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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE AND NAVIGATION

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(Unclassified Title)

E-1828

G&N SYSTEM DATA FOR MISSION AS-202 DEVELOPMENT ENGINEERING INSPECTION

by Apollo Staff
August 1965

[redacted]

INSTRUMENTATION LABORATORY

CAMBRIDGE 39, MASSACHUSETTS

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1.0 INTRODUCTION

The data in this report have been compiled to support the Spacecraft 011 (G&N 017) AS-202 Development Engineering Inspection.

It is intended to describe G&N system functions and performance. G&N functions are defined in the nominal timeline. Performance is defined by the results of an all-digital nominal mission simulation, and a statistical error analysis. Also included are a reliability assessment and an abbreviated failure effects analysis.

Additional data may be found in R-477 Rev. 1, July 1965.

2.0 NOMINAL TIMELINE OF GUIDANCE AND SPACECRAFT CONTROL FUNCTIONS AND TIMING TOLERANCES

2.1 Nominal Timeline

This timeline is an updated version of the one that appeared in R-477 Rev. 1, July 1965.

NORMAL SEQUENCE OF EVENTS - MISSION 202

S/C 011/MISSION CONTROL PROGRAMMER/G&N

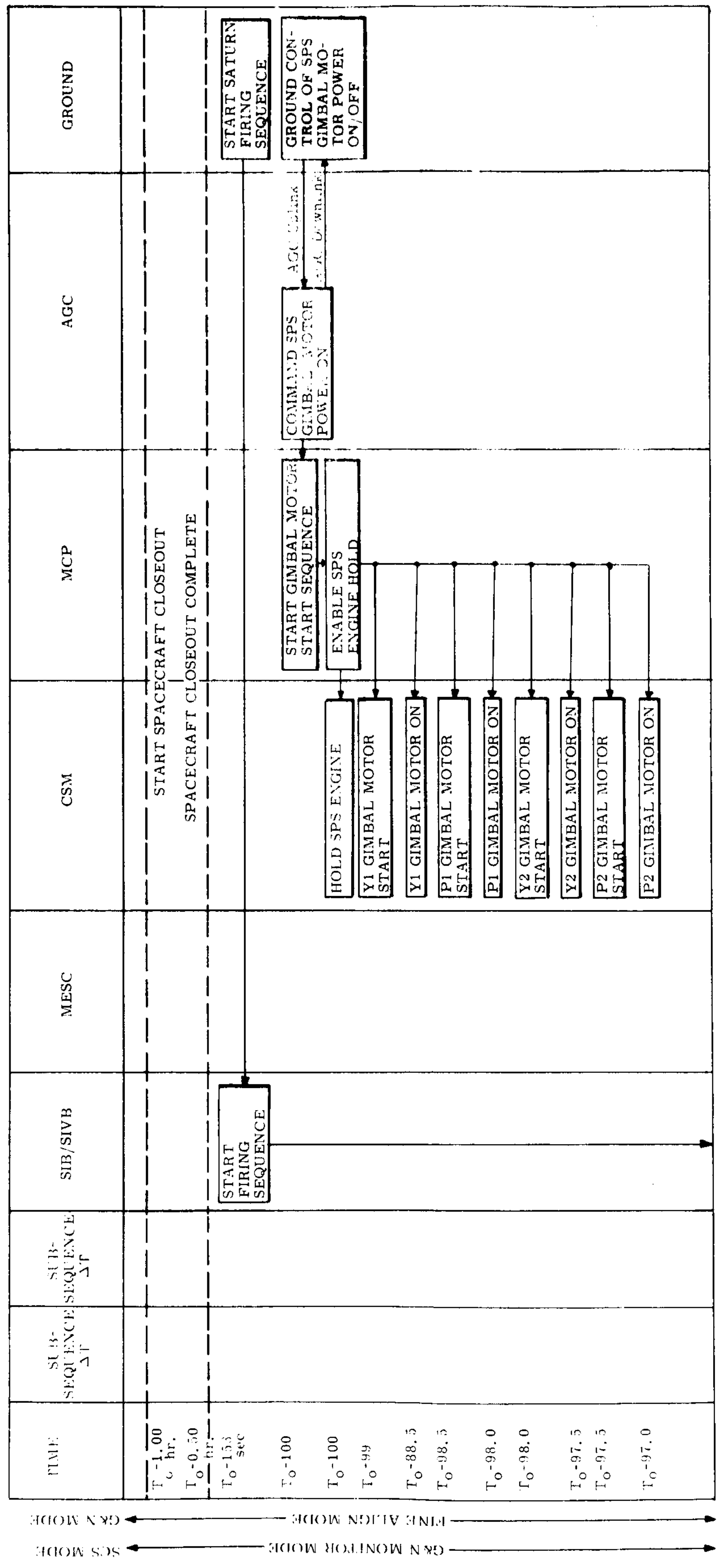
SCS MODE / G&N MODE	TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
						PRELAUNCH			
	T_o-12.00 hrs.							TURN ON G&N → ENABLE UPLINK → "FRESH START" OF AGC → AGC CLOCK ALIGNMENT	GROUND SYNCHRONIZATION OF AGC TIME THRU ACE (→ AGC CLOCK ALIGNMENT)
								→ LOAD MISSION DATA (A) IMU PARAMETERS (B) LAUNCH SITE VECTORS (C) POWERED FLIGHT PARAMETERS (D) OPTICAL TARGETS (E) BOOST MONITOR POLYNOMIALS	LOAD MISSION DATA VIA ACE (→ LOAD MISSION DATA)
FINE ALIGN MODE	T_o-11.25 hrs.							→ G&N STARTS GYROCOMPASSING MODE FOR IMU ALIGNMENT TO LAUNCH AZIMUTH. SET FINE ALIGN MODE IN G&N	
FINE ALIGN MODE	T_o-11.00 hrs.							→ OPTICS SIGHTING TO VERIFY GYROCOMPASSING	
FINE ALIGN MODE	T_o-10.25 hrs.							→ REPEAT OPTICS SIGHTING TO VERIFY GYROCOMPASSING →	

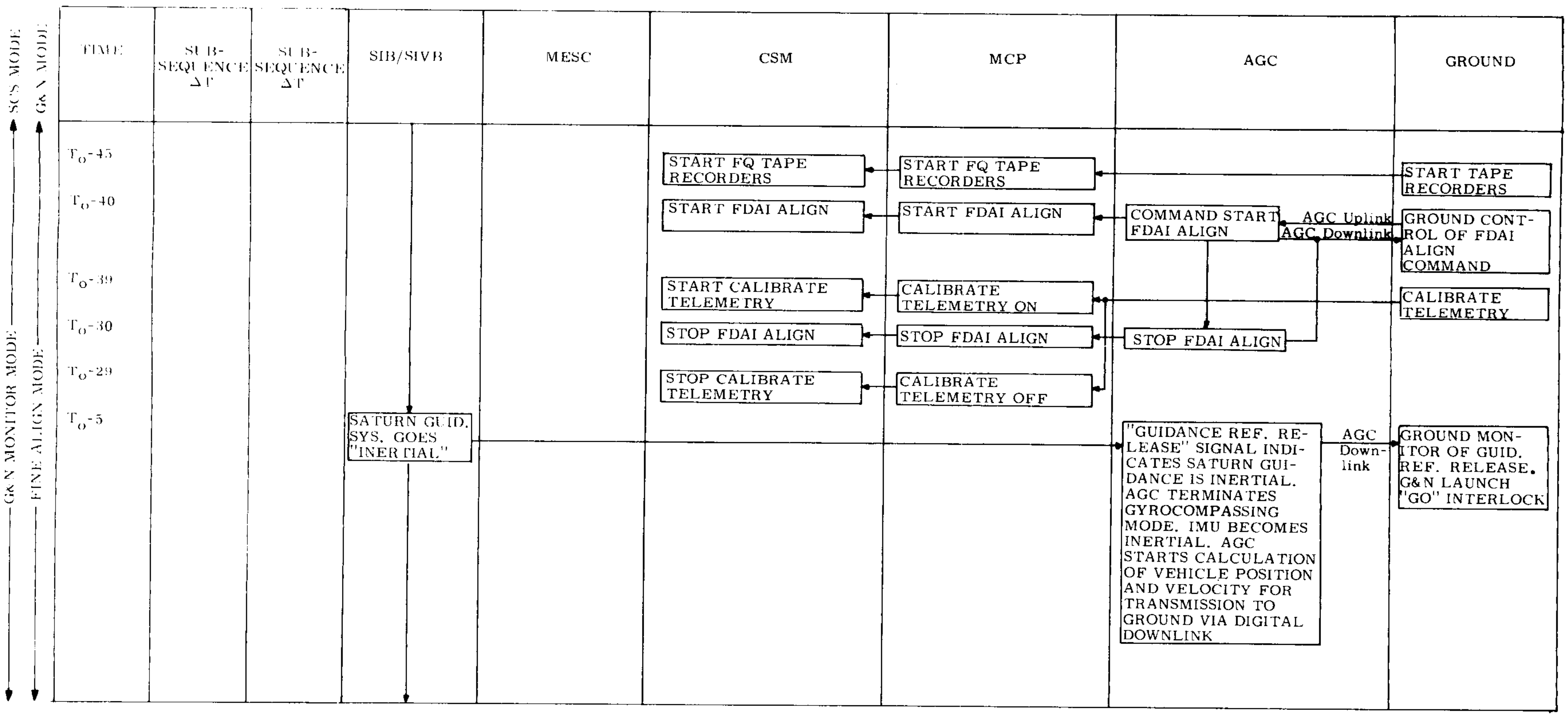
SCS MODE / G&N MODE

G&N MONITOR MODE (from T_0-5.00 hrs.)

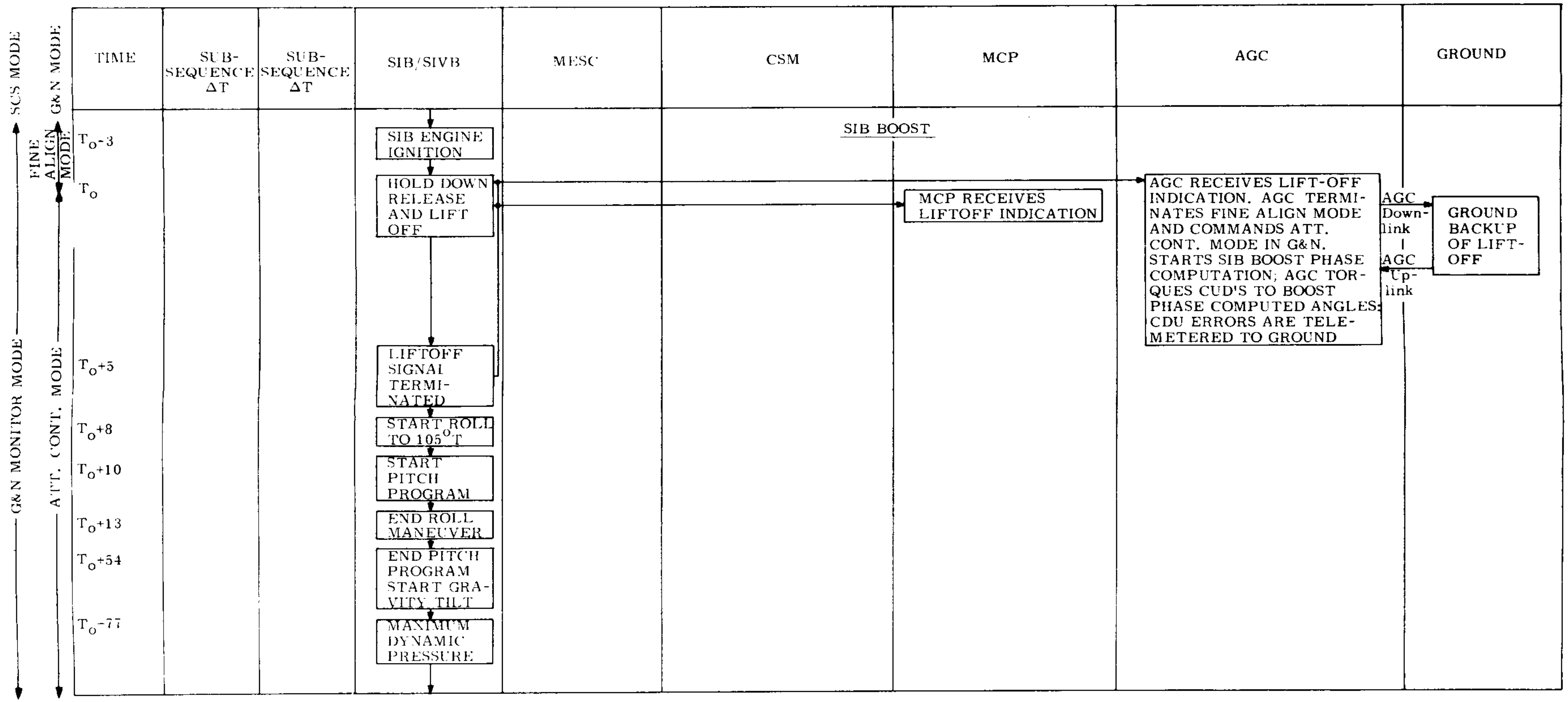
FINE ALIGN MODE

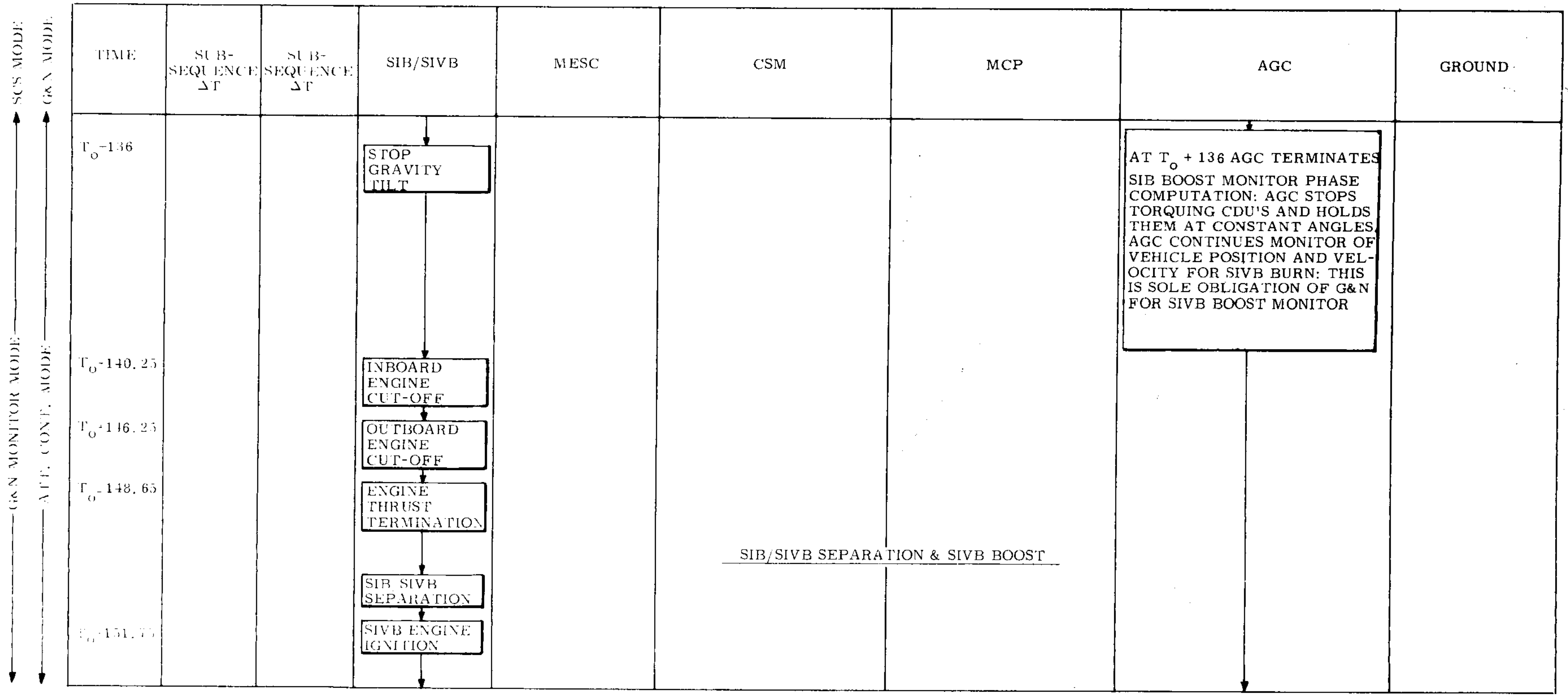
TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB SIVB	MESC	CSM	MCP	AGC	GROUND
T_0-9.75 hrs.								CLOSE OPTICS HATCH
T_0-5.00 hrs.						PROGRAMMER RESET		GROUND RESET OF MCP
						ARM GIMBAL MOTOR POWER ON/OFF. G&N BACKUP ABORT COMMAND. G&N FAIL, T/C SWITCHING. ARM G&N FAIL CIRCUITRY FOR INDICATION ONLY TO MCP. MCP WILL NOT REVERT TO BACKUP MODE UNTIL SIVB/CSM SEPARATION		

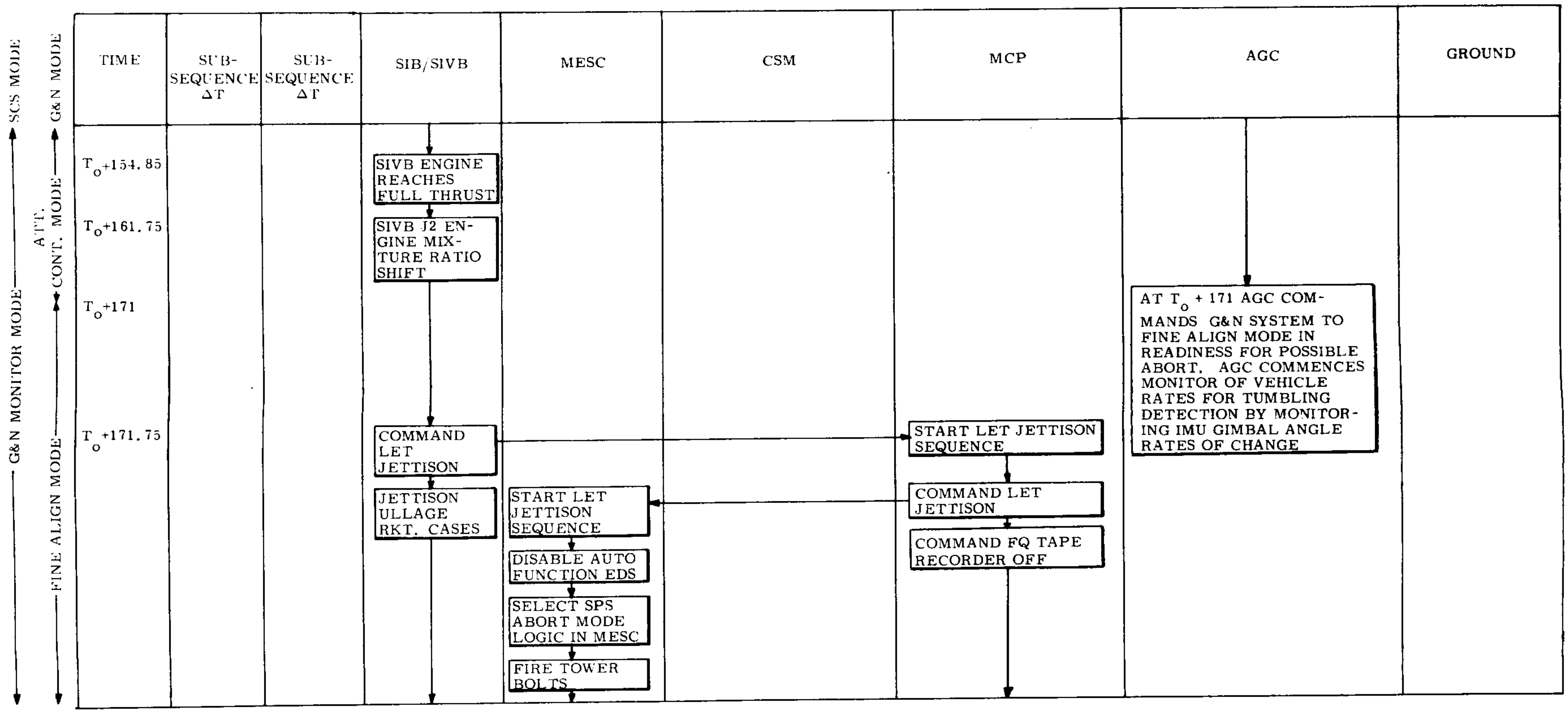

TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
T_o -1.00 hr.
T_o -0.50 hr.
T_o -153 sec
T_o -100
T_o -100
T_o -99
T_o -88.5
T_o -98.5
T_o -98.0
T_o -98.0
T_o -97.5
T_o -97.5
T_o -97.0
START SPACECRAFT CLOSEOUT
SPACECRAFT CLOSEOUT COMPLETE
START SATURN FIRING SEQUENCE
START FIRING SEQUENCE
GROUND CONTROL OF SPS GIMBAL MOTOR POWER ON/OFF
AGC Uplink
AGC Downlink
COMMAND SPS GIMBAL MOTOR POWER ON
START GIMBAL MOTOR START SEQUENCE
ENABLE SPS ENGINE HOLD
HOLD SPS ENGINE
Y1 GIMBAL MOTOR START
Y1 GIMBAL MOTOR ON
P1 GIMBAL MOTOR START
P1 GIMBAL MOTOR ON
Y2 GIMBAL MOTOR START
Y2 GIMBAL MOTOR ON
P2 GIMBAL MOTOR START
P2 GIMBAL MOTOR ON
G&N MODE
FINE ALIGN MODE
SCS MODE
G&N MONITOR MODE

