining \underline{R}_{WSF} , $-\underline{V}_{WSF}$.
4. Compute the central angle (ψ_{CM}) through which the CM must traverse between its position at TPI and the WS's position at rendezvous.

$$\psi_{CM} = \text{SGN}(\underline{R}_{CM} \times \underline{R}_{WSF} \cdot \underline{U}) \cos^{-1}(\underline{R}_{CM} \cdot \underline{R}_{WSF})$$

$$\text{if } \psi_{CM} < 0^\circ \text{ define } \psi_{CM} = \psi_{CM} + 2\pi$$

5. Using the Time-Theta method, determine the flight path angle γ required of the CM at the end of the TPI burn such that the time required by the CM to traverse the central angle of ψ_{CM} is the same as t_{21} .
6. Calculate the velocity to be gained.



$$\underline{\Delta V}_g = \underline{V}'_{CM} - \underline{V}_{CM}$$

Where:

$$\underline{V}'_{CM} = \sqrt{\frac{P\mu}{R_{CM}}} \left(\cot \gamma \cdot \text{unit } \underline{R}_{CM} + \underline{U}_N \times \text{unit } \underline{R}_{CM} \right)$$

P = semilatus rectum of the TPI orbit

$$\underline{U}_N = \text{unit} [\text{unit } \underline{R}_{WSF} \cdot \text{unit } \underline{R}_{CM}]$$

The velocity to be gained is burned out using the SPS and Lambert Aimpoint Guidance.

TPI TARGETING

TPI PAD DATA				NOMINAL	PRELIMINARY	FINAL
N37	HR	+		06		
TIG TPI	MIN	+		49		
	SEC	+		09.80		
N81	ΔV_X	+		18.8		
ΔV_{TPI}	ΔV_Y	+		00.7		
	ΔV_Z	-		08.4		
N59	$\Delta V_F/BT$	+		206.52		
$\Delta V_{LOS}/\Delta V_R/BT$		+		00.704		
	$\Delta V_D/BT$	+		01.106		

TPI ONBOARD DATA

Verb 37, Enter, 35 Enter
V50 N25 Flashing

R1: 00017 MINKEY option

PRO Accept MINKEY Option

V50 N18 Flashing Request Maneuver to Roll, Pitch, Yaw Angles

PRO Accept Automatic maneuver to Roll, Pitch, Yaw Angles

+	0	0				Hours	} TIG of TPI	N37	+	0	0			
+	0	0	0			Min			+	0	0	0		
+	0					Sec			+	0				
0	0	0	0	0		Precision Offsets		N55		0	0	0	0	
						Elevation Angle								
			b			Marks		N45				b		
			b			Time from Ignition (min:sec)						b		
-	0	0	0	0	1	MGA			-	0	0	0	0	1
+	0	0				Hours	} TIG of TPI	N37	+	0	0			
+	0	0	0			Min			+	0	0	0		
+	0					Sec			+	0				
0	0	0	0	0		Precision Offsets		N55		0	0	0	0	
						Elevation Angle								
						ΔV (TPI)		N58						
						ΔV (TPF)								
			b			Δ Time (TPI - NOMTPI)						b		
						ΔV_X	} Local Vertical TPI ft/sec	N81						
						ΔV_Y								
						ΔV_Z								
			b			Marks		N45				b		
			b			Time from Ignition (min:sec)						b		
						MGA								

NOTES $\Delta V < 10$ fps Automatic to P41
 $\Delta V \geq 10$ fps Automatic to P40

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
X N37 COMP LIMITS ± 10 MIN X
X CMC/MSFN WITHIN LIMITS GO ELEV OPTION X
X NO AGREEMENT GO TIME OPTION X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
X N81 COMP LIMITS $\pm 1.0, \pm 3.0, \pm 3.0$ FPS X
X CMC/CHART WITHIN LIMITS GO CMC X
X IF NOT CMC/MSFN WITHIN LIMITS GO CMC X
X ***** X
X IF NOT N81 COMP LIMITS ± 3.0 FPS X
X CHART/MSFN WITHIN LIMITS GO CHART X
X NO AGREEMENT GO MSFN X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

TPI - TRANSFER PHASE INITIATION

P40-SPS Thrusting

Automatic MINKEY Entry

V50 N 18 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 = 00204, 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 300 K ft Earth orbit

 $\Delta V \geq 10$ FPS

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

P41-RCS Thrusting

Automatic MINKEY Entry

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

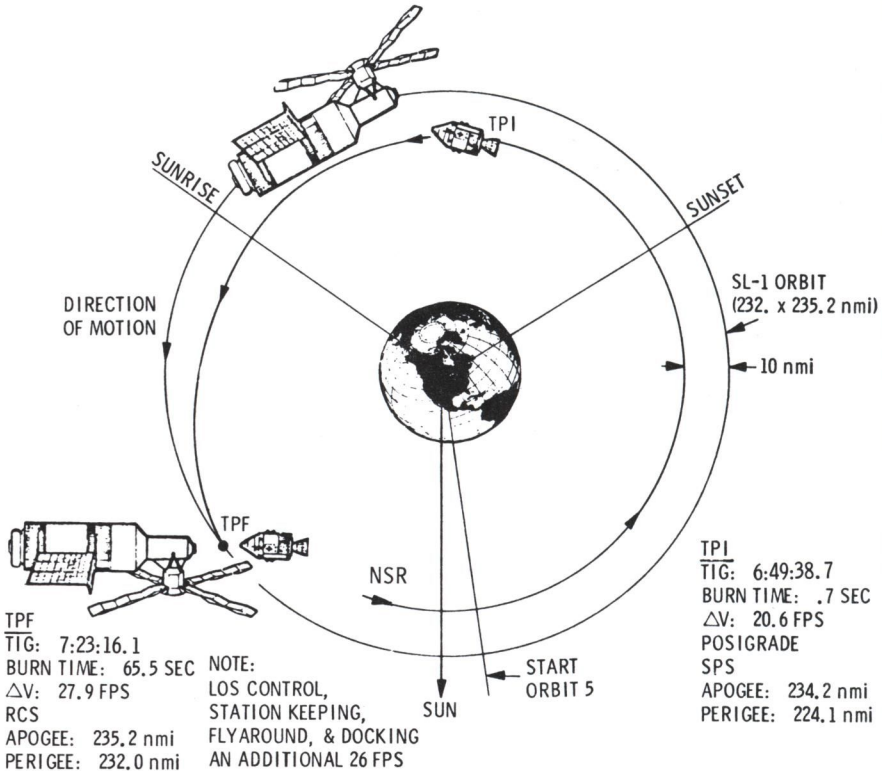
V16 N85 Flashing, Body Axes Residuals (to be Nulled)

 $\Delta V < 10$ FPS

					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
						Z (ft/s)
					X	
					Y	Trim
					Z	(ft/s)

TPI - TRANSFER PHASE INITIATION

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
TERMINAL PHASE INITIATION - TPI	0.7/20.6	06:49:39	SPS/G&N	P-35
	ΔV _x N85		+ x x x	h
	ΔV _y RESIDUALS (ft/s)		+ x x x	min GET
	ΔV _z (BODY AXIS)		+ x	s
<div> <div>-----•- V_xTRIM</div> <div>-----•- V_yTRIM</div> <div>-----•- V_zTRIM (ft/s)</div> </div>				

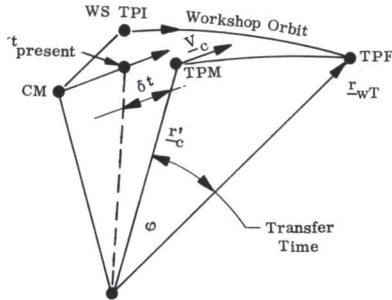


TPM TARGETING

The Terminal Phase Midcourse (TPM) Targeting Program (P36) computes the terminal phases midcourse correction maneuver. This maneuver ensures CM-WS rendezvous at the time established by in the TPI program.

The inputs used are:

1. CM and Workshop state vectors $\underline{r}_c, \underline{v}_c, \underline{r}_w, \underline{v}_w$
2. Intercept time, t_{TPF}
3. Number of precision offsets, N_1
4. Time delay, δt (time required to prepare for the maneuver).



The targeting sequence is:

1. Update the CM and WS positions and velocities to present time plus δt using coasting integration scheme. (Kepler update if rectification occurs)
2. Update workshop $\underline{r}_w, \underline{v}_w$ to time of TPF (t_{TPF}) obtain \underline{r}_{wT}
3. Compute Unit normal to CM plane and central angle (φ) between TPM and TPF

$$\underline{u} = \text{unit}(\underline{r}_c' \times \underline{v}_c)$$

$$\varphi = \pi + \cos^{-1} \left(\frac{(\underline{r}_c' \cdot \underline{r}_{wT})}{(\underline{r}_c' \cdot \underline{r}_{wT})} \right) \text{SIGN} \left[(\underline{r}_c' \times \underline{r}_{wT}) \cdot \underline{u} \right]$$

4. Solve for the initial velocity \underline{v}_c' given $\underline{r}_{wT}, \underline{r}_c'$, transfer time ($t_{TPF} - (t_{\text{present}} + \delta t)$) using initial velocity technique.
5. Solve for velocity to be gained for TPM.

$$\Delta \underline{V}_{TPM} = \underline{v}_c' - \underline{v}_c$$

directions for $\Delta \underline{V}_{TPM}$

$$\underline{Y} = (\underline{r}_c' \times \underline{v}_c)$$

$$\underline{Z} = \text{unit}(-\underline{r}_c')$$

$$\underline{X} = \underline{Y} \times \underline{Z}$$

6. Local vertical directions for $\Delta \underline{V}_{TPM}$

$$\Delta \underline{V}_{TPM}(\text{LV}) = \begin{bmatrix} \underline{X} \\ \underline{Y} \\ \underline{Z} \end{bmatrix} \Delta \underline{V}_{TPM}$$

7. LOS computations of $\Delta \underline{V}_{TPM}$

$$\underline{R}_1 = \frac{\text{UNIT}}{\text{UNIT}} (\underline{r}_w - \underline{r}_c')$$

$$\underline{R}_2 = \frac{\text{UNIT}}{\text{UNIT}} ((\underline{r}_c' \times \underline{v}_c) \times \underline{R}_1) \times \underline{R}_1$$

$$\underline{R}_3 = \underline{R}_1 \times \underline{R}_2$$

$$\Delta \underline{V}_{TPM}(\text{LOS}) = \begin{bmatrix} \underline{R}_1 \\ \underline{R}_2 \\ \underline{R}_3 \end{bmatrix} \Delta \underline{V}_{TPM}$$

The procedure is repeated twice for the number of midcourse burns required.

P36 TPM1 TARGETING

Verb 37, Enter, 36 Enter

V50 N25 Flashing

R1: 00017 MINKEY Option

Enter Reject MINKEY Option

V50 N18 Flashing Request Maneuver to Roll, Pitch, Yaw Angles

Enter Reject Automatic Maneuver

			b				MARKS	N45				b			
			b				Time from Ignition (min:sec)					b			
-	0	0	0	0	1		MGA		-	0	0	0	0	1	
					•		$\Delta V X$	} LOS TPM ft/sec	N59					•	
					•		$\Delta V Y$								•
					•		$\Delta V Z$								•
			b				MARKS	N45				b			
			b				Time from Ignition (min:sec)					b			
					•		MGA						•		

NOTES:

TPM-1
P41 - RCS THRUSTING

Automatic MINKEY Entry

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 at TIG-30) Velocity to be
Gained

V16 N85 Flashing, Body Axes Residuals (to be
Nulled)

$\Delta V < 10$ fps

					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

P36 - TPM2 TARGETING

Verb 37, Enter, 36 Enter

V50 N25 Flashing

R1: 00017 MINKEY Option

Enter Reject MINKEY Option

V50 N18 Flashing Request Maneuver to Roll, Pitch, Yaw Angles

Enter Reject Automatic Maneuver

			b			MARKS	N45				b		
			b			Time from Ignition (min:sec)					b		
-	0	0	0	0	1	MGA		-	0	0	0	0	1
					•	ΔVX	LOS TPM (ft/sec)	N59					•
					•	ΔVY							•
					•	ΔVZ							•
			b			MARKS	N45				b		
			b			Time from Ignition (min:sec)					b		
					•	MGA						•	

NOTES:

TPM-2
P41 - RCS THRUSTING

Automatic MINKEY Entry

V50 N18 Flashing, Request Maneuver to FDAI
R, P, Y Angles

V06 N18, FDAI R, P, Y Angles After Maneuver
to Burn Attitude

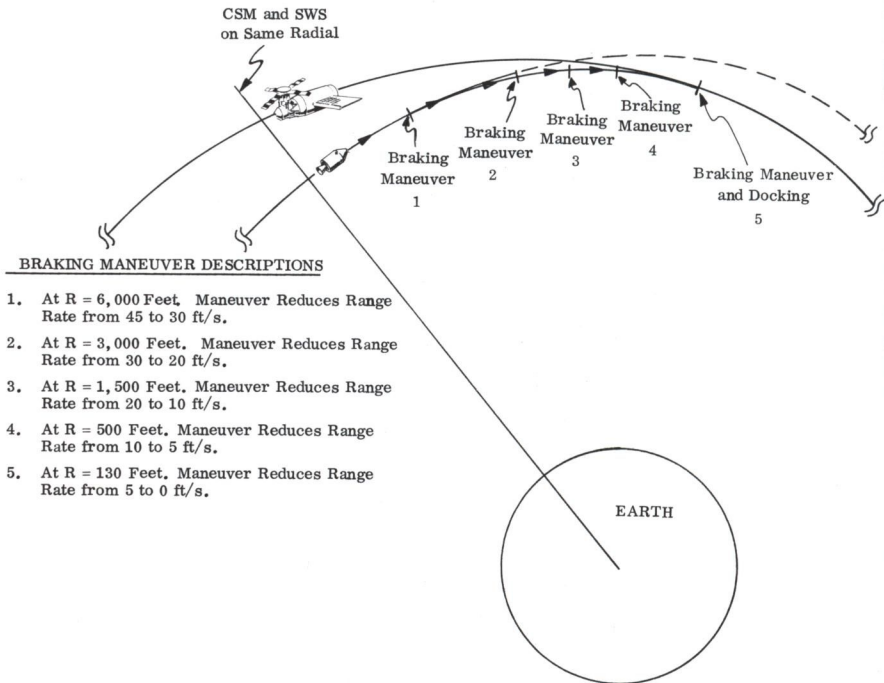
V06 N85, X, Y, Z Body Axes Velocity to
be Gained

V16 N85 (Average on at TIG-30) Velocity to
be Gained

V16 N85 Flashing, Body Axes Residuals (to
be nulled)

$$\Delta V < 10 \text{ fps}$$

					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	Trim (ft/s)
					Y	
					Z	

CSM RENDEZVOUS FINAL PHASE

BRAKING GATES			
R(NM)	\dot{R} (FPS)	SWS DIAMETER RETICLE ANG (DEG)	R (FT)
1.00	30	.2	6000
.50	20	.4	3000
.25	10	.8	1500
.08	5	2.5	500
.05		4.2	300
.03		6.3	200
.02		10.0	130

P37 - RENDEZVOUS
FINAL PROGRAM

Verb 37, Enter, 37 Enter

V50 N25 Flashing

R1: 00017 MINKEY Option

Enter	Reject	MINKEY Option
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12
13	13	13
14	14	14
15	15	15
16	16	16
17	17	17
18	18	18
19	19	19
20	20	20
21	21	21
22	22	22
23	23	23
24	24	24
25	25	25
26	26	26
27	27	27
28	28	28
29	29	29
30	30	30
31	31	31
32	32	32
33	33	33
34	34	34
35	35	35
36	36	36
37	37	37
38	38	38
39	39	39
40	40	40
41	41	41
42	42	42
43	43	43
44	44	44
45	45	45
46	46	46
47	47	47
48	48	48
49	49	49
50	50	50
51	51	51
52	52	52
53	53	53
54	54	54
55	55	55
56	56	56
57	57	57
58	58	58
59	59	59
60	60	60
61	61	61
62	62	62
63	63	63
64	64	64
65	65	65
66	66	66
67	67	67
68	68	68
69	69	69
70	70	70
71	71	71
72	72	72
73	73	73
74	74	74
75	75	75
76	76	76
77	77	77
78	78	78
79	79	79
80	80	80
81	81	81
82	82	82
83	83	83
84	84	84
85	85	85
86	86	86
87	87	87
88	88	88
89	89	89
90	90	90
91	91	91
92	92	92
93	93	93
94	94	94
95	95	95
96	96	96
97	97	97
98	98	98
99	99	99
100	100	100

V50 N18 Request Maneuver to Roll, Pitch, Yaw angles

			.	Range	nmi	N54				.	
			.	Range Rate	(ft/s)					.	
			.	Theta						.	
			.	Range		N54				.	
			.	Range Rate						.	
			.	Theta						.	
			.	Range		N54				.	
			.	Range Rate						.	
			.	Theta						.	
			.	Range		N54				.	
			.	Range Rate						.	
			.	Theta						.	
			.	Range		N54				.	
			.	Range Rate						.	
			.	Theta						.	

NOTES:

P48 - RENDEZVOUS
THRUST MONITOR PROGRAM

Verb 37, Enter, 48, Enter

[illegible]

			.	Range	N77					.	
			.	Range Rate						.	
			.	Theta						.	
			.	Hours	Time of Optimization N72					.	
			.	Min						.	
			.	Sec						.	
			.	Range	N76					.	
			.	Range Rate						.	
		b	.	Time from Optimization						b	
			.	Range	N77					.	
			.	Range Rate						.	
			.	Theta						.	
			.	ΔV_X	$\left. \begin{array}{l} \text{Body} \\ \text{Axis} \end{array} \right\}$ (ft/sec) N83					.	
			.	ΔV_Y						.	
			.	ΔV_Z						.	

NOTES:

P52 - IMU REALIGN

POST DOCKING

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 - Preferred, 2 - Normal,
3 - REFMMAT.

V51 Flashing - Please Mark

x	0	0	0	0		P52 Option	x	0	0	0	0	
+	0	0				Hours	} GET of Gyro Torquing	+	0	0		
+	0	0	0			Minutes		+	0	0	0	
+	0			.		Seconds					.	
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0		
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0		
						Outer	} Star Tracker Gimbal Angles (arc-min)	N14				
						Inner						
			.			Star Angle Difference	N05				.	
			.			Star Angle Measured					.	
		.				X } Gyro Y } Torquing Z } Angles (Degrees)	N93			.		
		.								.		
		.								.		
		.				X } Calculated Y } Gyro Z } Drift (meru)				.		
		.								.		
		.								.		

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star Tracker

DE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, Acrux

} Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P50 - ATM ORIENTATION DETERMINATION
(OPTION 1)

V37 Enter, 50 Enter

V04 N06 Flashing

R1: 00012

R2: 0000x ATM Sighting Option

1 = Acquisition Sun Sensor Mark

2 = Acquisition Sun Sensor/Star Tracker Mark

3 = Docking Angles

V51 Flashing - Please Mark

x	0	0	0	0		P50 - OPTION					x	0	0	0	0	
	0					Outer ST Gimbal Angle	} Mark, Read and Record		0							
	0					Inner ST Gimbal Angle			0							
x	0	0				Sensor/Star Code*		N71	x	0	0					
						Outer ST Gimbal Angle	} arc-min	N14								
						Inner ST Gimbal Angle										
						Docking Angle	$\left\{ \begin{array}{l} \alpha \\ \beta \\ \gamma \end{array} \right.$	Nom = 145	N23							
						(Load for Option 3)		Nom = 180								
								Nom = 0								

*Expected codes for option 2

00214 Canopus

00225 Acrux

00204 Archernar

P52 - IMU REALIGN
(POST DOCKING No. 2)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 - Preferred, 2 - Nominal,
3 - REFSMMAT.

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	+	0	0	0		
+	0			.		Seconds					.	
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0		
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0		
						Outer	Star Tracker Gimbal	N14				
						Inner	Angles (arc-min)					
			.			Star Angle Difference	N05				.	
			.			Star Angle Measured					.	
	.					X	Gyro	N93			.	
	.					Y	Torquing				.	
	.					Z	Angles (Degrees)				.	
		.				X	Calculated				.	
		.				Y	Gyro				.	
		.				Z	Drift (meru)				.	

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star Tracker

DE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, Acrux

Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P50 - ATM ORIENTATION DETERMINATION
(OPTION 2)

V37 Enter, 50 Enter

V04 N06 Flashing

R1: 00012

R2: 0000x ATM Sighting Option

1 = Acquisition Sun Sensor Mark

2 = Acquisition Sun Sensor/Star Tracker Mark

3 = Docking Angles

V51 Flashing - Please Mark

x	0	0	0	0		P50 - OPTION					x	0	0	0	0
	0					Outer ST Gimbal Angle	} Mark, Read and Record				0				
	0					Inner ST Gimbal Angle					0				
x	0	0				Sensor/Star Code*	N71	x	0	0					
						Outer ST Gimbal Angle	} arc-min	N14							
						Inner ST Gimbal Angle									
						Docking Angle	α	Nom = 145	N23						
						(Load for Option 3)	β	Nom = 180							
							γ	Nom = 0							

*Expected codes for option 2

00214 Canopus

00225 Acrux

00204 Archernar

P52 - IMU REALIGN

(Post Docking No. 3)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 - Preferred, 2 - Nominal,

3 - REFSMMAT

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	+	0	0	0		
+	0			.		Seconds					.	
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0		
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0		
						Outer	N14					
						Inner						
				.		Star Angle Difference	N05				.	
				.		Star Angle Measured					.	
		.				X	N93			.		
		.				Y				.		
		.				Z				.		
				.		X					.	
				.		Y					.	
				.		Z					.	

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
 C = 1, Sun Sensor
 C = 2, Star Tracker

DE = 46, Sun
 DE = 04, Achernar
 DE = 14, Canopus
 DE = 25, Acrux

Expected Codes for
 ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P51 - IMU ORIENTATION
DETERMINATION

V37 Enter, 51 Enter

V50 N25 Flashing

R1 00015 (Maneuver to Acquire Stars)

Enter IMU Coarse Aligns to 0,0,0

V41 N20E Enter Desired Gimbal Angles
No Attitude - light on, then off

V50 N25 Flashing

R1 00015 (Maneuver to Acquire Stars)

PRO

V51 Flashing - Please Mark

Orbital Assembly in Solar Inertial Attitude

Star Tracker locked on.

MARK Record Star Tracker Gimbal Angles

Star Tracker						P51 Option						Star Tracker					
x	0	0	0	1	5	V50 N25 Flashing						x	0	0	0	1	5
					•	R } IMU P } Gimbal (deg) Y } Angles											•
					•												•
					•												•
					•												•
x	0	0				Sensor/Celestial Body Code 1				N71	x	0	0				
x	0	0				Sensor/Celestial Body Code 2				N71	x	0	0				
	0					Outer (arc min) } Star Tracker Inner (arc min) } Gimbal angles				N14		0					
	0											0					
				•		Star Angle Difference (degrees)				N05						•	
				•		Star Angle (Measured)										•	

NOTES: Sensor/Celestial Body Code 00 CDE

C = 0 - CSM Optics
C = 1 - Sun Sensor
C = 2 - Star TrackerDE = 46 - Sun
DE = 04 - Achernar
DE = 14 - Canopus
DE = 25 - AcruxExpected codes for
ATM Sensor Sightings

P52 - IMU REALIGN
(Entry - 7 Check No. 1)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x

1 = Preferred, 2 - Nominal,

3 = REFSMMAT

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	+	0	0	0		
+	0			.		Seconds				.		
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0		
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0		
						Outer	} Star Tracker Gimbal N14					
						Inner						
			.			Star Angle Difference	N05			.		
			.			Star Angle Measured				.		
	.					X	} Gyro N93		.			
	.					Y			.			
	.					Z			.			
			.			X	} Calculated			.		
			.			Y				.		
			.			Z				.		

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star Tracker

DE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, Acrux

} Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P50-ATM ORIENTATION DETERMINATION
(Entry - 7 Check Option 2)

V37 Enter, 50 Enter

V04 N06 Flashing

R1: 00012

R2: 0000x ATM Sighting Option

1 = Acquisition Sun Sensor Mark

2 = Acquisition Sun Sensor/Star Tracker Mark

3 = Docking Angles

V51 Flashing - Please Mark

x	0	0	0	0		P50 - OPTION				x	0	0	0	0	
	0					Outer ST Gimbal Angle	} Mark, Read and Record		0						
	0					Inner ST Gimbal Angle			0						
x	0	0				Sensor/Star Code*	N71	x	0	0					
						Outer ST Gimbal Angle	} arc-min	N14							
						Inner ST Gimbal Angle									
						Docking Angle { α	Nom = 145	N23							
						(Load for	{ β	Nom = 180							
						Option 3)		{ γ	Nom = 0						

*Expected codes for option 2

00214 Canopus

00225 Acrux

00204 Archernar

P52 - IMU REALIGN
(ENTRY - 7 Check No. 2)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 - Preferred, 2 - Nominal,
3 - REFSMMAT.

V51 Flashing - Please Mark

x	0	0	0	0	0	P52 Option	x	0	0	0	0	0	0	
+	0	0				Hours	+	0	0					
+	0	0	0			Minutes	+	0	0	0				
+	0			.		Seconds					.			
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0				
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0				
						Outer	Star Tracker Gimbal N14							
						Inner		Angles (arc-min)						
				.		Star Angle Difference	N05				.			
				.		Star Angle Measured					.			
		.				X	Gyro Torquing Angles (Degrees) N93			.				
		.				Y				.				
		.				Z				.				
			.			X	Calculated Gyro Drift (meru)				.			
			.			Y					.			
			.			Z					.			

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star Tracker

DE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, Acrux

Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P51 - IMU ORIENTATION DETERMINATION

V37 Enter, 51 Enter

V50 N25 Flashing

R1 00015 (Maneuver to Acquire Stars)

Enter IMU Coarse Aligns to 0,0,0

V41 N20E Enter Desired Gimbal Angles
No Attitude - light on, then off

V50 N25 Flashing

R1 00015 (Maneuver to Acquire Stars)

PRO

V51 Flashing - Please Mark

Orbital Assembly in Solar Inertial Attitude

Star Tracker locked on.

MARK Record Star Tracker Gimbal Angles

Star Tracker						P51 Option		Star Tracker						
x	0	0	0	1	5	V50 N25 Flashing		x	0	0	0	1	5	
					•	R } P } Y }	IMU Gimbal (deg) Angles						•	
					•									•
					•									•
x	0	0				Sensor/Celestial Body Code 1		N71	x	0	0			
x	0	0				Sensor/Celestial Body Code 2		N71	x	0	0			
	0					Outer (arc min) Inner (arc min) }	Star Tracker Gimbal angles	N14		0				
	0								0					
				•		Star Angle Difference (degrees)		N05					•	
				•		Star Angle (Measured)							•	

NOTES: Sensor/Celestial Body Code 00 CDE

C = 0 - CSM Optics
C = 1 - Sun Sensor
C = 2 - Star Tracker

DE = 46 - Sun
DE = 04 - Achernar
DE = 14 - Canapus
DE = 25 - Acrux

Expected codes for
ATM Sensor Sightings

P52 - IMU REALIGN (CM)

(ENTRY Preferred Option)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 - Preferred, 2 - Nominal,
3 - REFSMMAT.

V51 Flashing - Please Mark

x	0	0	0	0		P52 Option	x	0	0	0	0	
+	0	0				Hours	GET of Gyro Torquing	+	0	0		
+	0	0	0			Minutes		+	0	0	0	
+	0			.		Seconds					.	
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0		
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0		
						Outer	Star Tracker Gimbal Angles (arc-min)	N14				
						Inner						
			.			Star Angle Difference	N05				.	
			.			Star Angle Measured					.	
		.				X	Gyro Torquing Angles (Degrees)	N93			.	
		.				Y				.		
		.				Z				.		
			.			X	Calculated Gyro Drift (meru)				.	
			.			Y					.	
			.			Z					.	

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star TrackerDE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, AcruxExpected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P52 - IMU REALIGN
(ENTRY REFSMMAT ALIGN)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU ALIGN Option

1 = Preferred, 2 - Nominal,

3 - REFSMMAT

V51 Flashing - Please Mark

x	0	0	0	0	0	P52 Option	x	0	0	0	0	0
+	0	0				Hours	+	0	0			
+	0	0	0			Minutes	+	0	0	0		
+	0			.		Seconds					.	
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0		
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0		
						Outer						
						Inner						
						Star Angle Difference	N05				.	
						Star Angle Measured					.	
			.			X				.		
			.			Y				.		
			.			Z				.		
			.			X				.		
			.			Y				.		
			.			Z				.		

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star Tracker

DE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, Acrux

Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

P52 - IMU REALIGN
(ENTRY REFSMMAT Align)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x IMU Align Option

1 = Preferred, 2 - Nominal

3 = REFSMMAT

V51 Flashing - Please Mark

x	0	0	0	0		P52 Option	x	0	0	0	0	
+	0	0				Hours	} GET of Gyro Torquing	+	0	0		
+	0	0	0			Minutes		+	0	0	0	
+	0			.		Seconds						.
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0		
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0		
						Outer	} Star Tracker Gimbal Angles (arc-min)	N14				
						Inner						
				.		Star Angle Difference	N05				.	
				.		Star Angle Measured					.	
		.				X } Gyro	N93			.		
		.				Y } Torquing				.		
		.				Z } Angles (Degrees)				.		
			.			X } Calculated				.		
			.			Y } Gyro				.		
			.			Z } Drift (meru)				.		

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star Tracker

DE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, Acrux

} Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

ENTRY PAD UPDATE

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			+	
P .05G	+			0	0	+			0	0
N61 LAT		0		.			0		.	
LONG				.					.	
RTOGO .05G	+			.		+			.	
VIO .05G	+			.		+			.	
RET .05G	x	x		.		x	x		.	
RET .2G	x	x		.		x	x		.	
N66 DRE				.					.	
BANK AN	R			/		R			/	
RET RB	x	x		.		x	x		.	
RET BBO	x	x		.		x	x		.	
RET EBO	x	x		.		x	x		.	
RET DROG	x	x		.		x	x		.	

ENTRY UPDATE PAD DESCRIPTION

Revoltuion number and landing area

Pitch angle at .05G (P .05G)

Latitude and longitude of splashdown point (LAT, LONG), noun 61 display

EMS initialization value for range-to-go at .05G (RTOGO .05G)

EMS initialization value of inertial velocity at .05G (VIO .05G)

Time to .05G referenced from retroburn (RET .05G)

Time to .2G referenced from retroburn (RET .2G)

Downrange error (DRE), noun 66 display

Bank angle, roll (R) first in specified direction

Time to bank angle reversal from retroburn (RET RB)

Time to S-Band blackout from retroburn (RET BBO)

Time to the end of S-Band blackout from retroburn (RET EBO)

Time to drogue chute deployment from retroburn (RET DROG)

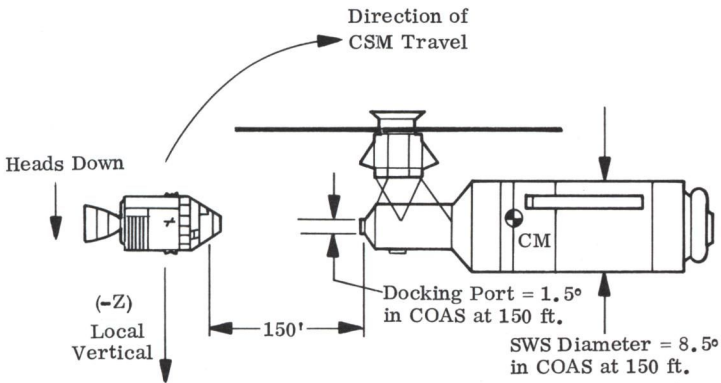
FLY AROUND MANEUVER

GET: ___ day ___ hr ___ min ___ sec

GMT: ___ day ___ hr ___ min ___ sec

Station Coverages: Merritt Island Tracking Station, Bermuda Tracking Station

Undocking Delta Velocity: .38 to .51 ft/s. Taken out by +X jet Thrust at approximately 57 ft. Separation (2 min: 25 sec after undocking)

Fly Around Maneuver: Thrust +X for 2.5 sec (~ 5 ft/s)
 Thrust Z for 1.5 sec

THRUST DIRECTION	RADIAL CLOSURE RATE	ANGULAR RATE	RCS PULSE DURATIONS
+X	Increase	Increase	0.5 sec
+Z	Increase	Decrease	
-Z	Decrease	Increase	

P30 - EXTERNAL ΔV
(Separation)

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GET I

V06 N81 Flashing, Load Desired ΔV

PURPOSE												
N33 HR	+	x	x				+	x	x			
MIN	+	x	x	x			+	x	x	x		
SEC	+	x					+	x				
N81 LOCAL $\Delta V X$		x										
VERT $\Delta V Y$		x						x				
$\Delta V Z$		x						x				
N22 R	+				0	0	+				0	0
P	+				0	0	+				0	0
Y	+				0	0	+				0	0
$\Delta V C$	x	x					x	x				
BT	x	x					x	x				
ΔV_{70}	x	x					x	x				
ULLAGE: _____ SECS _____ QUADS												
N47 WT	+ [] [] [] [] []					STAR [x] [x] [x] [x] [] GDC R [] [] []						
N48 PT	[] [x] [x] [] []					SFT + [] [] [] [] [] 0					P [] [] []	
YT	[] [x] [x] [] []					TRN + [] [] [] [] [] 0 0					Y [] [] []	

MANEUVER UPDATE (P30) PAD DESCRIPTION

GMT of ignition (GMTI) in noun 33 display

Change in velocity components in noun 81 display

Ground calculated S/C burn attitude relative to the IMU at GMTI called by V49 N22

EMS ΔV counter load ($\Delta V C$)

Burn duration (BT)

Change in velocity necessary to lower perigee below 70 nm (ΔV_{70})

Ullage duration, and number of quads (2 or 4) used

Vehicle weight, and pitch and yaw trim engine gimbal angles, for DAP data load

Star number, and optics shaft and trunnion angles

GDC align angles for failed IMU

CSM/OWS SEPARATION

P41 - RCS THRUSTING

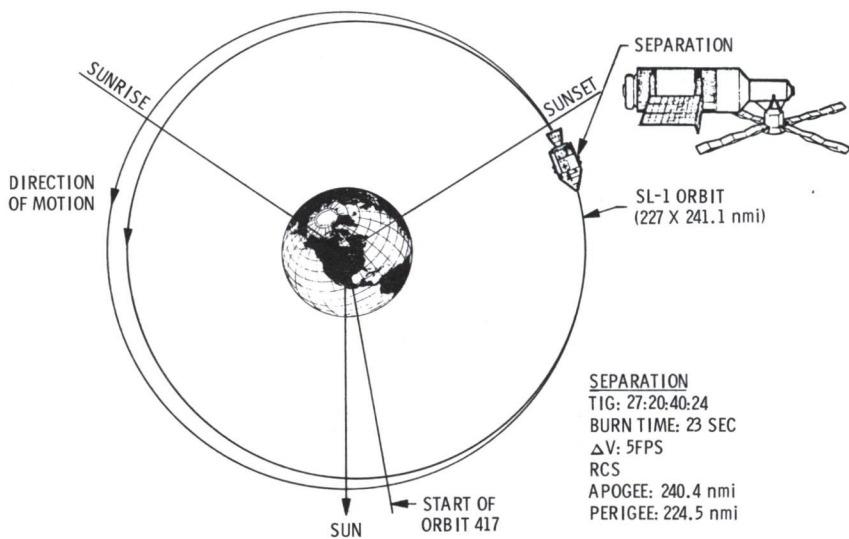
V37 Enter, 41 Enter

V50 N18 Flashing, Request Maneuver to FDAI
R, P, Y AnglesV06 N18, FDAI R, P, Y Angles After Maneuver to
Burn AttitudeV06 N85, X, Y, Z Body Axes Velocity to be
GainedV16 N85 (Average G on at TIG-30) Velocity to
be GainedV16 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	Trim (ft/s)
					Y	
					Z	

CSM/OVS - SEPARATION

EVENT	BT/ ΔV	G. E. T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
SEPARATION	11.5/5.0 4 JET	DAY 27 20:40:24.0	RCS/G&N P41-EXT ΔV	P30
	ΔV_x N85		+ x x x	h
	ΔV_y RESIDUALS (ft/s)		+ x x x	min GET
	ΔV_z (BODY AXIS)		+ x	s
<div> <div>-----V_{x_TRIM}</div> <div>-----V_{y_TRIM}</div> <div>-----V_{z_TRIM} (ft/s)</div> </div>				



P30 - EXTERNAL ΔV

(Shaping)

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GET I

V06 N81 Flashing, Load Desired ΔV

PURPOSE											
N33 HR	+	x	x				+	x	x		
MIN	+	x	x	x			+	x	x	x	
SEC	+	x					+	x			
N81 LOCAL ΔV_X		x					x				
VERT ΔV_Y		x					x				
ΔV_Z		x					x				
N22 R	+				0	0	+				0 0
P	+				0	0	+				0 0
Y	+				0	0	+				0 0
ΔVC	x	x					x	x			
BT	x	x					x	x			
ΔV_{70}	x	x					x	x			
ULLAGE: _____ SECS _____ QUADS _____											
N47 WT	+ [] [] [] [] []					STAR [x] [x] [x] [x] [] []			GDC R [] [] []		
N48 PT	[] [x] [x] [] []					SFT + [] [] [] [] [] 0			P [] [] []		
YT	[] [x] [x] [] []					TRN + [] [] [] [] [] 0 0			Y [] [] []		

MANEUVER UPDATE (P30) PAD DESCRIPTION

GMT of ignition (GMTI) in noun 33 display

Change in velocity components in noun 81 display

Ground calculated S/C burn attitude relative to the IMU at GMTI called by V49 N22

EMS ΔV counter load (ΔVC)

Burn duration (BT)

Change in velocity necessary to lower perigee below 70 nm (ΔV_{70})

Ullage duration, and number of quads (2 or 4) used

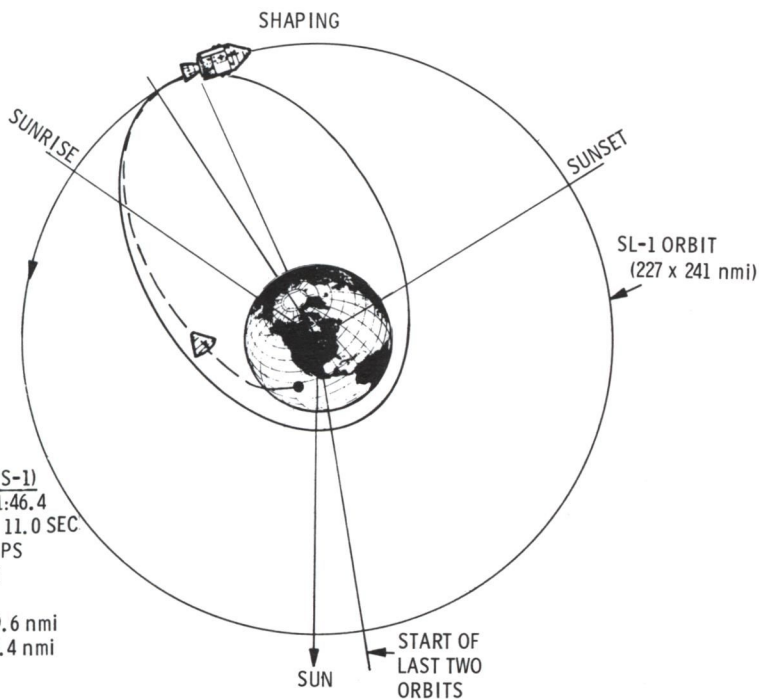
Vehicle weight, and pitch and yaw trim engine gimbal angles, for DAP data load

Star number, and optics shaft and trunnion angles

GDC align angles for failed IMU

SHAPING - SPS1

EVENT	BT/ΔV	G. E. T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
SHAPING	11.0/264.1	Day 27 21:01:46.4	SPS/G&N EXT ΔV	P-30
	ΔV _x N85		+ x x x	h
	ΔV _y RESIDUALS (ft/s)		+ x x x	min GET
	ΔV _z (BODY AXIS)		+ x	s
<div> <div>— · — · — V_{x_TRIM}</div> <div>— · — · — V_{y_TRIM}</div> <div>— · — · — V_{z_TRIM} (ft/s)</div> </div>				

SHAPING (SPS-1)

TIG: 27:21:01:46.4

BURN TIME: 11.0 SEC

ΔV: 264.1 FPS

RETRO GRADE

SPS

APOGEE: 229.6 nmi

PERIGEE: 90.4 nmi

P52 - IMU REALIGN (CM)(POST SHAPING)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000x

1 = Preferred, 2 = Nominal

3 = REFSMMAT

V51 Flashing

x	0	0	0	0		P52 Option		x	0	0	0	0	
+	0	0				Hours	} GET of Gyro Torquing	+	0	0			
+	0	0	0			Minutes		+	0	0	0		
+	0			.		Seconds						.	
x	0	0				Sensor/Celestial Body Code 1	N71	x	0	0			
x	0	0				Sensor/Celestial Body Code 2	N71	x	0	0			
						Outer	} Star Tracker Gimbal Angles (arc-min)	N14					
						Inner							
				.		Star Angle Difference	N05					.	
				.		Star Angle Measured						.	
		.				X	} Gyro Torquing Angles (Degrees)	N93			.		
		.				Y				.			
		.				Z				.			
			.			X	} Calculated Gyro Drift (meru)				.		
			.			Y					.		
			.			Z					.		

NOTES: Sensor/Celestial Body Code 00CDE

C = 0, CSM Optics
C = 1, Sun Sensor
C = 2, Star Tracker

DE = 46, Sun
DE = 04, Achernar
DE = 14, Canopus
DE = 25, Acrux

} Expected Codes for
ATM Sensor Sightings

N14 is applicable for Star Tracker (C = 2) sighting only

ENTRY PAD UPDATE

P61 Enter

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			+	
P .05G	+			0	0	+			0	0
N61 LAT		0		.		0		.		
LONG				.				.		
RTOGO .05G	+			.		+			.	
VIO .5G	+			.		+			.	
DET .05G	x	x		.		x	x		.	
RET .2G	x	x		.		x	x		.	
N66 DRE				.					.	
BAND AN	R			/		R			/	
RET RB	x	x		.		x	x		.	
RET BBO	x	x		.		x	x		.	
RET EBO	x	x		.		x	x		.	
RET DROG	x	x		.		x	x		.	

ENTRY UPDATE PAD DESCRIPTION

Revolution number and landing area

Pitch angle at .05G (P .05G)

Latitude and longitude of splashdown point (LAT, LONG), noun 61 display

EMS initialization value for range-to-go at .05G (RTOGO .05G)

EMS initialization value of inertial velocity at .05G (VIO .05G)

Time to .05G referenced from retroburn (RET .05G)

Time to .2G referenced from retroburn (RET .2G)

Downrange error (DRE), noun 66 display

Bank angle, roll (R) first in specified direction

Time to bank angle reversal from retroburn (RET RB)

Time to S-Band blackout from retroburn (RET BBO)

Time to the end of S-Band blackout from retroburn (RET EBO)

Time to drogue chute deployment from retroburn (RET DROG)

P30 - EXTERNAL ΔV

(Deorbit)

V37 Enter, 30 Enter

V06 N33 Flashing, Load Desired GET I

V06 N81 Flashing, Load Desired ΔV

PURPOSE																				
N33 HR	+	x	x								+	x	x							
MIN	+	x	x	x							+	x	x	x						
SEC	+	x									+	x								
N81 LOCAL ΔV_X		x										x								
VERT ΔV_Y		x										x								
ΔV_Z		x										x								
N22 R	+						0	0			+							0	0	
P	+						0	0			+							0	0	
Y	+						0	0			+							0	0	
ΔV_C	x	x									x	x								
BT	x	x									x	x								
ΔV_{70}	x	x									x	x								

ULLAGE: _____ SECS _____ QUADS _____

N47 WT + STAR xxxx GEC R

N48 PT xxx SFT +0 P

YT xxx TRN +00 Y

MANEUVER UPDATE (P30) PAD DESCRIPTION

GMT of ignition (GMTI) in noun 33 display

Change in velocity components in noun 81 display

Ground calculated S/C burn attitude relative to the IMU at GMTI called by V49 N22

EMS ΔV counter load (ΔV_C)

Burn duration (BT)

Change in velocity necessary to lower perigee below 70 nm (ΔV_{70})

Ullage duration, and number of quads (2 or 4) used

Vehicle weight, and pitch and yaw trim engine gimbal angles, for DAP data load

Star number, and optics shaft and trunnion angles

GDC align angles for failed IMU

DEORBIT MANEUVER

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 = 00204, 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 V1ashing V82 Enter
 V16 N44 Flashing, Apogee Altitude,
 Perigee Altitude, Time to Freefall
 to 300 k ft. Earth Orbit

					50-18	Roll
						Pitch (deg)
						Yaw
					06-18	Roll
						Pitch (deg)
						Yaw
					06-40	TFI (min:s)
						VG (ft/s)
						Δ VM (ft/s)
					06-40	TFC (min:s)
						VG (ft/s)
						Δ VM (ft/s)
					16-40	TFC (min:s)
						VG (ft/s)
						Δ VM (ft/s)
					85	X
						Y Residuals (ft/s)
						Z
					85	X
						Y TRIM (ft/s)
						Z
					44	HA (nmi)
						HP (nmi)
						TFF (min:s)

NOTES:

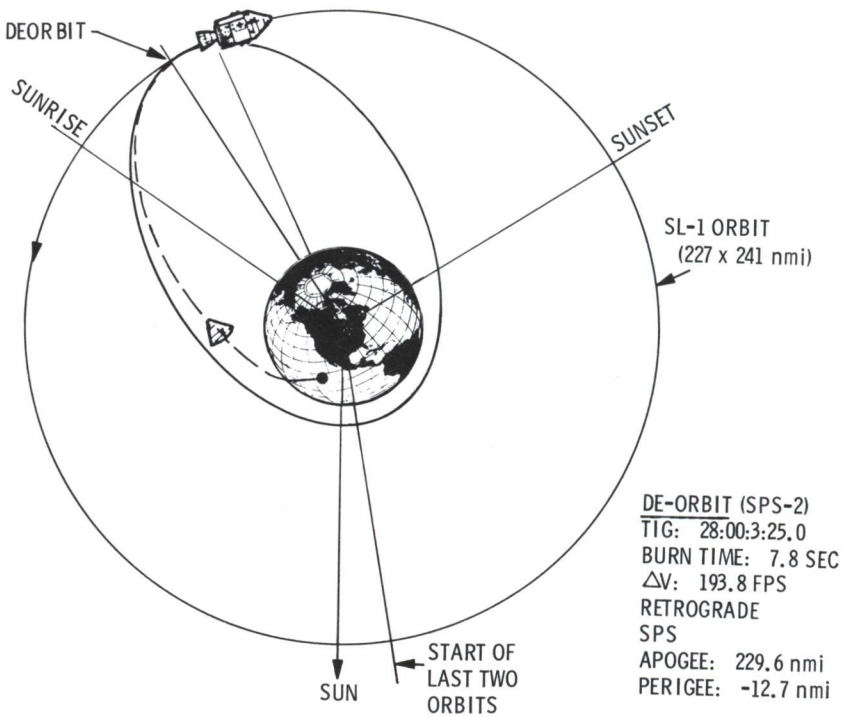
P41 - RCS THRUSTING

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	

DEORBIT - SPS2

EVENT	BT/ΔV	G.E.T.	PROPULSION/ GUIDANCE	PRETHRUST TARGETING
DEORBIT	7.8/193.8	Day 28 00:03:25.0	SPS/G&N	P-30
	ΔV _x N85		+ x x x	h
	ΔV _y RESIDUALS (ft/s)		+ x x x	min GET
	ΔV _z (BODY AXIS)		+ x	s
<div> <div>-----•- V_xTRIM</div> <div>-----•- V_yTRIM</div> <div>-----•- V_zTRIM (ft/s)</div> </div>				



APOLLO EARTH ENTRY

Aerodynamic Forces

The earth entry trajectory is shaped by the forces of gravity and atmospheric flow over the spacecraft surface. The latter force has two components, lift and drag.

Drag is a force directed opposite to the relative velocity vector and equal to:

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

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

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

where,

ρ = Atmospheric density (slugs/ft³)(1)

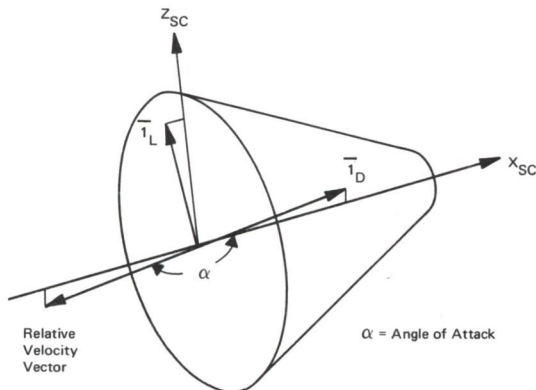
v = Relative velocity magnitude (ft/s)

C_D = Coefficient of drag (unitless)

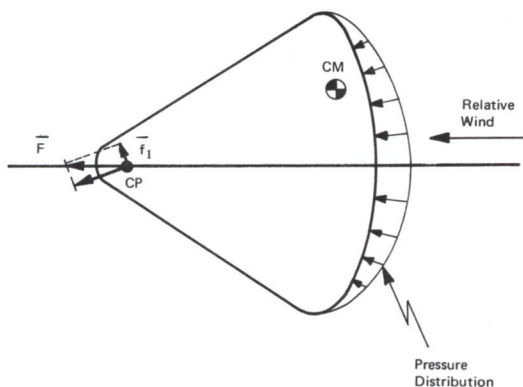
C_L = Coefficient of lift (unitless)

M = Mass of spacecraft (slugs)

S = Surface area presented to atmospheric flow (ft²)



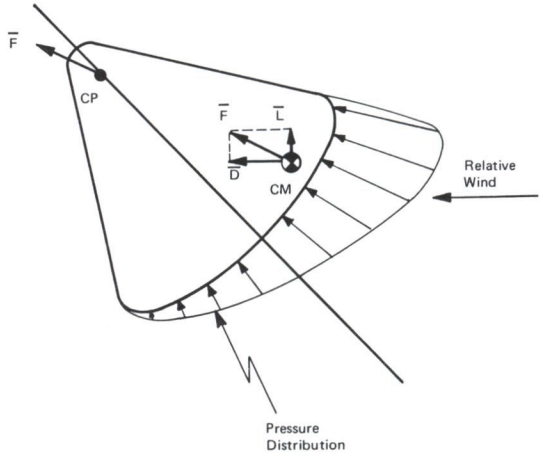
Aerodynamic lift (or C_L) is a consequence of the vehicle center-of-mass (CM)(2) being offset from its axis of symmetry. With the relative velocity vector along the axis of symmetry, the resulting symmetrical pressure distribution produces a resultant force (\vec{F}) through the center-of-pressure (CP)(3). The component of this force (\vec{F}_1) perpendicular to the line joining the CP and CM causes a torque about the CM. The spacecraft will rotate about the CM until a stable attitude is reached where the force \vec{F} is fully along the line joining the CM and CP.



