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APOLLO

GUIDANCE AND NAVIGATION

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GUIDANCE AND NAVIGATION SYSTEM OPERATIONS PLAN APOLLO MISSION 501

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1. INTRODUCTION

1.1 Purpose

This plan governs the operation of the Guidance and Navigation System and defines its functional interface with the spacecraft and ground support systems on Mission 501.

1.2 Authority

This plan constitutes a control document to govern the implementation of:

(1) Detailed G&N flight test objectives
(2) G&N interfaces with the spacecraft and launch vehicle
(3) Digital UPLINK to the Apollo Guidance Computer (AGC)
(4) AGC logic and timeline for spacecraft control*
(5) Guidance and navigation equations*
(6) Digital DOWNLINK from the AGC
(7) G&N System configuration

Revisions to this plan which reflect changes in control items (1) through (7) require approval of the NASA Configuration Control Board.

This plan also constitutes an information document to define:

(a) Trajectory uncertainties due to G&N component errors (Error Analysis)
(b) Trajectory deviations due to spacecraft performance variations and launch vehicle cut-off disperions (Performance Analysis)
(c) G&N instrumentation (PCM telemetry and on-board recording) exclusive of AGC DOWNLINK
(d) External tracking data

Revisions to this plan which reflect changes in information items (a) through (d) will not require approval of the NASA CCB.

*To support these functions this document contains a Control Data section which defines the reference trajectory, AGC memory data, and applicable mission data (mass, propulsion, aerodynamic, and SCS data)

2. G&N FLIGHT OPERATIONS SUMMARY

This section defines the mission plan as origianted by NASA and summarizes the manner in which the G&N system will operate to implement this plan as developed by MIT in cooperation with NASA and NAA/S&ID. This section is divided into three parts;

Par 2.1 Test Objectives

Par 2.2 Spacecraft and Mission Control

Par 2.3 Mission Description

2.1 Detailed G&N Test Objectives

(1) Evaluate performance of the following integrated G&N/Spacecraft modes of operation:

a. C-V Boost Monitor

b. Thrust Vector Control of CSM over full dynamic range

c. Orbit Attitude Control of CSM over full dynamic range

d. Lift Vector Control at lunar return conditions

(2) Determine accuracy of G&N system in computation of spacecraft position and velocity during all mission phases.

(3) Determine G&N environment during C-V Boost and full CSM thrust.

2.2 Spacecraft & Mission Control

2.2.1 Spacecraft Control

Spacecraft Control is implemented by the Apollo Guidance Computer (AGC) provided by MIT and the Mission Control Programmer (MCP) provided by NAA/S&ID. Basically, the MCP performs those non-guidance functions that would otherwise be performed by the crew, while the AGC initiates major modes which are dependent upon trajectory or guidance functions.

The functional interface between the AGC and the MCP is complex and its description is deferred until Section 4. The electrical interface is simple, being relay contacts in the AGC DSKY wired to the MCP, and is described in ICD MH01-01200-216. The following AGC output discrete signals are provided:

1) G&N ATT. CONTR. MODE SELECT
2) G&N ENTRY MODE SELECT
3) G&N ΔV MODE SELECT
4) +X TRANSLATION ON/OFF
5) CM/SM SEPARATION COMMAND
6) FDAI ALIGN
7) T/C ANTENNA SWITCH
8) G&N FAIL INDICATION

9) 0.05 g INDICATION

10) GIMBAL MOTOR POWER ON/OFF

11) SPARE

2.2.2 Mission Control

Mission Control is provided by the Houston Mission Control Center (MCC) via the Digital Command System (DCS), which has many discrete inputs to the spacecraft and an UPLINK to the AGC. The discrete commands to the spacecraft and the AGC UPLINK are described in Section 3.

The AGC UPLINK provides the MCC with the capability to enter the AGC with any instruction or data which can be entered manually via the DSKY keyboard. It is not planned to utilize this full capability for mission 501 however. It is specifically planned to use this link only as described in Section 3.

2.2.3 Guidance Errors

The performance of the G&N system for mission 501 has been estimated with and without navigation data inserted via the AGC UPLINK.

The most significant G&N error is that error in the critical path angle at entry. The next most significant error is manifested in the CEP at splash.

A complete breakdown of G&N errors is given Section 7.

2.3 Mission Description

The purpose of this section is to describe G&N functions during each mission phase. Note that these functions are described in greater detail, sufficient to specify the AGC program, in Section 4.

The reference trajectory is defined in Section 6 in sufficient detail to satisfy MIT's requirements for development of guidance equations, spacecraft control logic and determination of flight environment.

Section 8 presents those path and attitude characteristics resulting from guidance control which are believed to have significant effects on other spacecraft equipment and ground support systems.

2.3.1 Pre-Launch

During this phase the IMU stable member is held at a fixed orientation with respect to the earth. The X PIPA input axis is held to the local vertical (up) by torquing the stable member about Z and Y in response to Y and Z PIPA outputs. Azimuth orientation about the X axis is held by a gyro-compassing loop such that the Z PIPA axis points down-range at an azimuth of 71.9901 degrees East of True North. Initial azimuth is determined by tracking a ground target with the G&N Sextant at T_0-8.5 hours. Upon receipt of the GUIDANCE RELEASE signal from the Saturn I.U. the stable member is released to maintain a fixed orientation in inertial space for the remainder of the mission. In this manner the Saturn and Apollo IMU stable members retain a fixed relative orientation. Also, at the time of GUIDANCE RELEASE, the G&N system starts its computation of position and velocity, which continues until SPS first cut-off. No in-flight alignment of the IMU will be performed.

2.3.2 Saturn Boost - Pre LET Jettison

The boost trajectory is described in Fig. 6-3. Upon receipt of the LIFT-OFF signal from the Saturn I.U., 6 seconds after GUIDANCE RELEASE, the AGC will command the CDU's to the time history of gimbal angles associated with the nominal SI attitude polynomials. The GUIDANCE RELEASE signal is backed up by the LIFT-OFF signal. The CDU outputs after resolution will then represent vehicle attitude errors in spacecraft axes and will be displayed on the FDAI and telemetered to the ground.

This Saturn attitude monitor is a required element of the launch vehicle malfunction detection scheme, and, in association with computed position and velocity, constitutes the Boost Monitor data, provided by the G&N system during this period.

2.3.3 Post - LET Jettison Boost

The G&N system will not have the capability to control the SIVB. The CDU's will be switched to the Fine Align Mode and the system will monitor IMU gimbal angles to detect tumbling and will compute the free-fall time to entry interface altitude (280,000 ft.) from present position and velocity. These quantities are used in the Abort Logic and, in association with computed position and velocity, constitute the Boost Monitor data provided by the G&N system during this period.

2.3.4 Earth Orbit Coast

During the entire earth coast phase those programs active in the AGC during Post - LET jettison boost are continued. The errors in the AGC's knowledge of position and velocity will be accumulative. A state-vector update from the ground is required prior to the second SIVB ignition (TLI). The AGC position and velocity errors are minimized by providing an update as late in earth orbit coast as possible.

2.3.5 CSM/ SIVB Separation

There are three CSM/SIVB separation sequences, a normal sequence, an abort sequence, and a tumble sequence. In the normal sequence after the first 30 minutes of cold-soak coast, the Saturn system initiates the separation sequence and the MESC sends a separation signal to the AGC. The AGC then commands +X translation for six seconds to assure safe physical separation. Ninety seconds later, or 96 secs after separation, the AGC initiates the first SPS burn.

In the abort sequence, the AGC detects the separation signal and in addition a ground-commanded abort signal. Six seconds after the separation signal the AGC initiates an abort burn to an Atlantic recovery area.

If tumbling is detected by the AGC when the separation signal is received, a tumble-arrest burn is started three seconds after separation. When tumbling is arrested the AGC tests for abort and proceeds either to the abort burn or to the first SPS burn of the nominal mission.

2.3.6 CSM Aborts

The only abort program provided in Mission 501 controls a posigrade burn to an Atlantic recovery area.

2.3.7 First SPS Burn

This is normally a short (40-second) burn that raises the apogee acheived by the SIVB from approximately 9000 n mi to 9400 n mi. No ullage is providedprior to this burn in accordance with Mission 501 test objectives.

2.3.8 Coast Phase

Upon completion of the first SPS burn the AGC computes T_{ff} (400, 000 ft) and tests the calculated value against a criterion to determine if the first SPS burn was nominal or an alternate burn. Upon satisfactory completion of the T_{ff} test, the AGC will command the CSM to the cold-soak attitude. This attitude is held until the AGC calls up the manuever required for the second SPS burn.

The cold-soak attitude requirements and the AGC implementation to achieve this attitude are described more fully in Section 6.

In general, the requirement is to orient the CSM such that the vector from the earth center to the sun lies nearly in the X - Z plane of the S/C, and the angle between $+X_{S/C}$ and the solar vector (measured from $+X_{S/C}$ toward $-Z_{S/C}$) is between 30^o and 120^o. The orientation of the CSM about the solar vector will be defined in light of gimbal lock and communications constraints.

At a computed time from entry interface altitude the AGC will establish the Average G routine and begin calculation of free-fall time to 400, 000 ft. Prior to this time a state-vector update is required. An update of $T_{ff(min)}$ (described in Section 2. 3. 9) is also allowed.

2. 3. 9 Second SPS Burn

The second SPS burn is initiated by a free-fall time interrupt. When the AGC calculated free-fall time falls below $T_{ff(min)}$, the AGC sets the second SPS burn ignition time as T + 10 minutes. The ground can control the second SPS burn ignition time by updating $T_{ff(min)}$ in the time interval allowed.

Nominally, $T_{ff(min)}$ will be twenty minutes so that the second SPS burn is commenced when the free-fall time to 400, 000 ft is ten minutes. The ten-minute interval from $T_{ff(min)}$ to SPS second-burn ignition is used by the AGC to orient the CSM and for the downlink second SPS burn data. Second SPS burn cut off occurs approximately four minutes before 400,000 ft entry interface altitude is reached.

2. 3. 10

When T_{ff} equals 200 seconds (about 40 seconds after second SPS cutoff in the nominal mission), the CSM is oriented to the separation attitude ($+X_{S/C}$ axis up in the trajectory plane and tipped forward in the direction of motion 60 degrees above the velocity vector).

The separation attitude is held until the T_{ff} interrupt routine causes the AGC to issue the CM/SM SEPARATION COMMAND. After a time delay to allow for separation and stabilization, the G&N system will orient the CM to the computed entry attitude. The entry guidance equations, which are given in Section 5, are designed to provide a trajectory which will satisfy heat shield test objectives while achieving the designated. Pacific splash point.

2. 3. 11 Navigation Update

The ground may update the AGC state vector during the earth parking orbit and earth-intersecting coast phases, with certain AGC logic restrictions as defined in Section 4. $T_{ff(min)}$ may be updated during the earth-intersecting coast phase. The update procedure is defined in Section.3.

3. G&N SYSTEM DESCRIPTION

This section defines the specific provisions incorporated in the G&N System to mechanize the required system operations.

3.1 G&N Hardware Configuration

System 122 will be the G&N system for Mission 501. It is a Block I Series 100 system with one modification; the wiring of 11 spare relays and a special failure module in the main DSKY to the MCP to provide the AGC/MCP signal interface. A Block I Series 100 system is comprised of the following assemblies:

(a) Inertial Subsystem — Block I Series 100
- Inertial Measurement Unit (IMU)
- Inertial System CDU's (electro-mechanical) (ICDU's)
- Power Servo Assembly (PSA)
- IMU Control Panel

(b) G&N Harness — Block I Series 100

(c) Computer Subsystem — Block I Series 100
- Apollo Guidance Computer (AGC)
- Display and Keyboard (DSKY - Main Display Console)
- Display and Keyboard (DSKY - Lower Equip. Bay)
- Computer Harness

(d) Optics Subsystem — Block I Series 100
- Scanning Telescope (SCT)
- Sextant (SXT)
- Optical System CDU's (OCDU's)
- Power Servo Assembly (PSA)

Without giving a detailed analysis of each G&N Block configuration, a brief description of each and the reason for its evolution is useful in understanding G&N capabilities for Mission 501.

Block I is the original G&N design. It is composed of IMU, AGC, PSA, CDU's (mechanical), Harnesses, and OPTICS (sextant and telescope.) As the G&N flight requirements became more clearly defined it was apparent that Block I would need modification to qualify for flight.

Block I, Series 100 therefore evolved. It is the Block I system modified generally as follows:

(a) IMU - Vibration dampers added; moisture insulation added.
(b) AGC - Cooling interface modified; humidity proofing added.
(c) PSA - Cooling interface modified; humidity proofing added.
(d) CDU's - Minor electrical and mechanical changes.
(e) Harnesses - All wiring changed to teflon; connectors humidity proofed.
(f) OPTICS - Minor servo modifications.

When the full design and production schedule impact of the Series 100 modifications became clear the Block I Series 50 configuration was originated, being a limited 100 Series modification qualified for flight and available on an early schedule.

3.2 G&N/Spacecraft Signal Interfaces

3.2.1 Interface Controlling Documents (ICD's)

Below are listed the ICD's which are pertinent to an understanding and definition of the operational interfaces between the G&N system and the SC/BOOSTER. The majority of these are electrical ICD's (including in some cases function definitions). All of the additional existing ICS's pertaining to mechanical interfaces, thermal interfaces, material compatibility et cetera have not been listed as they are considered not to be within the scope of this document.

General Interfacing Area	ICD Title	ICD No.	Description
G&N/VEHICLE	Launch Vehicle to G&N Interface	MH01-01278-216	Signal interface and description: a) GUIDANCE REFERENCE RELEASE b) LIFTOFF c) SIVB ULLAGE*
" "	Vehicle Separation Signals to AGC	MH01-01280-216	Signal interface and description: a) CSM/SIVB SEPARATION (ABORT) b) CM/SM SEPARATION*
G&N/MCP	Outputs - AGC to Mission Control Programmer	MH01-01200-216	For detailed description refer to Section 3.2.2
G&N/SCS	Attitude Error Signal (see Fig. 3-1 also)	MH01-01224-216	Signal interface for: a) PITCH ERROR (BODY and BODY OFFSET) b) YAW ERROR (BODY) c) YAW ERROR (BODY OFFSET)

*Note: Not required for Mission 501.

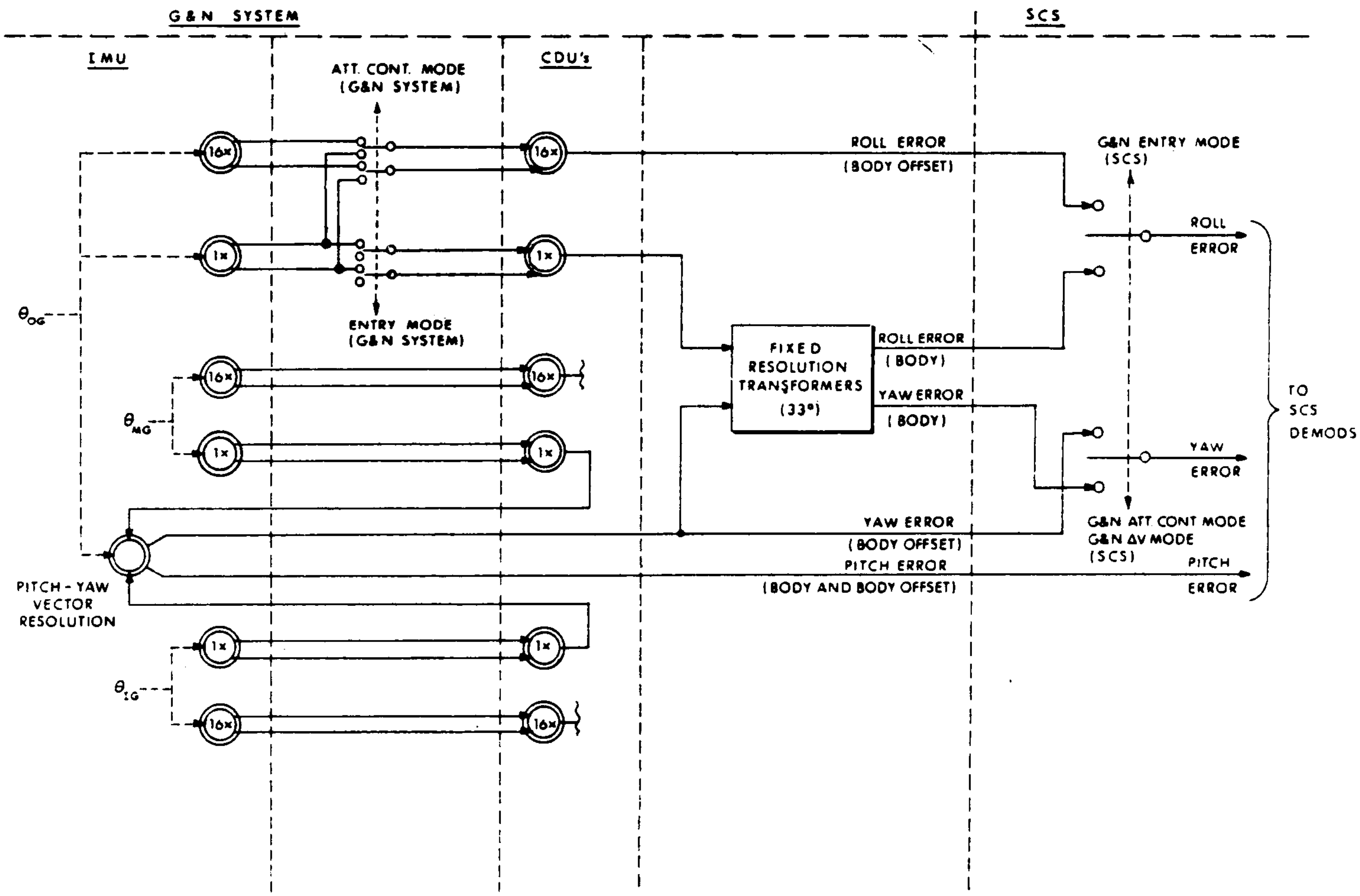


Fig. 3-1 G&N attitude error signal generation to SCS.

General Interfacing Area	ICD Title	ICD No.	Description
			d) ROLL ERROR (BODY) e) ROLL ERROR (BODY OFFSET) f) ERROR SIGNAL REFERENCE
" "	Total Attitude Signals	MH01-01225-216	Signal interface for: a) SINE AIG b) COS AIG c) SINE AMG d) COS AMG e) SIN AOG f) COS AOG g) ATTITUDE SIGNAL REFERENCE
" "	Engine ON-OFF Signal to SCS	MH01-01238-216	Electrical interface for the AGC command to the SPS engine.
G&N/UP and DOWN TELEMETRY SYSTEMS	Data Transmission to Operational PCM T/M equipment	MH01-01228-216	Electrical interface for all G&N PCM measurements. Should agree with information in Section 3.5.3.
" "	ACE Uplink, S/C Digital Up Data Link, Apollo Guidance Computer	MH01-01236-200	Electrical interface between AGC and S/C Updata Link Receiving equipment. Used both for receipt of ACE UPLINK transmissions during ground checkout and AGC UPLINK transmissions from ground during flight.
G&N/S/C/POWER	Guidance and Navigation Electrical Input Power	MH01-01227-216	Total AC and DC power specification from S/C for G&N

General Interfacing Area	ICD Title	ICD No.	Description
MISCELLANEOUS	Central Timing Equipment Synchronizing Pulse	MH01-01226-216	Electrical interface for G&N "SYNCH" pulse to S/C Central Timing System.

3.2.2 AGC Outputs to MCP

This interface is documented in ICD No. MH01-01200-216 and provides 11 relay closures in the main DSKY and 1 relay closure in the G&N Failure Detection Module. These relays provide functions as described below:

(1) G&N ATTITUDE CONTROL MODE SELECT

(2) G&N ENTRY MODE SELECT

(3) G&N ΔV MODE SELECT

(4) +X TRANSLATION ON/OFF

(5) CM/SM SEPARATION COMMAND

(6) FDAI ALIGN

This signal brings the backup attitude reference system (BMAG's caged to AGCU) to a zero reference determined by the current vehicle attitude. When initiated, the signal will be continued for 10 seconds.

(7) T/C ANTENNA SWITCH

The requirement for AGC control of T/C antenna switching has been deleted. This AGC output relay is now a spare; however its arming is under the control of the MCP, subject to the original logic designed for the T/C ANTENNA SWITCH function. (Refer Figure 3-2.)

(8) .05G INDICATION

G&N will sense .05G with the PIPA's, give this indication to the SCS (via the MCP) and the SCS system will inhibit pitch and yaw attitude control on the assumption that these axes will be stabilized by aerodynamic forces. Should the G&N .05G indication not be received by the MCP/SCS this attitude control would not be inhibited, and if sufficient pitch and yaw attitude errors are generated, RCS fuel would be wasted throughout entry.

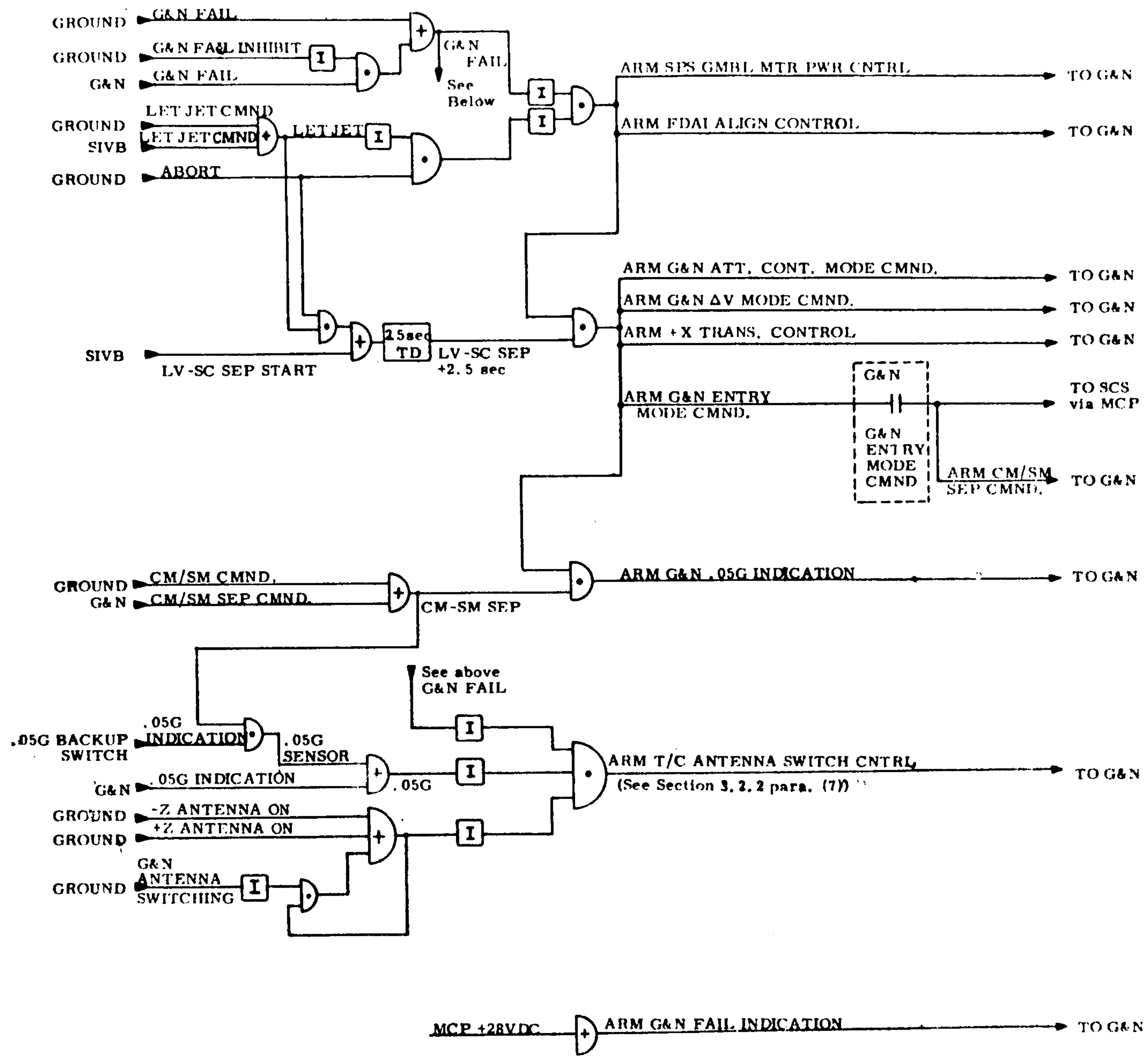


Fig. 3-2 Arming logic for G&N/MCP interface

The G&N entry program will attempt to null the pitch and yaw error signals during entry based on its estimation of the pitch and yaw trim angles of attack. MIT estimates that the resulting pitch and yaw attitude errors will not exceed the deadbands in the SCS. Should this be incorrect RCS fuel loss will occur. The G&N .05G indication is not used within the re-entry program, however, so should this function be backed up by a redundant CM sensor no AGC confusion should result.

(9) GIMBAL MOTOR POWER ON/OFF

The AGC must terminate SPS GIMBAL MOTOR POWER in order to key the MCP to select the appropriate SPS motor gimbal trim inputs.

(10) SPARE

There is one spare relay with no assigned function.

(11) G&N FAIL INDICATION

This signal is generated by the G & N Failure Detection Module. This module is mounted at the rear of the main DSKY and is electrically interposed between the NAA harness to the DSKY and the DSKY itself. The module operation is described in detail in Section 3. 6. Its operation with respect to the total G & N Failure Monitor System is shown in Fig. 3-3.

3.2.3 Detailed Interface Operation

Certain additional facts are pertinent to the use and comprehension of the AGC/MCP interface:

(1) The AGC must not command more than one SCS mode simultaneously. This requires termination of each mode before commanding the next; 250 ms has been established as sufficient time interval between termination and selection.

(2) The response of the SCS system to the commands and/or indication signals of the AGC via the MCP are subject to the arming of these command/indications by the MCP. The arming logic for the G&N/MCP interface is as shown in Figure 3-2.

(3) In all cases the MCP initiates the SIVB/CSM Separation Sequence. For normal cases its action is keyed upon notification from the Saturn. I. U. For boost aborts the ground must command the MCP to start the sequence.