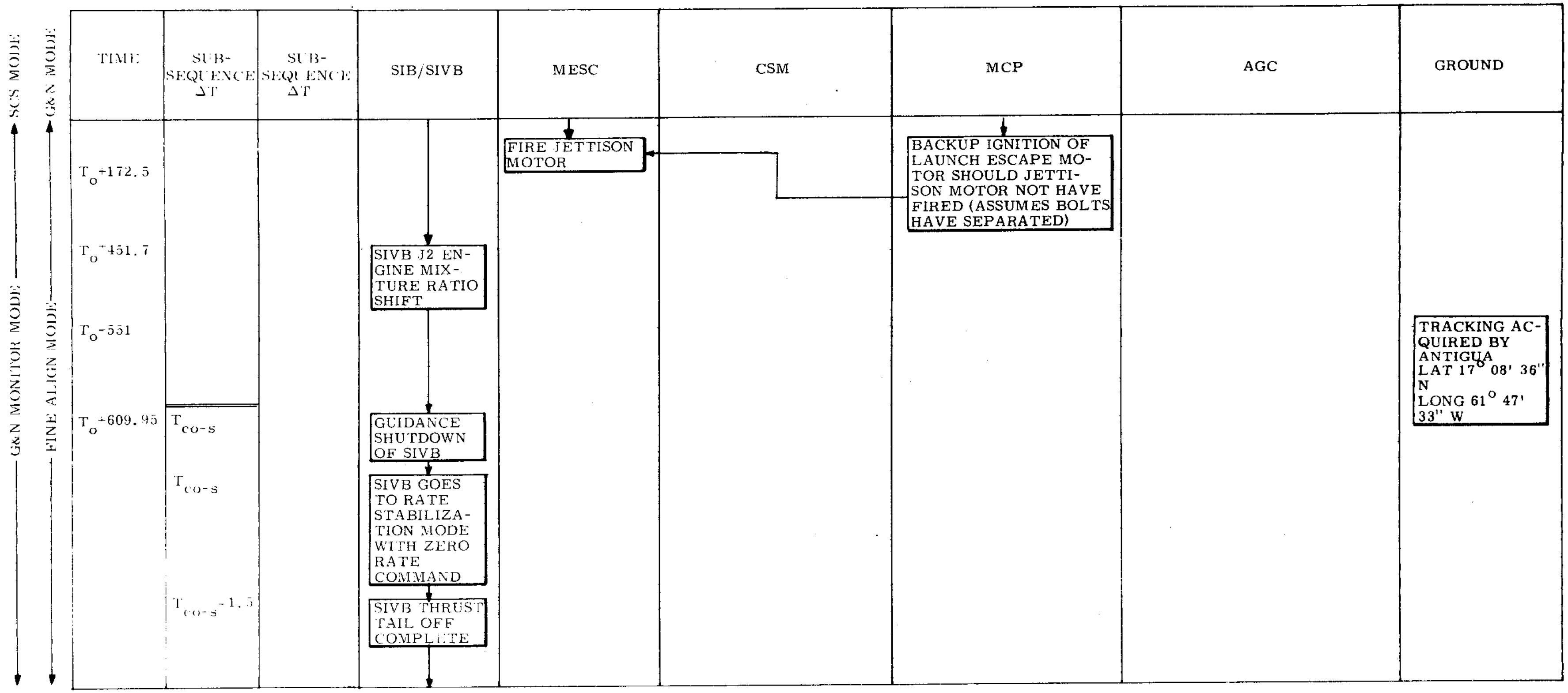


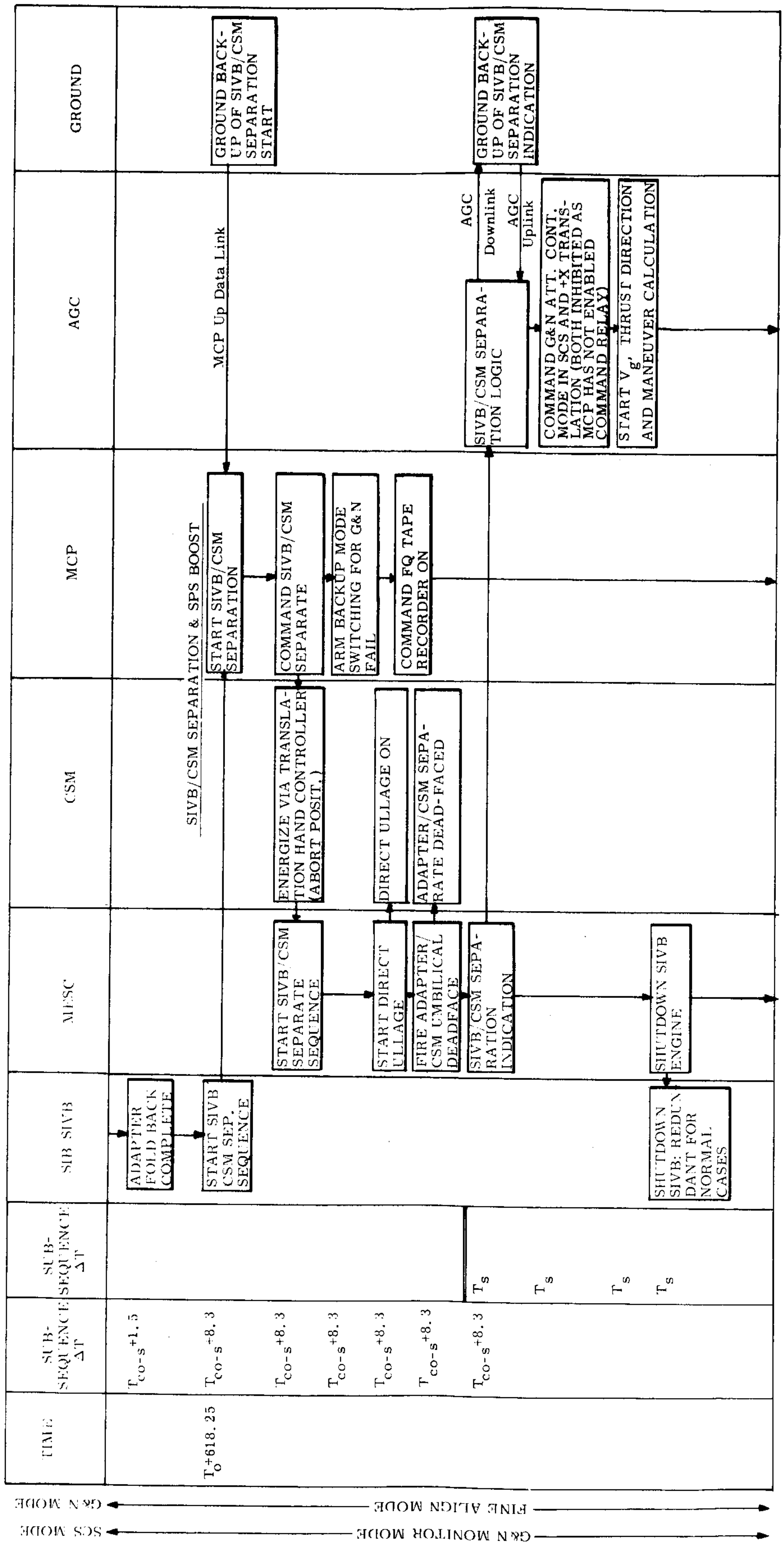
TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
T0-45
T0-40
T0-39
T0-30
T0-29
T0-5
START FQ TAPE RECORDERS
START FDAI ALIGN
START CALIBRATE TELEMETRY
STOP FDAI ALIGN
STOP CALIBRATE TELEMETRY
START FQ TAPE RECORDERS
START FDAI ALIGN
CALIBRATE TELEMETRY ON
STOP FDAI ALIGN
CALIBRATE TELEMETRY OFF
COMMAND START FDAI ALIGN
STOP FDAI ALIGN
AGC Uplink
AGC Downlink
START TAPE RECORDERS
GROUND CONTROL OF FDAI ALIGN COMMAND
CALIBRATE TELEMETRY
SATURN GUID. SYS. GOES "INERTIAL."
"GUIDANCE REF. RELEASE" SIGNAL INDICATES SATURN GUIDANCE IS INERTIAL. AGC TERMINATES GYROCOMPASSING MODE. IMU BECOMES INERTIAL. AGC STARTS CALCULATION OF VEHICLE POSITION AND VELOCITY FOR TRANSMISSION TO GROUND VIA DIGITAL DOWNLINK
AGC Down-link
GROUND MONITOR OF GUID. REF. RELEASE. G&N LAUNCH "GO" INTERLOCK
SCS MODE
G&N MONITOR MODE
G&N MODE
FINE ALIGN MODE


SCS MODE
G&N MODE
FINE ALIGN MODE
G&N MONITOR MODE
ATT. CONT. MODE
TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
SIB BOOST
T_o-3
T_o
T_o+5
T_o+8
T_o+10
T_o+13
T_o+54
T_o-77
SIB ENGINE IGNITION
HOLD DOWN RELEASE AND LIFT OFF
LIFTOFF SIGNAL TERMINATED
START ROLL TO 105°T
START PITCH PROGRAM
END ROLL MANEUVER
END PITCH PROGRAM START GRAVITY TILT
MAXIMUM DYNAMIC PRESSURE
MCP RECEIVES LIFTOFF INDICATION
AGC RECEIVES LIFT-OFF INDICATION. AGC TERMINATES FINE ALIGN MODE AND COMMANDS ATT. CONT. MODE IN G&N. STARTS SIB BOOST PHASE COMPUTATION; AGC TORQUES CUD'S TO BOOST PHASE COMPUTED ANGLES; CDU ERRORS ARE TELEMETERED TO GROUND
AGC Down-link
AGC Up-link
GROUND BACKUP OF LIFT-OFF


TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
To-136
To-140.25
To-146.25
To-148.65
To-151.75
STOP GRAVITY TILT
INBOARD ENGINE CUT-OFF
OUTBOARD ENGINE CUT-OFF
ENGINE THRUST TERMINATION
SIB SIVB SEPARATION
SIVB ENGINE IGNITION
SIB/SIVB SEPARATION & SIVB BOOST
AT To + 136 AGC TERMINATES SIB BOOST MONITOR PHASE COMPUTATION: AGC STOPS TORQUING CDU'S AND HOLDS THEM AT CONSTANT ANGLES. AGC CONTINUES MONITOR OF VEHICLE POSITION AND VELOCITY FOR SIVB BURN: THIS IS SOLE OBLIGATION OF G&N FOR SIVB BOOST MONITOR
SCS MODE
G&N MONITOR MODE
G&N MODE
ATT. CONT. MODE


TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
To+154.85
To+161.75
To+171
To+171.75
SIVB ENGINE REACHES FULL THRUST
SIVB J2 ENGINE MIXTURE RATIO SHIFT
COMMAND LET JETTISON
JETTISON ULLAGE RKT. CASES
START LET JETTISON SEQUENCE
DISABLE AUTO FUNCTION EDS
SELECT SPS ABORT MODE LOGIC IN MESC
FIRE TOWER BOLTS
START LET JETTISON SEQUENCE
COMMAND LET JETTISON
COMMAND FQ TAPE RECORDER OFF
AT To + 171 AGC COMMANDS G&N SYSTEM TO FINE ALIGN MODE IN READINESS FOR POSSIBLE ABORT. AGC COMMENCES MONITOR OF VEHICLE RATES FOR TUMBLING DETECTION BY MONITORING IMU GIMBAL ANGLE RATES OF CHANGE
SCS MODE
G&N MONITOR MODE
G&N MODE
ATT. CONT. MODE
FINE ALIGN MODE


SCS MODE
G&N MODE
G&N MONITOR MODE
FINE ALIGN MODE
TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
T_o+172.5
T_o+451.7
T_o-551
T_o+609.95
T_{co-s}
T_{co-s}
T_{co-s}-1.5
FIRE JETTISON MOTOR
BACKUP IGNITION OF LAUNCH ESCAPE MOTOR SHOULD JETTISON MOTOR NOT HAVE FIRED (ASSUMES BOLTS HAVE SEPARATED)
SIVB J2 ENGINE MIXTURE RATIO SHIFT
TRACKING ACQUIRED BY ANTIGUA LAT 17° 08' 36" N LONG 61° 47' 33" W
GUIDANCE SHUTDOWN OF SIVB
SIVB GOES TO RATE STABILIZATION MODE WITH ZERO RATE COMMAND
SIVB THRUST TAIL OFF COMPLETE


GROUND
AGC
MCP
CSM
MESC
SIB SIVB
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
TIME
SIVB/CSM SEPARATION & SPS BOOST
GROUND BACK-UP OF SIVB/CSM SEPARATION START
GROUND BACK-UP OF SIVB/CSM SEPARATION INDICATION
MCP Up Data Link
AGC Downlink
AGC Uplink
SIVB/CSM SEPARATION LOGIC
COMMAND G&N ATT. CONT. MODE IN SCS AND +X TRANSLATION (BOTH INHIBITED AS MCP HAS NOT ENABLED COMMAND RELAY)
START V_g, THRUST DIRECTION AND MANEUVER CALCULATION
START SIVB/CSM SEPARATION
COMMAND SIVB/CSM SEPARATE
ARM BACKUP MODE SWITCHING FOR G&N FAIL
COMMAND FQ TAPE RECORDER ON
ENERGIZE VIA TRANSLATION HAND CONTROLLER (ABORT POSIT.)
DIRECT ULLAGE ON
ADAPTER/CSM SEPARATE DEAD-FACED
START SIVB/CSM SEPARATE SEQUENCE
START DIRECT ULLAGE
FIRE ADAPTER/CSM UMBILICAL DEADFACE
SIVB/CSM SEPARATION INDICATION
SHUTDOWN SIVB ENGINE
ADAPTER FOLD BACK COMPLETE
START SIVB CSM SEP. SEQUENCE
SHUTDOWN SIVB: REDUNDANT FOR NORMAL CASES
T_s
T_s
T_s
T_s
T_co-s +1.5
T_co-s +8.3
T_co-s +8.3
T_co-s +8.3
T_co-s +8.3
T_co-s +8.3
T_co-s +8.3
T_o+618.25
G&N MODE
FINE ALIGN MODE
SCS MODE
G&N MONITOR MODE

SCS MODE ← G&N MONITOR MODE → ← G&N ATT. CONT. MODE →

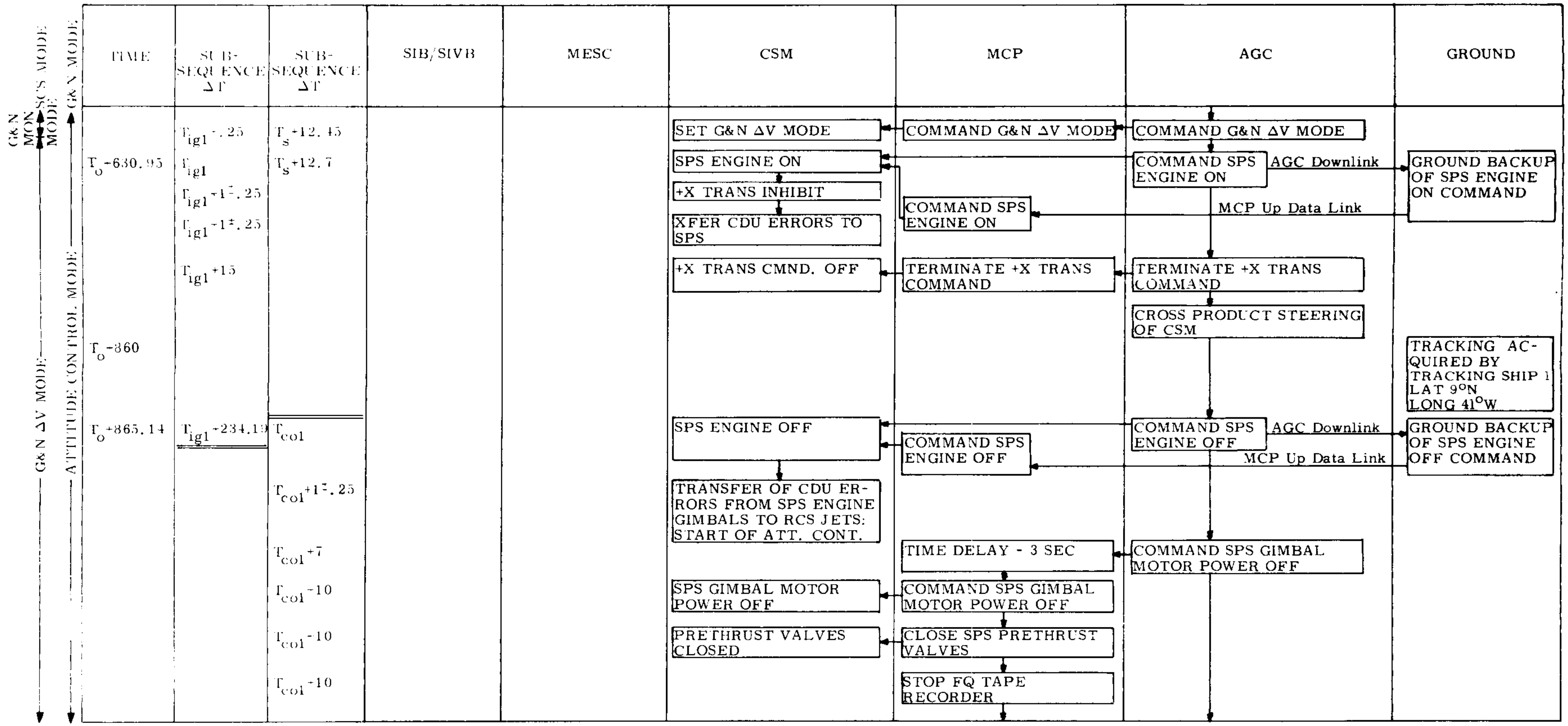
G&N MODE ← FINE ALIGN MODE →

TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		T_s+1.7		FIRE ADAPTER/ CSM SEPARATION SQUIBS	ADAPTER/CSM SEPARATION			
		T_s+2.5		SCS RCS ENABLE ON	SCS RCS ENABLE ON			
		T_s+2.5			ROLL CHANNEL UNDER CONTROL OF ROLL RATE GYRO: ATTITUDE ERROR SIGNAL AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N. PITCH AND YAW CHANNEL INHIBITED BY DIRECT ULLAGE			
		T_s+2.5				ARM G&N CONTROL RELAYS: (1) G&N ATT. CONT. MODE CMND. (2) G&N ΔV MODE CMND. (3) G&N ENTRY MODE CMND. (4) +X TRANS ON/OFF (5) CM/SM SEP CMND.		
		T_s+2.5			SET G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE (COMMANDED BY AGC AT T_s: ENABLED BY MCP ARMING)		
	T_{co-s}-10.8	T_s-2.5		SIVB/CSM SEPARATION COMMAND TERMINATED	DE-ENERGIZE VIA TRANSLATION HAND CONTROLLER (ABORT POSIT.)	AT RECEIPT OF +X TRANS ON (COMMANDED BY AGC AT T_s AND ARMED BY MCP AT T_s+2.5) (1) TERMINATE SIVB/CSM SEPARATION COMMAND		

TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		T_s+2.5			+X TRANS ON. INHIBITED IF NO RCS ENABLE (MESC ORIGINATED AT T_s+2.5 AND THEN ALSO BY DIRECT ULLAGE (MESC TERMINATED AT T_s+2.5)	(CONTINUED) (2) COMMAND +X TRANS ON		
		T_s+2.5		DIRECT ULLAGE COMMAND TERMINATED	DIRECT ULLAGE OFF			
		T_s+2.5			+X TRANS ON. PITCH & YAW ATTITUDE CONT. INHIBIT RELEASED. PITCH & YAW CHANNELS UNDER CONTROL OF PITCH & YAW RATE GYROS. ATT. ERROR SIGNALS AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N			
		T_s+2.5			SPS ENGINE HOLD DISABLED	DISABLE SPS ENGINE HOLD		
		T_s+2.5			GIMBALS TO TRIM POSITION #1	SELECT GIMBAL MOTOR TRIM POSITION #1		
		T_s+2.5			ARM SPS SOLONOIDS	ARM SPS SOLONOIDS		
		T_s+2.5			PRETHRUST VALVES OPENED	OPEN SPS PRETHRUST VALVES		
		T_s+2.5			+X TRANS LOGIC INTERLOCK TO TVC LOGIC	+X TRANS COMND. (TO TVC LOGIC ONLY)		
		T_s+5.5 -0.0 +2.0					COMMAND G&N SYSTEM TO ATTITUDE CONTROL MODE	
							START CDU DRIVE	
							STOP CDU TORQUING, AGC ASSUMES VEHICLE IS AT CORRECT ORIENTATION FOR 1ST SPS BURN	
	T_{ig1} -.5	T_s+12.2			TERMINATE G&N ATT. CONTROL MODE	TERMINATE G&N ATT. CONTROL MODE	TERMINATE G&N ATTITUDE CONTROL MODE	

SCS MODE ← G&N ATT. CONT. MODE → G&N MON MODE

G&N MODE ← FINE ALIGN MODE → ATT. CONT. MODE


G&N MON MODE
SCS MODE
G&N ΔV MODE
G&N MODE
ATTITUDE CONTROL MODE
TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
T_o-630.95
T_o-860
T_o+865.14
T_ig1-.25
T_ig1
T_ig1+1±.25
T_ig1-1±.25
T_ig1+15
T_ig1+234.19
T_s+12.45
T_s+12.7
T_col
T_col+1±.25
T_col+7
T_col-10
T_col-10
T_col-10
SET G&N ΔV MODE
SPS ENGINE ON
+X TRANS INHIBIT
XFER CDU ERRORS TO SPS
+X TRANS CMND. OFF
SPS ENGINE OFF
TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS: START OF ATT. CONT.
SPS GIMBAL MOTOR POWER OFF
PRETHRUST VALVES CLOSED
COMMAND G&N ΔV MODE
COMMAND SPS ENGINE ON
TERMINATE +X TRANS COMMAND
COMMAND SPS ENGINE OFF
TIME DELAY - 3 SEC
COMMAND SPS GIMBAL MOTOR POWER OFF
CLOSE SPS PRETHRUST VALVES
STOP FQ TAPE RECORDER
COMMAND G&N ΔV MODE
COMMAND SPS ENGINE ON
AGC Downlink
MCP Up Data Link
TERMINATE +X TRANS COMMAND
CROSS PRODUCT STEERING OF CSM
COMMAND SPS ENGINE OFF
AGC Downlink
MCP Up Data Link
COMMAND SPS GIMBAL MOTOR POWER OFF
GROUND BACKUP OF SPS ENGINE ON COMMAND
TRACKING ACQUIRED BY TRACKING SHIP 1 LAT 9°N LONG 41°W
GROUND BACKUP OF SPS ENGINE OFF COMMAND

TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		$T_{col}+10$			GIMBALS TO TRIM POSITION #2	SELECT GIMBAL MTR. TRIM POSITION #2		
		$T_{col}+10.50$			TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	
		$T_{col}+10.75$			SET G&N ATT. CONTL. MODE	COMMAND G&N ATT. CONTL. MODE	COMMAND G&N ATT. CONTL. MODE	
					COAST	COAST		
							COMPUTE ATTITUDE MANEUVER NECESSARY TO POINT +X AXIS TOWARD EARTH'S CTR.	
							COMMAND MANEUVER NOSE DOWN	
T_o+899		$T_{col}+29.86$					COMMAND PITCH/YAW MANEUVER TO TRACK LOCAL VERTICAL	
T_o+935								TRACKING LOST BY ANTIGUA (B. W. I.)
$T_o+1165.14$		$T_{col}+300$			START FDAI ALIGN	START FDAI ALIGN	COMMAND START FDAI ALIGN (AGC Downlink / AGC Uplink)	GROUND BACK-UP OF FDAI ALIGN COMMAND
		$T_{col}+310$			STOP FDAI ALIGN	STOP FDAI ALIGN	STOP FDAI ALIGN	

SCS MODE: G&N ΔV MODE → G&N MON MODE → G&N ATT. CONT. MODE

G&N MODE: ATT. CONT. MODE

TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
T_o-1230								TRACKING ACQUIRED BY ASCENSION IS. LAT. 07°57'05" S LONG. 14°24'45" W
T_o-1460								TRACKING LOST BY TRACKING SHIP 1
T_o+2200								TRACKING LOST BY ASCENSION IS.
								120 sec without ground coverage
T_o+2320								TRACKING ACQUIRED BY PRETORIA S. A. LAT. 25°56'14" S LONG. 28°22'64" W
T_o-2800								TRACKING LOST BY PRETORIA
								840 sec without ground coverage

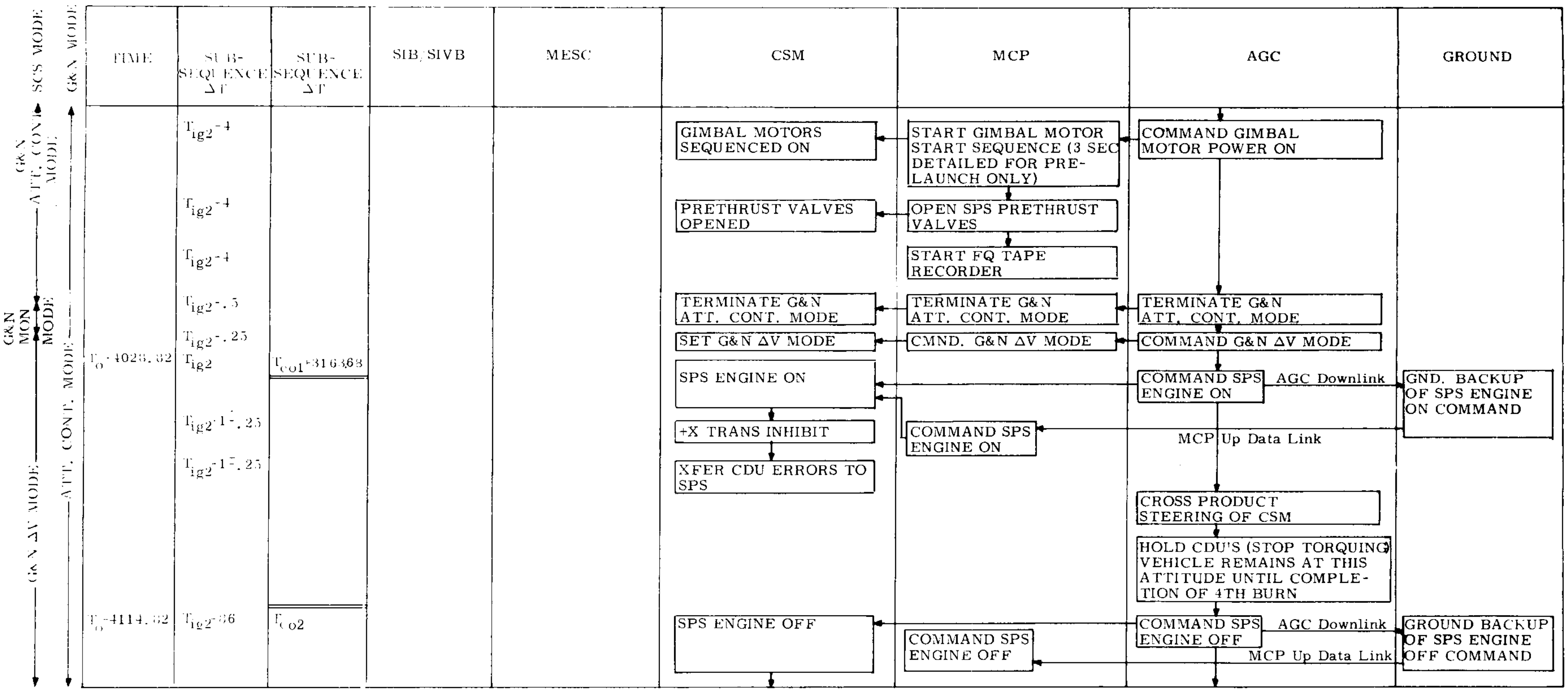
SCS MODE ← G&N ATT. CONT. MODE →

G&N MODE ← ATT. CONT. MODE →

TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
					2ND SPS BURN			
$T_o+2902.34$		$T_{col}+2036.86$					STOP LOCAL VERTICAL MODE AT $T_{col}+2037.2$ sec.	
$T_o+2902.34$							AGC CALCULATES (A) VEHICLE POSITION AND VELOCITY FOR 2ND BURN IGNITION (B) VEHICLE ATTITUDE REQUIRED FOR 2ND BURN IGNITION (C) COMMAND S/C MANEUVER TO THIS ATTITUDE	
T_o+3640								TRACKING ACQ. BY CARNARVON AUST. LAT. 24°52'00"S LONG. 113°38'00" E
	Completed at least by $T_{ig2}-50$						R. V. T. UPDATE ← AGC Uplink; AGC Downlink →	TRANSMIT R. V. T. AGC UPDATE
							BASED ON ELAPSED TIME FROM 1ST SPS BURN CUT-OFF AGC STARTS 2ND SPS BURN SEQUENCE	
$T_o-3998.82$	$T_{ig2}-30$	$T_{col}+3133.68$			+X TRANS. ON	COMMAND +X TRANS.	COMMAND +X TRANS.	