Notes:

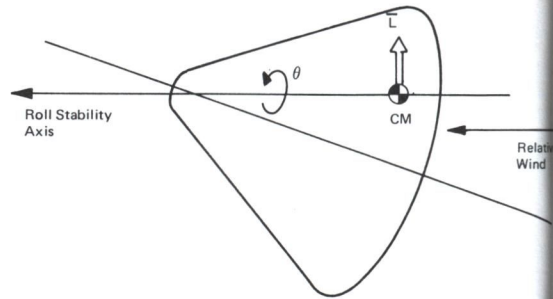
1. A slug is a constant, relating units in the equation
 $F(\text{pound-force}) = M(\text{slugs}) \times a(\text{ft/s}^2)$
2. Center-of-mass: The point where the mass of a body may be regarded as being concentrated, insofar as motion of translation is concerned.
3. Center-of-pressure: The point where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

In this stable attitude, the component of \vec{F} perpendicular to the relative velocity vector produces lift. Because of the spherical shape of the heat shield, the stable attitude remains relatively unchanged throughout the entry phases.

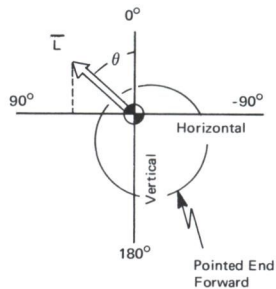


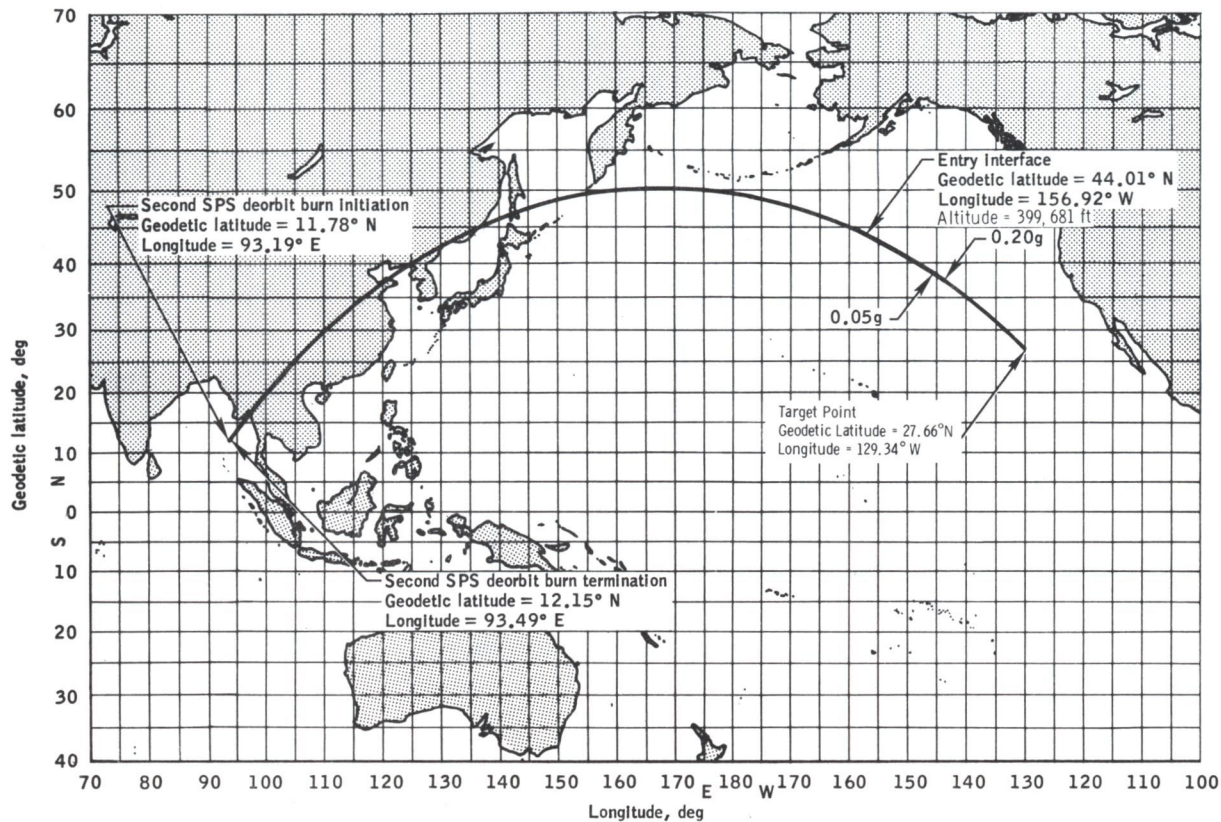
Lift Modulated Entry

During earth entry, steering is accomplished by orienting the lift vector (\vec{L}) so that the resulting specific forces satisfy the entry guidance objectives. The lift vector is rotated about the Roll Stability Axis according to roll commands issued by the AGC.



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

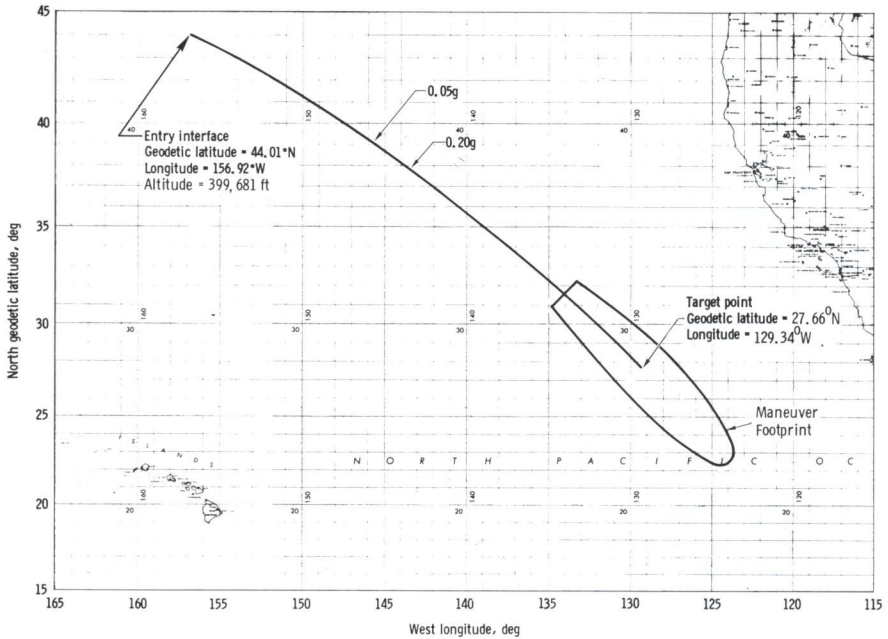




Entry Ground Trace for SPS Deorbit Maneuver

The entry control programs are designed to calculate the roll angle (ϕ) 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.

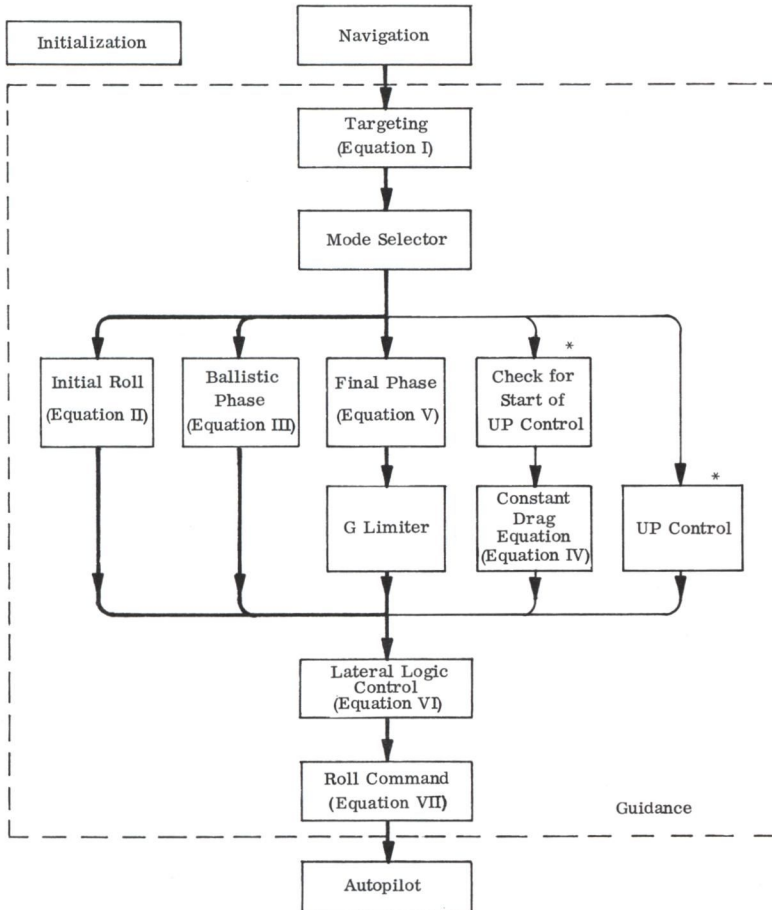
The maneuver footprint for a GNCS-controlled entry for the Skylab earth orbits uses mainly a ballistic entry and a modified roll angle lift controlled profile. A typical entry footprint is shown below. The constant drop and lift modulated flight is still available in the software coding but is not used.



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.

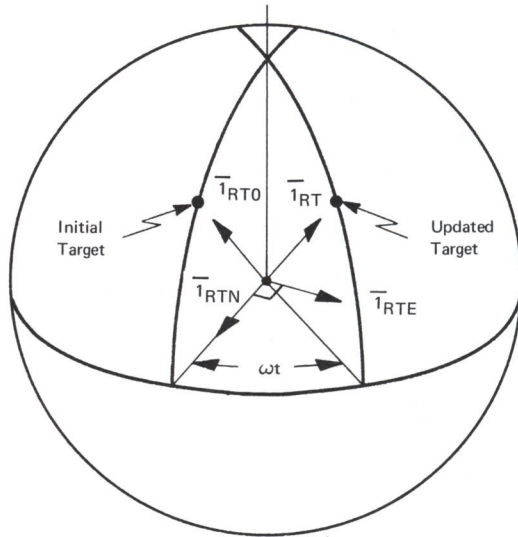
The guidance equations below are used during the entry phases associated with a nominal earth orbit entry. Equation 1 (targeting) is executed every pass through the computation loop. Equations III, and IV are executed during their particular entry phases for downrange steering. Lateral steering is done by Equation VI dependent upon certain logic constraints in the AGC. The roll angle needed to meet the above equations is calculated using Equation VII.



* Up control and constant drag are not used for earth orbit re-ENTRY but are characteristic of high velocity lunar return re-entry.

Equation I: Landing Point Targeting Equations

During the early entry phases, a unit vector is calculated which points from the earth's center to an estimated splash point. This initial target vector (\hat{I}_{RTO}), together with unit vectors in the equatorial plane directed easterly (\hat{I}_{RTE}) and in the target meridian (\hat{I}_{RTN}), is used as a reference from which a new target vector (\hat{I}_{RT}) is calculated based on an updated estimate of time-to-splash.



$$\vec{1}_{RT} = \vec{1}_{RT0} + \vec{1}_{RTN} [\cos(\omega t) - 1] + \vec{1}_{RTE} \sin(\omega t)$$

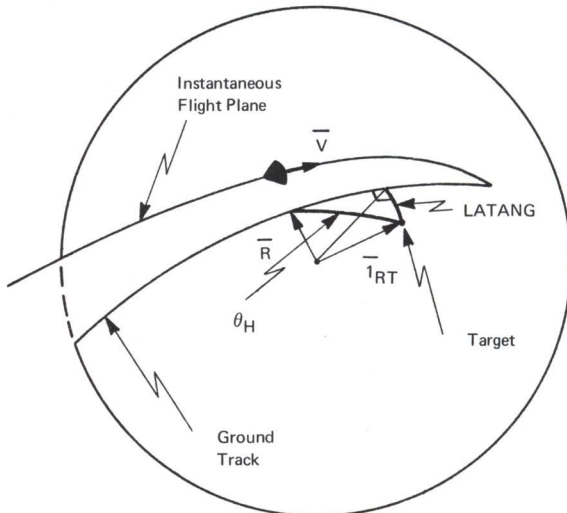
where (ωt) is the amount of earth's rotation for the difference between the old and new estimate of time-to-splash.

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

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

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

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



Equation II: Initial Roll Angle

The Initialization supplies the initial roll angle to the initial roll angle routine.

$$\theta_{\text{roll}} = \arccos \left(\overline{I_{RT}} \cdot \text{UNIT } \overline{R} \right) \text{ radians}$$

This is proportional to the updated remaining down range to go.

The remainder of the routine checks that the drag lift ratio and velocity are in the range of earth orbit re-entry and picks the desired life/drag ratio sign. In addition, the drag to lift ratio is limited such that drag acceleration does not exceed 1.5 g's. After the initial pass, the selector is set to pass through the ballistic equations.

Equation III: Ballistic Equation

During the ballistic mode, the attitude control is maintained for zero side slip, trim angle of attack. The roll control will be a constant roll angle that will include a cross range correction.

The routine also checks the total acceleration against a reference drag acceleration to decide when to use the final phase equations.

Equation IV: Constant-Drag Flight Equation

Reduction of near-parabolic velocities (associated with the lunar return mission) to a point where capture in the earth's atmosphere is assured, is accomplished by flying a constant-drag trajectory.

Constant-drag guidance is achieved using an on-board computed reference trajectory and constant guidance factors for compensation of off-nominal conditions. The control reference parameters are computed using the following constant drag relationships.

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

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

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

where

V = velocity (ft/s)

R = radial distance (ft)

g = gravity (ft/s²)

D_0 = desired drag level (ft/s²)

β = constant associated with atmosphere $\left(\frac{1}{R} \right)$

Gain factors were chosen which relate perturbations in drag and altitude rate to the reference L/D .

$$(L/D)_{\text{control}} = (L/D)_{\text{Ref}} + 0.01 (D - D_{\text{Ref}}) - 0.002 (\dot{R} - \dot{R}_{\text{Ref}})$$

The constant drag is included for reference and is not used in earth orbital entry.

Equation V: Final Phase Equation

Steering through the denser portions of atmosphere is accomplished using a terminal control method of guidance. A mean terminal glide trajectory is prestored into the AGC. Linear perturbation coefficients, used to adjust for deviations in flight parameters from nominal values, are also stored. Using velocity as the independent variable, the various quantities in storage are chosen which are used in the basic control equation:

$$(L/D)_{\text{control}} = (L/D)_{\text{Ref}} + K_1 \left\{ (R - R_{\text{Ref}}) + K_2 (D - D_{\text{Ref}}) + K_3 (\dot{R} - \dot{R}_{\text{Ref}}) \right\}$$

where

$$\begin{aligned} (L/D)_{\text{Ref}} &= \text{constant value } (\approx 0.27) \\ R_{\text{Ref}} &= \text{reference range-to-go (radians)} \\ D_{\text{Ref}} &= \text{reference drag (ft/s}^2\text{)} \\ \dot{R}_{\text{Ref}} &= \text{reference altitude rate (ft/s)} \\ K_1 &= \text{sensitivity of L/D to deviations in range (unitless)} \\ K_2 &= \text{sensitivity of range to deviations in drag level (radians/ft/s}^2\text{)} \\ K_3 &= \text{sensitivity of range to deviations in altitude rate (radians/ft/s)} \end{aligned}$$

Equation VI: Crossrange (or Lateral) Control

Crossrange control is maintained only when the lateral error (LATANG) is in excess of 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 components of lift causes the spacecraft to steer laterally toward the target.

Equation VII: Commanded Roll Angle Equation

Using previously determined quantities (K2ROLL and L/D_{control}) the commanded roll angle is calculated by

$$\text{ROLLC} = (\text{K2ROLL}) \arccos \left[\frac{L/D_{\text{control}}}{L/D_{\text{Ref}}} \right] \quad (\text{degrees})$$

where

$$L/D_{\text{Ref}} \approx 0.3 \text{ (unitless)}$$

Entry Control Programs

The guidance function, which incorporates the entry control equations previously described together with certain logic decisions, can be considered as a basic set of AGC software programs (P60's). The programs are associated with various phases of the entry profile as described below.

P61 - Entry Preparation Program

- a. Purpose: Start navigation, check IMU alignment, and provide EMS initialization data in case of communications failures.
- b. Initiation: Astronaut keys DSKY - V37E 61E
- c. Steering: None, lift vector is oriented full-up (0 degrees) or full-down (180 degrees), according to the astronaut specifications.
- d. DSKY Displays:

V06N61

R1 - Impact latitude	Latitude of splash point	XXX.XX deg
R2 - Impact longitude	Longitude of splash point	XXX.XX deg
R3 - Heads up/down	± 1	

V06N60

R1 - G max	Maximum predicted g-load	XXX.XX g
R2 - V predicted	Predicted velocity at EI (400 K ft)	XXXXX ft/s
R3 - γ_{EI}	Predicted entry angle at EI	XXX.XX deg

V06N63

R1 - RTOGO	Range-to-go from 290,000-foot altitude	XXXX.X nmi
R2 - V_{io}	Predicted velocity at 290,000-foot altitude	XXXXX ft/s
R3 - T_{fe}	Time to 290,000-foot altitude	XXbXX m/s

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 or V37E62E.
- 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	XXX.XX deg
R2 - Impact longitude	XXX.XX deg
Re - Heads up/down	± 00001
	+ Up
	- Down

V06N22

R1 - AOG	} Desired final gimbal angles at EI	XXX.XX deg
R2 - AIG		XXX.XX deg
R3 - AMG		XXX.XX deg

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	XXX.XX g
R2 - V_i	Present velocity	XXXXX. ft/s
R3 - RTOGO	Range to the target	XXXX.X nmi

P64 - Post 0.05 g Program

- a. Purpose: Perform initial steering while awaiting subsequent phases.
- b. Initiation: P64 is entered automatically when 0.05 g is sensed by the GNCS.
- c. Steering:

When 0.05 g is sensed, a calculation is made to determine position of spacecraft in the entry corridor, and the lift vector is positioned full-up or full-down accordingly. The orientation is maintained until a precomputed drag level is exceeded (somewhat less than 1.5 g).

A constant drag trajectory is flown (≈ 4 g) until the altitude rate becomes greater (more positive) than -700 ft/s.

Range-to-go checks are made to determine whether the available range will permit a controlled skip maneuver. Because the nominal range-to-target at EI is 1,250 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 the exit is made to the final phase.

- d. DSKY Displays

V06N74

R1 - BETA	Commanded roll angle (bank angle)	XXX.XX deg
R2 - V_i	Inertial velocity	XXXXX ft/s
R3 - G	Present g-load (drag acceleration)	XXX.XX g's

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 earth deorbit
 - 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

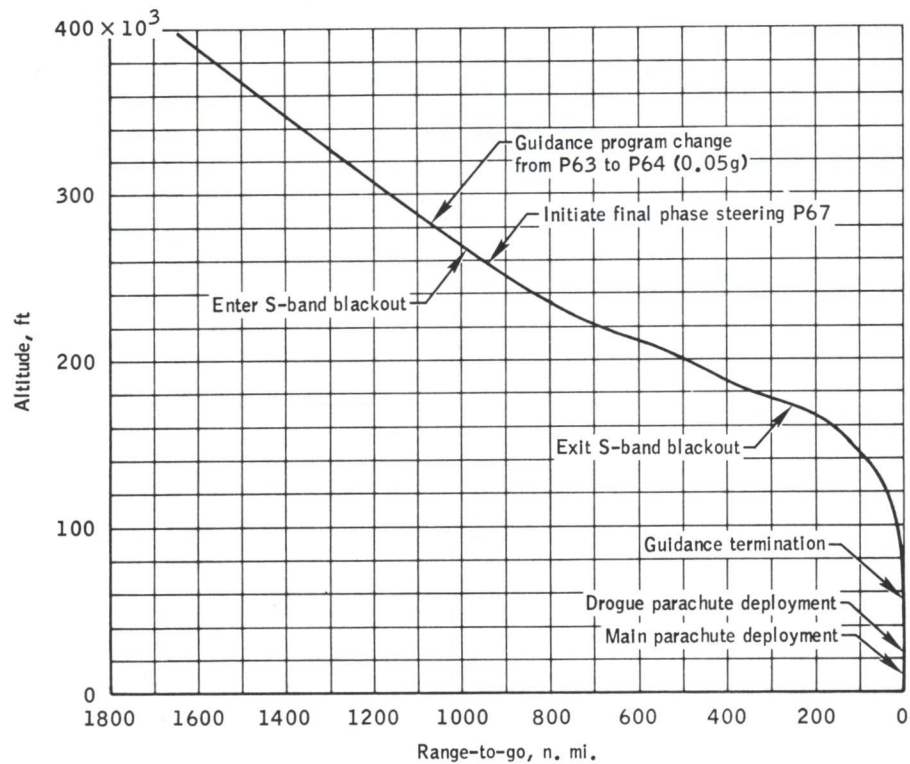
R1 - BETA	Commanded roll angle (bank angle)	XXX.XX deg
R2 - XRNERR	Crossrange error*	XXXX.X nmi
R3 - DWRNGER	Downrange error**	XXXX.X nmi

V16N67

R1 - RTOGO	Range to target	XXXX.X nmi
R2 - LAT	Present latitude	XXX.XX deg
R3 - LONG	Present longitude	XXX.XX deg

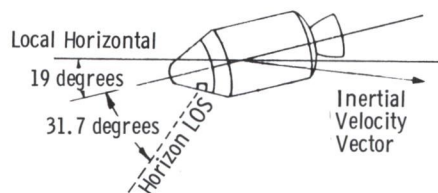
* Cross range error - Positive if target south of trajectory plane

** Down range error - Positive for overshoot.

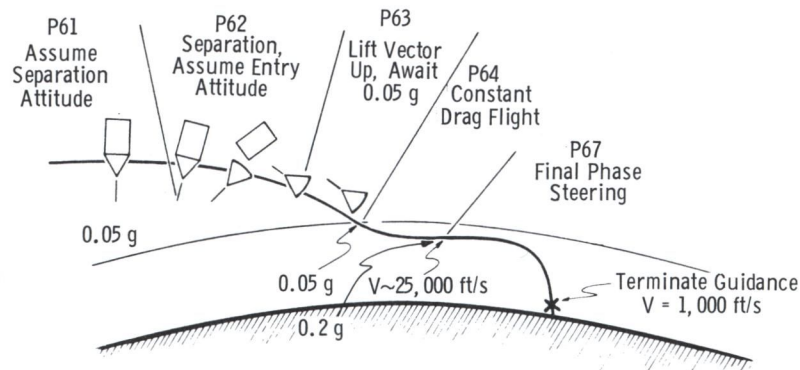
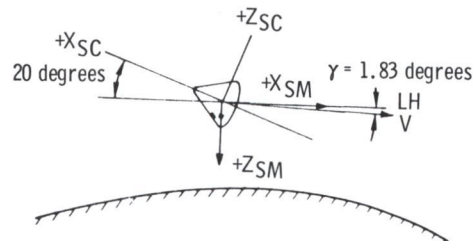


Altitude and Range Profile for Entry

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 Error Nmi Δ	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
Apollo 13	-21.66	165.37	-21.64	165.38	1.3	-21.64	165.36	3.9	-21.64	165.36	1.0	Lunar Return
Apollo 14	-27.02	172.65	-27.02	172.65	0	-27.00	172.659	1.3	-27.01	172.66	.62	Lunar Return
Apollo 15	-26.13	158.13	-26.13	158.13	0	-26.125	158.15	1.5**	-26.13	158.14	.63	Lunar Return
Apollo 16	-00.71	-156.18	-00.72	156.21	1.9	-00.74	-156.243	4.00**	Not Available			Lunar Return
Apollo 17	17.88°	166.13	17.88	166.11	1.2	Not Available			Not Available			Lunar Return
Mean Error					1.33			3.23			1.35	
STD Deviation					.996			+ 1.82			+0.61	

* Onboard data lost during entry - miss distance is best estimate

** Ship Report based on Nav Satellite Fix

ENTRY PAD UPDATES

P61

V37 Enter, 61 Enter

V06 N61 Flashing

V06 N60 Flashing, Record

V06 N63 Flashing, Used if no communication

P62

V50 N25 Flashing Request CM/SM Separation

V06 N61 Flashing

V06 N22 Monitor

P63

V06 N64 Monitor

AREA	x			—		x			—	
P .05G	+			0	0	+			0	0
N61 LAT		0					0			
LONG										
RTOGO .05G	+					+				
VIO .05G	+					+				
RET .05G	x	x				x	x			
RET .2G	x	x				x	x			
N66 DRE										
BANK AN	R			/		R			/	
RET RB	x	x				x	x			
RET BBO	x	x				x	x			
RET EBO	x	x				x	x			
RET DROG	x	x				x	x			

ENTRY UPDATE PAD DESCRIPTION

Revolution number and landing area

Pitch angle at .05G (P .05G)

Latitude and longitude of splashdown point (LAT, LONG), noun 61 display

EMS initialization value for range-to-go at .05G (RTOGO .05G)

EMS initialization value of inertial velocity at .05G (VIO .05G)

Time to .05G referenced from retroburn (RET .05G)

Time to .2G referenced from retroburn (RET .2G)

Downrange error (DRE), noun 66 display

Bank angle, roll (R) first in specified direction

Time to bank angle reversal from retroburn (RET RB)

Time to S-Band blackout from retroburn (RET BBO)

Time to the end of S-Band blackout from retroburn (RET EBO)

Time to drogue chute deployment from retroburn (RET DROG)

PERTURBATIONS

GYROCOMPASS BOOST MONITOR RENDEZVOUS DEORBIT ENTRY

GYRO COMPASSING PERTURBATION ANALYSIS

The perturbing of the gyro compassing loop results in two distinct type of errors.

They are:

- A temporary transient in gimbal angles that settles out in a length of time.
- Steady state changes in gimbal angles that reflect as misalignments for boost, and accelerometer and gyro errors during the boost phase.

The changes in steady state gimbal angles for changes in gyro drifts and accelerometers biases are drawn in Table A. The results were obtained from a computer simulation run.

The standoffs in gimbal angles for gyro drifts can be approximated by

$$\begin{bmatrix} \Delta AI \\ \Delta AM \\ \Delta Ao \end{bmatrix} = \frac{206}{3600} \begin{bmatrix} 0 & 0 & \frac{-\cos \Psi}{68.8 C_F K} \\ 0 & 0 & \frac{-\sin \Psi}{68.8 C_F K} \\ \frac{\cos \Psi}{\cos \lambda} & \frac{\sin \Psi}{\cos \lambda} & \frac{C_p}{\cos \lambda} \end{bmatrix} \begin{bmatrix} NBDy + ADSRay \\ NBDx \\ -NBDz - ADIAz \end{bmatrix}$$

where
 ΔAO

$\Delta AI, \Delta Am, \Delta Ao$ = the steady state gimbal angles standoff in degrees.

$NBDx, NBDy, NBDz$ = the changes in normal bias drift in meru that are not compensated for in the IMU compensation routine

Ψ = Gyro compass azimuth (east of north)

λ = Latitude of Local launch

C_p = Proportional gain (.062)

C_F = Filter gain (0.1)

K = Computer scaling (128)

$ADIAx, ADIAy, ADIAz$ = The change in acceleration sensitive drift not compensated in the IMU compensation routine.

$$68.8 = \frac{g}{K_{\text{pipa}}} \cdot \frac{K_{\text{gyro}}}{K_{\text{meru}}}$$

g = local gravity

After the gimbal angles have settled out, a change in launch azimuth may be required because of the time of launch changing. This is accomplished by computer entries of

V78E

Flashing

V06N29 Xsm Launch Azimuth

XXX.XX deg

V21E Load New Launch Azimuth

XXX.XX deg

GYRO COMPASSING PERURBATION ANALYSIS (cont)

PRO

The computer computes the changes required in gyro torquing, torques the gyros, enters a period of vertical erect for 320 seconds and then returns to gyro compassing.

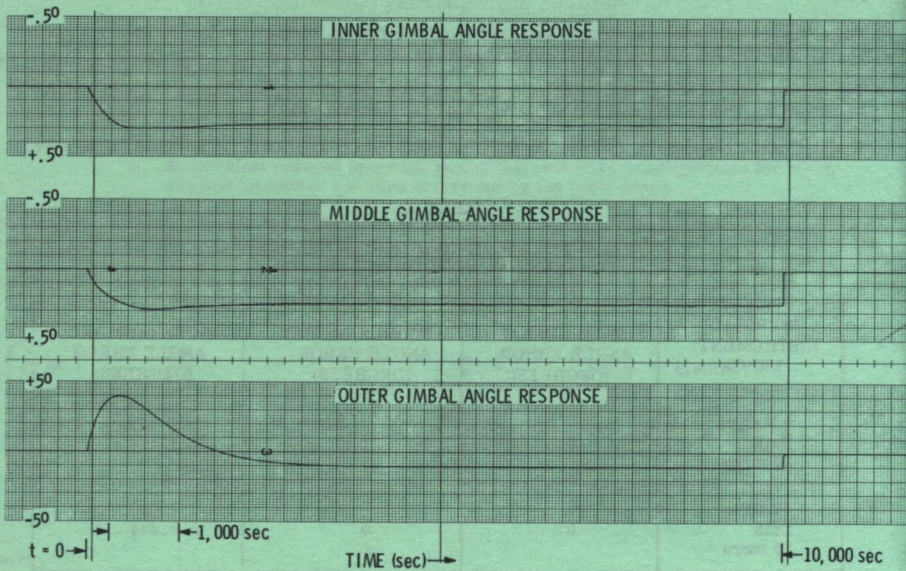
Typical reponses of the gimbal angles changes are shown for the nominal launch azimuth and the responses for launch azimuths at the "early" and "late" launch windows.

The size of the response is governed by the time earth rate compensation is not used on the gyros.

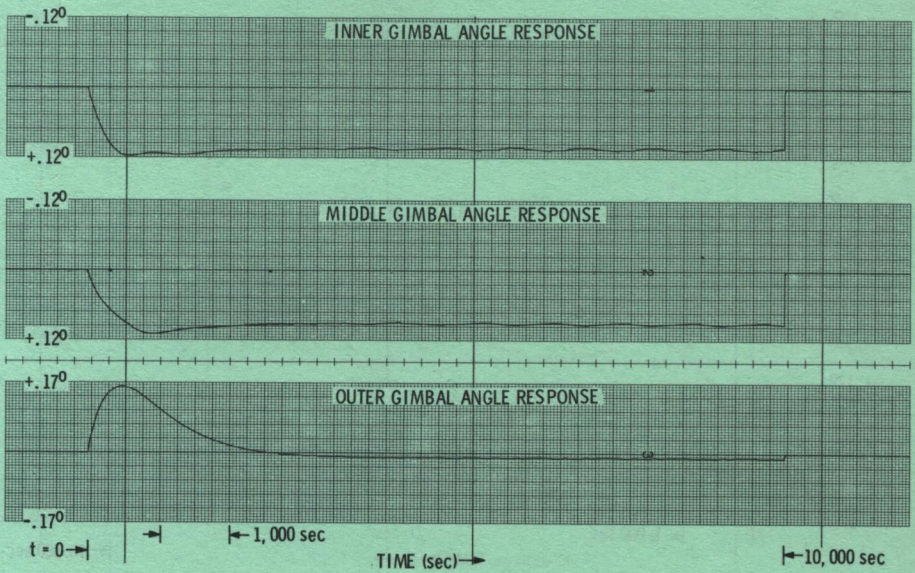
TABLE A
STEADY STATE GIMBAL ANGLE ERRORS
FOR INERTIAL INSTRUMENT ERRORS

INERTIAL INSTRUMENT ERROR	INNER GIMBAL ANGLE ERROR (DEGREES)	MIDDLE GIMBAL ANGLE ERROR (DEGREES)	OUTER GIMBAL ANGLE ERROR (DEGREES)
+ X Gyro Drift 10 meru	0	0	+.476
+Y Gyro Drift 10 meru	0	0	+.444
+Z Gyro Drift 10 meru	0	0	-.041
-X Gyro Drift 10 meru	0	0	-.476
-Y Gyro Drift 10 meru	0	0	-.444
-Z Gyro Drift 10 meru	0	0	+.041
X Pipa Bias +.032808 ft/s ²	-.059	0	+.020
Y Pipa Bias -.032808 ft/s ²	0	+.059	+.020
X PIPA Bias -.032808 ft/s ²	+.059	0	-.020
Y PIPA Bias -.032808 ft/s ²	0	-.059	-.020

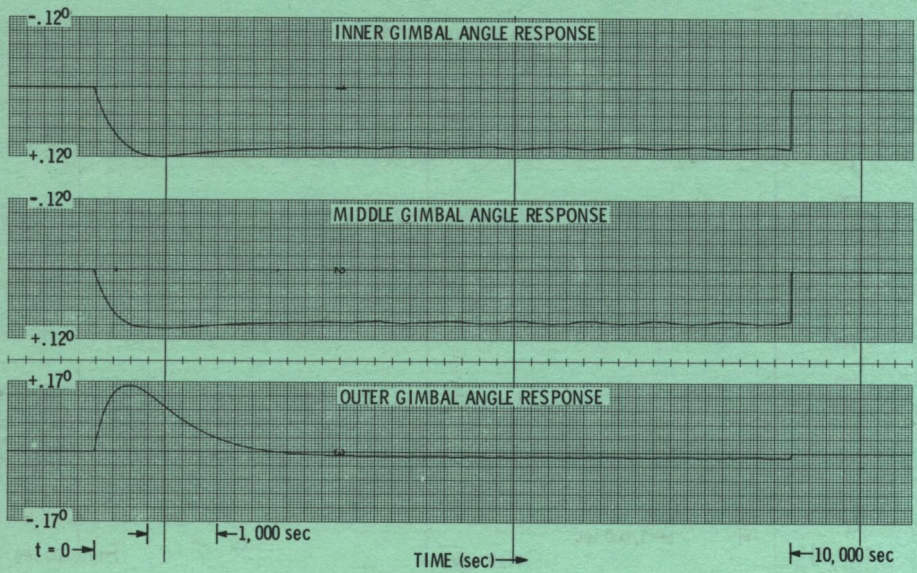
NOMINAL LAUNCH AZIMUTH GIMBAL ANGLE RESPONSES FOR GYRO COMPASSING



Nominal Launch Azimuth	=	47.035° East of North
Initial Inner Gimbal Angle	=	89.75°
Initial Middle Gimbal Angle	=	359.75°
Initial Outer gimbal Angle	=	138.035°
Final Inner Gimbal Angle	=	90°
Final Middle Gimbal Angle	=	0°
Final Outer Gimbal Angle	=	137.038°

"EARLY" LAUNCH AZIMUTH GIMBAL ANGLE RESPONSES FOR GYRO COMPASSING AFTER VERTICAL ERECT

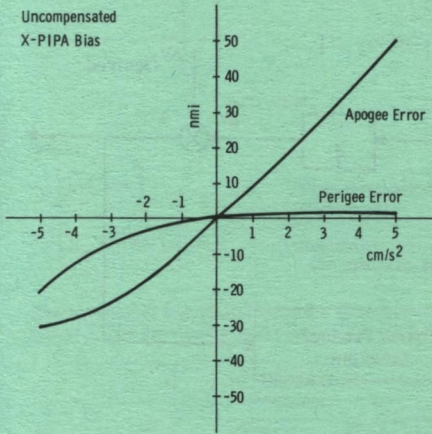
"Early" Launch Azimuth	=	51.701° East of North
Initial Inner Gimbal Angle	=	89.9°
Initial Middle Gimbal Angle	=	359.9°
Initial Outer Gimbal Angle	=	141.801°
Final Inner Gimbal Angle	=	90.0°
Final Middle Gimbal Angle	=	0°
Final Outer Gimbal Angle	=	141.705°

"LATE" LAUNCH AZIMUTH GIMBAL ANGLE RESPONSES FOR GYRO COMPASSING AFTER VERTICAL ERECT

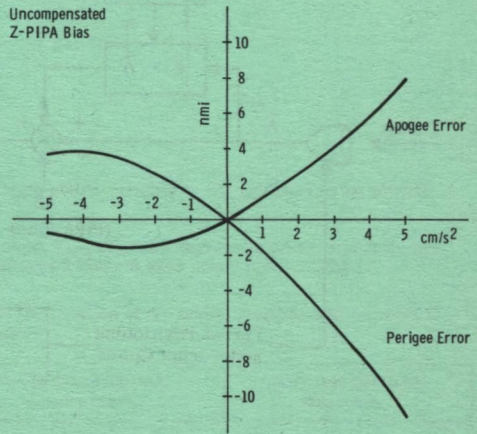
"Late" Launch Azimuth	=	37.849° East of North
Initial Inner Gimbal Angle	=	89.9°
Initial Middle Gimbal Angle	=	359.9°
Initial Outer Gimbal Angle	=	127.949°
Final Inner Gimbal Angle	=	90.0°
Final Middle Gimbal Angle	=	0°
Final Outer Gimbal Angle	=	127.849°

BOOST MONITOR ERRORS (SIGNIFICANT IMU ERRORS ONLY)

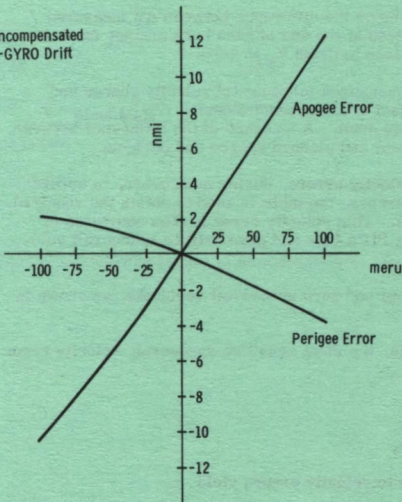
Uncompensated
X-PIPA Bias



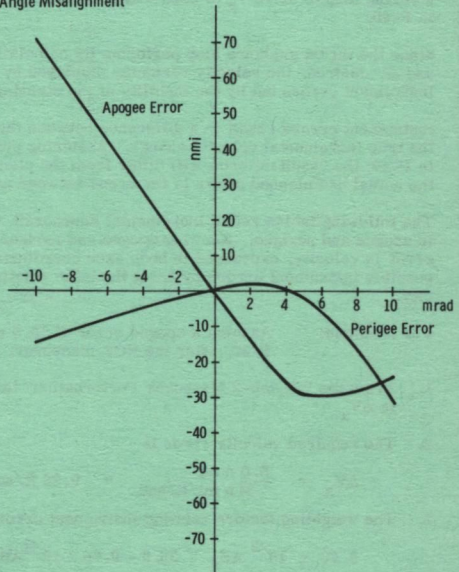
Uncompensated
Z-PIPA Bias



Uncompensated
Y-GYRO Drift

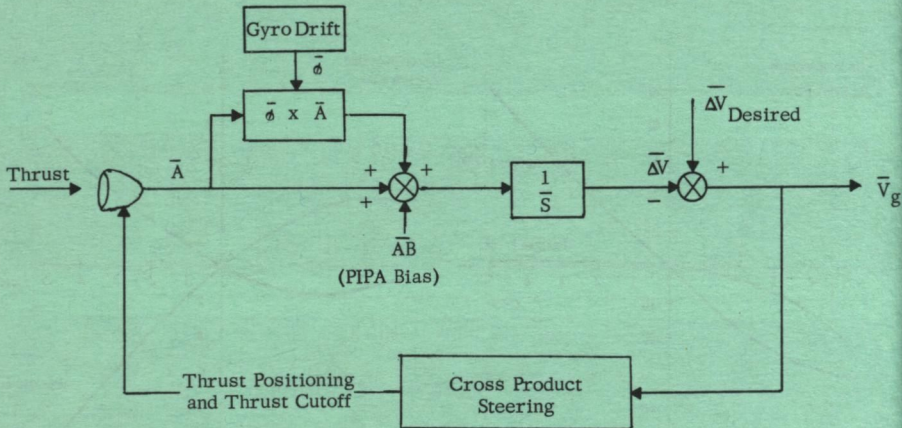


Initial INNER GIMBAL
Angle Misalignment



EFFECT OF INSTRUMENT ERRORS ON THRUST GUIDANCE

The thrust guidance used on Skylab, in simplified form, is as follows



The above steering loop attempts to drive V_g (velocity to be gained) to zero. The inability of the steering loop to drive V_g to zero will result in velocity residuals at the end of the burn as displayed in P-40.

Since the thrust guidance loop performs its calculations on the difference between ΔV measured and ΔV desired, the velocity residuals displayed by P-40 at the end of each burn are not caused by instrument errors but by the inability of the steering loop to drive V_g to zero.

Instrument errors result in a difference between the measured incremental velocity change and the true incremental velocity change. Assuming perfect cross product steering ($V_{\text{Residuals}} = 0$ in P-40) the resultant orbit will differ from the planned orbit. A measure of the difference between the actual and planned orbits is the error between actual and planned apogee and perigee.

The following tables relate incremental spacecraft velocity errors, during 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 apogee error of +5.0 n mi and zero spacecraft residuals, as shown in P-40, after the NC2 maneuver.

1. From the "Skylab-2 Maneuver Perturbation" table, the most sensitive spacecraft velocity error is ΔV_x .
2. The required velocity error is

$$\Delta V_x = \frac{5.0 \text{ n mi}}{.54 \text{ n mi/ft/sec}} = 9.26 \text{ ft/sec}$$

3. The weighting factors relating instrument errors to velocity errors yield

$$3.06 \times 10^{-2} AB_x \times 36.9 - 0.06 \times 10^{-2} AB_y \times 36.9 + 1.19 \times 10^{-2} AB_z \times 36.9 = 9.26 \text{ ft/sec}$$

$$1.13 AB_x - 0.02 AB_y + 0.44 AB_z = 9.26 \text{ ft/sec}$$

Therefore:

$$\text{Uncompensated } AB_x = 8.2 \text{ cm/sec}^2$$

$$\text{or } \text{Uncompensated } AB_z = 21 \text{ cm/sec}^2$$

AB_y contribution is negligible in comparison to AB_x and AB_z

EFFECT OF INSTRUMENT ERRORS ON THRUST GUIDANCE (CONTINUED)

The "Skylab-2 Maneuver Perturbation" table also gives the transformation from stable member spacecraft body control axes space as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{S/C \text{ CSM}} = \begin{bmatrix} R_x (-7.25^\circ) \end{bmatrix} \begin{bmatrix} SM-NB \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}$$

where:

$$\begin{bmatrix} SM-NB \end{bmatrix} = \text{Transformation from stable member to the nav base using gimbal angles}$$

$$\begin{bmatrix} R_x (-7.25^\circ) \end{bmatrix} = \text{Rotation matrix about } X_{NB} \text{ of } -7.25 \text{ degrees to transform from nav base space to spacecraft control axes space for the CSM}$$

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)
NC1	180	339	2
NC2	180	159	1
NCC	180	340	1
NSR	180	198	2
TPI	359	25	1
SHAPING	0	183	359
DEORBIT	0	180	359

For all maneuvers thrust is assumed along $+X_{S/C}$ axis

SKYLAB-2 MANEUVER PERTURBATIONS

MANEUVER	BODY AXES VELOCITY ERRORS	ERROR IN PERIGEE (nmi/ft/s)	ERROR IN APOGEE (nmi/ft/s)	STABLE MEMBER TO SPACECRAFT CONTROL AXES TRANSFORMATION [SC] = [M] [SM]	REFSMMAT [SM] = [REFSMMAT] [BRS] BRS = BASIC REFERENCE SYSTEM			
NC1	ΔV_x	-	0.58	$\begin{bmatrix} 0.932 & 0.033 & 0.361 \end{bmatrix}$	$\begin{bmatrix} 0.636 & -0.271 & 0.722 \end{bmatrix}$	$\begin{bmatrix} -0.367 & 0.717 & 0.593 \end{bmatrix}$	=	$\begin{bmatrix} \text{RENDEZVOUS} \end{bmatrix}$
	ΔV_y	-	-	$\begin{bmatrix} -0.018 & -0.990 & 0.138 \end{bmatrix}$	$\begin{bmatrix} -0.679 & -0.642 & 0.357 \end{bmatrix}$			
	ΔV_z	-	-	$\begin{bmatrix} 0.362 & -0.135 & -0.922 \end{bmatrix}$				
NC2	ΔV_x	0.05	0.54	$\begin{bmatrix} -0.932 & 0.017 & -0.362 \end{bmatrix}$	Same as NC1			
	ΔV_y	-	-	$\begin{bmatrix} 0.028 & -0.992 & -0.119 \end{bmatrix}$				
	ΔV_z	0.08	-0.07	$\begin{bmatrix} -0.361 & -0.121 & 0.925 \end{bmatrix}$				
NCC	ΔV_x	-	0.58	$\begin{bmatrix} 0.941 & 0.023 & 0.337 \end{bmatrix}$	Same as NC1			
	ΔV_y	-	-	$\begin{bmatrix} -0.023 & -0.991 & 0.130 \end{bmatrix}$				
	ΔV_z	-	-	$\begin{bmatrix} 0.337 & -0.130 & -0.933 \end{bmatrix}$				
NSR	ΔV_x	-	0.58	$\begin{bmatrix} -0.953 & 0.028 & 0.302 \end{bmatrix}$	Same as NC1			
	ΔV_y	-	-	$\begin{bmatrix} -0.064 & -0.992 & -0.109 \end{bmatrix}$				
	ΔV_z	-	-	$\begin{bmatrix} 0.297 & -0.123 & 0.947 \end{bmatrix}$				
TPI	ΔV_x	-	0.53	$\begin{bmatrix} 0.906 & 0.012 & -0.424 \end{bmatrix}$	Same as NC1			
	ΔV_y	-	-	$\begin{bmatrix} -0.071 & 0.990 & -0.123 \end{bmatrix}$				
	ΔV_z	-	0.26	$\begin{bmatrix} 0.418 & 0.142 & 0.897 \end{bmatrix}$				
SHAPING	ΔV_x	-0.54	-	$\begin{bmatrix} -0.998 & -0.019 & 0.054 \end{bmatrix}$	$\begin{bmatrix} 0.545 & -0.343 & 0.765 \end{bmatrix}$	$\begin{bmatrix} 0.659 & -0.389 & -0.644 \end{bmatrix}$	=	$\begin{bmatrix} \text{DEORBIT} \end{bmatrix}$
	ΔV_y	-	-	$\begin{bmatrix} -0.012 & 0.991 & 0.136 \end{bmatrix}$	$\begin{bmatrix} 0.518 & 0.855 & 0.014 \end{bmatrix}$			
	ΔV_z	-0.13	-	$\begin{bmatrix} -0.056 & 0.135 & -0.989 \end{bmatrix}$				

ΔV_{SC} ERRORS CAUSED BY GYRO DRIFTS $\vec{B} \times \vec{A}$ 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 AVERAGE ROUTINE)
ΔT_g	-	SEC (TIME FROM LAST ALIGNMENT TO BURN)

WEIGHT FACTORS RELATE PIPA BIAS AND GYRO DRIFTS TO VELOCITY ERROR.

NC-1

$$\begin{aligned}\Delta V_{xSC} &= -3.06 \times 10^{-3} AB_x \Delta T_p - 0.10 \times 10^{-2} AB_y \Delta T_p - 1.19 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{ySC} &= 0.58 \times 10^{-5} NBDX \Delta T_g - 0.22 \times 10^{-5} NBDY \Delta T_g + 1.47 \times 10^{-5} NBDZ \Delta T_g \\ &\quad + 5.95 \times 10^{-4} AB_x \Delta T_p + 3.25 \times 10^{-2} AB_y \Delta T_p - 4.51 \times 10^{-3} AB_z \Delta T_p \\ \Delta V_{zSC} &= 0.03 \times 10^{-5} NBDX \Delta T_g + 1.58 \times 10^{-5} NBDY \Delta T_g + 0.22 \times 10^{-5} NBDZ \Delta T_g \\ &\quad - 1.19 \times 10^{-2} AB_x \Delta T_p + 4.42 \times 10^{-3} AB_y \Delta T_p + 3.03 \times 10^{-2} AB_z \Delta T_p\end{aligned}$$

NC-2

$$\begin{aligned}\Delta V_{xSC} &= 3.06 \times 10^{-2} AB_x \Delta T_p - 0.06 \times 10^{-2} AB_y \Delta T_p + 1.19 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{ySC} &= -0.42 \times 10^{-5} NBDX \Delta T_g - 0.14 \times 10^{-5} NBDY \Delta T_g - 1.08 \times 10^{-5} NBDZ \Delta T_g \\ &\quad - 0.91 \times 10^{-3} AB_x \Delta T_p + 3.26 \times 10^{-2} AB_y \Delta T_p + 0.39 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{zSC} &= -0.32 \times 10^{-6} NBDX \Delta T_g + 1.16 \times 10^{-5} NBDY \Delta T_g - 1.40 \times 10^{-6} NBDZ \Delta T_g \\ &\quad + 1.18 \times 10^{-2} AB_x \Delta T_p + 3.97 \times 10^{-3} AB_y \Delta T_p - 3.03 \times 10^{-2} AB_z \Delta T_p\end{aligned}$$

NCC

$$\begin{aligned}\Delta V_{xSC} &= -3.09 \times 10^{-2} AB_x \Delta T_p - 0.07 \times 10^{-2} AB_y \Delta T_p - 1.11 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{ySC} &= 0.75 \times 10^{-6} NBDX \Delta T_g - 0.29 \times 10^{-6} NBDY \Delta T_g + 2.08 \times 10^{-6} NBDZ \Delta T_g \\ &\quad + 0.74 \times 10^{-3} AB_x \Delta T_p + 3.25 \times 10^{-2} AB_y \Delta T_p - 0.42 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{zSC} &= 0.05 \times 10^{-6} NBDX \Delta T_g + 2.21 \times 10^{-6} NBDY \Delta T_g + 0.29 \times 10^{-6} NBDZ \Delta T_g \\ &\quad - 1.11 \times 10^{-2} AB_x \Delta T_p + 0.42 \times 10^{-3} AB_y \Delta T_p + 3.06 \times 10^{-2} AB_z \Delta T_p\end{aligned}$$

NSR

$$\begin{aligned}\Delta V_{xSC} &= 3.13 \times 10^{-2} AB_x \Delta T_p - 0.92 \times 10^{-3} AB_y \Delta T_p - 0.99 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{ySC} &= 0.41 \times 10^{-6} NBDX \Delta T_g - 0.17 \times 10^{-6} NBDY \Delta T_g - 1.32 \times 10^{-6} NBDZ \Delta T_g \\ &\quad + 0.21 \times 10^{-2} AB_x \Delta T_p + 3.25 \times 10^{-2} AB_y \Delta T_p + 0.36 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{zSC} &= 0.09 \times 10^{-6} NBDX \Delta T_g + 1.38 \times 10^{-6} NBDY \Delta T_g - 0.15 \times 10^{-6} NBDZ \Delta T_g \\ &\quad - 0.97 \times 10^{-2} AB_x \Delta T_p + 0.40 \times 10^{-2} AB_y \Delta T_p - 3.11 \times 10^{-2} AB_z \Delta T_p\end{aligned}$$

TFI

$$\begin{aligned}\Delta V_{xSC} &= -2.97 \times 10^{-2} AB_x \Delta T_p - 0.04 \times 10^{-2} AB_y \Delta T_p + 1.39 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{ySC} &= 0.63 \times 10^{-6} NBDX \Delta T_g + 0.21 \times 10^{-6} NBDY \Delta T_g - 1.35 \times 10^{-6} NBDZ \Delta T_g \\ &\quad + 0.23 \times 10^{-2} AB_x \Delta T_p - 3.25 \times 10^{-2} AB_y \Delta T_p + 0.40 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{zSC} &= 0.11 \times 10^{-6} NBDX \Delta T_g - 1.48 \times 10^{-6} NBDY \Delta T_g - 0.19 \times 10^{-6} NBDZ \Delta T_g \\ &\quad - 1.37 \times 10^{-2} AB_x \Delta T_p - 0.47 \times 10^{-2} AB_y \Delta T_p - 2.94 \times 10^{-2} AB_z \Delta T_p\end{aligned}$$

SHAPING

$$\begin{aligned}\Delta V_{xSC} &= 3.28 \times 10^{-2} AB_x \Delta T_p + 0.06 \times 10^{-2} AB_y \Delta T_p - 0.18 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{ySC} &= -1.08 \times 10^{-6} NBDX \Delta T_g + 2.60 \times 10^{-6} NBDY \Delta T_g + 1.90 \times 10^{-5} NBDZ \Delta T_g \\ &\quad + 0.04 \times 10^{-2} AB_x \Delta T_p - 3.25 \times 10^{-2} AB_y \Delta T_p - 0.45 \times 10^{-2} AB_z \Delta T_p \\ \Delta V_{zSC} &= 0.22 \times 10^{-6} NBDX \Delta T_g - 1.91 \times 10^{-5} NBDY \Delta T_g + 2.61 \times 10^{-6} NBDZ \Delta T_g \\ &\quad + 0.18 \times 10^{-2} AB_x \Delta T_p - 0.44 \times 10^{-2} AB_y \Delta T_p + 3.25 \times 10^{-2} AB_z \Delta T_p\end{aligned}$$

TYPICAL EARTH ORBIT ENTRY POSITION ERROR SENSITIVITIES
AT GUIDANCE TERMINATION

ERROR SOURCE (ϵ)		EARTH ORBIT ENTRY	
		Downrange Error (nmi/ ϵ)	Crossrange Error (nmi/ ϵ)
GYRO BIAS DRIFT (meru)	NBDX	0.0	-0.19
	NBDY	-0.10	0.0
	NBDZ	0.0	0.26
ACCELEROMETER BIAS (cm/sec ²)	ACBX	4.52	0.0
	ACBY	0.0	5.80
	ACBZ	-3.66	0.0

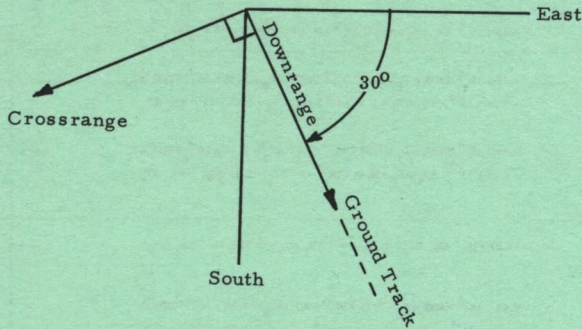
- NOTES: 1. Assumed accelerometer operation 15 minutes prior to EI (altitude of 400,000 feet).
2. Assumed IMU drift from 2.5 hours prior to EI.
3. Assumed IMU orientation is described by deorbit refsmmat such that at SPS-2

$$\bar{Z}_{SM} = -\text{Unit}(\bar{R})$$

$$\bar{Y}_{SM} = -\text{Unit}(\bar{R} \times \bar{V})$$

$$\bar{X}_{SM} = \bar{Y}_{SM} \times \bar{Z}_{SM}$$

4. Crossrange-downrange definition:



Nominal Earth Orbit Entry

DAP-1

DIGITAL AUTOPILOT

CSM-RCS DAP

TVC DAP

SATURN DAP

ENTRY DAP

DOCKED DAP

ATTITUDE ERROR DISPLAY

RATE FILTER

CSM DIGITAL AUTOPILOT

The CSM digital autopilot (DAP) provides a primary stabilization and control function and attitude error display for CSM or CSM/OWS coasting flight, CSM or CSM/OWS powered flight and CM entry, as well as a backup SATURN takeover function. The LM portions of the DAP remain in the software but are not applicable to the Skylab mission.