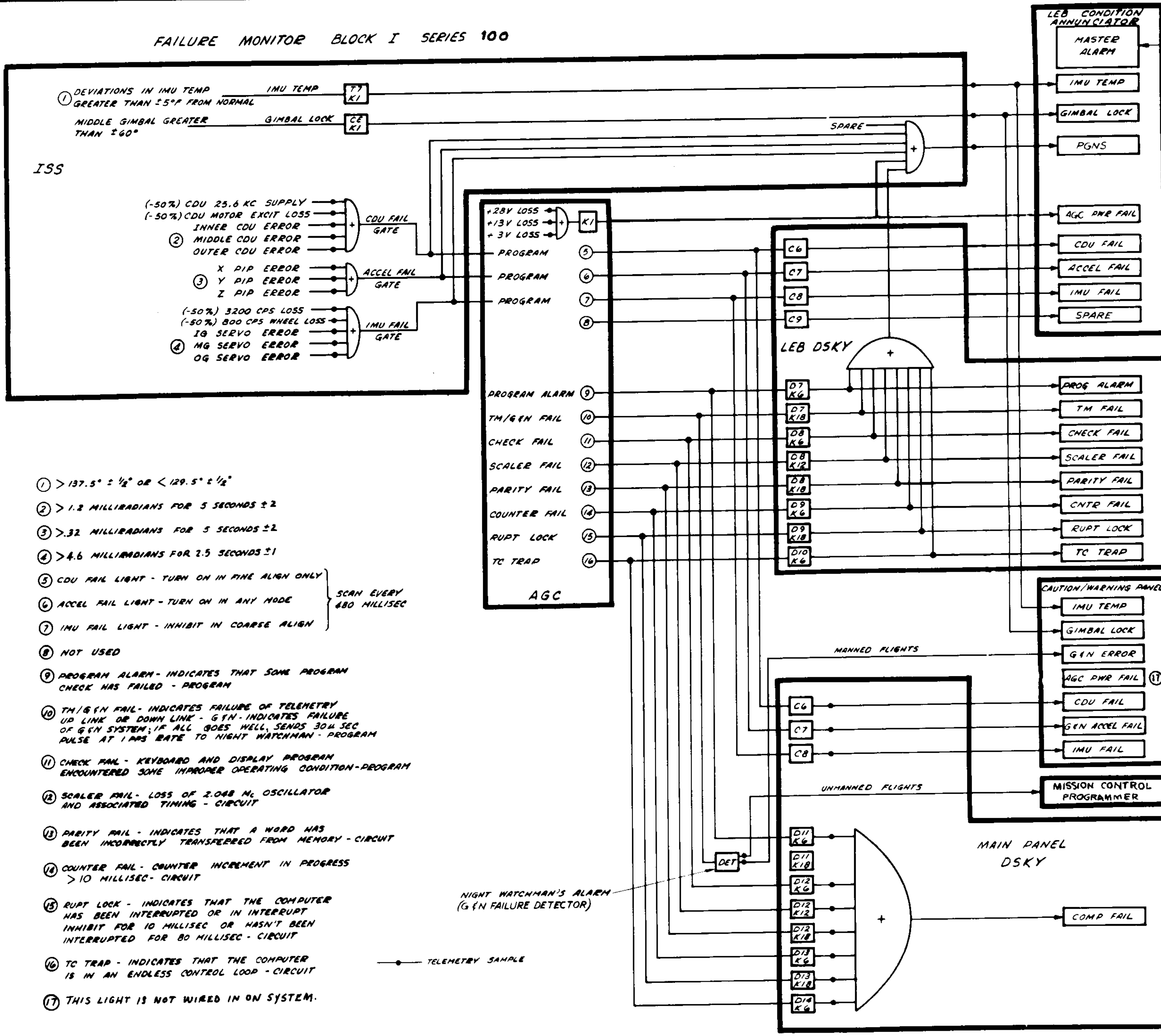


Fig. 3.3 G&N FAILURE MONITOR SYSTEM

3.3 Ground Commands

3.3.1 Digital UPLINK to AGC

By means of the AGC UPLINK, the ground can insert data or instruct the AGC in the same manner normally performed by the crew using the DSKY Keyboard. The AGC will be programmed to accept the following UPLINK inputs:

(1) SPS Gimbal Motor Power On/Off
(2) Liftoff (backup to discrete input)
(3) SIVB/CSM Separation (backup to discrete input)
(4) FDAI Align
(5) Abort Indication (required for abort logic as described earlier)
(6) State Vector Update (provides ground capability to update navigation data in the AGC)
(7) TFF MIN Update (provides ground capability to update T_{ff} criteria)
(8) L/O Time Update (provides ground capability to update AGC version of GET by updating the AGC Clock and DTEPOCH)
(9) AGC Clock Alignment

Operational procedures governing the use of these Uplink inputs must be developed to ensure proper operation within program constraints.

All infomation received by the AGC from the Uplink is in the form of keyboard characters. Each character transmitted to the AGC is triply redundant. Thus, if C is the 5-bit character code, then the 16-bit message has the form:

$$1C\bar{C}C$$

where $\bar{C}$ denotes the bit-by-bit complement of C. To these 16 bits of information the ground adds a 3-bit code specifying which system aboard the spacecraft is to be the final recipient of the data and a 3-bit code indicating which spacecraft should receive the information. The 22 total bits are sub-bit encoded (replacing each bit with a 5-bit code for transmission). If the message is received and successfully decoded, the receiver onboard will send back an 8-bit "message accepted pulse" to the ground and shift the original 16 bits to the AGC ($1C\bar{C}C$).

All uplink words given in this section are in the form transmitted from the uplink receiver to the AGC. Therefore they do not contain the vehicle or subsystem addresses added on by the ground facilities. For the purpose of this section, the following definitions hold.

(1) 1 uplink word = 1 character
(2) 5 characters or uplink words = contents of one AGC register

3.3.2 SPS Gimbal Motor Power On/Off

To turn the SPS Gimbal Motors on or off the following message must be sent

Verb 75 Enter	Refer to Table 3-1
X Enter	for codes

where the X above is a 1 if the motors are to be turned on or a 2 if they are to be turned off.

3.3.3 Liftoff

To provide a backup to the liftoff discrete the following message must be sent

Verb 75 Enter	Refer to Table 3-1
3 Enter	for codes

3.3.4 SIVB/CSM Separation

To provide a backup to the SIVB/CSM separation discrete the following message should be sent

Verb 75 Enter	Refer to Table 3-1
4 Enter	for codes

3.3.5 FDAI Align

To start an FDAI ALIGN sequence (terminated by program after 10 sec) the following message must be sent

V 75 Enter	Refer to Table 3-1
5 Enter	for codes

3.3.6 Abort Indication

To send an abort message to the AGC, the following special binary code should be sent via the uplink

1 10011 01100 10011	Abort

3.3.7 State Vector Update

To begin a state vector update on flight 501 the AGC must be in either P14 or P24 and the following 4 words must be sent via the uplink

Verb 76 Enter	Refer to Table 3-1 for codes

The AGC will then switch to P27 withthe resultant change in downlink list (see sec. 3.4).

In P27 the AGC will accept a complete ground navigation update in the format to be described.

The data itself will take the form of three (3) double-precision components of position, three (3) double-precision components of velocity, and double-precision time. The position and velocity components should be given in navigation ECI coordinates (see sec. 2.3.1) and the time should be in the time of the "fix" referenced to AGC CLOCK ZERO. The data must be sent in the following sequence:

Octal Identifier			
1	XXXXX	(most sig. part of X position)...	ENTER
2	XXXXX	(least sig. part of X position)...	ENTER
3	XXXXX	(most sig. part of Y position)...	ENTER
4	XXXXX	(least sig. part of Y position)...	ENTER
5	XXXXX	(most sig. part of Z position)...	ENTER
6	XXXXX	(least sig. part of Z position)...	ENTER
7	XXXXX	(most sig. part of X velocity)...	ENTER
10_8	XXXXX	(least sig. part of X velocity)...	ENTER
11_8	XXXXX	(most sig. part of Y velocity)...	ENTER
12_8	XXXXX	(least sig. part of Y velocity)...	ENTER
13_8	XXXXX	(most sig. part of Z velocity)...	ENTER
14_8	XXXXX	(least sig. part of Z velocity)...	ENTER
15_8	XXXXX	(most sig. part of time from AGC clock zero).............	ENTER
16_8	XXXXX	(least sig. part of time from AGC clock zero).............	ENTER

where each "X" and "ENTER" above represents an uplink word. If, for some reason, the ground wishes to resend any 5-uplink word group before the ENTER associated with that group has been transmitted, the "CLEAR" word should be sent and the 5-word group retransmitted.

After the Enter associated with the least sig. part of time, the AGC will wait for the ground to verify the parameters received by the AGC. This verification can make use of the special update downlist (see Sec. 3.4). The AGC indicates that it is waiting for this verification by flashing 21 02 in the Verb and Noun lights of the DSKY (21 01 was flashed when the data were being entered).

The ground station now has the following three options.

(1) If the update has a lot of components in error, the ground may terminate the load with a verb 34 Enter (a V34E will terminate the load at any time during P27) and the AGC will go back to P14 or P24, depending upon which had been on at beginning of P27.

(2) If the update is correct in all components, the ground will command the AGC to accept the update with a Verb 33 Enter (a V33E sent before V21 N02 is displayed will be ignored by the AGC) and the AGC will go back to P14 or P24 after setting the UPDATFLG (this flag is reset by either the average-G or orbital integration program when the data are used or by the initiation of another V76 update).

(3) If only a few components are in error, the ground may change one component at a time by sending the octal identifier of the component to be changed followed by an Enter, ie, 16 Enter, for the least sig. part of time (the DSKY will display V21 N01 after the octal identifier is entered; an octal identifier not between 1 and 16_8 will be ignored). The ground should then send the correct contents of that register followed by an Enter at which time the DSKY will again display V21 N02. This procedure may be repeated any number of times.

If a V76 update is attempted in any program other than P14 or P24, a "Check Fail" indication will be given and P27 will not be entered.

If the AGC receives an improperly coded word from the uplink receiver during the load (not $C\bar{C}C$), it will turn on bit 4 of OUT 1 which is transmitted via Downlink (see Sec. 3.4). When this occurs the ground station should send the following 3 uplink words:

Binary Uplink Word ($1C\bar{C}C$)	Equivalent Character (C)
1 00000 00000 00000	(to clear uplink buffer)
1 10010 01101 10010	ERROR RESET
1 11110 00001 11110	CLEAR

The ground station should then begin loading with the first word of the 5-word group it was sending when the alarm condition occurred.

If insufficient time remains,the AGC will change its program (out of P27) and proceed with the internally computed data.

The scale factors for AGC navigation updating are:

position	meters/2^{24}
velocity	(meters/C.S.)/2^7
"fix" time	C.S./2^{28}

(one C.S. = 0.01 sec)

The AGC is a fixed-point machine with the point just to the left of the most significant bit.

The scaling indicated above will be sufficient to force the 3 components of position and the 3 components of velocity and time to numbers less than one.

To form the double-precision quantities ready for coding and transmission the scaled magnitudes of time and each component of position and velocity should be expressed as two binary words as follows:

1st word	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}	2^{-9}	2^{-10}	2^{-11}	2^{-12}	2^{-13}	2^{-14}
2nd word	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		2^{-15}	2^{-16}	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}	2^{-24}	2^{-25}	2^{-26}	2^{-27}	2^{-28}

Each X above represents a binary bit of the appropriate magnitude, the place value of which is indicated below the corresponding X. Once the magnitude of the component is accounted for in the above 28 X's, the sign must be considered.

If the component is positive, the words remain as formed; if the component is negative, the "1's complement" of the 2 words is used (all 1's are replaced by 0's and all 0's by 1's).

The first word is then transformed into a 5-character octal word. The first character is the octal equivalent of the first three bits, the second character is the octal equivalent of the next three bits, et cetera. This word is referred to as the "most significant part" of data in the text above. Similarly the second word is transformed into a 5-character octal word which is the "least significant part" of data.

Each character must now be coded into a 16-bit uplink word for transmission. A table of the characters and their uplink-word is given in Table 3-1.

3.3.8 TFF MIN Update

To begin a TFF MIN update on flight 501 the AGC must be in either P14 or P24 and the UPDATFLG must be reset. The following 4 words must be sent via the uplink Verb 71 Enter (refer to Table 3-1 for codes). The AGC will then switch to P27 with the resultant change in downlink lists (see Sec. 3.4).

The data must be sent in the following order

Octal Identifier			
1	XXXXX	(most sig. part of TFF MIN)	ENTER
2	XXXXX	(least sig. part of TFF MIN)	ENTER

where each "X" and "ENTER" above represents an uplink word. If, for some reason, the ground wishes to resend any 5-uplink word group before the ENTER associated with that group has been transmitted, the "CLEAR" word should be sent and the 5-word group retransmitted.

The procedure for verifying, terminating, or making single line changes is the same as the procedure described in detail in Sec. 3.3.7 for the V76 update except that only octal identifiers 1 and 2 are not ignored and the UPDATFLG is not set after Verb 33 Enter.

A "Check Fail" indication will be given and P27 will not be entered if a V71 update is attempted when the AGC is not in P14 or P24 or when the UPDATFLG is set. The scale factors and coding for TFF MIN are the same as for the state vector time given in Sec. 3.3.7.

3.3.9 L/O Time Update

To begin a L/O time update on flight 501, the AGC must be in either P14 or P24 and the UPDATFLG must be reset. The following 4 words must be sent via the uplink Verb 77 Enter (refer to Table 3-1 for codes). The AGC will then switch to P27 with the resultant change in downlink lists (see Sec. 3-4).

The data must be sent in the following manner XXXXX Enter where the 5X's represent 5 octal characters which give centiseconds with a scale factor of 2^{-14}. The DSKY will display V21 N02 after the "Enter" is received and the procedure for verifying, terminating, or making single line changes is the same as the procedure described in Sec. 3.3.8 for the V71 update except that only an octal identifier of 1 is not ignored. The conditions producing a "Check Fail" indication are the same.

3.3.10 AGC Clock Align

To align the AGC clock two procedures are required. To set the AGC clock to a specific value, the following uplink words must be sent.

Verb 21 Noun 16 Enter (refer to Table 3-1 for codes)

This must be followed by ± XXXXX ENTER where each X represents one decimal digit, properly coded, and the total number represents the time in C.S. that will be set into the AGC clock. If it is required to zero the clock, all the X's should be zeros.

Since there are uncertainties in time of transmission, etc., it is anticipated that a time increment may be needed. To increment the AGC clock, the following uplink words must be sent

Verb 55 Enter (refer to Table 3-1 for codes)

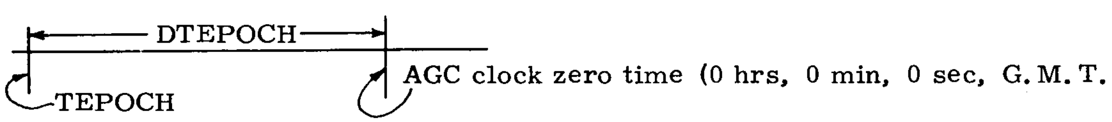
This must be followed by ± XXXXX ENTER where the total number represents the time increment in C. S.

The AGC must have had the latitude, azimuth, and time DTEPOCH (described below) loaded as three double-precision quantities during erasable memory initialization. The AGC uses these quantities to generate the matrix which relates the reference inertial-coordinate system to the stable member coordinate system. To do this the reference system must be rotated thru the following angles in the order given below.

(1) About reference Y-axis thru latitude angle of local vertical.

(2) About reference Z-axis thru the angle equal to the earth's angular rate times (DTEPOCH + AGC clock reading at G. R. R.); the Z axis of the reference coordinate must be parallel to the earth's spin axis and TEPOCH must be the time that the local vertical vector passed thru the +X +Z plane of the reference inertial system.

(3) About the local vertical vector (the SM desired X-axis) thru the azimuth angle (positive rotation is clockwise looking towards center of the earth).



The following restraints must be observed on the magnitudes of the times shown above.

(1) |DTEPOCH + AGC clock| at guidance reference release must be less than 2^{28} C.S. Since the AGC must use this time to determine the inertial platform coordinates at guidance reference release.

The AGC clock will be zeroed when it senses L/O and DTEPOCH will be changed accordingly.

TABLE 3-1

Character	Uplink Word
0	1 10000 01111 10000
1	1 00001 11110 00001
2	1 00010 11101 00010
3	1 00011 11100 00011
4	1 00100 11011 00100
5	1 00101 11010 00101
6	1 00110 11001 00110
7	1 00111 11000 00111
8	1 01000 10111 01000
9	1 01001 10110 01001
VERB	1 10001 01110 10001
NOUN	1 11111 00000 11111
ENTER	1 11100 00011 11100
ERROR RESET	1 10010 01101 10010
CLEAR	1 11110 00001 11110
KEY RELEASE	1 11001 00110 11001
+	1 11010 00101 11010
-	1 11011 00100 11011
ABORT	1 10011 01100 10011

NOTE: It is good operation procedure to end every uplink message with a KEY RELEASE.

3.4 AGC Digital Downlink

The AGC digital downlink consists of 50 words/sec on the high rate and 10 words/sec on the low rate. Each "word" contains 40 bits (a 16-bit register transmitted twice and an 8-bit "word order code"). Since the high rate will be used exclusively for flight 501, all further discussion will use the 50 words/sec rate.

The 40 bits of the word are shown below.

X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	P
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	P
X	X	X	X	X	X	X	X								
			W.O.C.												

where each X above represents a binary bit. The first 15 bits above carry the downlink information and the 16th bit provides odd parity for the first 16 bits. The second 16 bits are an exact reproduction of the first 16. The last eight bits are known as the Word Order Code and are used to distinguish between data words and ID or marker words. All eight-word order code bits are the same (0 for data words, 1 for ID and marker words.)

The digital downlink format is controlled by an AGC program which loads the next word to be transmitted into register OUT4. This program is entered on an interrupt caused by an "endpulse" from the telemetry system.

Before giving details of the AGC downlink a few important points on the downlink should be reviewed. Most of the downlink words are actually the contents of erasable memory registers which are used during the normal computations in the AGC. There is no special buffer set aside for telemetry words because of erasable memory size restrictions. The programs that use these erasable registers have no set phase relationship with the downlink program and, therefore, data which take more than one downlink word to transmit (i.e. double precision words, vectors, etc.) may have words from two different computation cycles. Some of these data arrays are associated with "markers" as explained in the following paragraphs.

Most telemetered parameters have negative numbers represented in ones complement form (exceptions will noted in detailed parameter description to follow). The sign information is carried in bit 15 (1 for minus, 0 for plus) and, in general, the signs of the most and least significant portions will not agree. The procedure for obtaining the sign and magnitude of a double-precision word with sign disagreement is as follows.

The first bit of each word indicates the sign of that word (1 for minus, 0 for plus) and the next 14 bits give the magnitude (in ones complement for minus signs). With double-precision words, the most significant word and the least significant word may have different signs. If either of the words has a magnitude of 0, the complement of that word should be used to force sign agreement. If neither word has a 0 magnitude, the following procedure should be followed. Examples are given for each case using words of 6 bits, 1 sign bit and 5 magnitude bits.

Case 1 Most Significant word sign bit equals 1

Least Significant word sign bit equals 0

Complement magnitude bits of most significant word and subtract magnitude bits of least significant word as in example below. The sign of the total quantity is minus

Most significant word equals 110011

Least significant word equals 001010

	01100	00000
		01010
Minus	(01011	10110)

Case 2 Most significant word sign bit equals 0

Least significant word sign bit equals 1

Complement magnitude bits of least significant word and subtract from most significant word as shown in example below. The sign of the total quantity is plus.

Most significant word equals 010011

Least significant word equals 101010

	10011	00000
		10101
Plus	(10010	01011)

The AGC is a fixed-point machine with the binary point assumed between bit 15 and bit 14. The scale factors included later in this section give the units divided by the proper number to cause the value of the parameter to be less than one. The bit weights for a double-precision word are:

Most Sig:

Sign 2^{-1} 2^{-2} 2^{-3} 2^{-4} 2^{-5} 2^{-6} 2^{-7} 2^{-8} 2^{-9} 2^{-10} 2^{-11} 2^{-12} 2^{-13} 2^{-14}

Bit Number:

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Least Sig:

Sign 2^{-15} 2^{-16} 2^{-17} 2^{-18} 2^{-19} 2^{-20} 2^{-21} 2^{-22} 2^{-23} 2^{-24} 2^{-25} 2^{-26} 2^{-27} 2^{-28}

The bit weights for a single-precision word are the same as those given for most sig. above.

The actual downlink formats are organized into 100-word lists. Each list, therefore, requires 2 sec to complete on the high bit rate. The general format for AGC downlink lists is given in Fig. 3.3. The seven phases referred to correspond to phases of the downlink program for Mission 501. For Flight 501 there are only two lists, the nonupdate list, which is transmitted throughout the flight except for the period of time the AGC is in P27 because of a V71, V76, or V77 update (see sec. 3.3), and the update list, which is transmitted during the period mentioned above. A computer restart while transmitting the update list may cause a premature return to the non-update list. With the exception of restarts, the list switches are only made in phase 1 and, therefore, the switchover occurs only after the list has been completely cycled through. If no update is attempted, the update list will never be transmitted during Flight 501.

Marker words are used to identify when updating of certain data words has been accomplished. When a marker word is sent, bit 9 of OUT 1 = 1, causing the word order code bits to be 1's. Marker words will not be transmitted during phases 1, 2, or 5.

There is a cell in the AGC's erasable memory called "TMMARKER". In phases 3 and 6, this cell is checked before a word is telemetered. If it is zero, then the normal word is sent. If it is non-zero, the contents of TMMARKER are added to 74000_8, (making bits 15 through 12 1's), bit 9 of OUT 1=1, and the quantity is placed in the telemetry output register of the computer (register OUT 4). The marker counter is decreased by 1. The setting of bit 9 of OUT 1-1 causes the word order code to be a 1: if data words are transmitted, this bit is set to 0. "TMMARKER" is set to zero after being sampled.

In phases 4 and 7, the process in the previous paragraph is performed unconditionally (i.e., regardless of whether the contents of TMMARKER are zero or not). Whenever a marker word is sent, the "marker count" is reduced by 1; since it is preset to 3 at the start of phase 3 and phase 6, the proper synchronism of output words is maintained. When the counter reaches zero, phase 4 (or 7) is terminated. If the contents of TMMARKER are zero, the terminology "dummy marker" is employed: note that it is not necessarily true that only dummy markers are sent in phase 4 and phase 7. In phase 3 and 6, the counter is not less than 0.

Only the least significant three bits of TMMARKER are set in the program. Bit 1 (called "Marker 1") is set to 1 after the PIP registers have been sampled and a new value for PIPTIME loaded. This action affects words 29-31 and words 78-79 of the non-update list. Marker 1 will be generated each 0.5 second before GRR is sensed, each 2.0 seconds between GRR and about 10.5 seconds after SPS1 cutoff, each 2.0 seconds between SPS2-30 seconds and splash, and each 2.5 seconds if an abort is encountered (reverting to 2.0 seconds when entry computations are started).

Phase No.	Word No.	Contents
1	1	ID WORD
2	2 ... 15	DSPTAB
	16 .. 27	COMMON GROUP
3	28 .. (48 + K)	PART A & K MARKERS
4	(49 + K) ... 51	DUMMY MARKERS OR ACTUAL MARKERS
5	52 ... 65	DSPTAB
6	66 ... (97 + J)	PART B & J MARKERS
7	(98 + J) ... 100	DUMMY MARKERS OR ACTUAL MARKERS

Fig. 3. 3 General AGC Downlink Format

Bit 2 (called "Marker 2") is set after position and velocity have been updated in the navigation computations. This action affects words 66-77 of the non-update list. Marker 2 will be generated each 2.0 seconds between GRR and the end of the local vertical phase, and each 2.0 seconds between SPS2-28 seconds and splash. It will be generated each 2.5 seconds if an abort is encountered (reverting to 2.0 seconds when entry computations are started). Interrupts are inhibited by the program from affecting words 66-77 while they are being updated and Marker 2 generated (a similar statement applies to the other two markers). The events flagged by Marker 1 and Marker 2 occur fairly close together in the program. The Navigation computations are employed to assist in maintaining local vertical (hence Marker 2 lasts longer than Marker 1 after SPS1 cutoff).

Bit 3 (called "Marker 3") is set after the desired value(s) of the CDU angles have been determined. This action affects words 32-34 of the non-update list. It is set at the normal computation cycle rate of once per 2 seconds for entry and once per 2.5 seconds for abort. During entry, it is related to word 32 of the non-update list (words 33 and 34 are also changing, but are not flagged by Marker 3).

The contents of TMMARKER are modified independently by these three bits; consequently, more than one of the three might be 1 for the same downlink word. It is reset only when being sampled for downlink transmission. So, if a Marker takes place during a telemetry phase when no markers are being sent, it will be sent at the next marker opportunity.

A list of the non-update format is given below. Word numbers which are followed by asterisks indicate the word may shift position due to marker words as explained in the preceeding paragraph.

W.O.C.	WD/NO.	DATA WORD	REMARKS
Pase 1			In this phase the check is made of whether the "normal" or the "uplink" list is to be sent and a cell set with the proper quantity accordingly.
1	1	ID WORD	ID word equals 110010000110111l. Bit 9 of OUT1=1 (Causes word order code to be 1's) ID different for uplink list. Least significant 11 bits are corresponding bits of "starting address" of non-uplink list (address of cell specifying final word to be sent).
Phase 2			In this phase "common List A" is sent consisting of 26 words. No markers are sent.
0	2	DSPTAB+0	Display
0	3	DSPTAB+1	Display
0	4	DSPTAB+2	Display
0	5	DSPTAB+3	Display
0	6	DSPTAB+4	Display
0	7	DSPTAB+5	Display
0	8	DSPTAB+6	Display
0	9	DSPTAB+7	Display
0	10	DSPTAB+8D	Display
0	11	DSPTAB+9B	Display
0	12	DSPTAB+10D	Display
0	13	DSPTAB+11D	Moding relays in DSKY
0	14	DSPTAB+12D	Moding relays in DSKY
0	15	DSPTAB+13D	MCP relays
0	16	Time 2 (most sig. bits)	AGC Clock Register

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	17	time 1 (least sig. Bits)	AGC Clock Register
0	18	IN 0	An input register
0	19	IN 2	An input register
0	20	IN 3	An input register
0	21	OUT 1	An output register
0	22	STATE	15 bits individually assigned meanings as flags, give information on state programs.
0	23	FLAGWRD 1	15 bits individually assigned meanings as flags, give information on state of programs
0	24	FLAGWRD 2	" " " " "
0	25	CDU X	Register gives actual X CDU angle
0	26	CDU Y	Register gives actual Y CDU angle
0	27	CDU Z	Register gives actual Z CDU angle

W.O.C.	WD/NO.	DATA WORD	REMARKS
Phase 3			In this phase "particular list A" is sent, consisting of 21 words. In addition, markers words will be sent if indicated, and a marker word takes precedence over data. A "marker counter" is set to 3 at the start of this phase and decremented whenever a marker word is sent; in Phase 4 marker "Dummy" words are sent until the counter is decremented to 0.
0	28*	REDO CNTR	REDOCNTR: a counter counting the number of restarts performed by the computer(a restart is caused by various difficulties such as a one-step loop, a power transient, a parity failure, etc.)
0	29*	DELV X	DELV X component of velocity increment. May be identical to X PIP sample if bias and scale factor correction small (amounting to less than one count), or if telemetered at the appropriate (small) time interval.
0	30*	DELV Y	DELVY, Y component of velocity increment. Similar comments to word 29.
0	31*	DELV Z	DELVZ Z component of velocity increment. Similar comments to word 29.

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	32*	THETAD +0	AGC register which gives desired CDU X angle
0	33*	THETAD + 1	AGC register which gives desired CDU Y angle
0	34*	THETAD + 2	AGC register which gives desired CDU Z angle
0	35*	RRECT+0 (most sig. bits of Xpos)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	36*	RRECT+1 (least sig.bits of X pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	37*	RRECT+2(most sig.bits of Y pos.)	SPS1 tailoff state vector component to be used in orbital integration program this register is time shared.
0	38*	RRECT+3(least sig. bits of Y pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	39*	RRECT+4(most sig. bits of Z pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	40*	RRECT+5(least sig. bits of Z pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	41*	VRECT+0(most sig. bits of X vel).	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	42*	VRECT+1(least sig. bits of X Vel.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	43*	VRECT+2(most sig. bits of Y vel.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	44*	VRECT+3(least sig. bits of Y vel.)	SPS1 tailoff state vector component to be used in orbital integration program,this register is time shared.
0	45*	VRECT+4(most sig. bits of Z vel).	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	46*	VRECT+5(least sig. bits of Z vel).	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	47*	T_{FF}(most sig. sig. bits)	Time of free-fall
0	48*	T_{FF} +1(least sig, bits)	Time of free-fall
Phase 4			In this phase the "marker counter" is checked (it was set in Phase 3 start) and "Dummy" markers equal to the present value of the marker counter(in number) are sent. If 3 different marker words were sent in Phase 3, nothing is sent in Phase 4; if no markers words were sent in Phase 3, three "Dummy" markers words are sent in Phase 4 etc.
1	49*	TM MARKER	Dummy markers if actual markers have not occurred above.
1	50*	TM MARKER	Dummy markers if actual markers have not occurred above.
1	51*	TM MARKER	Dummy markers if acutal markers have not occurred above.
			In this phase "common list B" is sent, consisting of 14 words.