SCS MODE ← G&N ATT. CONT. MODE →

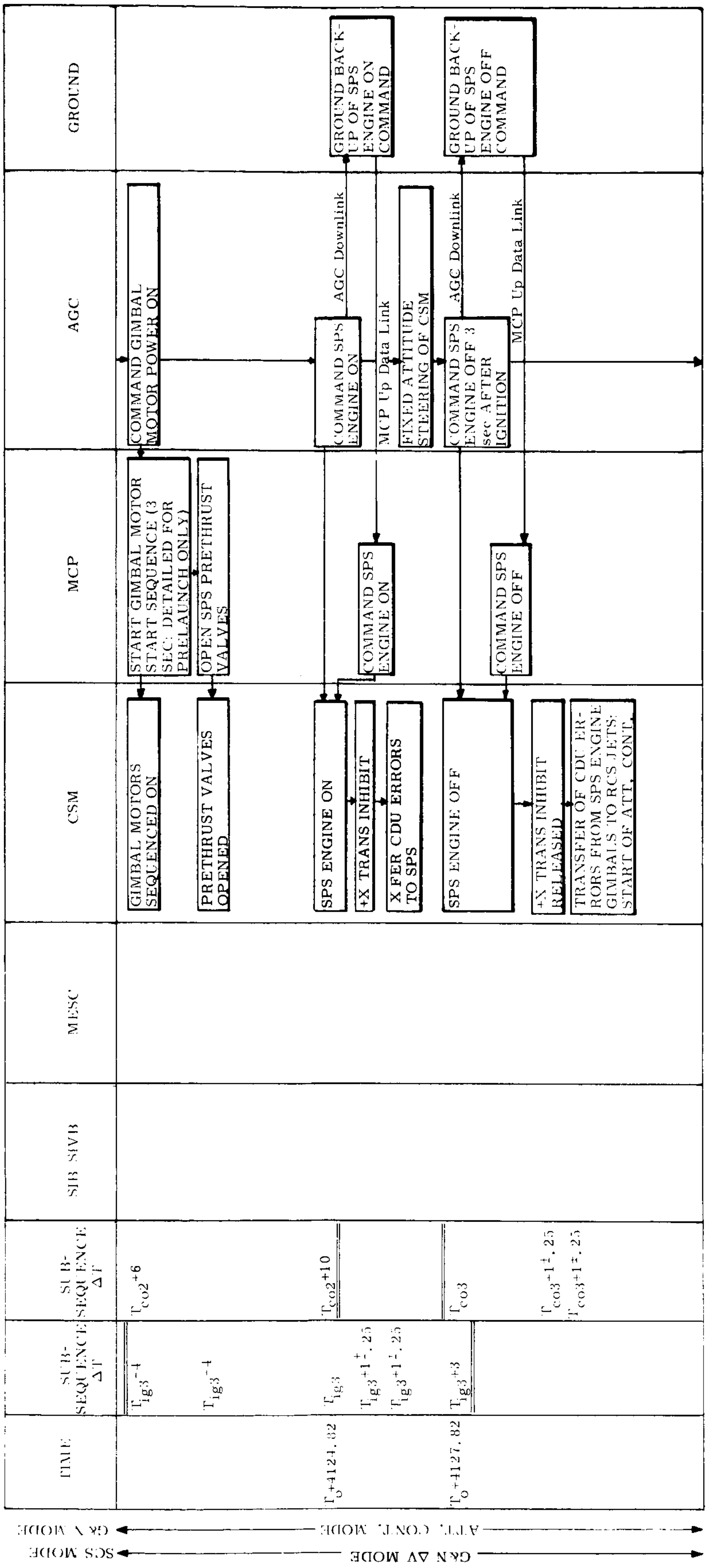
G&N MODE ← ATT. CONT. MODE →

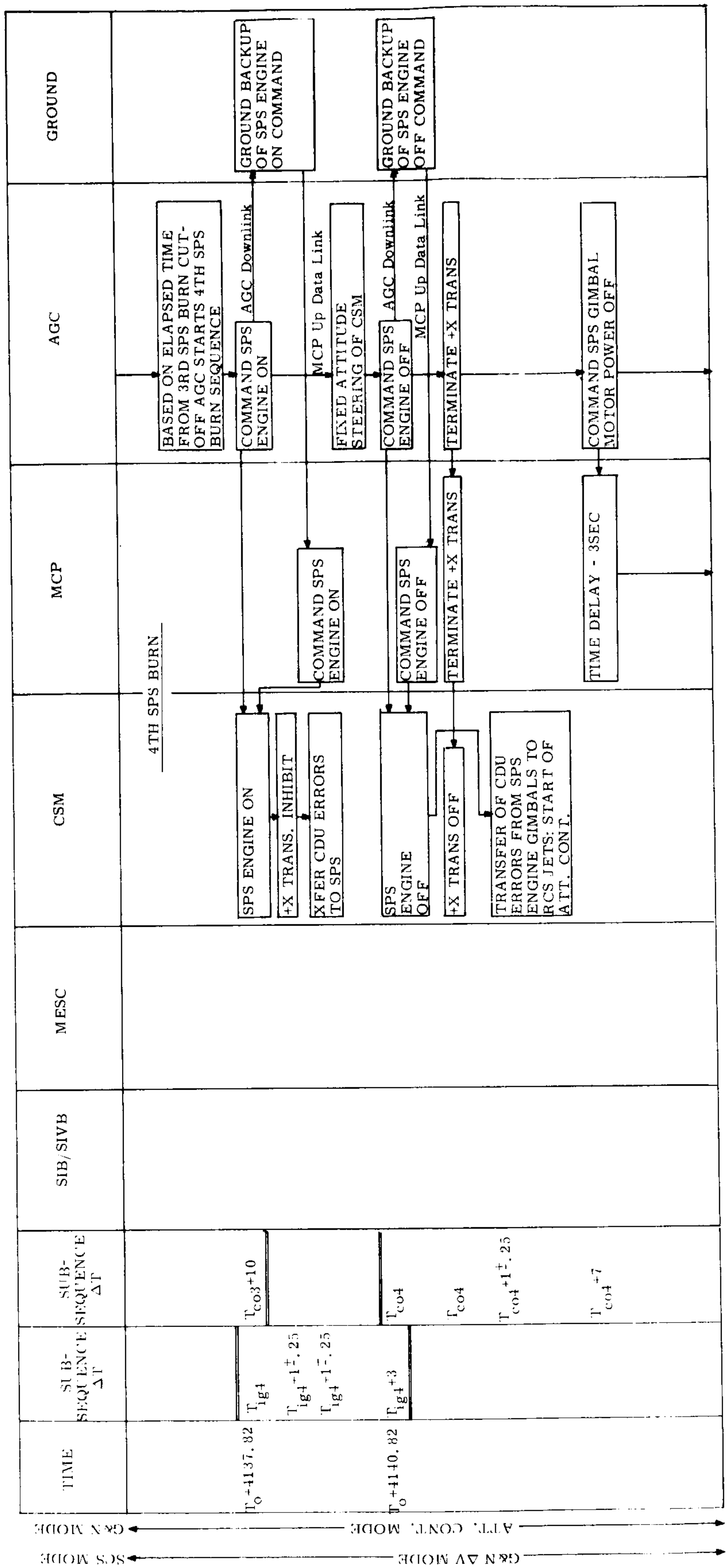

TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
T_{ig2}-4
T_{ig2}-4
T_{ig2}-4
T_{ig2}-.5
T_{ig2}-.25
T_{o}+4028.82
T_{ig2}
T_{co1}+316368
T_{ig2}+1+.25
T_{ig2}+1+.25
T_{o}+4114.82
T_{ig2}+86
T_{co2}
GIMBAL MOTORS SEQUENCED ON
START GIMBAL MOTOR START SEQUENCE (3 SEC DETAILED FOR PRE-LAUNCH ONLY)
COMMAND GIMBAL MOTOR POWER ON
PRETHRUST VALVES OPENED
OPEN SPS PRETHRUST VALVES
START FQ TAPE RECORDER
TERMINATE G&N ATT. CONT. MODE
TERMINATE G&N ATT. CONT. MODE
TERMINATE G&N ATT. CONT. MODE
SET G&N ΔV MODE
CMND. G&N ΔV MODE
COMMAND G&N ΔV MODE
SPS ENGINE ON
COMMAND SPS ENGINE ON
AGC Downlink
GND. BACKUP OF SPS ENGINE ON COMMAND
+X TRANS INHIBIT
COMMAND SPS ENGINE ON
MCP Up Data Link
XFER CDU ERRORS TO SPS
CROSS PRODUCT STEERING OF CSM
HOLD CDU'S (STOP TORQUING) VEHICLE REMAINS AT THIS ATTITUDE UNTIL COMPLETION OF 4TH BURN
SPS ENGINE OFF
COMMAND SPS ENGINE OFF
AGC Downlink
GROUND BACKUP OF SPS ENGINE OFF COMMAND
COMMAND SPS ENGINE OFF
MCP Up Data Link
G&N MODE
ATT. CONT. MODE
SCS MODE
G&N ATT. CONT. MODE
G&N MON MODE
G&N ΔV MODE

SCS MODE ← G&N ΔV MODE →

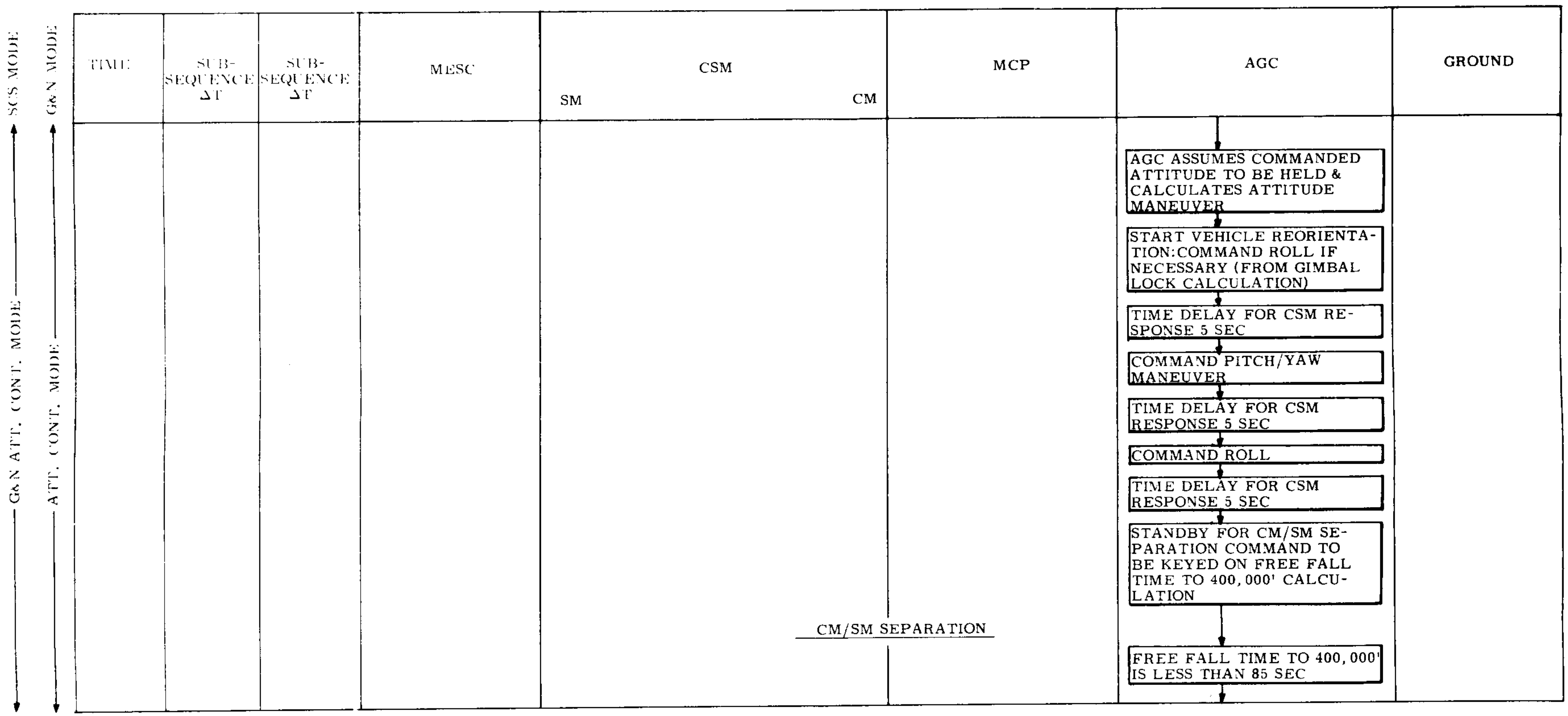
G&N MODE ← ATT. CONT. MODE →

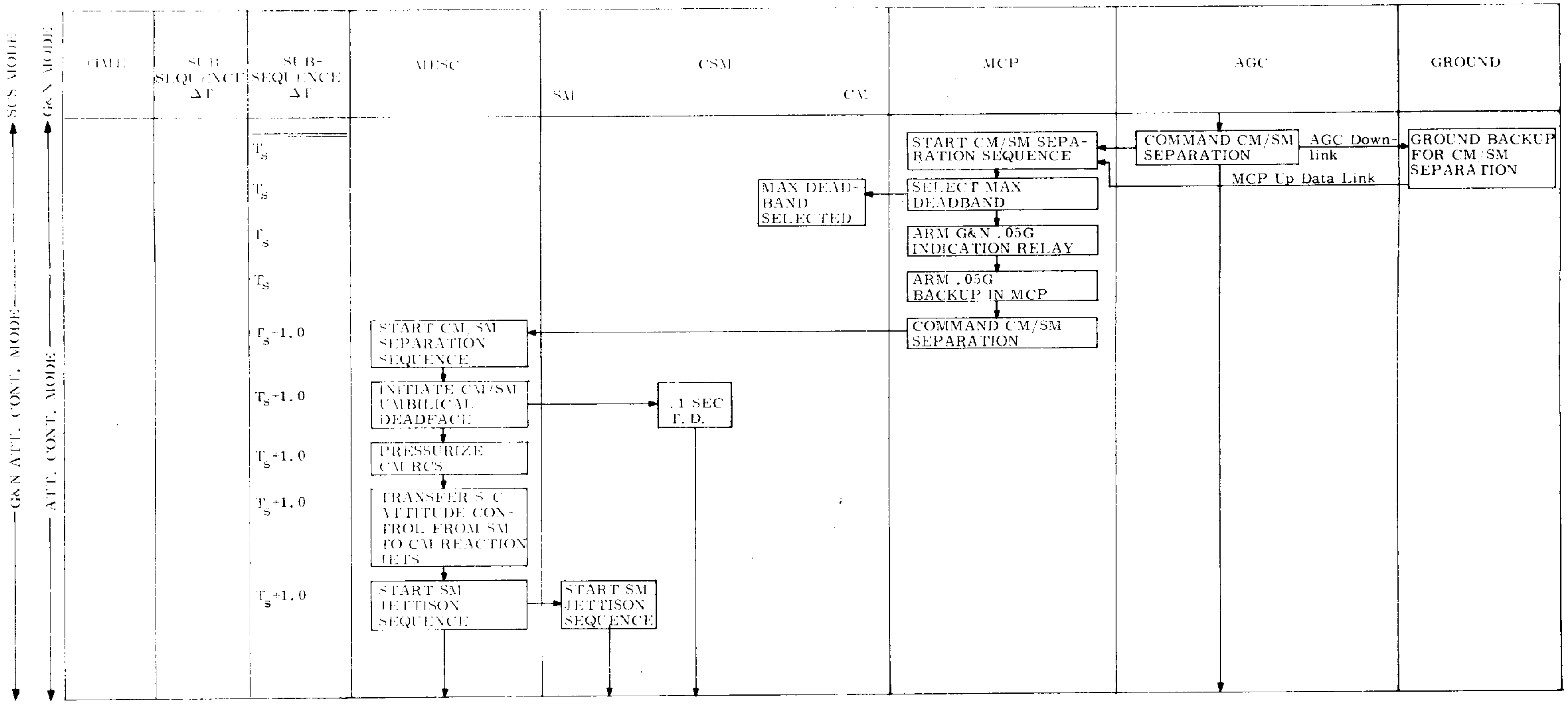
TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		$T_{co2}-.75$					SUBTRACT THE DIFFERENCE BETWEEN THE #2 AND #3 PITCH AND YAW GIMBAL MOTOR TRIM ANGLES FROM CDU'S TO ENSURE CONSTANT CSM ATTITUDE	
		$T_{co2}-1\pm.25$			RELEASE +X TRANS INHIBIT			
		$T_{co2}+1\pm.25$			TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS: START OF ATT. CONT.			
		$T_{co2}+2$				TIME DELAY - 3 SEC	COMMAND GIMBAL MOTOR POWER OFF	
		$T_{co2}+5$			GIMBAL MOTOR POWER OFF	COMMAND GIMBAL MOTOR PWR. OFF		
		$T_{co2}+5$			GIMBALS TO TRIM POSITION #3	SELECT GIMBAL TRIM POSITION #3		
		$T_{co2}+5$			PRETHRUST VALVES CLOSED	CLOSE SPS PRETHRUST VALVES		
					3RD SPS BURN		BASED ON ELAPSED TIME FROM 2ND SPS BURN CUT-OFF AGC STARTS 3RD SPS BURN SEQUENCE	


TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
SIB SIVB
MESC
CSM
MCP
AGC
GROUND
COMMAND GIMBAL MOTOR POWER ON
START GIMBAL MOTOR START SEQUENCE (3 SEC; DETAILED FOR PRELAUNCH ONLY)
OPEN SPS PRETHRUST VALVES
GIMBAL MOTORS SEQUENCED ON
PRETHRUST VALVES OPENED
COMMAND SPS ENGINE ON
AGC Downlink
GROUND BACK-UP OF SPS ENGINE ON COMMAND
MCP Up Data Link
COMMAND SPS ENGINE ON
SPS ENGINE ON
+X TRANS INHIBIT
X FER CDU ERRORS TO SPS
FIXED ATTITUDE STEERING OF CSM
COMMAND SPS ENGINE OFF 3 sec AFTER IGNITION
AGC Downlink
GROUND BACK-UP OF SPS ENGINE OFF COMMAND
MCP Up Data Link
COMMAND SPS ENGINE OFF
SPS ENGINE OFF
+X TRANS INHIBIT RELEASED
TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS; START OF ATT. CONT.
T_o+4124.82
T_o+4127.82
T_ig3-4
T_ig3-4
T_ig3
T_ig3+1±.25
T_ig3+1±.25
T_ig3+3
T_co2+6
T_co2+10
T_co3
T_co3+1±.25
T_co3+1±.25
G&N MODE
ATT. CONT. MODE
SCS MODE
G&N ΔV MODE

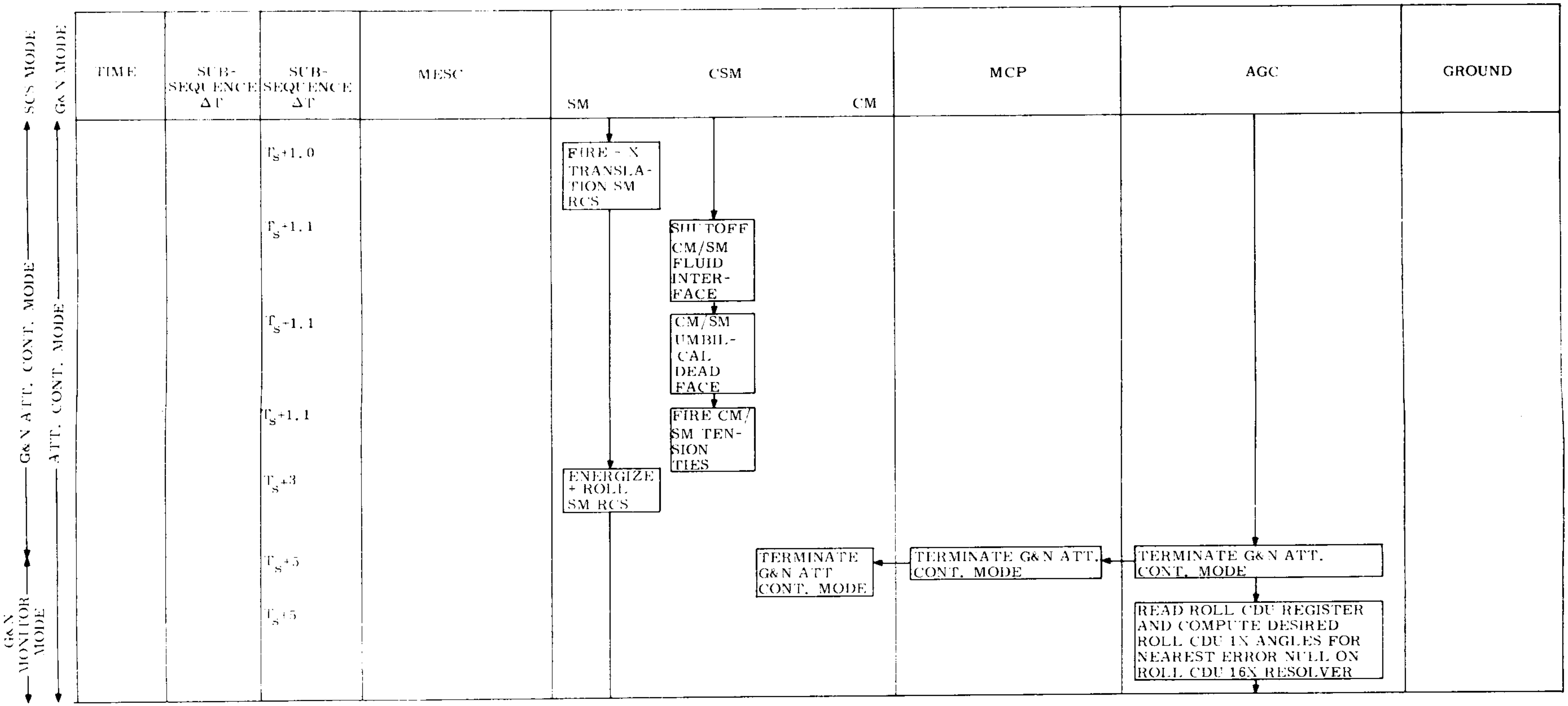

GROUND
AGC
MCP
CSM
MESC
SIB/SIVB
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
TIME
4TH SPS BURN
BASED ON ELAPSED TIME FROM 3RD SPS BURN CUT-OFF AGC STARTS 4TH SPS BURN SEQUENCE
COMMAND SPS ENGINE ON
AGC Downlink
GROUND BACKUP OF SPS ENGINE ON COMMAND
MCP Up Data Link
FIXED ATTITUDE STEERING OF CSM
COMMAND SPS ENGINE OFF
AGC Downlink
GROUND BACKUP OF SPS ENGINE OFF COMMAND
MCP Up Data Link
TERMINATE +X TRANS
COMMAND SPS GIMBAL MOTOR POWER OFF
COMMAND SPS ENGINE ON
COMMAND SPS ENGINE OFF
TERMINATE +X TRANS
TIME DELAY - 3SEC
SPS ENGINE ON
+X TRANS. INHIBIT
XFER CDU ERRORS TO SPS
SPS ENGINE OFF
+X TRANS OFF
TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS; START OF ATT. CONT.
T_co3+10
T_co4
T_co4
T_co4+1±.25
T_co4+7
T_ig4
T_ig4-1±.25
T_ig4+1±.25
T_ig4+3
T_o+4137.82
T_o+4140.82
G&N MODE
ATT. CONT. MODE
SCS MODE
G&N ΔV MODE