COASTING FLIGHT

The CSM coasting flight autopilot or reaction control system autopilot (RCS DAP) provides attitude and translation control in three CSM axes during nonthrusting phases of flight. The RCS DAP has three major modes of operation, Auto, Hold and Free, as commanded by the S/C CONTROL switch.

The Hold mode maintains or holds the spacecraft (S/C) at a desired attitude within the limits of an attitude deadband specified by the crew. Rotational hand controller (RHC) commands will be processed as the discrete commanded rate specified in the DAP variable load; a new desired attitude will be established and maintained upon release of the RHC.

The Auto mode enables rate and attitude commands from the steering routines to be processed by the DAP for maneuvering the S/C to a desired attitude at a specified rate. With the absence of maneuver commands, the Auto mode functions as an attitude hold mode. RHC commands are processed in the Auto mode as a discrete commanded rate and automatic maneuvering is terminated until resumed by crew action via the DSKY.

The Free mode of operation releases the S/C from all maneuvers and attitude hold commands, other than minimum impulse commands, and allows the S/C to drift freely. Minimum impulse commands are single 14-millisecond control jet firings which are commanded by the RHC or, if there are no RHC commands, by the minimum-impulse controller (MIC).

Translation hand controller (THC) commands are processed in any mode and are combined with rotation commands for the desired maneuver. When a combination rotation and translation is not possible, due to a quad failure, the rotation command has priority.

ERROR DISPLAY

The DAP also provides attitude error displays to the crew via the FDAI attitude error meters. There are three types of attitude error displays available. Each type of error display differences a set of reference angles with the present gimbal angles as read in N20, and transforms the differences to vehicle control axes. N20 is a set of CMC erasable counters which sum the incremental gimbal angle outputs of the CDU A/D converters. N20 cells are synched to the CDU read counters, and hence the gimbal resolvers, by means of a V40E which insures the cells and read counters are identically zero at that point in time. As the read counters are allowed to repeat the gimbal resolvers in the A/D Loops, the angle increments are summed in the erasable cells, thus repeating the gimbal resolvers. Care must be exercised to avoid overwriting the N20 cells, or ACDU's, since the CMC's knowledge of present gimbal angles will be destroyed.

- To provide a monitor of autopilot performance, the autopilot following errors or phase plane errors in control axis coordinates can be displayed by keying a V61E. The reference angles are known as desired CDU angles (DCDU) which describe the attitude at which the phase plane control law is exercised. This reference attitude is established by the DAP.
- To aid the crew in executing a manual maneuver, or for monitoring an automaneuver, the total attitude error with respect to the reference final desired maneuver angles in N22 can be displayed by Keying V62E. Final desired CDU angles (N22) are computed by the maneuver routines (R61, R63) for rendezvous pointing attitude and universal pointing attitude; P40, 41 for burn attitude and P52 and V41 for coarse align IMU. They are also manually loaded in the crew initiated maneuver (V49E) and are also known as FCDU angles. These are the "maneuver to" gimbal angles, provided a maneuver is in process and the maneuver routine is communicating maneuver commands to the DAP. The N22 angles may reflect the desired attitude of a completed maneuver and no longer influence operation of the DAP.

Total astronaut attitude error with respect to reference N17 angles can be displayed by Keying V63E thus providing another manual maneuver aid. N17 can be loaded with a snapshot of the present CDU angles by Keying V60E. Astronaut total attitude (N17) cells are not loaded internally by the CMC. They are a set of cells for use by, and loaded by the crew, possibly as an aid to manually maneuvering the vehicle to a crew specified attitude. The snapshot capability of V60E enables the crew to maneuver, and still maintain a set of reference angles for error display in returning to the original attitude.

POWERED FLIGHT

The powered flight autopilot stabilizes and controls the attitude of the spacecraft and maintains thrust vector control (TVC) during service propulsion system (SPS) thrusting. Pitch and Yaw axis control is achieved by TVC DAP generated commands to the SPS engine gimbal servos to maintain the thrust vector through the center of gravity of the vehicle. The TVC DAP also accepts angular rate commands from the steering program to position the thrust vector along a desired thrust direction.

Roll axis attitude and rate control during powered flight is accomplished by the TVC Roll DAP. Its function is strictly to provide attitude hold about the roll axis of the spacecraft by means of RCS thrusters.

ENTRY

The entry autopilot provides attitude control of the command module (CM) from separation from the service module (SM) to deployment of the drogue chutes. The DAP has an extra-atmospheric phase and an atmospheric phase. The extra-atmospheric phase provides three-axis spacecraft control for the trajectory segment prior to 0.05 g and accepts attitude commands from entry guidance to orient the S/C for the onset of 0.05 g. The atmospheric phase provides attitude control, after 0.05 g about entry roll or about the vector direction of S/C velocity relative to the air mass, to steer the S/C along the entry trajectory. The DAP accepts steering commands from the entry guidance programs.

SATURN TAKEOVER

In the event of a Saturn instrumentation unit (IU) fail, a capability is provided for the CMC to issue angular rate steering commands to the IU autopilot. CMC takeover of Saturn control, which is accomplished by means of the LV GUIDANCE switch, may be an automatic or manual steering mode.

The manual or stick mode is available by keying V46E, which terminates computation of automatic mode attitude errors. Discrete rate commands, based on erasable parameters, are initiated by means of the RHC and transmitted to the IU autopilot.

DAP DATA

The DAP registers containing the variable parameters which determine DAP selection and desired DAP performance are accessible by keying V48E.

CSM DAP CONTROL

V48E
Flashing V04 N46

	A	B	C	D	E
Register 1:	CONFIG	XTAC	XTBD	DB	RATE

CONFIG - Vehicle Configuration

- 0 = No DAP is requested
- 1 = CSM alone
- 2 = CSM and LM*
- 3 = SIVB, CSM and LM*(SIVB control)
- 6 = CSM and LM*(ascent stage only)

XTAC - X-Translations Using Quads AC

- 0 = Do not use AC
- 1 = Use AC

XTBD - X-Translations Using Quads BD

- 0 = Do not use BD
- 1 = Use BD

DB - Angular Deadband for Attitude Hold and Automatic Maneuvers

- 0 = ± 0.5 degree
- 1 = ± 5.0 degrees

RATE - RotationalRate 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

PRO

Flashing V06 N47

Register 1: CSM weight in pounds

Register 2: Other vehicle weight in pounds

PRO

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.

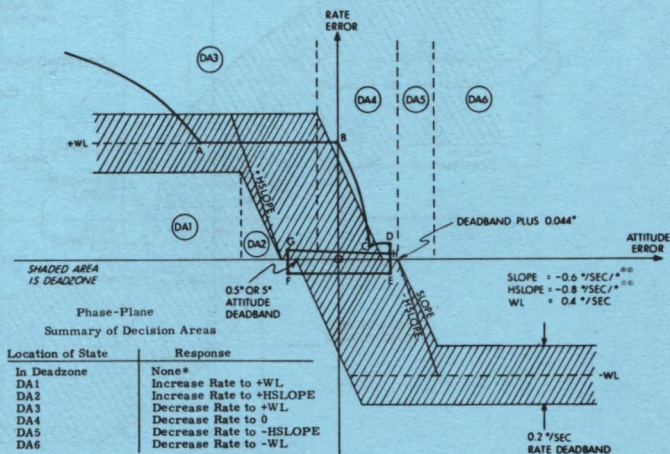
*Reference remains in Software Coding. Not used in Skylark computations.

CSM RCS PHASE-PLANE

The purpose of the CSM RCS Phase-Plane Logic is to compute and issue commands to the RCS thrusters in order to null spacecraft attitude and attitude rate errors. The thruster commands are in a form of a signed time, where the sign indicates the sense of rotation (positive or negative) and time is the duration of thrusting required to reach the phase-plane switching boundary. In order to achieve these ends, the phase plane is divided into decision areas (DA). A phase-plane, characteristic of that used for 3-axis control of the CSM, is shown with switching areas defined for vehicle states beyond the deadzone boundaries.

Only the positive rate error half of the phase-plane is implemented since vehicle states in the negative half plane can be mirrored in the positive half by inverting the signs of the attitude and rate errors.

It is apparent that large attitude errors are reduced by allowing the vehicle to drift freely at a rate error within the deadzone thus optimizing fuel usage. Once attitude errors have been reduced to within the deadband and rate errors are within the deadzone a minimum impulse (14 ms jet firings) limit cycle is reached.



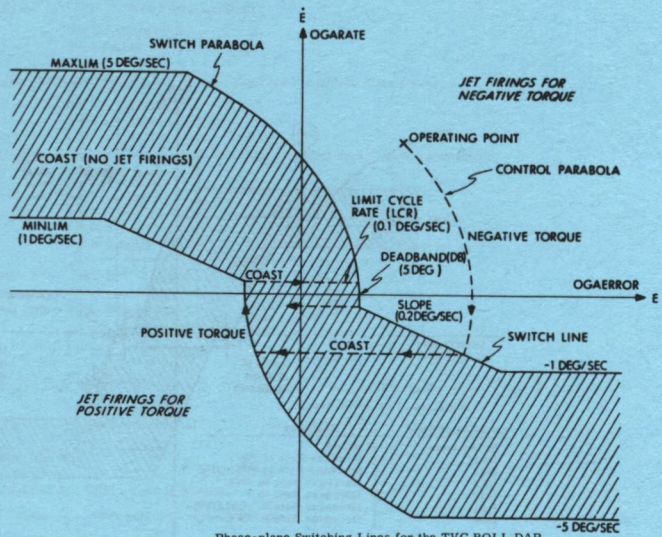
Forced-firing exception.

*° These values are stored in erasable memory and are therefore subject to change.

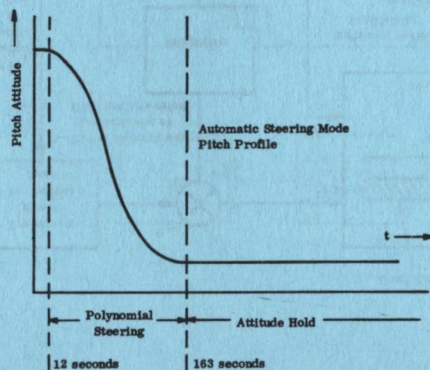
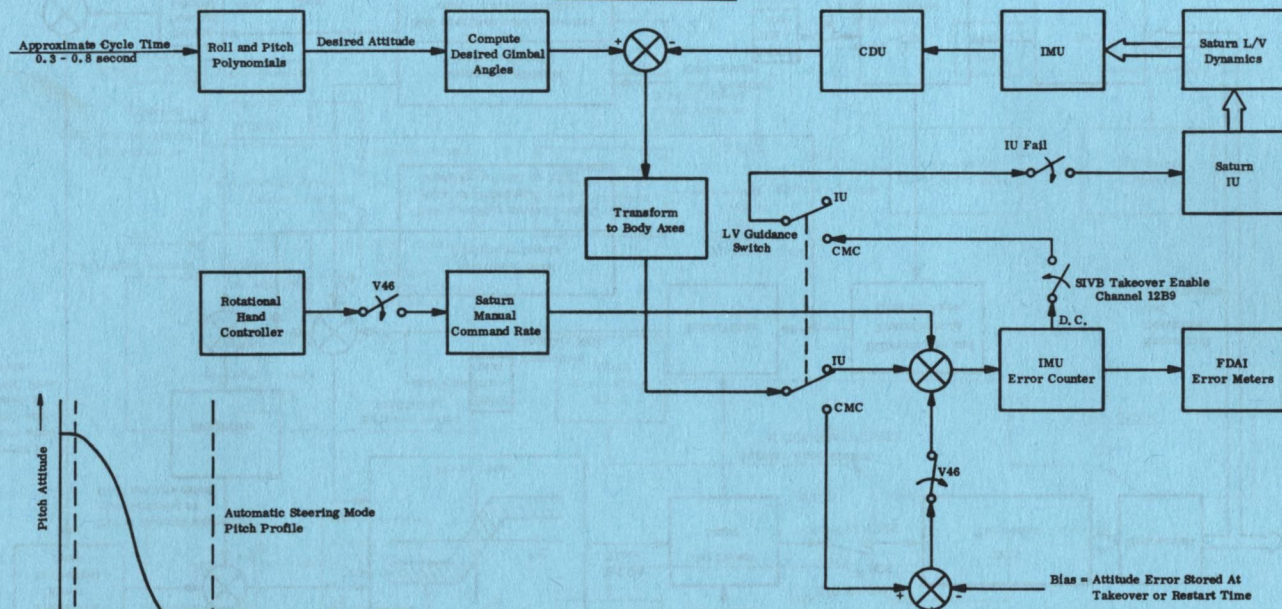
CSM RCS Phase Plane

TVC ROLL PHASE-PLANE

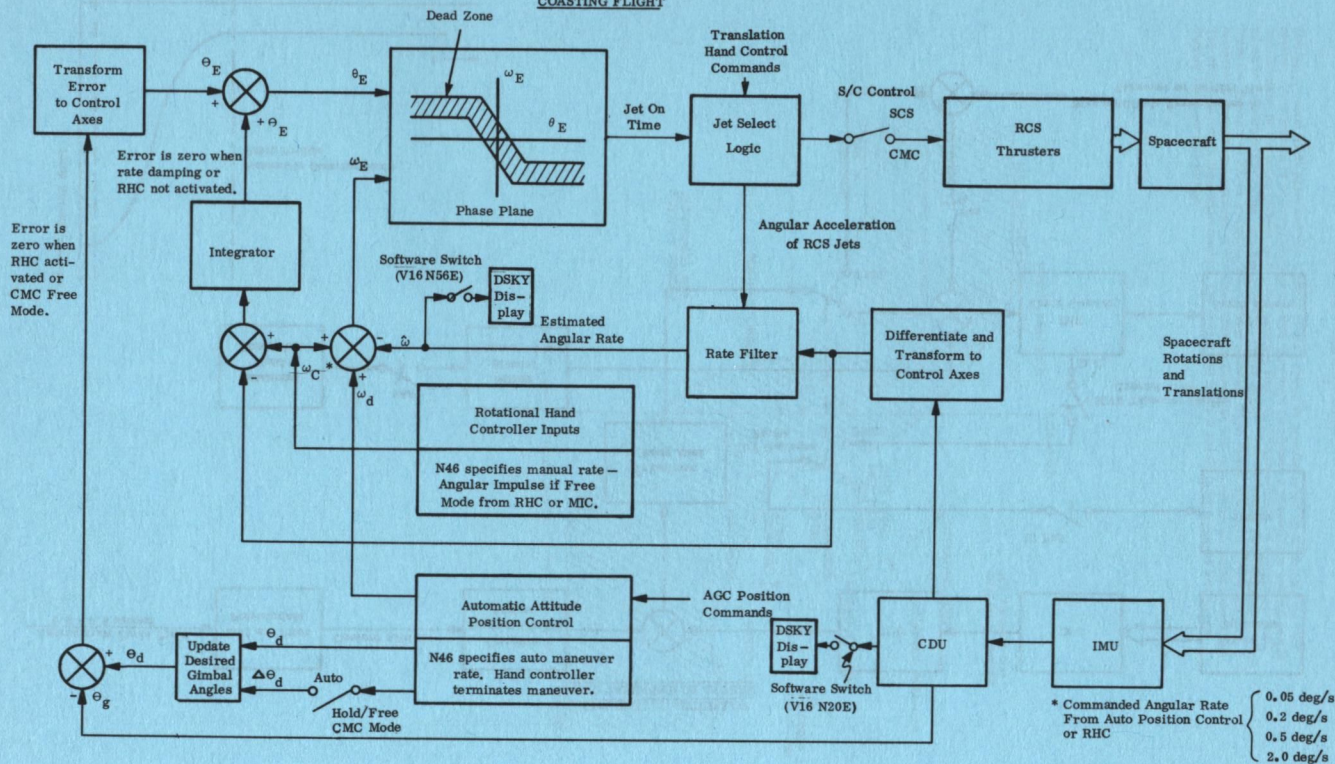
During powered flight pitch and yaw control of the vehicle is accomplished by gimballing the SPS engine. Roll control is accomplished using RCS thrusters and hence a phase-plane control law is implemented in the same fashion as for the coasting flight RCS phase-plane. A sample is shown which is characteristic of the implemented Roll phase-plane. The parabolic switching lines differ from the associated linear switching lines of the coasting flight phase-plane due to the low roll moment-of-inertia and because of the fixed attitude deadband and rate error deadzone boundaries. The switch parabola then approximates the actual roll control parabola or constant torque trajectory for 2 jet firings.

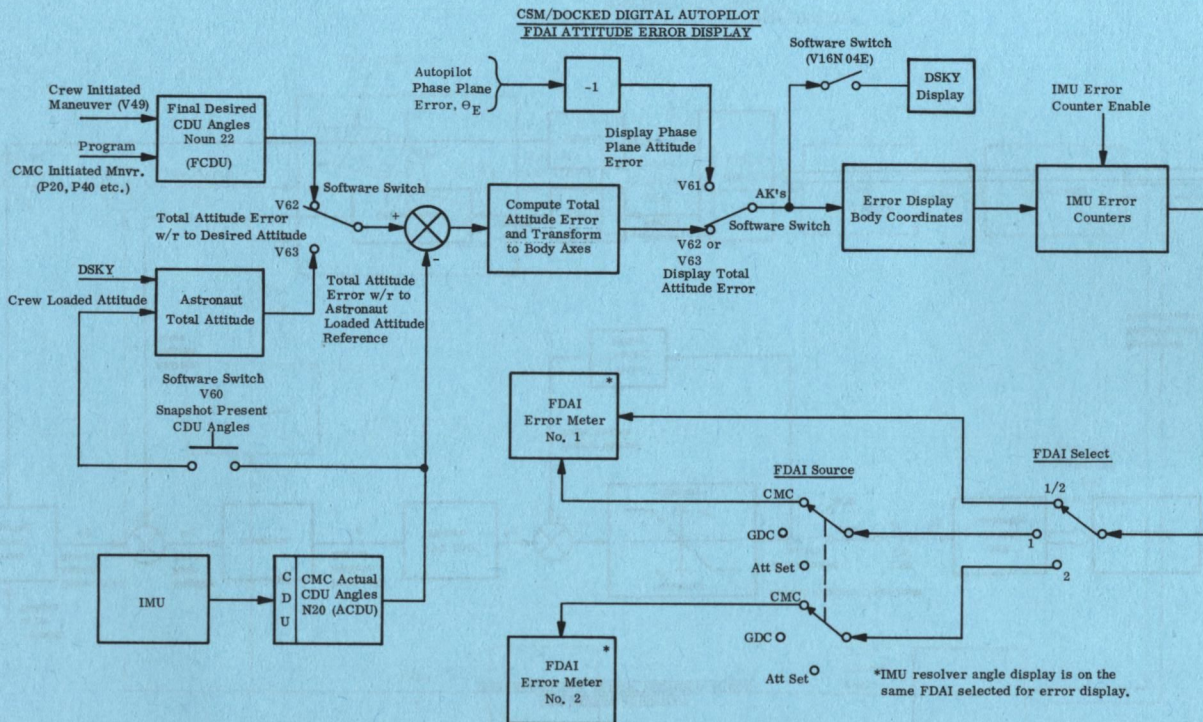


**CSM DIGITAL AUTOPILOT
CMC TAKEOVER OF SATURN**

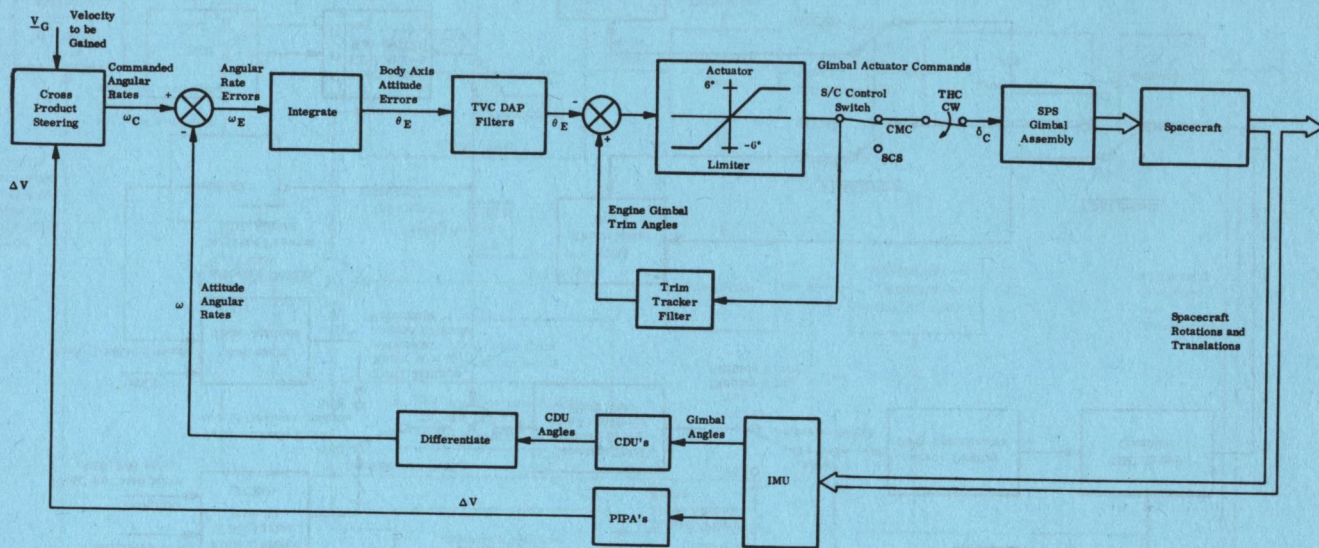


CSM DIGITAL AUTOPILOT COASTING FLIGHT

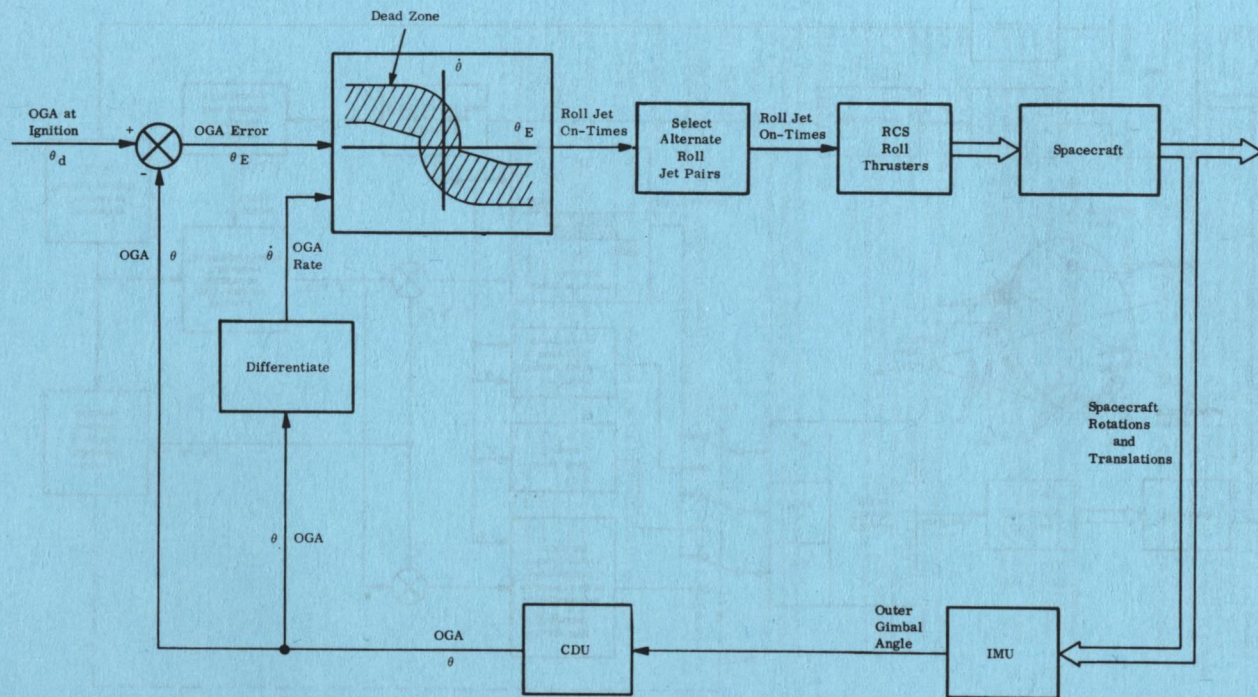


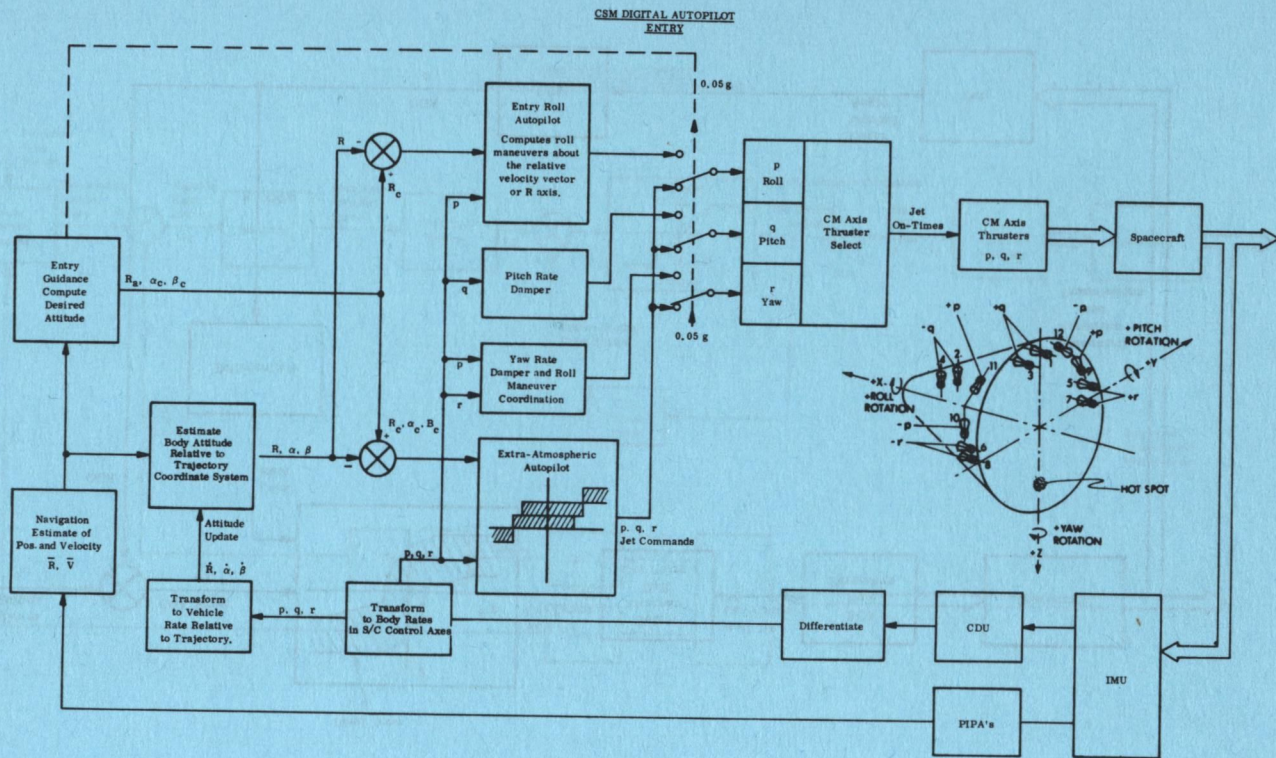


CSM DIGITAL AUTOPILOT
POWERED FLIGHT THRUST VECTOR CONTROL



CSM DIGITAL AUTOPILOT
POWERED FLIGHT ROLL ATTITUDE CONTROL





DOCKED DIGITAL AUTOPILOT

Digital autopilot (DAP) implementation for the docked Orbital Assembly (OA) is very similar to the CSM RCS DAP. Vehicle rate estimation and control is accomplished utilizing most of the RCS DAP software except that rate filter gains and phase plane switching logic decision values are different. Jet selection differs in that torque couples or Z/Y translation (force control) jets may be used for attitude control, since long moment arms from the RCS quads to the OA center of gravity result primarily in rotational torques for Z/Y translation jet firings. Docked DAP torque to inertia ratios for jet firings are not computed as in the RCS DAP but are provided as erasable memory constants as well as the effectiveness constants which convert torque couple firing times to force control jet firing times.

Attitude error parameters are computed as in the RCS DAP.

PITCH/YAW CONTROL

OA attitude control is accomplished using the SM RCS jets, but due to the significant differences in OA center of gravity and control geometry, the torque couple control exercised by the CSM results in greatly reduced control authority when docked to the orbital workshop. The docked DAP logic is designed to use Z and/or Y translation force jets to provide uncoupled rotation torques about the OA c.g. or torque couple jets normally used for CSM attitude control. While providing increased control authority, the force jet control mode also produces unwanted translations, although these are small due to the large mass of the OA.

ROLL CONTROL

Deployment of the ATM assembly results in a significant shift of the orbital assembly c.g. off the longitudinal centerline of the OA. This unbalances the torque produced by a pair of translation jets when in the force control mode and would produce a resultant roll torque along with the desired pitch or yaw torque. The autopilot compensates for this torque unbalance by unbalancing the firing times of the translation jets, thus cancelling the undesired roll effect. Roll phase plane commands are combined with the unbalanced roll torques to compute firing times which produce only desired phase plane torques.

TRANSLATION CONTROL

Since Y and Z translation jets result in torques about the OA c.g., they are used only for yaw and pitch attitude control. Therefore only X translations are practical and can be executed by either 2 or 4 jets. Minus X translations would not normally be done because of thruster impingement on the ATM and solar array.

RATE FILTER

The CSM RCS DAP rate filter is used for vehicle rate estimation in the docked DAP but with different filter gains being used for the steady state docked DAP.

MODE FUNCTIONS

Docked DAP Hold and Auto mode functions are the same as in the CSM DAP with the exception that only X THC commands will be honored.

Free mode functions include RHC angular impulse commands, MIC angular impulse commands, THC X translation commands and THC Y and Z deflections which result in Yaw and Pitch pulsed angular acceleration commands respectively. Effective 200 ms impulse firings are executed whether torque couple, force control or single jet force control. Undesired roll torques, resulting from single jet force commands are compensated for with the roll couple jets selected in DAPDTR3. Effective 50 ms impulse firings are executed for MIC deflections in the same manner as the RHC commands.

DOCKED DAP CONTROL

V44E

Flashing V05 N87

Register 1: DAPDATR3

A	B	C	D	E
ROLL CONTROL	ACXTRANS	BDXTRANS	PITCH CONTROL	YAW CONTROL

Roll Control - quad preference for phase plane roll command. If an inhibited jet is encountered in a preferred quad, automatically uses other two quads for roll.
 0 = BD Preference
 1 = AC Preference

ACXTRANS - X translations using quads AC
 0 = Do not use AC
 1 = Use AC

BDXTRANS - X translations using quads BD
 0 = Do not use BD
 1 = Use BD

Pitch Control - Preferred use of pitch torque couple or Z translation force jets for pitch control.
 0 = Use torque couple for pitch control.
 1 = Use Z force control for pitch

Yaw Control - Preferred use of Yaw torque couple or Y translation force jets for yaw control.
 0 = Use torque couple for yaw control
 1 = Use Y force control for yaw

Register 2: CH5FAIL

Bit	8	7	6	5	4	3	2	1
	B-4	B-3	D-4	D-3	A-4	A-3	C-4	C-3

Octal value 00200 00100 00040 00020 00010 00004 00002 00001

CH5FAIL bit positions correspond to Channel 5 output jet command bits.
 0 = Use selected jet
 1 = Do not use selected jet

Register 3: CH6FAIL

Bit	8	7	6	5	4	3	2	1
	C-2	C-1	A-2	A-1	D-2	D-1	B-2	B-1

octal value 00200 00100 00040 00020 00010 00004 00002 00001

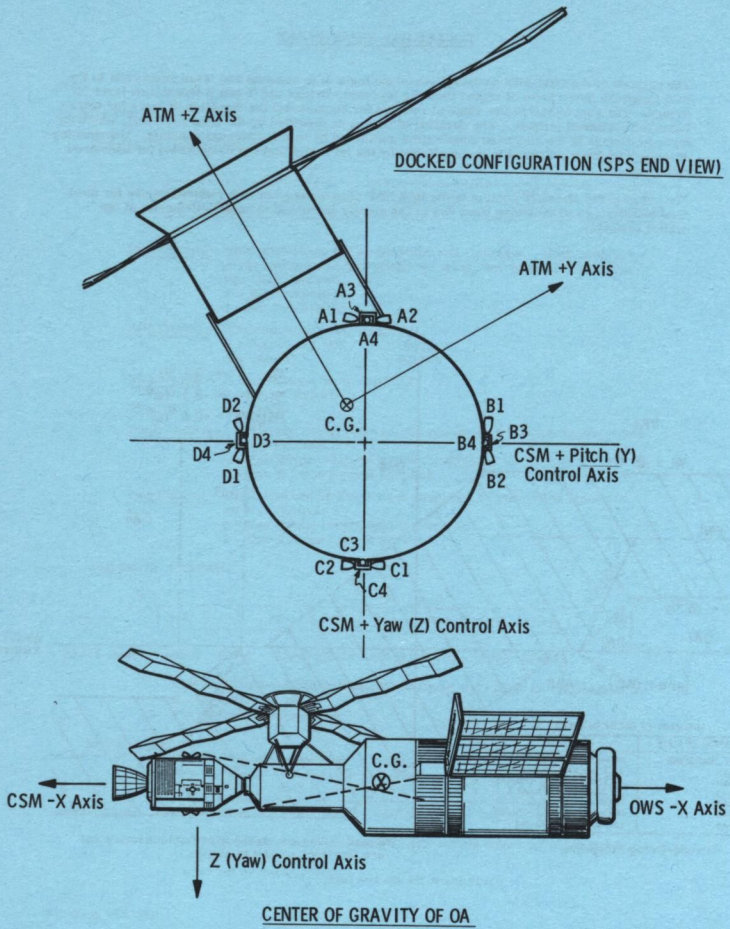
CH6FAIL bit positions correspond to Channel 6 output jet command bits.
 0 = Use selected jet
 1 = Do not use selected jet.

PRO

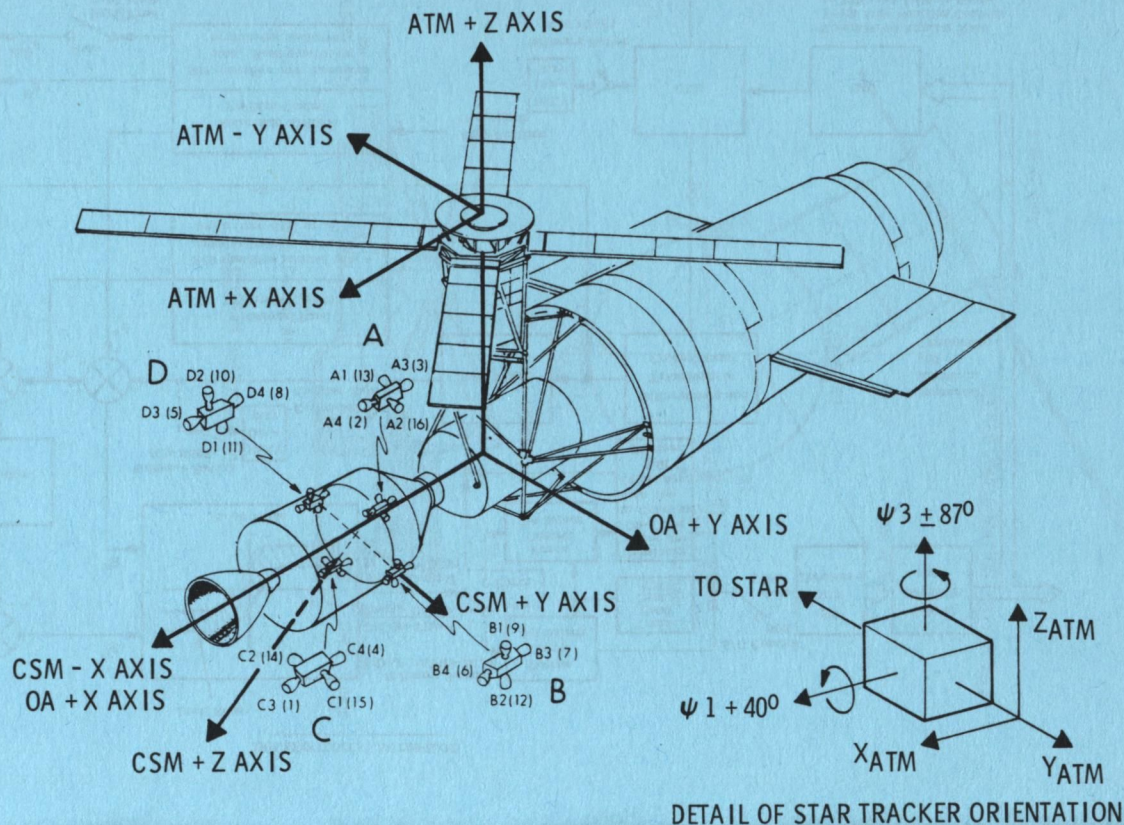
Flashing V06 N89

Register 1: Desired DAP Maneuver Rate X.XXXXX"/s
 *Register 2: Desired DAP Angular Deadband XXX.XX"

* If the DAP deadband (R2 of N89) is respecified, a V45E must be performed to incorporate the new parameter in the docked autopilot logic.



ORBITAL ASSEMBLY CONFIGURATION



STATE ESTIMATOR

The purpose of the state estimator is to compute attitude rate based on the attitude information obtained from the CDU. The problem then is to estimate the state vector based on noisy measurements of one element of the state vector. The solution of the problem is patterned after Kalman filtering and uses a recursive filter with gains based on engineering considerations rather than statistical optimization.

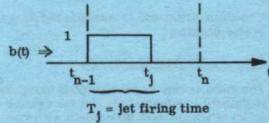
STATE EQUATION (Continuous System)

$$\dot{\underline{X}}(t) = [A(t)] \underline{X}(t) + [B(t)] \underline{u}(t) + \underline{n}(t) \quad (1)$$

$$\begin{bmatrix} \dot{\theta}(t) \\ \dot{\omega}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \theta(t) \\ \omega(t) \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ b(t) & 0 \end{bmatrix} \begin{bmatrix} u_j \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

The process noise vector $\underline{n}(t)$ is assumed zero

u_j is assumed constant over sample interval

STATE EQUATION (Discrete System)

$$\underline{X}(t_n) = [\theta(t_n, t_{n-1})] \underline{X}(t_{n-1}) + \int_{t_{n-1}}^{t_n} [\theta(t_n, \tau)] [B(\tau)] u(\tau) d\tau \quad (2)$$

or:

$$\underline{X}_n = [\theta_{n-1}] \underline{X}_{n-1} + [G_{n-1}] \underline{u}_{n-1} \quad (3)$$

STATE TRANSITION MATRIX

$$[\theta_{n-1}] = [\theta(t_n, t_{n-1})] = \begin{bmatrix} 1 & (t_n - t_{n-1}) \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} \quad (4)$$

$T = t_n - t_{n-1}$

DRIVING MATRIX

$$\begin{aligned} [G_{n-1}] &= \int_{t_{n-1}}^{t_n} [\theta(t_n, \tau)] [B(\tau)] d\tau = \int_{t_{n-1}}^{t_n} \begin{bmatrix} 1 & t_n - \tau \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 \\ b(\tau) & 0 \end{bmatrix} d\tau \\ &= \int_{t_{n-1}}^{t_n} \begin{bmatrix} b(\tau) (t_n - \tau) & 0 \\ b(\tau) & 0 \end{bmatrix} d\tau = \begin{bmatrix} T_j(T - T_j/2) & 0 \\ T_j & 0 \end{bmatrix} \end{aligned} \quad (5)$$

MEASUREMENT EQUATION

$$\hat{\theta}_n = \theta(t_n) + n_{CDU} \quad (n_{CDU} = \text{measurement noise, primarily CDU quantizing error}) \quad (6)$$

NOMENCLATURE

$\underline{X}(t)$	= state vector
$\underline{u}(t)$	= control or driving vector
$\underline{n}(t)$	= process noise vector
$\theta(t)$	= spacecraft attitude
$\omega(t)$	= spacecraft attitude rate
u_j	= angular acceleration due to RCS jets
$\hat{\theta}$	= measured spacecraft attitude (CDU angles)
t_n, t_{n-1}	= time of present and past state vector estimates, respectively
$\rho(t)$	= measurement residual (difference of measured and predicted attitude)
T	= control sample interval (0.1 sec)
T_j	= duration of jet firing

STATE ESTIMATOR MECHANIZATION

The state estimator is mechanized as a two part process: state vector extrapolation and state vector updating.

State Vector Extrapolation

The state vector is extrapolated using equation (3) where the state transition matrix $[\phi_{n-1}]$ is defined in equation (4) and the driving matrix $[G_{n-1}]$ in equation (5). The process noise is assumed to be random with zero mean so that the best estimate of its effect on the state vector is zero.

$$\theta'_n = \hat{\theta}_{n-1} + T \hat{\omega}_{n-1} + T_j (T - T_j/2) u_j \quad (7)$$

$$\omega'_n = \hat{\omega}_{n-1} + T_j u_j \quad (8)$$

In the CSM DAP filter the term $T_j (T - T_j/2) u_j$, due to thruster firing angular acceleration, is considered negligible and is neglected.

State Vector Updating

The state vector is updated based on the weighting functions and the measurement residual.

$$\hat{\theta}_n = \theta'_n + K_{\theta} (\tilde{\theta}_n - \theta'_n) = \theta'_n + K_{\theta} \rho_n \quad (9)$$

$$\hat{\omega}_n = \omega'_n + K_{\omega} (\tilde{\omega}_n - \omega'_n) = \omega'_n + K_{\omega} \rho_n \quad (10)$$

The measurement residual $\rho(t)$ is the difference between the actual measurement $\tilde{\theta}_n$ and the expected measurement θ'_n . The expected measurement is equal to the extrapolated estimate of spacecraft attitude, because the measurement noise, n_{CDU} , is assumed to be random with zero mean and the best estimate of its effect on the measurement is therefore zero.

To obtain the filter equations for ρ and $\hat{\omega}$:

$$\rho_n = (\tilde{\theta}_n - \theta'_n) \quad (11)$$

Combining equations (11) and (7)

$$\rho_n = \tilde{\theta}_n - \hat{\theta}_{n-1} - T \hat{\omega}_{n-1} \quad (12)$$

Adding $-\tilde{\theta}_n$ to equation (9)

$$\hat{\theta}_n - \tilde{\theta}_n = \theta'_n - \tilde{\theta}_n + K_{\theta} \rho_n = -\rho_n + K_{\theta} \rho_n \quad (13)$$

Changing n to $n-1$ and solving equation (13) for $\hat{\theta}_{n-1}$

$$\hat{\theta}_{n-1} = \tilde{\theta}_{n-1} - \rho_{n-1} (1 - K_{\theta}) \quad (14)$$

Combining equations (12) and (14)

$$\rho_n = \tilde{\theta}_n - \tilde{\theta}_{n-1} + \rho_{n-1} (1 - K_{\theta}) - T \hat{\omega}_{n-1} \quad (15)$$

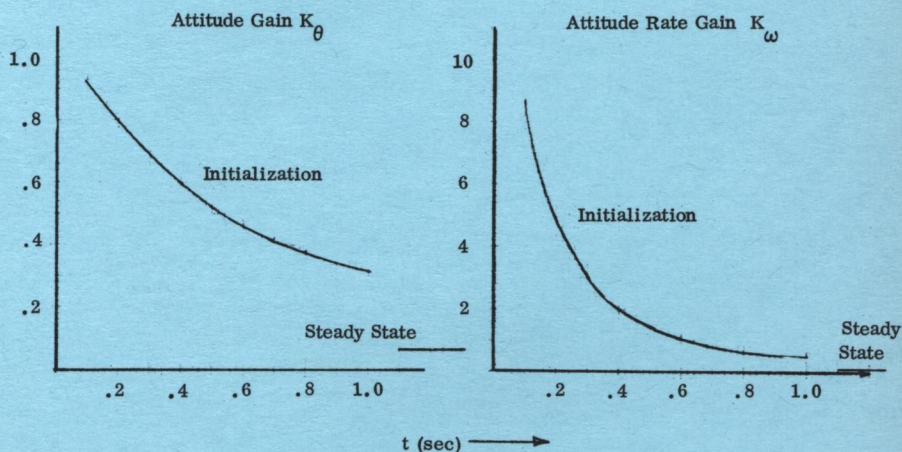
Combining equations (8) and (10)

$$\hat{\omega}_n = \omega'_n + K_{\omega} \rho_n = \hat{\omega}_{n-1} + K_{\omega} \rho_n + T_j u_j \quad (16)$$

Equations (15) and (16) are the recursive equations used by the rate filter to estimate vehicle attitude rates.

Weighting Functions

The weighting functions are variable with time over the first ten DAP cycles after rate filter initialization. Thereafter a steady state value is used to weight the measurement residuals.



SCIENCE

**KALMAN FILTERING
NAVIGATION
ORBITAL MECHANICS
ORBITAL DISTURBANCES**

COASTING FLIGHT NAVIGATION

The purpose of Coasting Flight Navigation is to estimate spacecraft position and velocity of the CSM or orbital workshop. The estimates are computed using orbital mechanics and optics or VHF tracking measurements to improve the accuracy of the orbital mechanics. The navigation sightings are incorporated into the position and velocity estimates using a modified Kalman filter which is a recursive optimal estimator that is characterized by the following computational procedure.

1. Extrapolate the state vector ahead to time t_n , using the best estimate of the state at time t_{n-1} .

$$\hat{\underline{X}}'_n = [\phi_{n-1}] \hat{\underline{X}}_{n-1}$$

2. Extrapolate the error covariance matrix in a similar manner.

$$[E'_n] = [\phi_{n-1}] [E_{n-1}] [\phi_{n-1}]^T + [U_{n-1}] \quad (U_{n-1} = \text{process noise})$$

3. Compute the optimal gain matrix.

$$[K_n^*] = [E'_n] [H_n]^T [H_n E'_n H_n^T + V_n]^{-1} \quad (V_n = \text{measurement noise})$$

4. Calculate a measurement vector for time t_n .

$$\hat{\underline{Y}}'_n = [H_n] \hat{\underline{X}}'_n$$

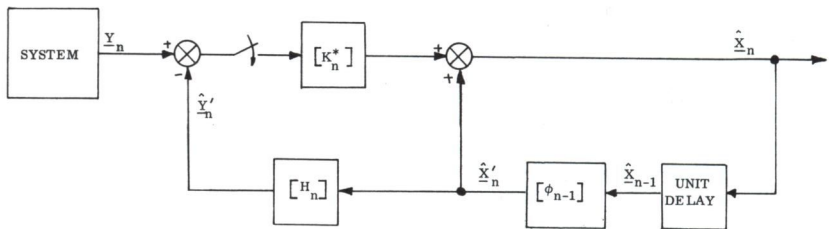
5. Update the estimate of the state vector, using the extrapolated state $\hat{\underline{X}}'_n$, the optimal gain $[K_n^*]$, the extrapolated measurement $\hat{\underline{Y}}'_n$, and the actual measurement at time t_n , \underline{Y}_n .

$$\hat{\underline{X}}_n = \hat{\underline{X}}'_n + [K_n^*] (\underline{Y}_n - \hat{\underline{Y}}'_n)$$

6. Update the error covariance matrix in a similar manner.

$$[E_n] = [E'_n] - [K_n^*] [H_n] [E'_n]$$

This procedure is illustrated by the following block diagram.