W.O.C.	WD/NO.	DATA WORD	REMARKS
Phase 5			No markers are sent. Because of Phase 4, the "word number" is valid.
0	52	DSPTAB+0	Displays
0	53	DSPTAB+1	Displays
0	54	DSPTAB+2	Displays
0	55	DSPTAB+3	Displays
0	56	DSPTAB+4	Displays
0	57	DSPTAB+5	Displays
0	58	DSPTAB+6	Displays
0	59	DSPTAB+7	Displays
0	60	DSPTAB+8D	Displays
0	61	DSPTAB+9D	Displays
0	62	DSTAB+10D	Displays
0	63	DSTAB+11D	Moding relays in DSKY
0	64	DSTAB+12D	Moding relays in DSKY
0	65	DSPTAB+13D	MCP relays
Phase 6			In this phase "particular list B" is sent, consisting of 32 words In addition, marker words will be sent (see discussion under Phase 3). The "marker counter" is set to 3 at the start of this phase.
0	66 *	R_N+0(most sig. bits)	Output of average G routine
0	67*	R_N+1 (least sig. bits)	Output of average G routine

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	68*	R_N+2 (most sig. bits)	Output of average G routine
0	69*	R_N+3 (least sig. bits)	Output of average G routine
0	70*	R_N+4 (least sig. bits	Output of average G routine
0	71*	R_N+5 (least sig. bits)	Output of average G routine
0	72*	V_N+0 (most sig. bits)	Output of average G routine
0	73*	V_N +1 (least sig. bits)	Output of average G routine
0	74*	V_N+2 (most sig. bits)	Output of average G routine
0	75*	V_N+3 (least sig. bits)	Output of average G routine
0	76*	V_N+4 (most sig. bits)	Output of average G routine
0	77*	V_N +5 (least sig. bits)	Output of average G routine
0	78*	PIPTIME (most sig. bits)	Time that the PIP registers are read and therefore the time corresponding to position and velocity above during average G task and time for VRECT and RRECT after they are frozen
0	79*	PIPTIME +1 (least sig. bits)	
0	80*	TIME 2 GR (most sig. bits)	
0	81*	TIME 2 GR+1 (least sig. bits)	2 registers which contain the time of guid. ref, release these registers are time shared

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	82*	TCUTOFF (most sig. bits)	2 registers which contain the time of lift-off, or time of engine on or off, depending on which was last to occur
0	83*	TCUTOFF+1 (least sig. bits)	
0	84*	RAVEGON +0 (most sig. bits of X pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	85*	RAVEGON+1 (least sig. bits of X pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	86*	RAVEGON+2 (most sig. bits of Y pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	87*	RAVEGON+3 (Least sig. bits of Y pos.)	Position from orbital in[illegible]ration program to be used for SPS2 burn this register is time shared.
0	88*	RAVEGON+4 (most sig. bits of Z pos.)	Position from orbital integraion program to be used for SPS2 burn this register is time shared.
0	89*	RAVEGON+5 (least sig. bits of Z pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	90*	VAVEGON+0 (most sig. bits of X Vel.)	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	91*	VAVEGON+1 (least sig. bits of X vel).	Velocity from orbital integratiom program to be used for SPS2 burn this register is time shared.
0	92*	VAVEGON+2 (most sig. bits of Y vel.)	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	93*	VAVEGON+3 (least sig. bits of Y vel.)	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	94*	VAVEGON+4 (most sig. bits of Z vel).	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	95*	VAVEGON+5 (least sig. bits of Z vel).	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	96*	TAVEGON (most sig. bits)	Time that average G program will be activated for SPS2 burn this register is time shared.#
0	97*	TAVEGON+1 (least sig. bits)	Time that average G program will be activated for SPS2 burn this register is time shared.#
Phase 7			In this phase the "marker counter" is checked (it was set in Phase 6 start), and "Dummy " marker words equal in number to the present value of the marker counter are sent (see discussion under Phase 4.
1	98*	TM MARKER	Dummy markers if actual markers have not occurred above
1	99*	TM MARKER	Dummy markers if actual markers have not occured above.
1	100*	TM MARKER	Dummy markers if actual markers have not occurred above.

Note TAVEGON is a ΔT measured relative to PIPTIME, therefore the absolute SPS2 average G on time = TAVEGON + PIPTIME.

W.O.C.	WD/NO.	DATA WORD	REMARKS
Phase 1			
1	1	ID WORD	ID word equals 1100100000000011. Bit 9 of OUT1=1 (causes word order code to be 1's) see comments under Phase 1 of non-update list.
Phase 3			In this phase "particular list A" (uplink format) is sent. As discussed above, no markers are sent, but since the "marker counter" is set to 3 at the start of phase 3, 3 dummy markers will be sent in phase 4, a total of 21 words are sent.
0	28*	SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	29*	STCNTR	Indicates which component of update is presently being loaded.
0	30*	STBUFF+0	1st component of update buffer, cell used for other purposes before update and will have some initial value.
0	31*	STBUFF+1	2nd component of update buffer, cell used for other purposes before update and will have some initial value.
0	32*	STBUFF+2	3rd component of update buffer, cell used for othe purposes before update and will have some initial value.
0	33*	STBUFF+3	4th component of update buffer, cell used for other purposes before update and will have some initial value.
0	34*	STBUFF +4	5th component of update buffer, cell used fpr other purposes before update and will have some initial value.

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	35*	STBUFF+5	6th component of update buffer, cell used for other purposes before update and will have some initial value.
0	36*	STBUFF+6	7th component of update buffer, cell used for other purposes before update and will have some initial value.
0	37*	STBUFF+7	8th component of update buffer, cell used for other purposes before update and will have some initial value.
0	38*	STBUFF+8D	9th component of update buffer, cell used for other purposes before update and will have some initial value.
0	39*	STBUFF+9D	10th component of update buffer, cell used for other purposes before update and will have some initial value
0	40*	STBUFF+10D	11th component of update buffer, cell used for other purposes before update and will have some initial value.
0	41*	STBUFF+11D	12th component of update buffer, cell used for other purposes before update and will have some initial value
0	42*	STBUFF+12D	13th component of update buffer, cell used for other purposes before update and will have some initial value.
0	43*	STBUFF+13D	14th component of update buffer, cell used for other purposes before update and will have some initial value.
0	44*	SPARE	Contents of first 16 bits have set pattern of 1010101010101011.

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	45*	SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	46*	SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	47*	UPOLDMD	Contents indicate whether update was initiated in P14 or P24.
0	48*	UPDATE ID	Contents indicated whether a V71, V76, or V77 update.
Phase 6			In this phase "particular list B" (uplink format) is sent. As discussed above, no marker words are sent, but since the "marker counter" is set to 3 at the start of this phase, 3 "Dummy" marker words will be sent in Phase 7. A total of 32 words are sent.
0	66*	TCUTOFF	Same comment as on preceding list, will be SPS1 cutoff time at this point in flight.
0	67*	TCUTOFF+1	
0	68*	RAVEGON+0	Same comment as on preceding list.
0	69*	RAVEGON+1	Same comment as on preceding list.
0	70*	RAVEGON+2	Same comment as on preceding list.
0	71*	RAVEGON+3	Same comment as on preceding list.
0	72*	RAVEGON+4	Same comment as on preceding list.
0	73*	RAVEGON+5	Same comment as on preceding list.
0	74*	VAVEGON+0	Same comment as on preceding list.
0	75*	VAVEGON+1	Same comment as on preceding list.

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	76*	VAVEGON+2	Same comment as on preceding list.
0	77*	VAVEGON+3	Same comment as on preceding list.
0	78*	VAVEGON+4	Same comment as on prededing list.
0	79*	VAVEGON+5	Same comment as on preceding list.
0	80*	TAVEGON	Same comment as on preceding list.
0	81*	TAVEGON+1	Same comment as on preceding list.
0	82*	SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	83*	STCNTR	Indicates which component of update is presently being loaded.
0	84*	STBUFF+0	1st component of update buffer.
0	85*	STBUFF+1	2nd conponent of update buffer.
0	86*	STBUFF+2	3rd component of update buffer.
0	87*	STBUFF+3	4th component of update buffer.
0	88*	STBUFF+4	5th component of update buffer.
0	89*	STBUFF+5	6ht component of update buffer.
0	90*	STBUFF+6	7th component of update buffer.
0	91*	STBUFF+7	8th component of update buffer.
0	92*	STBUFF+8D	9th component of update buffer.
0	93*	STBUFF+9D	10th component of update buffer.

W.O.C.	WD/NO.	DATA WORD	REMARKS
0	94*	STBUFF+10D	11th component of update buffer.
0	95*	STBUFF+11D	12th component of update buffer.
0	96*	STBUFF+12D	13th component of update buffer.
0	97*	STBUFF+13D	14th component of update buffer.

More detailed information on the contents of the data words will be included in future revisions to this document.

3.5 Analog Data Telemetry and Recording

3.5.1 Types

The inflight information from G&N is of three types: PCM telemetry of the AGC DIGITAL DOWNLINK (PCMD*), PCM telemetry of low bandwidth G&N measurement (PCM +, PCM, PCME*), and on-board recording of high bandwidth G&N measurements FQ-TR*. The first type, AGC DIGITAL DOWNLINK, is described in section 3.4. The last two types, although including information in discrete form, are considered to be analog data.

3.5.2 Authorization

The PCM telemetry of the low bandwidth measurements and the on-board recording of the high bandwidth measurements have been defined by NASA in (1) APOLLO CM/SM BLOCK I, OPERATIONAL BASELINE MASTER MEASUREMENT LIST No. 8 of 15 September 1965 and (2) APOLLO CM/SM BLOCK I R AND D BASELINE MASTER MEASUREMENT LIST No. 8 of 15 September 1965 and are as listed below.

3.5.3 PCM Telemetry

The G&N PCM telemetry measurements are all classified OPERATIONAL.*

Identification	Function	Type	Sample Rate/Sec.
CG 0001 V	Computer Digital Data (DIGITAL DOWNLINK)	PCMD	50 (refer Sec. 3.4)
CG 1101 V	-28 VDC Supply	PCM+	1
CG 1110 V	2.5 VDC TM Bias	PCM+	1
CG 1503 X	+28 VDC IMU Operate	PCME	10
CG 1513 X	+28 VDC IMU Standby	PCME	10
CG 1523 X	+28 VDC AGC Operate	PCME	10
CG 1533 X	+28 VDC OPTICS Operate	PCME	10
CG 2110 V	IGA Torque Motor Input	PCM	10
CG 2112 V	IGA 1X Res Output, sine, in phase	PCM	10
CG 2113 V	IGA 1X Res Output, cos, in phase	PCM	10
CG 2117 V	IGA Servo Error, in phase	PCM	100
CG 2140 V	MGA Torque Motor Input	PCM	10
CG 2142 V	MGA 1X Resolver Output, sine, in phase	PCM	10
CG 2143 V	MGA 1X Resolver Output, cos, in phase	PCM	10
CG 2147 V	MGA Servo Error in phase	PCM	100

* See definitions - Section 3.5.5

Identification	Function	Type	Sample Rate/Sec.
CG 2170 V	OGA Torque Motor Input	PCM	10
CG 2172 V	OGA 1X Resolver Output sine, in phase	PCM	10
CG 2173 V	OGA 1X Resolver Output, cos, in phase	PCM	10
CG 2177 V	OGA Servo Error, in phase	PCM	100
CG 2206 V	IGA CDU 1X Res. Error, in phase	PCM	10
CG 2236 V	MGA CDU 1X Res. Error, in phase	PCM	10
CG 2266 V	OGA CDU 1X Res. Error, in phase	PCM	10
CG 2300 T	PIPA Temp.	PCM+	1
CG 2301 T	IRIG Temp.	PCM+	1
CG 2302 C	IMU Heater Current	PCM+	1
CG 2303 C	IMU Blower Current	PCM+	1
CG 3104 V	SXT Trun MDA Input in phase	PCM	10
CG 3105 V	SXT Trun Tach Feedback, in phase	PCM	10
CG 3114 V	SXT Shaft MDA Input, in phase	PCM	10
CG 3115 V	SXT Shaft Tach Feedback, in phase	PCM	10
CG 3141 V	Trun CDU 16X Res. Error, in phase	PCM	10
CG 3211 V	Shaft CDU 16X Res. Error, in phase	PCM	10
CG 4300 T	AGC Temp.	PCM	1
CG 5000 X	PIPA FAIL	PCME	10
CG 5001 X	IMU FAIL	PCME	10
CG 5002 X	CDU FAIL	PCME	10
CG 5003 X	Gimbal Lock Light	PCME	10
CG 5005 X	G&N Error Light(Err Detect)	PCME	10
CG 5006 X	IMU Temp. Light	PCME	10
CG 5007 X	Zero Encoder Light	PCME	10
CG 5008 X	IMU Delay Light	PCME	10
CG 5020 X	AGC Alarm #1 (Program)	PCME	10
CG 5021 X	AGC Alarm #2 (AGC Activity)	PCME	10

Identification	Function	Type	Sample Rate/Sec.
CG 5022 X	AGC Alarm #3 (G&N ERROR)	PCME	10
CG 5023 X	AGC Alarm #4 (PROG CHK FAIL)	PCME	10
CG 5024 X	AGC Alarm #5 (Scaler FAIL)	PCME	10
CG 5025 X	AGC Alarm #6 (Parity FAIL)	PCME	10
CG 5026 X	AGC Alarm #7 (Counter FAIL)	PCME	10
CG 5027 X	AGC Alarm #8 (Key Release)	PCME	10
CG 5028 X	AGC Alarm #9 (RUPT Lock)	PCME	10
CG 5029 X	AGC Alarm #10 (TC Trap)	PCME	10
CG 5030 X	AGC Power Fail Light	PCME	10
CG 6000 P	IMU Pressure	PCM	1
CG 6020 T	PSA Temp, 1 Tray 3	PCM	1
CG 6021 T	PSA Temp, 2 Tray 2	PCM	1
CG 6022 T	PSA Temp, 3 Tray 4	PCM	1

3.5.4 Flight Qualification Tape Recorder (FQ-TR)

There are no G&N Flight Qualification Tape Recorder Measurements on Mission 501.

3.5.5 Definitions

OPERATIONAL	NAA defined as those measurements which will remain fixed for a block of vehicles fulfilling similar type missions. In the case of G&N however there are some differences between OPERATIONAL PCM on Mission 204 and other Block I G&N missions.
FLIGHT QUALIFICATION	NAA defined as those measurements required early in the flight program to qualify the vehicle for flight, after which they may no longer be needed.
PCM	Pulse code modulated analog measurements digitally coded into 8 bit words for operational telemetry.

PCM + — Flight critical PCM measurements, which would continue to be monitored if PCM system is operated in "slow format" mode (not anticipated on Mission 501.)

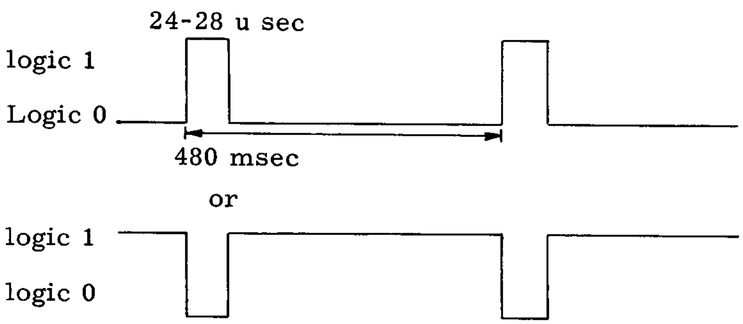
PCME — Special PCM measurements to monitor discrete events (i.e. on/off, open/close) using only 1 bit words.

FQ-TR — Measurements recorded on flight qualification tape recorder.

3.6 G&N Failure Detection Module

The module is composed of two sections:

(1) ELECTRONICS SECTION - Monitors the T/M ALARM signal from the AGC to the NAV DSKY. This signal is under the control of the AGC UPLINK and DOWNLINK programs and is used to control the TELEMETRY ALARM light in the NAV DSKY. Superimposed on the AGC UPLINK and DOWNLINK program's control of the signal is control by the NIGHT WATCHMAN program. This program briefly complements the existing state of the signal and then restores its initial condition.



The ELECTRONICS SECTION of the G&N Failure Detection Module monitors only the brief complement of the signal. If the complement is lacking for more than 1.6 sec $\left({}^{-0.6}_{+1.6}\right)$ the ELECTRONICS SECTION generates the NIGHT WATCHMAN's alarm, which is a contact closure to the MCP (the G&N FAIL INDICATION), G&N ERROR LIGHT, and the S/C TELEMETRY SYSTEM, ("G&N ERROR," a TM discrete as distinguished from AGC Digital Downlink.) Should the complement pulse be restored the NIGHT WATCHMAN's alarm is removed.

(2) WIRING JUNCTION BOX

(a) Routes the NIGHT WATCHMAN's alarm to the NAA harness for the MCP, S/C TELEMETRY SYSTEM and the G&N ERROR LIGHT in the CAUTION and WARNING PANEL.

(b) Routes all remaining wires of the DSKY interface directly through the module.

The logic of the generation of the G&N FAIL INDICATION is thus under the control of the NIGHT WATCHMAN'S ALARM program. This program monitors G&N activity in two phases completing a monitor cycle in 480 ms.

The first phase involves the examination of an error register (OLDERR). Should this register indicate an error present, the complement pulse would not be generated and a G&N FAIL INDICATION would result. The error register will include the following error indications;

(1) The failure of an AGC RESTART sequence. This sequence is automatically done when the AGC's normal sequences have been momentarily interrupted by failures such as TC TRAP, PARITY FAIL or a momentary loss of PRIMARY POWER. The RESTART sequence will normally perform a limited recycle of the interrupted sequences restoring the initial conditions within milliseconds.

(2) The receipt by the AGC of an indication from the Inertial Subsystem error detection circuitry of an IMU FAIL or ACCEL FAIL. Each of these fail indications is a summation of several relevant analog parameters, any one of which will cause a fail indication if exceeding the following criteria.

(a) IMU FAIL

IG Servo Error - greater than 4.6 mr for 2.5 ±1 sec.
MG Servo Error - greater than 4.6 mr for 2.5 ±1 sec.
OG Servo Error - greater than 4.6 mr for 2.5 ±1 sec.
3200 ∿ supply - decrease to 50% of normal level
800 ∿ wheel supply - decrease to 50% of normal level

The receipt of this fail indication is ignored by the AGC program when the G&N system is in the Coarse Align Mode and during the 5 second interval following Coarse Align. In this mode (used only during pre-launch alignment for Mission 501) the servo errors normally exceed the criteria above.

(b) ACCEL FAIL

X PIPA Error - greater than .32 mr for 5 ±2 sec.
Y PIPA Error - greater than .32 mr for 5 ±2 sec.
Z PIPA Error - greater than .32 mr for 5 ±2 sec.

The receipt of this fail indication is ignored by the NIGHT WATCHMAN during the coasting phase.

The second phase exercises the AGC executive programs by a request for a new job (NEWJOB) via a periodic programmed interrupt (T4RUPT) with a high job priority (36 - the highest available with the exception of an alarm priority.) This new job examines bit 4 of register OUT 1 and complements it as described above. Should the executive routines or the interrupt processes be disabled (as, for instance, if an AGC program had become trapped in a loop) the NEWJOB request would not be honored, the complement pulse would not be generated, and a G&N FAIL INDICATION would result.

The G&N FAIL INDICATION can also be sent to the MCP via the Up Data Link (UDL) based upon ground assessment of tracking or telemetry data. Upon receipt of G&N FAIL INDICATION the MCP immediately disables all mode commands from the AGC and commands the SCS system to SCS ΔV MODE. The attitude reference becomes the BMAGS/AGCU. The SCS system is now no longer responsive to any G&N-originated attitude signals, attitude error signals, engine on-off commands (disabled by removal of ΔV mode), or AGC commands via the MCP.

The MCP can be reset to retransfer S/C control to G&N; however, this command must come from the ground.

4. MISSION LOGIC AND TIMELINE

4.1 Operational Constraints

The G&N system, the MCP, and the ground command systems to the G&N and the MCP must be operated within certain constraints both in normal and backup modes.

4.1.1 MCP Ground Commands

The following list details the MCP real-time commands (RTC's) planned for support of Mission 501. This list is restricted to commands to the Mission Control Programmer and is exclusive of commands to the SIVB and AGC Uplink commands:

RTC #	02...04	Fuel Cell Purge (cell#1 - cell#3)
etc.	05	Reset RTC 02-04
	10	Lifting Entry - Necessary for no-roll entry in the SCS entry mode
	11	Direct Thrust On - Turns on SPS engine; backup to onboard command in case of malfunction.
	12	Direct Thrust Off - Turns off SPS engine; backup to onboard command in case of malfunction.
	13	Reset RTC 10-12
	14	Direct rotation + pitch
	15	Direct rotation - pitch
	16	Direct rotation + yaw
	17	Direct rotation - yaw
	20	Direct rotation + roll
	21	Direct rotation - roll
	22	Direct Ullage
	23	Reset RTC 14-22
	24/32	SM Quad A Propellant Off/On
	25/33	SM Quad B Propellant Off/On
	26/34	SM Quad C Propellant Off/On
	27/35	SM Quad D Propellant Off/On
	30/36	CM System A Propellant Off/On
	31/37	CM System B Propellant Off/On
	40	Let Jettison Start-Backup to onboard command from SIVB

41	G&N Failure - Backup to G&N function
42	G&N Failure Inhibit - Reset G&N failure
43	Reset RTC 41-42
44	Roll Rate Gyro Backup-Switches roll BMAG to rate mode and uses this gyro for roll rate data
45	Pitch Rate Gyro Backup - Switches pitch BMAG to rate mode and uses this gyro for pitch rate data
46	Yaw Rate Gyro Backup - Switches yaw BMAG to rate mode and uses this gyro for yaw data
47	FDAI align
50	Reset RTC 44-47
51	-Z Antenna ON
52	+Z Antenna ON
53	G&N Antenna Switching - Enable of G&N command capability for Antenna switching
54	Roll A and C Channel Disable - Disables the automatic A and C RCS channels
55	Roll B and D Channel Disable - Disables the automatic B and D RCS roll channels
56	Pitch Channel Disable - Disables the automatic pitch RCS channels
57	Yaw Channel Disable - Disables the automatic yaw RCS channels
60	Reset RTC 54-57
61	CM/SM Separation - Backup to onbaord command from the G&N
62	UDL S Band RCVR ON
63	UDL UHF RCVR ON
64	H_2 #2 Htr Fan
65	O_2 #2 Htr Fan
66	H_2 #1 Htr Fan
67	O_2 #1 Htr Fan
70	Reset RTC 64-67
71	Abort (Also Backup for SIVB/CSM Separation Start)
72	Reset RTC 73-77

Commands 14-17, 20-21, and 54-57 will be used to control S/C attitude in cases where the G&N is not operable.

Of these commands only six are intimately concerned with G&N operation; RTC 11, 12, 22, 41, 42 and 71.

RTC 11- Direct Thrust On:	AGC Engine On logic presently includes a monitor of ΔV to ensure engine ignition. This monitor continues for 20 sec after sensing no thrust during which time the ground might start the SPS engine. If suitable ΔV has not been sensed after 10 seconds the AGC would exit from thrust vector control and hold attitude until the free-fall interrupt occurs. Should the ground successfully start the engine within 10 sec the AGC will guide the burn normally. It must be assumed however that as the AGC Engine On command did not work correctly, AGC Engine Off will not either. The ground must therefore command a timely "Thrust Off" compatible with the AGC TVC calculation.
RTC 12 - Direct Thrust Off	The ground may thus inhibit starting of or may stop the SPS thrust. Should AGC-controlled firing be inhibited or shutdown the ΔV monitor logic would after 20 seconds exit from thrust vector control and hold attitude until the free-fall interrupt occurs.
RTC 22 - Direct Ullage:	A backup command for ground use during a ground controlled burn in the SCS ΔV mode. Its use during G&N controlled flight would inhibit G&N attitude control with the possibility of the G&N being unaware of the loss.
RTC 41 - G&N Failure:	This command is a ground backup for the G&N originated command. All control of the vehicle by the G&N is thereby inhibited.

RTC 42 - G&N Failure Inhibit:	This command overrides the G&N FAIL signal. Use of this command does not guarantee that the AGC will correctly resume control of the S/C.
RTC 71- Abort	This command initiates SIVB/CSM Separation in a boost abort. For appropriate AGC action, it must be accompanied by an abort command to the AGC via AGC Uplink. The G&N BACKUP ABORT command, previously a backup to RTC 71, has been deleted from the AGC/MCP interface (see para. 3.2.2 section 10).

4.1.2 Backup Attitude Reference System

The backup attitude reference system is the SCS BMAGs in conjunction with AGCU. G&N control of the CSM orientation is always done with consideration for the maintenance and accuracy of this system. As the SCS system is presently designed, the BMAGs operate as free gyros in the G&N ΔV MODE; in other modes they are caged through the AGCU.

As the mechanical stops of the BMAG's are at $\pm 17^{\circ}$ it is apparent that, during boost (Monitor MODE) and attitude maneuvers (G&N ATTITUDE CONTROL OR ENTRY MODES) both involving angular changes of over 17°, the BMAG's must be caged. In the G&N ΔV mode however, should attitude changes over 17° occur, integrity of the backup attitude system will be lost. Such changes are not anticipated in the nominal mission.

The rate limits of the backup attitude reference system in the caged mode are 5°/sec in Pitch and Yaw and 20°/sec in Roll. To preclude controlling the S/C rates beyond which the backup attitude reference system can maintain its reference, the G&N will limit its command rate to the CSM and CM.

4.1.3 External Data Requirements

G&N requirements for external data fall into three categories:

a) Navigation Data via the Uplink
State Vector updates are required for successful G&N control.

b) Radar Tracking Data for Post Flight Analysis

Tracking data requirements, to a degree of accuracy and completeness which would permit the most comprehensive determination of G&N flight performance, are given in Table 4-1. Subsequent revisions of this plan will reflect more realistic requirements.

c) Radar Tracking Data for Real-Time Monitor of G&N

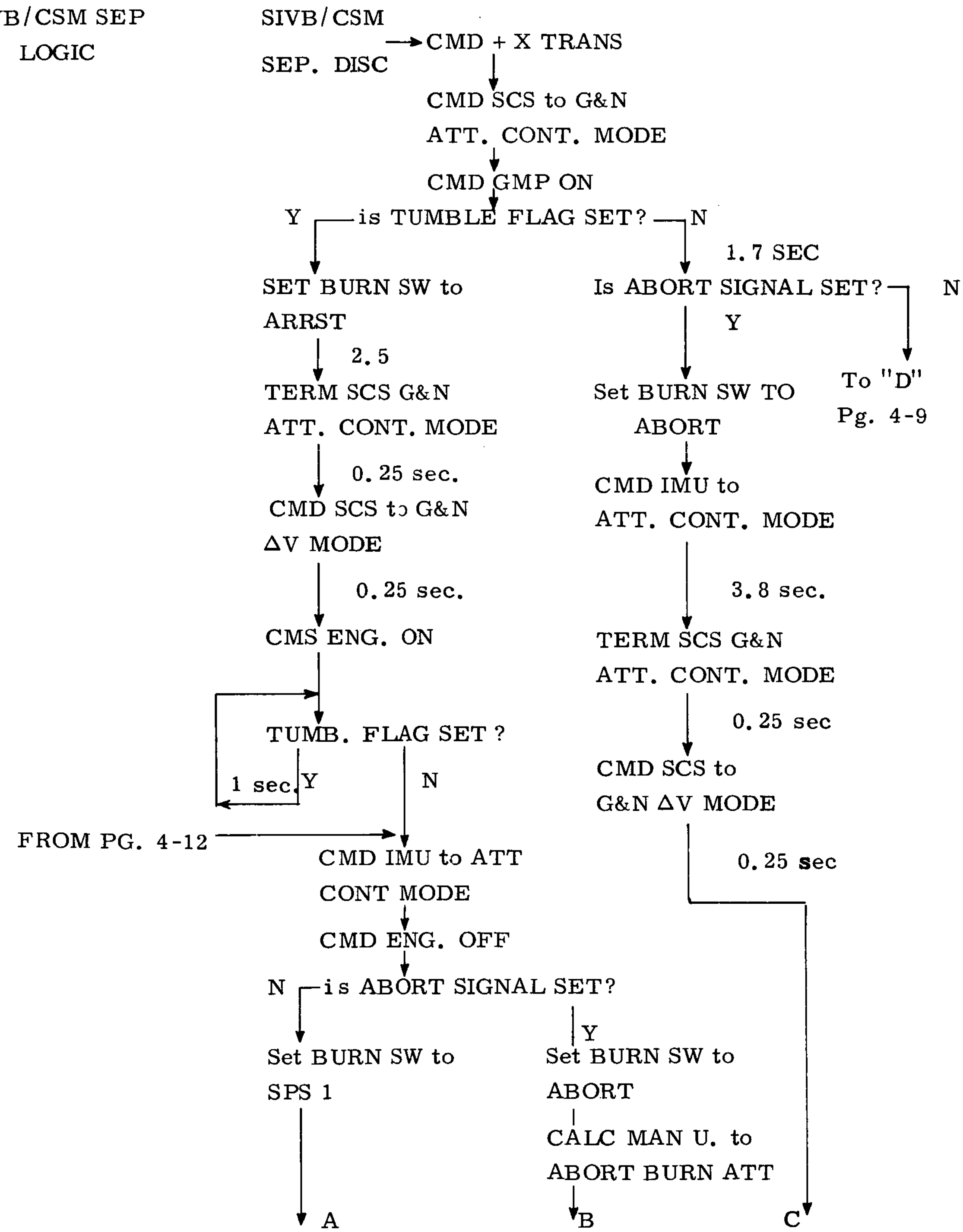
This requirement is given by Table 4-2, which is derived from the total indication error expected in the position and velocity data telemetered to the ground via the AGC DOWNLINK.