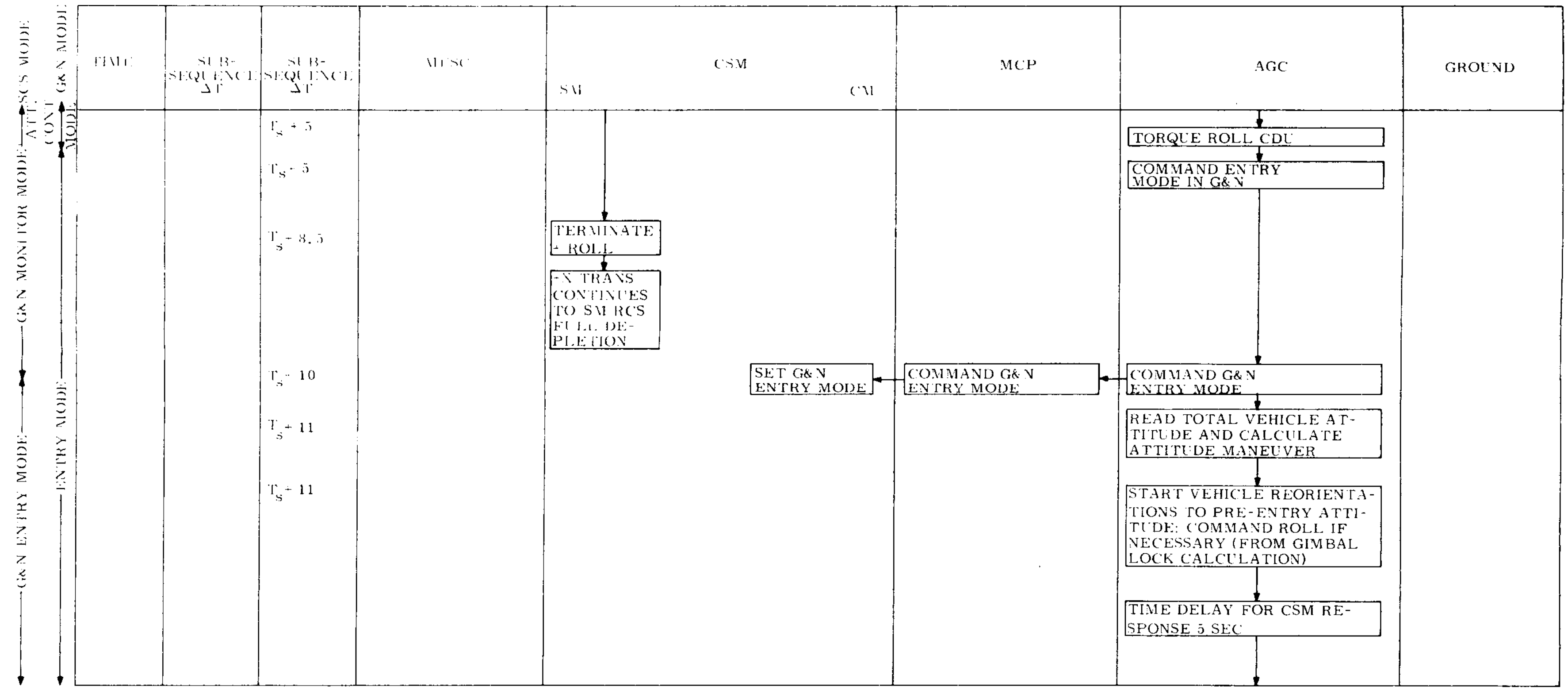
SCS MODE	G&N MODE	TIME	SUB-SEQUENCE ΔT	SUB-SEQUENCE ΔT	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
G&N ΔV MODE	ATT. CONT. MODE			$T_{co4}+10$			SPS GIMBAL MOTOR POWER OFF	COMMAND SPS GIMBAL MOTOR POWER OFF		
				$T_{co4}+10$			PRETHRUST VALVES CLOSED	CLOSE SPS PRETHRUST VALVES		
G&N MON MODE				$T_{co4}+10.50$			TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	
G&N ATT. CONT. MODE				$T_{co4}+10.75$			SET G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE	
									HOLD ATTITUDE UNTIL FREE FALL INTERRUPT	
		T_o+4040								TRACKING ACQUIRED BY TRACKING SHIP #2, LAT. 7.5°S LONG. 132.0°E
		T_o+4160								TRACKING LOST BY CARNARVON AUST
							CM/SM SEPARATION ORIENTATION	CM/SM SEPARATION ORIENTATION	FREE FALL TIME TO 400,000 FT. IS LESS THAN 160 SEC	
									INTERRUPT PROGRAMS IN PROCESS AND RESET SYSTEM. RESET ALL MODES AND COMMAND ATTITUDE CONTROL MODE IN G&N (REDUNDANT) AND G&N ATT. CONT. MODE IN SCS (REDUNDANT)	

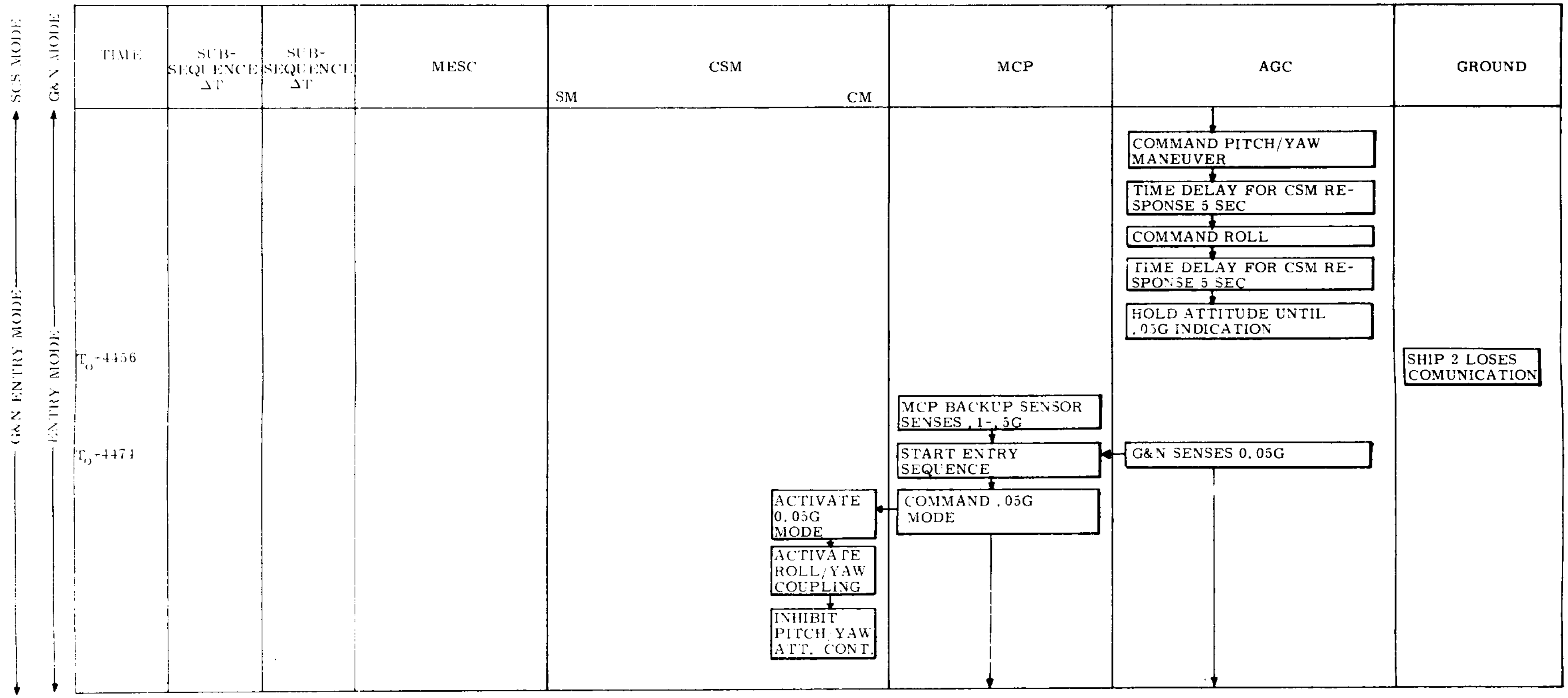

SCS MODE
G&N ATT. CONT. MODE
G&N MODE
ATT. CONT. MODE
TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
MESC
CSM
SM
CM
MCP
AGC
GROUND
AGC ASSUMES COMMANDED ATTITUDE TO BE HELD & CALCULATES ATTITUDE MANEUVER
START VEHICLE REORIENTATION:COMMAND ROLL IF NECESSARY (FROM GIMBAL LOCK CALCULATION)
TIME DELAY FOR CSM RESPONSE 5 SEC
COMMAND PITCH/YAW MANEUVER
TIME DELAY FOR CSM RESPONSE 5 SEC
COMMAND ROLL
TIME DELAY FOR CSM RESPONSE 5 SEC
STANDBY FOR CM/SM SEPARATION COMMAND TO BE KEYED ON FREE FALL TIME TO 400,000' CALCULATION
CM/SM SEPARATION
FREE FALL TIME TO 400,000' IS LESS THAN 85 SEC



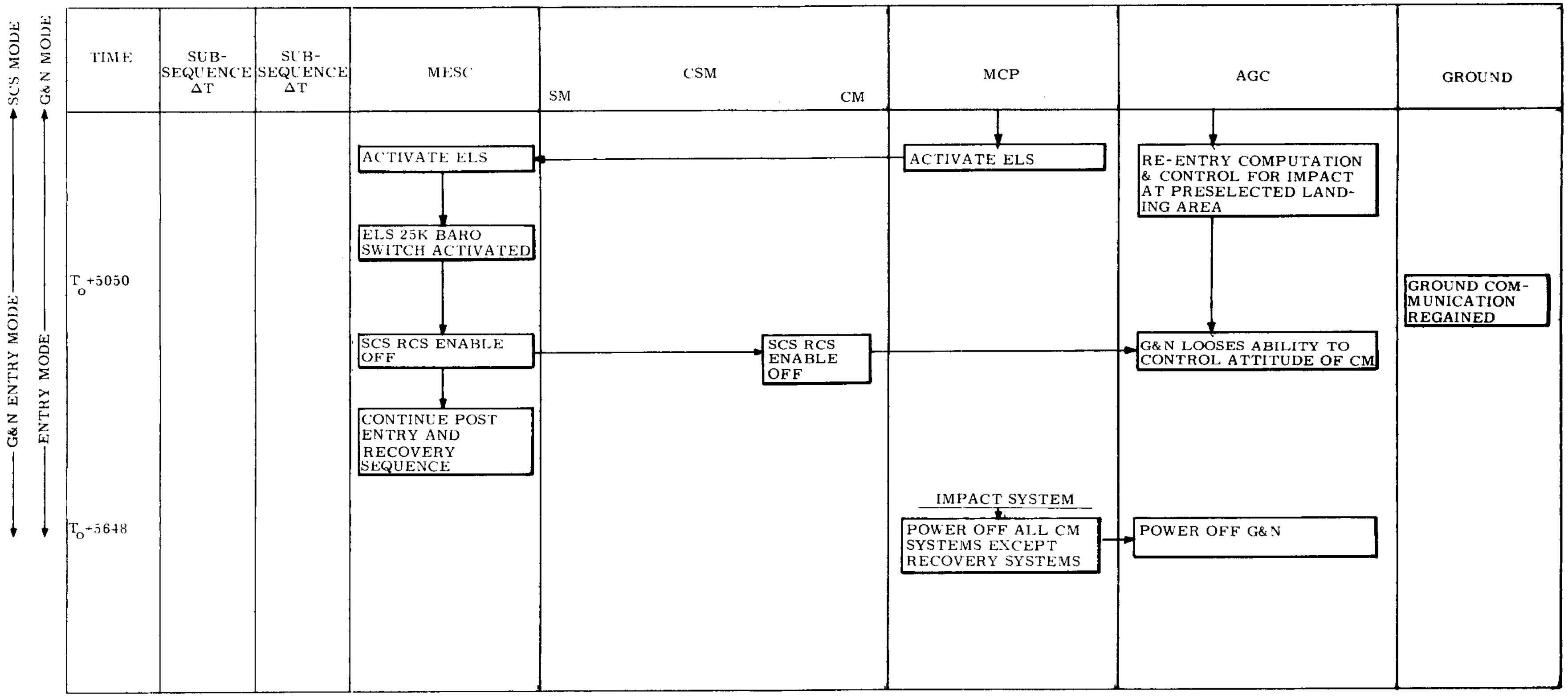
TIME
SUB SEQUENCE ΔT
SUB-SEQUENCE ΔT
MESC
CSM
SM
CM
MCP
AGC
GROUND
START CM/SM SEPARATION SEQUENCE
SELECT MAX DEADBAND
ARM G&N .05G INDICATION RELAY
ARM .05G BACKUP IN MCP
COMMAND CM/SM SEPARATION
COMMAND CM/SM SEPARATION
AGC Down-link
MCP Up Data Link
GROUND BACKUP FOR CM/SM SEPARATION
MAX DEAD-BAND SELECTED
START CM/SM SEPARATION SEQUENCE
INITIATE CM/SM UMBILICAL DEADFACE
PRESSURIZE CM RCS
TRANSFER S/C ATTITUDE CONTROL FROM SM TO CM REACTION JETS
START SM JETTISON SEQUENCE
START SM JETTISON SEQUENCE
.1 SEC T. D.
T_s
T_s
T_s
T_s
$T_s-1.0$
$T_s+1.0$
$T_s+1.0$
$T_s+1.0$
$T_s+1.0$
SCS MODE
G&N ATT. CONT. MODE
G&N MODE
ATT. CONT. MODE


TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
MESC
CSM
SM
CM
MCP
AGC
GROUND
Ts+1.0
Ts+1.1
Ts+1.1
Ts+1.1
Ts+3
Ts+5
Ts+5
FIRE - X TRANSLATION SM RCS
SHUTOFF CM/SM FLUID INTERFACE
CM/SM UMBILICAL DEAD FACE
FIRE CM/SM TENSION TIES
ENERGIZE + ROLL SM RCS
TERMINATE G&N ATT CONT. MODE
TERMINATE G&N ATT. CONT. MODE
TERMINATE G&N ATT. CONT. MODE
READ ROLL CDU REGISTER AND COMPUTE DESIRED ROLL CDU 1X ANGLES FOR NEAREST ERROR NULL ON ROLL CDU 16X RESOLVER
SCS MODE
G&N ATT. CONT. MODE
G&N MONITOR MODE
G&N MODE
ATT. CONT. MODE


TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
MLSC
CSM
SM
CM
MCP
AGC
GROUND
$T_s + 5$
$T_s + 5$
$T_s + 8.5$
$T_s + 10$
$T_s + 11$
$T_s + 11$
TORQUE ROLL CDU
COMMAND ENTRY MODE IN G&N
TERMINATE + ROLL
-N TRANS CONTINUES TO SM RCS FULL DE-PLETION
SET G&N ENTRY MODE
COMMAND G&N ENTRY MODE
COMMAND G&N ENTRY MODE
READ TOTAL VEHICLE AT-TITUDE AND CALCULATE ATTITUDE MANEUVER
START VEHICLE REORIENTA-TIONS TO PRE-ENTRY ATTI-TUDE: COMMAND ROLL IF NECESSARY (FROM GIMBAL LOCK CALCULATION)
TIME DELAY FOR CSM RE-SPONSE 5 SEC
SCS MODE
ATT. CONT MODE
G&N MONITOR MODE
G&N ENTRY MODE
G&N MODE
ENTRY MODE



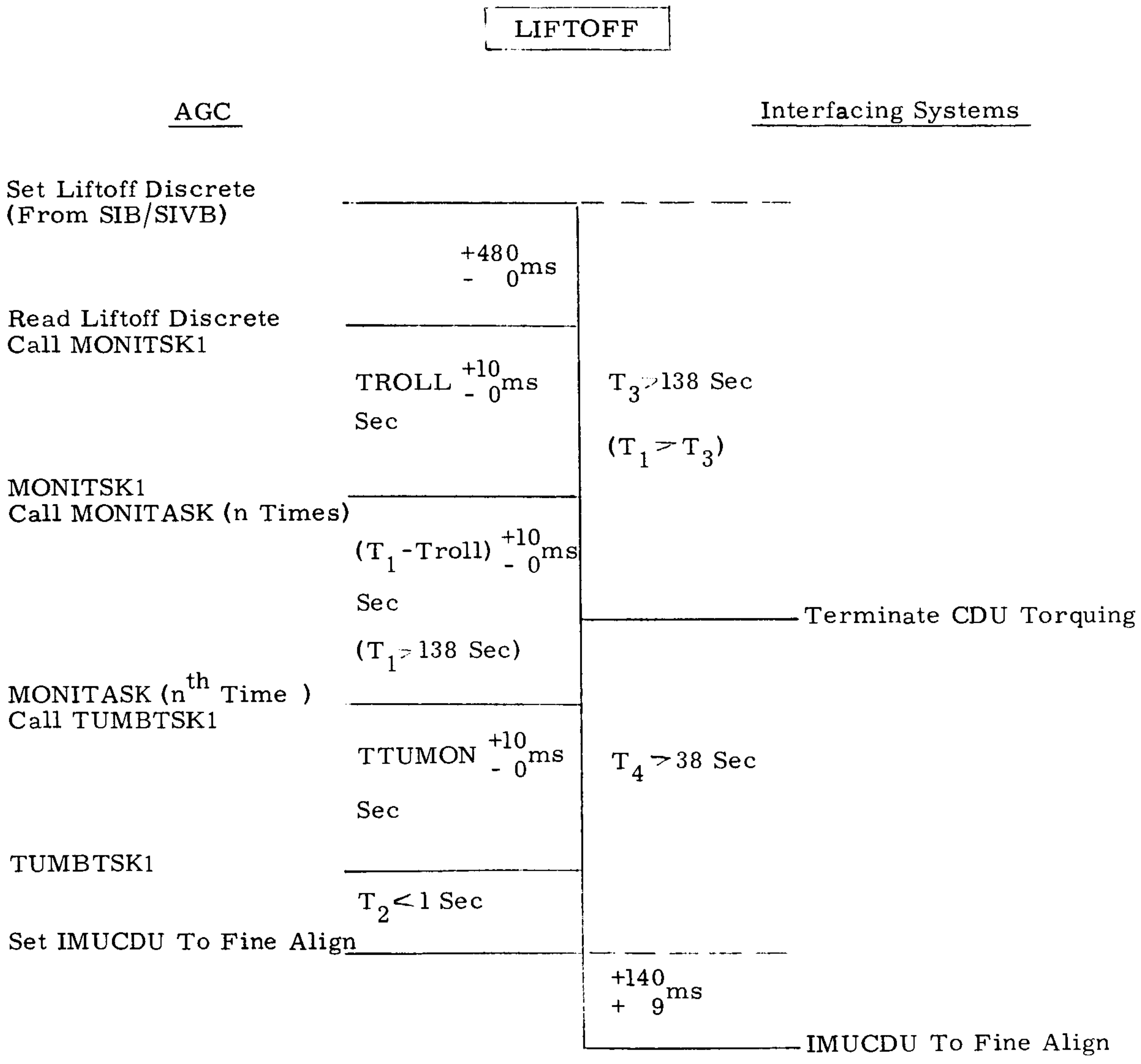
TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
MESC
CSM
SM
CM
MCP
AGC
GROUND
COMMAND PITCH/YAW MANEUVER
TIME DELAY FOR CSM RE-SPONSE 5 SEC
COMMAND ROLL
TIME DELAY FOR CSM RE-SPONSE 5 SEC
HOLD ATTITUDE UNTIL .05G INDICATION
SHIP 2 LOSES COMUNICATION
MCP BACKUP SENSOR SENSES .1-.5G
START ENTRY SEQUENCE
G&N SENSES 0.05G
COMMAND .05G MODE
ACTIVATE 0.05G MODE
ACTIVATE ROLL/YAW COUPLING
INHIBIT PITCH YAW ATT. CONT.
T0-4456
T0-4471
SCS MODE
G&N ENTRY MODE
G&N MODE
ENTRY MODE

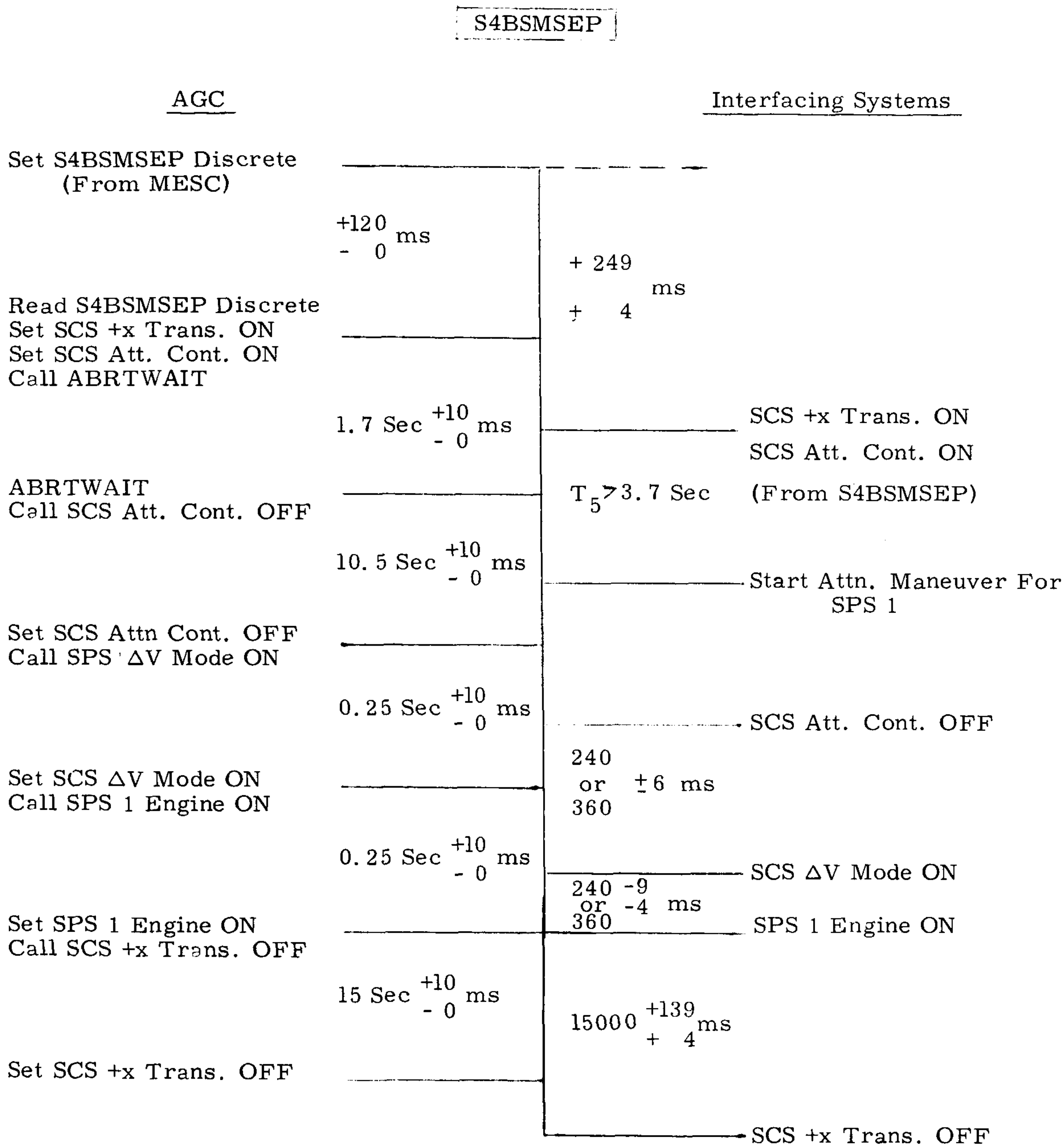


SCS MODE
G&N MODE
G&N ENTRY MODE
ENTRY MODE
TIME
SUB-SEQUENCE ΔT
SUB-SEQUENCE ΔT
MESC
CSM
SM
CM
MCP
AGC
GROUND
T0+5050
T0+5648
ACTIVATE ELS
ELS 25K BARO SWITCH ACTIVATED
SCS RCS ENABLE OFF
CONTINUE POST ENTRY AND RECOVERY SEQUENCE
SCS RCS ENABLE OFF
ACTIVATE ELS
IMPACT SYSTEM
POWER OFF ALL CM SYSTEMS EXCEPT RECOVERY SYSTEMS
RE-ENTRY COMPUTATION & CONTROL FOR IMPACT AT PRESELECTED LANDING AREA
G&N LOOSES ABILITY TO CONTROL ATTITUDE OF CM
POWER OFF G&N
GROUND COMMUNICATION REGAINED

2.2 Timing Tolerances:

Tolerances on the sequential timing of discrete events are listed below. Certain of these may change if the AGC program changes. The times are to receipt of the signal by the interfacing system (usually the DSKY), and are quoted from the preceding event unless otherwise noted. Times T_1-T_7 are not, as yet, specified as they are especially program dependent and difficult to predict.