Basic Recursive Procedure of Kalman Filtering.

MODIFICATIONS TO THE BASIC KALMAN FILTER

The basic Kalman filter outlined on the previous page was modified for use in Coasting Flight Navigation in the following aspects.

1. Instead of extrapolating the error covariance matrix, $[E]$, the square root of the error covariance matrix is extrapolated. This insures that the covariance matrix will always be positive semi-definite and avoids the usual difficulties that occur when computation techniques yield a negative error covariance matrix. The square root of the error covariance matrix is called the error transition matrix $[W]$.
2. The state vector and error transition matrix are extrapolated by integrating their respective second order differential equations via the coasting integration routine. This is done in lieu of the state transition approach and eliminates the necessity of computing a new time varying transition matrix for each measurement interval.
3. The update of the state vector after each measurement must first be displayed and approved by the astronaut before it is incorporated into the state vector. This eliminates the possibility of an erroneous update due to an improper mark.
4. Only one measurement is incorporated at a time. This reduces the dimension of the filter equations and changes the matrix inversion in the optimal gain equation to a scalar division.

STATE VECTOR DEFINITION

The state vector for coasting flight navigation is defined as the deviation of the spacecraft position and velocity from a reference conic.

$$\text{State Vector} = \underline{x}(t) = \begin{bmatrix} \frac{\delta \underline{r}}{\delta \underline{v}} \end{bmatrix} = \begin{bmatrix} \delta r_x \\ \delta r_y \\ \delta r_z \\ \delta v_x \\ \delta v_y \\ \delta v_z \end{bmatrix} = \begin{bmatrix} \text{Deviations from} \\ \text{conic position} \\ \\ \text{Deviations from} \\ \text{conic velocity} \end{bmatrix}$$

Deviations from the reference conic are assumed to be Gaussian distributed with a known mean and variance. The mean is estimated via the precision integration routines or obtained from MSFN. The variance is given by the error covariance matrix, which is precomputed and entered via erasable data load.

CORRELATION BETWEEN BASIC KALMAN FILTER TERMINOLOGY AND COASTING FLIGHT TERMINOLOGY

The following table lists the correlation between basic Kalman filter terminology as used on the previous page and Coasting Flight Navigation terminology to be used on the following pages.

CELESTIAL NAVIGATION TERMINOLOGY	KALMAN FILTER TERMINOLOGY	CORRELATION
\underline{b} = geometry vector of dimension "D"	$[H]$ = measurement matrix	$\underline{b}^T \Rightarrow [H]$
\underline{w} = weighting vector of dimension "D"	$[K_n^*]$ = optimal gain matrix	$\underline{w} \Rightarrow [K_n^*]$
$[W]$ = error transition matrix of dimension "D x D"	$[E]$ = error covariance matrix	$[E] \Rightarrow [W W^T]$
\underline{x} = state vector	\underline{x} = state vector	$\underline{x} \Rightarrow \underline{x}$
$\hat{\sigma}^2$ = a priori measurement error variance (scalar)	$[V]$ = covariance of the measurement noise	$\hat{\sigma}^2 \Rightarrow [V]$
δQ = measurement deviation (scalar)	$(\hat{\underline{y}}_n - \underline{y}_n)$ = measurement residual	$\delta Q \Rightarrow (\hat{\underline{y}}_n - \underline{y}_n)$

COASTING INTEGRATION ROUTINE

The Coasting Integration routine is a standardized subroutine used to integrate spacecraft state vector to specific times. It is used during the P20 - Rendezvous navigation program to extrapolate the state vector and error transition matrix ahead to the measurement time by direct numerical integration of their differential equations.

STATE VECTOR EQUATIONS

The basic equation describing spacecraft motion is

$$\begin{bmatrix} \dot{\underline{r}} \\ \dot{\underline{v}} \end{bmatrix} = \begin{bmatrix} 0 & I \\ -\frac{\mu}{|\underline{r}|^3} & 0 \end{bmatrix} \begin{bmatrix} \underline{r} \\ \underline{v} \end{bmatrix} + \begin{bmatrix} 0 \\ \underline{a}_d \end{bmatrix} \quad (1)$$

where

\underline{r} = spacecraft position vector

\underline{v} = spacecraft velocity vector

\underline{a}_d = disturbance acceleration vector

μ = primary planet gravitation constant

When the disturbance, \underline{a}_d , is small, then Encke's method of differential accelerations can be used to solve Equation 1. Encke's method divides spacecraft motion into two parts: (1) conic or osculating orbital motion which would result if $\underline{a}_d = \underline{0}$ and (2) deviation from conic motion as a result of $\underline{a}_d \neq \underline{0}$.

$$\underline{r} = \underline{r}_{\text{conic}} + \underline{\delta r} \quad (2)$$

$$\underline{v} = \underline{v}_{\text{conic}} + \underline{\delta v} \quad (3)$$

where

$\underline{r}, \underline{v}$ = spacecraft position and velocity

$\underline{r}_{\text{conic}}, \underline{v}_{\text{conic}}$ = conic position and velocity

$\underline{\delta r}, \underline{\delta v}$ = deviations from conic position and velocity

Substitution of Equations 2 and 3 into the basic equation of motion, Equation 1, yields differential equations for the conic position and velocity and the deviation from conic position and velocity.

Conic Motion Equation

$$\begin{bmatrix} \dot{\underline{r}}_{\text{conic}} \\ \dot{\underline{v}}_{\text{conic}} \end{bmatrix} = \begin{bmatrix} 0 & I \\ -\frac{\mu}{|\underline{r}_{\text{conic}}|^3} & 0 \end{bmatrix} \begin{bmatrix} \underline{r}_{\text{conic}} \\ \underline{v}_{\text{conic}} \end{bmatrix} \quad (4)$$

Deviation Equation

$$\begin{bmatrix} \dot{\underline{\delta r}} \\ \dot{\underline{\delta v}} \end{bmatrix} = \begin{bmatrix} 0 & I \\ G & 0 \end{bmatrix} \begin{bmatrix} \underline{\delta r} \\ \underline{\delta v} \end{bmatrix} + \begin{bmatrix} 0 \\ \underline{a}_d \end{bmatrix} \quad \text{Subject to initial conditions } \begin{cases} \underline{\delta r}(t_0) = \underline{0} \\ \underline{\delta v}(t_0) = \underline{0} \end{cases} \quad (5)$$

where

$$G = \frac{\mu}{r_{\text{conic}}^3} \begin{bmatrix} 3 \underline{r}_{\text{conic}} \underline{r}_{\text{conic}}^T - r_{\text{conic}}^2 [I] \end{bmatrix}$$

The conic motion equation is solved explicitly using Kepler's subroutine. The deviation equation is solved by direct numerical integration and is called the "state equation"; it can be written in the form

$$\dot{\underline{x}} = [F] \underline{x} + \underline{C} \quad (6)$$

ERROR TRANSITION MATRIX EQUATIONS

The accuracy of the state vector estimation process is characterized by the error covariance matrix which expresses the mean squared error of each state vector element in matrix form

state vector estimation error

$$\underline{e} = \hat{\underline{x}} - \underline{x} \quad (7)$$

where

\underline{e} = estimation error

$\hat{\underline{x}}$ = estimated state vector

\underline{x} = actual state vector

error covariance matrix

$$[E] = \langle \underline{e} \underline{e}^T \rangle \quad (8)$$

where

$[E]$ = error covariance matrix

$\langle \rangle$ = denotes "expected value"

If the state vector is described by Equation 6, then the error covariance matrix is described by

$$\dot{E} = FE + EF^T \quad (\text{neglecting process noise}) \quad (9)$$

and the error transition matrix is described by

$$\dot{W} = FW \quad (10)$$

where

$$[WW^T] = [E]$$

Equation 10 is the differential equation describing the error transition matrix and is solved by direct numerical integration.

SUMMARY

TIME DOMAIN EQUATIONS	STATE TRANSITION EXTRAPOLATION	NUMERICAL INTEGRATION EXTRAPOLATION
$\dot{\underline{x}} = F\underline{x} + \underline{C}$	$\hat{\underline{x}}' = [\phi] \hat{\underline{x}}$	$\hat{\underline{x}}' = \hat{\underline{x}}(t_n) + \int_{t_n}^{t_{n+1}} F \hat{\underline{x}} dt$
$\dot{E} = FE + EF^T$	$E' = \phi E \phi^T$	
$\dot{W} = FW$		$W' = W(t_n) + \int_{t_n}^{t_{n+1}} FW dt$

MEASUREMENT INCORPORATION ROUTINE

The Measurement Incorporation routine, like the Coasting Integration routine, is used by navigation programs. Its purpose is to compute a state vector update based on the information obtained from the sightings. The procedure for updating the state vector can be divided into three parts.

1. Compute a geometry vector, \underline{b} , based on the state vector and type of navigation sighting that is being made.
2. Compute a state vector update.
3. Update the state vector and error transition matrix if the astronaut approves of the incorporation.

GEOMETRY VECTOR

The geometry vector relates the measurement, \hat{Y}'_n , to the state vector, $\hat{\underline{x}}'_n$, according to Equation 11

$$\hat{Y}'_n = \underline{b}^T \hat{\underline{x}}'_n \quad (11)$$

where

\hat{Y}'_n = the expected measurement (a scalar)

\underline{b} = geometry vector ($n \times 1$ column vector)

$\hat{\underline{x}}'_n$ = state vector extrapolated to the measurement time via the Coasting Integration routine.

The state vector for coasting flight navigation is a deviation from a reference (osculating) orbit and the measurement variable can also be thought of as a deviation from a reference or nominal. Thus the measurement vector can be determined by taking the derivative of the measurement with respect to the state vector.

The geometry vectors and measurement residuals are given for the optics and VHF range measurements.

Optics

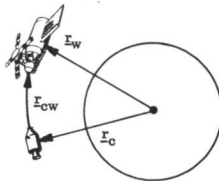
The CSM to WS LOS in reference coordinates

$$\underline{U}_m = [\text{REFSMMAT}]^T [\text{NBSM}] \underline{U}_{NB}$$

where:

\underline{U}_{NB} = Optics LOS in Nav Base coordinates

$[\text{NBSM}]$ = Gimbal angle transformation matrix from Nav Base to stable member coordinates



$\underline{r}_{cw} = \underline{r}_w - \underline{r}_c$ \underline{r}_w and \underline{r}_c are WS and CSM position vector estimates

$\underline{U}_{cw} = \text{unit}(\underline{r}_{cw})$

$$\underline{b} = \begin{bmatrix} \pm \frac{(\underline{U}_{cw} \times \underline{U}_m)}{|\underline{r}_{cw}|} \\ 0 \end{bmatrix} \quad + (-) \text{ if CSM (WS) state being updated}$$

$$\delta Q = |\underline{r}_{cw}| \cos^{-1} (\underline{U}_{cw} \times \underline{U}_m) \cdot \underline{U}_m - \pi/2$$

VHF RANGE

$$\underline{b} = \begin{bmatrix} \pm \underline{U}_{cw} \\ 0 \end{bmatrix}$$

$$\delta Q = R_m - r_{cw}$$

where R_m = measured VHF range

COMPUTE THE STATE VECTOR UPDATE

The computation of the state vector update encompasses Steps 3, 4, and 5 of the basic Kalman filtering procedure.

1. Compute the optimal gain matrix

$$[K_n^*] = [E' H^T] [H E' H^T + V]^{-1} \quad (12)$$

or, in the terminology of coasting flight navigation,

$$\begin{aligned} \underline{\omega} &= [W' W'^T \underline{b}] [\underline{b}^T W' W'^T \underline{b} + \bar{\alpha}^2] \\ &= \frac{W' \underline{z}}{(z^2 + \bar{\alpha}^2)} \end{aligned} \quad (13)$$

where

$\underline{\omega}$ = optimal gain vector

W' = error transition matrix extrapolated forward by the Coasting Integration routine

\underline{z} = $W'^T \underline{b}$ (a vector used to simplify computations)

$z^2 = \underline{z}^T \underline{z} = \underline{b}^T W' W'^T \underline{b}$ (analogous to $H E' H^T$)

$\bar{\alpha}^2$ = measurement noise covariance (an erasable data load or fixed memory constant which depends on which navigation program is in use)

$(z^2 + \bar{\alpha}^2)$ is a scalar and eliminates the necessity of matrix inversion

2. Compute the expected measurement based on the extrapolated state vector.

$$\hat{Y}_n' = \underline{b}^T \hat{x}_n' \quad (14)$$

where

\hat{Y}_n' = expected measurement from current navigation sighting

\underline{b} = geometry vector

\hat{x}_n' = extrapolated state vector

3. Compute the state vector update

$$\underline{\delta x} = \underline{\omega} \delta Q = \underline{\omega} (Y_n - \hat{Y}_n') \quad (15)$$

where

$\underline{\delta x}$ = state vector update

$\underline{\omega}$ = optimal weighting vector

δQ = measurement residual

Y_n = information from current navigation sighting

\hat{Y}_n' = expected measurement

UPDATE THE STATE VECTOR AND ERROR TRANSITION MATRIX

Before the state vector update, $\underline{\delta x}_n$ is incorporated into the state vector, it is displayed to the astronaut for his approval. This is to prevent erroneous tracking data from being used to update the state. When astronaut approval has been issued, the state vector and error transition matrix are updated as follows:

UPDATE THE STATE VECTOR

$$\hat{x}_n = \hat{x}_n' + \underline{\delta x} \quad (16)$$

where

\hat{x}_n = best estimate of state at time t_n

\hat{x}_n' = state vector extrapolated ahead from time t_{n-1} to t_n

$\underline{\delta x}$ = state vector update

UPDATE THE ERROR TRANSITION MATRIX

The equation governing updating of the error covariance matrix is given in Step 6 of the basic Kalman filtering procedure.

$$[E_n] = [E_n'] - [K_n^*] [H_n] [E_n'] \quad (17)$$

This can be rewritten in terms of coasting flight navigation terminology

$$[WW^T] = [W'W'^T] - \underline{\omega} \underline{b}^T [W'W'^T] \quad (18)$$

Equation 18 can be separated to obtain an equation for updating only the error transition matrix $[W]$ instead of the product $[WW^T]$.

$$[W] = [W'] - \frac{\underline{\omega} \underline{z}^T}{1 + \frac{\underline{\omega}^T \underline{\bar{\alpha}}^2}{z^2 + \underline{\bar{\alpha}}^2}} \quad (19)$$

where

- $[W]$ = updated error transition matrix
- $[W']$ = extrapolated error transition matrix
- $\underline{\omega}$ = optimal gain vector
- \underline{z} = $W'^T \underline{b}$
- z^2 = $\underline{z}^T \underline{z}$
- $\underline{\bar{\alpha}}^2$ = measurement noise covariance

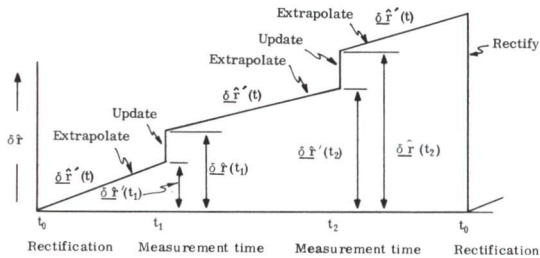
SUMMARY

The total spacecraft position and velocity is kept current through extrapolation, updating, and rectification. Rectification is a process used to redefine the reference trajectory by adding the deviations, $\underline{\delta r}$ and $\underline{\delta v}$, to the osculating elements, \underline{r}_{conic} and \underline{v}_{conic} , thereby redefining the osculating orbit and reducing the deviation state vector to zero.

$$\begin{bmatrix} \underline{r}_{conic} \\ \underline{v}_{conic} \end{bmatrix} = \begin{bmatrix} \underline{r}_{conic} \\ \underline{v}_{conic} \end{bmatrix} + \begin{bmatrix} \underline{\delta r} \\ \underline{\delta v} \end{bmatrix} \quad (20)$$

$$\begin{bmatrix} \underline{\delta r} \\ \underline{\delta v} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (21)$$

This process is used to preserve the efficiency of Encke's method and is illustrated below.



INITIALIZING THE COASTING FLIGHT NAVIGATION PROGRAMS

Each of the navigation programs is initialized prior to use by specifying the measurement variance, $\bar{\alpha}^2$, and the initial error transition matrix, [W]. The measurement variance gives a confidence level for the navigation instruments by specifying the variance of all the error sources associated with the instrument. The W matrix gives a confidence level for the initial estimate of the state vector by specifying the mean squared error to the position and velocity estimates. [W] is initialized as a diagonal matrix which says that initially the position and velocity errors are independent.

MEASUREMENT VARIANCE	INITIAL "W" MATRIX
RENDEZVOUS	NAVIGATION P-20
PROGRAM(CSM)	
<p>OPTICAL TRACKING</p> $\bar{\alpha}^2 = \text{Var}_{\text{SXT}} + \text{Var}_{\text{IMU}} + \frac{\text{Var}^*_{\text{INT}}}{r_{\text{cw}}^2}$ $= (0.2 \text{ mr})^2 + (0.2 \text{ mr})^2 + \frac{\text{Var}^*_{\text{INT}}}{r_{\text{cw}}^2}$ <p>VHF RANGING</p> $\bar{\alpha}^2 = \text{Max} \left\{ \text{Var}^*_R + \frac{\text{Var}^*_{\text{INT}}}{r_{\text{cw}}^2}, \frac{\text{Var}^*_{\text{MIN}}}{r_{\text{cw}}^2} \right\}$ <p>ALTERNATE LOS</p> $\bar{\alpha}^2 = \text{Var}^*_{\text{ALT}} + \text{Var}_{\text{IMU}} + \frac{\text{Var}^*_{\text{INT}}}{r_{\text{cw}}^2}$ $= \text{Var}^*_{\text{ALT}} + (0.2 \text{ mr})^2 + \frac{\text{Var}^*_{\text{INT}}}{r_{\text{cw}}^2}$	$[W] = \begin{bmatrix} W^*_{\text{RRI}} & 0 \\ 0 & W^*_{\text{rvi}} \end{bmatrix}$

*The variables are stored in erasable memory.

ERASABLE DATA LOAD PARAMETERS

PARAMETER ($\bar{\alpha}^2$)	DATA LOAD MNEMONIC	VALUE	PARAMETER [W]	DATA LOAD MNEMONIC	VALUE
$\text{Var}_{\text{INT}}(\text{CSM})$	INTVAR	$(60 \text{ m})^2$	$W_{\text{r}}(\text{CSM})$	WRENDVEL	10 ft/s
$\text{Var}_R(\text{CSM})$	RVAR	0.0	$W_{\text{rr}}(\text{CSM})$	WRENDPOS	10,000 ft
$\text{Var}_{\text{R min}}(\text{CSM})$	RVARMIN	$(200 \text{ ft})^2$			
$\text{Var}_{\text{ALT}}(\text{CSM})$	ALTVAR	$(3.9 \text{ mrad})^2$			

A. ORBITAL RELATIONSHIPS

Assuming a spherical planet, the equation of motion for a satellite is given by

$$\frac{d^2 \vec{r}}{dt^2} = - \frac{\mu}{r^3} \vec{r} \quad (1)$$

where

$$\mu = (M_{\text{Planet}} + M_{\text{Satellite}}) G$$

G = gravitational constant

The solution of Equation 1 is:

$$r = \frac{h^2/\mu}{1 + e \cos f} \quad (2)$$

where

h = angular momentum of the satellite

e = eccentricity of the orbit

f = true anomaly

which is the polar equation of a conic. The conic will be an ellipse, a parabola, or a hyperbola. Treating the parabola as a special case of the ellipse and considering only the hyperbola and ellipse, the following relationships are obtained:

Angular Momentum	$\vec{h} = \vec{r} \times \vec{v} = r^2 \dot{f} = \text{constant}$
Velocity	$v^2 = \mu (2/r - 1/a)$
Apogee	$r_a = a (1 + e)$
Semilatus Rectum	$p = h^2/\mu$
Semimajor Axis	$a = r\mu/(2\mu - rv^2)$ Negative for hyperbola
Eccentricity	$e = (1 - h^2/\mu a)^{1/2}$
Perigee	$r_p = a (1 - e)$
True Anomaly	$\cos f = \frac{p}{re} - \frac{1}{e}, \sin f = \frac{h}{\mu re} \vec{r} \cdot \vec{v}$

Ellipse Only

Period	$P = 2\pi (a^3/\mu)^{1/2}$
Mean Motion	$n = \mu^{1/2}/a^{3/2}$
Mean Anomaly	$M = n (t - \tau)$
	$\tau = \text{time of perigee passage}$
Eccentric Anomaly	$E - e \sin E = M \text{ (Kepler's Equation)}$
	$\tan (E/2) = [(1 - e)/(1 + e)]^{1/2} \tan (f/2)$

Hyperbola Only

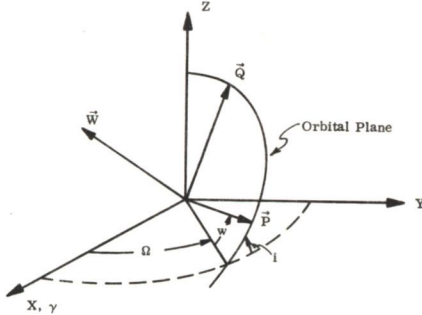
Mean Motion	$\gamma^2 = \mu/a^3$
Mean Anomaly	$M = \gamma (t - \tau)$
	$\tau = \text{time of perigee passage}$
Eccentric Anomaly	$H - e \sinh H = M$
	$\tanh (H/2) = [(e - 1)/(e + 1)]^{1/2} \tan (t/2)$

From these relationships, given an initial position and velocity vector, the orbit and orbit parameters are uniquely determined.

B. THE ORBIT IN SPACE

The orbit in space is defined by an orthogonal set of axes along perigee, the semilatus rectum, and the angular momentum vector. The ordered set of right hand rotations (Euler angles) to achieve this orientation from the earth-centered-inertial (ECI) frame are illustrated in Figure 1 and given by the expression

$$\begin{bmatrix} P \\ Q \\ W \end{bmatrix}_{\text{Orbit}} = \begin{bmatrix} R_Z(w) \\ R_X(i) \\ R_Z(\Omega) \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} = [A] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} \quad (3)$$



where

Ω = longitude of ascending node

i = angle of incidence

w = argument of perigee

Figure 1. The Orbit in Space

The angles Ω , i , and w are generally unknowns; therefore, the elements in $[A]$ must be evaluated by some other means. To this end, Equation 3 is expressed as follows:

$$\begin{bmatrix} P \\ Q \\ W \end{bmatrix} = \begin{bmatrix} P_X & P_Y & P_Z \\ Q_X & Q_Y & Q_Z \\ W_X & W_Y & W_Z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} = [B] \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI}} \quad (4)$$

The unit vector along perigee (that is, P_X , P_Y , P_Z) can be determined by Equation 141, Page 20 of Battin as follows:

$$\vec{P} = \frac{1}{\mu e} \left[\left(v^2 - \frac{\mu}{r} \right) \vec{r} - (\vec{r} \cdot \vec{v}) \vec{v} \right] \quad (5)$$

where

v = absolute magnitude of velocity

r = absolute magnitude of the radius vector

\vec{v} = inertial velocity

\vec{r} = radius vector

C. ORBIT DETERMINATION

The problem of orbit determination can be stated as follows: Given an initial \vec{r}_1 and corresponding \vec{v}_1 vector expressed in ECI coordinates, determine the position and velocity in ECI coordinates at some time, t_2 .

From what has been presented so far, the approach would be to determine if the conic is a hyperbola or an ellipse. Then use the corresponding form of Kepler's equation to solve for the true anomaly and through the orbit-in-space-transformation determine the position and velocity at t_2 .

This method has the undesirable feature of first determining if the conic is a hyperbola or an ellipse and requires two sets of equations.

A more unified approach as presented by Battin is the universal conic equations which are given by

$$\vec{r}(t_2) = \left[1 - \frac{X^2}{r_1} C(X^2 \alpha_1) \right] \vec{r}_1 + \left[\Delta t - \frac{X^3}{\sqrt{\mu}} S(X^2 \alpha_1) \right] \vec{v}_1 \quad (9)$$

$$\vec{v}(t_2) = \frac{\sqrt{\mu}}{r_2 r_1} \left[\alpha_1 X^3 S(X^2 \alpha_1) - X \right] \vec{r}_1 + \left[1 - \frac{X^2}{r_2} C(X^2 \alpha_1) \right] \vec{v}_1 \quad (10)$$

where

$$C(X^2 \alpha_1) = \frac{1}{2!} - \frac{X^2 \alpha_1}{4!} + \frac{(X^2 \alpha_1)^2}{6!} - \dots$$

$$S(X^2 \alpha_1) = \frac{1}{3!} - \frac{X^2 \alpha_1}{5!} + \frac{(X^2 \alpha_1)^2}{7!} - \dots$$

$$\Delta t = t_2 - t_1$$

$$\alpha_1 = \frac{1}{a} = \frac{2}{r_1} - \frac{v_1^2}{\mu}$$

$$X = \frac{E_2 - E_1}{\sqrt{\alpha_1}} \quad \text{for ellipse}$$

$$X = \frac{H_2 - H_1}{\sqrt{-\alpha_1}} \quad \text{for hyperbola}$$

The parameter X which is required for Equations 9 and 10 is determined as follows: An initial guess for X is given by

$$X = X_1 + S \left[1 - F_3 S(1 - 2 F_3 S) - \frac{1}{6} \left(\frac{1}{r_1} - \alpha_1 \right) S^2 \right] \quad (11)$$

where

$$X_1 = 0 \text{ for the first iteration and } X \text{ for subsequent iterations}$$

$$F_3 = \frac{\vec{r}_1 \cdot \vec{v}_1}{2 r_1 \sqrt{\mu}}$$

$$S = \frac{\sqrt{\mu}}{2 r_1} (t_2 - t_1)$$

Having an initial guess for X, an improved value is obtained by a Newton-Raphson iteration scheme as follows:

$$X_{n+1} = X_n - \frac{F(X_n)}{F'(X_n)} \quad (12)$$

where

$$F(X_n) = \left[\frac{\vec{r}_1 \cdot \vec{v}_1}{\sqrt{\mu}} X_n^2 C(X_n^2 \alpha_1) + (1 - r_1 \alpha_1) X_n^3 S(X_n^2 \alpha_1) + r_1 X_n \right] - \sqrt{\mu} \Delta t$$

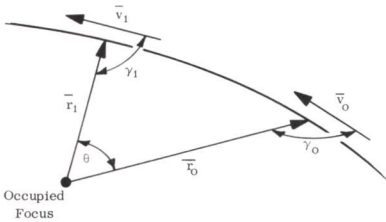
$$F'(X_n) = \frac{\vec{r}_1 \cdot \vec{v}_1}{\sqrt{\mu}} \left[X_n - \alpha_1 X_n^3 S(X_n^2 \alpha_1) \right] + \left[(1 - r_1 \alpha_1) X_n^2 C(X_n^2 \alpha_1) + r_1 \right]$$

The iteration scheme of Equation 12 continues until $x_{n+1} - x_n$ is sufficiently small. The good initial guess provided by Equation 11 limits the iteration to two or three in most cases. The value for x_{n+1} is then substituted into Equations 9 and 10, thereby specifying \vec{r}_γ and \vec{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_0 , v_0 , and Δt , solve for r_1 , v_1 .
- 2 - Lambert's Problem given r_0 , r_1 , and Δt , solve for conic parameters.
- 3 - Time - Theta Problem given r_0 , v_0 , and θ , solve for Δt .
- 4 - Time - Radius Problem given r_0 , v_0 , and r_1 , solve for Δt .

where:



f = true anomaly measured from pericenter

Δt = flight time from r_0 to r_1

p = semilatus rectum

$\alpha = 1/a$, a = semimajor axis

γ = flight path angle

θ = true anomaly difference ($f_1 - f_0$)

The equation set used for solution of the above problem is

$$13. \quad \sqrt{\mu} \Delta t = \sqrt{p} \cot \gamma_0 x^2 C(\alpha x^2) + (1 - r_0 \alpha) x^3 S(\alpha x^2) + r_0 x$$

$$14. \quad \cot \frac{\theta}{2} = \frac{r_0 [1 - \alpha x^2 S(\alpha x^2)]}{\sqrt{p} x C(\alpha x^2)} + \cot \gamma_0$$

$$15. \quad \frac{p}{r_0} = \frac{1 - \cos \theta}{\frac{r_0}{r_1} - \cos \theta + \sin \theta \cot \gamma_0}$$

$$16. \quad \frac{r}{\mu} v^2 = 2 - r \alpha$$

$$17. \quad r \alpha = 2 - \frac{p}{r} (1 + \cot^2 \gamma)$$

$$18. \quad \cot \frac{\theta}{2} = \frac{\cot \gamma_0 + \frac{r_0}{r_1} \cot \gamma_1}{\left(1 - \frac{r_0}{r_1}\right)}, \quad r_0 \neq r_1$$

$$19. \quad \frac{p}{r_0} = \frac{2 \left(\frac{r_0}{r_1} - 1 \right)}{\left(\frac{r_0}{r_1} \right)^2 \left(1 + \cot^2 \gamma_1 \right) - \left(1 + \cot^2 \gamma_0 \right)}$$

$$20. \quad r_1 = \left[1 - \frac{x^2}{r_0^2} C(\alpha x^2) \right] r_0 + \left[\Delta t - \frac{x^3}{\sqrt{\mu}} S(\alpha x^2) \right] v_0$$

$$21. \quad v_1 = \frac{\sqrt{\mu}}{r_0 r_1} \left[\alpha x^3 S(\alpha x^2) - x \right] r_0 + \left[1 - \frac{x^2}{r_1} C(\alpha x^2) \right] v_0$$

$$22. \quad \cot \gamma = \frac{\mathbf{r} \cdot \mathbf{v}}{|\mathbf{r} \times \mathbf{v}|}$$

Therefore:

- 1 Kepler's Solution. Compute $r_0 \alpha$ using Equation 16; compute x using Equation 13 and $\sqrt{p} \cot \gamma_0 = \frac{r_0 \cdot v_0}{\sqrt{\mu}}$; compute r_1 and v_1 using Equations 20 and 21.
- 2 Lambert's Solution. Guess a $\cot \gamma_0$; compute p/r_0 and $r_0 \alpha$ using Equations 15 and 17; compute x using Equation 14 iteratively; compute Δt using Equation 13. If Δt disagrees with the desired Δt , adjust $\cot \gamma_0$ and repeat.
- 3 Time - Theta Solution. Compute $\cot \gamma_0$, $r_0 \alpha$, and p/r_0 using Equations 22, 16, and 17; solve for x using Equation 14 iteratively; compute Δt using Equation 13.
- 4 Time - Radius Solution. Compute $\cot \gamma_0$, $r_0 \alpha$, p/r_0 , 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 the earth. Therefore, Equation 1 must be modified as follows:

$$\frac{d^2 \vec{r}}{dt^2} + \frac{\mu}{r^3} \vec{r} = \vec{a}_d \quad (23)$$

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 $\frac{\mu}{r^3}$, the two-body orbit given by Equation 1 is used as a reference or osculating orbit which is perturbed by \vec{a}_d . The actual position and velocity vectors are, therefore, given by

$$\begin{aligned} \vec{r} &= \vec{r}_c + \vec{\delta} \\ \vec{v} &= \vec{v}_c + \vec{\sigma} \end{aligned} \quad (24)$$

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

$$\frac{d^2 \vec{\delta}}{dt^2} = -\frac{\mu}{r_c^3} \left[\left[1 - \frac{r_c^3}{r^3} \right] \vec{r} - \vec{\delta} \right] + \vec{a}_d \quad (25)$$

subject to the initial conditions

$$\vec{\delta}(t_0) = 0, \quad \frac{d\vec{\delta}}{dt}(t_0) = \vec{\sigma}(t_0) = 0$$

This method (Equation 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

$$\left(1 - \frac{r_c^3}{r^3} \right) = \frac{1}{r^3} \left(1 + \frac{\rho^2}{1 + \rho} \right) \quad [(\vec{r}_c + \vec{r}) \cdot \vec{\delta}] \quad \text{where } \rho = r_c/r$$

Equation 25, therefore, becomes

$$\frac{d^2 \vec{\delta}}{dt^2} = \frac{\mu}{r_c^3} \left\{ \frac{\vec{r}}{r^3} \left(1 + \frac{\rho^2}{1 + \rho} \right) [(\vec{r}_c + \vec{r}) \cdot \vec{\delta}] - \vec{\delta} \right\} + \vec{a}_d \quad (26)$$

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, $\delta(t)$ must remain small. Therefore, a new osculating conic must be defined by the total position and velocity vectors $\mathbf{r}(t)$ and $\dot{\mathbf{v}}(t)$ when $\delta(t)$ 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 ($\delta(t)$) reach a predetermined limit.

E. DISTURBING FUNCTIONS

The form of the disturbing acceleration \mathbf{a}_D in general will be quite complicated. For the Skylab mission only the gravitational perturbations for the non-spherical shape of the earth are considered.

The form of this is:

$$\mathbf{a}_D = \mathbf{a}_{DE} = \frac{\mu_E}{r^2} \sum_{i=2}^4 J_{iE} \left(\frac{R_E}{r} \right)^i \left[P'_{i+1}(\cos \varphi) \frac{\mathbf{u}_r}{r} - P'_i(\cos \varphi) \frac{\mathbf{u}_z}{r} \right]$$

where

$$\begin{aligned} P'_2(\cos \varphi) &= 3 \cos \varphi \\ P'_3(\cos \varphi) &= 1/2 (15 \cos^2 \varphi - 3) \\ P'_4(\cos \varphi) &= 1/3 (7 \cos \varphi P'_3 - 4 P'_2) \\ P'_5(\cos \varphi) &= 1/4 (9 \cos \varphi P'_4 - 5 P'_3) \end{aligned}$$

are derivatives of Legendre Polynomials

$$\cos \varphi = \frac{\mathbf{u}_r}{r} \cdot \frac{\mathbf{u}_z}{r}$$

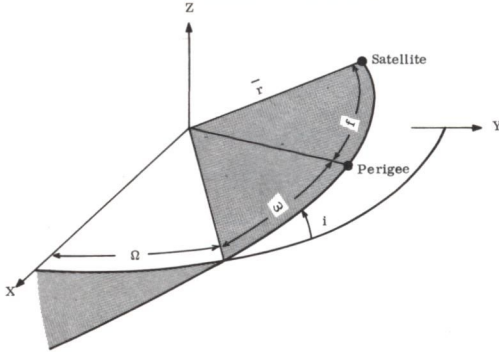
$$\frac{\mathbf{u}_z}{r} = \text{unit vector of the earth's true north polar axis expressed in the Basic Reference Systems.}$$

J_2, J_3, J_4 are the coefficients of the second, third, and fourth harmonics of the earth's potential functions and R_E is the mean equatorial radius of the earth.

$$\begin{aligned} J_{2E} &= .10827 \times 10^{-2} \\ J_{3E} &= -.256 \times 10^{-5} \\ J_{4E} &= -.158 \times 10^{-5} \\ R_E &= 6,378, 160.0 \text{ meters} \\ \mu_E &= .2986012 \times 10^{-5} \text{ m}^3/\text{sec}^2 \end{aligned}$$

These are all fixed memory constants in the AGC.

F. DISTURBANCE ACCELERATION/OSCULATING ELEMENTS



- a = Semimajor Axis (ft)
 e = Eccentricity
 i = Orbital Inclination
 f = Central Angle From Perigee
 r = Position (ft)
 Ω = Longitude of the Ascending Node
 ω = Argument of Perigee
 n = Mean Motion = $\sqrt{\frac{\mu}{a^3}}$ s^{-1}
 μ_E = 1.41×10^{17} ft^3/s^2

$$N, R, T = ft/s^2$$

Acceleration Normal
To Orbital Plane (N)

$$\frac{da}{dt} = \frac{de}{dt} = 0$$

$$\frac{di}{dt} = \frac{r \cos(\omega + f)}{na^2 \sqrt{1-e^2}} N$$

$$\frac{d\Omega}{dt} = \frac{r \sin(\omega + f)}{na^2 \sqrt{1-e^2} \sin(i)} N$$

$$\frac{d\omega}{dt} = \cos(i) \frac{d\Omega}{dt} N$$

Acceleration Along
Radial Line (R)

$$\frac{da}{dt} = \frac{2e \sin(f)}{n \sqrt{1-e^2}} R$$

$$\frac{de}{dt} = \frac{\sqrt{1-e^2} \sin(f)}{na} R$$

$$\frac{di}{dt} = \frac{dr}{dt} = 0$$

$$\frac{d\omega}{dt} = -\frac{\sqrt{1-e^2} \cos(f)}{nae} R$$

Acceleration Along
Track (T)

$$\frac{da}{dt} = \frac{2a \sqrt{1-e^2}}{nr} T$$

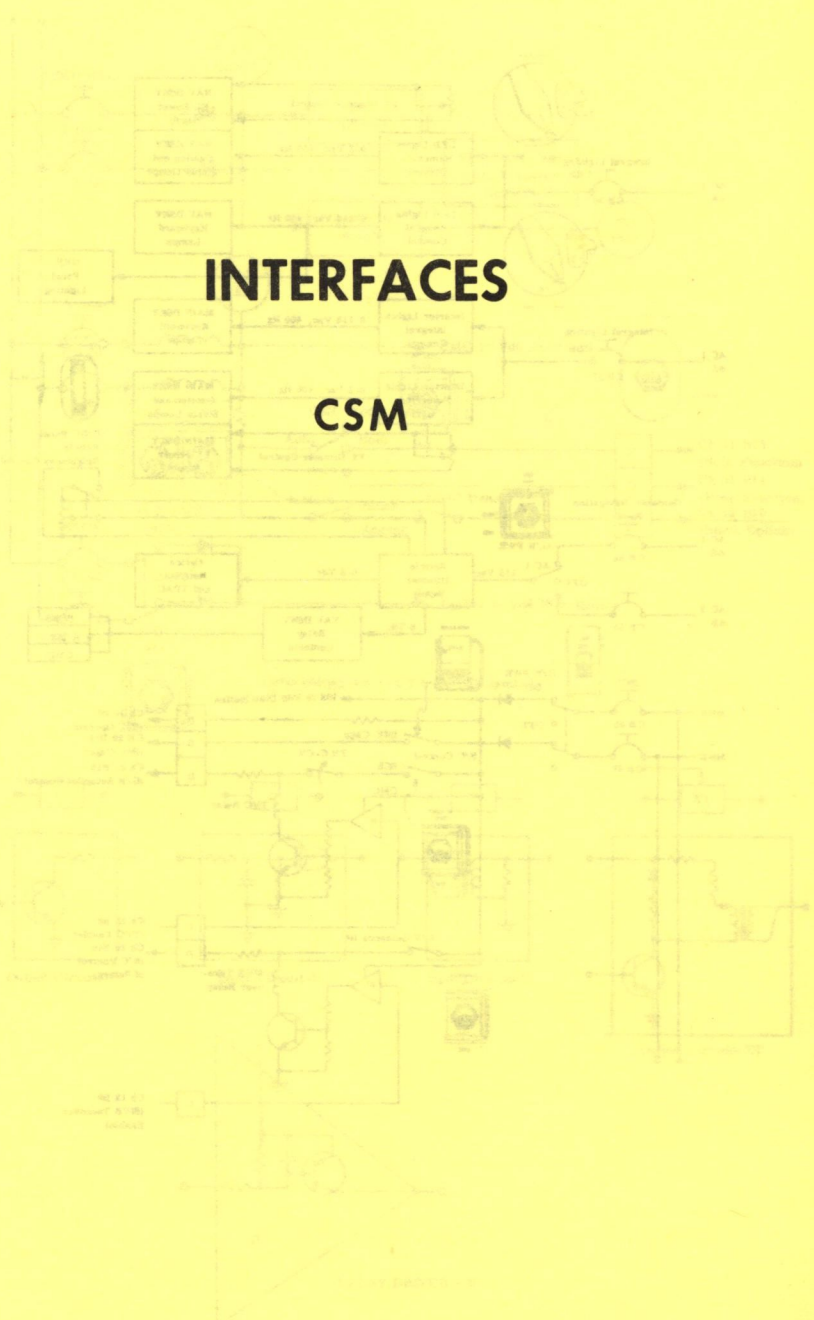
$$\frac{de}{dt} = \frac{\sqrt{1-e^2}}{na^2 e} \left[\frac{a^2 (1-e^2)}{r} - r \right] T$$

$$\frac{di}{dt} = \frac{dr}{dt} = 0$$

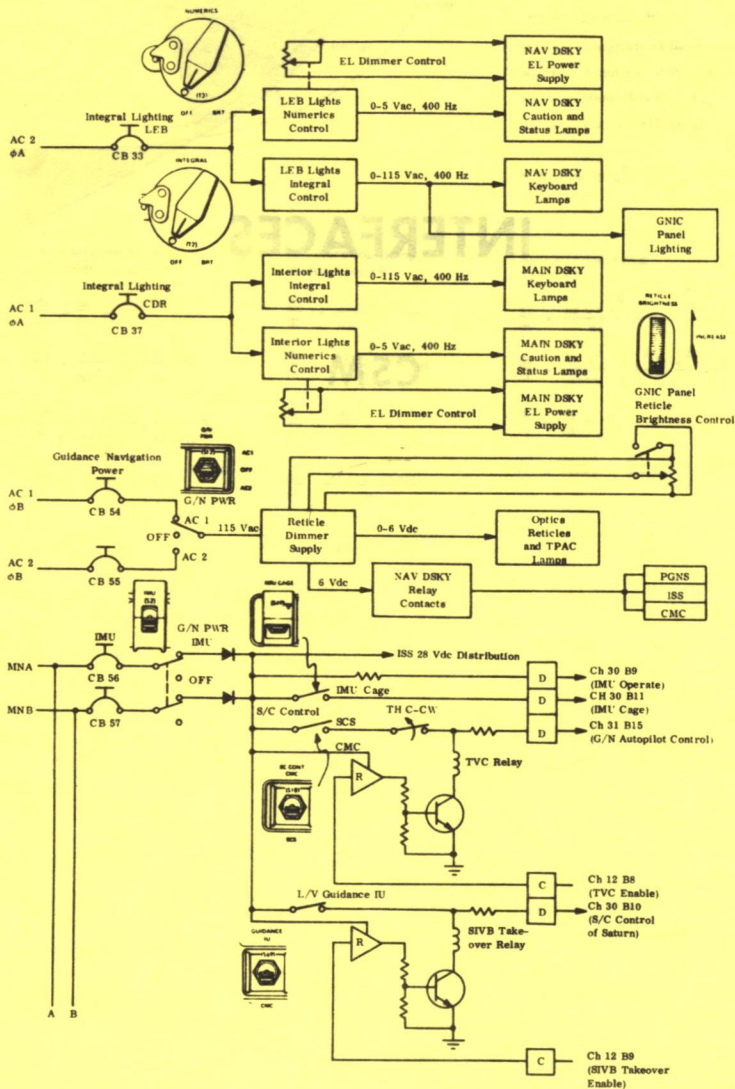
$$\frac{d\omega}{dt} = \frac{\sqrt{1-e^2}}{nae} \left(\frac{2+e \cos(f)}{1+e \cos(f)} \right) \sin(f) T$$

INTERFACES

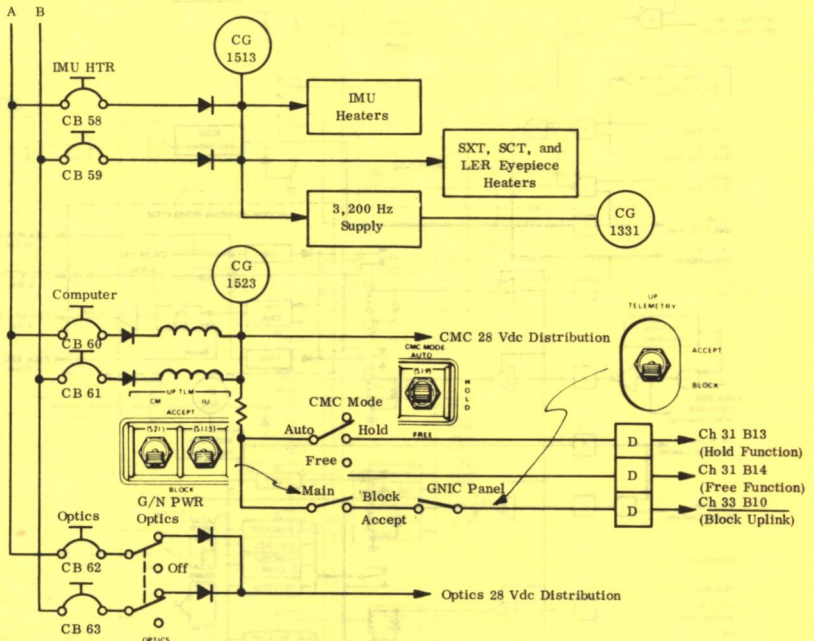
CSM



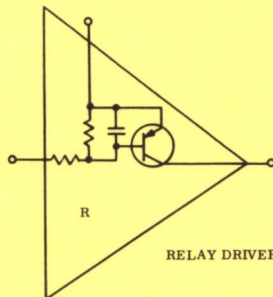
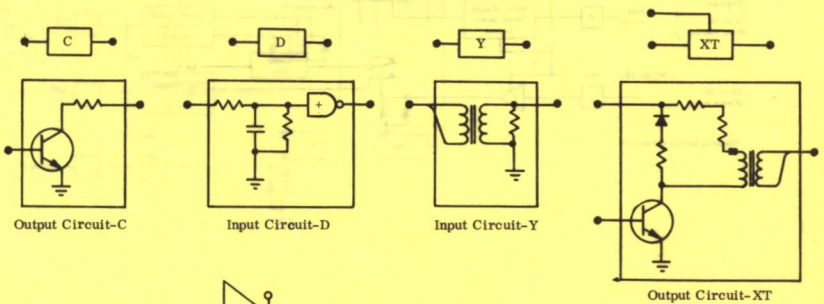
POWER AND LIGHTING



POWER AND LIGHTING

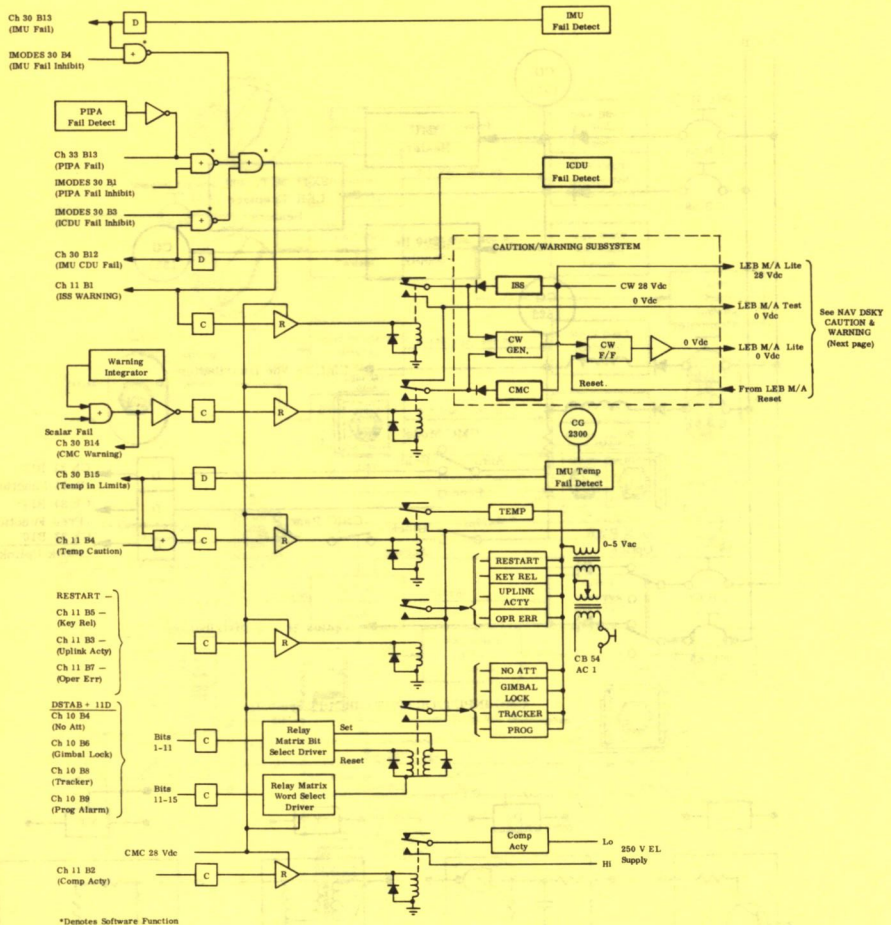


CMC INPUT/OUTPUT CIRCUIT Symbols



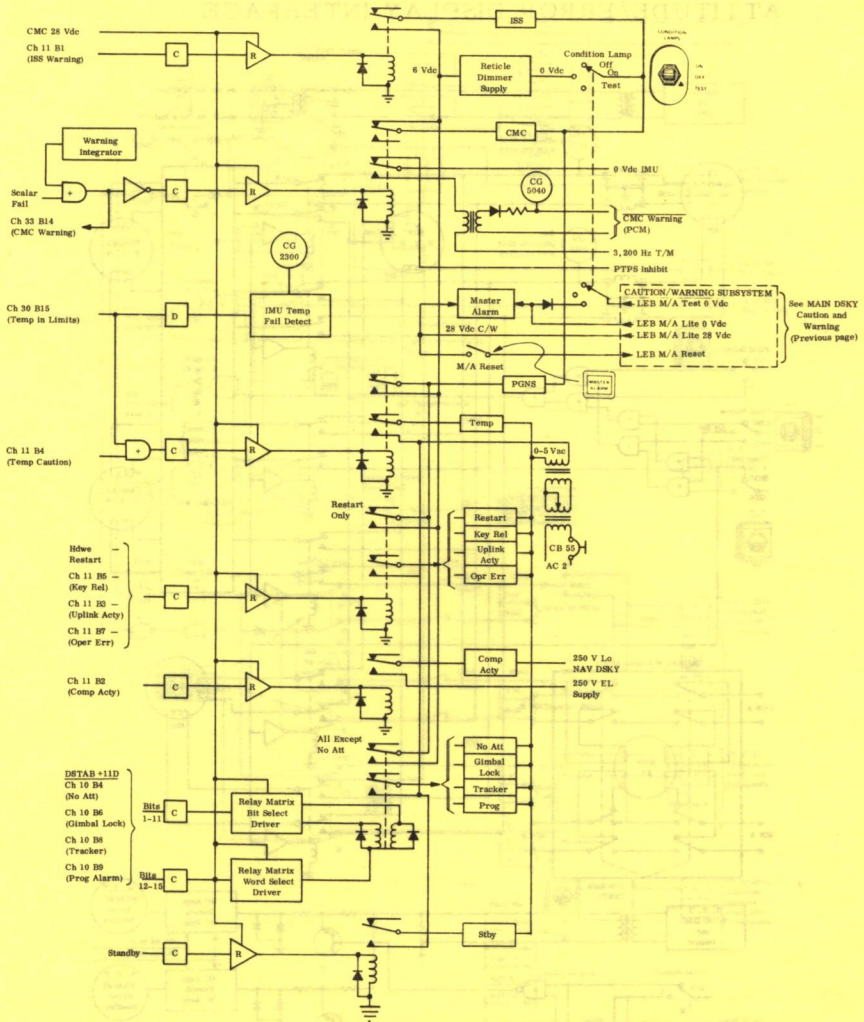
RELAY DRIVER - R

CAUTION, STATUS, AND WARNING (MAIN DSKY)