4.2 501 AGC

NAME	ACTIVITY
Initialization P01	Manual → START P01
Gyro Compassing P02	AGE or UPLINK → START P02
Optical Verification P03	MANUAL → START p03 (does not interfere with P02)
Inertial Reference P04	GRR → START P04 ↓ TERMINATE GYRO COMPASSING ↓ START READING PIPAS ↓ COMPUTE REFSMAT ↓ TRANSFORM STATE VECTOR TO IMU CO-ORDINATES ↓ START AVE G ↓ CALCULATE T_{FF} (280,000 ft.)
Pre LET-JET Boost Monitor P11	L/O → START P11 ↓ If GRR not received Perform P04 Function ↓ COMMAND INU ATT. CONT. MODE ↓ UPDATE TARGET VECTORS TO L/O TIME ↓ Call P14 at T_o + 183 sec. ↓ TORQUE CDU's to BOOST POLYNOMINALS ↓
*Post LET-JET Boost Monitor P14	START P14 (called) COMMAND IMU to FINE ALIGN MODE START COMPUTATION OF GIMBAL ANGLE RATES (TUMBLE MONITOR)

*MIT/IL will provide update capability (P27) during post LET-JET boost monitor (P14) at specified time intervals. The allowed update will be $\overline{R}$, $\overline{V}$, T which are required for Mission success.

NAME	ACTIVITY
Uplink Abort COMMAND	UPLINK→SET ABORT FLAG
SIVB/CSM SEP LOGIC	



NAME

SIVB/CSM SEP
LOGIC (Cont.)

ACTIVITY

A

TERM. +X TRANS

SET T_{IGN} = T + 94.3 sec

CALC. MANU. to
SPS 1 ATT.

MANEUVER to
SPS 1 ATT.

89.5 sec (allowed)

TERM SCS G&N
ATT. CONT. MODE

0.25 sec

CMD. SCS to G&N
ΔV MODE

0.25 sec

CMD. ENG. ON

B

MANEUVER to
ABORT BURN ATT

C

CMD Eng ON

Do ABORT BURN
STEERING

(Posigrade to
Alt. Recovery)

STEERING OR
T_{FF} INTRPT
EXITS TO
ENGINE OFF
ROUTINE

ENGINE OFF
ROUTINE EXITS
TO ATT. HOLD
(P23)

SPS1 PRE-THRUST

P31

NOTE: SPS1 IS A NO ULLAGE BURN

from D Page 4-7

↓ N

Set BURN SW TO SPS1

↓

Set T_{IGN} = T + 94.3 Sec.

↓

CMD IMU TO ATT. CONT. MODE

↓ 4.3 Sec.

TERM. +X TRANS

↓

CALC. MANU. to SPS 1 ATT.

↓

MANEUVER TO SPS1 ATT.

↓ 89.5 (allowed)

TERM SCS G&N ATT. CONT. MODE

↓ 0.25 Sec.

CMD SCS TO G&N ΔV MODE

↓ 0.25 Sec.

CMD ENGINE ON

SPS1 BURN → Called by ENGINE ON Routine

↓

TVC STEERING

↓

STEERING EXITS TO ENGINE OFF ROUTINE

↓

ENGINE OFF ROUTINE EXITS TO COLD SOAK (P21)

CSM COLD SOAK MANEUVER

P21

CALLED BY ENGINE OFF ROUTINE

↓

TERM. READING PIPAS

↓

TERM. AVE G

↓

CALC. MANU. TO COLD SOAK

↓

CALL MANEUVER TO COLD SOAK ATTITUDE

↓ 300 SEC

CMD FDAI ALIGN ON

↓ 10 SEC

CMD FDAI ALIGN OFF

↓

GO TO P24

HOLD ATTITUDE (ACCEPT STATE VECTOR AND T_{FF} (MIN) UPDATE)

P24

CALLED BY P21

↓

CALL P25 AT T + X sec

↓

ENABLE T_{FF} MIN UPDATE

↓

ENABLE $\bar{R}, \bar{V}$, T UPDATE

SPS2 IGNITION TIME DETERMINATION P25

CALLED BY P24

↓

START AVE G

↓

NOTE: $\bar{R}, \bar{V}$, T UPDATE REQUIRED FOR MISSION SUCCESS

SPS2 IGNITION TIME DETERMINATION P25 (Cont.)

CAL T_{FF} (400,000 FT)

BLOCK UPLINK

WAIT FOR T_{FF} INTERRUPT LOGIC TO DETECT $T_{FF} < T_{ff(min)}$ N

Y

SET $T_{IGN} = T + 10$ MIN

CMD FDAI ALIGN ON

10 SEC

CMD FDAI ALIGN OFF

CALC MANU TO SPS2 ATT

DO MANEUVER TO SPS2 ATTITUDE

WAIT UNTIL T_{IGN} - 30 Sec

CMD + X TRANS

18 Sec

CMD GMP ON

11.5 Sec

TERM SCS G&N ATT CONT MODE

0.25 Sec

CMD SCS TO G&N ΔV MODE

0.25 Sec

CMD ENGINE ON

SPS2
P42

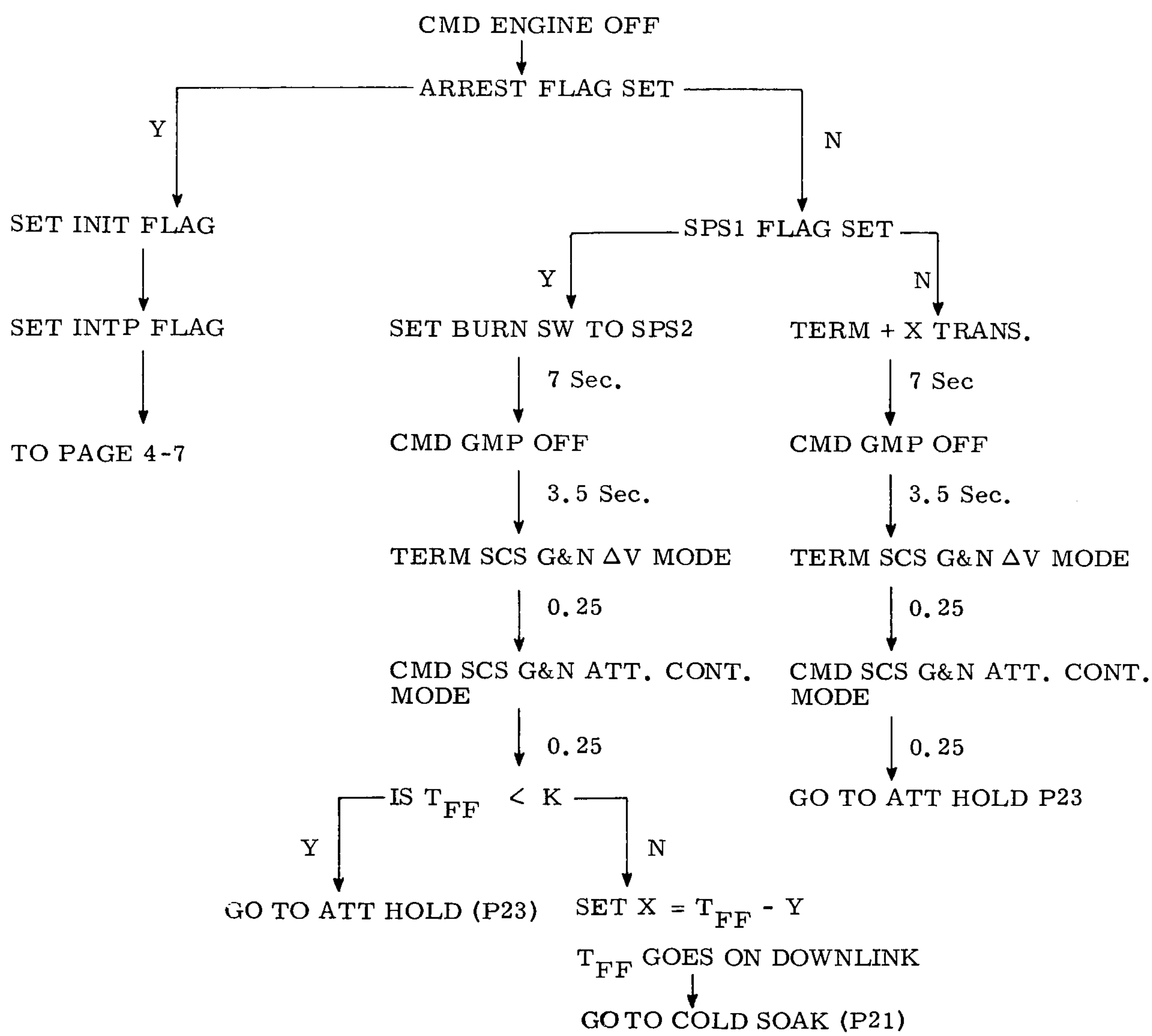
CALLED BY ENG ON ROUTINE

TVC STEERING

STEERING EXITS TO ENGINE OFF ROUTINE

ENGINE OFF ROUTINE EXITS TO ATT HOLD (P23)

ENGINE OFF ROUTINE



P61

MANEUVER TO

C/MSC Sep.

START BY INTERRUPT (T_{FF} < 200 Sec.)

↓

CALC MAN FOR CM/SM

SEP. ATT.

↓

Call Att. Man. to Sep. Att

↓

Wait until T_{FF} < 95 sec

Y ↓ N

Kill Att Man.

↓ 5 sec

TERM PRESENT SCS G&N MODE

↓

Call CDU X Scaling Job

↓ 5 sec

CMD ISS to ENTRY MODE

↓

CMD SCS to G&N

RE-ENTRY MODE

↓

CMD CM/SM SEP

↓

Call P62 at T + 5 sec

P62

Re-Entry

Maneuver

Start P 62 (called)

↓

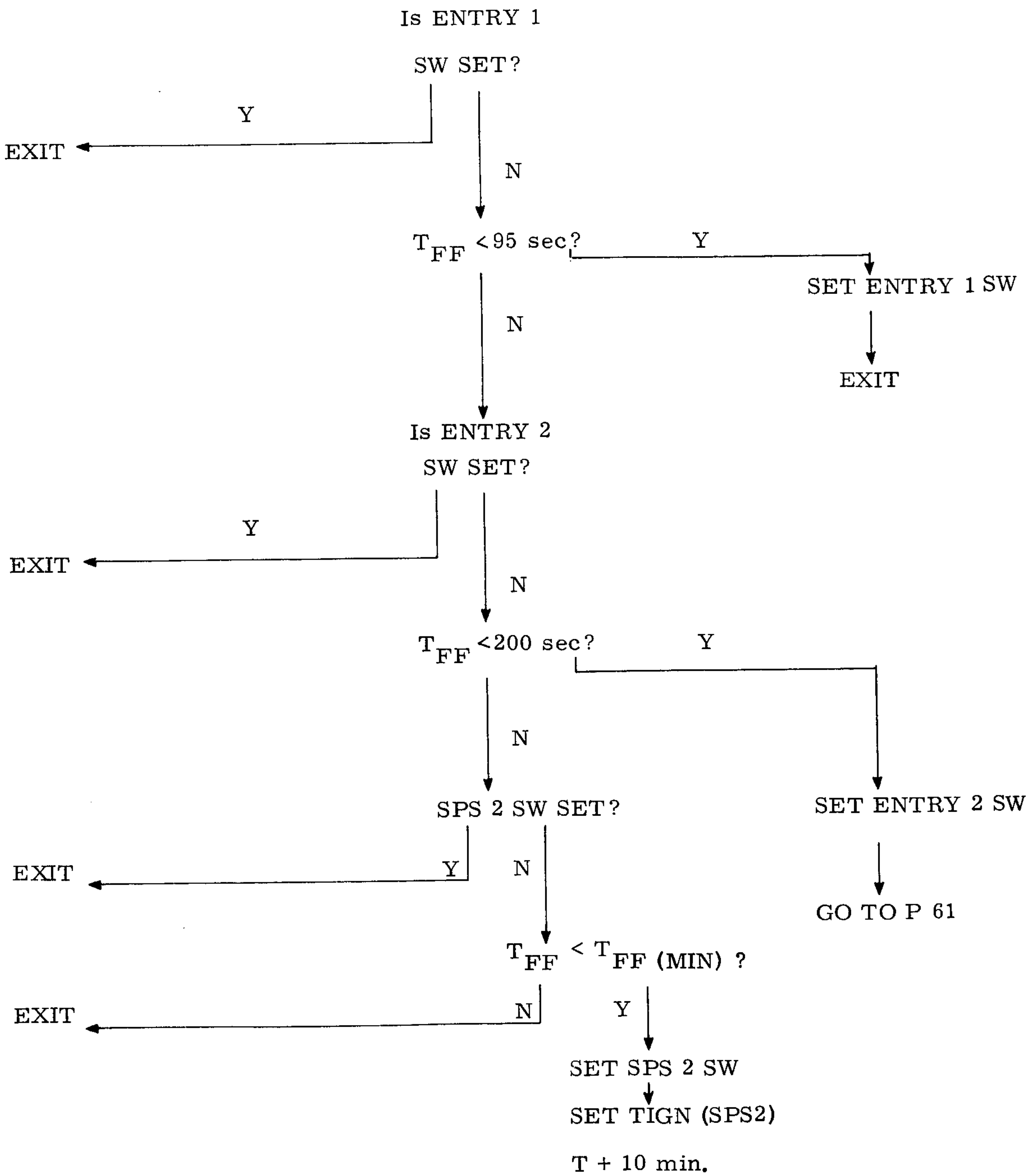
Calculate Maneuver to
attain Trim Attitude

↓

Call Att Man. to Entry

Att.

T_{FF} IN TERRUPT LOGIC



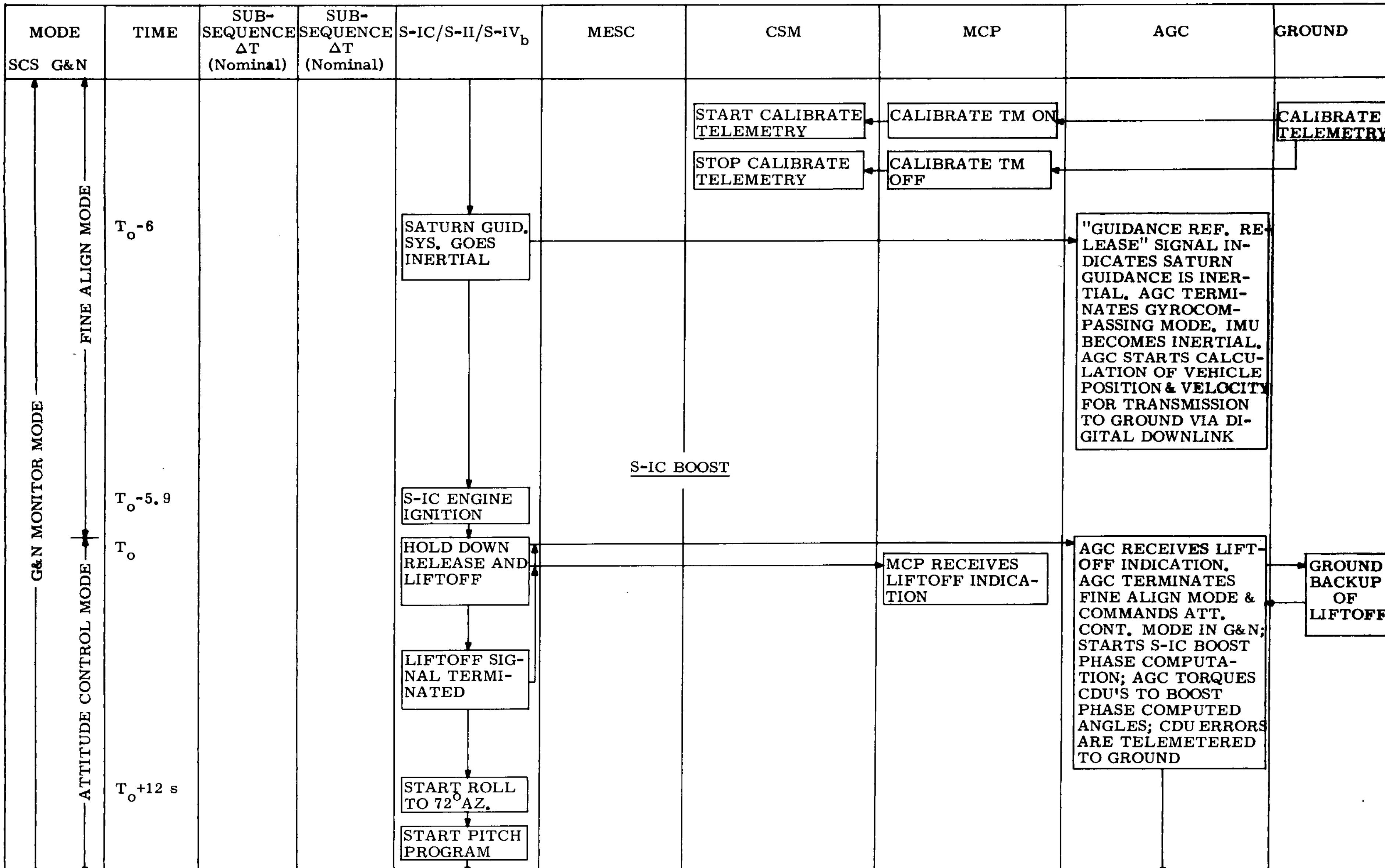
NORMAL SEQUENCE OF EVENTS - MISSION 501

S/C / MISSION CONTROL PROGRAMMER / G&N

MODE SCS	MODE G&N	*TIME	SUB-SEQUENCE ΔT (Nominal)	SUB-SEQUENCE ΔT (Nominal)	S-IC/S-II/S-IV$_b$	MESC	CSM	MCP	AGC	GROUND
						PRE LAUNCH				
		T_o-11.75 hrs.							TURN ON G&N → ENABLE UPLINK → "FRESH START" OF AGC → 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
									AGC CLOCK ALIGNMENT	GROUND SYNCHRONIZATION OF AGC TIME THRU ACE
	FINE ALIGN MODE	T_o-8.75 hrs.							G&N STARTS GYROCOMPASSING MODE FOR IMU ALIGNMENT TO LAUNCH AZIMUTH SET FINE ALIGN MODE IN G&N.	
	FINE ALIGN MODE	T_o-8.50 hrs.							OPTICS SIGHTING TO VERIFY GYROCOMPASSING	
	FINE ALIGN MODE	T_o-7.75 hrs.							REPEAT OPTICS SIGHTING TO VERIFY GYROCOMPASSING	

* ABSOLUTE TIMES ARE ONLY APPROXIMATE SINCE THEY ARE TAKEN FROM THE PRELIMINARY REFERENCE TRAJECTORY

MODE SCS	MODE G&N	TIME	SUB-SEQUENCE ΔT (Nominal)	SUB-SEQUENCE ΔT (Nominal)	S-IC/S-II/S-IV$_b$	MESC	CSM	MCP	AGC	GROUND
	FINE ALIGN MODE	T_o-5.75 hrs.								CLOSE OPTICS HATCH
G&N MONITOR MODE		T_o-5.0 hrs.						PROGRAMMER RESET; ARM GIMBAL MOTOR POWER ON-OFF; G&N BACKUP ABORT COMMAND; G&N FAIL T/C SWITCHING; FDAI ALIGN CMD. ARM G&N FAIL CIRCUITRY FOR INDICATION ONLY TO MCP. MCP WILL NOT REVERT TO BACKUP MODE UNTIL SIVB CSM SEPARATION		GROUND RESET OF MCP
		T_o-1.00 hr.				START S/C CLOSEOUT				
		T_o-.5 hr.				S/C CLOSEOUT COMPLETE				
		T_o-.5 hr.							VERIFY MISSION DATA LOAD	VERIFY MISSION DATA LOAD
		T_o-153 sec.			START FIRING SEQUENCE					START SATURN FIRING SEQUENCE

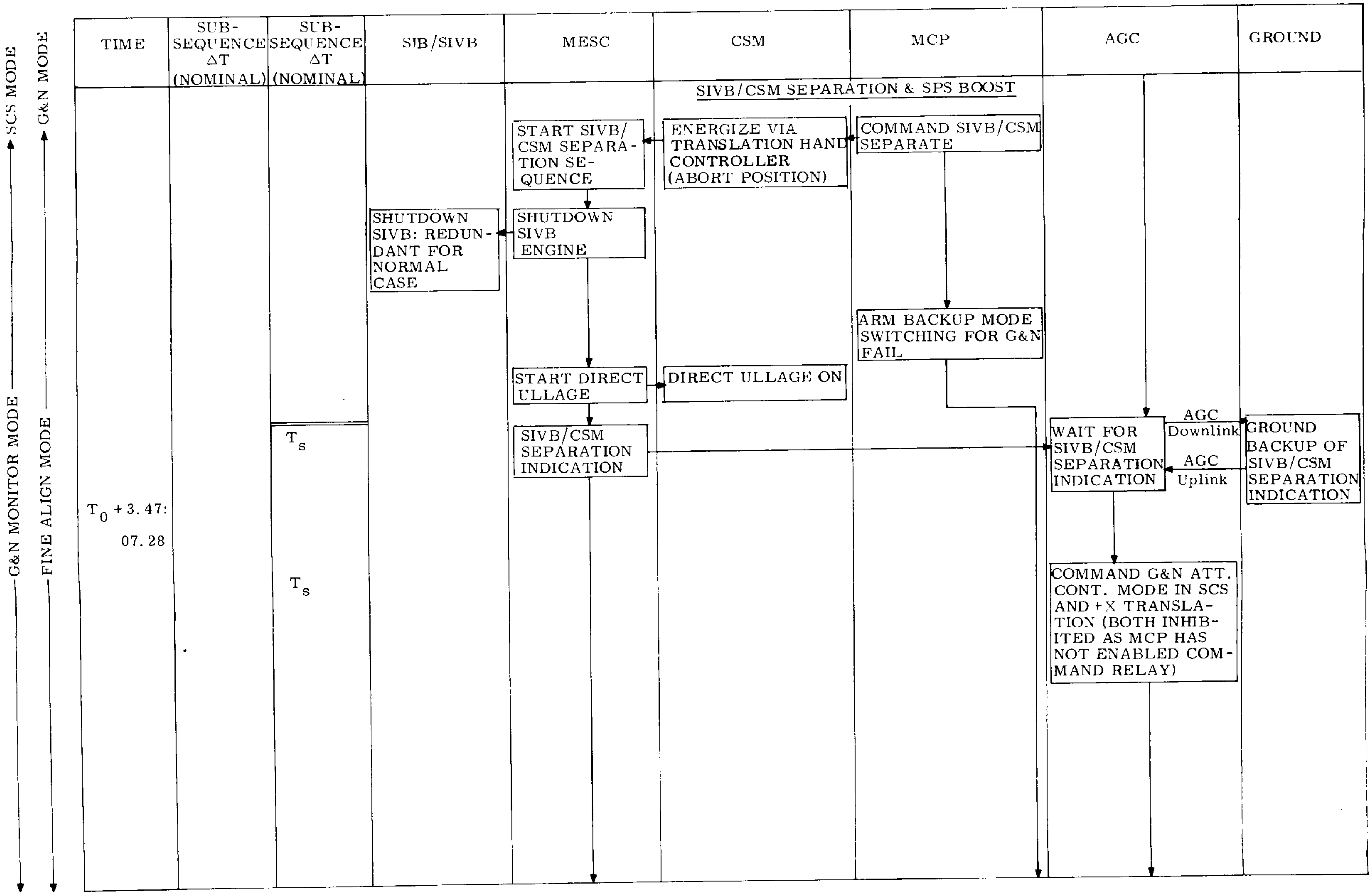

MODE
SCS G&N
TIME
SUB-SEQUENCE ΔT (Nominal)
SUB-SEQUENCE ΔT (Nominal)
S-IC/S-II/S-IVb
MESC
CSM
MCP
AGC
GROUND
G&N MONITOR MODE
FINE ALIGN MODE
ATTITUDE CONTROL MODE
To-6
To-5.9
To
To+12 s
START CALIBRATE TELEMETRY
CALIBRATE TM ON
CALIBRATE TELEMETRY
STOP CALIBRATE TELEMETRY
CALIBRATE TM OFF
SATURN GUID. 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 & VELOCITY FOR TRANSMISSION TO GROUND VIA DIGITAL DOWNLINK
S-IC BOOST
S-IC ENGINE IGNITION
HOLD DOWN RELEASE AND LIFTOFF
MCP RECEIVES LIFTOFF INDICATION
AGC RECEIVES LIFTOFF INDICATION. AGC TERMINATES FINE ALIGN MODE & COMMANDS ATT. CONT. MODE IN G&N; STARTS S-IC BOOST PHASE COMPUTATION; AGC TORQUES CDU'S TO BOOST PHASE COMPUTED ANGLES; CDU ERRORS ARE TELEMETERED TO GROUND
GROUND BACKUP OF LIFTOFF
LIFTOFF SIGNAL TERMINATED
START ROLL TO 72° AZ.
START PITCH PROGRAM

MODE SCS	MODE G&N	TIME	SUB-SEQUENCE ΔT (Nominal)	SUB-SEQUENCE ΔT (Nominal)	S-IC/S-II/S-IV$_b$	MESC	CSM	MCP	AGC	GROUND
G&N MONITOR MODE	ATTITUDE CONTROL MODE				END ROLL MANEUVER					
		T_o+35			END PITCH PROGRAM START GRAVITY TILT					
		T_o+78s			MAXIMUM DYNAMIC PRESSURE					
		T_o+132s			STOP GRAVITY TILT				AT $T_o+\Delta T_2$ AGC TERMINATES S-IC BOOST MONITOR PHASE COMPUTATION; HOLDS CDU'S AT CONSTANT ANGLES. AGC CONTINUES MONITOR OF VEHICLE POSITION & VELOCITY	
		T_o+144.85	T_1-4.0s		INBOARD ENG. CUTOFF					
		T_o+148.85	T_1		OUTBOARD ENG. CUTOFF					
					ENGINE THRUST TERMINATION					
						S-IC/S-II SEP + S-II BOOST				
					S-IC/S-II SEP					
		T_o+151.36	T_1+2.51s		S-II IGNITION					
					S-II ENGINE REACHES FULL THRUST					
		T_o+151.36			S-II START PITCH UP RATE OF 1.0°/sec					