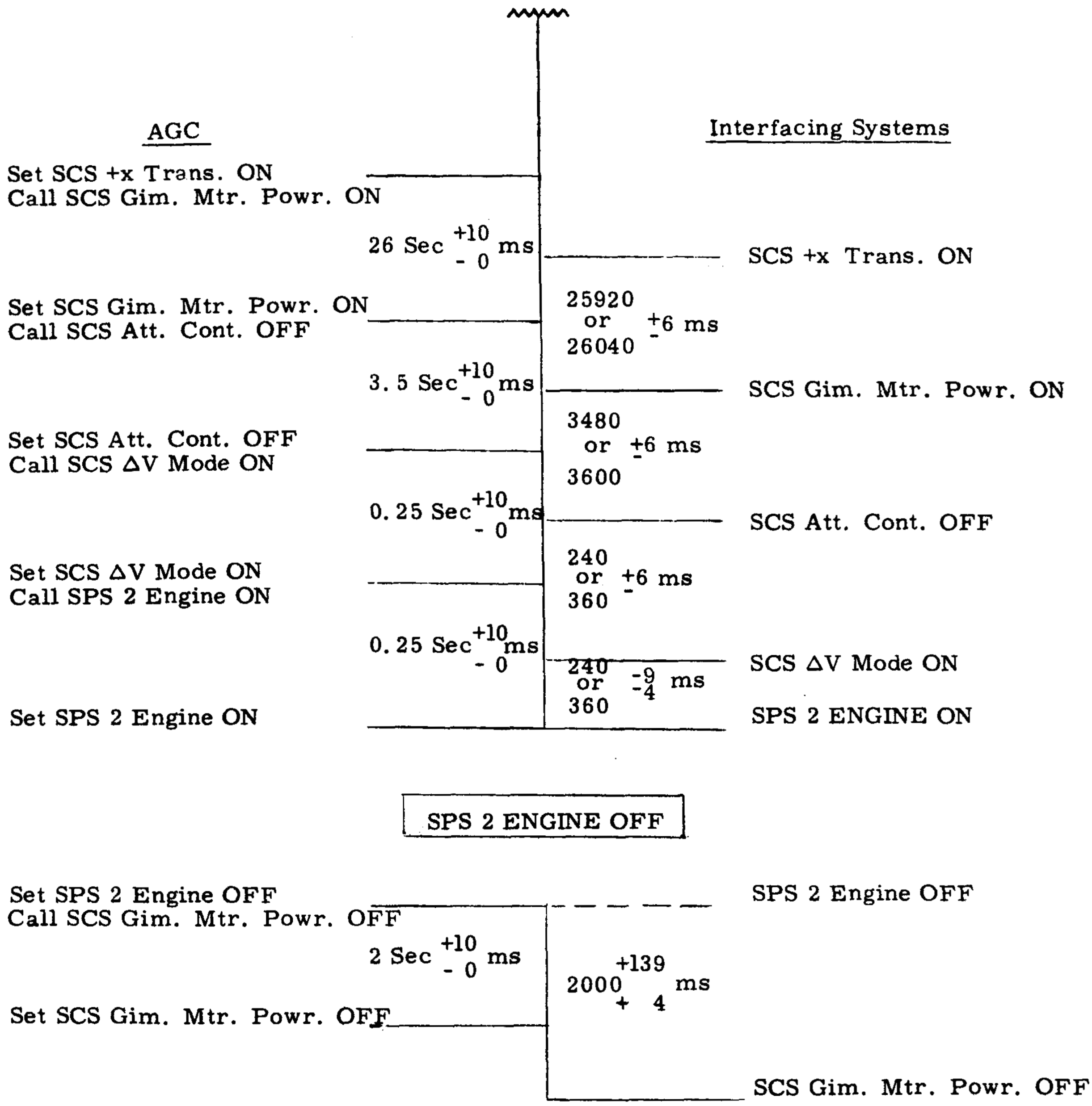

S4BSMSEP
AGC
Interfacing Systems
Set S4BSMSEP Discrete
(From MESC)
+120 ms
- 0
+ 249 ms
+ 4
Read S4BSMSEP Discrete
Set SCS +x Trans. ON
Set SCS Att. Cont. ON
Call ABRTWAIT
1.7 Sec +10 ms
- 0
SCS +x Trans. ON
SCS Att. Cont. ON
ABRTWAIT
Call SCS Att. Cont. OFF
T5 > 3.7 Sec
(From S4BSMSEP)
10.5 Sec +10 ms
- 0
Start Attn. Maneuver For SPS 1
Set SCS Attn Cont. OFF
Call SPS ΔV Mode ON
0.25 Sec +10 ms
- 0
SCS Att. Cont. OFF
240 or 360 ±6 ms
Set SCS ΔV Mode ON
Call SPS 1 Engine ON
0.25 Sec +10 ms
- 0
SCS ΔV Mode ON
240 or 360 -9 -4 ms
Set SPS 1 Engine ON
Call SCS +x Trans. OFF
SPS 1 Engine ON
15 Sec +10 ms
- 0
15000 +139 ms
+ 4
Set SCS +x Trans. OFF
SCS +x Trans. OFF

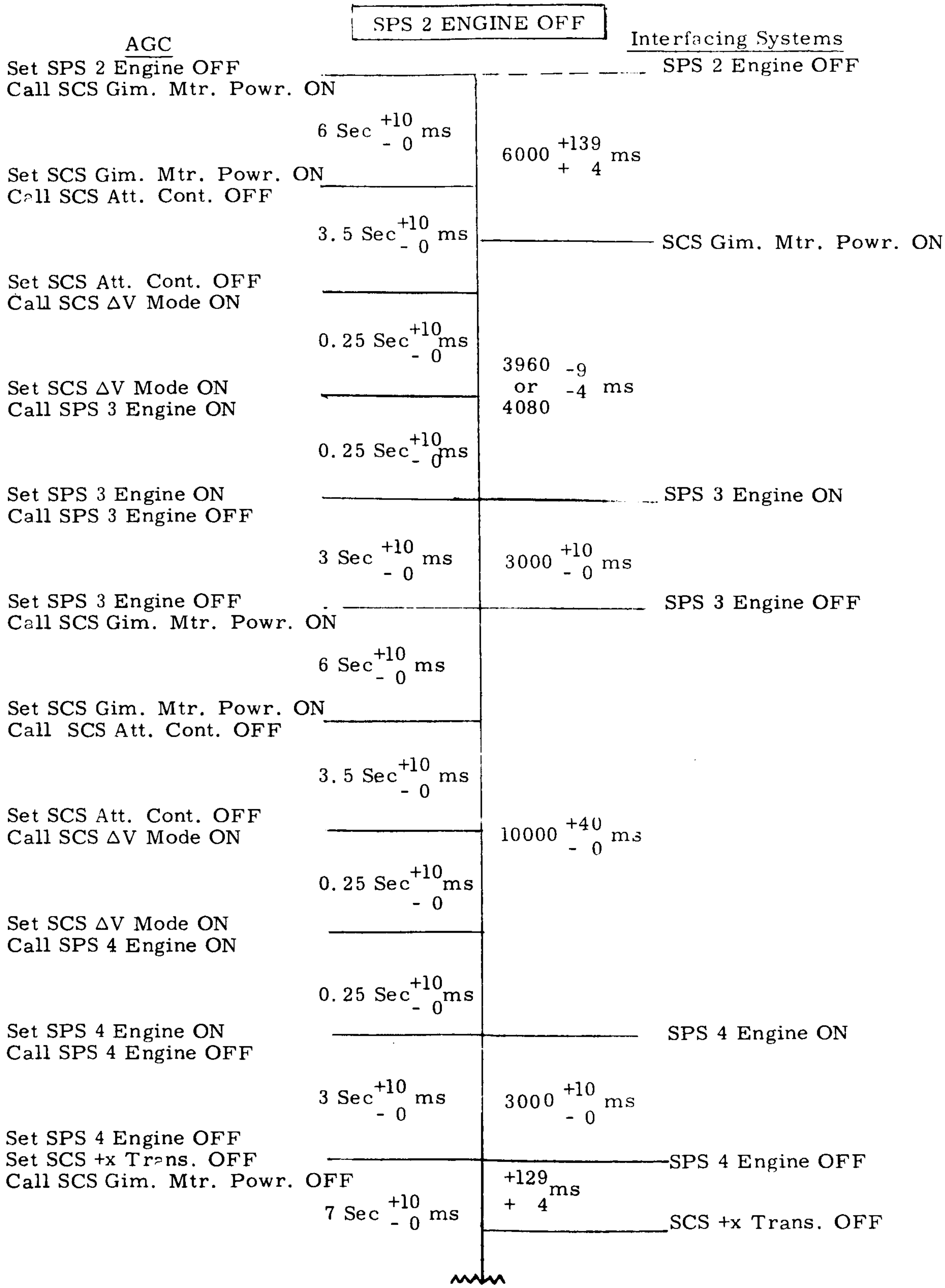
SPS 1 ENGINE OFF

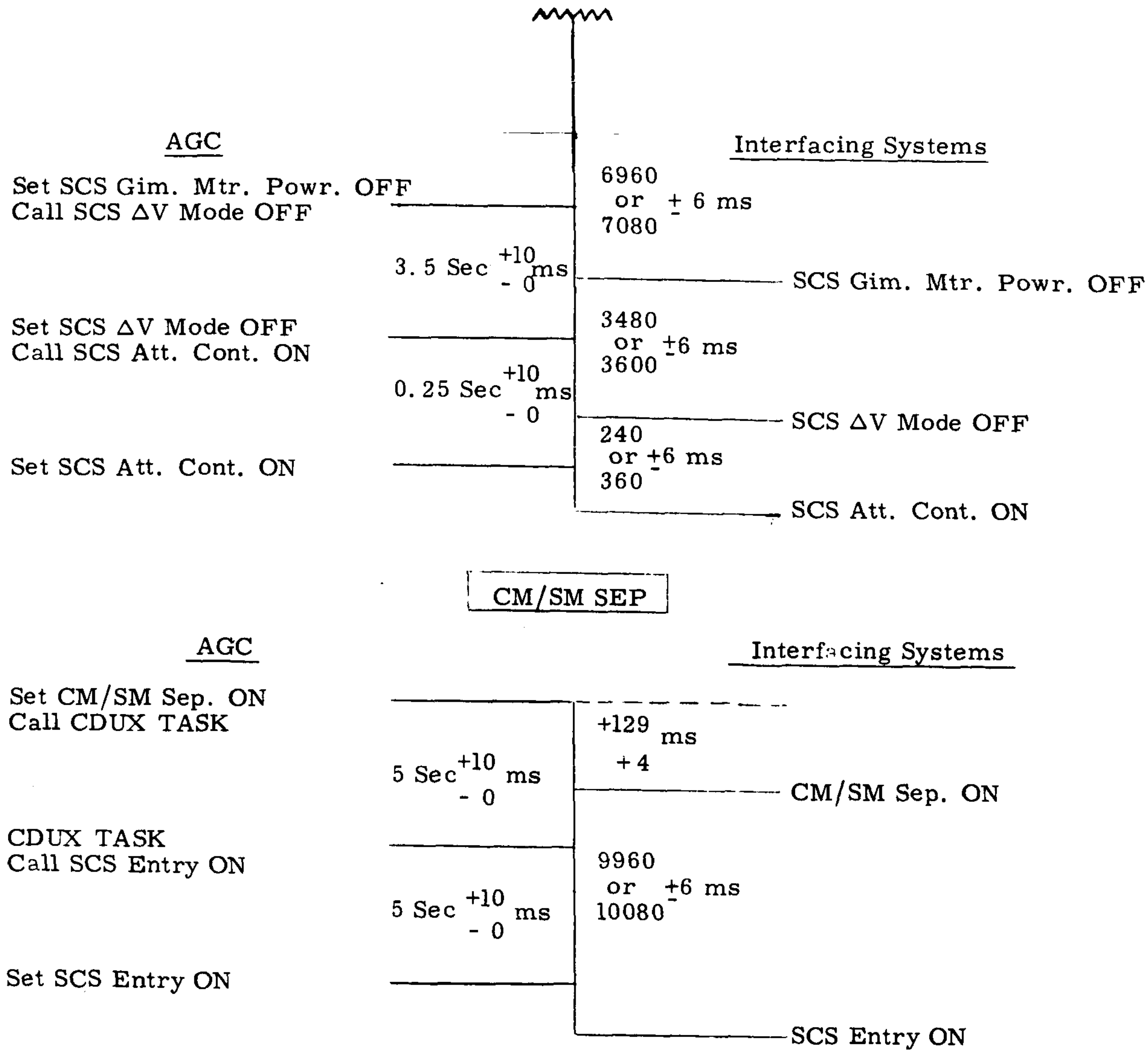
AGC			Interfacing Systems
Set SPS 1 Engine OFF Call SCS Gim. Mtr. Powr. OFF			SPS 1 Engine OFF
	7 Sec $^{+10}_{-0}$ ms	7000 $^{+139}_{+4}$ ms	
Set SCS Gim. Mtr. Powr. OFF Call SCS ΔV Mode OFF			
	3. 5 Sec $^{+10}_{-0}$ ms		SCS Gim. Mtr. Powr. OFF
Set SCS ΔV Mode OFF Call SCS Att. Cont. ON		3480 or 3600 ± 6 ms	
	0. 25 Sec $^{+10}_{-0}$ ms		SCS ΔV Mode OFF
Set SCS Att. Cont. ON		240 or 360 ± 6 ms	
			SCS Att. Cont. ON

SPS 1 ENGINE OFF

AGC			Interfacing Systems
Set SPS 1 Engine OFF Call COASTPHS			SPS 1 Engine OFF
	10 Sec $^{+10}_{-0}$ ms	$T_6 > 10$ Sec	
COASTPHS Call FDA I Align ON			
	290 Sec $^{+10}_{-0}$ ms		Start Att. Maneuver to Vertical
Set FDA I Align ON Call FDA I Align OFF		300, 000 $^{+149}_{+4}$ ms(From SPS 1 Engine OFF)	
	10 Sec $^{+10}_{-0}$ ms		FDA I Align ON
Set FDA I Align OFF Call Uptask		9960 or 10080 ± 6 ms	
	Tcoast Sec $^{+10}_{-0}$ ms		FDA I Align OFF
Uptask Call SCS +x Trans. ON			
	20 Sec $^{+10}_{-0}$ ms	f (TCOAST + 20 Sec) ± 6 ms	


AGC
Interfacing Systems
Set SCS +x Trans. ON
Call SCS Gim. Mtr. Powr. ON
26 Sec +10 - 0 ms
SCS +x Trans. ON
Set SCS Gim. Mtr. Powr. ON
Call SCS Att. Cont. OFF
25920 or 26040 ±6 ms
3.5 Sec +10 - 0 ms
SCS Gim. Mtr. Powr. ON
Set SCS Att. Cont. OFF
Call SCS ΔV Mode ON
3480 or 3600 ±6 ms
0.25 Sec +10 - 0 ms
SCS Att. Cont. OFF
Set SCS ΔV Mode ON
Call SPS 2 Engine ON
240 or 360 ±6 ms
0.25 Sec +10 - 0 ms
SCS ΔV Mode ON
240 or 360 -9 -4 ms
Set SPS 2 Engine ON
SPS 2 ENGINE ON
SPS 2 ENGINE OFF
Set SPS 2 Engine OFF
Call SCS Gim. Mtr. Powr. OFF
SPS 2 Engine OFF
2 Sec +10 - 0 ms
2000 +139 + 4 ms
Set SCS Gim. Mtr. Powr. OFF
SCS Gim. Mtr. Powr. OFF


SPS 2 ENGINE OFF
AGC
Interfacing Systems
Set SPS 2 Engine OFF
Call SCS Gim. Mtr. Powr. ON
SPS 2 Engine OFF
6 Sec +10 - 0 ms
6000 +139 + 4 ms
Set SCS Gim. Mtr. Powr. ON
Call SCS Att. Cont. OFF
3.5 Sec +10 - 0 ms
SCS Gim. Mtr. Powr. ON
Set SCS Att. Cont. OFF
Call SCS ΔV Mode ON
0.25 Sec +10 - 0 ms
3960 or 4080 -9 -4 ms
Set SCS ΔV Mode ON
Call SPS 3 Engine ON
0.25 Sec +10 - 0 ms
Set SPS 3 Engine ON
Call SPS 3 Engine OFF
SPS 3 Engine ON
3 Sec +10 - 0 ms
3000 +10 - 0 ms
Set SPS 3 Engine OFF
Call SCS Gim. Mtr. Powr. ON
SPS 3 Engine OFF
6 Sec +10 - 0 ms
Set SCS Gim. Mtr. Powr. ON
Call SCS Att. Cont. OFF
3.5 Sec +10 - 0 ms
Set SCS Att. Cont. OFF
Call SCS ΔV Mode ON
10000 +40 - 0 ms
0.25 Sec +10 - 0 ms
Set SCS ΔV Mode ON
Call SPS 4 Engine ON
0.25 Sec +10 - 0 ms
Set SPS 4 Engine ON
Call SPS 4 Engine OFF
SPS 4 Engine ON
3 Sec +10 - 0 ms
3000 +10 - 0 ms
Set SPS 4 Engine OFF
Set SCS +x Trans. OFF
Call SCS Gim. Mtr. Powr. OFF
SPS 4 Engine OFF
+129 + 4 ms
7 Sec +10 - 0 ms
SCS +x Trans. OFF


AGC
Interfacing Systems
Set SCS Gim. Mtr. Powr. OFF
Call SCS ΔV Mode OFF
6960
or ± 6 ms
7080
3.5 Sec +10 -0 ms
SCS Gim. Mtr. Powr. OFF
Set SCS ΔV Mode OFF
Call SCS Att. Cont. ON
3480
or ±6 ms
3600
0.25 Sec +10 -0 ms
SCS ΔV Mode OFF
240
or ±6 ms
360
Set SCS Att. Cont. ON
SCS Att. Cont. ON
CM/SM SEP
AGC
Interfacing Systems
Set CM/SM Sep. ON
Call CDUX TASK
+129 +4 ms
5 Sec +10 -0 ms
CM/SM Sep. ON
CDUX TASK
Call SCS Entry ON
9960
or ±6 ms
10080
5 Sec +10 -0 ms
Set SCS Entry ON
SCS Entry ON

CM/SM SEP

AGC		Interfacing Systems
Set CM/SM Sep. ON Call CDUX TASK		$^{+129}_{+\ \ 4}$ ms
	5 Sec $^{+10}_{-\ 0}$ ms	CM/SM Sep. ON
CDUX TASK Establishing CDUX JOB		
	$T_7 > 0$ Sec	$f(T_7 + 5\ \text{Sec}) \pm 6$ ms
Set SCS Monitor (no) Mode ON (SCS Att. Cont. OFF)		
		SCS Monitor (no) Mode ON (SCS Att. Cont. OFF)

0. 05 G SENSED

AGC		Interfacing Systems
Set 0. 05 G Ind. ON		$^{+129}_{+\ \ 4}$ ms
		0. 05 G Ind. ON

3.0 G&N/SPACECRAFT PERFORMANCE ON THE ALL-DIGITAL SIMULATION

The following summary of results was taken from an all-digital simulation of a nominal SA-202 trajectory. The simulation starts at the instant of SIVB booster cut-off. The initial conditions corresponding to this time were taken from the MSC-MSFC Joint Reference Trajectory No. 65-FMP-1, dated April 12, 1965.