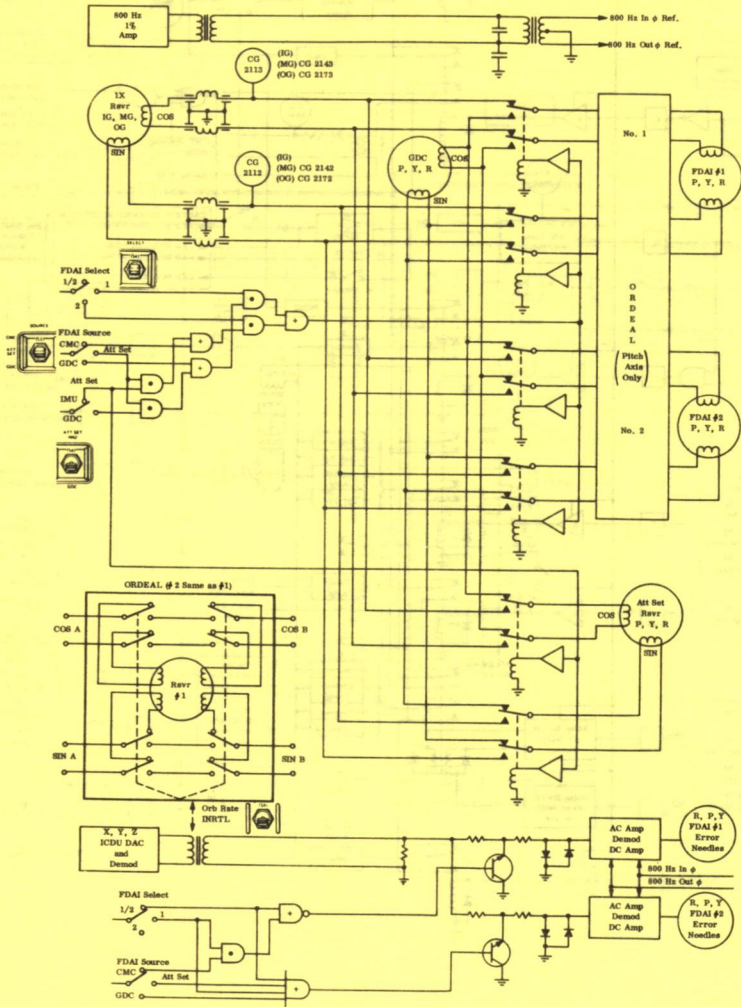


IF-5

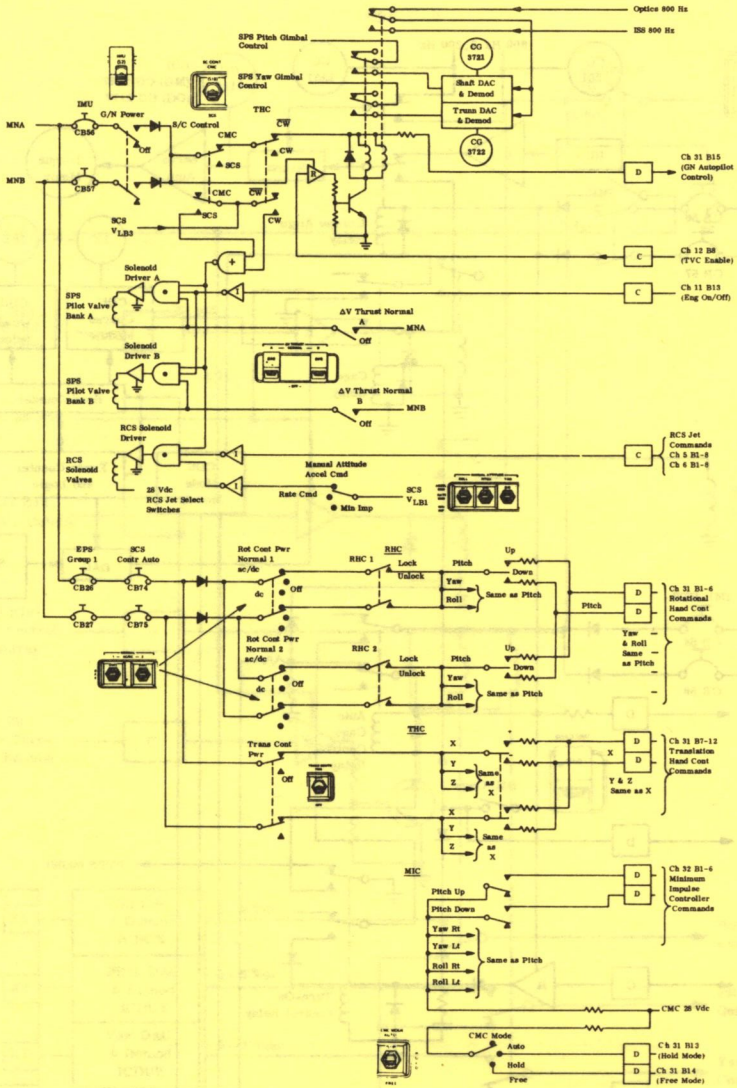
CAUTION, STATUS, AND WARNING (NAV DSKY)

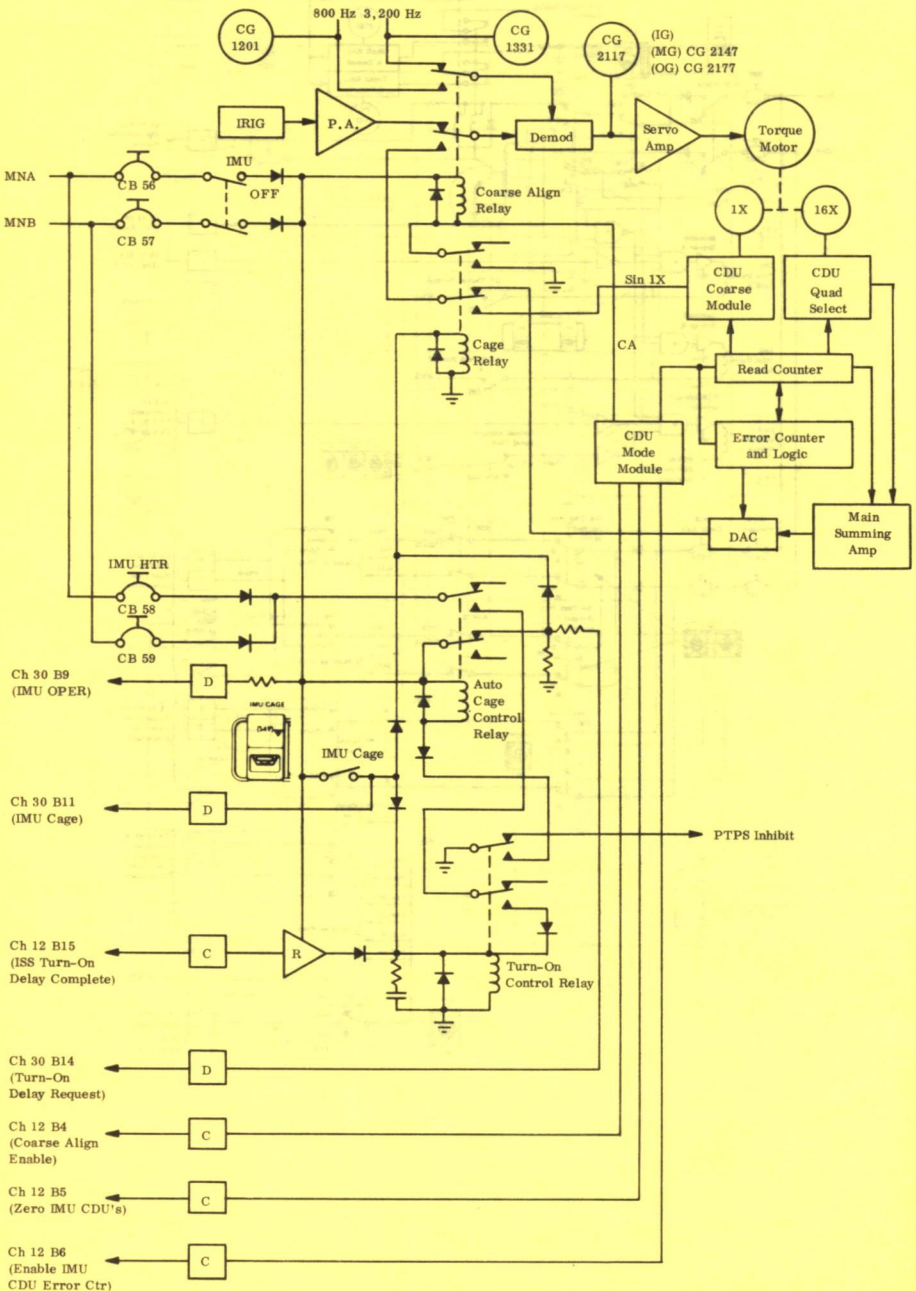


ATTITUDE/ERROR DISPLAY INTERFACE



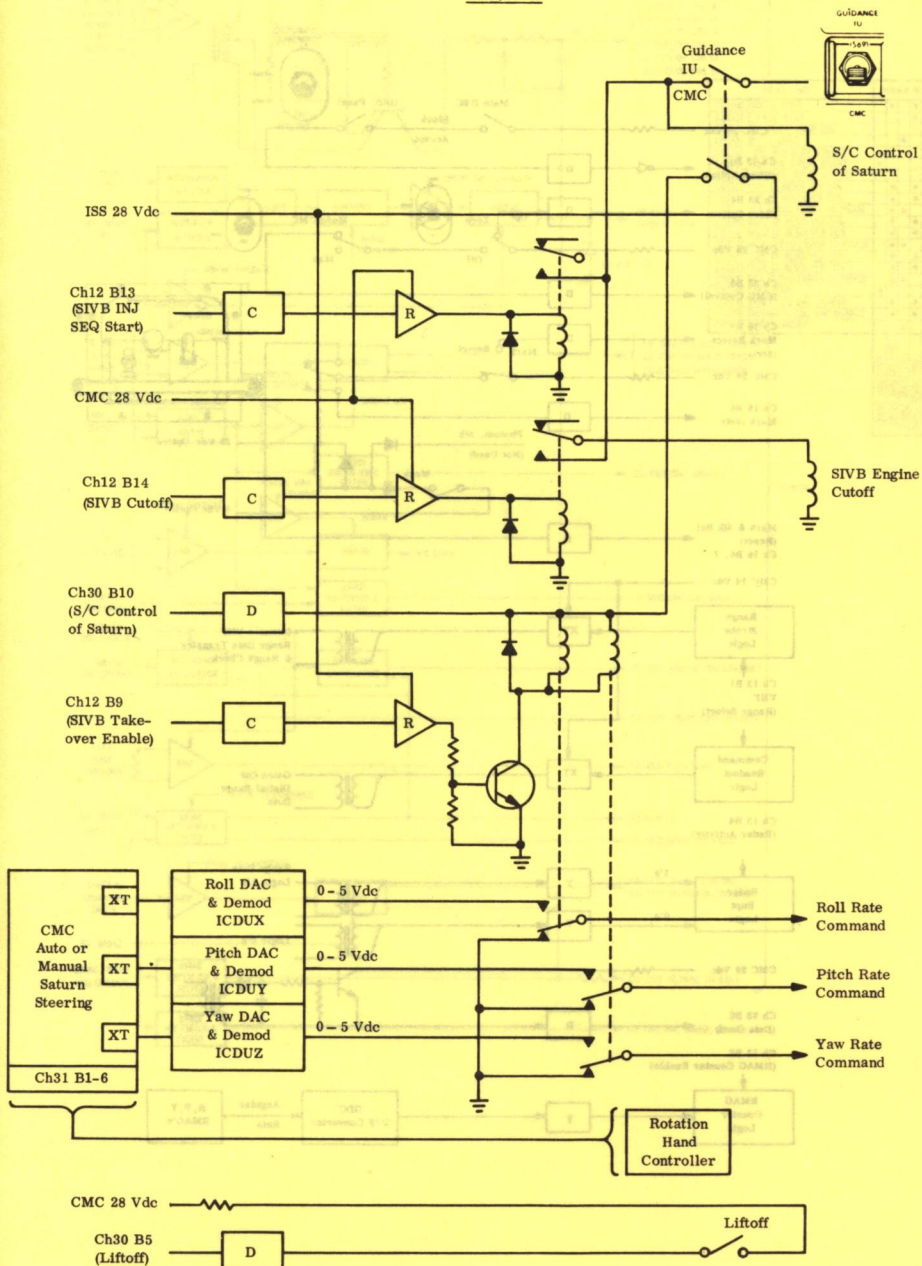
AUTOPILOT INTERFACES



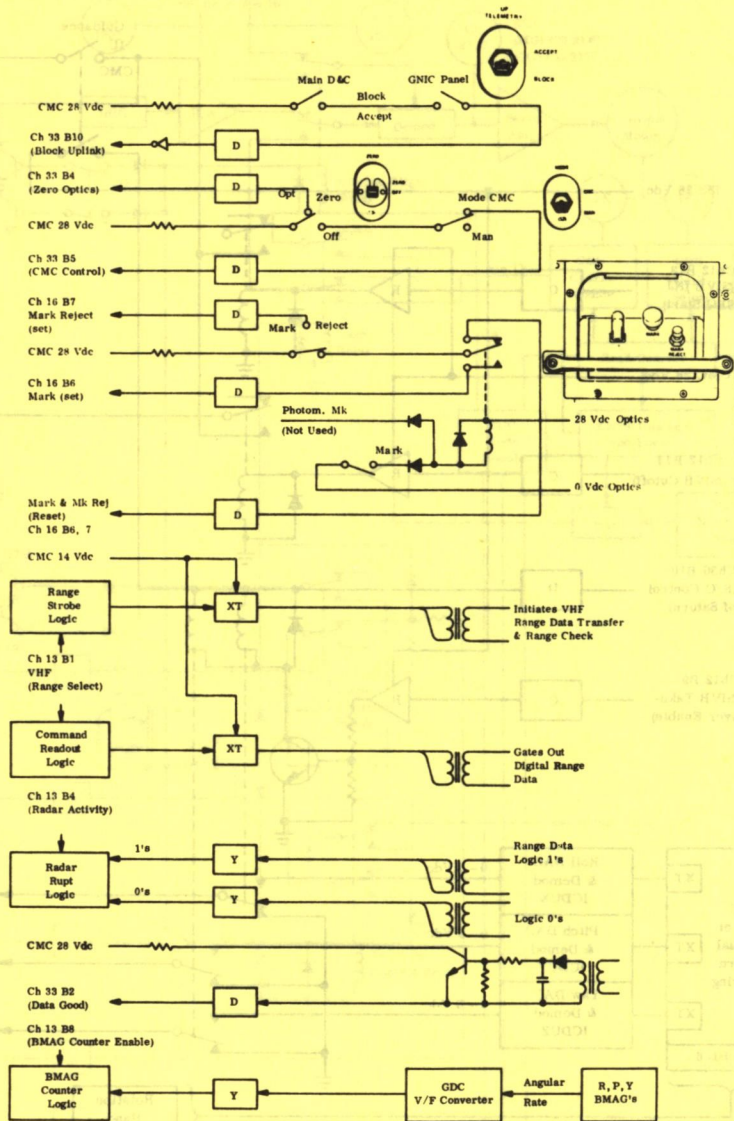


IF-9

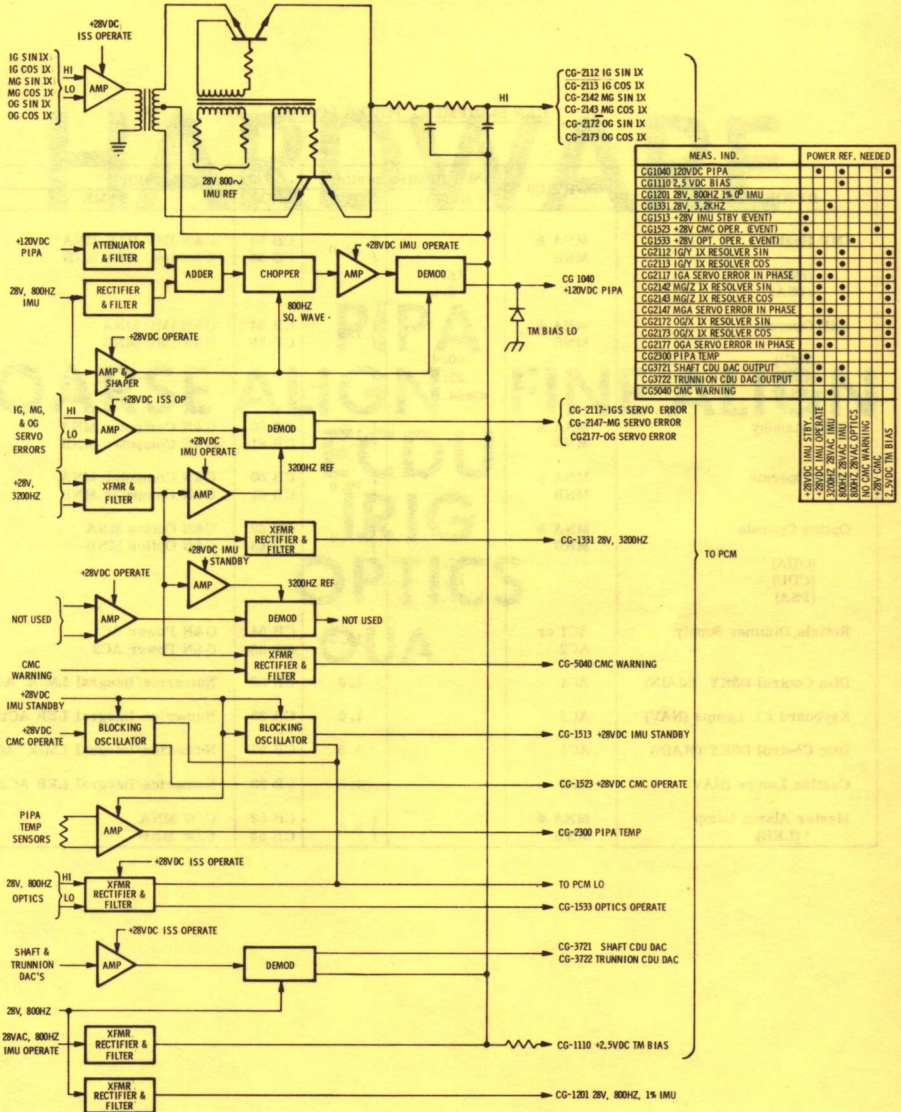
G&N/SIVB



OPTICS & VHF & BMAG INTERFACE



G&N SIGNAL CONDITIONER INTERFACE

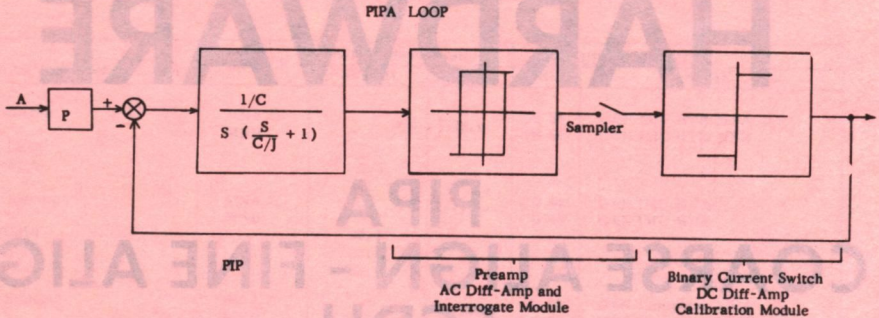


G&N EQUIPMENT POWER LOADS

DESCRIPTION	PWR BUS	PWR DISSIP (watts)		CIRCUIT BREAKER	
		PARTIAL	TOTAL	NO.	NAME
IMU Heater	MNA & MNB		} 22.0	CB 58	G&N IMU HTR MNA
(IMU)		16.5		CB 59	G&N IMU HTR MNB
(PSA)		5.5			
IMU Operate	MNA & MNB		} 183	CB 54	G&N IMU MNA
(IMU)				CB 55	G&N IMU MNB
(CDU)		60.4			
(PSA)		33.0 64.0			
CMC Standby	MNA & MNB		} 15.0	CB 60	G&N Computer MNA
				CB 61	G&N Computer MNB
CMC Operate	MNA & MNB		} 70.0	CB 60	G&N Computer MNA
				CB 61	G&N Computer MNB
Optics Operate	MNA & MNB		} 87.0	CB 62	G&N Optics MNA
(OUA)				CB 63	G&N Optics MNB
(CDU)		27.3			
(PSA)		19.3 40.4			
Reticle Dimmer Supply	AC1 or AC2		} 15.3	CB 54	G&N Power AC1
				CB 55	G&N Power AC2
Dim Control DSKY (MAIN)	AC1		1.0	CB 37	Numerics/Integral LMDC AC1
Keyboard EL Lamps (NAV)	AC2		1.0	CB 33	Numerics/Integral LEB AC2
Dim Control DSKY (MAIN)	AC1		4.5	CB 37	Numerics/Integral LMDC AC1
Caution Lamps (NAV)	AC2		4.5	CB 33	Numerics/Integral LEB AC2
Master Alarm Lamp (LEB)	MNA & MNB		} 3.5	CB 52	C/W MNA
				CB 53	C/W MNB

HARDWARE

PIPA
COARSE ALIGN - FINE ALIGN
ECDU
IRIG
OPTICS
OUA



- 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.

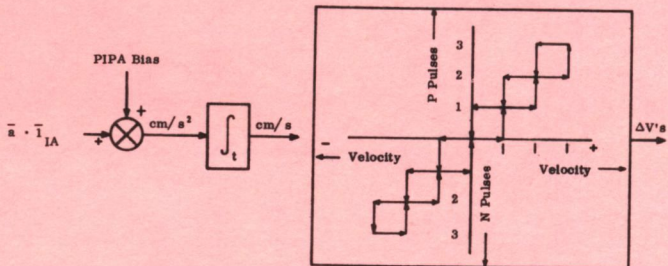
The AC Diff-Amp and Interrogate Module provides additional amplification (3050 V/V), peak detects float position, and sets a flip-flop. One state of the flip-flop indicates float position on the plus side of null and the other state means float position on the minus side of null.

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.



Each ΔV Command Module = 5.85 cm/s

PIPA CHARACTERISTICS

PARAMETER			CM
1.	Maximum measurable acceleration		19.1 g's
2.	Scale factor		5.85 cm/sec/pulse
3.	Pendulosity	P	0.25 $\frac{\text{dyne cm}}{\text{cm/sec}^2}$
4.	Torque to balance	T	4680 dyne cm
5.	PIP float inertia	J	14.0 $\frac{\text{dyne cm}}{\text{rad/sec}^2}$
6.	PIP viscous damping	C	12×10^4 $\frac{\text{dyne cm}}{\text{rad/sec}}$
7.	PIP break point	C/J	8550 rad/sec
8.	PIP time constant	J/C	.117 ms
9.	Total torque constant		.42 dyne cm/ma ²
10.	Nominal torque current		105 ma

SUSPENSION CHARACTERISTICS

- Radial Force 2.3 grams per .0001" min
- Suspension current 65 ± 6 ma
the two ends (SG & TG) matched with 3 ma
- Phase angle of current lags $45^\circ \pm 2.8^\circ$
- Suspension stiffness 30×10^{-3} grams/micro-inch

TYPICAL TEMPERATURE CHARACTERISTICS

- Scale Factor 150 ppm/ $^\circ\text{F}$ CM
- Bias .05 cm/sec²/ $^\circ\text{F}$ CM

$^\circ\text{F}$ Actual PIPA Temperature

PIPA PARAMETERS

Primary PIPA parameters are scale factor and bias. Specification values across ISS, G&N, and S/C testing are as shown in Table I-1.

Table I-1

PIPA Coefficient Stability Criteria				
Coefficient	Units	D ₁	D ₂	D ₃
PIPA Bias (A _B)	cm/sec ²	0.50	0.70	0.90
PIPA Scale Factor SF	ppm	400	500	600

PIPA bias in a unity gravity field (A_B) must be within 0.30 cm/sec² of that evaluated in a zero gravity (a_g) 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)
A _B	cm/sec ²	±9.14
SF	ppm	±1900

PIPA COMPENSATION

	Register
X PIPA Bias	1452
Y PIPA Bias	1454
Z PIPA Bias	1456

$$\text{PIPA Bias CM} = (.0005569) (\text{Reg Contents in Decimal}) \text{ cm/sec}^2$$

The correction to the PIPA's is

$$\text{PIPA}_C = (1 + \text{SFE}_I) \text{PIPA}_I - \text{BIAS}_I \Delta t$$

where

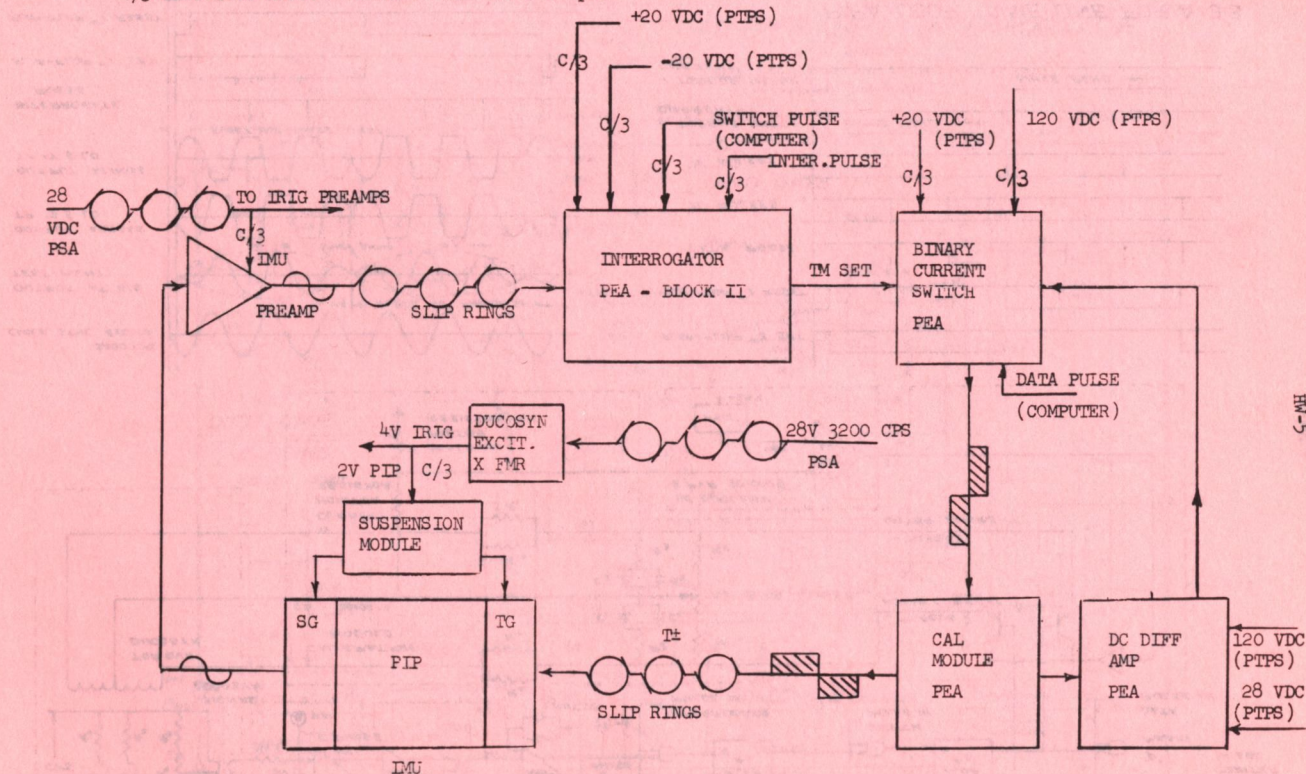
PIPA_C is the compensated data for the Ith PIPA denoted PIPAX_C, PIPAY_C, PIPAZ_C

$$\text{SFE} = \frac{\text{SF} - \text{SF}_{\text{nom}}}{\text{SF}_{\text{nom}}} \quad (\text{erasable load})$$

$$\text{SF} = \frac{\text{Scale-factor CM/Sec}}{\text{Pulse}}$$

BIAS_I is the bias for the Ith PIPA (an erasable load)

C/3 indicates assets common to all three loops.

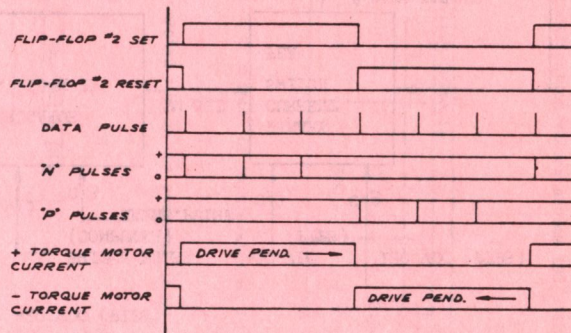
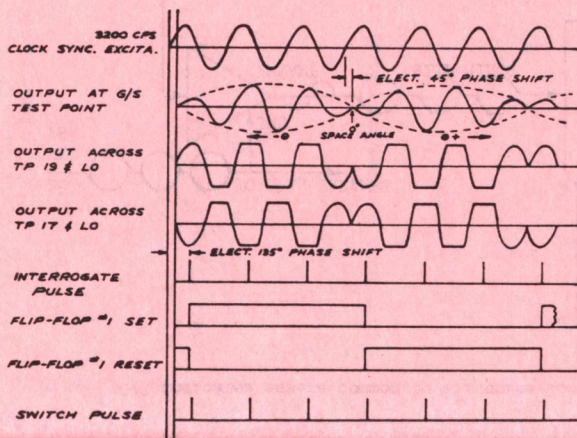
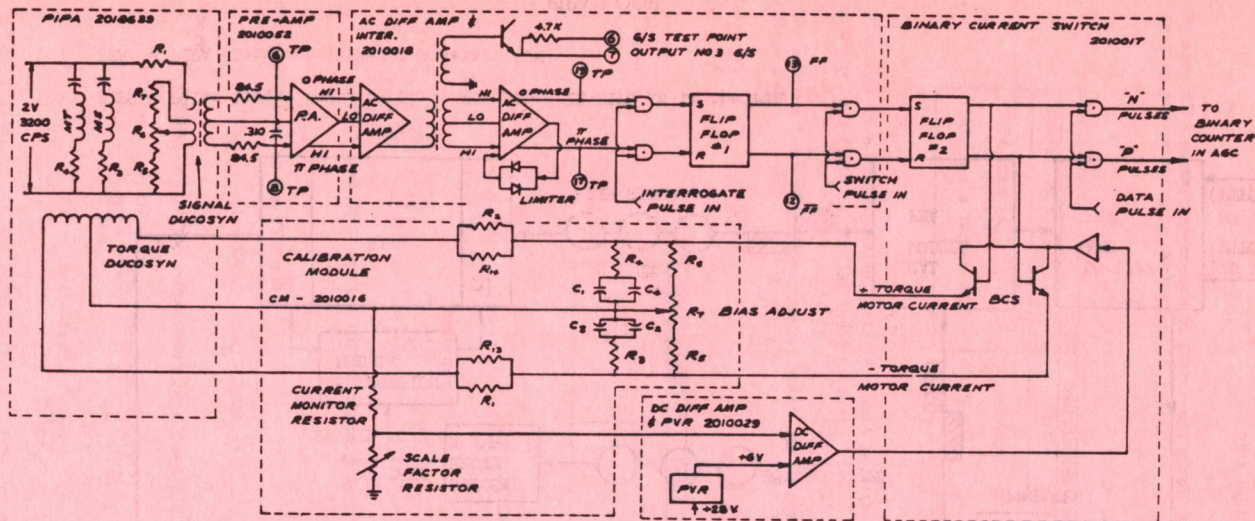


IM-5

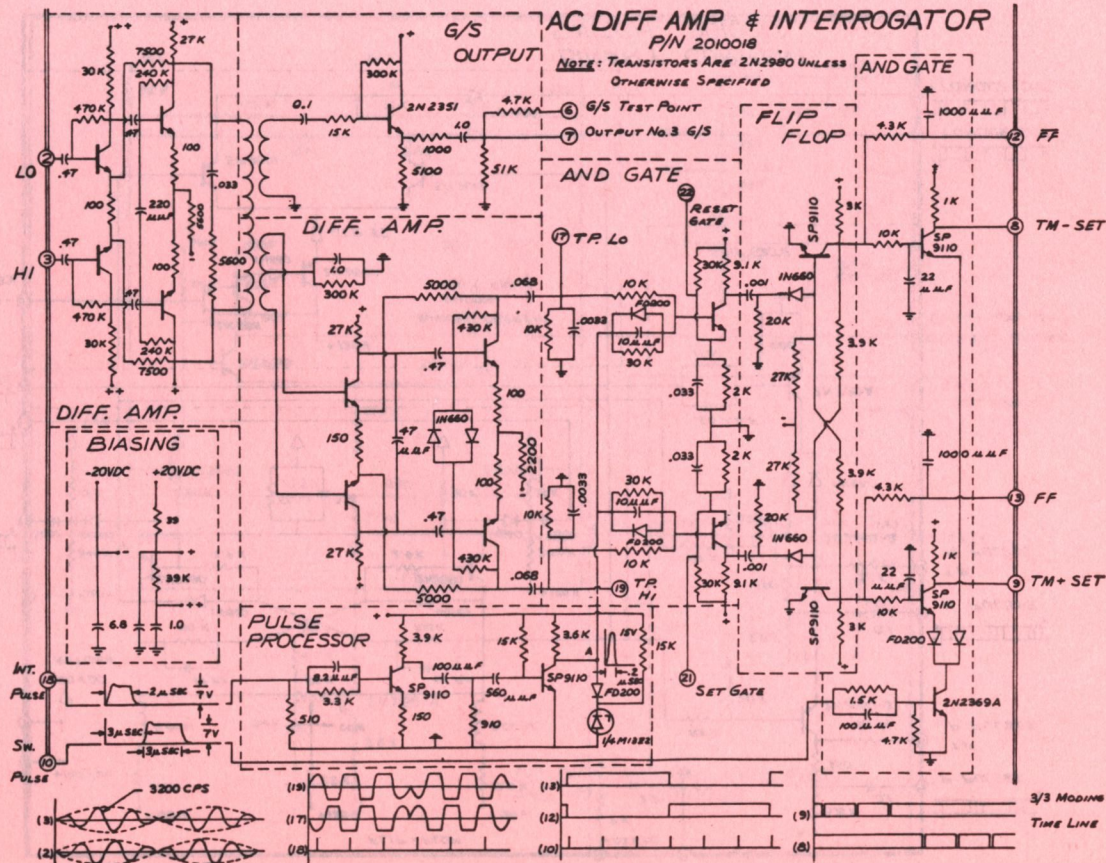
PTPS = Pulse Torque Power Supply. For Block II PTPS is in the PSA

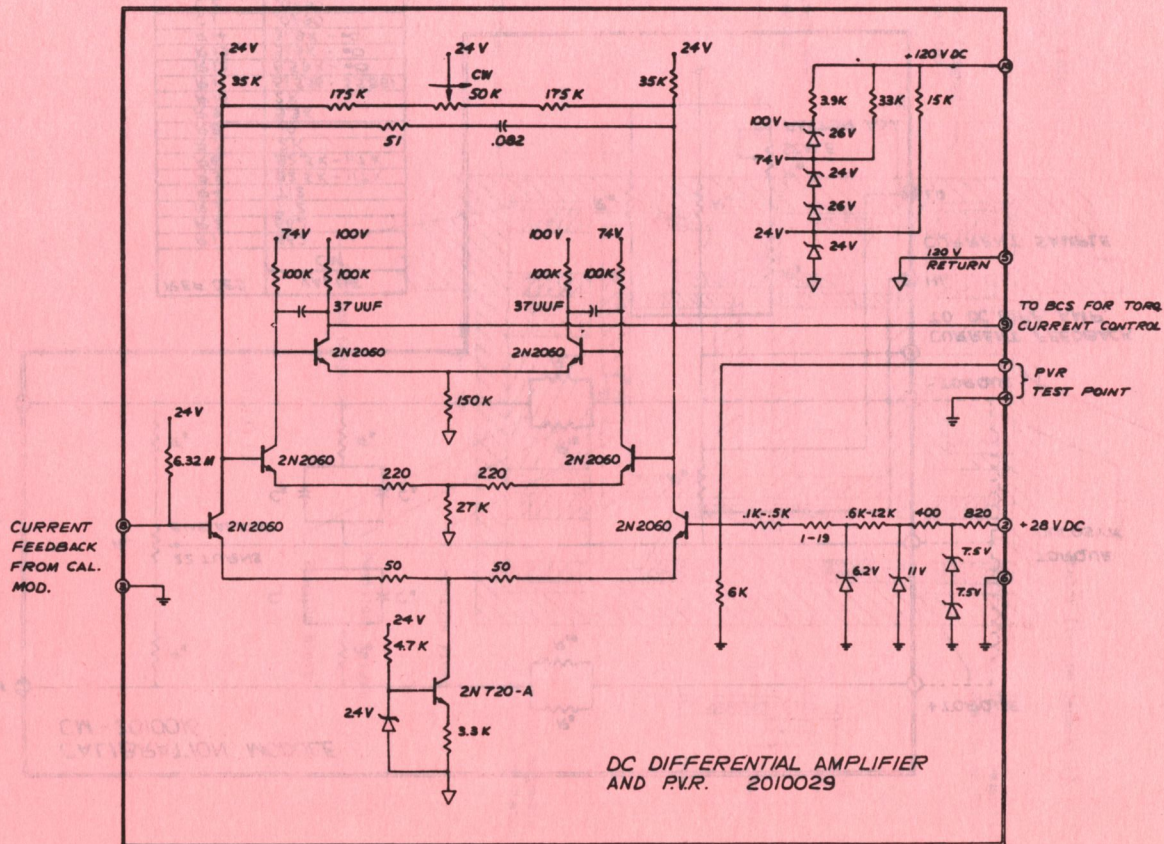
PEA = PIPA Electronics Header Assembly (CM)

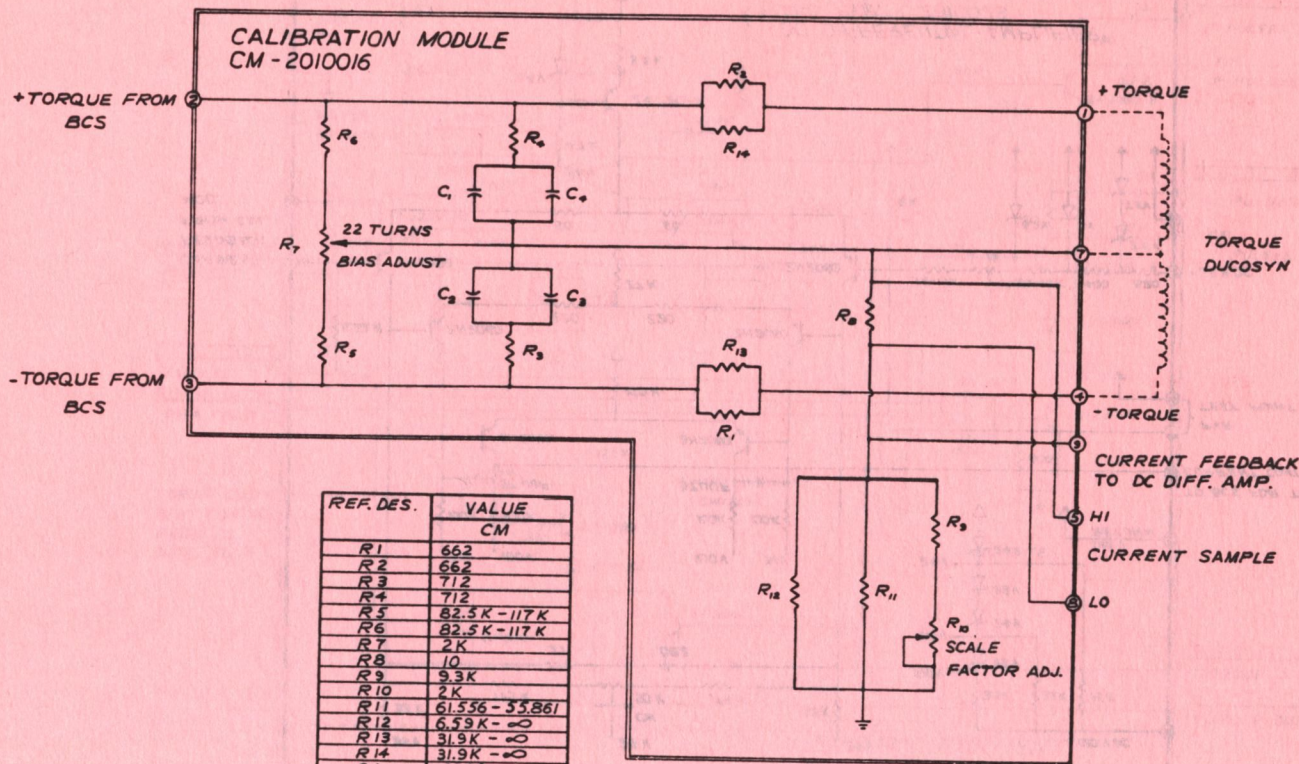
PIPA LOOP



PIPA LOOP TIME LINE FOR A 3:3
MODING CYCLE









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.

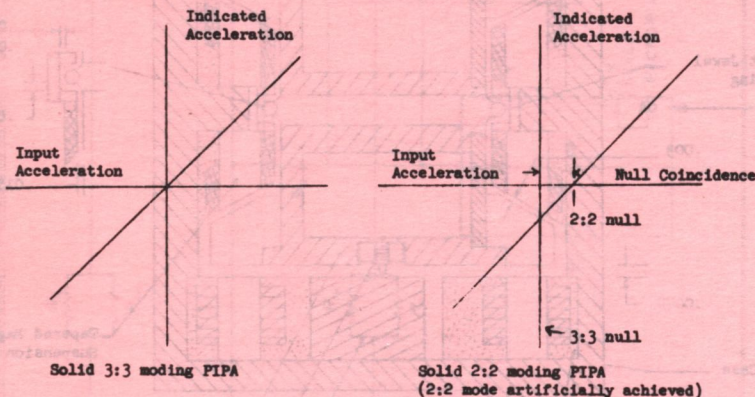


Figure 1

At higher levels of test, subtle changes in configuration due to integration of the PIPA loop into the G&W System can cause the PIPA to dual mode, i.e. the stable 3:3 mode may be replaced by a bistable 2:2 and 3:3 mode. Bistable moding causes no net delta V output and is manifest as a deadzone to near null inputs. This deadzone is checked at the ISS level of test to assure that it is less than 50 arc seconds (0.0075 ft/sec^2 or 0.23 cm/sec^2).

For an input acceleration of A_{33} (Figure 2), a dual moding PIPA will issue zero ΔV 's and mode 3:3.

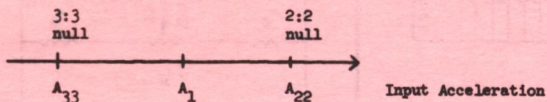


Figure 2

For an input acceleration of A_{22} , a dual moding PIPA will also issue zero ΔV 's and mode 2:2. For an input acceleration between the A_{33} and A_{22} limits, the PIPA will issue zero ΔV 's and dual mode from 2:2 to 3:3 at a rate of 5 or 6 times per second. The amount of time spent in 2:2 or 3:3 moding is dependent on the input acceleration A_1 .

HISTORY OF IN-FLIGHT PIPA PERFORMANCE

		AVG IN-FLIGHT ERROR*	CHANGE FROM (PREFLIGHT) COMP	LUNAR ORBITAL DEVIATIONS	
				MINIMUM	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	-0.43
	Z	-0.68	-	+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 0.0	-0.05 Pre-DOI -0.15 Post-Ascent		
	Y	0.0 0.0	0.0 Pre-DOI -0.18 Post-Ascent		
	Z	0.0 0.0	-0.06 Pre-DOI +0.29 Post-Ascent		
Apollo 13	CM X	-0.204	-		
	Y	-0.195	-		
	Z	+0.006	-1.63		
	LM X	+1.50	-		
	Y	-1.35	-		
	Z	-1.52	-		
Apollo 14	CM X	-0.02	-0.10	-0.34	-0.55
	Y	-0.02	+0.08	-0.18	0.12
	Z	-0.02	+2.77	-0.195	-0.45
	LM X	0.3	-		
	Y	-0.35	-		
	Z	-0.14	-		
Apollo 15	CM X	0.03	-	0.04	0.13
	Y	-0.04	-	-0.09	0.16
	Z	-0.05	-	-0.18	-0.34
	LM X	0.0 Pre-Descent -0.02 Post-Ascent	0.20 Pre-Ascent 0.36 Post-Ascent		
	Y	-0.02 Pre-Descent 0.01 Post-Ascent	0.34 Pre-Ascent - Post-Ascent		
	Z	0.03 Pre-Descent -0.01 Post-Ascent	- Pre-Ascent -0.16 Post-Ascent		
Apollo 16	CM X	+0.04	-	0.0	0.0
	Y	-0.2	-	+0.5	+0.10
	Z	Zbias Ranged from 0.22 to 0.53 During Coast Phases, and Several Updates were Necessary.		+0.02	+0.15
	LM X	-0.01	-		
	Y	+0.04	-		
	Z	+0.01	+0.09		
Apollo 17	CM X	-0.01	+0.22	+0.08	+0.43
	Y	+0.07	+0.07	-0.10	+0.01
	Z	+0.04	+0.04	+0.69	+0.74
	LM X	+0.04			
	Y	-0.05			
	Z	-0.02			

*Deviations from compensation updates when made, or from preflight loads when no update was made.
All units cm/s²

**This IMU was turned off for ~27 hours on the lunar surface.

*** Earth orbit deviations.

NOTE: Variations of CM bias in lunar orbit caused by variations in coolant temperature.

DMU COARSE ALIGN LOOP

The coarse align loop drives the DMU gimbals to the angles commanded by the computer with an accuracy of $\pm 1.5^\circ$. The coarse align mode also acts as a caging mode when a gimbal lock condition is approached.

The three basic elements of the coarse align loop are the Digital Computer which issues angle commands ($\Delta\theta_0$) and moding discretes, the DMU, and the ECDU which encodes gimbal position and provides position and rate feedback for proper loop operation.

DMU FINE ALIGN LOOP

The fine align loop drives the DMU gimbals to the computer commanded angles $\pm 80''$ by pulse torquing the gyros. Pulse torquing is a computer controlled switching of a constant current source to a gyro torquer winding. The current produces gyro torque, a corresponding precession rate, and hence, gimbal position.

DMU INERTIAL MODE

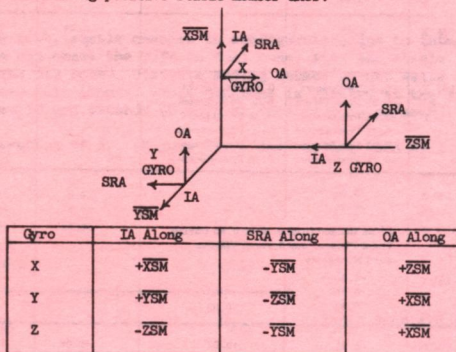
The elements of the inertial mode are the gyro, stabilization amplifier, and gimbal torque motor. The gyro senses inertial rotation about its input axis and supplies torquing to the gimbal via the stabilization amplifier to compensate for the motion.

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		
	NRD	ADIA	ADGRA
w_{XSM}	+NRDX	+ADIAx (a_{XSM})	-ADGRAx (a_{YSM})
w_{YSM}	+NRDy	+ADIAy (a_{YSM})	-ADGRAy (a_{ZSM})
w_{ZSM}	-NRDz	+ADIAz (a_{ZSM})	+ADGRAz (a_{YSM})

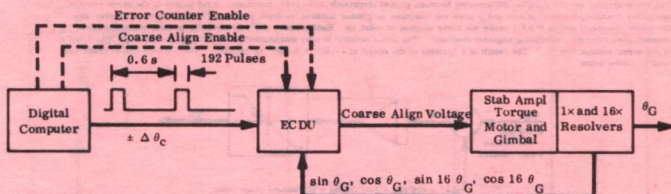
a_{XSM} a_{YSM} a_{ZSM} is positive along positive stable member axes.



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 (5.4 degrees) at a rate of 3,200 pulses/second. Each burst requires 60 milliseconds. The delay 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 IRG 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 ($\Delta\theta^2$) to increment the error counter. This signal also changes the read counter high speed pulse rate (P_1 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 ($P_E = \Delta\theta^2$ or $\Delta\theta_C$) to increment the error counter. Absence of this discrete zeroes 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.

$$Y = \bar{E} \cdot C_A + \text{CDUZ}$$

where

- a. The presence of Y inhibits P_1 pulses from incrementing the read counter
- b. \bar{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

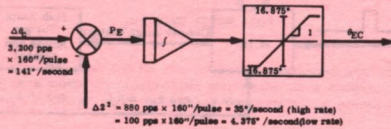
Inhibiting the read counter in this fashion will prevent gimbal drift due to residual voltages within the loop. The fine error will accumulate to a value such that the effect of residual voltages is cancelled.

ECU 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 ($\Delta\theta^2$) from the read counter loop. Computer command pulses ($\Delta\theta_c$) cause the error counter to count up. Read counter ($\Delta\theta^2$) pulses will, in turn, count the error counter down, thereby, producing negative feedback. The error counter is also mechanized to inhibit (P_g) pulses when Bits 7 and 8 of the error counter are "1." The result is a limiting of the output at $11.25^\circ \pm 0.625^\circ$ or 16.875° . The total functional characteristic is shown below.



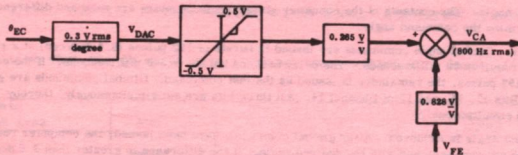
Error Counter

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.



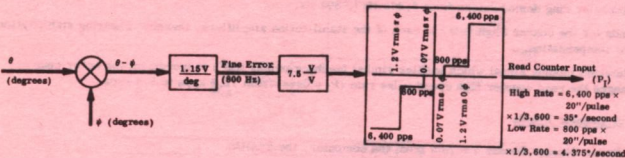
Coarse Align Mixing Amplifier

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 $-\sin(\theta - \phi) = -\sin\theta \cos\phi + \cos\theta \sin\phi$. Functionally, this network compares the gimbal angle (θ) as represented by the 16-speed resolver signals to the read counter angle (ϕ) and generates an error signal used to drive the read counter loop.