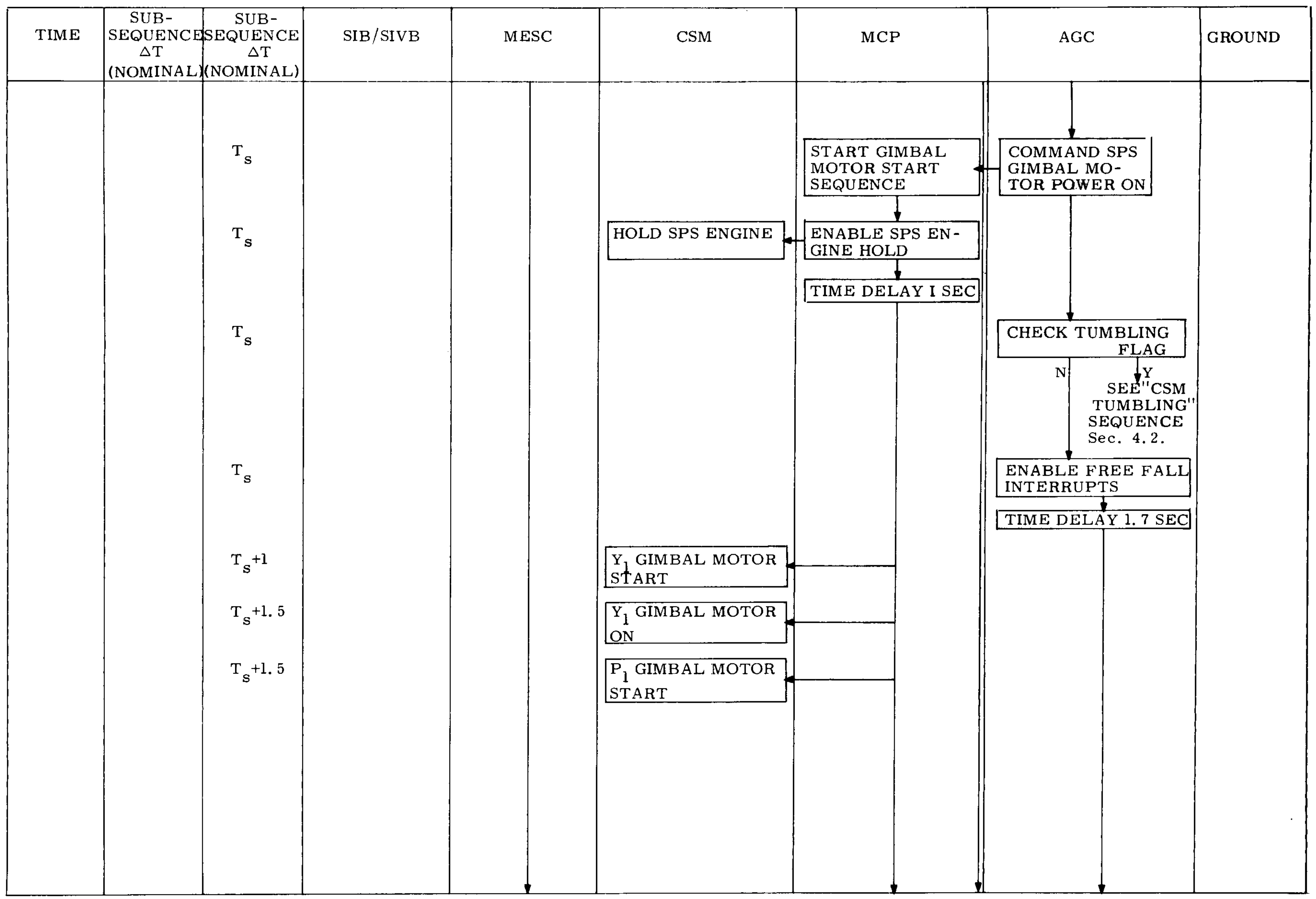
MODE SCS	MODE G&N	TIME	SUB-SEQUENCE ΔT (Nominal)	SUB-SEQUENCE ΔT (Nominal)	S-IC/S-II/S-IV_b	MESC	CSM	MCP	AGC	GROUND
G&N MONITOR MODE	ATT. CONT. MODE	T_o+161.36			CHANGE MIX-TURE RATIO TO 5.4					
		T_o+162.36			S II STARTS PITCH DOWN RATE OF 0.1023°/sec					
	FINE ALIGN MODE	T_o+183.10	T_1+34.25s						AT T_o+183s AGC COMMANDS G&N SYS. TO FINE ALIGN MODE IN READINESS FOR POSSIBLE ABORT. AGC COMMENCES MONITOR OF VEHICLE RATES FOR TUMBLING DETECTION BY MON-ITORING IMU GIMBAL ANGLE RATES OF CHANGE.	
		T_o+183.85	T_1+35s		COMMAND LET JET.			START LET JETTI-SON SEQUENCE		
					JETTISON ULLAGE ROCKET CASES	START LET JETTISON SEQUENCE		COMMAND LET JETTISON		
						DISABLE AUTO FUNCTION EDS				
						SELECT SPS ABORT MODE LOGIC IN MESC				
						FIRE TOWER BOLTS				
						FIRE JETTISON MOTOR		BACKUP INGITION OF LAUNCH ESCAPE MOTOR SHOULD JETTISON MOTOR NOT HAVE FIRED (ASSUMES BOLTS HAVE SEPARATED)		
					CHANGE MIX-TURE RATIO TO 4.7					

MODE SCS G&N	TIME	SUB-SEQUENCE ΔT (Nominal)	SUB-SEQUENCE ΔT (Nominal)	S-IC/S-II/S-IV$_b$	MESC	CSM	MCP	AGC	GROUND
SCS: G&N MONITOR MODE; G&N: FINE ALIGN MODE									
	T_o+510.69			S-II ENGINES CUTOFF					
				S-II/SIVB SEPARATION					
	T_o+512.45	T_2		SIVB IGNITION					
		T_2+3.1s		SIVB ENGINE REACHES FULL THRUST				AGC UPDATES POSITION & VELOCITY EVERY TWO SECONDS	
				CONTINUE PITCH DOWN RATE OF .1023°/sec UNTIL SIVB CUTOFF					
				SIVB ENGINE MIXTURE RATIO SHIFT					
	T_o+681.08			STOP PITCH DOWN RATE					
	T_o+681.08	T_2+168.63		SIVB ENGINE CUTOFF					
					START TWO ORBIT COAST				
	T_o+691.08			PITCH RATE OF .5°/sec INITIATED TO PLACE LONGITUDINAL AXIS IN PHASE OF LOCAL HORIZONTAL				$\bar{R}$, $\bar{V}$, T. UPDATE	TRANSMIT $\bar{R}$, $\bar{V}$, T. UPDATE

MODE SCS	MODE G&N	TIME	SUB-SEQUENCE ΔT (Nominal)	SUB-SEQUENCE ΔT (Nominal)	S-IC/S-II/S-IV$_b$	MESC	CSM	MCP	AGC	GROUND
G&N MONITOR MODE	FINE ALIGN MODE				CHANGE PITCH RATE TO A PITCH DOWN RATE OF .06813°/sec				UPDATE POSITION & VELOCITY EVERY TWO SECONDS	
					TERMINATE PITCH RATE					
		T_o+3:03: 57.05			START SIVB ATTITUDE ORIENTATION AND PRE-IGNITION SEQUENCE					
		T_o+3:08: 56.36			END ATTITUDE MANEUVER HOLD ATTITUDE UNTIL IGNITION					
						S-IV$_b$ 2ND BURN				
		T_o+3:11: 27.05	T_2		SIVB IGNITION					
		T_o+3:17: 07.28	T_2+340.23	T_{co}	SIVB CUTOFF					
					SIVB GOES TO RATE STABILIZATION MODE WITH ZERO RATE COMMAND					
						S-IV$_b$/CSM SEP + COAST				
		T_o+3:47: 07.28		T_{co}+30 m	START SIVB CSM SEPARATION			START SIVB-CSM SEPARATION	MCP Up Data Link	GROUND BACK UP OF SIVB-CSM SEPARATION START



TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
SIVB/CSM SEPARATION & SPS BOOST
COMMAND SIVB/CSM SEPARATE
ENERGIZE VIA TRANSLATION HAND CONTROLLER (ABORT POSITION)
START SIVB/CSM SEPARATION SEQUENCE
SHUTDOWN SIVB ENGINE
SHUTDOWN SIVB: REDUNDANT FOR NORMAL CASE
ARM BACKUP MODE SWITCHING FOR G&N FAIL
START DIRECT ULLAGE
DIRECT ULLAGE ON
SIVB/CSM SEPARATION INDICATION
WAIT FOR SIVB/CSM SEPARATION INDICATION
AGC Downlink
AGC Uplink
GROUND BACKUP OF SIVB/CSM SEPARATION INDICATION
COMMAND G&N ATT. CONT. MODE IN SCS AND +X TRANSLATION (BOTH INHIBITED AS MCP HAS NOT ENABLED COMMAND RELAY)
T_s
T_s
T_0 +3.47: 07.28
SCS MODE
G&N MONITOR MODE
G&N MODE
FINE ALIGN MODE



SCS MODE ← G&N MONITOR MODE →

G&N MODE ← FINE ALIGN MODE →

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		T_s+1.7		FIRE ADAPTER CSM SEPARATION SQUIB'S	ADAPTER CSM SEPARATION			
		T_s+1.7					CHECK ABORT FLAG Y: SEE "ABORT WITH OUT TUMBLING" SEQUENCE Sec. 4.2 N:	
		T_s+1.7					CHANGE FREE FALL ALTITUDE FROM 280,000 FT TO 400,000 FT	
		T_s+1.7					CALL "SPS ENGINE ON" IN 58.3 SEC	
		T_s+1.7					START V_g, THRUST DIRECTION AND MANEUVER CALCULATION	
		T_s+2.0			P_1 GIMBAL MOTOR ON			
		T_s+2.0			Y_2 GIMBAL MOTOR START			
		T_s+2.5			Y_2 GIMBAL MOTOR ON			
		T_s+2.5			P_2 GIMBAL MOTOR START			
		T_s+2.5		SCS RCS ENABLE ON	SCS RCS ENABLE ON			
					ROLL CHANNEL UNDER CONTROL OF ROLL RATE GYRO: ATTITUDE ERROR AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N PITCH AND YAW CHANNEL INHIBITED BY DIRECT ULLAGE			

SCS MODE ← G&N MONITOR MODE →

G&N MODE ← FINE ALIGN MODE →

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		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		
		T_s+2.5			SET G&N ATT. CONT. MODE	COMMAND G&N TEST CONT. MODE (COMMANDED BY AGC AT T_s: ENABLED BY MCP ARMING)		
		T_s+2.5			+X TRANS ON. INHIBITED IF NO RCS ENABLE (MESC ORIGINATED AT T_s +2.5) AND THEN ALSO INHIBITED BY DIRECT ULLAGE (MESC TERMINATED WHEN SIVB/CSM SEP CMND. IS TERMINATED BY THE MCP.)	COMMAND +X TRANS ON (COMMANDED BY AGC AT T_s: ENABLED BY MCP ARMING)		
		T_s+2.5			SPS ENGINE HOLD DISABLED	DISABLE SPS ENGINE HOLD		
		T_s+2.5			ARM SPS SOLONOIDS	ARM SPS SOLONOIDS		
		T_s+2.5			SPS GIMBALS GO TO TRIM POSITION #1	SELECT GIMBAL MOTOR TRIM POSITION #1		
		T_s+2.5			PRETHRUST VALVES OPENED	OPEN SPS PRETHRUST VALVES		

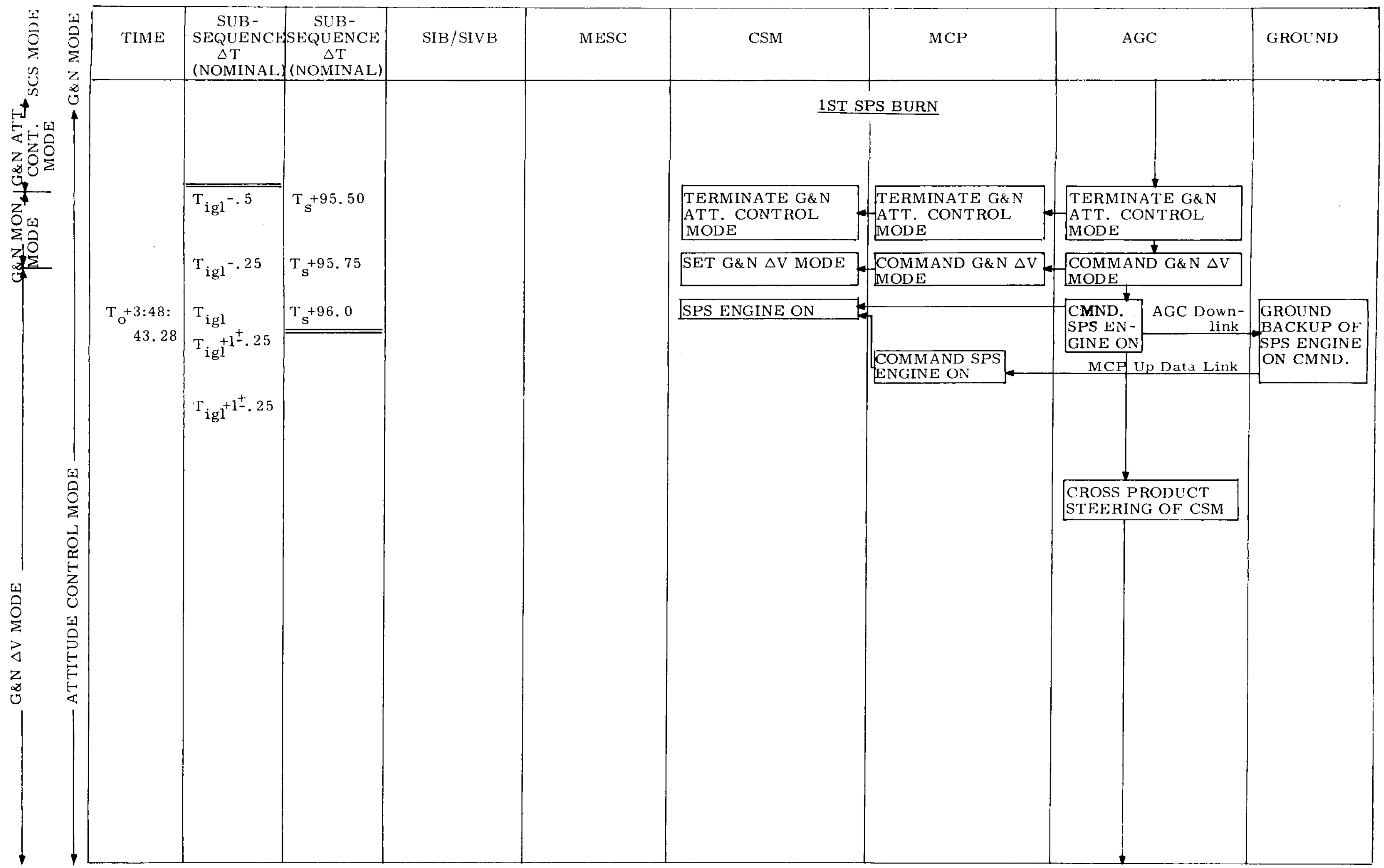
G&N MODE ← FINE ALIGN MODE →

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

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		T_s+2.5			+X TRANS LOGIC INTERLOCK TO TVC LOGIC	+X TRANS COMND. (TO TVC LOGIC ONLY)		
		T_s+3.0		SIVB/CSM SEPARATION COMMAND TERMINATED	DEENERGIZE VIA TRANSLATION HAND CONTROLLER (ABORT POSITION)	TERMINATE SIVB/CSM SEPARATION COMMAND		
		T_s+3.0		DIRECT ULLAGE COMMAND TERMINATED	DIRECT ULLAGE OFF			
		T_s+3.0			+X TRANS ON (INHIBIT RELEASED). PITCH AND YAW ATTITUDE CONTROL ON (INHIBIT RELEASED). PITCH & YAW UNDER CONTROL OF RATE GYROS. ATTITUDE ERRORS AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N.			
		T_s+3.0			P_2 GIMBAL MOTOR ON			
	T_s+3.7-0.3 +1.7						COMMAND G&N SYSTEM TO ATTITUDE CONTROL MODE	
		T_s+6.0			+X TRANS COMND. OFF	TERMINATE +X TRANS COMMAND	TERMINATE +X TRANS COMMAND	
							STOP CDU TORQUING AGC ASSUMES VEHICLE IS AT CORRECT ORIENTATION FOR 1ST SPS BURN	

SCS MODE — G&N ATT. CONT. MODE

G&N MODE — FINE ALIGN MODE — ATT. CONT. MODE


TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
1ST SPS BURN
T_o+3:48:43.28
T_{igl}-.5
T_{igl}-.25
T_{igl}
T_{igl}+1±.25
T_{igl}+1±.25
T_s+95.50
T_s+95.75
T_s+96.0
TERMINATE G&N ATT. CONTROL MODE
SET G&N ΔV MODE
SPS ENGINE ON
TERMINATE G&N ATT. CONTROL MODE
COMMAND G&N ΔV MODE
COMMAND SPS ENGINE ON
TERMINATE G&N ATT. CONTROL MODE
COMMAND G&N ΔV MODE
CMND. SPS ENGINE ON
AGC Down-link
MCP Up Data Link
CROSS PRODUCT STEERING OF CSM
GROUND BACKUP OF SPS ENGINE ON CMND.
SCS MODE
G&N ATT. CONT. MODE
G&N MON MODE
G&N ΔV MODE
G&N MODE
ATTITUDE CONTROL MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
T_o+3:49:23.28	T_{igl}+40.0	T_{col}			SPS ENGINE OFF	COMMAND SPS ENGINE OFF	COMND. SPS ENGINE OFF AGC Down-link MCP Up Data Link	GROUND BACKUP OF SPS ENGINE OFF CMND.
		$T_{col}+1^{+}_{-}.25$			PITCH AND YAW CONTROL INHIBIT RELEASED TO RCS.			
		$T_{col}+7$				TIME DELAY -3 SEC	COMMAND SPS MOTOR POWER OFF	
		$T_{col}+10$			SPS GIMBAL MOTOR POWER OFF	COMMAND SPS GIMBAL MOTOR POWER OFF		
		$T_{col}+10$			PRETHRUST VALVES CLOSED	CLOSE SPS PRETHRUST VALVES		
		$T_{col}+10$			SPS GIMBALS CMND. TO TRIM POSITION #2. RESPONSE INHIBITED WITHOUT GIMBAL MOTOR POWER			
		$T_{col}+10$				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. CONT MODE	COMMAND G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE	

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

G&N MODE: ATTITUDE CONT. MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
					COAST		CHECK $T_{ff} < K$ (N / Y*)	
							COMPUTE ATTITUDE MANEUVER NECESSARY TO ACHIEVE COLD SOAK ATTITUDE	
							START MANEUVER	
							MANEUVER COMPLETED HOLD COLD SOAK ATTITUDE	
T_o+3:54: 23:28		T_{col}+300			START FDAI ALIGN	START FDAI ALIGN	COMMAND START FDAI ALIGN	
		T_{col}+310			STOP FDAI ALIGN	STOP FDAI ALIGN	STOP FDAI ALIGN	

SCS MODE ← G&N ATT. CONT. MODE →

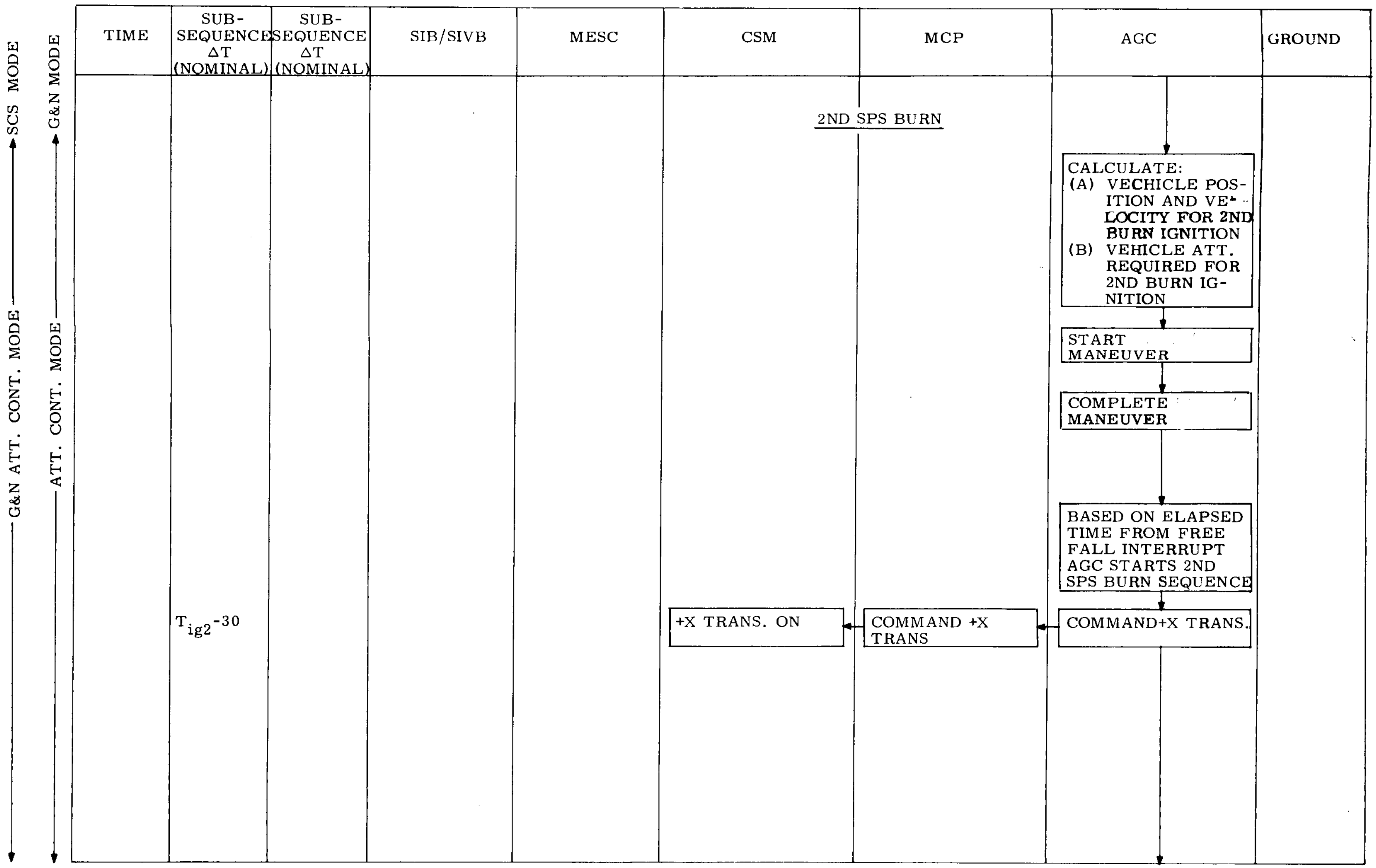
G&N MODE ← ATT. CONT. MODE →

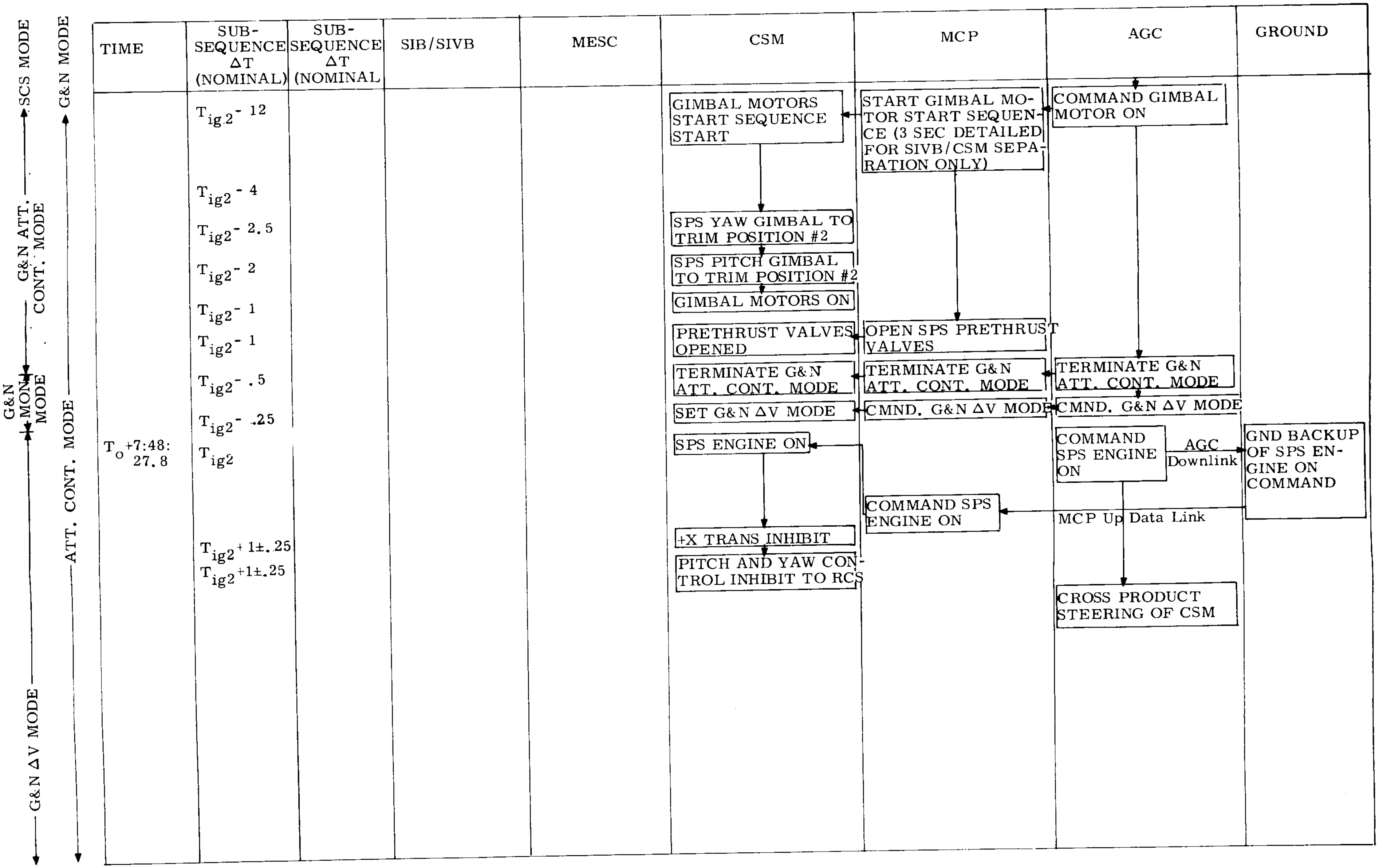
* See Section 4.2

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
							$\bar{R}, \bar{V}, T$, UPDATE AGC Uplink AGC Down-link	TRANSMIT $\bar{R}, \bar{V}$, T. AGC UPDATE
							T_{ff} CRI-TERIA UPDATE AGC Uplink AGC Down-link	T_{ff} CRITERIA UPDATE
T_o^+		T_{ff} = —					(1) START AVE G (2) START FREE FALL CALC (400,000') (3) BLOCK UPLINK	
							WAIT FOR FREE FALL INTERRUPT	
	T_{ign2}-10 m.	T_{ff}=20 m. (Nom.)					FREE FALL TIME IS LESS THAN T_{ff} MIN (NOMINAL 20 MIN) (1) SET T_{ign2}=T+10MIN	