<table>
<tr><th>TIME FROM LIFT-OFF</th><th>ACTION</th><th>PERFORMANCE RESULT</th></tr>
<tr><td>609.96</td><td>Start of Simulation</td><td>Time corresponds to SIVB booster shut-down. Delay of 8.3 secs follows till start of SIVB/CSM Separation sequence.</td></tr>
<tr><td>618.26</td><td>Receipt of SIVB/CSM Separation Discrete</td><td>AGC will delay any action for 1.7 secs while waiting for VERB 77 Abort Command.</td></tr>
<tr><td>618.28</td><td>Command SCS G&N Att. Control Mode and TX Translation</td><td>See Note 1.</td></tr>
<tr><td>619.96</td><td>Start AGC SPS1 Thrust Attitude Computation</td><td>AGC received No. VERB77. Computes two consecutive values of required velocity for computation of SPS1 initial thrust attitude.</td></tr>
<tr><td>622.97</td><td>Command IMU to Att. Control Mode</td><td>IMU in Fine Align Mode up to this time. AGC now computes maneuver sequence.</td></tr>
<tr><td>623.50</td><td>Start of Vehicle Pitch/Yaw Maneuver.</td><td>Maneuver angle 9.85° (Includes nominal SPS1 c.g. Off-set)</td></tr>
<tr><td>630.53</td><td>Command SCS G&N Monitor Mode.</td><td>AGC removes SCS G&N Att. Control Mode Command prior to commanding ΔV Mode. (See Note 1)</td></tr>
<tr><td>630.77</td><td>Command SCS G&N ΔV Mode.</td><td>See Note 1.</td></tr>
<tr><td>630.97</td><td>Command SPS Engine On</td><td>Engine On 12.7 $^{-0.0}_{+0.1}$ Secs after SIVB/CSM Sep. discrete.
Attitude maneuver not yet complete. AGC will not issue steering commands until two consecutive required velocity values have been computed. Thrust ΔV monitoring commences.</td></tr>
<tr><td>631.00</td><td>Vehicle pitch/yaw maneuver completed (Roll maneuver inhibited for pre-SPS1).</td><td>
<table>
<tr><th></th><th>X</th><th>Y</th><th>Z</th></tr>
<tr><td>Initial euler[2] set</td><td>-179.98°</td><td>75.98°</td><td>-0.01°</td></tr>
<tr><td>Desired euler[2] set</td><td>-178.47°</td><td>83.98°</td><td>-6.97°</td></tr>
<tr><td>Final euler[2] set</td><td>-175.49°</td><td>83.99°</td><td>-10.07°</td></tr>
<tr><td>Jet - Secs</td><td>0.37</td><td>3.64</td><td>2.78</td></tr>
<tr><td>RCS Fuel used</td><td colspan="3">5.06 lbs</td></tr>
<tr><td>Maneuver Time[3]</td><td colspan="3">7.50 secs</td></tr>
</table>
</td></tr>
<tr><td>634.6</td><td>Start of Steering Commands.</td><td>AGC computes steering commands, using cross-product steering with C = 1/2.</td></tr>
<tr><td>860.6</td><td>Last Steering Update</td><td>At next velocity-to-go (Vg) computation, AGC will determine that less than 4 secs to engine-off.</td></tr>
<tr><td>864.75</td><td>Command SPS Engine OFF</td><td>Vg remaining after thrust tail-off = 0.30 ft/sec. Fuel used during SPS1 burn = 15,816 lbs.</td></tr>
<tr><td>871.85</td><td>Command SCS Gimbal Motor Power OFF</td><td>See Note 1.</td></tr>
<tr><td>875.33</td><td>Command SCS G&N Monitor Mode.</td><td>See Note 1.</td></tr>
<tr><td>875.57</td><td>Command SCS G&N Att. Control Mode.</td><td>See Note 1.</td></tr>
<tr><td>875.93</td><td>Start of Vehicle Pitch/Yaw Maneuver.</td><td>At 10.5 $^{-0.0}_{-2.0}$ Secs after SPS1 Cut-off.
AGC freezes R, V, T for orbital integration to SPS 2 ignition point.
AGC error[4] in R = 55 ft. (See Note 4).
AGC error[4] in V = 0.19 ft/sec (See Note 4).
AGC also initiates maneuver to nose-down local vertical attitude. Maneuver angle = 123.02°.</td></tr>
</table>

TIME FROM LIFT-OFF	ACTION	PERFORMANCE RESULT	X	Y	Z
911.93	Vehicle Pitch/Yaw Maneuver completed. Start of vehicle roll maneuver.	Initial euler[2] set	103.80°	87.88°	77.77°
		Desired euler[2] set	4.45°	-32.45°	-178.19°
		Final	4.10°	-32.01°	-177.92°
		Jet - Secs	0.31	5.32	0.48
		Fuel used	4.54 lbs		
		Maneuver Time[3]	36.0 secs		
917.43	Vehicle roll maneuver completed.	Initial euler[2] set	4.10°	-32.01°	-177.92°
		Desired euler[2] set	0.88°	-32.50°	179.88°
		Final euler[2] set	-0.68°	-36.35°	178.65°
		Jet - Sec	0.89	2.33	0.42
		Fuel used	3.20 lbs		
		Maneuver Time[3]	5.5 secs		
		Vehicle now in local vertical control.			
1164.77	Command FDAI Align ON				
1165.96		At this time the IMU Gimbal Angles are as follows: AOG = 179.9° AIG = 96.3° AMG = 0.8°			
1174.85	Command FDAI Align OFF				
2903.0 (approx.)	Terminate local vertical control.	Summary of local vertical phase:			
		Jet Secs	0.88	1.39	4.68
		Fuel used	4.92 lbs		
		Max. deviation	< 0.4°		
		AGC now performs orbital integration to SPS2 ignition point, and establishes initial thrust attitude. Time taken for this is approx. 40 secs.			
2944.19	Start vehicle pitch/yaw maneuver.	Maneuver angle = 5.72°			
2950.69	Vehicle maneuver completed.	Initial euler[2] set	-179.24°	-35.15°	0.09°
		Desired euler[2] set	-178.86°	-31.63°	-4.19°
		Final	-178.30°	-31.61°	-3.93°
		Jet - Sec	0.22	1.56	1.91
		Fuel used	2.77 lbs		
		Maneuver Time[3]	6.50 secs		
		AGC now in idling state till receipt of update. Vehicle holds attitude.			
3998.45	Command SCS + X Translation	No update simulated. AGC error in R = 1125 feet, V = 1.07 ft/sec (See Note 4).			
4024.49	Command SCS Gimbal Motor Power ON	(See Note 1)			
4027.97	Command SCS G&N Monitor Mode	(See Note 1)			
4028.21	Command SCS G&N ΔV Mode	(See Note 1)			
4028.43	Command SPS Engine ON	AGC action basically similar to Start of SPS1 burn.			
4111.0 (Approx)	Last Steering Update.	At next V_g computation. AGC determines that less than 10 secs to engine-off.			

TIME FROM LIFT-OFF	ACTION	PERFORMANCE RESULT
4113.90	Command SPS Engine OFF	AGC cuts off burn six seconds early to allow for SPS3.4, by subtracting the expected thrust ΔV from Vg.
4114.7 (Approx.)	Command CDU's to SPS3 trim position.	AGC subtracts stored nominal value of SPS2 c.g. change from CDU's ΔCDUX = -1.02^{o} ΔCDUY = -0.81^{o} ΔCDUZ = -1.57^{o}
4115.93	Command SCS Gimbal Motor Power OFF	See Note 1
4120.01	Command SCS Gimbal Motor Power ON	See Note 1
4123.90	Command SPS Engine ON	Start of timed SPS3 burn.
4126.90	Command SPS Engine OFF	
4136.90	Command SPS Engine ON	Start of timed SPS 4 burn.
4139.90	Command SPS Engine OFF	
4139.93	Command SCS +X Translation OFF	Vg remaining after SPS tail-off = 14.35 ft/sec. (The 11.63 ft/sec which is due to +X Translation ΔV, has been accomodated by perturbing the SPS2 aim point). Fuel used during SPS2, 3, 4 = 6187.3 lbs. Error in R = 1254 ft V = 1.27 ft/sec (see Note 4)
4147.01	Command SCS Gimbal Motor Power OFF	(See Note 1)
4150.49	Command SCS G&N Monitor Mode	(See Note 1.)
4150.73	Command SCS G&N Att. Control Mode	(See Note 1).
		AGC now commands a fixed inertial attitude, waiting for the computed time of free-fall to 400,000 ft to fall below 160 secs.
4246.42		AGC computed free-fall time = 158.31 Actual computed free-fall time = 160.73
4247.54	Start Vehicle Pitch/Yaw Maneuver.	Maneuver angle = 69.22^{o} This is maneuver to the CM/SM separation attitude.
4270.04	Maneuver Completed	Initial euler[2] set: -177.55^{o} / -30.71^{o} / -0.71^{o} Desired euler[2] set: -0.48^{o} / -80.10^{o} / 178.60^{o} Final euler[2] set: 0.30^{o} / -80.13^{o} / 179.53^{o} Jet-Secs: 0.03 / 3.86 / 0.07 Fuel used: 2.82 lbs Maneuver Time[3]: 22.50 secs Angle above inertial velocity vector = 61.47^{o}
4322.20		AGC computed free-fall time = 84.10 Actual computed free fall time = 84.52
4322.81	Command SCS CM/SM Separation	After issuing command, AGC waits 5 secs before switching to 16X resolver on IMU.
4327.85	Command SCS G&N Monitor Mode.	AGC now computes new CDU position to align 16X resolver to present 1X position. Monitor mode inhibits response to resulting large attitude error signals.

TIME FROM LIFT-OFF	ACTUAL	PERFORMANCE RESULT	X	Y	Z
4327.97	Command IMU to Re-entry Mode.	AGC now allows 5 secs for CDUX to settle to new position.			
4332.89	Command SCS G&N Entry Mode.	AGC now computes maneuver to pre-entry attitude.			
4333.74	Start CM Pitch/Yaw Maneuver	Maneuver angle = 135.04°			
4372.74	CM Maneuver Complete	Initial euler[2] set	0.82°	-79.98°	179.94°
		Desired euler[2] set	7.71°	54.65°	172.85°
		Final euler[2] set	2.35°	56.35°	177.92°
		Jet-Sec	0.00	0.66	0.00
		Fuel used	0.44 lbs		
		Maneuver time[3]	39.0 secs		
4378.24	CM Roll Maneuver Compl Complete	Initial euler[2] set	2.35°	56.35°	177.92°
		Desired euler[2] set	1.71°	54.93°	177.76°
		Final euler[2] set	2.14°	59.63°	177.81°
		Jet - Sec	0.00	0.18	0.00
		Fuel used	1.21 lbs		
		Maneuver time[3]	5.5 secs		
4407.4	Arrive at 400,000 ft altitude above Fischer ellipsoid.	Inertial velocity magnitude = 2,8697.2 ft/sec Inertial flight path angle = 3.574°			
4483.01	Send .05G Indication				
4560.42	First Peak Heat Rate (at least 75 BTU/sq ft/sec)	Heat rate (total) = 83.9 BTU/sq ft/sec)			
4968.42	Second Peak Heat Rate (at least 60 BTU/sq ft/sec).	Heat rate (total) = 53.61 BTU/sq ft/sec.			
5226.42	End of simulation (inaccurate below MACH2) Mission objective total heat load = 20 - 40,000 BTU/ft^2 Target 17.25°N 170.00°E	Altitude above Fischer ellipsoid = 39,503 ft Inertial velocity magnitude = 1,544.7 ft/sec Latitude = 17.257°N Longitude = 169.982°E Total Heat Load = 21,931 BTU/ft^2 Miss Distance = 1.12 n.m. AGC error in R = 1527 ft V = 1.77 ft/sec (See Note 4).			

NOTE 1 Variations in timing intervals between discrete commands is explained in Section 2.2. Another 5-10 ms for relay delays must be added to the command times to obtain the signals that actually cross the AGC-MCP interface.

NOTE 2 The euler set is x, y, z from lift-off axes (x along local vertical, z in direction of down-range at 105° E of N, and y along z * x).

NOTE 3 Maneuver time is quantized to 0.5 sec. The angle is metered out exactly, however. Each maneuver is followed by a five second setting period before the next commences.

NOTE 4 Position and velocity errors are due to algorithim and round-off only. No inertial errors are simulated. Also errors are assumed zero at the start of the simulation.

4.0 G&N ERROR ANALYSIS

This section provides the results of G&N Error Analysis. Table 4-1 summarizes the one-sigma total error at each major event time and breaks these down into the contributions of IMU errors accumulated during each powered phase. Tables 4-2 through 4-10 break down each line of Table 4-1 into the contributions of each IMU sensor error term.

On the basis of these data the following key errors are estimated.

	With no navigational update	With perfect navigational update at time of SPS 2nd Burn ignition
Entry γ_i (one sigma)	0.128	0.004 degree
Entry V_i (one sigma)	9.3	0.3 ft/sec
CEP at Pacific Recovery Point:	9.9	1.0 nm

These error tables assume that IMU System No. 017 will be used for the 202 flight. The AGC will have the capability of providing compensation for the measured average values of the following IMU errors: accelerometer bias errors, accelerometer scale factor errors, gyro bias drift, and gyro acceleration sensitive drift errors. Since the average IMU errors will be compensated for during both pre-launch and in-flight phases, it is the deviation from the measured average errors that will cause the indication errors during flight. Based on System 017 test measurements the anticipated one-sigma IMU error uncertainties relative to average values at time of actual 202 launch are as follows:

One-Sigma IMU Error Uncertainties (System 017)

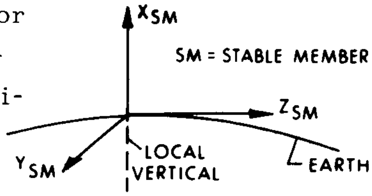
	Input Axis			
	X	Y	Z	
Accelerometer bias (ACB)	0.071	0.230	0.111	cm/sec^2
Accelerometer scale factor (SFE)	34	57	109	ppm
Accelerometer non-linearity	10	10	10	$\mu g/g^2$
Gyro bias drift (BD)	2.0	2.3	1.3	meru
Gyro input axis accel. sens. drift (ADIA)	2.5	6.7	6.5	meru/g
Gyro spin ref. axis accel. sens. drift (ADSRA)	4.8	1.8	1.2	meru/g
Gyro acceleration squared sens. drift	0.3	0.3	0.3	$meru/g^2$
Accelerometer IA misalignments				
Non-orthogonality X to Y	0.265	-	-	mr
Non-orthogonality X to Z	0.146	-	-	mr
Y about X_{SM}	-	0.034	-	mr

The average errors, as well as the rms error deviations from the average, were computed on the basis of test measurements made after the G&N system had been assembled and checked out. The error data given for accelerometer non-linearity and for gyro acceleration squared sensitive drift were not obtained from IMU test measurements but rather from general tests made of IMU components of identical design.

All tables, except 4-6, 4-8, and 4-10, assume no navigational update at any phase of flight. Tables 4-6, 4-8, and 4-10 assume perfect navigation update at time of SPS 2nd Burn ignition.

The following comments explain the terminology, method of analysis and the basic assumptions used.

1) The IMU Stable Member axes are aligned prior to launch relative to local vertical axes as indicated in sketch. X_{SM} is up along local vertical at instant of launch, while Z_{SM} is along local horizontal pointed down-range at an azimuth of 105 degrees.



2) The data in the error tables are given relative to local vertical axes (altitude, track, range) at the paricular event designated.

3) Only the significant error figures have been listed in the error tables.

4) No realignment of the Stable Member was assumed.

5) Accelerometer bias errors affect indication errors in two ways. First, they affect the initial pre-launch alignment of the Stable Member. Second, they affect the in-flight computation of position and velocity. The two effects are summed in the tables, since the accelerometer bias error prior to launch is assumed to be correlated with the bias error during flight.

6) Accelerometer inputs to the AGC are not used during the free-fall phases of the trajectory.

7) The item "Uncorrelated SM Alignment Errors" in the error tables do not include the alignment errors due to accelerometer bias errors or to gyro bias and acceleration sensitive drift. Since, for these particular IMU errors, the pre-launch error is assumed correlated with the in-flight error, the two effects are algebraically summed in the tables. Note that the azimuth alignment error is affected primarily by the Z gyro bias drift effect on the gyro-compassing loop

during pre-launch alignment. The RSS azimuth alignment error due to all IMU errors is 1.60 mr., of which the Z gyro bias drift error of 1.3 meru is responsible for 1.43 mr.

The uncorrelated SM alignment error about azimuth of 0.50 mr. is caused primarily by misalignment of the Z gyro input axis relative to the Z stable member axis. The 0.5 mr. figure is an estimate based on specifications, since specific measurement data was not available for System 017.

8) The position and velocity errors given in the tables were computed as follows. Approximate error equations were derived for the effect of each IMU component error on indication of trajectory position and velocity. The basic assumptions were: 1. that the errors were small relative to the parameters being measured, and 2. that the IMU component errors were statistically independent of each other. The equations took into account the effect of the platform error on the gravity vector computation. The error equations required as inputs acceleration and position vectors. These were generated at each time step by a reference trajectory. At important times, such as SIVB cutoff, detailed printouts were made giving the position and velocity errors due to each IMU error together with the RSS of these errors relative to desired coordinate axes.

Table 4-1
202 Trajectory Errors (Summary)

Event	Time From Start mins	Type of Error	Position Error nms			Velocity Error ft/sec		
			Alt	Track	Range	Alt	Track	Range
SIVB Cutoff	10.17	1) Total Indication Errors	0.20	1.48	0.12	5.2	34.3	2.7
SPS 1st Burn Cutoff	14.41	1) Total Indication Errors	0.43	2.98	0.29	7.4	37.4	3.7
Coast End (SPS 2nd Burn Ignition)	67.14	1) Total Indication Errors	2.61	2.71	8.75	54.2	33.7	9.1
SPS 2nd Burn Cutoff	68.56	1) Total Indication Errors 2) Effect of IMU Errors during SPS 2nd Burn	2.52 0.01	3.22 0.01	9.09 0.01	56.8 1.7	33.0 1.9	9.4 0.8
Entry Start (at altitude of 400,000 ft)	73.37	1) Total Indication Errors 2) Effect of IMU Errors during SPS 2nd Burn	1.90 0.11	4.62 0.10	10.14 0.02	64.1 2.1	23.0 1.7	9.3 0.3
Entry End (at altitude of 24,000 ft)	87.33	1) Total Indication Errors 2) Effect of IMU Errors during SPS 2nd Burn & Entry	3.41 0.81	6.04 1.34	10.74 0.33	85.3 23.0	19.4 32.2	24.4 6.7

Note: "Total Indication Errors" refers to the difference between indicated and actual spacecraft position and velocity where the indicated trajectory is in error because of the presence of IMU errors since trajectory start.

Table 4-2 Total Indication Errors at SIVB Cutoff (202)

Error (axes: A, R, T)				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt	Track	Range	Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		-2677			-10.19	
		About Y_I		0.04 mr	167		-269	0.78		-0.72
		About Z_I		0.04 mr		214			0.50	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	844		-235	3.50		-0.91
	Accel. IA Mlm	Y about X_I		0.034 mr		182			0.69	
	Bias Error	ACBX	Eff on Init Mlm	.071 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		-452		125	-1.61		0.41
			Combined Eff		-452		125	-1.61		0.41
		ACBY	Eff on Init Mlm	.230 cm/sec^2		1254			2.92	
			Eff on Pwr Flt			-1334			-4.19	
			Combined Eff			-80			-1.27	
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	-473		761	-2.22		2.05
			Eff on Pwr Flt		-191		-617	-0.67		-1.93
			Combined Eff		-664		144	-2.89		0.12
	Scale Factor Error	SFEX		34 PPM	-207		57	-0.60		0.14
		SFEY		57 PPM		0			0	
		SFEZ		109 PPM	-172		-559	-0.71		-2.13
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-83		23	-0.21		0.05
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-23		-73	-0.09		-0.28
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		781			2.97	
			Eff on Pwr Flt			-184			-1.09	
			Combined Eff			597			1.88	
		BDY	Eff on Init Mlm	2.3 meru	3	-3627	0	0.02	-13.81	0
			Eff on Pwr Flt		183	0	-179	1.18	0	-0.83
			Combined Eff		186	-3627	-179	1.20	-13.81	-0.83
		BDZ	Eff on Init Mlm	1.3 meru	-5	7652	1	-0.04	29.13	0
			Eff on Pwr Flt		0	69	0	0	0.27	0
			Combined Eff		-5	7721	1	-0.04	29.40	0
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		976			3.72	
			Eff on Pwr Flt			-252			-1.22	
			Combined Eff			724			2.50	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		-129		113	-0.89		0.60
			Combined Eff		-129		113	-0.89		0.60
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			[illegible]	
			Eff on Pwr Flt			266			1.22	
			Combined Eff			266			1.22	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 $meru/g^2$		-43			-0.19	
		$A^2D_{(SRA)(SRA)Y}$		0.3 $meru/g^2$	31		-28	0.21		-0.14
		$A^2D_{(IA)(IA)Z}$		0.3 $meru/g^2$		18			0.08	
Root Sum Square Error (in ft and ft/sec)					1232	9008	729	5.20	34.25	2.68
Root Sum Square Error (in nm and ft/sec)					0.20	1.48	0.12	5.2	34.3	2.7

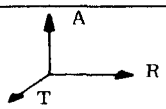
Table 4-3 Total Indication Errors at SPS 1st Burn Cutoff

Error (axes: A, R, T)				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt	Track	Range	Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		-5,394			-11.12	
		About Y_I		0.04 mr	270		-539	0.88		-0.90
		About Z_I		0.04 mr		333			0.41	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	1721		-961	4.60		-2.10
	Accel. IA Mlm	Y about X_I		0.034 mr		367			0.76	
	Bias Error	ACBX	Eff on Init Mlm	.071 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		-882		490	-2.37		1.08
			Combined Eff		-882		490	-2.37		1.08
		ACBY	Eff on Init Mlm	.230 cm/sec^2		1952			2.43	
			Eff on Pwr Flt			-2549			-5.32	
			Combined Eff			-597			-2.89	
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	-762		1524	-2.49		2.55
			Eff on Pwr Flt		-728		-1023	-1.87		-2.10
			Combined Eff		-1490		501	-4.36		0.45
	Scale Factor Error	SFEX		34 PPM	-349		189	-0.75		0.29
		SFEY		57 PPM		0			0	
		SFEZ		109 PPM	-692		-980	-1.76		-1.98
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-132		71	-0.27		0.10
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-90		-126	-0.22		-0.23
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		1573			3.24	
			Eff on Pwr Flt			-506			-1.49	
			Combined Eff			1067			1.75	
		BDY	Eff on Init Mlm	2.3 meru	14	-7309	-4	0.07	-15.06	-0.01
			Eff on Pwr Flt		438	-1	-539	1.63	0	-1.37
			Combined Eff		452	-7310	-543	1.70	-15.06	-1.38
		BDZ	Eff on Init Mlm	1.3 meru	-29	15418	9	-0.16	31.77	0.03
			Eff on Pwr Flt		0	139	0	0	0.25	0
			Combined Eff		-29	15557	9	-0.16	32.02	0.03
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		1967			4.05	
			Eff on Pwr Flt			-591			-1.46	
			Combined Eff			1376			2.59	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		-328		378	-1.23		1.02
			Combined Eff		-328		378	-1.23		1.02
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			583			1.17	
			Combined Eff			583			1.17	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 meru/g^2		-95			-0.22	
		$A^2D_{(SRA)(SRA)Y}$		0.3 meru/g^2	78		-92	0.29		-0.24
		$A^2D_{(IA)(IA)Z}$		0.3 meru/g^2		40			0.08	
Root Sum Square Error (in ft and ft/sec)					2642	18126	1780	7.41	37.37	3.70
Root Sum Square Error (in nm and ft/sec)					0.43	2.98	0.29	7.4	37.4	3.7

Table 4-4 Total Indication Errors at Coast End (SPS 2nd Burn Ignition)

	Error (A ↑, → R, ↙ T)			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt	Track	Range	Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		4913			10.03	
		About Y_I		0.04 mr	-2574		3320	-4.06		1.92
		About Z_I		0.04 mr		-319			-0.35	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	163		-17056	15.49		1.90
	Accel. IA Mlm	Y about X_I		0.034 mr		-334			-0.08	
	Bias Error	ACBX	Eff on Init Mlm	$.071\ cm/sec^2$	0		0	0		0
			Eff on Pwr Flt		-80		8803	-7.99		-0.98
			Combined Eff		-80		8803	-7.99		-0.98
		ACBY	Eff on Init Mlm	$.230\ cm/sec^2$	-42	-1864	299	-0.29	-2.05	0.01
			Eff on Pwr Flt		28	2318	-376	0.32	4.80	0.02
			Combined Eff		-14	454	-77	0.03	2.75	0.03
		ACBZ	Eff on Init Mlm	$.111\ cm/sec^2$	7282	101	-9395	11.53	0.14	-5.45
			Eff on Pwr Flt		-14034	-238	40205	-42.32	-0.39	7.85
			Combined Eff		-6752	-137	30810	-30.79	0.25	2.40
	Scale Factor Error	SFEX		34 PPM	-557		3929	-3.86		0
		SFEY		57 PPM		0			0	
		SFEZ		109 PPM	-13286		38062	-40.06		7.43
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	-256		1529	-1.53		0.03
		NCYY		$10\ \mu g/g^2$		0			0	
		NCZZ		$10\ \mu g/g^2$	-1602	-27	4630	-4.87		0.89
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		-1433			-2.93	
			Eff on Pwr Flt			437			1.38	
			Combined Eff			-996			-1.55	
		BDY	Eff on Init Mlm	2.3 meru	82	6657	-1061	0.92	13.59	0.04
			Eff on Pwr Flt		-3596	-43	2533	-3.98	-0.06	2.89
			Combined Eff		-3514	6614	1472	-3.06	13.53	2.93
		BDZ	Eff on Init Mlm	1.3 meru	-173	-14042	2238	-1.93	-28.67	-0.09
			Eff on Pwr Flt		-2	-128	20	-0.02	-0.23	0
			Combined Eff		-175	-14170	2258	-1.95	-28.90	-0.09
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-1791			-3.66	
			Eff on Pwr Flt			525			1.33	
			Combined Eff			-1266			-2.33	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		2661		-1717	2.82		-2.15
			Combined Eff		2661		-1717	2.82		-2.15
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			-533			-1.05	
			Combined Eff			-533			-1.05	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$0.3\ meru/g^2$		86			0.20	
		$A^2D_{(SRA)(SRA)Y}$		$0.3\ meru/g^2$	-621		406	-0.65		0.50
		$A^2D_{(IA)(IA)Z}$		$0.3\ meru/g^2$		-36			-0.07	
Root Sum Square Error (in ft and ft/sec)					15863	16494	53176	54.19	33.70	9.14
Root Sum Square Error (in nm and ft/sec)					2.61	2.71	8.75	54.2	33.7	9.1