Rate Select and Up/Down Logic

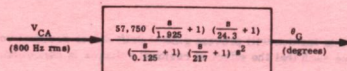
Rate select and up/down logic is generated from the fine error signal (an analog measure of the error between resolver angle and read counter angle) by Schmitt trigger type level detectors. The rate select and up/down logic processes the sampled output of the Schmitt triggers to determine at which rate 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

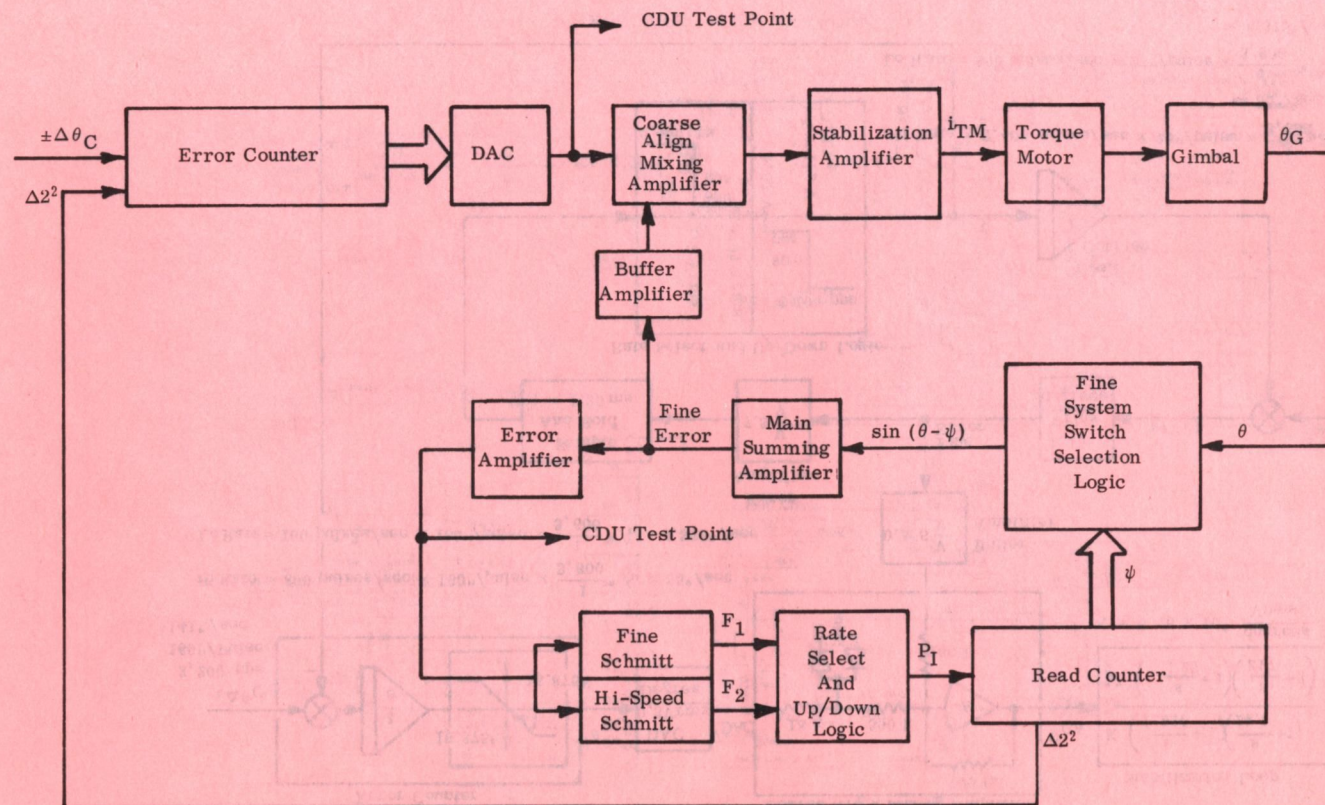
The read counter is a 16-stage digital counter with an IMU angle granularity of 30 seconds/Alt. Inputs to the read counter are controlled by rate select and up/down logic. The output is used by the fine system switch selection logic to produce the fine error signal. Access by the computer is to the low order bit ($\Delta\theta^2$). Access by the error counter is to the third order bit ($\Delta\theta^3$). Functionally, the read counter is represented as an integrator with a count rate in degrees/second and an output in degrees.

Stabilization Loop

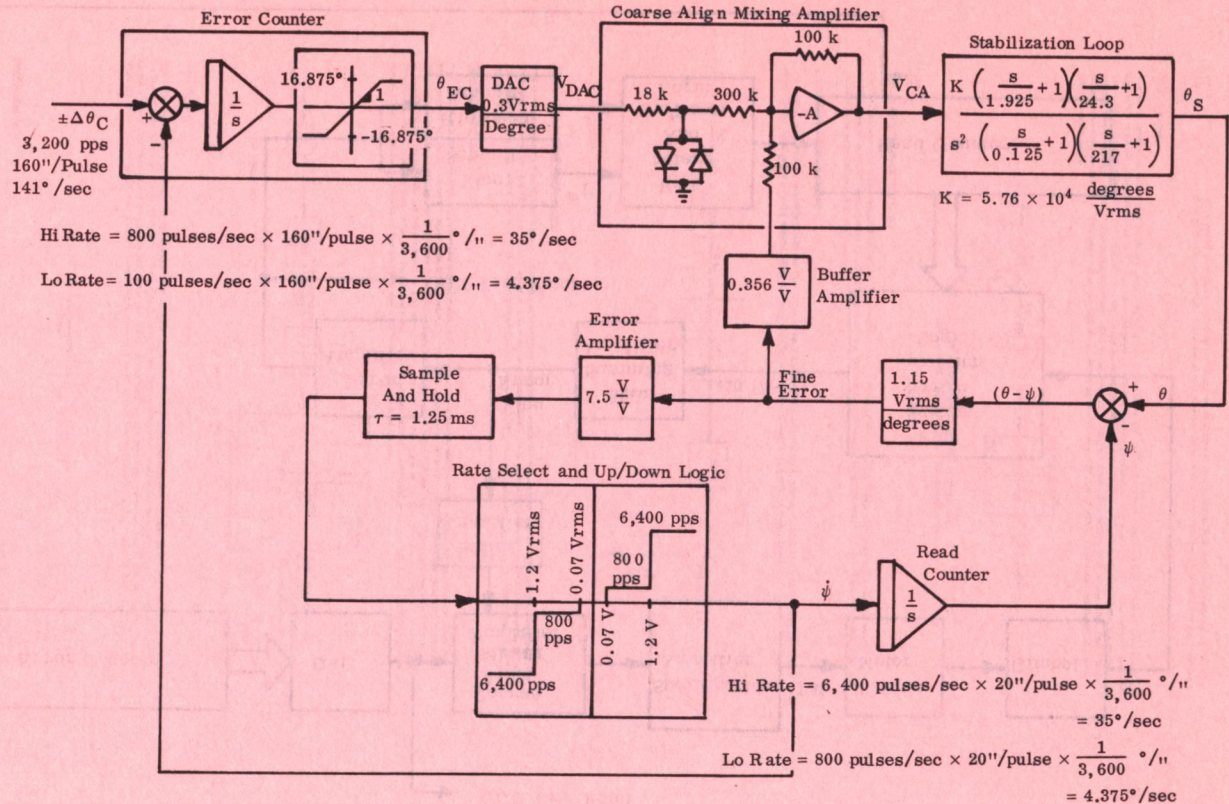
The analog part of the coarse align servomechanism consists of the stabilization amplifier, torque motor, and gimbal. The overall transfer function of the above three elements is as shown below.



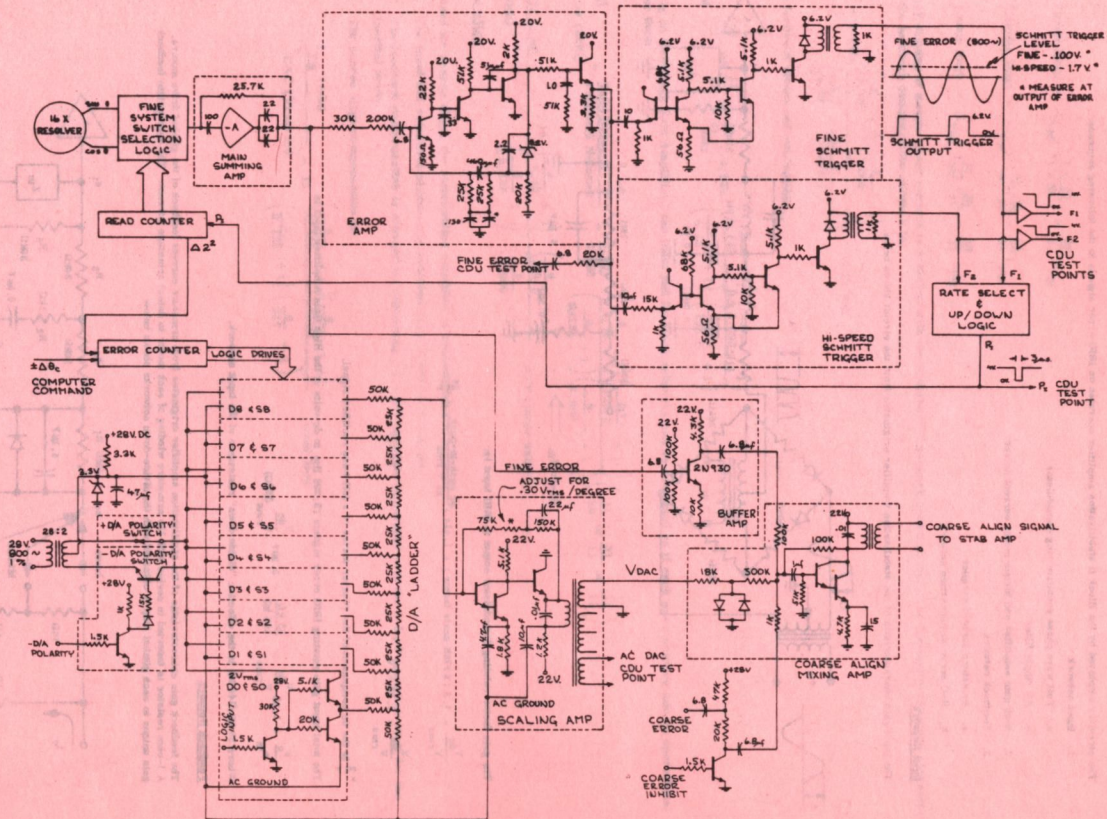
IMU COARSE ALIGN BLOCK DIAGRAM



IMU COARSE ALIGN FUNCTIONAL BLOCK DIAGRAM



ECDU COARSE ALIGN NETWORK



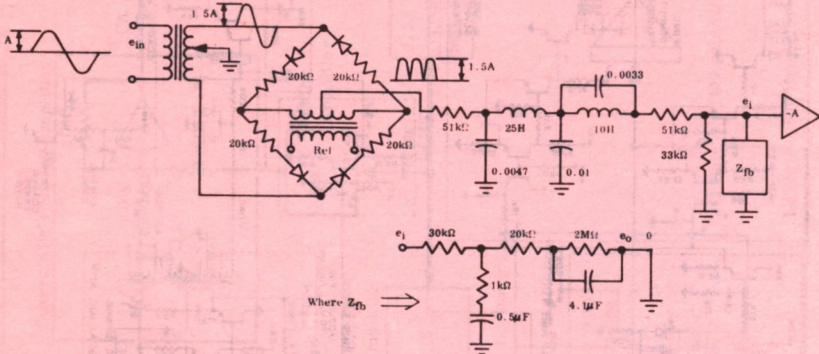
IMU INERTIAL MODE

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

Input Network

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.

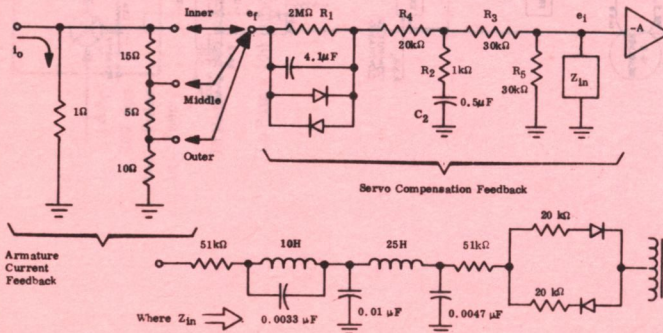
The total input gain relating IRIG error signals (3,200 Hz) to dc volts at the High Gain Amplifier input is

$$\frac{e_0}{e_{in}} = 1.35 \frac{V_{dc}}{V_{rms}} \times \frac{33 \text{ k}\Omega}{145 \text{ k}\Omega} = 0.307 \frac{V_{dc}}{V_{rms}} \text{ (IRIG)}$$

Where $33 \text{ k}\Omega / 145 \text{ k}\Omega$ is the effective "divide down" resistance of the input network.

Feedback Network

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:

$$\frac{e_o}{e_{fb}} = 0.020 \left(\frac{\frac{s}{0.125} + 1}{\frac{s}{4.12} + 1} \right) \left(\frac{\frac{s}{2.000} + 1}{\frac{s}{102.5} + 1} \right) \text{ volts/volt}$$

with the feedback diodes not conducting.

$$\frac{e_o}{i_{TM}} = \left(\frac{30}{31} \text{ or } \frac{15}{31} \text{ or } \frac{10}{31} \right) 0.020 \left(\frac{\frac{s}{0.125} + 1}{\frac{s}{4.12} + 1} \right) \left(\frac{\frac{s}{2.000} + 1}{\frac{s}{102.5} + 1} \right)$$

Assuming an Ideal High Gain Amplifier, the input and feedback networks can be combined as if each were working into an operational amplifier thus:

$$\frac{i_{TM}}{V_{rms} \text{ (IRIG)}} \approx \frac{\text{Input Network}}{\text{Feedback Network}} = \frac{0.307}{0.020} \left(\frac{\frac{s}{4.12} + 1}{\frac{s}{0.125} + 1} \right) \left(\frac{\frac{s}{102.5} + 1}{\frac{s}{2.000} + 1} \right) \left(\frac{31}{30} \text{ or } \frac{31}{15} \text{ or } \frac{31}{10} \right)$$

$$\frac{i_{TM} \text{ (Ade)}}{V_{IRIG} \text{ (Vrms ac)}} = \frac{15 \left(\frac{\frac{s}{4.12} + 1}{\frac{s}{0.125} + 1} \right) \left(\frac{\frac{s}{102.5} + 1}{\frac{s}{2.000} + 1} \right)}{\left(\frac{s}{0.125} + 1 \right) \left(\frac{s}{2.000} + 1 \right)} \text{ A/V (inner axis)}$$

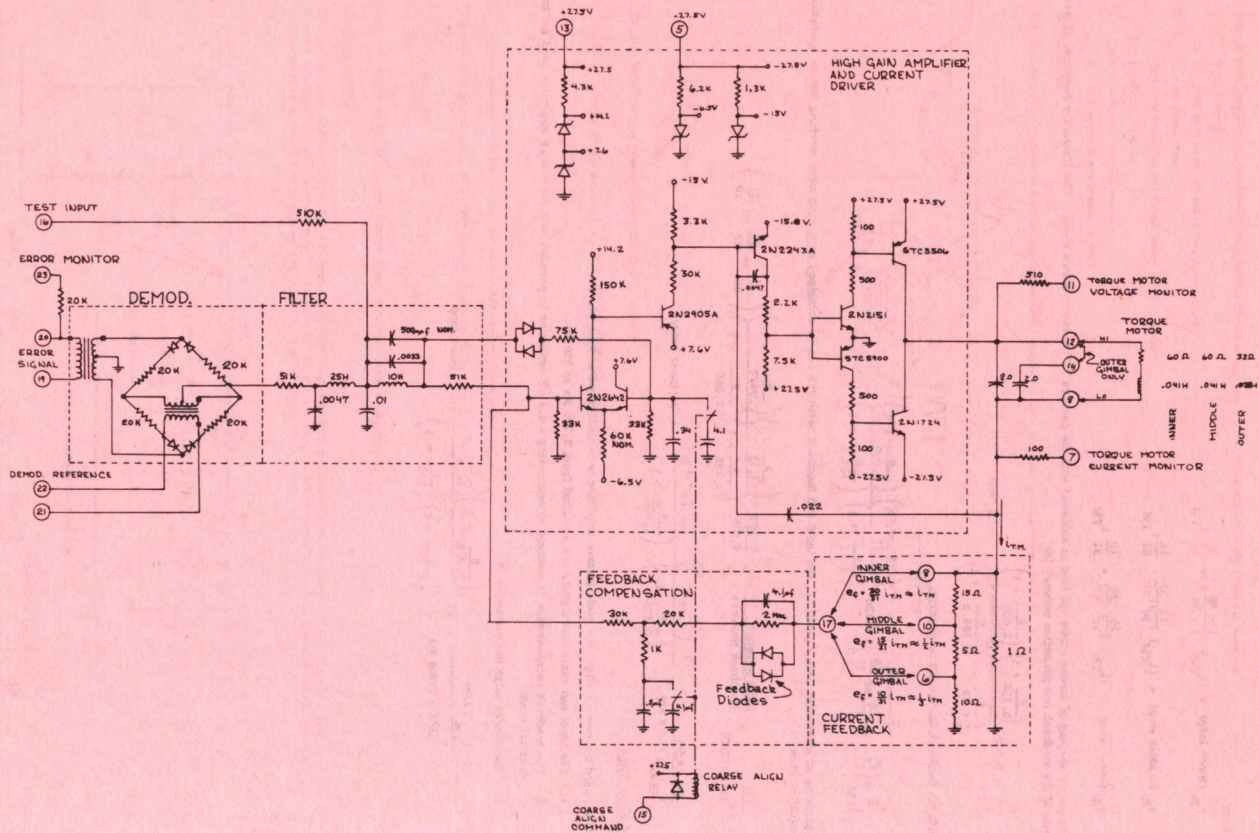
Coarse Align

When used for coarse align, the stabilization amplifier is reconfigured as follows:

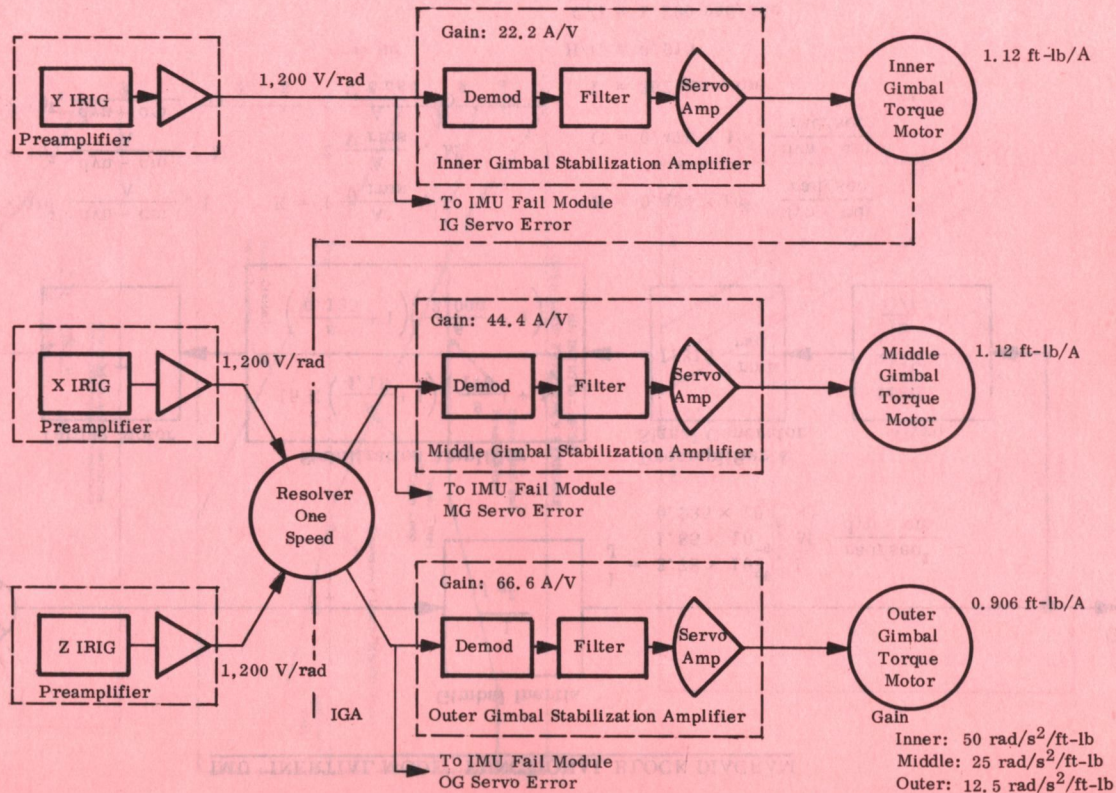
1. The input and reference signals are switched from 3,200 Hz to 800 Hz.
2. The feedback compensation is changed by connecting a 4.1 μ F capacitor in parallel with the 0.5 μ F capacitor used for the inertial mode.
3. The coarse align compensation is:

$$\frac{i_{TM} \text{ (Ade)}}{V_{DAC} \text{ (Vrms ac)}} = 15 \left(\frac{\frac{s}{1.925} + 1}{\frac{s}{0.125} + 1} \right) \left(\frac{\frac{s}{24.3} + 1}{\frac{s}{217} + 1} \right) \text{ inner loop}$$

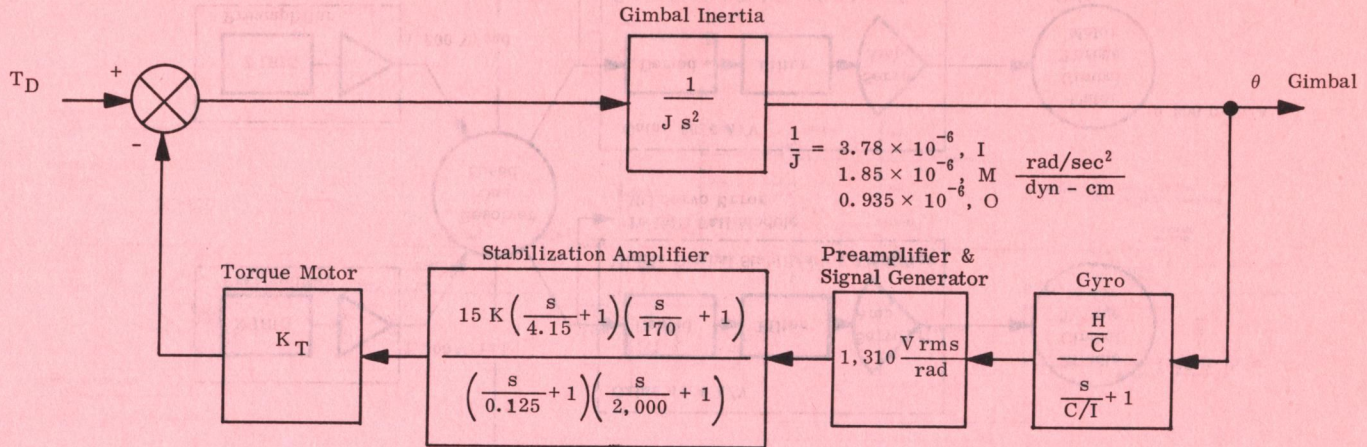
IMU STABILIZATION AMPLIFIER



IMU "INERTIAL MODE" BLOCK DIAGRAM



IMU "INERTIAL MODE" FUNCTIONAL BLOCK DIAGRAM



$$K_T = 1.52 \times 10^7 \frac{dyn - cm}{A}, I$$

$$1.52 \times 10^7 \frac{dyn - cm}{A}, M$$

$$1.23 \times 10^7 \frac{dyn - cm}{A}, O$$

$$K = 1 \frac{A}{V_{rms}}, I$$

$$2 \frac{A}{V_{rms}}, M$$

$$3 \frac{A}{V_{rms}}, O$$

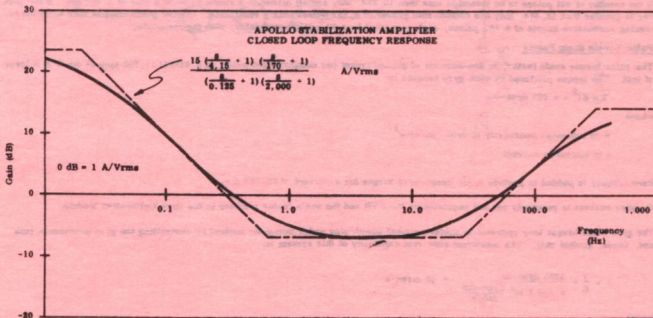
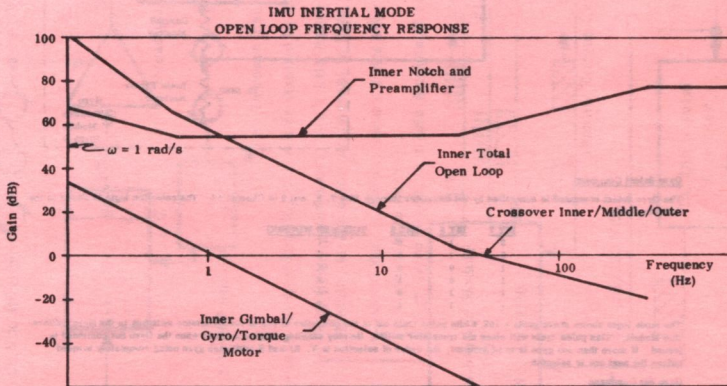
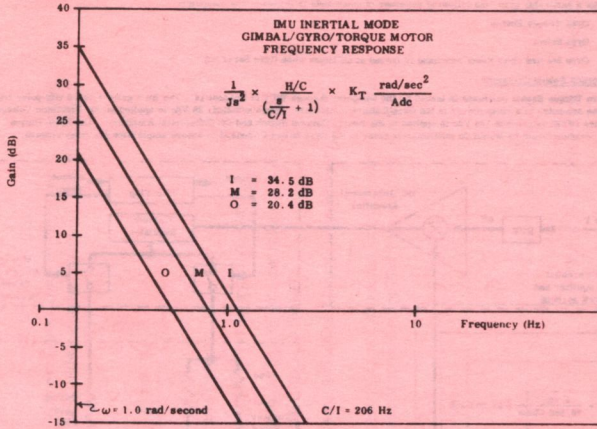
$$H = 0.434 \times 10^6 \frac{dyn - cm}{rad/sec}$$

$$C = 0.475 \times 10^6 \frac{dyn - cm}{rad/sec}$$

$$I = 367 gm - cm^2$$

$$H/C = 0.915$$

$$C/I = 1,290 rad/sec$$



GYRO PULSE TORQUING

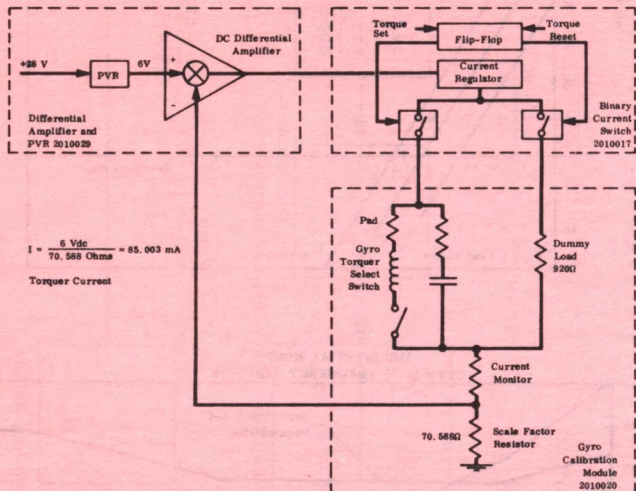
Gyro torque, its corresponding precession rate, and hence gimbal position are controlled by regulating the pulse width of gyro torquer current. In the Fine Align mode, the length of the torquer current pulse is precisely controlled by the computer to achieve a desired gimbal position.

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 torque 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 $0.617981 \pm 1,750$ ppm at the G & N level of test. The torque produced by each gyro torquer is:

$$T = K i^2 = 4,335 \text{ dyne-cm}$$

where

K is microsyn sensitivity in dyne-cm/amp²

i is microsyn current

Each torquer is added 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:

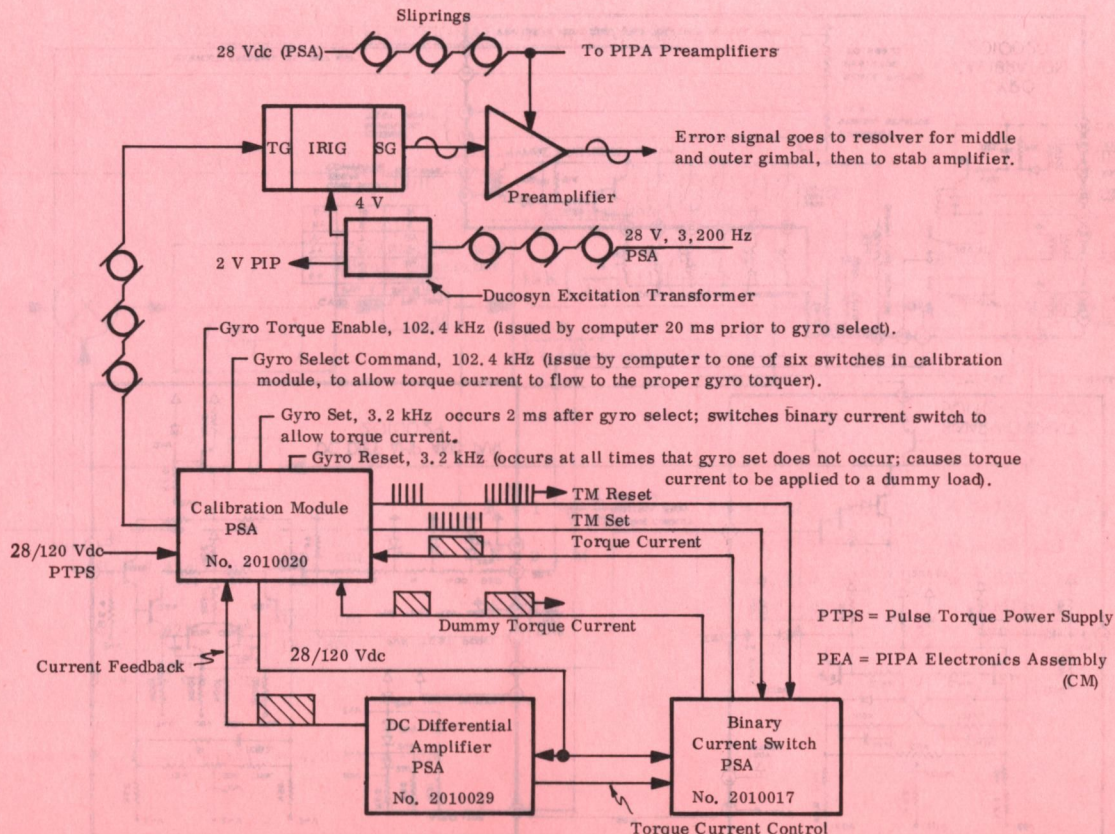
$$\dot{\theta} = \frac{T}{H} = \frac{4,335 \text{ dyne-cm}}{0.434 \times 10^6 \text{ dyne-cm rad/s}} = 10 \text{ mrad/s}$$

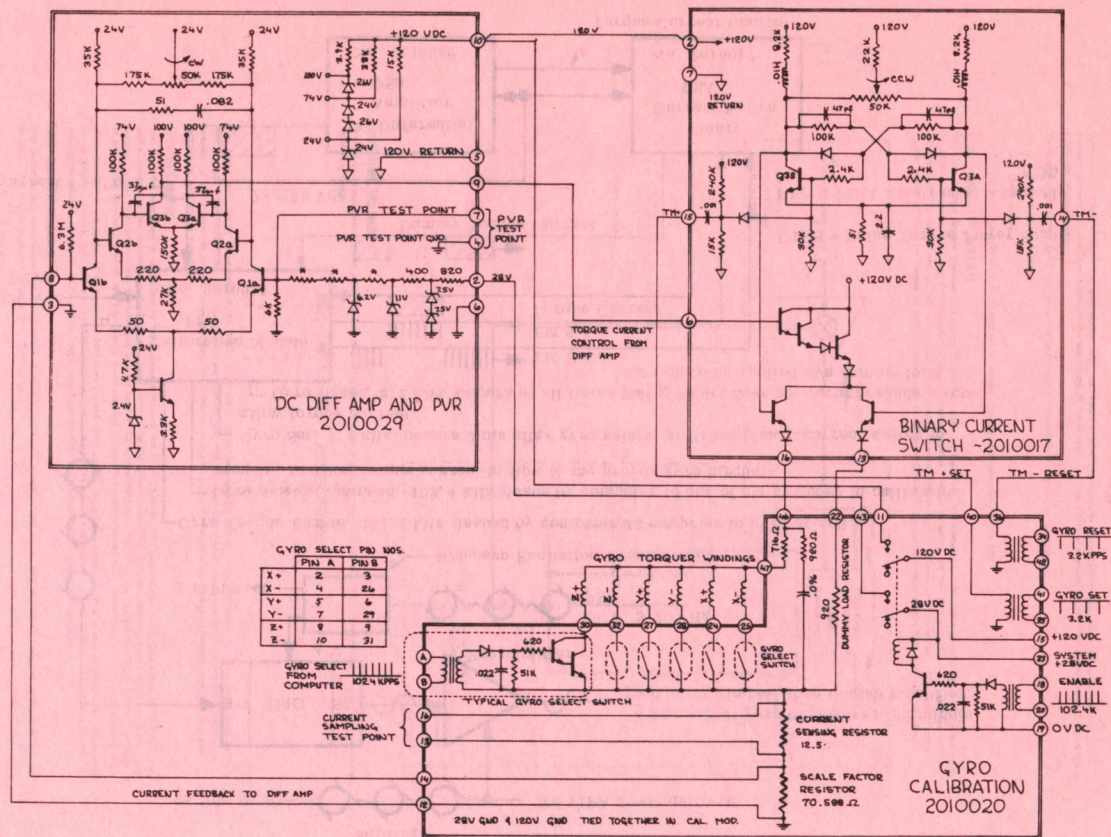
where

T = microsyn torque

H = gyro angular momentum

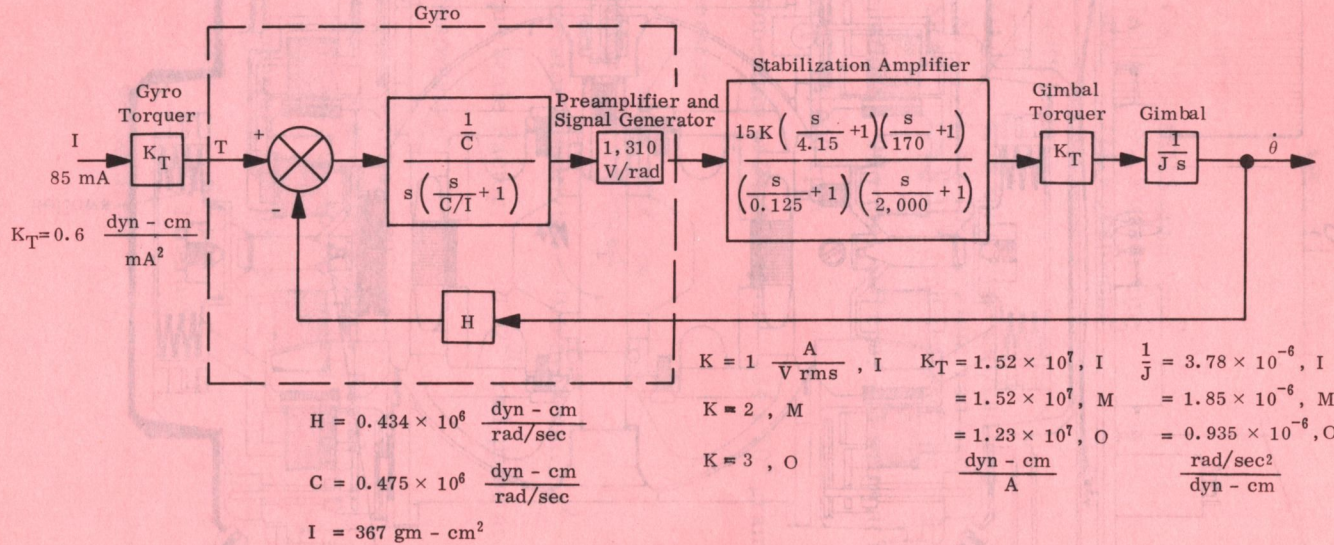
GYRO PULSE TORQUING LOOP





GYRO PULSE TORQUING LOOP

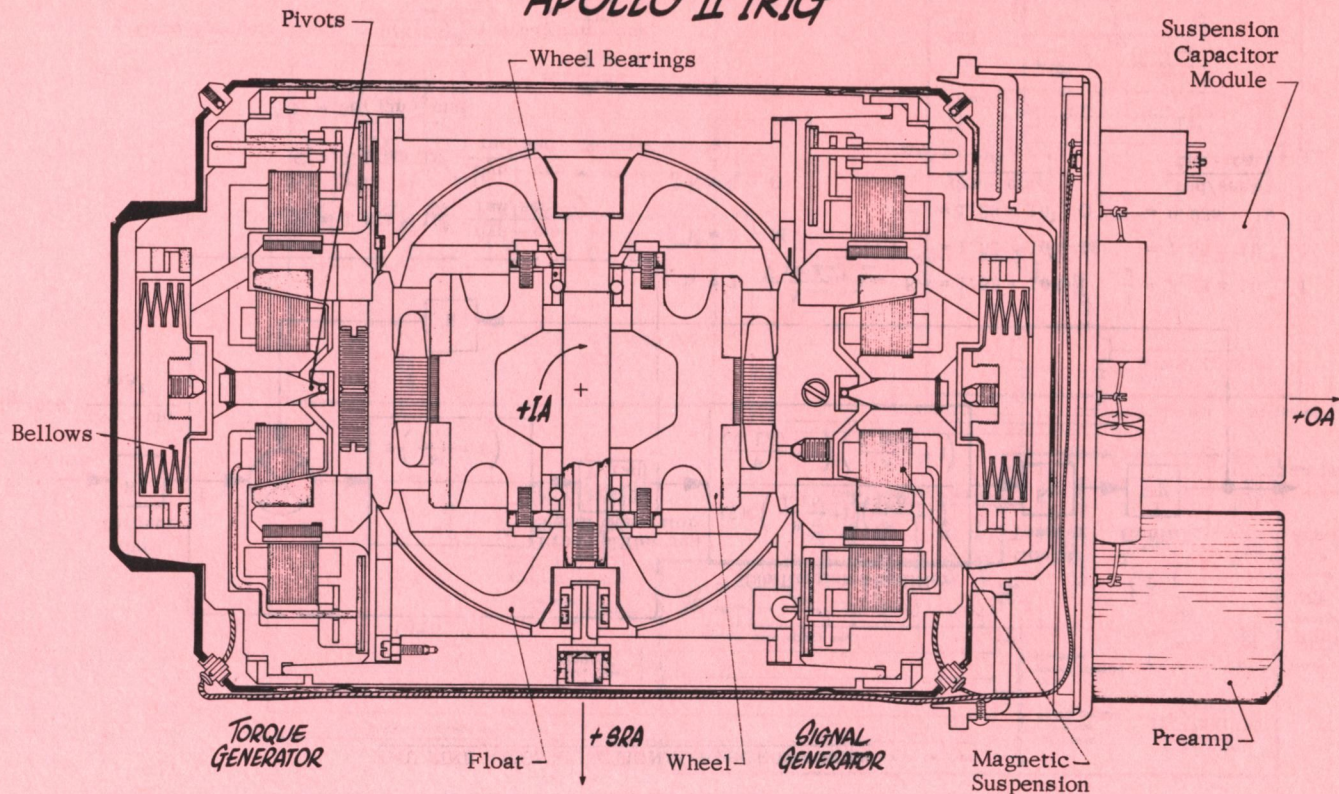
IMU FINE ALIGN FUNCTIONAL BLOCK DIAGRAM



HW-29

$$\text{Gyro Torque} = K_T I^2 = 0.6 (85)^2 = 4,335 \text{ dyn} - \text{cm}$$

APOLLO II IRIG



APOLLO 25 IRIG

Moments of Inertia:

about OA: 367.3 gram-cm²
 about IA: 650.8 gram-cm²
 about SRA: 724.9 gram-cm²

Damping Coefficients:

about OA: 4.75×10^5 dyne-cm/rad/sec
 about IA: 1.5×10^9 dyne-cm/rad/sec
 about SRA: 1.5×10^9 dyne-cm/rad/sec

Wheel Excitation: 28 volts, 800 cps, 4.5 watts at synchronism

Wheel Speed: 24,000 rpm

Angular Momentum at 24,000 rpm: 434×10^3 gram-cm² sec

Signal Generator:

Input: 4 volts, 3200 cps
 Sensitivity: 10 mv/mrad

Torque Generator Sensitivity: 0.6 dyne-cm/ma²

Pulse Torque Scale Factor: $\pi/2^{20}$ rad/pulse at 3200 pps

Magnetic Suspension:

Input: 4 volts, 3200 cps
 Stiffness: 6 gm/0.0001 inches Radial
 0.8 gm/0.0001 inches Axial

Typical Temperature Sensitivity

Scale Factor: 400 ppm/^oF
 Drift: 0.2 meru/^oF

Actual IRIG temperature

GYRO PARAMETERS

Primary gyro parameters are ADIA, ADSRA, NBD and scale factor. Specification values across ISS, G&N, and S/C testing are as shown in Table II-1.

Table II-1 Gyro Coefficient Stability Criteria					
Coefficient	Units	D1	D2	D3	Max
Acceleration Drift along the IA (ADIA)	meru/g	17	33	40	100
Acceleration Drift along the SRA (ADSRA)	meru/g	14	21	25	40
Non-Acceleration Bias Drift (NBD)	meru	6	9	11	15

Gyro scale factor limits are ± 1750 ppm.

The maximum value of gyro performance parameters which can be compensated for by the computer is shown in Table II-2.

Table II-2		
Coefficient	Units	Max Value CM
ADIA	meru/g	862
ADSRA	meru/g	862
NBD	meru	128.7

IMU GYRO COMPENSATION

The compensated PIPA data is used to compute the IRIG torquing necessary to cancel the NBD, ADIA and ADSRA gyro coefficients. The computations are

$$XIRIG = -ADIA_X PIPAX_C + ADSRA_X PIPAY_C - NBD_X \Delta t$$

$$YIRIG = -ADIA_X PIPAY_C + ADSRA_X PIPAZ_C - NBD_Y \Delta t$$

$$ZIRIG = -ADIA_Z PIPAZ_C - ADSRA_Z PIPAY_C + NBD_Z \Delta t$$

where

XIRIG, YIRIG, ZIRIG are gyro drift compensations

NBDX, NBDY, NBDZ are gyro bias drifts (an erasable load)

ADSRA_X, ADSRA_Y, ADSRA_Z are gyro drifts due to acceleration in spin reference axis (an erasable load)

ADIA_X, ADIA_Y, ADIA_Z are gyro drifts due to acceleration in the input axis (an erasable load)

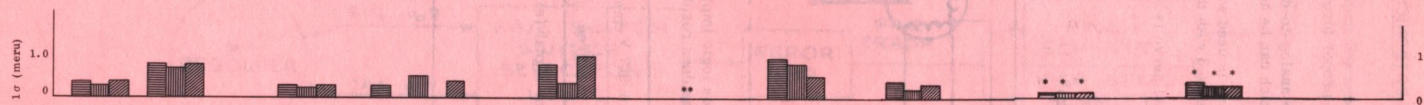
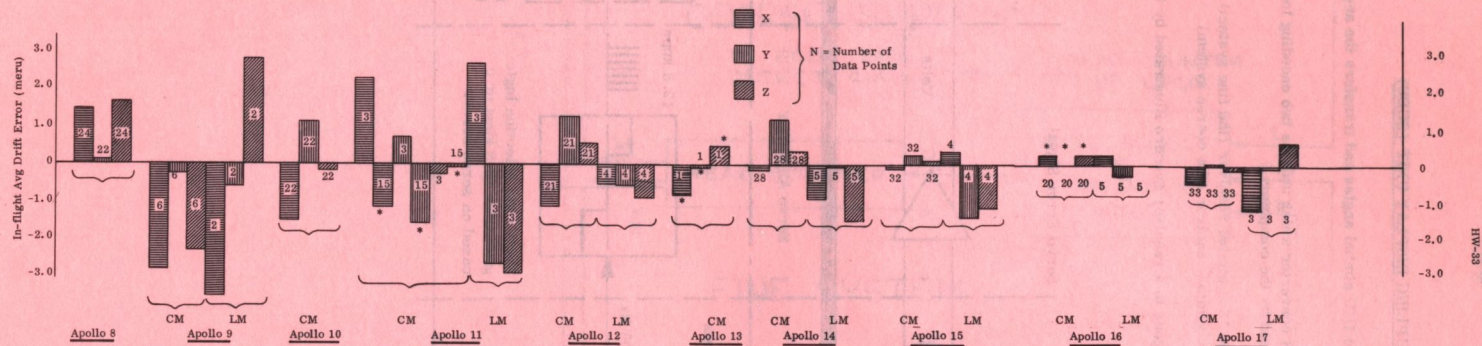
When the magnitude of any IRIG command exceeds two pulses, the commands are sent to the gyros.

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.

$$GYRO\ DRIFT\ NBD = (.007835) (\text{Reg Contents in Decimal}) \text{MERU}$$

HISTORY OF IN-FLIGHT GYRO DRIFT ERRORS



*After in-flight compensation change

** Insufficient number of data points

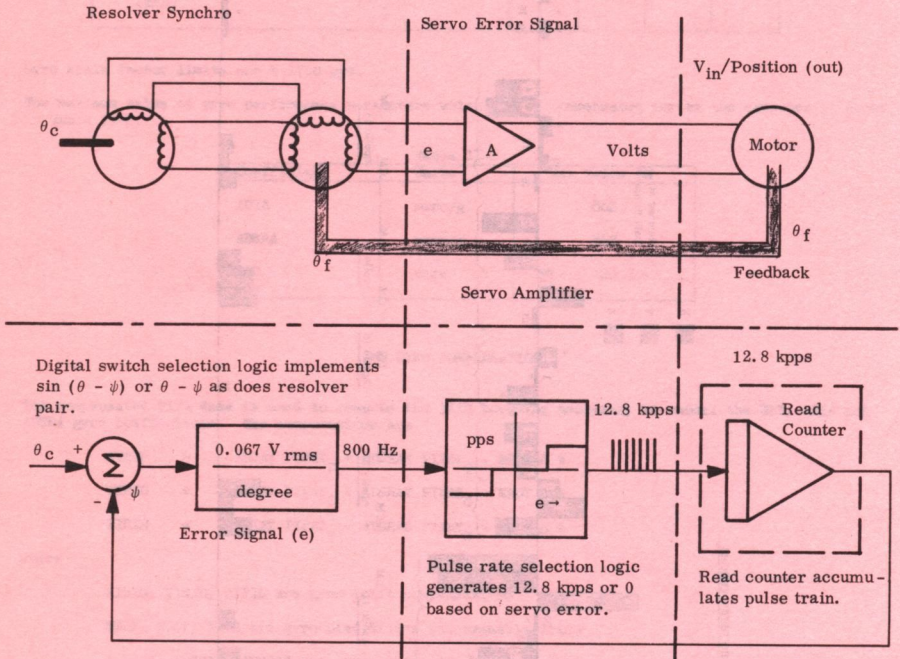
ELECTRONICS COUPLING DISPLAY UNIT (ECDU)

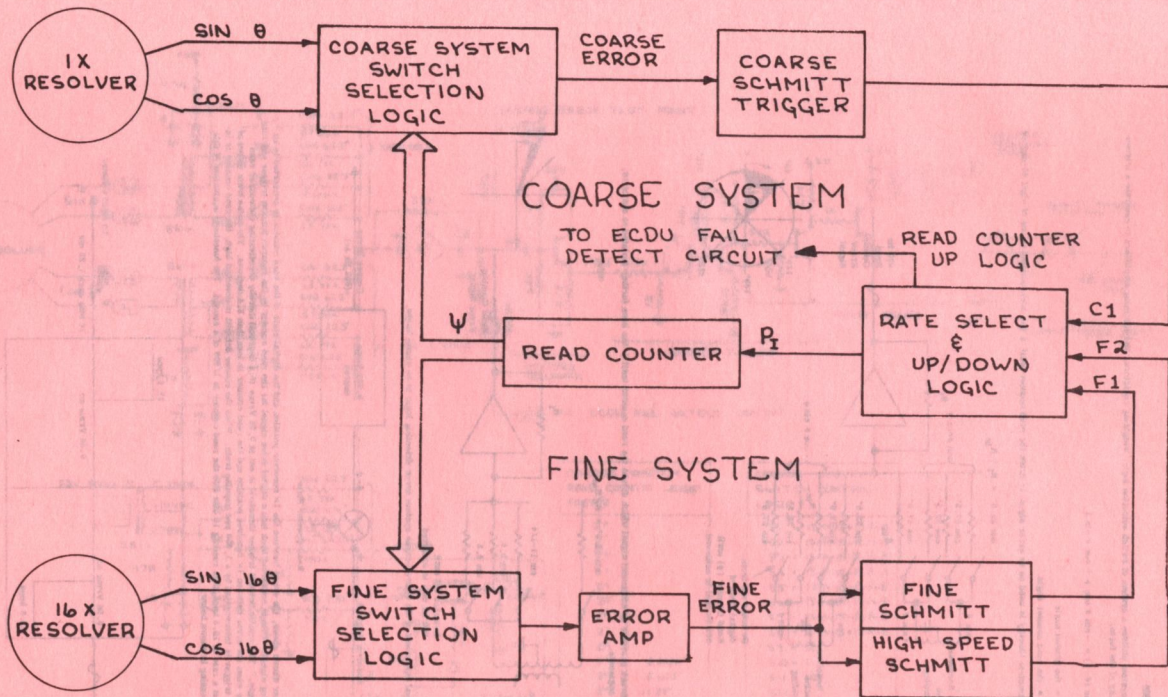
The ECDU encodes and scales the IMU gimbal angles and transfers the angles to the computer in the proper format.

The ECDU is an analog-to-digital converter which utilizes two encoding loops and one read counter which can be accessed by the computer.

One encoding loop is used with the $16 \times$ gimbal resolver (the fine system); the other encoding loop is used with the $1 \times$ gimbal resolver (the coarse system).

The ECDU digital servo is analogous to a resolver synchro illustrated by the following diagram.





ECDU
READ COUNTER LOOP
BLOCK DIAGRAM

ELECTRONIC COUPLING DATA 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 16x gimbal resolver angles. The other, a "coarse system," encodes 1x 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:

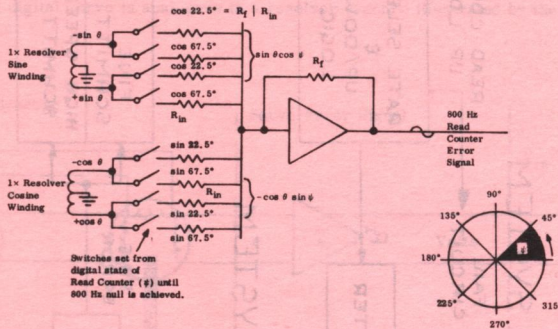
$$-\sin(\theta - \phi) = -\sin \theta \cos \phi + \cos \theta \sin \phi$$

where

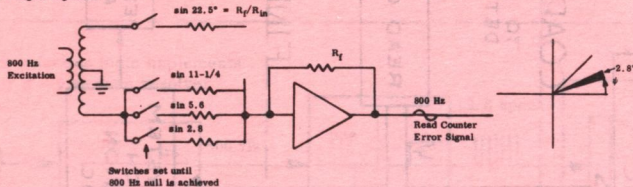
θ = the gimbal angle

ϕ = the read counter angle

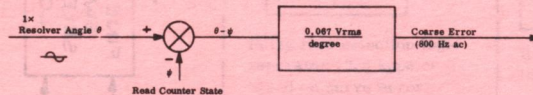
This trigonometric identity is used as an error signal to drive the read counter until ϕ has been isolated to one of eight 45-degree segments



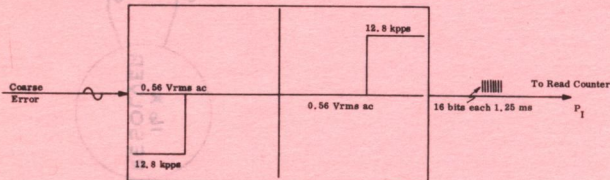
A ladder network provides an additional signal which drives the read counter until ϕ has been further isolated to one of 16, 2.8-degree segments.