SCS MODE ← G&N ATT. CONT. MODE →

G&N MODE ← ATT. CONT. MODE →


TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
2ND SPS BURN
CALCULATE:
(A) VECHICLE POSITION AND VELOCITY FOR 2ND BURN IGNITION
(B) VEHICLE ATT. REQUIRED FOR 2ND BURN IGNITION
START MANEUVER
COMPLETE MANEUVER
BASED ON ELAPSED TIME FROM FREE FALL INTERRUPT AGC STARTS 2ND SPS BURN SEQUENCE
COMMAND+X TRANS.
COMMAND +X TRANS
+X TRANS. ON
Tig2-30
SCS MODE
G&N ATT. CONT. MODE
G&N MODE
ATT. CONT. MODE

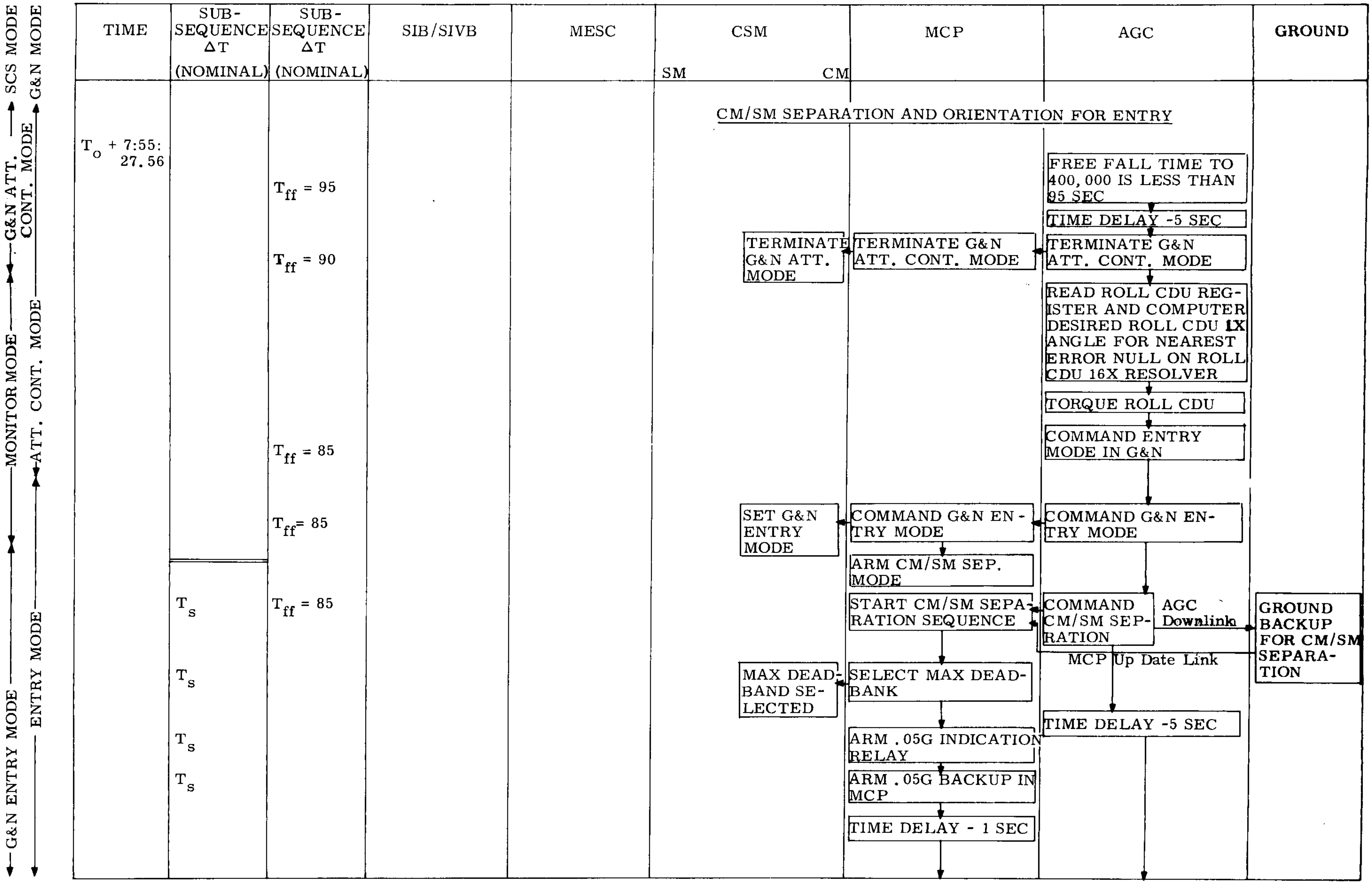

SCS MODE
G&N ATT. CONT. MODE
G&N MON. MODE
G&N ΔV MODE
G&N MODE
ATT. CONT. MODE
TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
T ig2 - 12
T ig2 - 4
T ig2 - 2.5
T ig2 - 2
T ig2 - 1
T ig2 - 1
T ig2 - .5
T ig2 - .25
T ig2
T ig2 + 1±.25
T ig2 +1±.25
T o +7:48: 27.8
GIMBAL MOTORS START SEQUENCE START
SPS YAW GIMBAL TO TRIM POSITION #2
SPS PITCH GIMBAL TO TRIM POSITION #2
GIMBAL MOTORS ON
PRETHRUST VALVES OPENED
TERMINATE G&N ATT. CONT. MODE
SET G&N ΔV MODE
SPS ENGINE ON
+X TRANS INHIBIT
PITCH AND YAW CONTROL INHIBIT TO RCS
START GIMBAL MOTOR START SEQUENCE (3 SEC DETAILED FOR SIVB/CSM SEPARATION ONLY)
OPEN SPS PRETHRUST VALVES
TERMINATE G&N ATT. CONT. MODE
CMND. G&N ΔV MODE
COMMAND SPS ENGINE ON
COMMAND GIMBAL MOTOR ON
TERMINATE G&N ATT. CONT. MODE
CMND. G&N ΔV MODE
COMMAND SPS ENGINE ON
AGC Downlink
MCP Up Data Link
CROSS PRODUCT STEERING OF CSM
GND BACKUP OF SPS ENGINE ON COMMAND

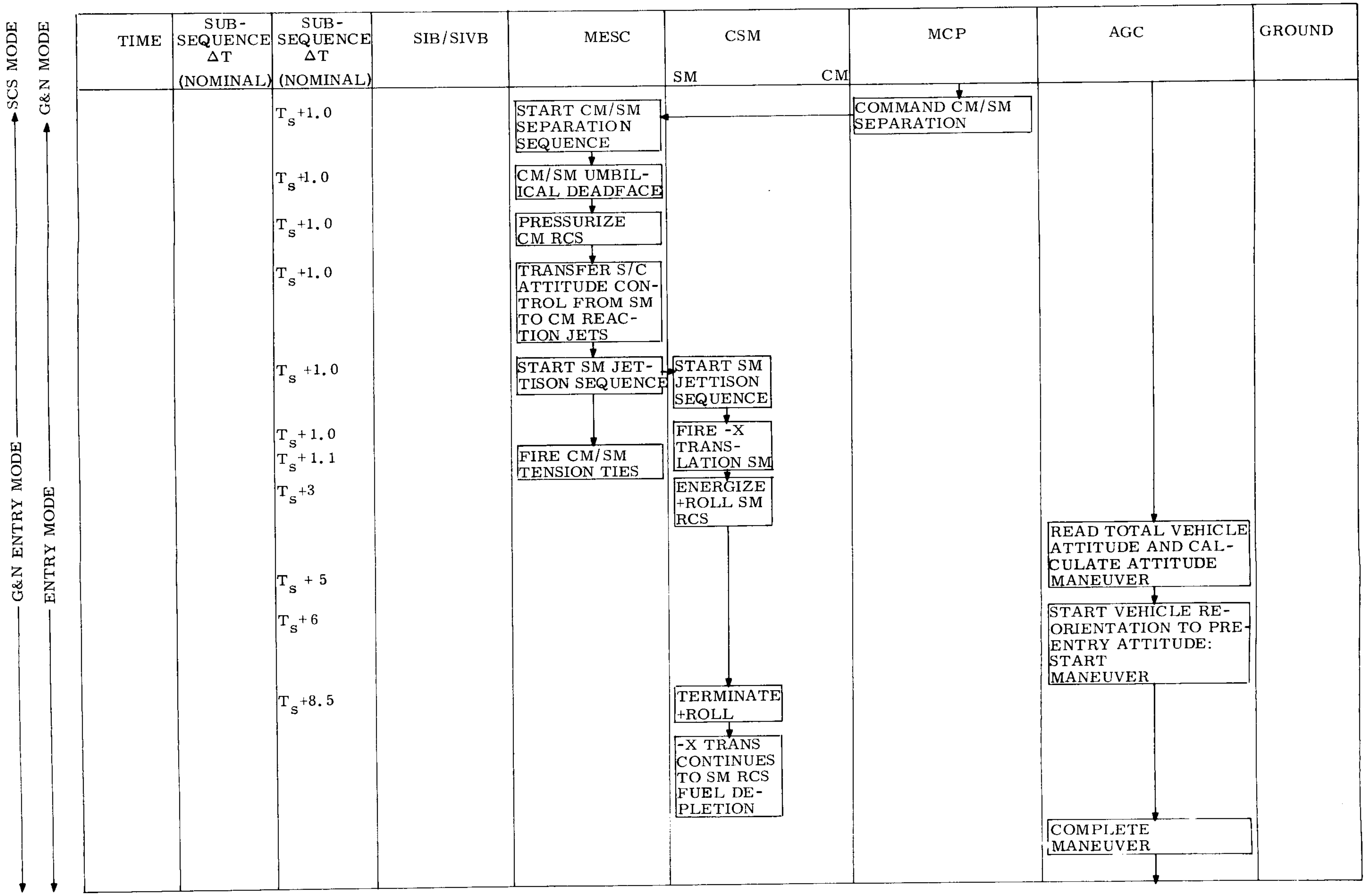
MODE SCS	MODE G&N	TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	S-IC S-II/S-IV$_b$	MESC	CSM	MCP	AGC	GROUND
G&N ΔV MODE	ATTITUDE CONTROL MODE	T_o+7:53 02.56	T_{co}	T_{ig}+274.76			SPS ENGINE OFF		COMMAND SPS AND +X TRANS OFF	GROUND BACKUP OF SPS ENGINE OFF COMMAND
			T_{co}+1.0				RELEASE +X TRANS INHIBIT	COMMAND SPS ENGINE OFF	MCP Up Data Link	
			T_{co}+7.0				TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS: START ATT. CONT.	TIME DELAY 3 sec	COMMAND SPS GIMBAL MOTOR POWER OFF	GROUND BACKUP OF GIMBAL MOTOR POWER ON OFF
			T_{co}+10.0				SPS GIMBAL MOTOR POWER OFF	COMMAND SPS GIMBAL MOTOR POWER OFF		
							PRETHRUST VALVES CLOSED	CLOSE SPS PRETHRUST VALVES		
G&N MON MODE			T_{co}+10.5				TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	
G&N ATT CONT. MODE			T_{co}+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_{co}+40 sec							

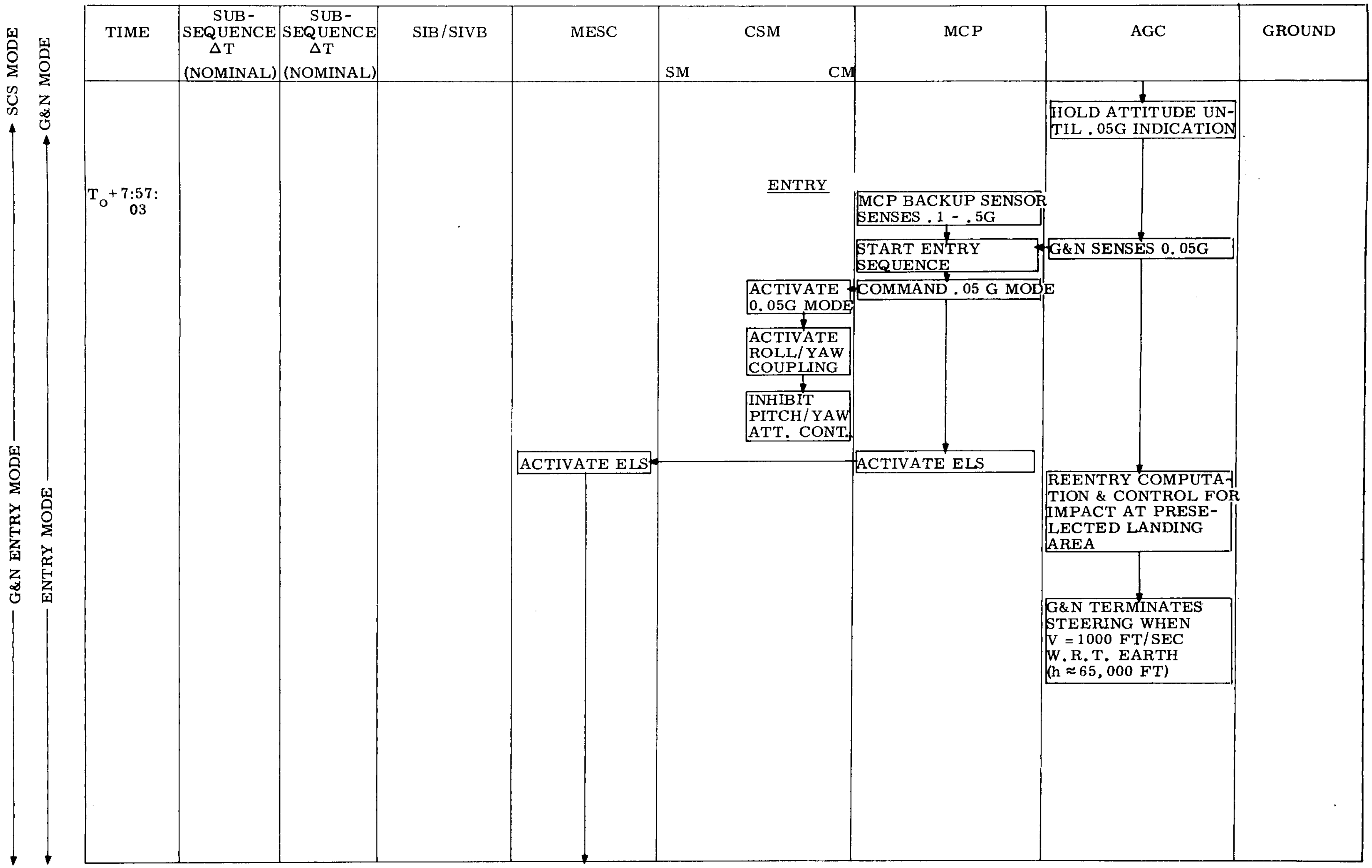
TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
T_o +7:53:42.56	T_{co} +40 sec				CM/SM SEPARATION ORIENTATION		FREE FALL TIME TO 400,000 FT IS LESS THAN 200 SEC → READ TOTAL VEHICLE ATTITUDE AND CALCULATE ATTITUDE MANEUVER → START VEHICLE REORIENTATION TO CM/SM SEPARATION ATTITUDE: START MANEUVER → COMPLETE MANEUVER → STANDBY FOR CM/SM SEPARATION COMMAND TO BE KEYED ON FREE FALL TIME TO 400,000' CALCULATION	

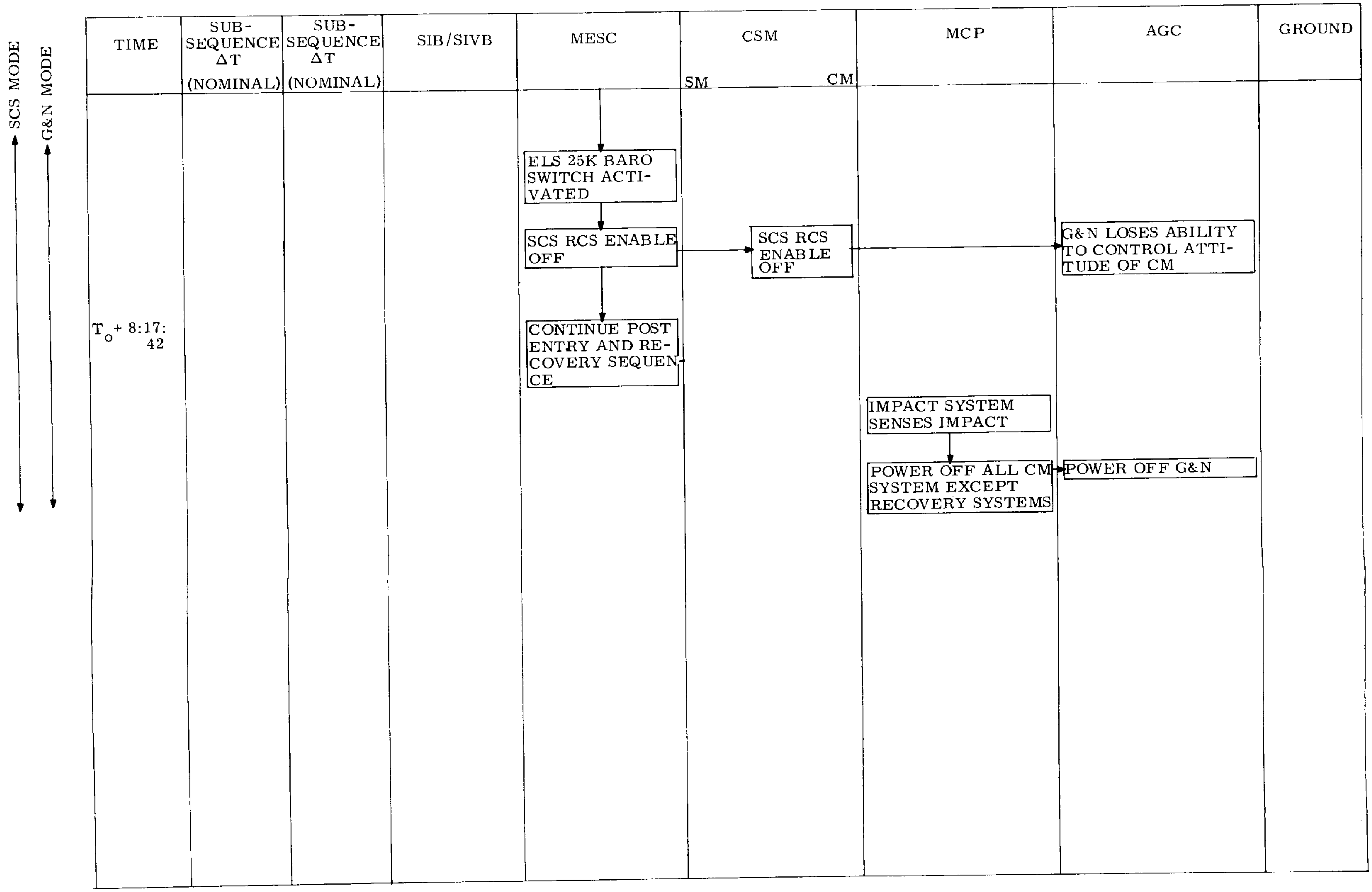
SCS MODE ← G&N ATT. CONT. MODE →

G&N MODE ← ATT. CONT. MODE →


SCS MODE
G&N ATT. CONT. MODE
MONITOR MODE
G&N ENTRY MODE
G&N MODE
ATT. CONT. MODE
ENTRY MODE
TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
SM
CM
MCP
AGC
GROUND
CM/SM SEPARATION AND ORIENTATION FOR ENTRY
To + 7:55: 27.56
Tff = 95
Tff = 90
Tff = 85
Tff= 85
Tff = 85
Ts
Ts
Ts
Ts
FREE FALL TIME TO 400,000 IS LESS THAN 95 SEC
TIME DELAY -5 SEC
TERMINATE G&N ATT. CONT. MODE
TERMINATE G&N ATT. CONT. MODE
TERMINATE G&N ATT. MODE
READ ROLL CDU REGISTER AND COMPUTER DESIRED ROLL CDU 1X ANGLE FOR NEAREST ERROR NULL ON ROLL CDU 16X RESOLVER
TORQUE ROLL CDU
COMMAND ENTRY MODE IN G&N
COMMAND G&N ENTRY MODE
COMMAND G&N ENTRY MODE
SET G&N ENTRY MODE
ARM CM/SM SEP. MODE
COMMAND CM/SM SEPARATION
AGC Downlink
GROUND BACKUP FOR CM/SM SEPARATION
MCP Up Date Link
START CM/SM SEPARATION SEQUENCE
SELECT MAX DEAD-BANK
MAX DEAD-BAND SELECTED
TIME DELAY -5 SEC
ARM .05G INDICATION RELAY
ARM .05G BACKUP IN MCP
TIME DELAY - 1 SEC


TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
SM
CM
MCP
AGC
GROUND
COMMAND CM/SM SEPARATION
START CM/SM SEPARATION SEQUENCE
CM/SM UMBILICAL DEADFACE
PRESSURIZE CM RCS
TRANSFER S/C ATTITUDE CONTROL FROM SM TO CM REACTION JETS
START SM JETTISON SEQUENCE
FIRE CM/SM TENSION TIES
START SM JETTISON SEQUENCE
FIRE -X TRANSLATION SM
ENERGIZE +ROLL SM RCS
TERMINATE +ROLL
-X TRANS CONTINUES TO SM RCS FUEL DEPLETION
READ TOTAL VEHICLE ATTITUDE AND CALCULATE ATTITUDE MANEUVER
START VEHICLE REORIENTATION TO PRE-ENTRY ATTITUDE: START MANEUVER
COMPLETE MANEUVER
T_s+1.0
T_s+1.0
T_s+1.0
T_s+1.0
T_s +1.0
T_s+1.0
T_s+1.1
T_s+3
T_s + 5
T_s+6
T_s+8.5
SCS MODE
G&N ENTRY MODE
G&N MODE
ENTRY MODE


SCS MODE
G&N ENTRY MODE
G&N MODE
ENTRY MODE
TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
SM
CM
MCP
AGC
GROUND
T_O + 7:57:03
ENTRY
HOLD ATTITUDE UNTIL .05G INDICATION
MCP BACKUP SENSOR SENSES .1 - .5G
G&N SENSES 0.05G
START ENTRY SEQUENCE
ACTIVATE 0.05G MODE
COMMAND .05 G MODE
ACTIVATE ROLL/YAW COUPLING
INHIBIT PITCH/YAW ATT. CONT.
ACTIVATE ELS
ACTIVATE ELS
REENTRY COMPUTATION & CONTROL FOR IMPACT AT PRESELECTED LANDING AREA
G&N TERMINATES STEERING WHEN V = 1000 FT/SEC W.R.T. EARTH (h ≈ 65,000 FT)


TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
SM
CM
MCP
AGC
GROUND
SCS MODE
G&N MODE
T_o + 8:17:42
ELS 25K BARO SWITCH ACTIVATED
SCS RCS ENABLE OFF
CONTINUE POST ENTRY AND RECOVERY SEQUENCE
SCS RCS ENABLE OFF
G&N LOSES ABILITY TO CONTROL ATTITUDE OF CM
IMPACT SYSTEM SENSES IMPACT
POWER OFF ALL CM SYSTEM EXCEPT RECOVERY SYSTEMS
POWER OFF G&N

5. GUIDANCE EQUATIONS FOR CSM

5.1 Powered Flight Guidance Scheme

The guidance scheme for Mission 501 is the same as that planned for all Apollo CSM powered flights. It is based on the possibility of an analytical description of a required velocity ($\underline{v}_r$) which is defined as the velocity required at the present position $\underline{r}$, in order to achieve the stated objective of a particular powered flight maneuver.

If $\underline{v}$ is the present velocity, then the velocity to be gained ($\underline{v}_g$) is given by

$$\underline{v}_g = \underline{v}_r - \underline{v} \tag{5-1}$$

Differentiation of both sides yields

$$\dot{\underline{v}}_g = \dot{\underline{v}}_r - \dot{\underline{v}} \tag{5-2}$$

$$= \dot{\underline{v}}_r - \underline{g} - \underline{a}_T \tag{5-3}$$

$$= \underline{b} - \underline{a}_T \tag{5-4}$$

where

$$\underline{b} = \dot{\underline{v}}_r - \underline{g} \tag{5-5}$$

and $\underline{g}$ is the gravitational acceleration.

The steering command is developed by formulating a desired thrust acceleration ($\underline{a}_{T_D}$) as that which satisfies the equation

$$\underline{a}_{T_D} \times \underline{v}_g = c\underline{b} \times \underline{v}_g \tag{5-6}$$

where c is a constant scalar.

Hence a measure of the error between $\underline{a}_{T_D}$ and the actual acceleration $\underline{a}_T$ is given by

$$\underline{\omega}_c = \frac{\underline{v}_g \times \dot{\underline{m}}}{|\underline{v}_g|\ |\underline{m}|} \tag{5-7}$$

where

$$\dot{\underline{m}} = c\,\underline{b} - \underline{a}_T \qquad (5\text{-}8)$$

It can be verified that $\underline{\omega}_c$ is also the axis about which the thrust vector should be rotated to null the error. Hence $\underline{\omega}_c$ is used in forming the steering command.

Once a required velocity $\underline{v}_r$ is defined satisfactorily, the procedure for the generation of the error vector $\underline{\omega}_c$ is the same for all phases of powered flight. The equations for the required velocity for the various phases are described in the succeeding pages. Descriptions of the initial alignment procedure, ignition and cutoff logic and implementation in AGC are also included.

5.2 Nominal Mission

5.2.1 Required Velocity

The required velocity for the first and second burns of the nominal mission is defined as that velocity which will put the vehicle in an elliptical trajectory of predefined parameters (semi latus rectum p and eccentricity e). The values used are

First Burn	Second Burn
$p = 3.2849 \times 10^7$ ft	$p = 4.1969 \times 10^7$ ft
$e = 0.59588$	$e = 0.99913$

These numbers correspond to the trajectory described in Section 6. The value of c in Eq (5-6) is 1.0.

The required velocity can be written as

$$\underline{v}_r = \underline{i}_r\, v_{rad} + \underline{i}_H\, v_H \qquad (5\text{-}9)$$

where

$$v_{rad} = \pm \left[\frac{\mu}{p}\left(e^2 - \left(\frac{p}{r} - 1\right)^2\right)\right]^{1/2} \qquad (5\text{-}10)$$

$$v_H = + \left[\frac{\mu p}{r^2}\right]^{1/2} \qquad (5\text{-}11)$$

$$p = a(1 - e^2) \qquad (5\text{-}12)$$

$$\underline{i}_r = \frac{\underline{r}}{r} \qquad (5\text{-}13)$$

and

$$\underline{i}_H = \text{UNIT}\,(\underline{i}_N \times \underline{i}_r) \tag{5-14}$$

The positive sign is used in Eq (5-10) for the radial velocity during first burn and the negative sign is used during second burn.

5.2.2 Yaw Steering

Plane control during the nominal mission is achieved by specifying the normal ($\underline{i}_N$) to the required plane appearing in Eq (5-14). The required trajectory plane is defined to be the plane containing the present vector (r) and the landing site vector taken as point of drogue chute deployment at 24,000 ft ($\underline{r}_{LS}$; 31.03N, 198.02E) at the nominal time (31,140-sec) of landing and is given by

$$\underline{i}_N = \text{UNIT}\,(\underline{r} \times \underline{r}_{LS})\ \text{Sign}\ \ (\underline{r} \times \underline{r}_{LS}) \cdot \underline{i}_w \tag{5-15}$$

where $\underline{i}_w$ is the earth's polar unit vector. At cutoff the vehicle velocity will be equal to $\underline{v}_r$, thereby ensuring the trajectory plane to be $\underline{i}_N$ according to Eqs (5-9) and (5-14).

During the third and fourth burns, no computations are made for $\underline{v}_r$. The desired thrust direction is held fixed at the direction computed at the end of the second burn.