Table 4-5 Total Indication Errors at SPS 2nd Burn Cutoff



	Error			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt	Track	Range	Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		5833			10.05	
		About Y_I		0.04 mr	-2580		3778	-4.36		2.01
		About Z_I		0.04 mr		-344			-0.22	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	-221		-16869	15.86		2.09
	Accel. IA Mlm	Y about X_I		0.034 mr		-397			-0.68	
	Bias Error	ACBX	Eff on Init Mlm	.071 m/sec^2	0		0	0		0
			Eff on Pwr Flt		130		8698	-7.92		-1.26
			Combined Eff		130		8698	-7.92		-1.26
		ACBY	Eff on Init Mlm	.230 cm/sec^2		-2019			-1.30	
			Eff on Pwr Flt			2713			3.82	
			Combined Eff			694			2.52	
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	7300	114	-10690	12.36	0.15	-5.71
			Eff on Pwr Flt		-13580	-275	42415	-44.50	-0.41	8.01
			Combined Eff		-6280	-161	31725	-32.14	-0.26	2.30
	Scale Factor Error	SFEX		34 PPM	-490		3982	-3.92		-0.08
		SFEY		57 PPM		0			0	
		SFEZ		109 PPM	-12868		40137	-42.39		7.21
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-232	-7	1558	-1.57	-0.01	0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-1550	-32	4883	-5.14	0	0.88
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		-1701			-2.93	
			Eff on Pwr Flt			595			2.10	
			Combined Eff			-1106			-0.83	
		BDY	Eff on Init Mlm	2.3 meru	54	7904	-1063	0.96	13.63	0.06
			Eff on Pwr Flt		-3607	-49	3226	-2.89	-0.06	3.77
			Combined Eff		-3553	7855	2163	-1.93	13.57	3.83
		BDZ	Eff on Init Mlm	1.3 meru	-114	-16672	2243	-2.03	-28.76	-0.14
			Eff on Pwr Flt		-1	-110	20	-0.02	0.66	0
			Combined Eff		-115	-16782	2263	-2.05	-28.10	-0.14
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-2127			-3.67	
			Eff on Pwr Flt			649			1.38	
			Combined Eff			-1478			-2.29	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		2716		-2213	2.96		-2.36
			Combined Eff		2716		-2213	2.96		-2.36
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			-588			-0.13	
			Combined Eff			-588			-0.13	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 $meru/g^2$		104			0.20	
		$A^2D_{(SRA)(SRA)Y}$		0.3 $meru/g^2$	-634		521	-0.70		0.54
		$A^2D_{(IA)(IA)Z}$		0.3 $meru/g^2$		-40			-0.01	
Root Sum Square Error (in ft and ft/sec)					15327	19545	55225	56.79	32.98	9.42
Root Sum Square Error (nm and ft/sec)					2.52	3.22	9.09	56.8	33.0	9.4

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Table 4-6 Effect of IMU Errors during SPS 2nd Burn at SPS 2nd Burn Cutoff

	Error		A ↑, R →, T ↙	RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt	Track	Range	Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		29			0.65	
		About Y_I		0.04 mr	4		2	0.09		0.04
		About Z_I		0.04 mr		4			0.09	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0			
		X to Z		0.146 mr	7		-5	0.16		-0.11
	Accel. IA Mlm	Y about X_I		0.034 mr		2			0.05	
	Bias Error	ACBX	Eff on Init Mlm	.071 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		8		-5	0.18		-0.12
			Combined Eff		8		-5	0.18		-0.12
		ACBY	Eff on Init Mlm	.230 cm/sec^2		23			0.53	
			Eff on Pwr Flt			-31			-0.69	
			Combined Eff			-8			-0.16	
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	-12		-5	-0.27		-0.12
			Eff on Pwr Flt		8		12	0.19		0.27
			Combined Eff		-4		7	-0.08		0.15
	Scale Factor Error	SFEX		34 PPM	3		-2	0.06		-0.04
		SFEY		57 PPM		0			0	
		SFEZ		109 PPM	-4		-5	-0.08		-0.11
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	1		0	0.01		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	0		0	0		0
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		-8			-0.19	
			Eff on Pwr Flt			34			0.78	
			Combined Eff			26			0.59	
		BDY	Eff on Init Mlm	2.3 meru	0	-46	0	0	-1.05	0
			Eff on Pwr Flt		70	0	33	1.62	0	0.75
			Combined Eff		70	-46	33	1.62	-1.05	0.75
		BDZ	Eff on Init Mlm	1.3 meru		-81			-1.83	
			Eff on Pwr Flt			38			0.87	
			Combined Eff			-43			-0.96	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-10			-0.24	
			Eff on Pwr Flt			5			0.12	
			Combined Eff			-5			-0.12	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		-11		-5	-0.25		-0.11
			Combined Eff		-11		-5	-0.25		-0.11
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			37			0.86	
			Combined Eff			37			0.86	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 $meru/g^2$		1			0.02	
		$A^2D_{(SRA)(SRA)Y}$		0.3 $meru/g^2$	2		1	0.06		0.03
		$A^2D_{(IA)(IA)Z}$		0.3 $meru/g^2$		2			0.05	
Root Sum Square Error (in ft and ft/sec)					72	83	35	1.67	1.89	0.80
Root Sum Square Error (in nm and ft/sec)					0.01	0.01	0.01	1.7	1.9	0.8

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Table 4-7 Total Indication Errors at Entry Start

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt	Track	Range	Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		8,440			7.06	
		About Y_I		0.04 mr	-2,296		5,359	-5.61		2.07
		About Z_I		0.04 mr		-389			-0.07	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	-1,795		-15,760	15.95		2.64
	Accel. IA Mlm	Y about X_I		0.034 mr		-574			-0.48	
	Bias Error	ACBX	Eff on Init Mlm	.071 cm/sec^2	0	0	0	0	0	0
			Eff on Pwr Flt		996	-37	8,041	-8.01	-0.03	-1.61
			Combined Eff		996	-37	8,041	-8.01	-0.03	-1.61
		ACBY	Eff on Init Mlm	.230 cm/sec^2	-12	-2,280	314	-0.34	-0.40	0
			Eff on Pwr Flt		-18	3,672	-367	0.39	2.48	0.04
			Combined Eff		-30	1,392	-53	0.05	2.08	0.04
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	6,496	162	-15,163	15.87	0.17	-5.85
			Eff on Pwr Flt		-10,069	-398	49,458	-51.33	-0.40	7.66
			Combined Eff		-3,573	-236	34,295	-35.46	-0.23	1.81
	Scale Factor Error	SFEX		34 PPM	-147		4,072	-4.24		-0.15
		SFEY		57 PPM		0			0	
		SFEZ		109 PPM	-9,670		46,740	-49.03		7.03
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-103		1,625	-1.70	0	0
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-1,154		5,678	-5.93		0.85
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		-2,462			-2.06	
			Eff on Pwr Flt			1,177			1.73	
			Combined Eff			-1,285			-0.33	
		BDY	Eff on Init Mlm	2.3 meru	-47	11,436	-1,038	1.10	9.57	0.10
			Eff on Pwr Flt		-2,948	-70	5,600	-4.25	-0.08	3.32
			Combined Eff		-2,995	11,366	4,562	3.15	9.49	3.42
		BDZ	Eff on Init Mlm	1.3 meru	100	-24,124	2,190	-2.32	-20.19	-0.20
			Eff on Pwr Flt		0	90	20	-0.02	0.66	0
			Combined Eff		100	-24,034	2,210	-2.34	-19.53	-0.20
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-3,077			-2.58	
			Eff on Pwr Flt			1,016			1.03	
			Combined Eff			-2,061			-1.55	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		2,583		-3,992	4.23		-2.48
			Combined Eff		2,583		-3,992	4.23		-2.48
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			-591			0.12	
			Combined Eff			-591			0.12	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		156			0.15	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	-603		936	-0.99		0.58
		$A^2D_{(IA)(IA)Z}$		.3 meru/g^2		-41			0.01	
Root Sum Square Error (in ft and ft/sec)					11,542	28,053	61,622	64.05	23.00	9.25
Root Sum Square Error (in nm and ft/sec)					1.90	4.62	10.14	64.1	23.0	9.3

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Table 4-8 Effect of IMU Errors During SPS 2nd Burn at Entry Start

	Error (axes A, R, T)			RMS Error	Final Position Error in Local Axes (in feet) Alt	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		219			0.60	
		About Y_I		0.04 mr	38		1	0.12		0
		About Z_I		0.04 mr		30			0.08	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	39		-55	0.13		-0.15
	Accel. IA Mlm	Y about X_I		0.034 mr		15			0.04	
	Bias Error	ACBX	Eff on Init Mlm	.071 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		43		-61	0.14		-0.17
			Combined Eff		43		-61	0.14		-0.17
		ACBY	Eff on Init Mlm	.230 cm/sec^2		176			0.49	
			Eff on Pwr Flt			-233			-0.64	
			Combined Eff			-57			-0.15	
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	-106		-3	-0.34		0
			Eff on Pwr Flt		101		60	0.32		0.16
			Combined Eff		-5		57	-0.02		0.16
	Scale Factor Error	SFEX		34 PPM	15		-22	0.05		-0.06
		SFEY		57 PPM		0			0	
		SFEZ		109 PPM	-43		-26	-0.14		-0.07
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	3		-5	0.01		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	2		1	0.01		0
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		-64			-0.18	
			Eff on Pwr Flt			260			0.72	
			Combined Eff			196			0.54	
		BDY	Eff on Init Mlm	2.3 meru	0	-353	0	0	-0.97	0
			Eff on Pwr Flt		642	0	19	2.06	0	0.02
			Combined Eff		642	-353	19	2.06	-0.97	0.02
		BDZ	Eff on Init Mlm	1.3 meru		-615			-1.68	
			Eff on Pwr Flt			291			0.80	
			Combined Eff			-324			-0.88	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-80			-0.22	
			Eff on Pwr Flt			39			0.11	
			Combined Eff			-41			-0.11	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		-99		-29	-0.32		0
			Combined Eff		-99		-29	-0.32		0
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			287			0.79	
			Combined Eff			287			0.79	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 $meru/g^2$		5			0.01	
		$A^2D_{(SRA)(SRA)Y}$		.3 $meru/g^2$	22		1	0.07		0
		$A^2D_{(IA)(IA)Z}$		.3 $meru/g^2$		18			0.05	
Root Sum Square Error (in ft and ft/sec)					655	636	111	2.10	1.74	0.29
Root Sum Square Error (in nm and ft/sec)					0.11	0.10	0.02	2.1	1.7	0.3

Table 4-9 Total Indication Errors at Entry End (24, 000 ft)

Error (A, R, T axes)				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		10,024			0.22	
		About Y_I		0.04 mr	-3,490		7,745	-10.66		-1.70
		About Z_I		0.04 mr		-545			-0.58	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	-533		-10,703	12.46		6.24
	Accel. IA Mlm	Y about X_I		0.034 mr	3	682	-40	0.04	0.02	0.02
	Bias Error	ACBX	Eff on Init Mlm	.071 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		168		4,237	-6.68		-5.65
			Combined Eff		168		4,237	-6.68		-5.65
		ACBY	Eff on Init Mlm	.230 cm/sec^2		-3,196			-3.41	
			Eff on Pwr Flt			1,226			-7.82	
			Combined Eff			-1,970			-11.23	
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	9,874		-21,917	30.17		4.83
			Eff on Pwr Flt		-15,172		55,021	-63.25		-18.46
			Combined Eff		-5,298		33,104	-33.08		-13.63
	Scale Factor Error	SFEX		34 PPM	-651		3,796	-4.37		-0.93
		SFEY		57 PPM		0			-0.03	
		SFEZ		109 PPM	-16,755		52,656	-66.50		-16.41
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-366		1,353	-2.04		-1.22
		NCYY		10 $\mu g/g^2$		-11			-0.05	
		NCZZ		10 $\mu g/g^2$	-1,935		6,350	-7.68		-2.07
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		-2,924			-0.06	
			Eff on Pwr Flt			2,843			7.72	
			Combined Eff			-81			7.66	
		BDY	Eff on Init Mlm	2.3 meru	-113	-16,194	967	-0.68	-0.35	-0.64
			Eff on Pwr Flt		-9,109	-82	8,330	-34.31	0.06	-6.95
			Combined Eff		-9,222	-16,276	9,297	-34.99	-0.29	-7.59
		BDZ	Eff on Init Mlm	1.3 meru	-195	-28,170	1,682	-1.18	-0.61	-1.12
			Eff on Pwr Flt		1	-2,878	10	-0.07	-11.01	-0.35
			Combined Eff		-194	-31,048	1692	-1.25	-11.62	-1.47
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-3,655			-0.08	
			Eff on Pwr Flt			1,227			-0.76	
			Combined Eff			-2,428			-0.84	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0	0	0	0	0	0
			Eff on Pwr Flt		4,155	61	-7,096	11.52	-0.05	1.13
			Combined Eff		4,155	61	-7,096	11.52	-0.05	1.13
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			-2,836			-7.31	
			Combined Eff			-2,836			-7.31	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		241			0.39	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	-991		1,652	-2.84		-0.36
		$A^2D_{(IA)(IA)Z}$		.3 meru/g^2		-204			-0.59	
Root Sum Square Error (in ft and ft/sec)					20,710	36,716	65,268	85.31	19.36	24.43
Root Sum Square Error (in nm and ft/sec)					3.41	6.04	10.74	85.3	19.4	24.4

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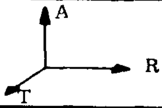
Table 4-10 Effect of IMU Errors during SPS 2nd Burn and Entry at Entry End (24,000 ft)



	Error			RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt. (vel)	Track (vel)	Range (vel)
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		1,210			5.46	
		About Y_I		0.04 mr	-173		-95	-0.99		-0.29
		About Z_I		0.04 mr		-220			-0.94	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.265 mr	0		0	0		0
		X to Z		0.146 mr	-9		-396	-0.22		-1.64
	Accel. IA Mlm	Y about X_I		0.034 mr		82			0.37	
	Bias Error	ACBX	Eff on Init Mlm	.071 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		-112		-958	-0.30		-1.67
			Combined Eff		-112		-958	-0.30		-1.67
		ACBY	Eff on Init Mlm	.230 cm/sec^2		-1,292			-5.52	
			Eff on Pwr Flt			-2,990			-5.34	
			Combined Eff			-4,282			-10.86	
		ACBZ	Eff on Init Mlm	.111 cm/sec^2	489		270	5.26		-0.81
			Eff on Pwr Flt		2,101		-481	2.80		0.82
			Combined Eff		2,590		-211	8.06		0.01
	Scale Factor Error	SFEX		34 PPM	61		168	0.23		0.77
		SFEY		57 PPM		0			-0.04	
		SFEZ		109 PPM	-401		110	-1.64		0.31
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g^2	-26		-158	-0.12		-0.57
		NCYY		10 μg/g^2		-11			-0.05	
		NCZZ		10 μg/g^2	33		-8	0.17		-0.03
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.0 meru		-353			-1.59	
			Eff on Pwr Flt			1,655			8.15	
			Combined Eff			1,302			6.56	
		BDY	Eff on Init Mlm	2.3 meru	-51	-1,954	8	0.38	-8.81	-0.10
			Eff on Pwr Flt		-4,073	2	-1670	-21.69	0	-6.06
			Combined Eff		-4,124	-1,952	-1662	-21.31	-8.81	-6.16
		BDZ	Eff on Init Mlm	1.3 meru		-3,399			-15.34	
			Eff on Pwr Flt			-2,677			-11.15	
			Combined Eff			-6,076			-26.49	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-441			-1.99	
			Eff on Pwr Flt			70			-0.22	
			Combined Eff			-371			-2.21	
		ADSRAY	Eff on Init Mlm	1.8 meru/g	0		0	0		0
			Eff on Pwr Flt		396		235	2.24		0.56
			Combined Eff		396		235	2.24		0.56
		ADIAZ	Eff on Init Mlm	6.5 meru/g		0			0	
			Eff on Pwr Flt			-1,909			-7.89	
			Combined Eff			-1,909			-7.89	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		69			0.48	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	-116		-60	-0.67		-0.22
		$A^2D_{(IA)(IA)Z}$		.3 meru/g^2		-143			-0.63	
Root Sum Square Error (in ft and ft/sec)					4,908	8,129	2,003	23.00	32.23	6.70
Root Sum Square Error (in nm and ft/sec)					0.81	1.34	0.33	23.0	32.2	6.7

5.0 FAILURE EFFECTS ANALYSIS

5.1 Summary

Catastrophic failures are considered as to their effect on the S/C. Other possible failures are less serious, and their effect is assumed to be such as to degrade the nominal terminal dispersion. The effect of serious failure is discussed for each appropriate time interval and G&N configuration.

Most failures would be detected by the failure monitor circuits, however a significant delay time is accumulated between the occurrence of a failure and removal of the G&N steering signals. The effects of failures integrated over the associated delay time to steering signal removal is not assessed. Such assessment on final disposition of the S/C is best done through simulation effort.

5.2 G&N Configurations for this Mission

5.2.1 Pre LET Jetison Boost Monitor

The AGC computes a nominal attitude reference and drives the CDU's. Steering error signals are sent to the FDAI and are used as a monitor signal along with position and velocity obtained from accelerometer information. The functions required are listed below.

a. CDU D/A (Attitude Error Signals)

b. STABILIZATION

c. ACCEL. MEASUREMENT

d. AGC

    1. LIFT OFF
    2. READACC1
    3. SERVICER (CALCRVG, CALCTFF)

5.2.2 Post LET Jetison Boost Monitor

After LET jettison the G&N is switched to Fine Align so as to detect tumbling by tracking the gimbal angles. At SIVB-CSM separation the G&N tests for tumbling and, if it is present arrests it. The functions required through and including tumble arrest are listed below.

a. CDU A/D (Gimbal Angle read in to AGC)

b. STABILIZATION

c. ACCEL. MEASUREMENT

d. AGC

    1. TUMBLTSK1
    2. READACC1
    3. SERVICER
    4. S4BSMSEP

5.2.3 Attitude Maneuver and SPS 1 Burn

After separation (and tumble arrest if applicable) the G&N orients the S/C properly and guides (cross product steering) either abort or first SPS burn. Abort burn occurs if tumbling or the UPLINK ABORT signal were present at separation. The functions required are listed below.

a. CDU D/A
b. STABILIZATION
c. ACCEL MEASUREMENT
d. AGC
    1. READACC1
    2. SERVICER (STEER LAW)
    3. ATTIJOB
    4. DOMANU
    5. ENGINEON (ROLL JOB)
    6. ENGINEOFF

5.2.4 COAST PHASE to SPS 2 BURN

After SPS 1 cutoff the G&N controls a local vertical attitude for part of the free-fall interval and then holds the S/C at the orientation for the second SPS burn. The functions required are listed below. The accelerometer measurement function is operative but ignored during this free-fall interval.

a. CDU D/A
b. STABILIZATION
c. AGC
    1. COASTPHS
    2. VERTASK (VERTJOB, CALCRVG)
    3. ATTIJOB
    4. DOMANU

5.2.5 SPS 2 BURN

This is the same as SPS 1 Burn (5.2.3), except the AGC does not do ATTIJOB or DOMANU.

5.2.6 SPS 3 and SPS 4 BURN

This is nearly the same as (5.2.5). The difference is that the steering law and acceleration measurement are not used. The S/C is held to a fixed attitude and thrust is turned on and off on time bases.

5.2.7 Separation and Entry

After SPS 4 cutoff the G&N controls proper attitude for CM/SM separation. The G&N then reorients the CM for Entry. After .05G's the G&N controls a lifting entry. The G&N functions are still as for (5.2.3), except the AGC does:

a. READACC1
b. SERVICER
c. SEPMANU
d. ENTAJOB
e. REENTRY CONTROL

The above configurations are summarized in Table 5-1.

5.3 G&N Failures

5.3.1 CDU D/A

Through the CDU the AGC indicates to the S/C the desired orientation with respect to the stable platform.

a. Failures accepted as normal dispersions are increased RMS read-in or read-out and acceptable bias read errors.

b. Failures considered catastrophic as to their effect on the S/C are (1) No change in commanded angle and (2) saturated rate of change of angle.

c. There is no internal CDU failure indication used. The G&N is removed from operation (if necessary) by detecting the failure from telemetered data and sending G&N fail via the UPLINK. (Refer to Par 5.5). There is a delay of approximately 20 seconds from the time of failure in the G&N to the time the G&N is removed from operation.

5.3.2 CDU A/D

The AGC reads the orientation of the S/C with respect to the stable platform via the CDU's.

5.3.3 Stabilization

This loop isolates the stable platform from S/C motion.

a. Failures accepted as normal dispersion are increased platform drift, and dynamic degradation other than loss of the platform.

b. Failure considered as catastrophic is loss of stabilization. (i.e. loss of the guidance reference.)

c. The above failures inherently include the effects of failures in the temperature control system and the power distribution system.

d. The considered failure will provide an internal G&N failure signal and automatic removal of the G&N from operation.

e. There is a time lag of 2 seconds from loop failure to removal of the G&N.

G&N Inertial Subsystem

Time Interval	CDU D/A	CDU A/D	STAB	ACCEL
1. Pre LET Jet. Boost Mon.	x		x	x
2. Post LET Jet. Boost Mon.		x	x	x
3. Att. Mon. & SPS1	x		x	x
4. Coast	x		x	
5. SPS2	x		x	x
6. SPS3 & 4	x		x	
7. Separation & Entry	x		x	x

G&N AGC

Time Interval	L/O	READ ACCI	SERV-ICER	TUMB TASK	S4B SM TASK	ATTI JOB	DO MANU	ENG ON	ENG OFF	COAST PH	VER TASK
1. Pre LET Jet. Boost Mon.	x	x	x								
2. Post LET Jet. Boost Mon.		x	x	x	x						
3. Att. Mon. & SPS1		x	x			x	x	x	x		
4. Coast						x	x			x	x
5. SPS2		x	x					x	x		
6. SPS3 & 4		x	x					x	x		
7. Separation & Entry		x	x							{ SEP MANU ENTA JOB RE-ENTER CONTROL	

Table 5-1

Summary of G&N Configuration

5.3.4 Acceleration Measurement

For this function the system senses acceleration, integrates it and provides the ΔV indications to the AGC.

a. Failures accepted as normal dispersion are changes in flight of the accelerometer bias level and scale factor.

b. Failures considered catastrophic are (1) saturated ΔV outputs and (2) no ΔV output to the AGC.

c. The above failures inherently include the effects of failures in the temp. control and power systems.

d. Failures that cause saturated ΔV outputs are internally detected and provide an automatic indication and removal of the G&N.

e. Failures that cause no ΔV output may not be detected internally and must be detected on the ground from telemetry data.

f. There is a time delay of 5 seconds from loop failure to removal of the G&N for internally detected failures. For those detected from telemetry the time delay is approximately 20 seconds.

5.3.5 AGC

The AGC has an internal failure detection system. Most failures of the AGC will be temporary and the AGC will restart the programs running at some convenient point. If the AGC fails catastrophically the G&N fail signal will occur and remove the G&N from operation.

5.3.6 Summary of Considered Failure Modes

CDU D/A

A-1. No change in angle

A-2. Maximum rate of change

CDU A/D

B-1. No change in angle

B-2. Maximum rate of change

STABILIZATION

C-1. Total loss (tumble)

ACCELERATION MEASUREMENT

D-1. No ΔV output

D-2. Maximum ΔV output

5.4 Effect of Failures on S/C

In this section the effects of the described failures will be discussed for each mission interval. Refer to 5.3.6 for failure mode symbol definitions.

5.4.1 From L/O to LET JETTISON

This interval includes the S-1 burn and part of the SIV Burn. The G&N acts as a guidance monitor. During SI flight the CDU's are driven in a programmed fashion. During SIV flight they are held fixed at the final S-1 orientation.

FAILURE		S/C EFFECT
A-1 A-2	(a)	The ground will detect these failures from T/M data and may remove the G&N outputs by using the UPLINK G&N FAIL signal.
	(b)	The ground can continue the boost attitude monitor function by observing S/C attitude by means of the gimbal 1X Resolver T/M data.
	(c)	The G&N cannot be used beyond this interval
	(d)	The S/C will see no effect.
	(e)	The computation of position and velocity will be valid
B-1 B-2		DO NOT APPLY FOR THIS INTERVAL
C-1	(a)	The G&N will automatically provide the G&N FAIL signal to the MCP.
	(b)	The G&N cannot continue a guidance monitor function of any kind.
	(c)	The G&N cannot be used beyond this point.
	(d)	The S/C will see no effect.
	(e)	The computation of position and velocity will be wrong.
D-1	(a)	The ground will detect this failure from T/M data and may remove the G&N outputs.
	(b)	The attitude error data for guidance monitor will be correct.
	(c)	The computation of position and velocity will be wrong.
	(d)	The G&N will provide attitude data but cannot provide steering control beyond this point.
D-2	(a)	The G&N will automatically provide the G&N FAIL signal.
	(b)	The attitude error data for guidance monitor will be correct.
	(c)	The computation of position and velocity will be wrong.
	(d)	The G&N will provide attitude data but cannot provide steering control beyond this point.