The functional equivalent of the entire coarse system error detecting logic is as shown below.



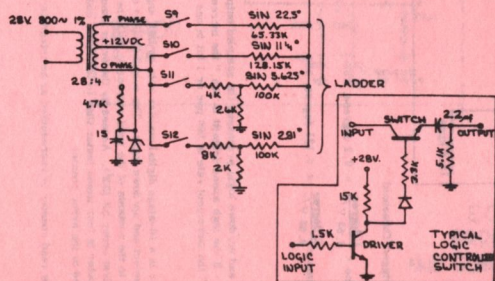
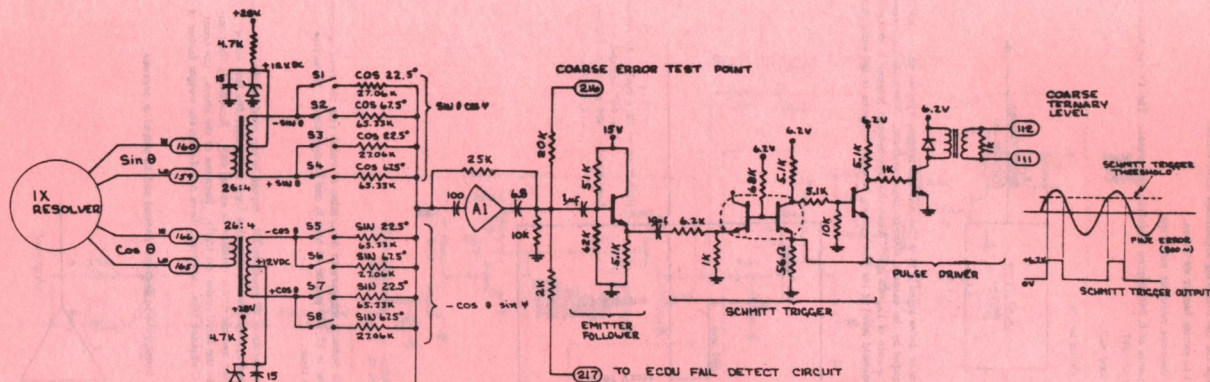
In the manner shown above, the error between the 1x resolver position and the digital state of the read counter is converted to an 800 Hz analog signal. This is converted back into a digital drive signal for the read counter by the "coarse Schmitt trigger and rate selection logic." The coarse Schmitt trigger threshold is set at 0.56 Vrms (8.4 degrees) thereby deactivating the coarse read counter loop when the error between 1x resolver position and the read counter is less than 8.4 degrees. The pulse train output of the Schmitt trigger is interrupted by a 1,600 cps impulse train. When the coarse Schmitt is detected high, the read counter is incremented at a rate of 13.9 kpps, this reading 16 bits into the read counter in 1/600 of a second. The functional equivalent of this signal processing is shown below.



$$16 \text{ bits} \times \frac{800 \text{ bursts}}{\text{second}} \times \frac{20 \text{ arc-sec}}{\text{bit}} = 70^\circ/\text{second}$$

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	2.8/25°
2 ¹⁰	5.6/25°
2 ¹¹	11.25°
2 ¹²	22.5°
2 ¹³	45°
2 ¹⁴	90°
2 ¹⁵	180°

COARSE SYSTEM
SWITCH CONTROL
LOGIC *

S1	= 13-M-B + 13-R-B
S2	= 13-M-15 + 13-R-B
S3	= 13-M-15 + 13-R-B
S4	= 13-M-15 + 13-R-B
S5	= 13-M-15 + 13-R-B
S6	= 13-M-15 + 13-R-B
S7	= 13-M-15 + 13-R-B
S8	= 13-M-15 + 13-R-B
S9	= 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 2⁰ POSITION

ECDU
COARSE SYSTEM
SWITCHING NETWORK

ELECTRONIC COUPLING DATA UNIT ECDU (CONTINUED)

Fine System

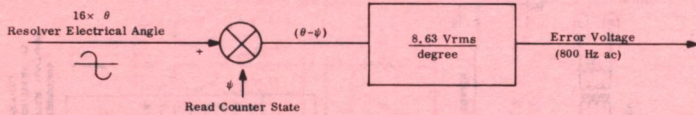
The fine system utilizes a system of switch selection logic, weighting resistors, and summing amplifiers to generate the trigonometric identity.

$$-\sin(\theta - \psi) = \sin \theta \cos \psi + \cos \theta \sin \psi$$

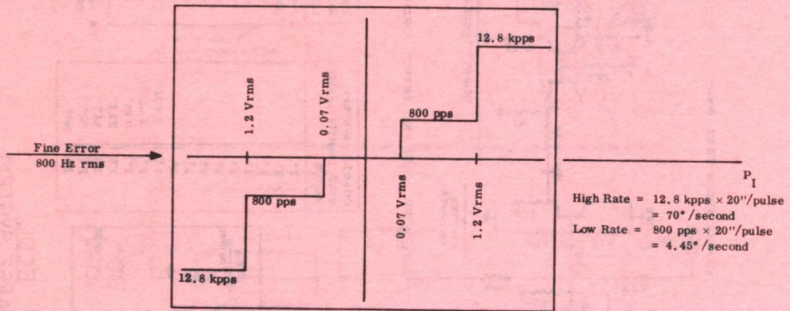
This identity is used as an error signal to drive the read counter until ψ is isolated to one of 256, 0.088-degree segments. Mechanization of this identity is similar to that of the coarse system except for the following significant differences.

1. The fine system generates an internal reference $\cos(\theta - \psi)$ to excite ladder switches.
2. The $16\times$ 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 $1\times$ 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 tandem. 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

$$1.2 \text{ Vrms} \times \frac{1 \text{ degree}}{8.63 \text{ V/}^\circ} = 2.2 \text{ degrees, } 16\times$$

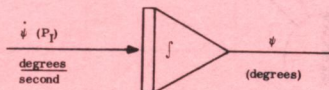
$$0.07 \text{ Vrms} \times \frac{1 \text{ degree}}{8.63 \text{ V/}^\circ} = 0.131 \text{ degree, } 16\times$$

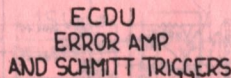
The rate select and up/down logic processes the sampled output of the Schmitt triggers to determine at which rate the read counter is incremented. If the high speed Schmitt is "on," the increment rate is 12,800 pps or 16 bits in one sample time. If the fine Schmitt is "on," the increment rate is 800 pps or 1 bit in one sample time.

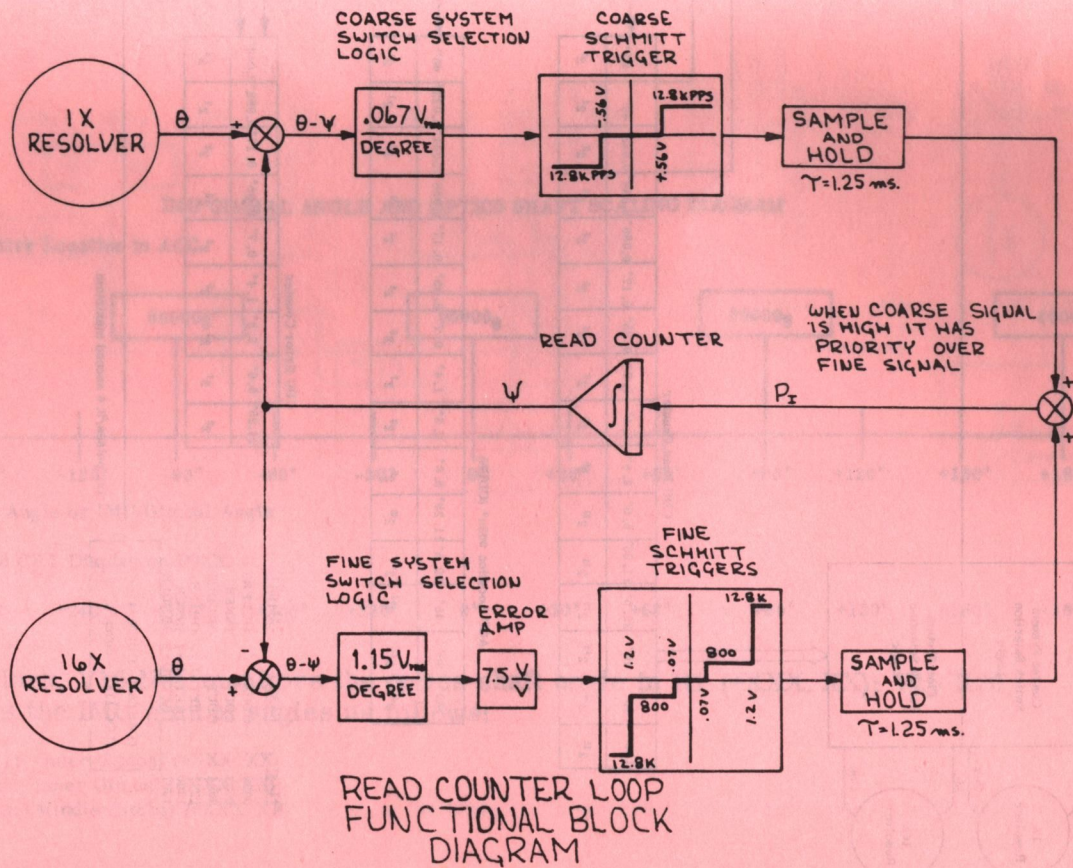
Read Counter

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 (Δ^2). Access by the error counter is to the third order bit (Δ^3). 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.

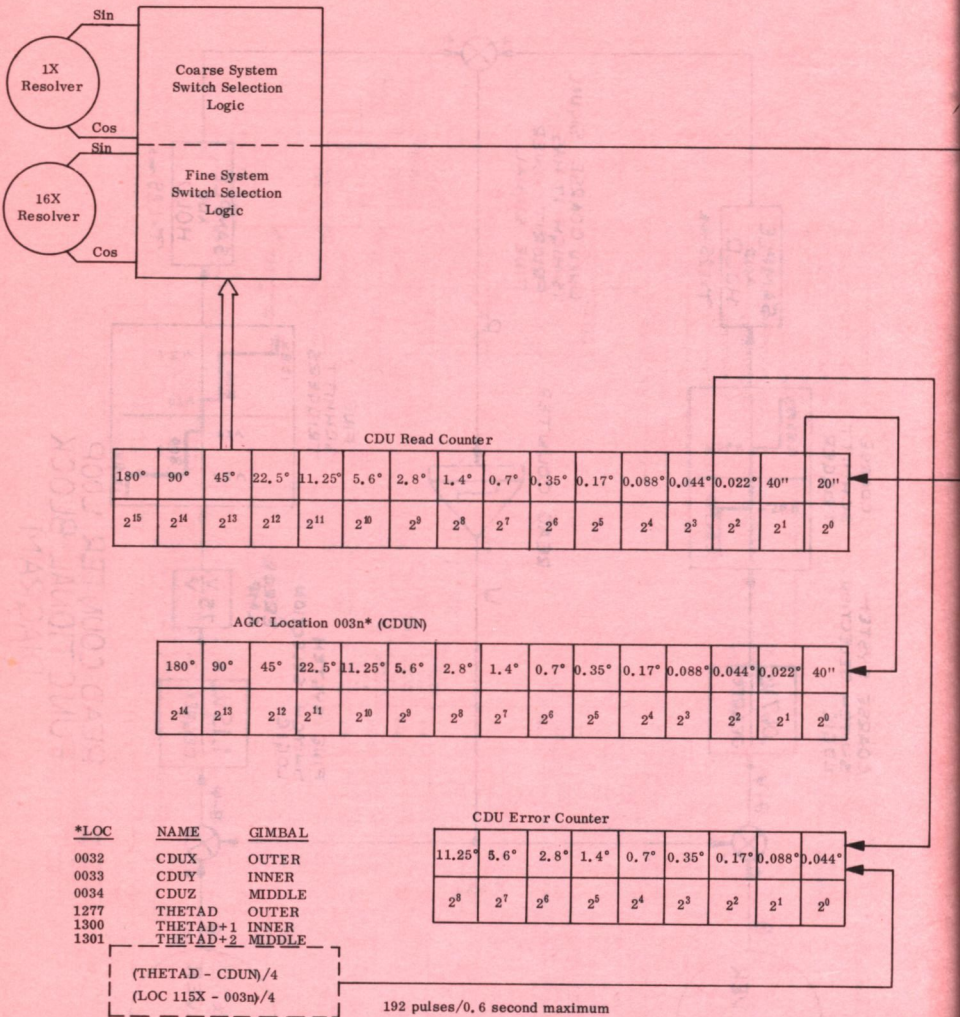
Functionally, the read counter is represented as an integrator with a count rate in degrees/second and an output in degrees.





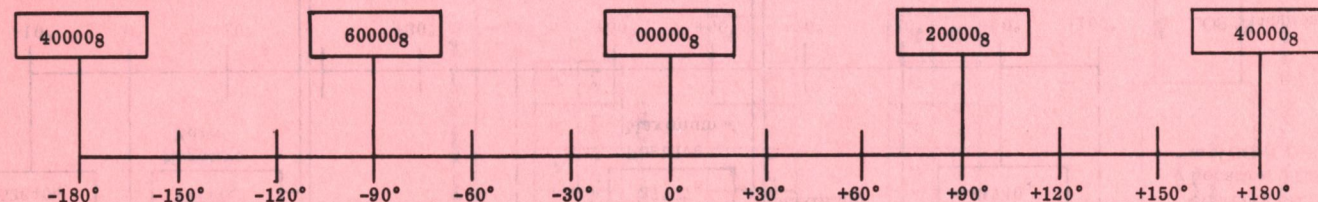


IMU/CDU/AGC INTERFACE DIAGRAM



IMU GIMBAL ANGLE AND OPTICS SHAFT SCALING DIAGRAM

Contents of Respective Location in AGC



Actual Optics Shaft Angle or IMU Gimbal Angle

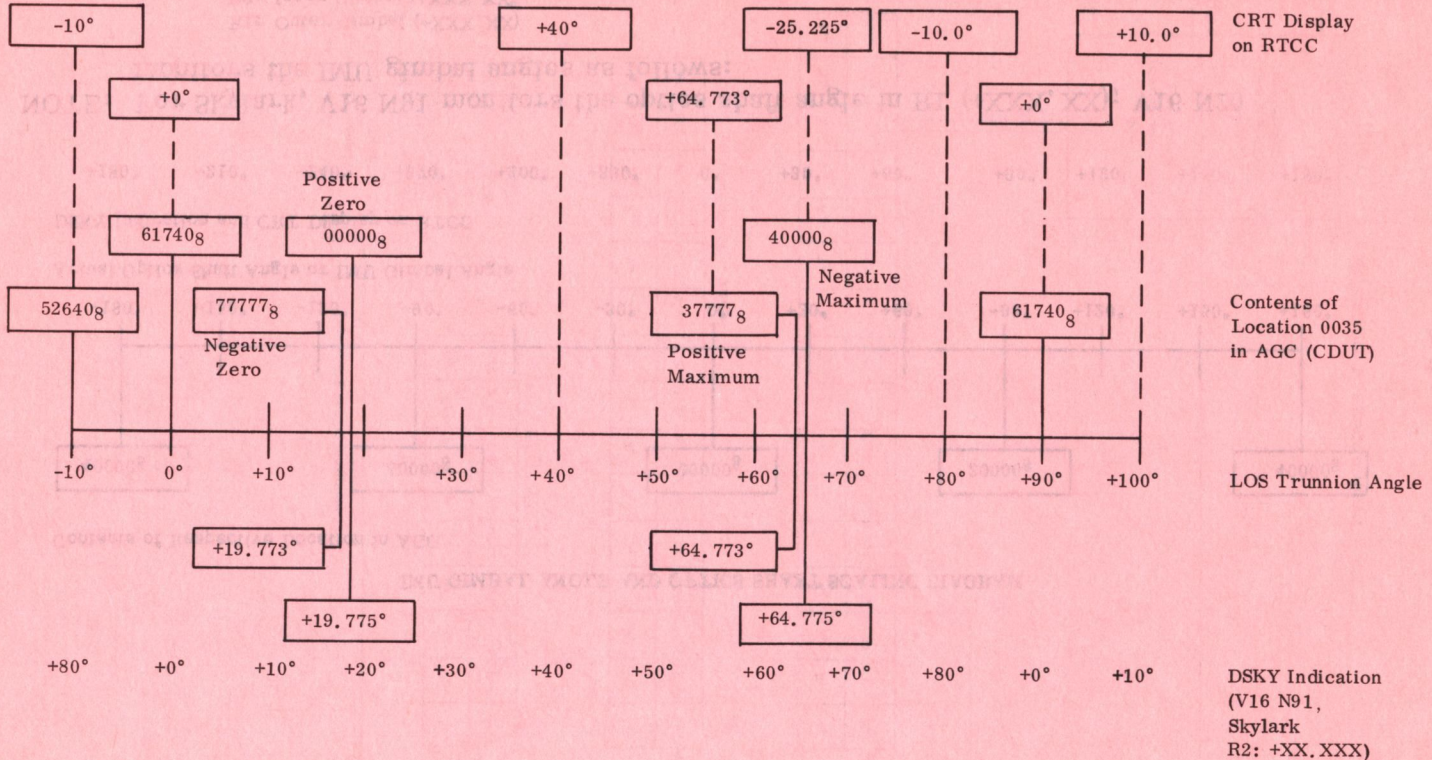
DSKY Indication and CRT Display on RTCC

+180° +210° +240° +270° +300° +330° 0° +30° +60° +90° +120° +150° +180°

NOTE: For Skylark, 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)

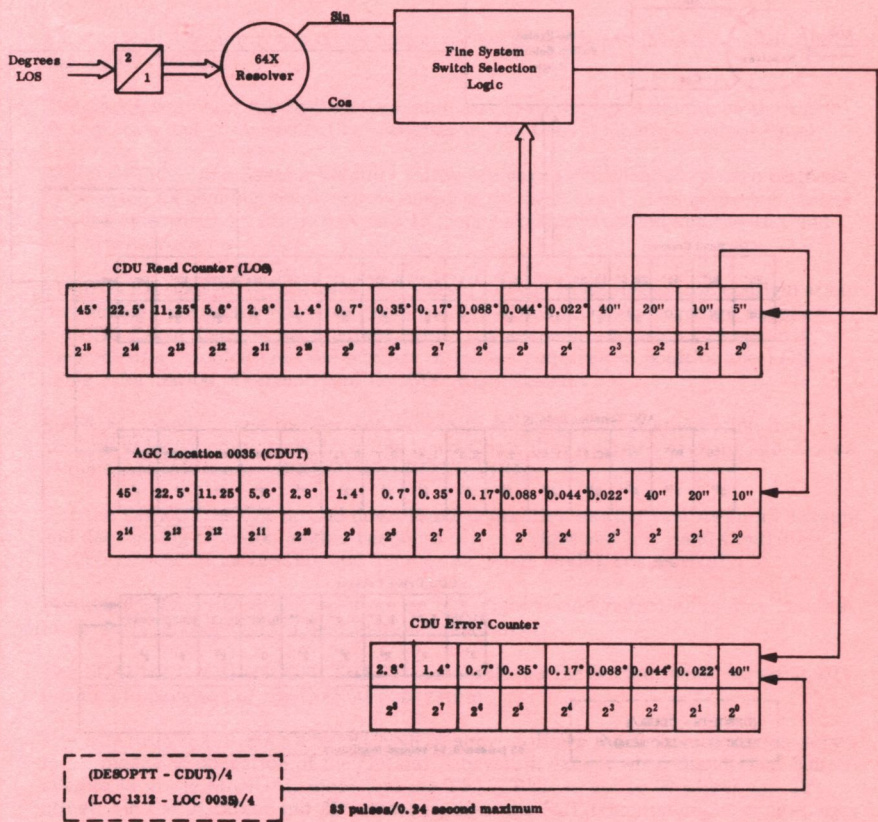
OPTICS TRUNNION SCALING DIAGRAM



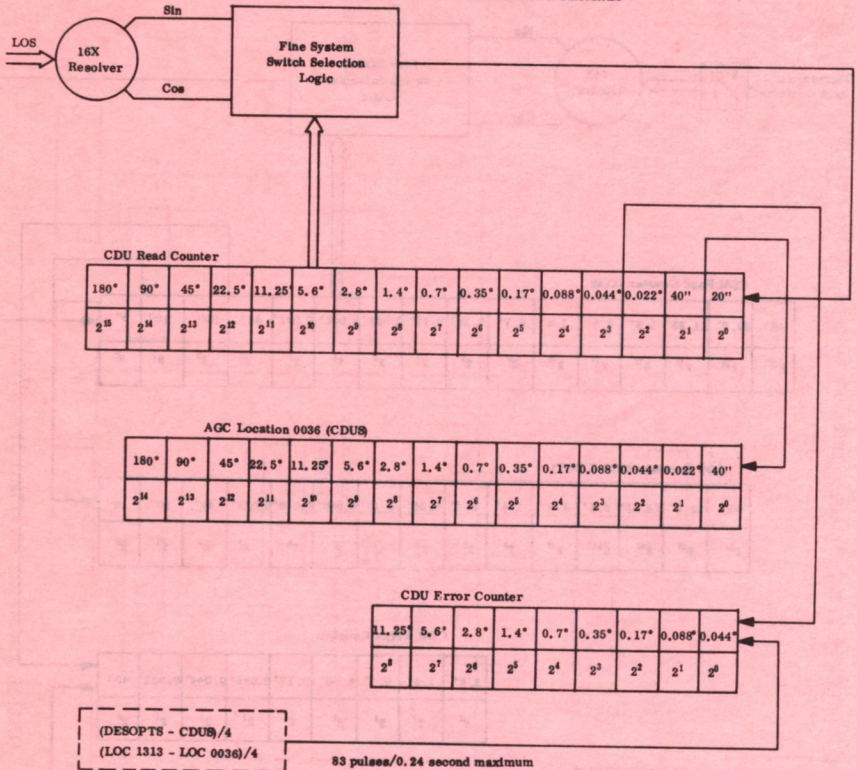
HW-44

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.

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 1/2 X resolvers for shaft.

COMPUTER operate optics uses the Sextant servos in an integrator configuration that accepts position commands from the CDU DAC's. The computer supplies the CDU Error Counter with pulses every .24 seconds. At each .24 seconds, the computer recalculates the number of pulses required to position the LOS using information obtained from the CDU Read Counter.

MANUAL mode uses the Sextant servos in an integrator configuration that accepts velocity commands from the Hand Controller. There are two sub-modes of the MANUAL mode, DIRECT and RESOLVED.

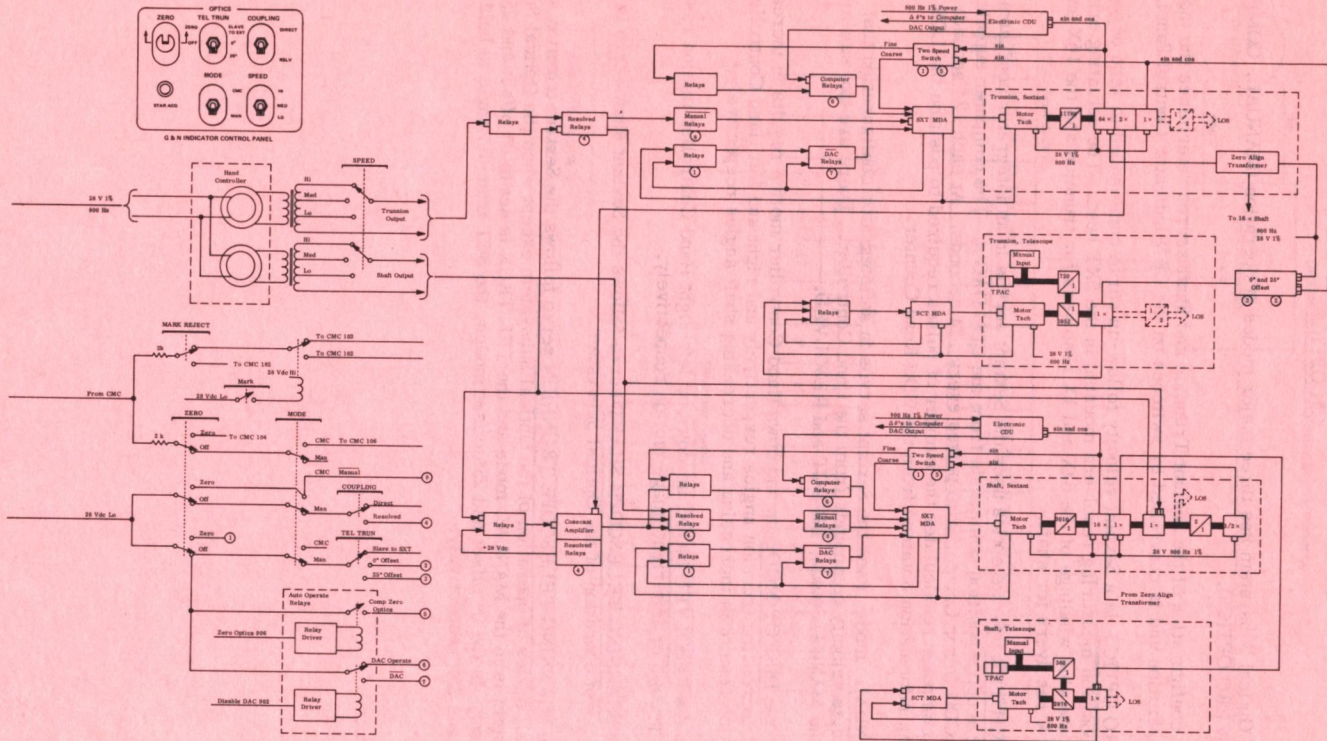
For the DIRECT MODE up and down Hand Controller motion results in increasing and decreasing trunnion angles respectively and right and left Hand Controller motion results in increasing and decreasing shaft angles respectively.

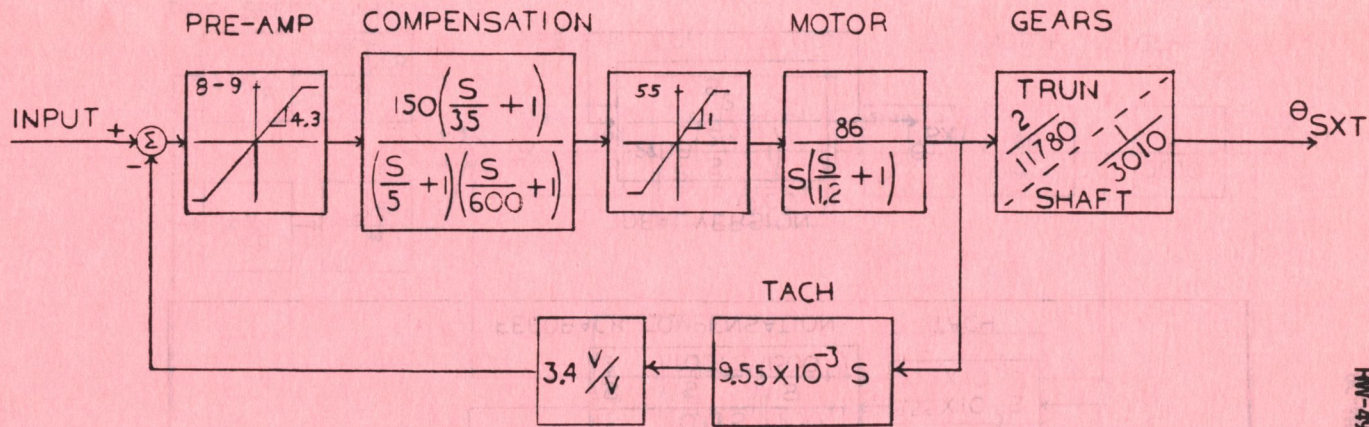
For the RESOLVED MODE up-down or left-right Hand Controller motion results in up-down or left-right image motion respectively.

The SCANNING TELESCOPE SHAFT servo follows the Sextant shaft servo in all modes of operation of the Optical Subsystem.

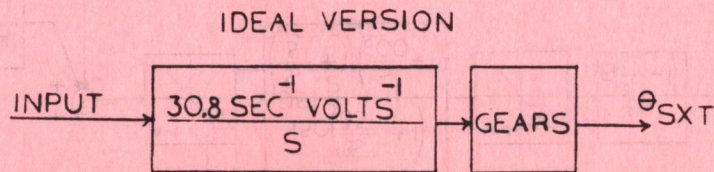
The SCANNING TELESCOPE TRUNNION servo follows the Sextant trunnion servo in all modes of operation of the Optical Subsystem except when the Optical Subsystem is in the MANUAL mode and the TEL TRUN is set to 0° offset and 25° offset. In the 0° offset and 25° offset modes, the SCT trunnion angle is held at 0° and 25° respectively.

BLOCK II OPTICAL SUBSYSTEM FUNCTIONAL DIAGRAM



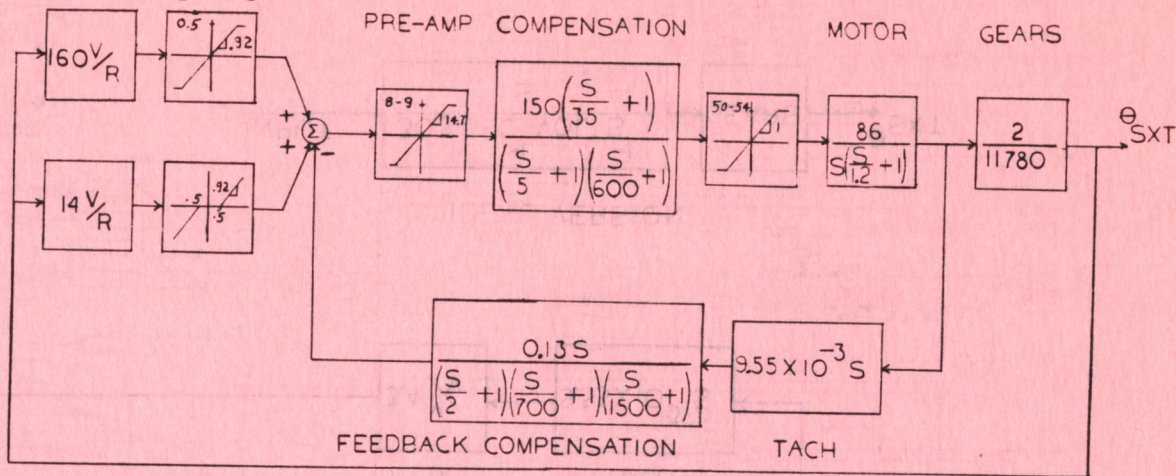


HW-49



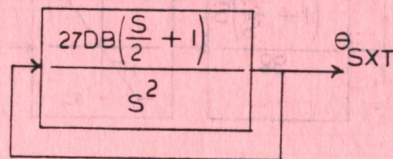
SXT INTEGRATORS

RESOLVERS AND
TWO SPEED SWITCH



HW-50

IDEAL VERSION



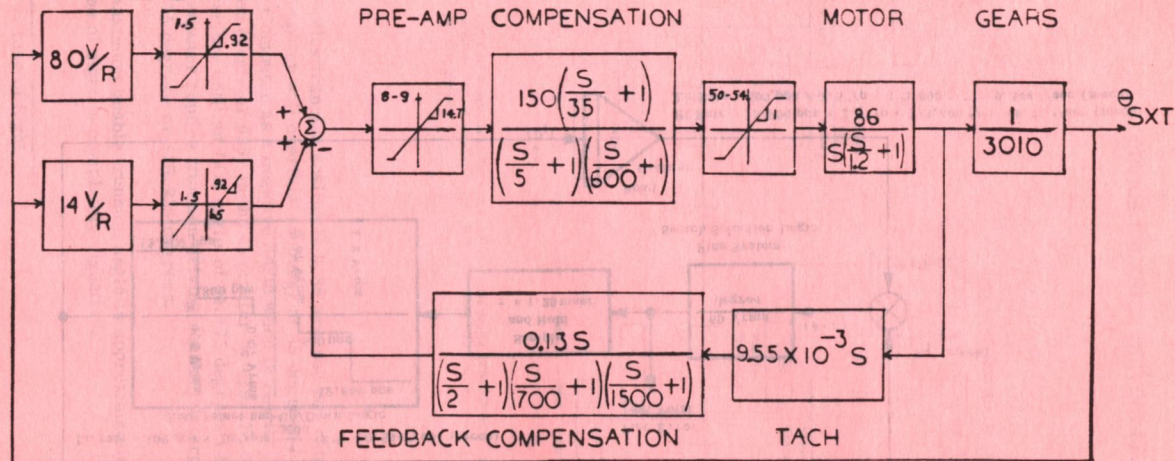
TRUNNION ZERO OPTICS SERVO

RESOLVERS AND TWO SPEED SWITCH

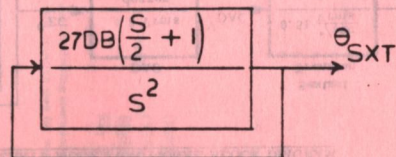
PRE-AMP COMPENSATION

MOTOR

GEARS

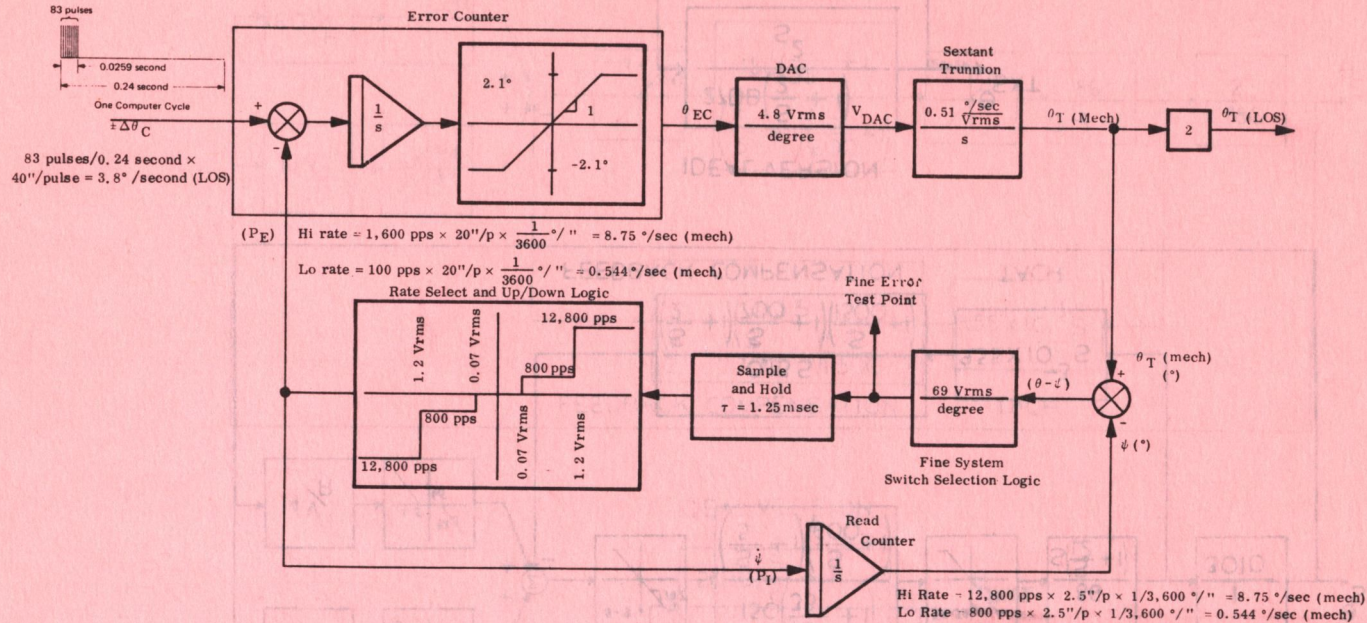


IDEAL VERSION

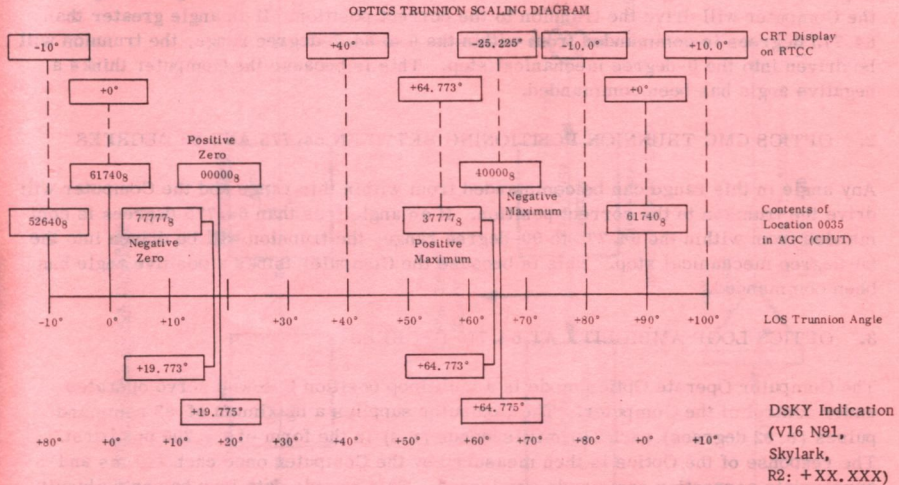


SHAFT ZERO OPTICS SERVO

TRUNNION COMPUTER OPERATE MODE FUNCTIONAL BLOCK DIAGRAM



OPTICS TRUNNION DRIVING LIMITATIONS



NOTE: CDUT (LOC 0035) is loaded with a -19.775° bias during ZERO OPTICS. This bias produces positive driving commands for angles up to +64.775° in the CMC mode. Without the bias, the CMC mode would drive the trunnion to the negative stop for command angles of 45° or greater.

Since optics trunnion scaling is 9.88 arc-sec per data bit, the 14-bit CDUT register in the Computer will overflow (40000g) at 45 degrees LOS*. This overflow is interpreted by the Computer as a negative angle when in reality it is not. By biasing the CDUT location (register 035) in the Computer by -19.775 degrees, the counter (035) will not overflow until an LOS angle of 64.775 degrees (40000g) is reached. In this case, the Computer (optics trunnion driving routine) interprets an overflow as -45.000 degrees + 19.775 degrees or -25.225 degrees.

The maximum usable trunnion angle is approximately 57 degrees. Beyond this angle the line of sight is completely vignettged.

*LOS = Line of Sight

The operational effects of trunnion biased overflow on the CMC Operate Optics mode is summarized below.

1. OPTICS CMC TRUNNION POSITIONING BETWEEN 0 AND 64.773 DEGREES

Any angle in this range can be commanded from within the 0 to 64.7-degree range and the Computer will drive the trunnion to the correct position. If an angle greater than 64.773 degrees is commanded from within the 0 to 64.7-degree range, the trunnion will be driven into the 0-degree mechanical stop. This is because the Computer thinks a negative angle has been commanded.

2. OPTICS CMC TRUNNION POSITIONING BETWEEN 64.775 AND 90 DEGREES

Any angle in this range can be commanded from within this range and the Computer will drive the trunnion to the correct position. If an angle less than 64.775 degrees is commanded from within the 64.775 to 90-degree range, the trunnion will be driven into the 90-degree mechanical stop. This is because the Computer thinks a positive angle has been commanded.

3. OPTICS LOOP AMBIGUITY AT 64.775 DEGREES

The Computer Operate Optics mode is a multiloop position followup servo operated under control of the Computer. The Computer supplies a maximum of 83 command pulses (0.92 degrees) each 240 milliseconds (ms) in the form of a 3,200 pps burst. The response of the Optics is then measured by the Computer once each 240 ms and appropriate correction commands are issued. This sample data loop has an ambiguity at 64.775 degrees for the following two cases.

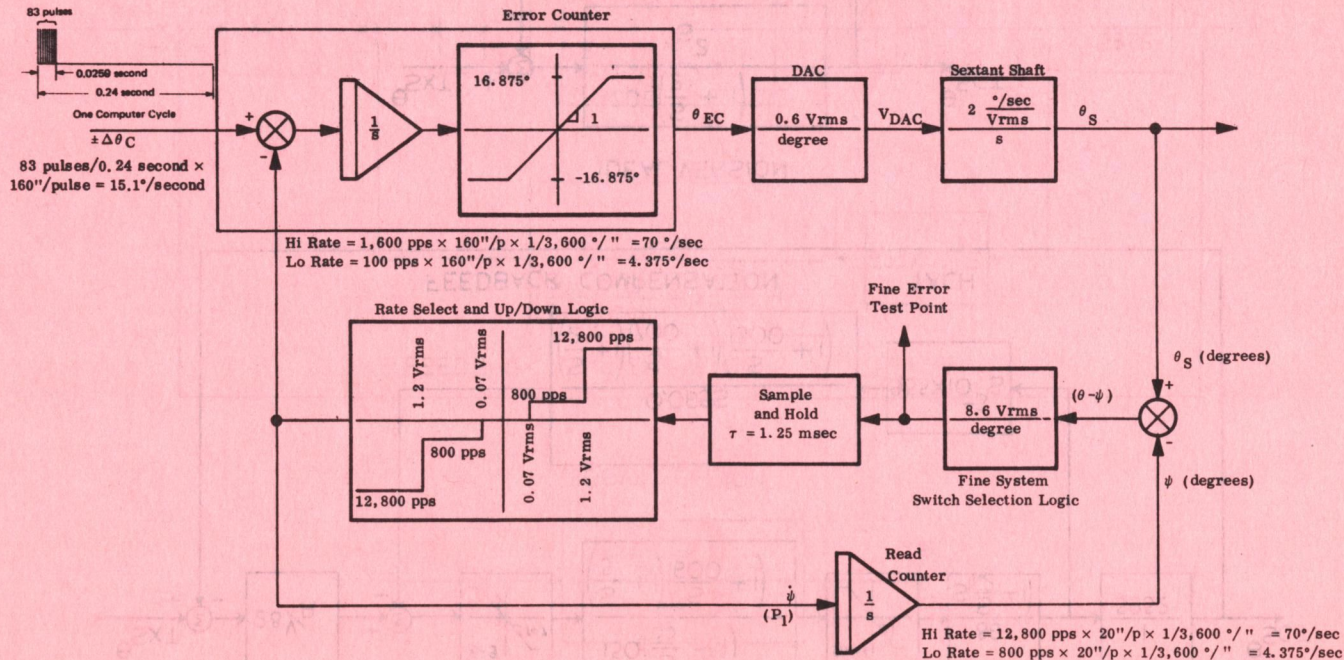
a. Case 1: Initial Trunnion Between 0 and 64.773 Degrees and Angle Close to 64.773 Degrees is Commanded

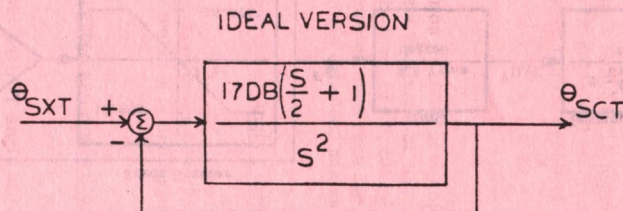
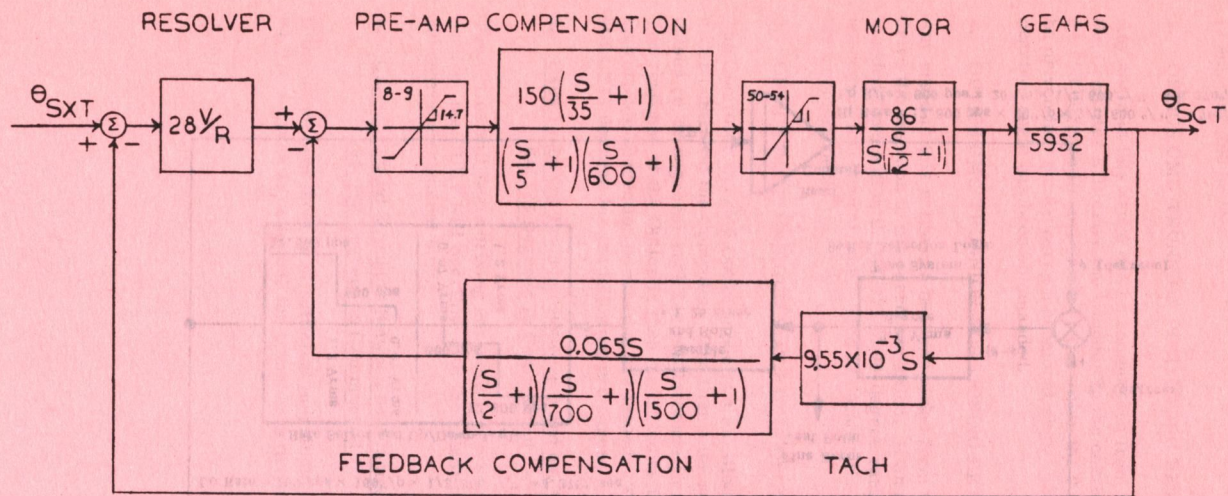
The Optics will begin driving correctly. If a servo overshoot beyond 64.773 degrees occurs, the CDUT will overflow with the result that the trunnion is driven into the 90-degree mechanical stop.

b. Case 2: Initial Trunnion Between 64.775 and 90 Degrees and Angle Close to 64.775 Degrees is Commanded

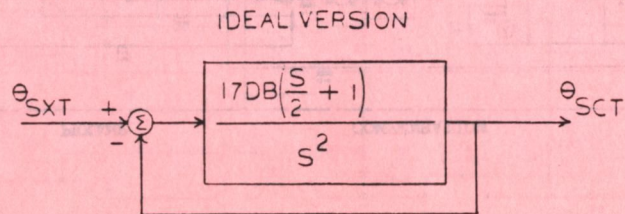
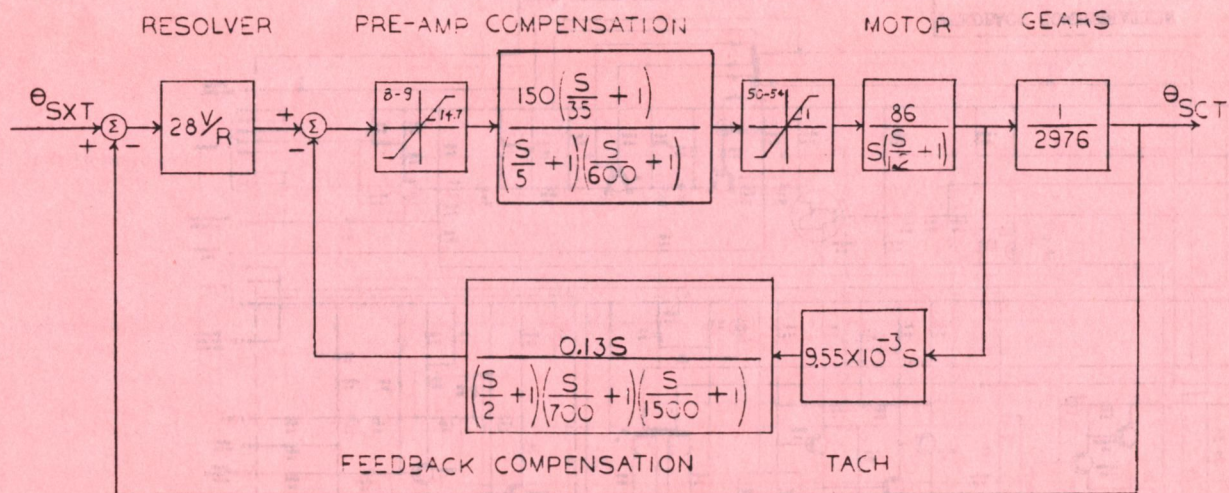
If the servo overshoot is of sufficient magnitude such that a CDUT angle of less than 64.775 degrees is detected, the trunnion is driven into the 0-degree mechanical stop.