5.2.3 Engine Ignition

In the nominal mission, the engine is always ignited after a fixed interval of time from a previous event. The first burn is initiated 96.0 seconds after receipt of SIV-B/CSM separation signal, and the second burn 600 seconds after T_{ff} falls below the criterion ($T_{ff\,(min)}$).

5.2.4 Engine Cutoff

During all the burns a time to cutoff (T_g) is continuously being estimated from the equation

$$T_g = k\,\underline{v}_g \cdot \underline{m} / \left|\underline{m}\right| \tag{5-16}$$

where k is a factor that is a first approximation to the thrust acceleration increase over 4 sec for SPS1 and SPS2. The value(s) of k have not yet been determined. The accuracy of T_g increases as $T_g \rightarrow 0$, because as $\underline{v}_g \rightarrow 0$, $\underline{b} \rightarrow 0$.

When T_g falls below the critical value of 4.0 seconds, the clock is set to turn off the engine T_g seconds later.

5.3 Aborts During Boost

The guidance equations for aborts during boost have been designed to meet the following constraints that have been imposed on the spacecraft attitude.

The visual horizon is to be kept on a hairline on the forward window during the entire powered flight and this line should be independent of the time at which abort is initiated.

The window geometry indicates that this requires the thrust direction to be between 4° and 36° to the line of sight to the visual horizon. Within this limitation, the larger tha angle the greater is the interval of time before nominal SIV-B cutoff during which the capability exists to reach a particular recovery area in the event of an abort. Hence a thrust angle of 35° to the line of sight to the horizon is used (see Fig. 5.1).

5.3.1 Required Velocity

The definition of a required velocity, in the usual sense, consistent with the direction of thrust pre-specified as above, is not possible. Hence, a pseudo required velocity is defined for aborts which, when incorporated into the general steering scheme, will satisfy not only the constraint on the thrust direction but also permit recovery from a specified landing area.

Let $\underline{r}_e$ be the entry position (400,000 ft) corresponding to a free fall from the present position. Then we can write

$$x = \tan \frac{\theta_f}{2} \tag{5-17}$$

$$= \frac{r_e - r}{r_e \cot\gamma + r \cot\gamma_e} \tag{5-18}$$

and

$$\sin\theta_f = \frac{2x}{x^2 + 1} \tag{5-19}$$

$$\cos\theta_f = \frac{1 - x^2}{1 + x^2} \tag{5-20}$$

where

$$\cot\gamma = \frac{\underline{v} \cdot \underline{i}_r}{\underline{v} \cdot \underline{i}_H}, \tag{5-21}$$

$$\cot\gamma_e = r/p \left[e^2 - \left(\frac{p}{r_e} - 1 \right)^2 \right]^{1/2} \tag{5-22}$$

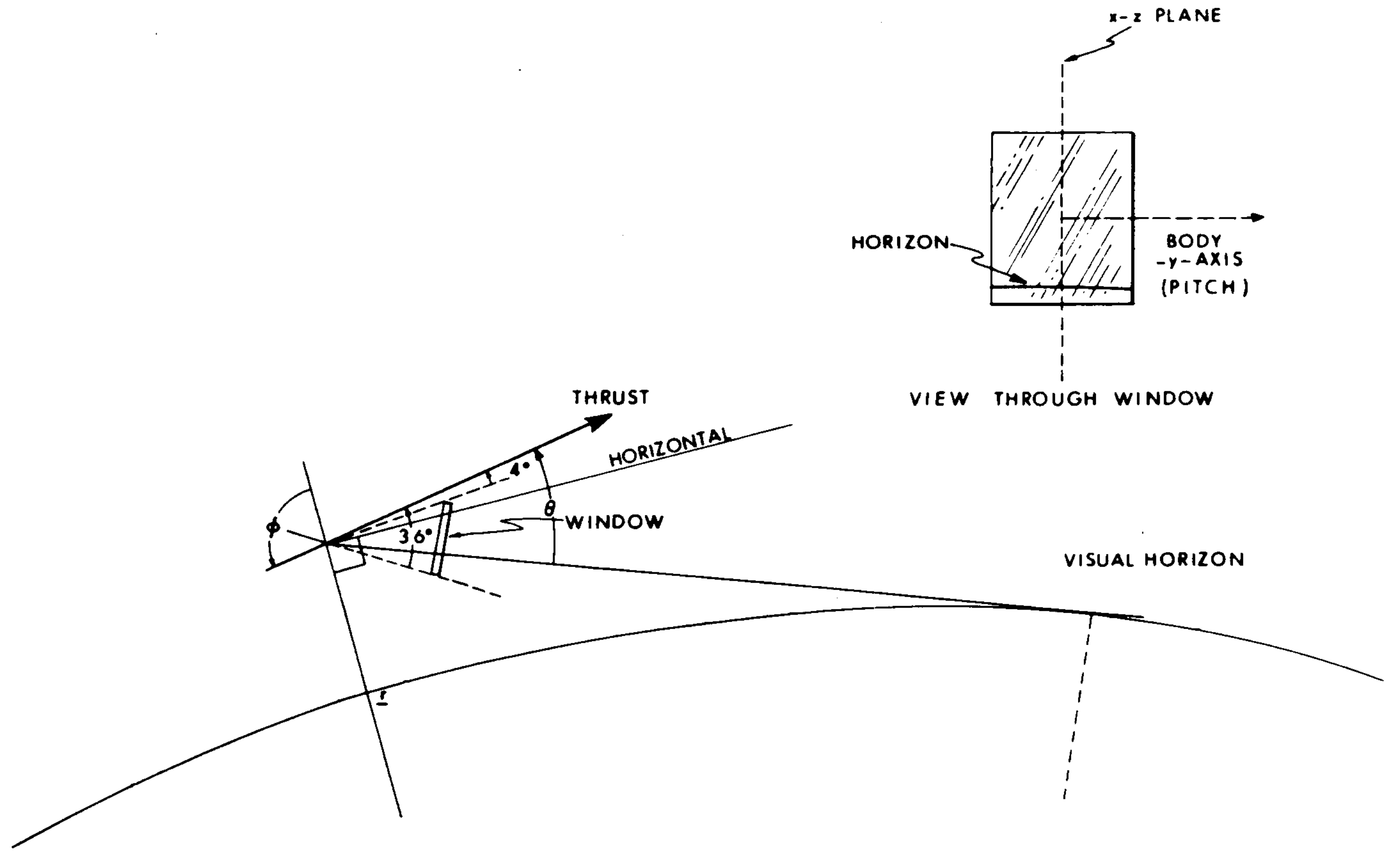


Fig. 5-1 Window Geometry

$$\underline{i}_H' = \underline{i}_p \times \underline{i}_r \tag{5-23}$$

$$\underline{i}_p = \text{UNIT}\ (\underline{r} \times \underline{v}) \tag{5-24}$$

θ_f is the free-fall central angle to the entry point,

r_e is the radius at 400,000 ft altitude,

γ_e is the flight path angle w.r.t the local vertical at entry

γ is the present flight path angle (w.r.t. vertical)

The entry-point is given by

$$\underline{r}_e = r_e\ (\underline{i}_r \cos\theta_f + \underline{i}_{H'} \sin\theta_f) \tag{5-25}$$

If perigee is higher than r_e, $\underline{r}_e$ does not exist.

Now let $\underline{r}_T$ be the desired landing site (target vector) at the nominal time. The target vector for aborts is the inertial position of 28.3°N and 340.5°E longitude at 1350 seconds from lift-off. This choice corresponds to minimum plance change for aborts at 681.075 seconds from the nominal boost trajectory. The normal (1_N) to the desired plane is defined in section 5.3.2.

The desired entry point ($\underline{r}_{ed}$) is a function of the entry velocity and flight path angle. This vector is computed during each computational repetition as a function of the expected entry velocity and the inertial location of the nominal landing site.

If the engine were to be cut-off at the present time, the velocity at entry (v_e) will be (from the vis-viva integral)

$$v_e = \left[v^2 + 2\mu \left(\frac{1}{r_e} - \frac{1}{r} \right) \right]^{1/2} \tag{5-25a}$$

Based on this velocity v_e an anticipated entry range (ϕ_e) is computed from an empirical formula

$$\phi_e = \frac{6076.15}{R_e}\ (-15064 + 0.64286 v_e + 0 v_e^2) \tag*{(5-25b)\#}$$

if $v_e > 24600$ ft/sec, and

$$\phi_e = \frac{6076.15}{R_e}\ (750) \tag{5-25c}$$

if $v_e < 24600$ ft/sec.

*It should be noted that Eq. (5-25b) does not take into account the entry flight path angle. The coefficients are precomputed on the basis of the nominal trajectory and hence the flight path angle is implied in Eq. (5-25b).

The desired entry vector ($\underline{r}_{ed}$) is computed as

$$\underline{r}_{ed} = r_e \left(\underline{1}_{r_{LS}} \cos\phi_e - \text{UNIT}\left(\underline{1}_N \times \underline{1}_{r_{LS}}\right) \sin\phi_e\right) \qquad (5\text{-}25d)$$

At cut-off, $\underline{r}_{ed} = \underline{r}_e$ and the actual entry velocity is v_e, satisfying the entry range equation.

The error d can be written as

$$d = \underline{r}_{ed} - \underline{r}_e \qquad (\text{-}26)$$

The rate of change of this error is computed by differencing $\underline{r}_e$ as

$$\dot{d} = \frac{\Delta d}{\Delta t} \qquad (5\text{-}27)$$

$$= \left| \underline{r}_{e_n} - \underline{r}_{e_{n-1}} \right| / \Delta t \qquad (5\text{-}28)$$

where the subscript n denotes the nth computational repetition.

Observing that $d/\dot{d}$ is a measure of the time to cutoff (T_g), let the magnitude of $\underline{v}_g$ be defined as

$$\underline{v}_g = \frac{d}{\dot{d}} \underline{a}_T \qquad (5\text{-}29)$$

or

$$\underline{v}_g = \frac{d}{\Delta d} \Delta V \qquad (5\text{-}30)$$

where $\underline{\Delta v}$ is the velocity increment measured with the accelerometers in the interval Δt. This formulation of $|\underline{v}_g|$ enables the cutoff Eq (5-16) to be used in terminating an abort burn.

Now consider Eq (6). Set c = 0; then

$$\underline{a}_{T_D} \times \underline{v}_g = 0 \qquad (5\text{-}31)$$

If the direction of $\underline{v}_g$ is chosen as the desired and known direction of $\underline{a}_T$, the specified constraint on the spacecraft attitude will be satisfied.

Figure 5-1 shows the geometry of the spacecraft window. The angle ϕ between the thrust and $\underline{r}$ is given by

$$\phi = \theta + \sin^{-1}\left(\frac{R_{vh}}{|\underline{r}|}\right) \tag{5-32}$$

where θ is the specified an gle (35^{o}) to the horizon and R_{vh} is the radius to the visual horizon.

From Eq (5-32) and Eq (5-30) we can define $\underline{v}_g$ as

$$\underline{v}_g = \frac{d}{\Delta d}\left|\underline{\Delta v}\right|(-\cos\phi\ \underline{i}_r + \sin\phi\ i_{H'}) \tag{5-33}$$

5.3.2 Yaw and Roll Steering

The development of Eq (5-33) is based on $\underline{i}_r$ and $\underline{i}_{H'}$ which are both in the present trajectory plane according to Eq (5-23). However, normally a plane change will be required to reach the same landing site from different points of aborts on the boost trajectory.

Let the plane containing the present position r and the target vector (see Section 5.3.1) $\underline{r}_T$ be defined by

$$\underline{i}_N = \text{UNIT}\ (\underline{r} \times \underline{r}_T)\ \text{Sign}\ \ (\underline{r} \times \underline{r}_T) \cdot \underline{i}_w \tag{5-34}$$

The velocity increment along $\underline{i}_p$ (normal to $\underline{v}$) to null the error between $\underline{i}_p$ and $\underline{i}_N$ is given by (see Fig. 5-2)

$$\Delta v_N = |v|\ (\underline{i}_p \times \underline{i}_N) \cdot \underline{i}_r \tag{5-35}$$

which is equivalent to

$$\Delta v_N = |v|\ (-\underline{i}_{H'}) \cdot \underline{i}_N$$

The acceleration along $\underline{i}_p$ required to accomplish the plane change is given by

$$\underline{a}_N = \underline{i}_p\ \frac{\Delta v_N}{T_g + \delta} \tag{5-36}$$

where δ is a small scalar (5 seconds). In order to prevent large yaw rate commands, a limit of 8 ft/sec^2 is imposed on the magnitude of $\underline{a}_N$.

Equation (5-33) can be now modified to include yaw steering, as

$$\underline{v}_g = \underline{i}_T \frac{d}{\Delta d} \left|\Delta V\right| \tag{5-37}$$

where

$$\underline{i}_T = \text{UNIT}\left[-\underline{i}_r \cos\phi + \text{UNIT}\left(\underline{i}_H{}' a_T \cos 20^\circ + a_n\right) \sin\phi\right] \tag{5-38}$$

and a_T is the magnitude of the thrust acceleration, and the cos 20° term compensates in part for the approximation of projecting the thrust vector onto the horizontal plane.

The required velocity is given by

$$\underline{v}_r = \underline{v} + \underline{v}_g \tag{5-39}$$

where $\underline{v}_g$ is given by Eq (5-37). With the required velocity so computed and with c = 0, the same steering (Eq 5-6) as for the nominal mission is used.

The rate command resulting from the required velocity $\underline{v}_r$ has only pitch and yaw components. However, the vehicle must be rolled such that the pitch axis is in the horizontal plane (see Fig. 5-2). This is achieved by generating a roll command ($\underline{\omega}_R$) proportional to the cross product of the desired pitch-axis vector, unit ($\underline{r} \times \underline{i}_{roll}$), with the actual pitch axis unit vector, $\underline{i}_{pitch}$.

$$\underline{\omega}_R = K_{roll}\left[\underline{i}_{roll} \cdot \left(\underline{i}_{pitch} \times \text{UNIT}\left[\underline{r} \times \underline{i}_{roll}\right]\right) \underline{i}_{roll}\right] \tag{5-39a}$$

where K_{roll} = 0.05 for 501.

The roll rate command is added to the rate command generated from Eq (5-7).

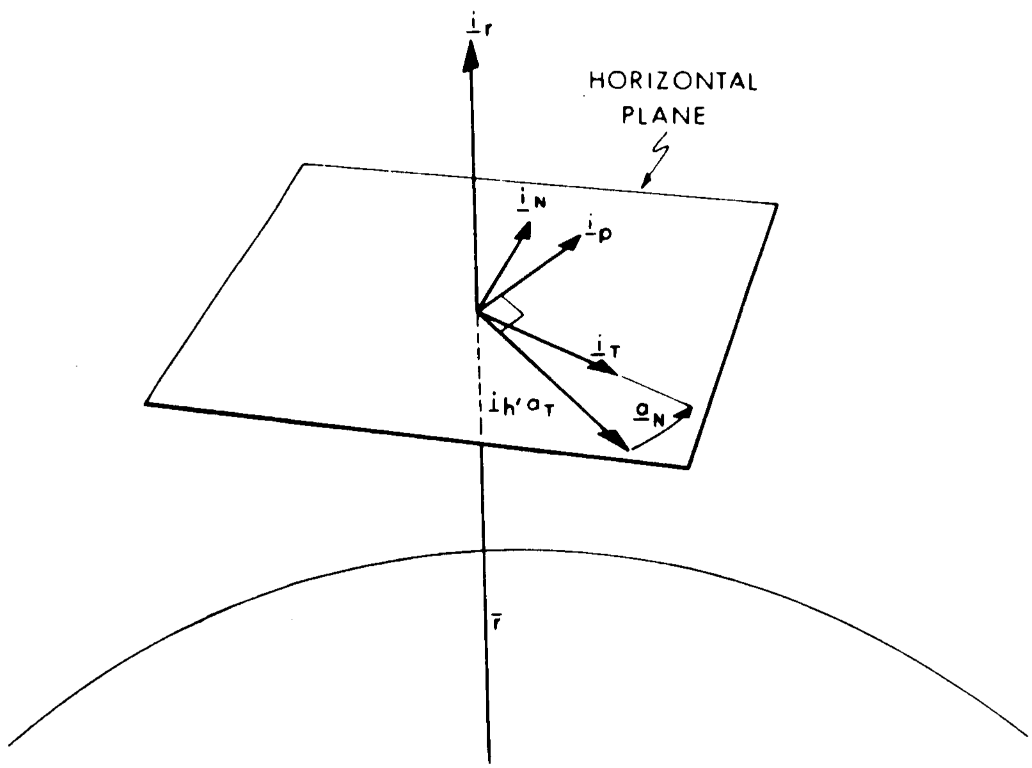


Fig. 5-2 Computation of $\underline{a}_n$ and $\underline{i}_t$

5.3.3 Engine Cutoff

When T_g falls below 4.0 secs, the clock is set to turn off the engine T_g seconds later under normal area control. However, the engine will be turned off if any one of the following violations has occurred before $T_g < 4.0$ secs.

a) Free-fall time to 400,000 ft* is below 200 seconds

b) $\underline{r}_e$ is beyond $\underline{r}_T$. That is,

$$\underline{r} \cdot \underline{r}_e < \underline{r} \cdot \underline{r}_T \tag{5-40}$$

c) If term in square brackets in Eq. (5-22) is negative, (i.e. if $\cot^2 \gamma_e$ is negative).

d) If the free-fall angle θ_f exceeds 53.13° (i.e. if x in Eq.(5-17) exceeds 1/2).

5.4 AGC Computations

Since the information about the thrust acceleration comes from the accelerometers in the form of velocity increments (Δv), the computations in the AGC are in terms of increments of velocity rather than instantaneous acceleration. The repetetive guidance computations are shown in the form of a block diagram in Fig. 5-3. The computational blocks are common to all powered flight maneuvers except the computation of $\underline{v}_r$ described in the preceeding sections.

5.4.1 Average $\underline{g}$ Equations

The vector position and velocity are updated in each computational cycle with a set of equations based on the average gravitational acceleration written as

$$\underline{r}_n = \underline{r}_{n-1} + \Delta t \left(\underline{v}_{n-1} + \underline{g}_{n-1} \frac{\Delta t}{2} + \frac{\Delta \underline{v}}{2} \right) \tag{5-46}$$

$$\underline{g}_n = \frac{-\mu}{r_n^2} \left[\left[1 + \left(\frac{r_e}{r_n} \right)^2 J(1 - 5 \sin^2 \phi) \right] \underline{i}_{r_n} + \left(\frac{r_e}{r_n} \right)^2 2J \sin \phi \; \underline{i}_w \right] \tag{5-47}$$

*280,000 ft. in case of aborts during boost phase.

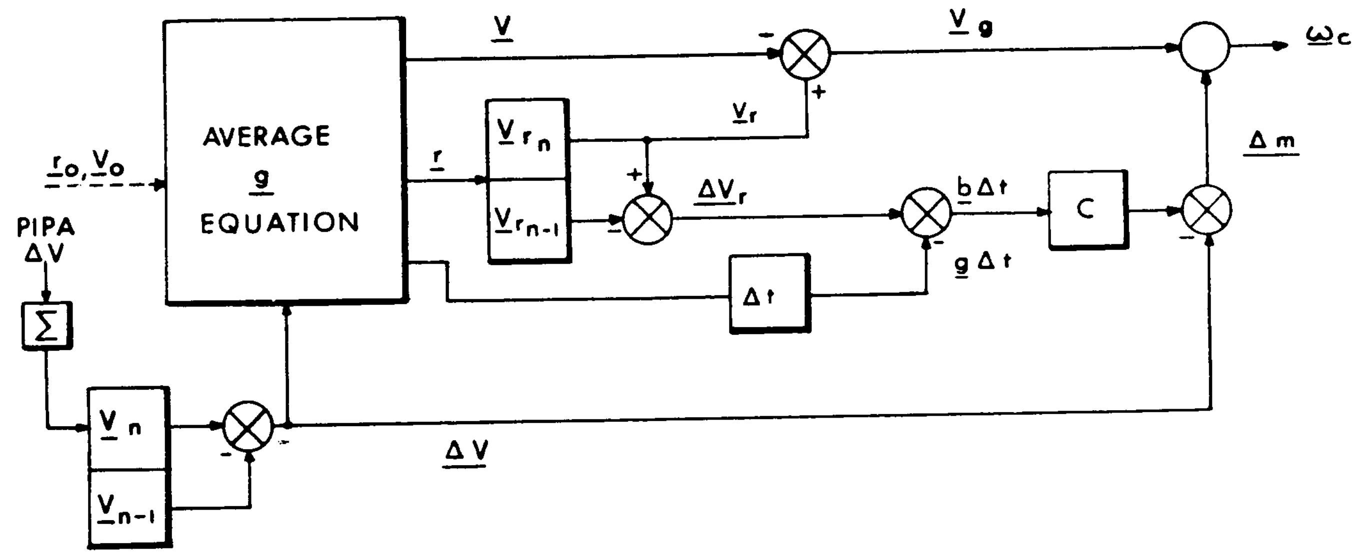


Fig. 5-3 Block Diagram of AGC Guidance Computations

and

$$\underline{v}_n = \underline{v}_{n-1} + \frac{(g_{n-1} + g_n)}{2} \Delta t + \Delta \underline{v} \tag{5-48}$$

where the subscript n denotes the nth computational repetition.

$J = 1.62346 \times 10^{-3}$, the first gravitation harmonic coefficient.

$\sin\phi$ = sin (Geocentric Latitude)

$= \underline{i}_{r_n} \cdot \underline{i}_w$

5.4.2 Steering Command

The vector $\underline{b}$ was defined in Eq. (5.5) as

$$\underline{b} = \dot{\underline{v}}_r - \underline{g} \tag{5-5}$$

In the AGC (as shown in Fig. 5-3), the increment ($\underline{b}\,\Delta t$) is computed as

$$\underline{b}\,\Delta t \cong \Delta \underline{v}_r - \underline{g}\,\Delta t \tag{5-49}$$

Then the steering command in Eq.(5-7) can be written as

$$\Delta \underline{\theta}_c = \frac{\underline{v}_g \times \Delta \underline{m}}{|\underline{v}_g||\Delta \underline{m}|} \Delta t \tag{5-50}$$

where

$$\Delta \underline{\theta}_c = \underline{\omega}_c \;\Delta t \tag{5-51}$$

$$\Delta \underline{m} = c\,\underline{b}\,\Delta t - \Delta \underline{v} \tag{5-52}$$

Before being output to the attitude control system, the steer law command is modified as follows:

$$\Delta \underline{\theta}_{out} = K_1 \Delta \underline{\theta}_c + K_2 \Sigma \Delta \underline{\theta}_c$$

For 501 $K_1 = 1/8$, $K_2 = 1/100$, and the second term is limited in magnitude to 1^o.

5.4.3 Orbital Integration Equations

Position and velocity during the free-fall phases of the mission are calculated by a direct numerical integration of the equations of motion. Since the disturbing accelerations are small the technique of differential acceleration due to Encke is mechanized in the AGC, as described in MIT Report R-467, The Compleat Sunrise.

5.5 Initial Thrust Alignment

Before the engine is ignited for any particular maneuver, the vehicle should be oriented so that on ignition the thrust is in the desired direction at that point. Since the time of ignition is known beforehand, the position and velocity at ignition can be computed prior to the arrival of the vehicle at that point. By integrating over Δt seconds from that point, the vectors $\underline{v}_g$ and $\underline{b\Delta t}$ can be computed as shown in Fig. 5-3.

The desired thrust direction can be now calculated (prior to arrival at the ignition point) as

$$\underline{i}_T = \text{UNIT}\left[\underline{q} + \left(a_T^2 - \left|\underline{q}\right|^2\right)^{1/2} \underline{i}_g\right] \tag{5-53}$$

where

$$\underline{i}_g = \text{UNIT}\ (\underline{v}_g) \tag{5-54}$$

and

$$\underline{q} = c\underline{b} - (\underline{i}_g \bullet c\underline{b})\underline{i}_g \tag{5-55}$$

and a_T is an estimate of the magnitude of the thrust acceleration.

Once $\underline{i}_T$ is computed from Eq.(5-53), the vehicle is oriented prior to arrival at the ignition point such that the thrust axis is along $\underline{i}_T$, and the pitch axis is along the desired pitch axis vector, UNIT ($\underline{r} \times i_{roll}$) i.e. a wings-level, z(yaw) - axis up roll attitude, using the general attitude maneuver program described in 5.6.

5.6 Attitude Maneuvers

5.6.1 Technique

The technique of computing large attitude maneuver sequences with the Block I G&N System depends on the geometry of Fig. 5-4 and 5-5.

Briefly:

1. A pure spacecraft roll (rotation about $\underline{X}_{SC}$) will force $\underline{X}_{NB}$ to describe a cone of half angle 33° about $\underline{X}_{SC}$ (See Fig. 5-4).

2. Gimbal lock is arbitrarily defined to occur when the outer gimbal axis (OGA, $\underline{X}_{NB}$) cuts into a cone of half angle 30° about the inner gimbal axis (IGA, $\underline{Y}_{SM}$). This condition results in a middle gimbal angle exceeding 60° (See Fig. 5-5).

Because the 33° cone can enclose the 30° cone, it is possible to attain any attitude of the S/C X-axis by specifying the appropriate vehicle roll attitude that avoids gimbal lock.

Maneuvers are performed as combinations of pure S/C roll sequences and S/C pitch/yaw sequences. An attempt is always made to achieve the desired orientation of the S/C X-axis with a planar pitch/yaw rotation from the present orientation. If $\underline{X}_{NB}$ were to cut into the lock area during this maneuver, the sequence is recomputed to include a roll to reposition $\underline{X}_{NB}$ before the pitch/yaw maneuver.

A final roll is always made to attain the desired final roll attitude.

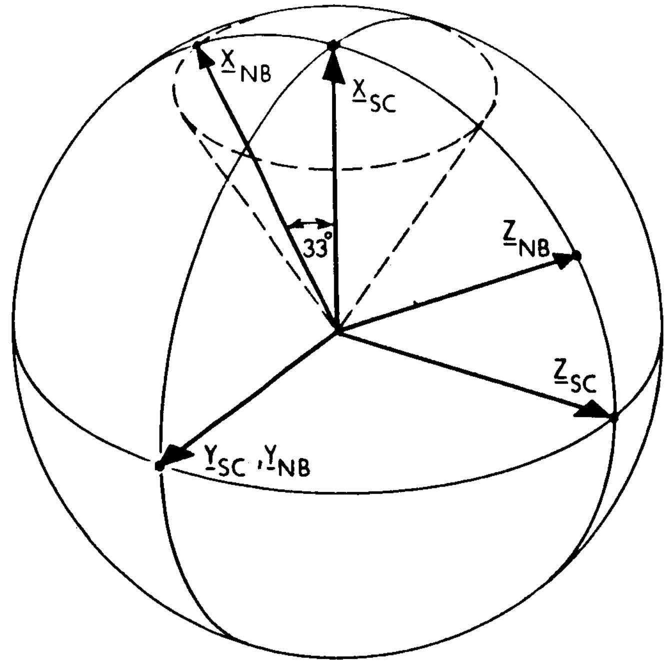


Figure 5-4

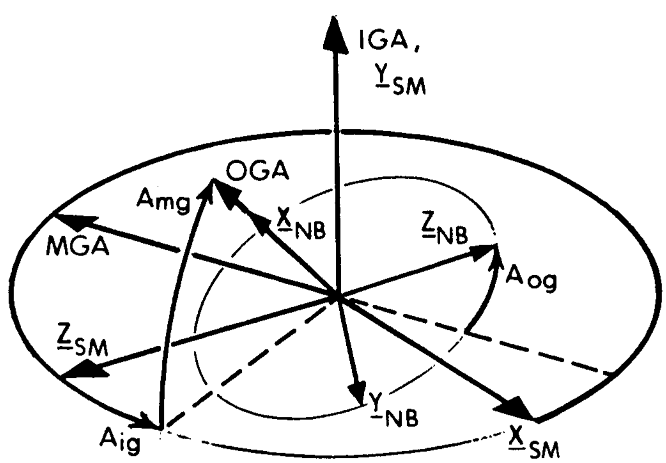


Figure 5-5

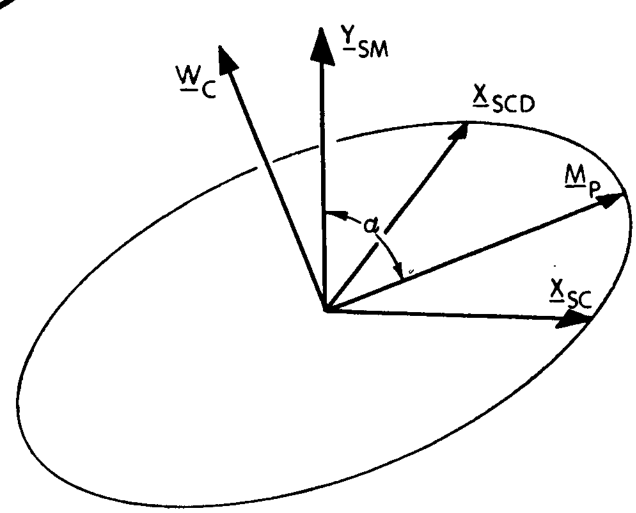


Figure 5-6

Under some extreme conditions it is not possible to avoid gimbal lock with a roll, pitch/yaw, roll sequence. In these cases it becomes necessary to perform more than one pitch/yaw sequence, with attendant additional roll sequences.