5.4.2 From LET JETTISON to SIVB-CSM Separation and TUMBLE ARREST (if needed)

After LET Jettison the G&N is moded to fine align. The function of the G&N is to determine if the S/C is tumbling by reading and differentiating the CDU angular output. In addition the G&N computes position and velocity.

FAILURE		S/C EFFECT
A-1		DO NOT APPLY FOR THIS INTERVAL
A-2		
B-1	(a)	The G&N will indicate no tumbling when there really may be tumbling.
	(b)	The ground will detect this failure and may remove the G&N outputs.
	(c)	The ground can detect the presence of tumbling from the gimbal 1X Resolver T/M.
	(d)	The computation of position and velocity is valid.
B-2	(a)	The G&N will indicate tumbling when there really may not be tumbling.
	(b)	After SIV-CSM Separation the G&N will cause the SPS to ignite at SEP + 3.0 secs. for tumble arrest and will not shut down the SPS.
	(c)	The ground will detect this failure and remove the G&N outputs. The G&N FAIL signal will automatically cause shut down of SPS thrust.
	(d)	The ground can verify tumbling from the gimbal 1X Resolver T/M. (i.e. platform is good.)
	(e)	The computation of position and velocity is valid.
C-1	(a)	The G&N will automatically provide the G&N FAIL signal to the MCP.
	(b)	This failure will cause a false tumbling indication.
	(c)	The G&N cannot be used beyond this point.
	(d)	The computation of position and velocity is wrong.
D-1	(a)	The ground will detect this failure from T/M data and may remove the G&N outputs.
	(b)	The attitude data is correct so tumbling arrest and the abort decision will proceed normally.
	(c)	The computation of position and velocity is wrong.
	(d)	The G&N cannot provide steering control beyond this point.
D-2	(a)	The G&N will automatically provide the G&N FAIL signal.
	(b)	The attitude data is correct so tumble arrest and abort decision will proceed normally.
	(c)	The G&N cannot provide steering control beyond this point.
	(d)	The computation of position and velocity is wrong.

5.4.3 From TUMBLE ARREST (or no TUMBLE G&N TAKEOVER) to end of SPS1 BURN

The G&N assumes steering control, orients the CSM properly and provides steering control for SPS1 burn or for ABORT burn.

FAILURE		S/C EFFECT
A-1	(a)	The ground will detect this failure from T/M data and may remove the G&N outputs.
	(b)	Before SPS ignition this failure will result in incorrect initial thrust orientation. After SPS ignition the steering loop will get no response in the failed axes.

(c) Position and velocity will be computed correctly.

(d) The attitude reference is correct and such data is available from the gimbal 1X Resolver T/M.

A-2 (a) The ground will detect this failure from T/M data and remove the G&N outputs.

(b) The commanded S/C attitude will continually change at a high rate.

(c) Position and velocity will be correct unless gimbal lock occurs and the gimbals tumble.

(d) The attitude reference will be correct unless gimbal lock occurs and this data is available from the gimbal 1X Resolver T/M.

B-1 DO NOT APPLY FOR THIS INTERVAL

B-2

C-1 (a) The G&N will automatically provide the G&N FAIL signal.

(b) The attitude reference for steering is lost.

(c) Position and velocity are wrong.

(d) The S/C orientation or steering will be uncontrolled for two (2) seconds and then the SPS will shut down.

D-1 (a) The ground will detect this failure from T/M and may remove the G&N outputs.

(b) The steering signals computed will be incorrect and the G&N should not be used for steering beyond this interval.

(c) The attitude reference is correct.

(d) The computation of position and velocity is wrong.

D-2 (a) The G&N will automatically provide the G&N FAIL signal.

(b) The S/C will be incorrectly steered for five (5) seconds and then the SPS will be shut down.

(c) Position and velocity data are wrong.

(d) The attitude reference is correct.

5.4.4 From SPS1 CUTOFF to SPS2 IGNITION

The G&N provides attitude control. After SPS 1 C/O the CSM is held in local vertical (x-axis down) attitude until the CSM is approximately oriented for second burn. The attitude for second burn ignition is then achieved and held. For much of this time interval ground communication is lost.

FAILURE S/C EFFECT

A-1 (a) The ground will detect this failure and may remove the G&N outputs when ground communication is obtained.

(b) The CSM Attitude will be incorrect if failure occurs before assuming fixed attitude.

(c) The G&N cannot be used for steering control.

(d) Position and velocity are correct.

(e) The platform is correct and CSM attitude can be obtained from gimbal 1X Resolver T/M output.

A-2 (a) The ground will detect this failure and remove G&N outputs when ground communication is obtained.

(b) The CSM attitude will be incorrect.

(c) The G&N cannot be used for steering control.

(d) Position and velocity are correct unless gimbal lock occurs.

(e) The platform is correct unless gimbal lock occurs and CSM attitude can be obtained from gimbal 1X Resolver T/M output.

B-1 DO NOT APPLY FOR THIS INTERVAL

B-2

C-1 (a) This failure will cause the G&N outputs to be removed automatically after two (2) seconds.

(b) The S/C attitude will be incorrect.

(c) The G&N cannot be used for steering control.

(d) Position and velocity are correct since no computation is made in this interval.

D-1 DO NOT APPLY FOR THIS INTERVAL

D-2

NOTE: If failure A-1, A-2 or C-1 occur prior to the 10 second FDAI align interval it would result in loss of the SCS backup reference.

5.4.5 SPS2 BURN

The G&N controls steering during this interval, just as it did for SPS1 burn.

FAILURE   S/C EFFECT

A-1 (a) The ground will detect this failure from T/M data and may remove the G&N outputs.

(b) The steering loop will get no response in the failed axes.

(c) Position and velocity will be computed correctly.

(d) The attitude reference is correct and such data is available from the gimbal 1X Resolver T/M.

A-2 (a) The ground will detect this failure from T/M data and remove the G&N outputs.

(b) The commanded S/C attitude will continually change at a high rate.

(c) Position and velocity will be correct unless gimbal lock occurs and the gimbals tumble.

(d) The attitude reference will be correct unless gimbal lock occurs and this data is available from the gimbal 1X Resolver T/M.

B-1 DO NOT APPLY FOR THIS INTERVAL

B-2

C-1 (a) The G&N will automatically provide the G&N FAIL signal.

(b) The attitude reference for steering is lost.

(c) Position and velocity are wrong.

(d) The S/C orientation or steering will be uncontrolled for two (2) seconds and then the SPS will shut down.

D-1 (a) The ground will detect this failure from T/M data and remove the G&N outputs.

(b) The steering signals computed will be incorrect.

(c) The G&N should not be used for steering beyond this failure.

(d) The attitude reference is correct.

(e) The computation of position and velocity is wrong.

D-2 (a) The G&N will automatically provide the G&N FAIL signal.

(b) The S/C will be incorrectly steered for five (5) seconds and then the SPS will be shut down.

(c) Position and velocity data are wrong.

(d) The attitude reference is correct.

5.4.6 SPS3 and SPS 4 BURN

After SPS 2 C/O a fixed attitude is held and these short burns are accomplished on time bases.

FAILURE S/C EFFECT

A-1 (a) Since attitude is fixed this failure will have no effect during this interval.

(b) The G&N cannot be used for subsequent operations.

A-2 (a) The ground will detect this failure from T/M, however the operation most likely will be finished before the G&N outputs can be removed.

(b) Position and velocity are correct unless gimbal lock occurs.

(c) The small velocity gained by one or both of these burns will be in undesired direction.

(d) Unless gimbal lock occurs the platform is correct and attitude information is available from 1X gimbal resolver T/M.

(e) The G&N cannot be used for subsequent operation.

B-1 DO NOT APPLY FOR THIS INTERVAL

B-2

C-1 (a) The G&N will automatically provide the G&N FAIL signal after two (2) seconds. The SPS is inhibited from ignition following this signal.

(b) The small velocity gained will be in an undesired direction.

(c) The G&N cannot be used to control subsequent operations.

(d) Position and velocity change due to this burn will be measured incorrectly.

D-1 (a) The ground will detect this failure and should not send the G&N FAIL signal until the start of entry.

(b) Position and velocity change due to this burn will be measured incorrectly.

(c) The G&N can control orientation for CM/SM Separation and ENTRY.

D-2 (a) The G&N will provide the G&N FAIL signal after five (5) seconds.

(b) Position and vecloity are wrong.

(c) The G&N cannot be used for ENTRY control.

(d) The G&N may be used for orientation for CM/SM Separation and Entry by a ground G&N FAIL INHIBIT signal.

(e) There will be errors in computation of T_{FF} because of the incorrect position and velocity data.

5.4.7 Pre-Entry

After SPS 4 C/O the CSM is oriented for separation. After CM-SM separation the CM is orientated for ENTRY.

FAILURE S/C EFFECT

A-1 (a) The ground will detect these failures and remove G&N outputs.

A-2 (b) The two orientation maneuvers and CM-SM separation (or some part of this operation) will have to be controlled from the ground.

(c) Position and velocity are correct.

(d) The platform is correct and attitude is available from gimbal 1X Resolver T/M.

(e) ENTRY will be done by back-up system.

B-1 DO NOT APPLY

B-2

C-1 (a) The G&N will automatically provide the G&N FAIL signal after two (2) seconds.

(b) Orientation for Separation and ENTRY will have to be controlled from

th the ground.

(c) ENTRY will be done on back-up.

(d) Position and velocity and T_{FF} will be in error.

D-1 (a) The ground will detect this failure and should provide the G&N FAIL signal at ENTRY start.

(b) The platform is correct.

(c) Position and velocity and T_{FF} are correct until Entry start.

D-2 (a) The G&N will automatically provide the G&N FAIL signal.

(b) Position, velocity and T_{FF} will be wrong.

(c) The orientation will have to be done from the ground.

(d) ENTRY will be done on back-up.

(e) The platform altitude is correct and the ground can use 1X gimbal Resolver T/M to aid in ground orientation process.

5.4.8 Entry

The G&N provides lifting control during ENTRY. During ENTRY there is no ground communication.

FAILURE	S/C EFFECT
A-1	(a) This failure will not be detected.
	(b) The steering loop will get no response on the failed axis.
	(c) Position and velocity are correct.
	(d) The platform attitude is correct.
A-2	(a) This failure will not be detected
	(b) The G&N will cause continuous roll steering of CM.
	(c) Position and velocity will be correct.
	(d) The platform altitude is correct.
B-1 B-2	DO NOT APPLY
C-1	(a) The G&N will provide the G&N FAIL signal after two (2) seconds.
	(b) Position and velocity will be wrong.
	(c) The platform is lost.
	(d) The SCS back-up will control ENTRY with I.C. errors due to two(2) second delay in G&N removal.
D-1	(a) This failure will not be detected.
	(b) Entry steering will be incorrect.
	(c) The platform attitude is correct.
	(d) Position and velocity will be wrong.
D-2	(a) The G&N will automatically provide the G&N FAIL signal after five (5) seconds.
	(b) Position and velocity are wrong.
	(c) The platform attitude is correct.
	(d) The SCS back-up will control ENTRY with I.C. errors due to five (5) second delay in G&N removal.

5.5 Ground Failure Detection

5.5.1 CDU D/A

In reference to figure 1 there are four loops operative in the CDU D/A operation. Of these four, loops A and B as shown in the figure are of primary interest.

Loop A includes the AGC, DAC, Motor-tach, MDA, CDU 1X Res, and the Digital Encoder. Loop B includes the CDU 1X Res, the Co-ord Tran. Resolver Chain, SCS, S/C, IMU Gimbals, and the IMU Resolvers.

The outputs of the starred items will be telemetered. The resolver outputs appear on PCM at 10 samples/sec. The AGC registers appear on the digital downlink at 1 sample/2 seconds. In summary the four available signals are:

NAME		T/M	DATA
1.	CDU Ref.	DWNLNK (1SPS2)	AGC computed - Desired CDU Pos.
2.	CDU Reg.	DWNLNK (1SPS2)	Actual CDU Pos. as seen by AGC
3.	CDU 1X Res.	PCM (10 SPS)	Error Signal - Approx ($\alpha_{CDU} - \alpha_{IMU}$)
4.	IMU 1X Res.	PCM (10 SPS)	Two signals (Sine & Cosine) that can be used to R/O actual gimbal angles.

On the ground it will be appropriate to compare, after appropriate data reduction; signals (1) and (4). For proper system operation these angles will be nearly equal, in fact the difference should be equivalent (in angle) to signal (3). Unless the above conditions are maintained the G&N fail signal should be transmitted via the UPLINK.

5.5.2 CDU A/D

In reference to figure 2 there are two loops operative on the CDU A/D operation. Of these two the outer loop is of primary interest.

This loop includes the IMU 1X Res., CDU 1X Res, MDA, Motor-Tach, Digital Encoder, and AGC-CDU register.

The outputs of the starred items will be telemetered. The resolver outputs appear on PCM at 10 SPS. The AGC register appears on the Digital Downlink at 1 sample/2 seconds. In summary the three signals available are:

NAME		T/M	DATA
1.	CDU Reg.	DWNLNK (1SPS2)	Actual CDU Pos. as seen by AGC
2.	CDU 1X Res.	PCM (10 SPS)	Error Signal - Approx. $\alpha_{CDU} - \alpha_{IMU}$
3.	IMU 1X Res.	PCM (10 SPS)	Two signals (Sine & Cosine) that can be used to R/O actual gimbal angles.

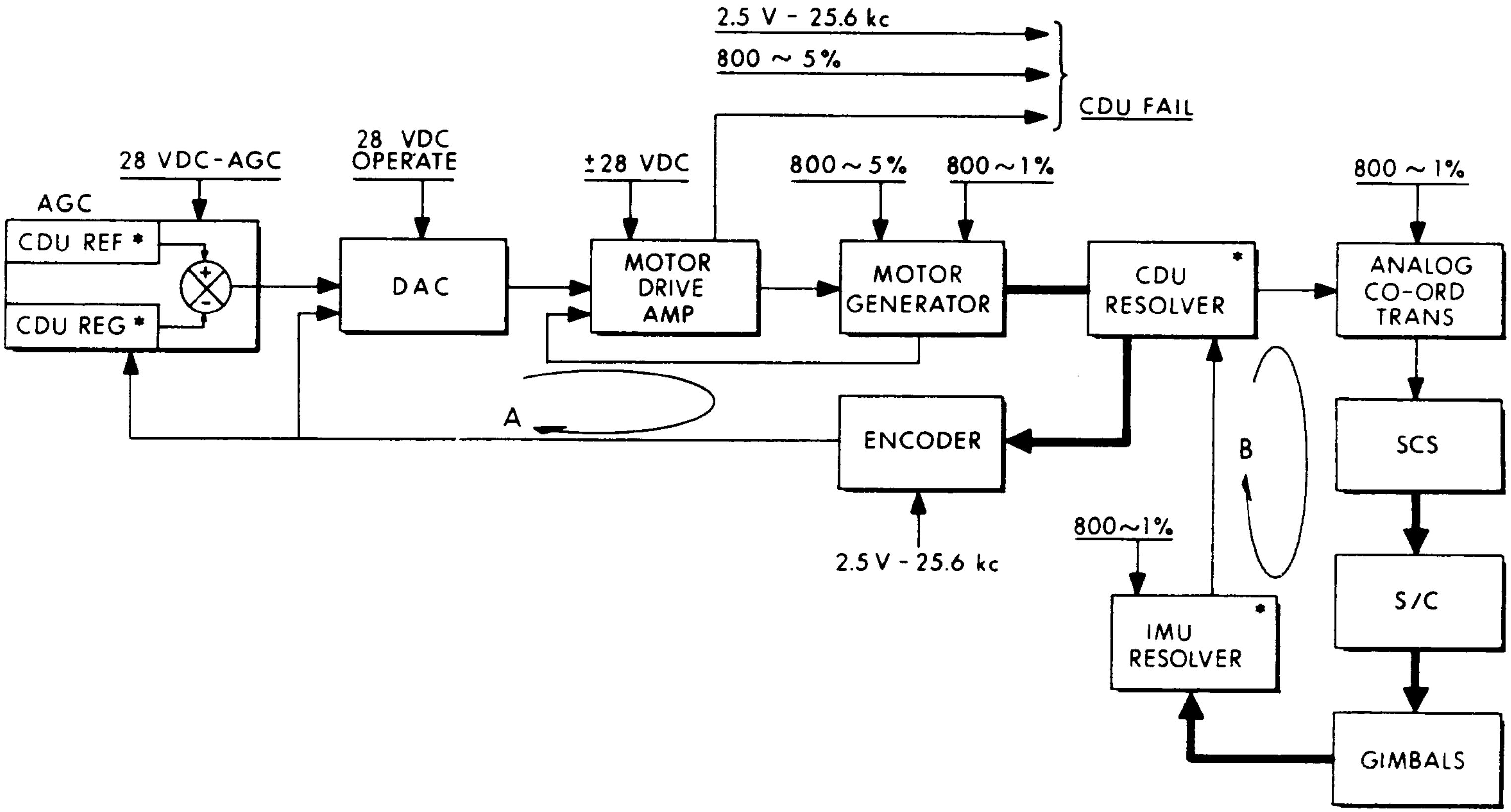


Fig. 5-1 CDU D/A attitude error signals.

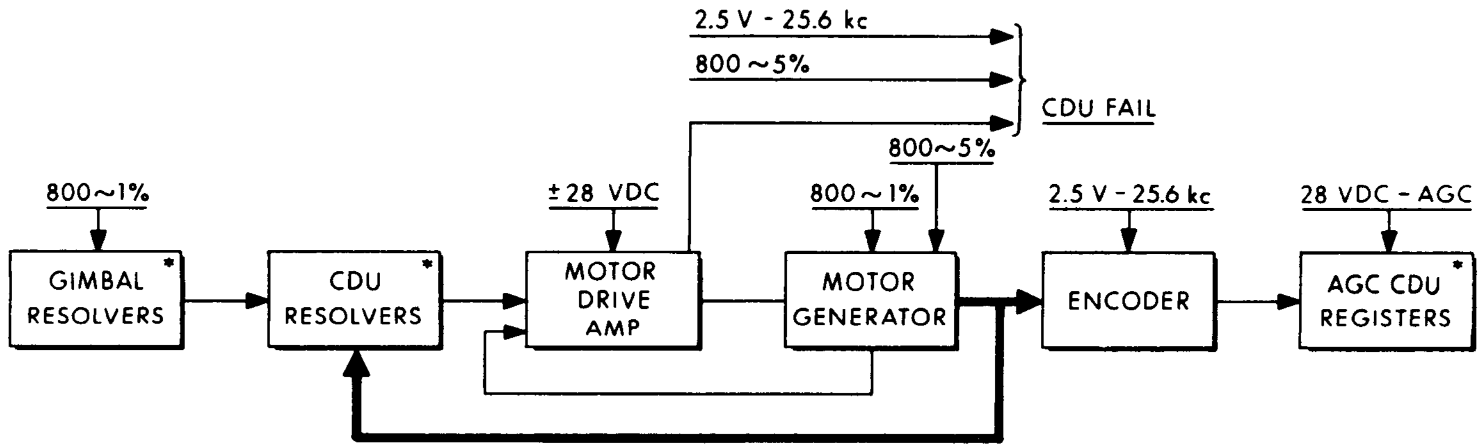


Fig. 5-2 CDU loop A/D --Gimbal angle read-in to AGC.

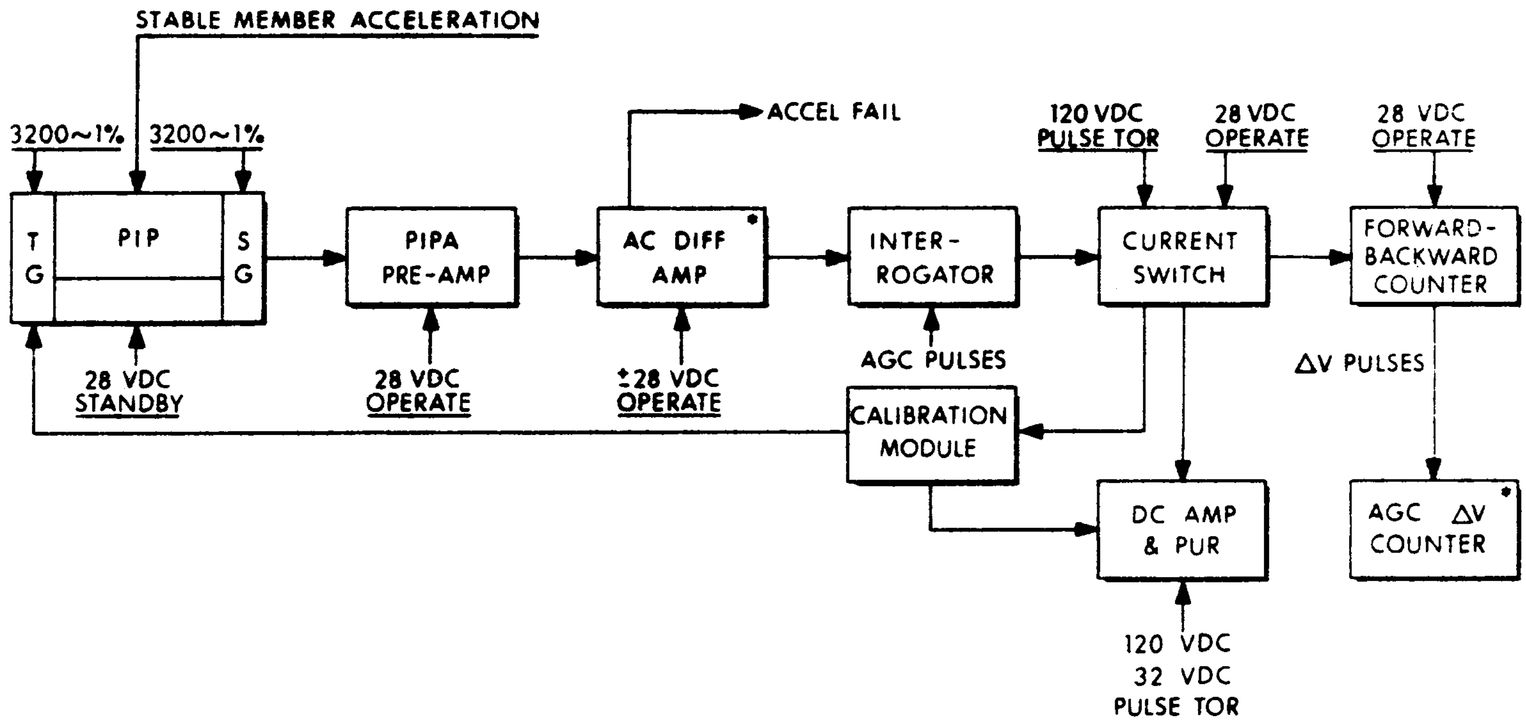


Fig. 5-3 Acceleration measurement loop.

On the ground it will be appropriate to compare, after reduction, signals (1) and (3). For proper operation, these angles will be nearly equal in fact the difference should be equivalent (in angle) to signal (2). Unless the above conditions are maintained the G&N fail should be transmitted via the UPLNK.

5.5.3 Acceleration Measurement

In reference to figure 5-3, the signals telemetered are indicated by stars.

The AGC ΔV COUNTER appears at 1 sample/2 seconds. The signal generator output appears at 10 SPS.

The loop includes the PIP, Pre-Amp, AC Diff Amp, Interrogator, Current Switch, Forward-Backward Counter, Calibration Module, DC Amp & PRR, and AGC Register.

In summary the available signals are:

NAME	T/M	DATA
1. ΔV CTR	1 SP 2 sec	AGC velocity increments
2. S.G. Output	10 SPS	Demodulated 3200 cps output indicative of float motion

On the ground it will be appropriate to watch signal (1) and see that the incrementing does not stop while signal (2) indicates an acceleration level. If signal (2) should disappear this also indicates failure.

The large majority of loop failures will cause signal (2) to saturate. In this event the G&N will automatically provide the G&N FAIL signal after a 5 sec delay.

6.0 G&N RELIABILITY ASSESSMENT

Using predicted failure rates the G&N assembly breakdown for AGE 017 is as follows:

Assembly	λ	Operating Time	λt
IMU	170	1.4	
ISS Elec.	224	1.4	
IMU CDU (3)	111	1.4	
AGC	342	1.4	
DSKY	12	1.4	
D&C	6	1.4	
TOTAL			1211 failures per million missions

Prob. Success $= 1 - 1211 \times 10^{-6} = .9988$

E-1828

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