SHAFT COMPUTER OPERATE MODE FUNCTIONAL BLOCK DIAGRAM



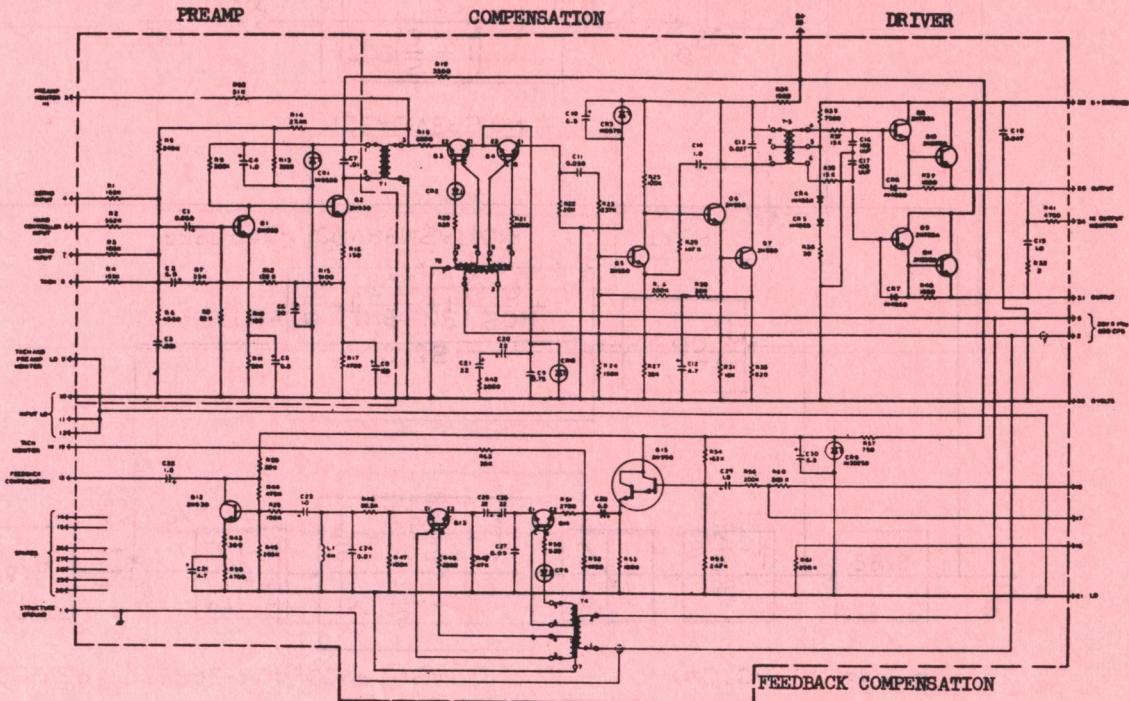


SCT TRUNNION SERVO



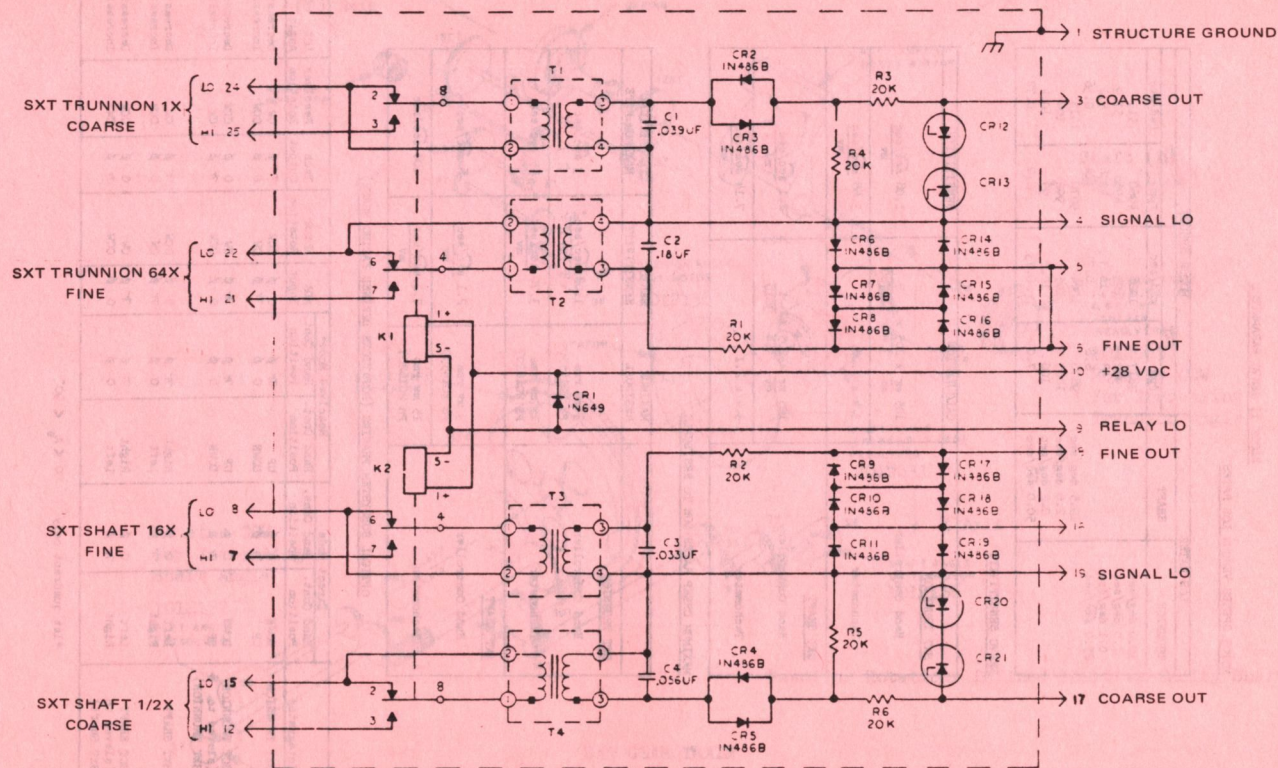
SCT SHAFT SERVO

OPTICS MOTOR DRIVE AMPLIFIER



HW-58

OPTICS TWO SPEED SWITCH



BLOCK II SERVO PARAMETERS

MOTOR SPEEDS VERSUS LOS RATES

LOS RATES		MOTOR SPEEDS			
TRUNNION	SHAFT	SXT		SCT	
		rpm	rad/sec	rpm	rad/sec
10.0 deg/sec		9817	1028	4960	519
1.0 deg/sec		982	103	496	51.9
0.1 deg/sec		98	10.3	49.6	5.2
25.0 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 sec/sec	7.0	0.73	6.9	0.72

SERVO SENSITIVITY

	CALCULATION	SENSITIVITY
<u>SXT TRUNNION</u>		
Hand Controller	$105 \frac{\text{mv}}{\text{mv}} \times 205 \times \frac{2}{3.4 \times 11,780}$	$1.08 \frac{\text{sec/sec}}{\text{mv}}$
Tachometer	3.4×1.08	$3.68 \frac{\text{sec/sec}}{\text{mv}}$
<u>SXT SHAFT</u>		
Hand Controller	$105 \frac{\text{mv}}{\text{mv}} \times 205 \times \frac{1}{3.4 \times 3010}$	$2.1 \frac{\text{sec/sec}}{\text{mv}}$
Tachometer	3.4×2.1	$7.14 \frac{\text{sec/sec}}{\text{mv}}$

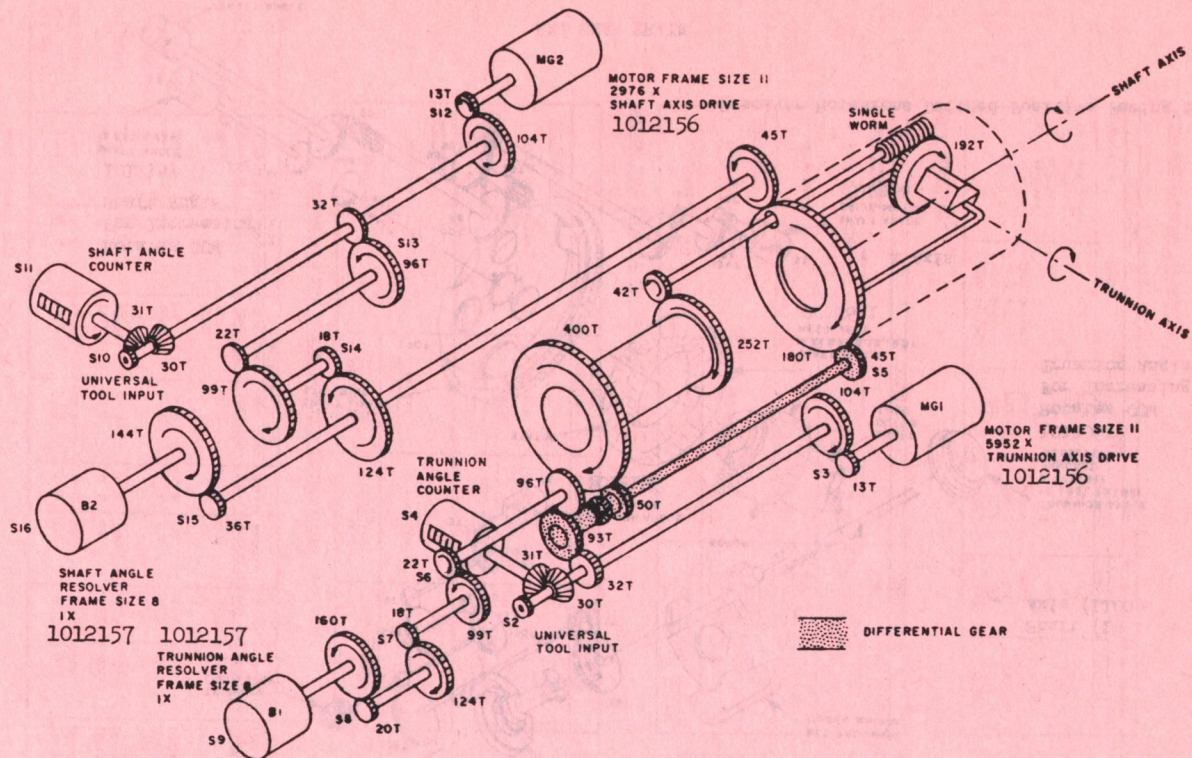
MAXIMUM CREEP RATES DUE TO RESIDUALS

	MAXIMUM RESIDUAL	SERVO SENSITIVITY	THEORETICAL MAXIMUM RATE
<u>SXT TRUNNION</u>			
Hand Controller	3 mv rms PS 2014550	$1.08 \frac{\text{sec/sec}}{\text{mv}}$	$3 \frac{\text{sec}}{\text{sec}}$
Tachometer	15 mv rms PS 2016207	$3.70 \frac{\text{sec/sec}}{\text{mv}}$	$55 \frac{\text{sec}}{\text{sec}}$
<u>SXT SHAFT</u>			
Hand Controller	3 mv rms PS 2014550	$2.1 \frac{\text{sec/sec}}{\text{mv}}$	$6 \frac{\text{sec}}{\text{sec}}$
Tachometer	15 mv rms PS 2016207	$7.2 \frac{\text{sec/sec}}{\text{mv}}$	$108 \frac{\text{sec}}{\text{sec}}$

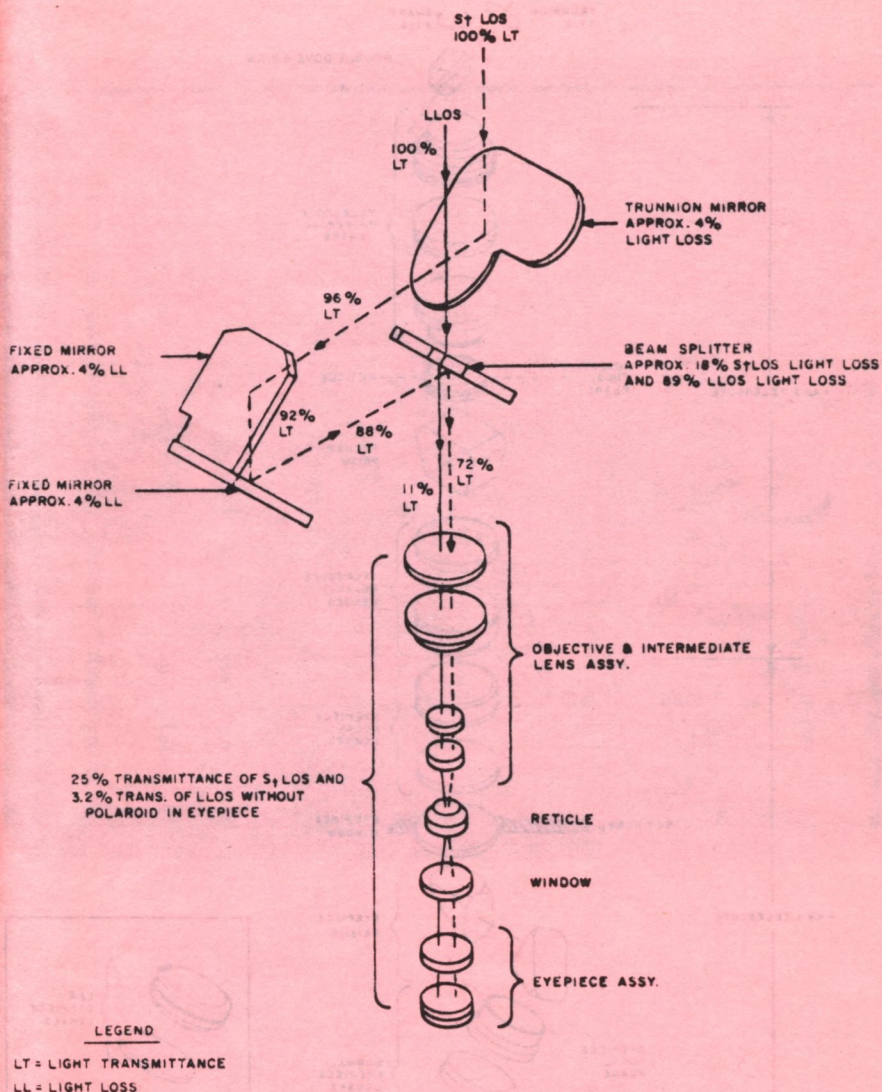
OPTICAL SUBSYSTEM PHASING (ROTATIONS DEFINED FACING SHAFT)

Integrator	Direct Mode		Resolved Mode*		MDA Input	Motor Rotation	Tach Output	Resolver Rotation	LOS Angle
	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position					
SXT TRUNNION	DOWN	0 β	UP	π β	0 β	CCW	π β	CW	Decreasing
	UP	π β	DOWN	0 β	π β	CW	0 β	CCW	Increasing
SCT TRUNNION (slaved to SXT TRUNNION)	DOWN	0 β	UP	π β	π β	CW	0 β	CCW	Decreasing
	UP	π β	DOWN	0 β	0 β	CCW	π β	CW	Increasing
SXT SHAFT	Left	0 β	Right	π β	0 β	CCW	π β	CW	Decreasing
	Right	π β	Left	0 β	π β	CW	0 β	CCW	Increasing
SCT SHAFT (slaved to SXT Shaft)	Left	0 β	Right	π β	π β	CW	0 β	CCW	Decreasing
	Right	π β	Left	0 β	0 β	CCW	π β	CW	Increasing

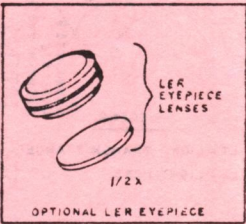
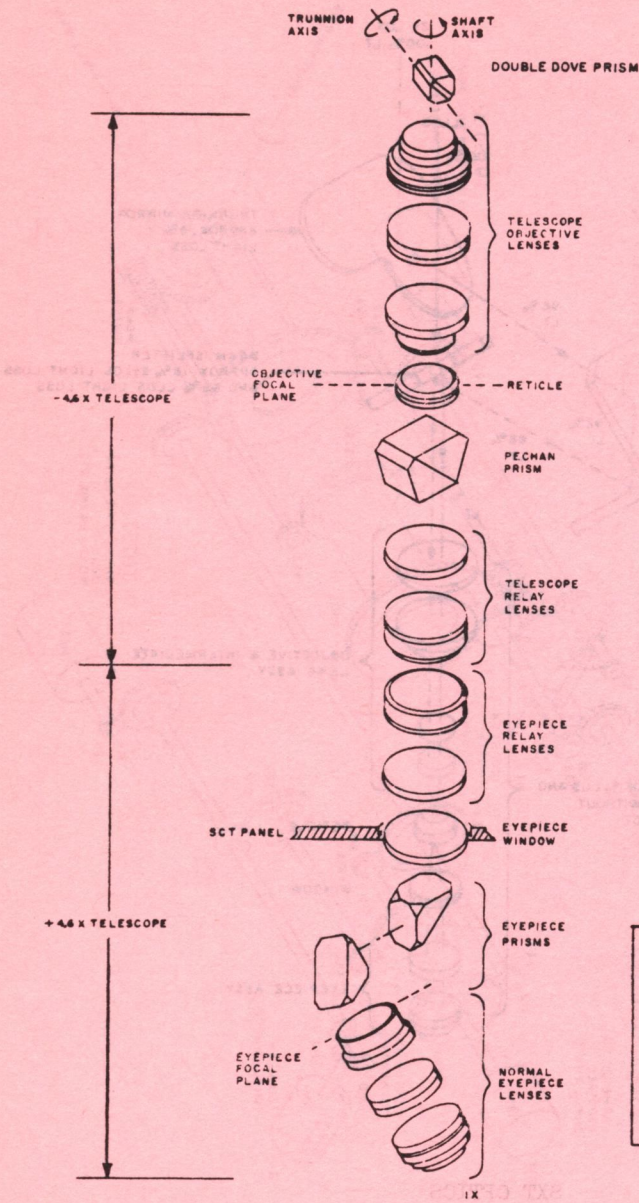
*1st quadrant only $0 < A_b < 90^\circ$



SCT GEAR TRAIN



SXT OPTICS



VERB LIST

50 PLEASE PERFORM
51 PLEASE MARK
53 PLEASE MARK ALT LOS
54 REND COAS MARK
56 TERMINATE P20
58 STICKFLAG (R)/V50N18FLAG(S)
64 OPTICS ANGLE TRANSFORM
76 ENABLE VHF DATA PROC
77 DISABLE VHF DATA PROC
85 REND PARAM DISP NO. 2
86 REJECT REND COAS MARK
87 ENABLE VHF RANGE MARKS
88 DISABLE VHF RANGE MARKS
93 ENABLE W - MATRIX INIT
96 TERM SV INTEG (CALL P00)

25 PLEASE PERFORM
28 TIG NC2
33 TIG
34 T EVENT (PROGRAM)
37 TIG TPI
40 TF GET1/TFC - V.G - ΔV
45 MARKS - TF GET1 - M.GA
49 $\Delta P.O.S$ - $\Delta V.E.L$ - CODE
53 RANGE - R.R - P.HI
54 RANGE - R.R - THE.TA
56 VEHICLE RATE
58 $\Delta V.T.P.I$ - $\Delta V.T.P.F$ - $\Delta T2$
59 $\Delta V.L.O.S.X$ - $\Delta V.L.O.S.Y$ - $\Delta V.L.O.S.Z$
70 SENSOR/CODE (BEFORE MK)
71 SENSOR/CODE (AFTER MK)

NOUN LIST

04 ATT ERR
05 ANG SEP ERR - ANG S.E.P
06 OPTION CODE
09 ALARM CODES
11 TIG NCC
13 TIG NSR
14 STAR TRKR OG, 16
16 T EVENT (EXT VERB)
18 AUTO MNVR
19 STAR TRKR OG
20 PRES ICDU ANG
22 NEW ICDU ANG
23 DOCKING ANGLES

72 TIME OF OPT
75 $\Delta H.N.S.R$ - $\Delta T1$ - $\Delta T2$
76 RANGE - R.R - TIME FR OPT
77 RANGE - R.R - THE.TA/P.HI
78 YAW - PITCH - OMICRON
81 ΔV LOCAL VERT
82 $\Delta V.N.S.R$ LOCAL VERT
84 $\Delta V.NEXT$ - $\Delta H.NEXT$ - $\Delta V.THIRD$
85 VG CONTROL AXES
88 X.Y.Z PLANET
91 PRESENT SHAFT - T.RUN
92 COMMAND SHAFT - T.RUN
93 TORQUING ANG
94 ALT LOS SHAFT - T.RUN
95 TIG NCI

INCREASE

STAR LIST

00 PLANET
01 ALPHERATZ
02 DIPHDA
03 NAVI
04 ACHERNAR
05 POLARIS
06 ACAMAR
07 MENKAR
10 MIRFAK
11 ALDEBARAN
12 RIGEL
13 CAPELLA
14 CANOPUS
15 SIRIUS
16 PROCYON
17 REGOR
20 DNOCES
21 ALPHARD
22 REGULUS
23 DENEbola
24 GIENAH
25 ACRUX
26 SPICA

27 ALKAID
30 MENKENT
31 ARCTURUS
32 ALPHECCA
33 ANTARES
34 ATRIA
35 RASALHAGUE
36 VEGA
37 NUNKI
40 ALTAIR

41 DABIH
42 PEACOCK
43 DENEb
44 ENIF
45 FOMALHAUT
46 SUN
47 EARTH

NOUN CODES

P5X: N70/71 RI: SENSOR/STAR CODE 00CDE

C = 0 CSM OPTICS

C = 1 SUN SENSOR (DE = 46)

C = 2 STAR TRKR (DE = 04, 14, OR 25)

N06 OPTIONS:

P50

1 = ACQ SS

2 = ACQ SS/ST

3 = INDEP. SOURCE

P52/4

1 = PREFERRED

2 = NOMINAL

3 = REFSMMAT

P55

1 = IMU ALIGNED

2 = IMU NOT ALIGNED

P20

0 = RNDZ (POINT)

1 = CEL BODY (POINT)

2 = ROTATE

4 = RNDZ (3-AXIS)

5 = CEL BODY (3-AXIS)

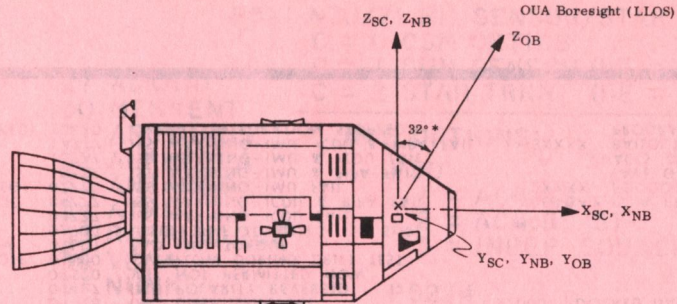
ALARM CODES (V05N09)

00107	STAR TRACKER OUT OF LIMITS	00501	NOT ENOUGH JETS FOR ROLL (DOCKED)	20607	NO CONIC SOLUTION
00110	MK REJECT ENTERED & IGNORED	00600	FAILURE IN PHASE MATCH ITERATION	21204	NEG OR ZERO WAITLIST CALL
00113	NO INBITS (CH 16)	00601	FAILURE IN HEIGHT MANEUVER ITERATION	21206	TWO DISPLAYS ATTEMPTED AT ONCE
00114	MORE MKS THAN DESIRED	00602	FAILURE IN OUTER LOOP ITERATION	21210	TWO PROGRAMS USING AT ONCE
00115	V41N91 WITH OPTICS NOT IN CMC	00603	FAILURE IN ORDPI ITERATION	21302	SORT CALLED WITH NEG ARGUMENT
00116	OPTICS SW MOVED BEFORE 15 SEC	00611	NO TIG FOR ELEV ANGLE GIVEN	21501	DSKY ALARM DURING INTERNAL USE
00117	V41N91 BUT OPTICS NOT READY	00777	ISS WARNING-PIPA FAIL	21502	ILLEGAL FLASHING DISPLAY
00120	ZERO OPTICS FIRST	01102	CMC SELF TEST ERROR	21521	KEYED P01 AFTER LIFTOFF
00121	CDUS BAD DURING MK-REPEAT	01105	DOWNLINK TOO FAST	31104	DELAY ROUTINE IS BUSY
00205	PIPA SATURATED	01106	UPLINK TOO FAST	31201	EXEC OVERFLOW-NO VAC AREAS
00206	CANNOT ZERO ICDU-WITH ALARMS	01107	PHASE TABLE FAIL-ERASABLE BAD	31202	EXEC OVERFLOW-NO CORE SETS
00207	NEED 90 SEC FOR ISS TURN ON	01301	ARCSIN/ARCCOS INPUT>ONE	31203	WAITLIST OVERFLOW-MANY TASKS
00210	IMU NOT OPERATING	01407	VG INCREASING	31211	CANNOT INTERRUPT EXTENDED VERB
00211	COARSE ALIGN ERROR>2 DEG	01426	IMU UNSATISFACTORY	32000	DOCKED DAP CYCLES OVERLAP
00212	PIPA FAIL BUT PIPA NOT IN USE	01427	IMU POLARITY REVERSED		
00213	IMU NOT ON-TURN ON IMU	01520	V37 NOT PERMITTED NOW		
00214	PROGRAM USING IMU BUT IMU OFF	01600	OVERFLOW DURING DRIFT TEST		
00217	COARSE ALIGN/TORQUING PROBLEM	01601	BAD IMU TORQUE		
00220	IMU NOT ALIGNED/NO REFSMMAT	01703	INSUF TIME TO INTEG-TIG SLIP		
00401	DESIRED MGA TOO LARGE	03777	ISS WARNING-ICDU FAIL		
00402	DO SECOND MINKEY PULSE TORQUE	04777	ISS WARNING-ICDU & PIPA FAIL		
00404 *	TGT OUT OF VIEW (TRUN> 90 DEG)	07777	ISS WARNING-IMU FAIL		
00405	STAR PAIR NOT AVAILABLE	10777	ISS WARNING-IMU & PIPA FAIL		
00406	P20 NOT OPERATING	13777	ISS WARNING-IMU & ICDU FAIL		
00421	W MATRIX OVERFLOW	14777	ISS WARNING-IMU, ICDU & PIPA FAIL		
00500	NOT ENOUGH JETS FOR P/Y (DOCKED)	20430	ORBITAL INTEGRATION STOPPED		

NOTE :

00404 * IS A PRIORITY ALARM
 2XXXX POODOO-NO RESTART LT-F37
 (AVE G ON OR EXT VERB -
 ACTS AS BAILOUT)
 3XXXX BAILOUT-NO RESTART LT-
 PROGRAM CONTINUES

OUA LINE OF SIGHT TO IMU STABLE MEMBER TRANSFORMATIONS



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} \cos 32^* & 0 & \sin 32^* \\ 0 & 1 & 0 \\ -\sin 32^* & 0 & \cos 32^* \end{bmatrix} \begin{bmatrix} \cos AS & -\sin AS & 0 \\ \sin AS & \cos AS & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos AT & 0 & \sin AT \\ 0 & 1 & 0 \\ -\sin AT & 0 & \cos AT \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ St \text{ LOS} \end{bmatrix}$$

* 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

DRIVE RATES

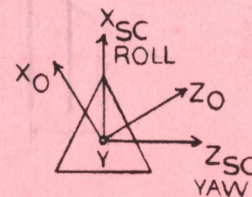
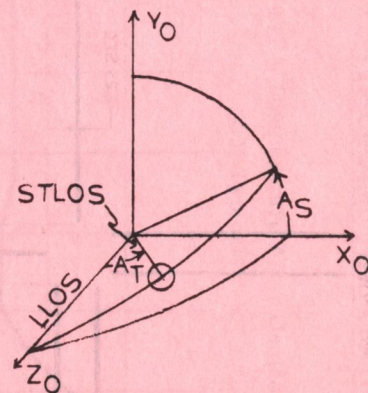
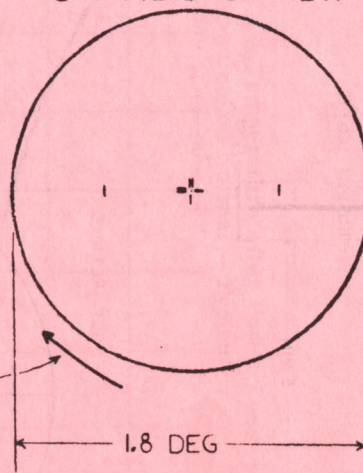
	TRUNNION	SHAFT
HI	10.0 DEG/S	19.5 DEG/S
MED	1.0 DEG/S	2.0 DEG/S
LO	0.1 DEG/S	0.2 DEG/S
MIN	25 SEC/S	50 SEC/S
CMC	3.8 DEG/S	15.1 DEG/S

RETICLE ROTATION WITH
OPTICS HAND CONTROLLER
FULL RIGHT (MANUAL DIRECT
MODE)

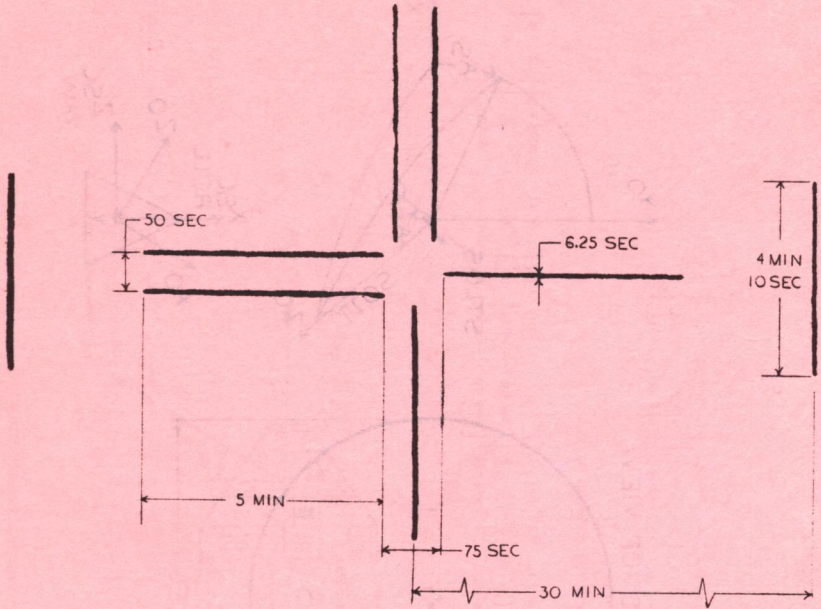
SXT LOS MECHANICAL LIMITS

TRUNNION 0(0,-10) TO 90(10,0) DEG
SHAFT 270(0,-10) TO -270(-10,0) DEG

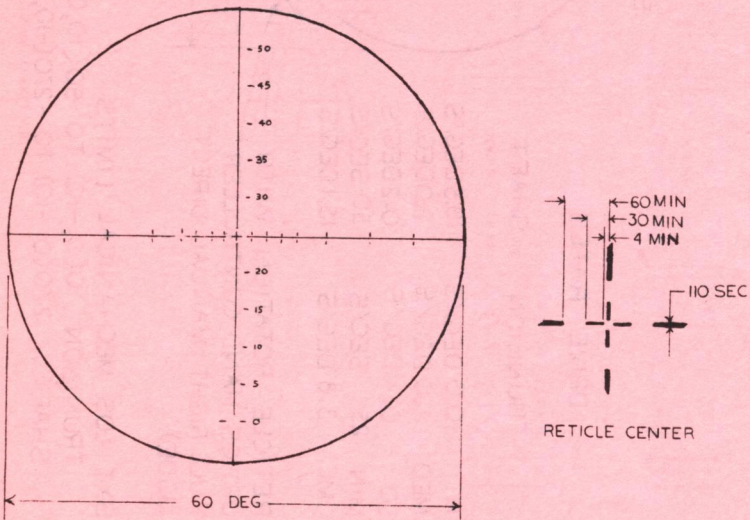
SXT FIELD OF VIEW



SXT VACUUM RETICLE



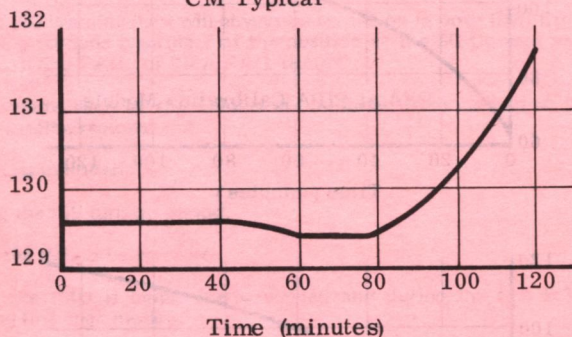
SCT RETICLE



TYPICAL IMU TEMPERATURE

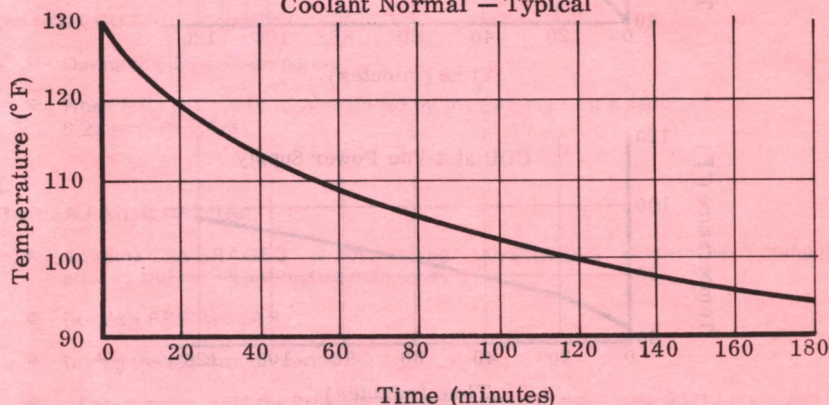
PIPA Temperature After Coolant Loss

CM Typical



PIPA Temperature After Power Loss

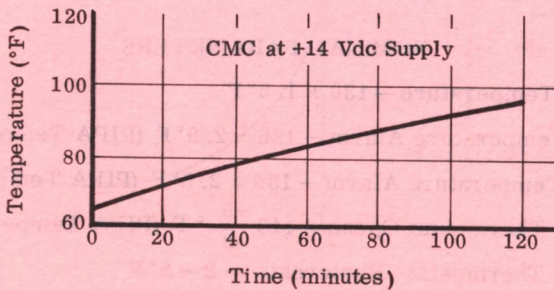
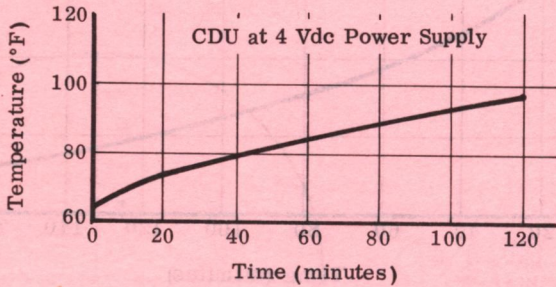
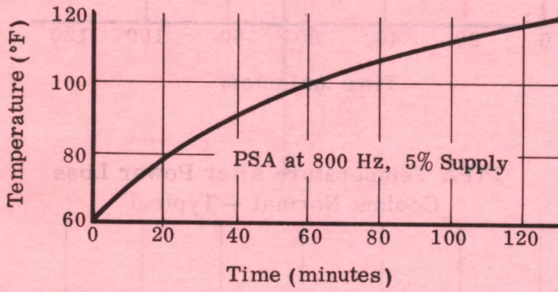
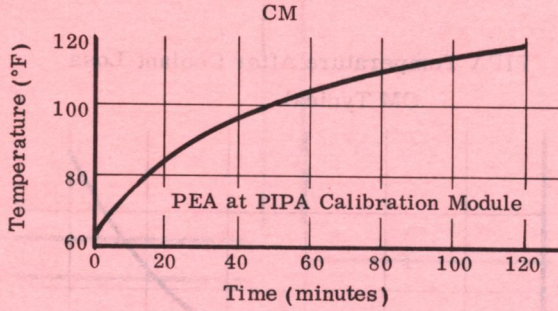
Coolant Normal — Typical



NOMINAL PARAMETERS

- PIPA Temperature — $130 \pm 1.5^\circ\text{F}$
- Low Temperature Alarm — $126 \pm 2.5^\circ\text{F}$ (PIPA Temperature)
- High Temperature Alarm — $135 \pm 2.5^\circ\text{F}$ (PIPA Temperature)
- Safety Thermostat Opens — $140^{+5}_{-2}^\circ\text{F}$ (PIPA Temperature)
- Safety Thermostat Hysteresis — $2 - 5^\circ\text{F}$

TYPICAL HEADER TEMPERATURES AFTER
COOLANT LOSS



ISS WARNING LIGHT

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 8.22 seconds (CSM).

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 8.22 seconds (CSM).

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 $> 3 \text{ Vrms}$ (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-23).
- 28 Vac, 800 Hz, 5%, Phase B (to wheel supply) $< 14 \text{ V}$. 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%, $< 14 \text{ V}$. 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 $> 2 \text{ Vrms}$ ($\theta - \psi > 30^\circ$). 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-37).
- IG or MG or OG fine error $> 1 \text{ Vrms}$ ($\theta - \psi > 0.7^\circ$). This is an 800 Hz signal and is detected at the output of the main summing amplifier (see page HW-40).
- IG or MG or OG read counter limit cycle $> 160 \text{ Hz}$. This signal is detected from the upline output of the read counter up-down counter (see page HW-35).
- IG or MG or OG $\cos(\theta - \psi) < 2 \text{ Vrms}$. This is an 800 Hz signal and is detected at the output of the ladder amplifier (see page HW-40).
- +14 Vdc CDU power supply $< +8 \text{ Vdc}$. 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.

AGC WARNING

The AGC Warning light will be turned on as a result of the following:

- Scalar Failure
- Scalar Double Failure
- AGC Power Failure
- AGC Counter Failure
- AGC V FAIL (STANDBY)
- AGC Restart (Hardware)

In addition, the Pulse Torque Power Supply Inhibit is generated every time a AGC Warning is generated. The effect is to open up the acceleratometer loops and prevent any pulse torquing of gyros.

Scalar Failure

Occurs if Stage 17 of the scalar 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 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 Power Failure

Occurs when the prime +28 VDC power to the computer is lost. This failure causes an immediate turn on of the AGC 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 input/output, (Time 1 and Time 2), \pm CDU X, Y, Z, PIPA X, Y, Z, shaft and trunnion angles, Rate Hand Controllers R, P, Q, etc.

AGC Voltage FAIL (STANDBY)

The occurrence of a Voltage Failure while the computer is in the STANDBY mode will cause the AGC 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 Warning is generated for the following alarms:

- Oscillator Failure
- Transfer Control (TC) Trap
- Parity Alarm
- Nightwatchman Fail
- Interrupt (RUPY) Lock
- Voltage Fail

The RESTART inhibits access to memory temporarily and then transfers control to address 4000. This address is the beginning of the RESTART program and processing continues from this point.

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 losses of information, time and/or thrust.

Oscillator Fail

Occurs if loss of oscillator 1.024 MHz 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 work in fixed or erasable memory whose address in 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 voltages (+28, +14, or +4 VDC) are out of limits for 157 to 470 microseconds.

These limits are:

- +28 VDC supply $< 20.0 \pm 0.3$ Vdc
- +16 VDC $< +14$ VDC supply $> +12.5$ VDC
- +4.4 VDC $< +4$ VDC supply $> +3.65$ VDC

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 Warning light.

All of the AGC Warning 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.

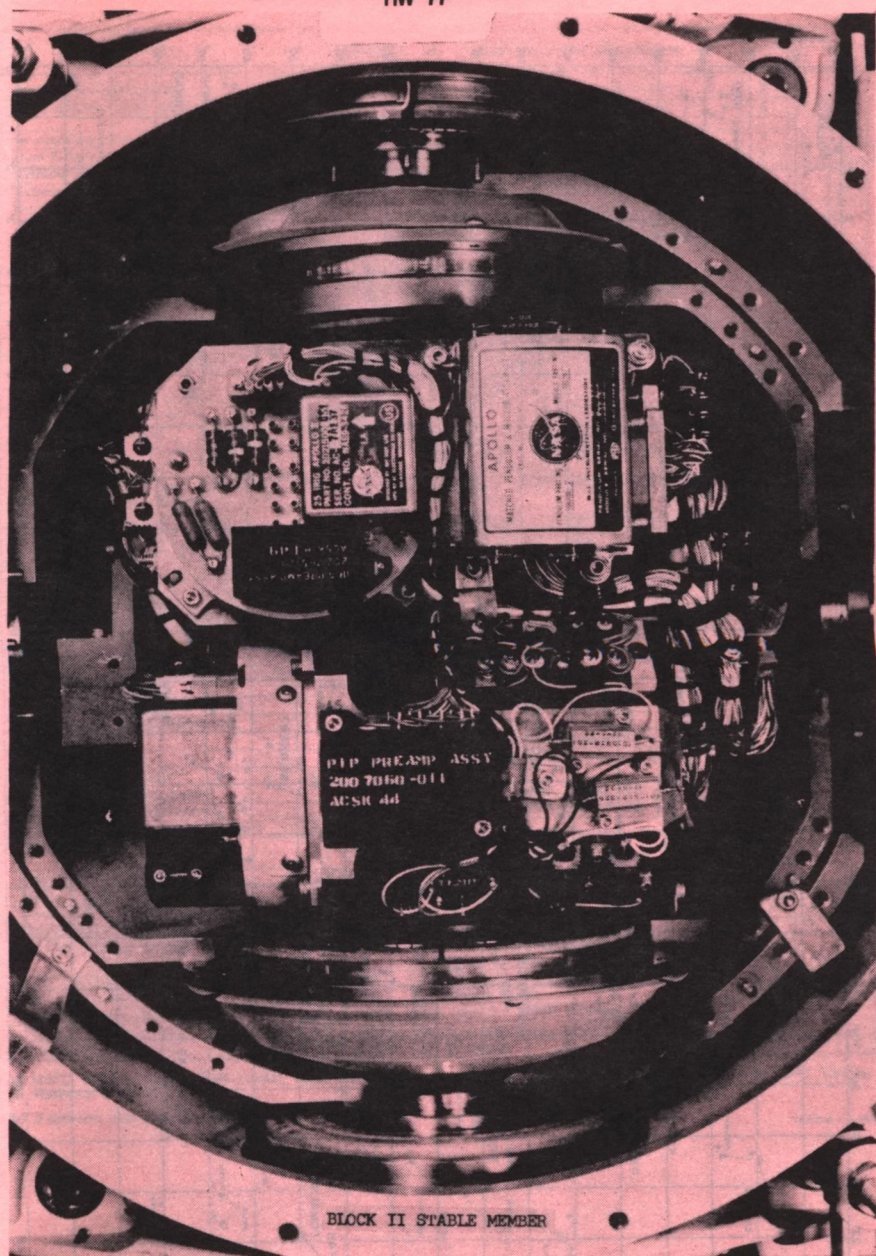
The filter operates such that an output will occur if input pulses occur at a rate of greater than 0.9 pps or 6 consecutive stretched (160 milliseconds) pulses occur or a single event longer than .960 seconds, then the AGC Warning lasts for a minimum of 5 seconds.

V35E - Test Lights

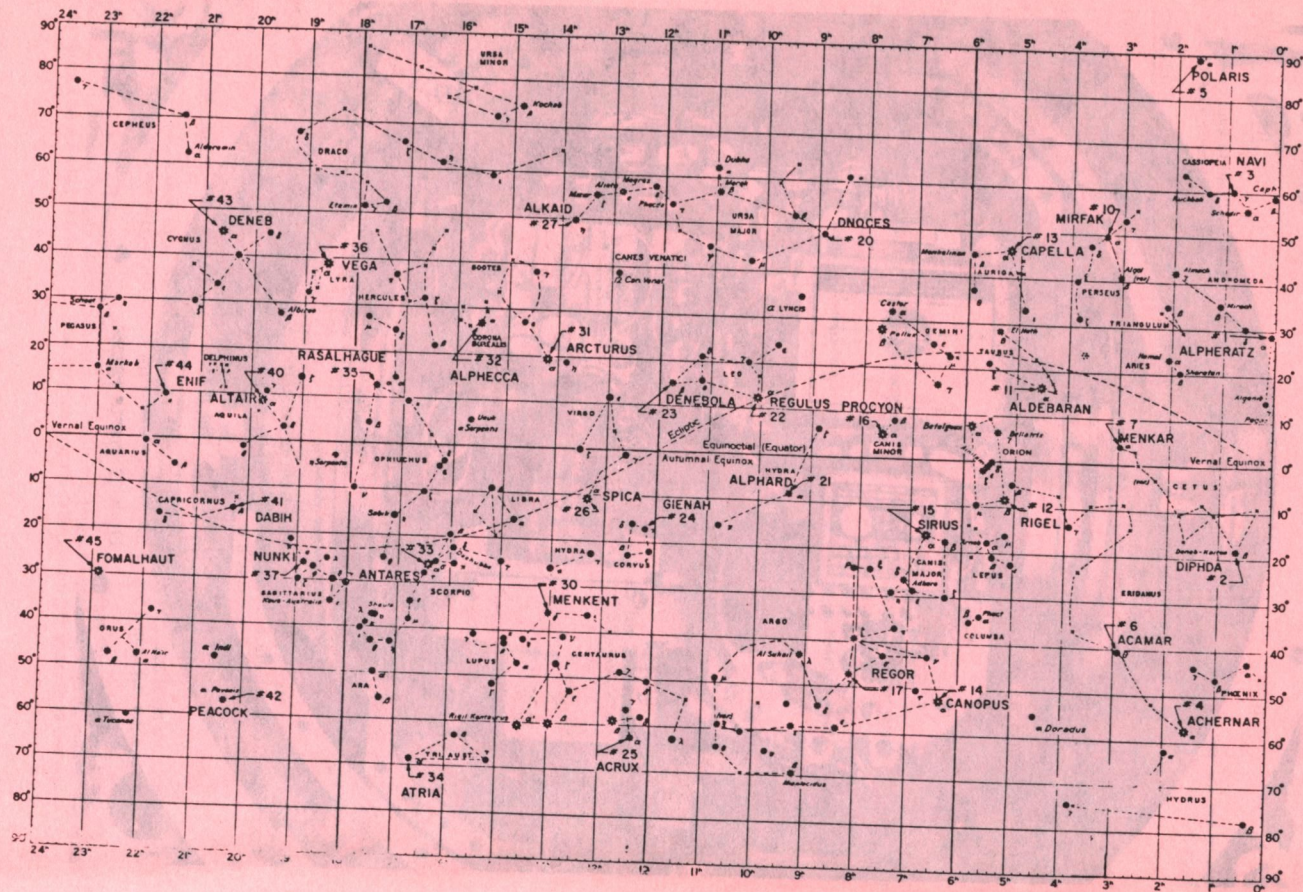
The computer has a test light routine, called by V35E, that tests all the lights on the DSKY. All "8's" and "+" signs are displayed along with each light turned on for 5 seconds minimum.

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-77



BLOCK II STABLE MEMBER



SKYLAB EXPERIMENTS

TITLE	COGNIZANT AGENCY(a)	INVESTIGATOR AND AFFILIATION(b)	MISSIONS		
			1	2	3
White-light coronagraph	MSFC	Dr. Gordon Newkirk, High Altitude Obs.	X	X	X
X-ray spectrographic telescope	MSFC	Dr. M. Zombeck, American Science and Engineering	X	X	X
uv scanning polychromator spectroheliometer	MSFC	Dr. Edward Reeves, Harvard College Obs.	X	X	X
Dual X-ray telescope	MSFC	Mr. James Milligan	X	X	X
Extreme uv coronal spectroheliograph	MSFC	Mr. J. D. Purcell, Naval Research Lab.	X	X	X
Extreme uv spectrograph	MSFC	Mr. J. D. Purcell, Naval Research Lab.	X	X	X
Nuclear emulsion	MSFC	Dr. M. M. Shapiro, Naval Research Lab.	X		
uv stellar astronomy	MSC	Dr. K. G. Henize and Dr. James Wray, Northwestern Univ.	X	X	
X-ray uv solar photography	MSC	Dr. R. Tousey, Naval Research Lab.	X		
Potato respiration	MSC	Dr. B. W. Pince, Space Defense Corp.			X
uv airglow horizon photography	MSC	Dr. D. Packer, Naval Research Lab.		X	
Gegenschein zodiacal light	MSFC	Dr. J. Weinberg, Dudley Obs.		X	
Particle collection	MSC	Dr. C. L. Hemmenway, Dudley Obs.	X	X	
Galactic X-ray mapping	MSFC	Dr. W. Kraushaar, Univ. of Wisconsin		X	
Multispectral photographic facility	MSC	Mr. A. L. Grandfield	X	X	X
Infrared spectrometer	MSC	Dr. T. Barnett	X	X	X
10-band multispectral scanner	MSC	Dr. C. L. Korb	X	X	X
Microwave scatterometer	MSC	Mr. D. Evans	X	X	X
Radiation in spacecraft	MSC	Capt. M. F. Schneider, USAF	X		
Expandable airlock technology	MSFC	Mr. F. W. Forbes, USAF Wright-Patterson Air Force Base (AFB)	X	X	
Thermal control coatings	MSFC	Mr. Carl Boebel, USAF Wright-Patterson AFB	X	X	
Material processing in space	MSFC	Mr. P. G. Parks	X		
Effects of zero-g on human cells	MSC	Dr. P. O. Montgomery, Dallas County Hospital	X		
Circadian rhythm, pocket mice	ARC	Dr. C. S. Pittendrigh, Princeton Univ.		X	
Circadian rhythm, vinegar gnat	ARC	Dr. C. S. Pittendrigh, Princeton Univ.		X	
Crew vehicle disturbances	LaRC	Mr. B. A. Conway		X	
Precision optical tracking	MSFC	Mr. John Gould	X	X	X
Coronagraph contamination measurement	MSC	Dr. G. P. Bonner		X	
Contamination measurement	MSFC	Dr. J. Muscari, Martin Marietta Corp.	X		
Zero-g flammability	MSFC	Mr. Howard Kimzey		X	
Gravity substitute workbench	MSFC	Mr. J. Rendall	X		
Extravehicular- and intravehicular-activity hardware evaluation	MSC	Mr. John Jackson	X	X	
Astronaut-maneuvering equipment	MSC	Maj. C. E. Whitsett, USAF		X	
Foot-controlled maneuvering unit	LaRC	Mr. D. E. Hewes		X	
Mineral balance	MSC	Dr. G. D. Whedon, National Institute of Health	X	X	X
Bone densitometry	MSC	Dr. Pauline Mack, Texas Women's Univ.	X	X	X
Bioassay of body fluids	MSC	Dr. C. Leach	X	X	X
Specimen mass measurement	MSC	Col. John Ord, USAF, Brooks AFB	X	X	X
Lower-body negative pressure	MSC	Col. John Ord, USAF, Brooks AFB	X	X	X
Inflight lower-body negative pressure	MSC	Dr. R. J. Johnson	X	X	X
Vectorcardiogram	MSC	Capt. Newton W. Alliebach, USN, Bureau of Medicine and Surgery	X	X	X
Cytogenetic studies of blood	MSC	Dr. M. Shaw, Univ. of Texas Medical Center	X	X	X
Man's immunity in vitro aspects	MSC	Dr. Stephen Ritzman, Shriners' Burn Institute	X	X	X
Blood volume and red-cell life span	MSC	Dr. Phillip Johnson, Baylor Univ.	X	X	X
Red-blood-cell metabolism	MSC	Mr. Charles Mengel, Univ. of Missouri	X	X	X
Human vestibular function	MSC	Dr. Ashton Graybiel, Naval Aviation Medical Institute	X	X	
Time and motion study	MSC	Dr. J. F. Kubis, Fordham Univ.	X	X	X
Metabolic activity	MSC	Mr. Edward Michel	X	X	X
Body-mass measurement	MSC	Col. John Ord, USAF, Brooks AFB	X	X	X
Thermal control coatings	MSFC	Mr. E. C. McKannon	X		
Inflight aerosol analysis	MSFC	Dr. W. Leavitt	X	X	X

(a) MSFC, Marshall Space Flight Center; MSC, Manned Spacecraft Center; ARC, Ames Research Center; and LaRC, Langley Research Center.

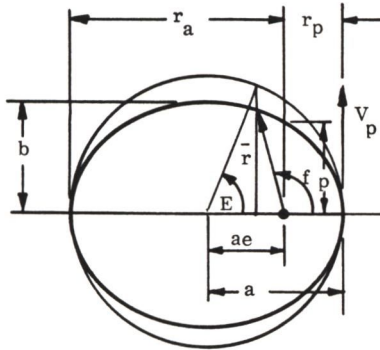
(b) If different from cognizant agency.

NASA — MSC

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ELLIPSE



Semiminor Axis

$$b = \sqrt{r_a r_p}$$

Semimajor Axis

$$a = \frac{r_a + r_p}{2}$$

Eccentricity

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} < 1$$

Position

$$r = \frac{a(1-e^2)}{1+e \cos f} = a (1 - e \cos E)$$

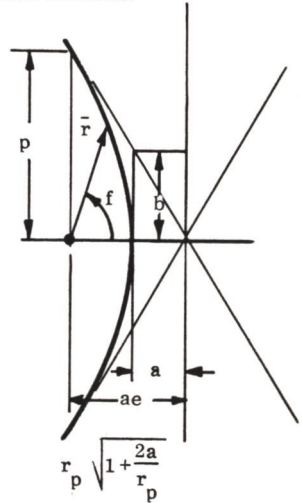
Velocity

$$V = \left[\frac{\mu}{a} \left(\frac{1+2e \cos f + e^2}{1 - e^2} \right) \right]^{1/2}$$

Semilatus Rectum

$$p = a (1 - e^2)$$

HYPERBOLA



$$\frac{\mu}{V_\infty^2}$$

$$\sqrt{1 + \left(\frac{b}{a}\right)^2} > 1$$

$$\frac{a(e^2 - 1)}{1 + e \cos f}$$

$$\left[\mu \left(\frac{2}{r} + \frac{1}{a} \right) \right]^{1/2}$$

$$a (e^2 - 1)$$

$$V_\infty^2 = \frac{\mu}{a}$$