5.6.2 Method of Analysis

S/C attitudes are specified with unit vectors. Maneuvers are defined by vector cross-products, and therefore normally follow the shortest route. Let

$$\underline{X}_{SC} \quad = \text{present S/C roll axis}$$

$$\underline{X}_{SCD} \quad = \text{desired S/C roll axis}$$

Plane of pitch/yaw maneuver is defined by

$$\underline{W}_C = \text{unit } (\underline{X}_{SC} \times \underline{X}_{SCD}) \tag{5-56}$$

This plane is closest to Y_{SM} at "max point" M_p (Fig. 5-6) defined by vector

$$\underline{M}_p = \text{UNIT } (\underline{W}_C \times \underline{Y}_{SM}) \times \underline{W}_C)) \tag{5-57}$$

If angle $\alpha \geq 63^o$ (i.e. $33^o + 30^o$), then gimbal lock is impossible, and the planned pitch/yaw can be done without an initial roll. If $\alpha < 63^o$ the 33^o cone will cut or enclose the 30^o, and certain roll attitudes will become illegal, depending on the direction of motion, as demonstrated by the heavy arcs of Figs. 5-7 through 5-11. The circles are the intersections of the 30^o and 33^o cones with the unit sphere.

It is now necessary to examine the conditions at each end of the trajectory to determine the correct roll attitude to be used.

If $\underline{X}_{SC}$ were to pass through a max point on the way to the desired attitude, the condition of Fig. 5-7 pertains. That portion of the arc on the 33^o circle which allows acceptable positions of $\underline{X}_{NB}$ is marked by a "normal" begin limit NB, and a "normal" end limit NE. These are referenced from the positive trajectory direction by positive rotations NBL and NEL about $\underline{M}_p$. The trajectory of Fig. 5-8 demonstrates the existence of two acceptable arcs NB_1 NE_1 and NB_2NE_2, defined by four normal limit angles NBL_1, NEL_1, NBL_2 and NEL_2.

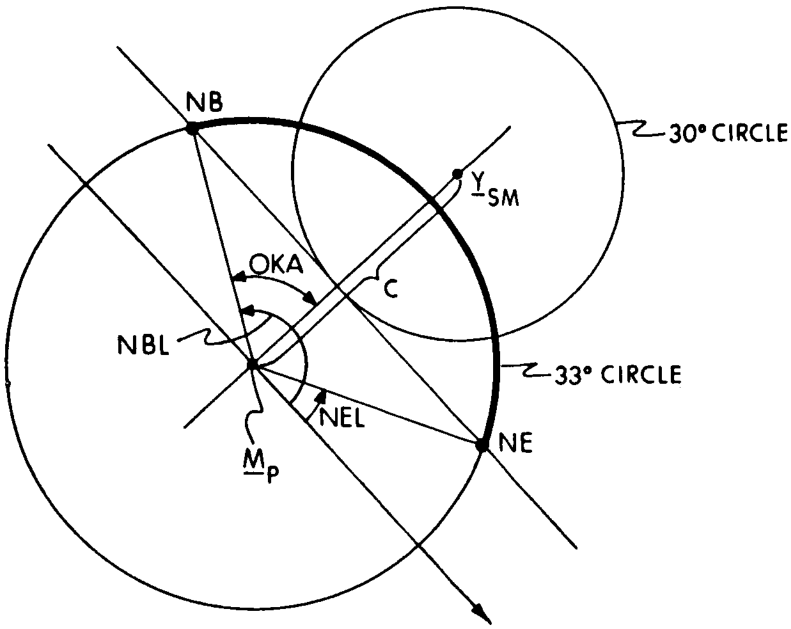


Figure 5-7

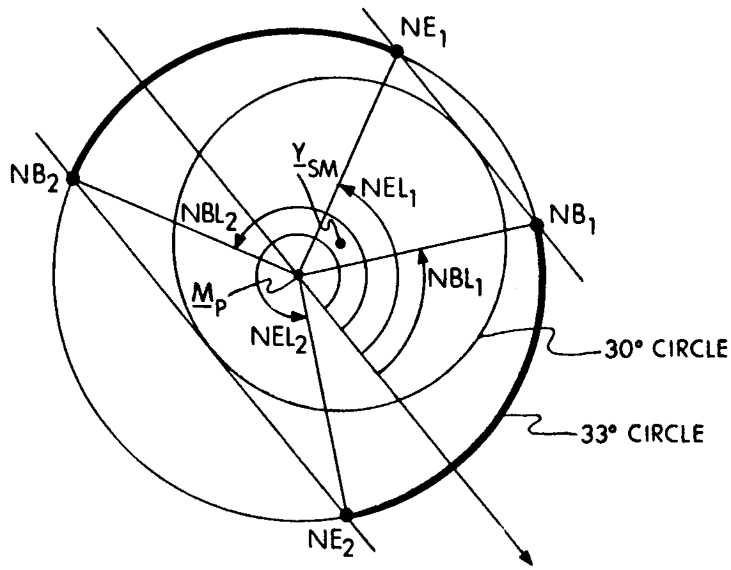


Figure 5-8

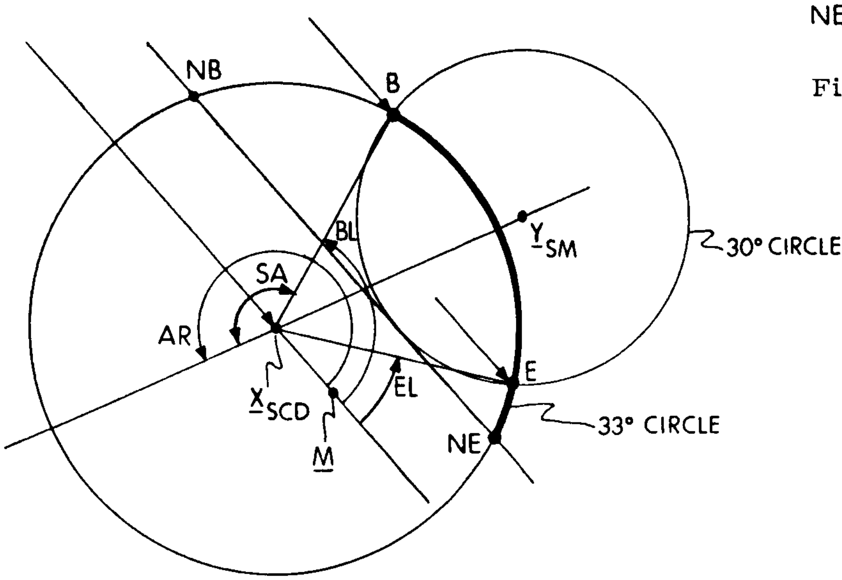


Figure 5-9

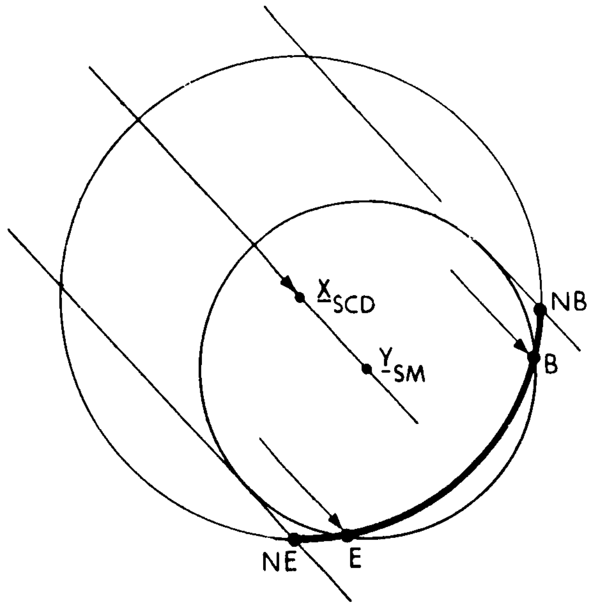


Figure 5-10

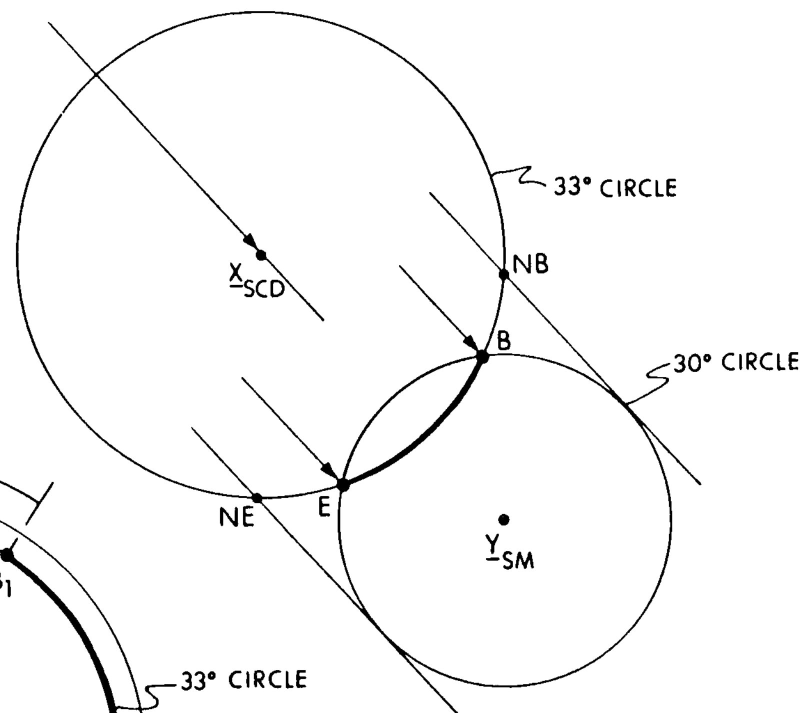


Figure 5-11

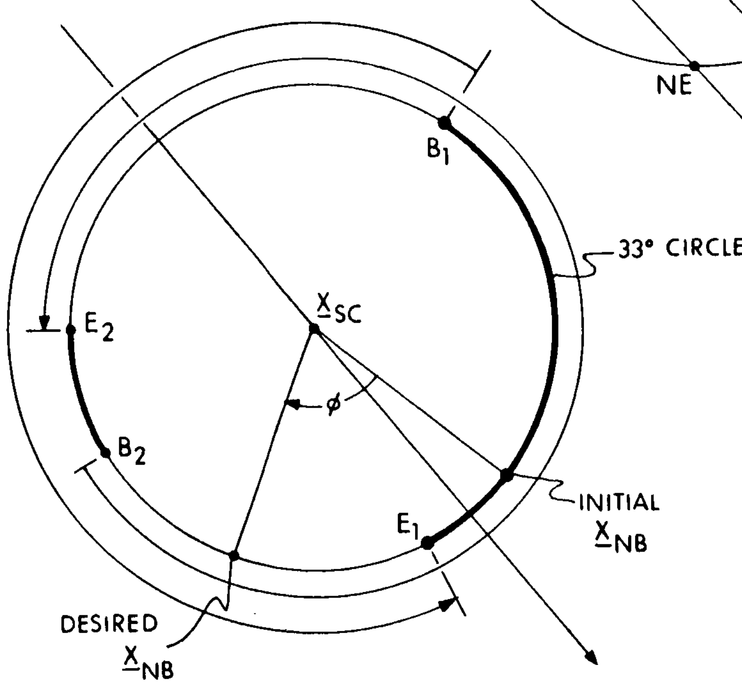


Figure 5-12

The general expression for a normal limit angle is:

$$N(B, E)\ L = \pm\ 180^{\circ} \pm 90^{\circ} + OKA \tag{5-58}$$

where

$$OKA = \cos^{-1} (\tan (30^{\circ} - c)/\tan 33^{\circ}) \tag{5-59}$$

and c is the angle between $\underline{M}_p$ and $\underline{Y}_{SM}$ (See Fig. 5-7).

The signs in Eq.(5-58) are determined by the geometry of the maneuver.

For motion of $\underline{X}_{SC}$ through a max point the normal limits clearly define regions on the 33° circle where $\underline{X}_{NB}$ is acceptable.

For the condition where the trajectory does not pass through a given max point, but either end of the trajectory lies close to the max point, other limit points can be used to define the acceptable portions of the arc. Figure 5-9 depicts a final desired position $\underline{X}_{SCD}$ for which the 30° and 33° circles intersect. The heavy portions of the arc are unacceptable regions for $\underline{X}_{NB}$.

To define the arc, two "end" limits are specified as the intersections of the 30° and 33° circles. Using the direction of motion as a reference line and the convention of positive rotation about $\underline{X}_{SCD}$ the two "end" limit angles in Fig. 5-9 are given by:

$$BL = AR - SA \tag{5-60}$$

$$EL = AR + SA \tag{5-61}$$

where AR is measured to a line from $\underline{X}_{SCD}$ pointing away from $\underline{Y}_{SM}$, SA is always positive, and angles may exceed 2π.

For the condition of Fig. 5-9, B is acceptable as a limit. E is not acceptable because during the maneuver it will cross the forbidden area inside the 30° circle. E is said to be a "shaded" limit, and this end of the arc must be defined by the normal limit NE, whose locus is the tangent to the 30° circle.

Other end conditions can result in both limits being "shaded", so that the "normal" limits must be used to define the acceptable arc (See Fig. 5-10), or in neither limit being shaded (See Fig. 5-11), so that both can be used to define the arc.

Figures 5-9, 5-10, and 5-11 can be used to describe conditions at the beginning of the trajectory by replacing $\underline{X}_{SCD}$ with $\underline{X}_{SC}$ and reversing the direction of motion.

To determine the roll attitude necessary for a given maneuver the following steps are taken:

1) Determine if trajectory includes a max point. If it does, compute and save the normal limit angles.

2) Determine if either end of the trajectory is within 63^o of $\pm \underline{Y}_{SM}$ (i.e. do 30^o and 33^o cones intersect the beginning or the end of the trajectory?)

If the results of steps (1) and (2) are both "no", the planned pitch/yaw maneuver can be made without an initial roll, and steps (3) through (10) can be skipped.

3) If step (2) yields a "yes", determine if the beginning of the trajectory is within 63^o of $\pm \underline{Y}_{SM}$. If it is not, skip to step (5). If it is, determine whether $\underline{X}_{SC}$ will move toward or away from the max point. If towards, the max point has already been determined in step (1) and its normal limits saved. If away from, compute the end limits for the beginning of the trajectory. (If the result of step (1) was "no", motion of $\underline{X}_{SC}$ towards a max point is a special case. Since $\underline{X}_{SCD}$ is closer to gimbal lock than $\underline{X}_{SC}$, its limits will include those associated with $\underline{X}_{SC}$, and steps (3) and (4) may be omitted).

4) Determine if either of the end limits computed in step (3) is "shaded" or not. If shading exists, replace either or both end limits with the corresponding normal limits, and save the results.

5) If step (2) yielded a "yes", determine if the end of the trajectory is near a max point. If it is, determine whether this max point is on the trajectory (i.e. if it has already been covered in step (1)). If not, compute the end limits for the end of the trajectory.

6) Repeat step (4) for the end limits of step (5).

7) Combine the limit angles computed in steps (1) through (6) and determine those portions of the 33^o circle that are acceptable throughout the trajectory.

At this point the 33^o circle can be mapped out for acceptable and non-acceptable arcs. This has been done for a random example in Fig. 5-12. Acceptable portions of the circle as determined by steps (1) through (6) are the arcs $B_1 E_1$ and B_2E_2. Only those portions where acceptable arcs overlap are allowed for $\underline{X}_{NB}$, i.e. arcs B_1E_2 and $B_2 E_1$.

8) Determine if the initial roll attitude is such that the position of $\underline{X}_{NB}$ on the 33^{o} circle is acceptable. If it is, no initial roll is needed. If it is not, specify a desired $\underline{X}_{NB}$ position midway on an overlapping region.

9) Define a roll maneuver ϕ so that $\underline{X}_{NB}$ will move around the 33^{o} cone the shorter way to its desired position. (See Fig. 5-11).

10) Check if the roll maneuver of step (9) forces $\underline{X}_{NB}$ to move into the 30^{o} cone around $\underline{Y}_{SM}$. If it does, reverse the direction of the roll and cause $\underline{X}_{NB}$ to move the longer way around the 33^{o} cone.

11) Following the completion of the roll maneuver, perform the pitch/yaw maneuver defined in direction by Eq. (5-56) and in magnitude by

$$\theta = \begin{Bmatrix} \sin^{-1} \left(\left| \underline{X}_{SC} \times \underline{X}_{SCD} \right| \right) \\ \\ \cos^{-1} \left(\left| \underline{X}_{SC} \cdot \underline{X}_{SCD} \right| \right) \end{Bmatrix} \qquad (5\text{-}62)$$

If the results of step (7) indicate that there are no overlapping acceptable arcs, the planned single pitch/yaw maneuver cannot be done. In this case the maneuver is "split" into two equal co-planar pitch/yaw maneuvers. $\underline{X}_{NB}$ is rolled mid-way into the acceptable region associated with the start of the trajectory and half the pitch/yaw is performed. At the start of the second half of the trajectory, the required roll attitudes are re-evaluated from scratch as if the remainder of the pitch/yaw were a fresh maneuver.

For the case where the required pitch/yaw maneuver is greater than 179^{o} Eqs.(5-56) & (5-62)are not used to define the trajectory, since $\underline{W}_{C}$ becomes indeterminate in direction. A more convenient choice is made:

$$\underline{W}_{C} = \text{UNIT} \left(\underline{X}_{SC} \times \left(\underline{X}_{SC} \times \underline{Y}_{SM} \right) \right) \qquad , \qquad (5\text{-}63)$$

This ensures the greatest angle between $\underline{Y}_{SM}$ and the trajectory plane, minimizing the need for initial roll maneuvers.

5.6.3 Mechanization

The attitude maneuver computations in the AGC are performed by two distinct routines. The first, CALCMANU, analyses the maneuver and generates the sequences of submaneuvers as described in Section 5.6.2. It requires as input the desired orientation of the spacecraft in the form of three unit vectors, $\underline{X}$, $\underline{Y}$, $\underline{Z}_{SCD}$ (along the roll, pitch, yaw axes) expressed in stable member coordinates. The output is a unit vector determining the axis of rotation, W_C (Eq.(5-56)), the magnitude of the rotation about this axis, θ (Eq.(5-62)), and a switch setting indicating a roll or a pitch/yaw maneuver.

The second routine, DOMANU, processes these outputs and generates CDU commands to drive the vehicle in the specified manner. For AS-501 spacecraft angular rates are limited in command to 4^o/sec in pitch/yaw and 7.2^o/sec in roll for CSM maneuvers, and 4^o/sec and 15^o/sec, respectively, for CM maneuvers. The general expression for a vehicle rate is:

$$\frac{d\underline{\theta}}{dt} = (4,\ 7.2,\ 15)\ \underline{W}_C \qquad (5\text{-}64)$$

Maneuver commands are computed at fixed intervals. Rate equations are therefore expressed in incremental form:

$$\begin{aligned} \underline{\Delta\theta} &= \Delta t\ (4,\ 7.2,\ 15)\ \underline{W}_C \qquad (5\text{-}65) \\ &= k\ \underline{W}_C \end{aligned}$$

The quantity k is the magnitude of the output command at each iteration. The command stays at this level until:

$$\theta - \Sigma k \leq k \qquad (5\text{-}66)$$

i.e. until the maneuver rotation is less than k degrees from completion. The final increment is then $\theta - \Sigma k$ degrees. The vector $\underline{\Delta\theta}$ expressed in stable member coordinates, is resolved into gimbal (CDU) coordinates, as follows:

$$\begin{aligned} \Delta A_{og} &= \Delta\theta_x - \cos A_{og} \tan A_{mg} \Delta\theta_y + \sin A_{og} \tan A_{mg} \Delta\theta_z \\ \Delta A_{ig} &= \cos A_{og} \sec A_{mg} \Delta\theta_y - \sin A_{og} \sec A_{mg} \Delta\theta_z \qquad (5\text{-}67) \\ \Delta A_{mg} &= \sin A_{og} \Delta\theta_y + \cos A_{og} \Delta\theta_z \end{aligned}$$

where a positive gimbal angle increment represents a clockwise rotation of a gimbal about the positive direction of its axis. (See Fig. 5-5 for definition of gimbal axes.)

From the above it can be seen that a maneuver is treated as a constant rate for a fixed time. No attempt is made to modify commands with the inverse responses of either the CDU's or the spacecraft. In order to accomodate the resulting lag in the response of the system, a five-second "settling" period is inserted after each maneuver to allow the spacecraft to settle into the desired orientation. During this 5-second period the program returns to the routine CALCMANU to check that the maneuver was satisfactorily performed, and to provide DOMANU with initial conditions for the next maneuver in sequence.

Due to the noncommutativity of finite angles, the expressions in Eqs.(5-67) may, for large maneuvers at the higher rates, result in a deviation of the commanded spacecraft axes from the desired trajectory plane. CALCMANU always checks whether $\underline{X}_{SC}$ and $\underline{X}_{SCD}$ are greater than 3 degrees apart. If they are, a "corrective" pitch/yaw maneuver is demanded to bring them into coincidence. DOMANU performs this correction, and eventually returns to CALCMANU. If, finally, the test shows the separation to be less than 3 degrees, CALCMANU computes the exact desired set of gimbal angles and "snaps" the CDU's to these values. The final values are a set of euler angles, θ, ψ, ϕ extracted from the matrix identity:

$$\begin{pmatrix} X_{SCDX} & X_{SCDY} & X_{SCDZ} \\ Y_{SCDX} & Y_{SCDY} & Y_{SCDZ} \\ Z_{SCDX} & Z_{SCDY} & Z_{SCDZ} \end{pmatrix} =$$

$$\begin{pmatrix} \cos 33 & 0 & \sin 33 \\ 0 & 1 & 0 \\ \sin 33 & 0 & \cos 33 \end{pmatrix} \begin{pmatrix} \cos\phi\cos\psi & \sin\psi & -\sin\theta\cos\psi \\ -\cos\theta\sin\psi\cos\phi + \sin\theta\sin\phi & \cos\psi\cos\phi & \sin\theta\sin\psi\cos\phi + \cos\theta\sin\phi \\ \cos\theta\sin\psi\sin\phi + \sin\theta\cos\phi & -\cos\psi\sin\phi & -\sin\theta\sin\psi\sin\phi + \cos\theta\cos\phi \end{pmatrix} \quad (5\text{-}68)$$

where $\theta = A_{ig}$ (CDUY)

$\psi = A_{mg}$ (CDUZ)

$\phi = A_{og}$ (CDUX)

5.7 Time of Free-Fall to Entry

The time of free-fall from any position $\underline{r}$ to the entry interface altitude is given by

$$t_f = \sqrt{\frac{a^3}{\mu}} \left[\Delta E - \Delta S_E \right] \tag{5-69}$$

where

$$\Delta E = 2 \tan^{-1} \left(\frac{\Delta S_E}{2 - \frac{r}{a} - \frac{r_e}{a}} \right) \tag{5-70}$$

$$\Delta S_E = - \left[\frac{r_e}{a} \left(2 - \frac{r_e}{a} \right) - p/a \right]^{1/2} - \frac{\underline{v} \cdot \underline{r}}{\sqrt{a\mu}} \tag{5-71}$$

$$p = \frac{(\underline{r} \times \underline{v}) \cdot (\underline{r} \times \underline{v})}{\mu} \tag{5-72}$$

$$a = \left(\frac{2}{r} - \frac{\underline{v} \cdot \underline{v}}{\mu} \right)^{-1} \tag{5-73}$$

$\underline{v}$ is the velocity at $\underline{r}$ and r_e is the entry interface radius.

5.8 Entry Guidance

Included in this section is a set of flow charts that describe the logic and equations that control the entry vehicle. The value and definition of constants is given in Section 6. A thorough description is provided in MIT Report R-532 (Vol 1) Reentry Guidance for Apollo.

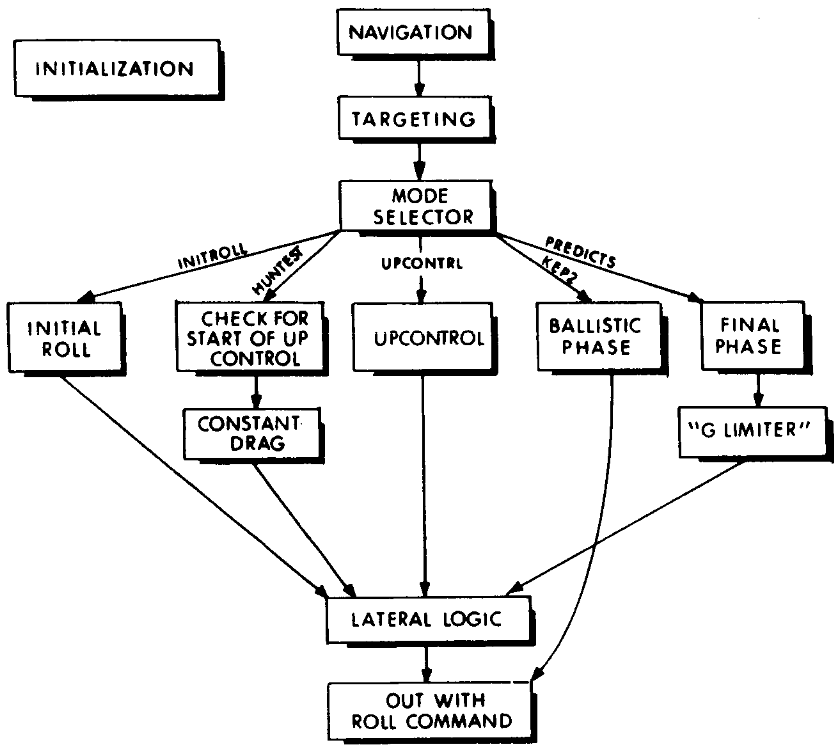


Fig. 5-13. Computer Logic

READ & CLEAR PIPAS
SAVE VEL INCREMENT
AS $\overline{DELV}$

$$\overline{TEM} = \overline{VI} + DT\,\frac{\overline{G}}{2} + \frac{\overline{DELV}}{2}$$
$$\overline{R} = \overline{R} + DT\,\overline{TEM}$$

$$R = ABVAL(\overline{R})$$
$$SL = UNIT(\overline{R}) \cdot \overline{UZ}$$

$$\frac{\overline{G}}{2} = -\frac{MUE}{2R^2}\left[\left(1 + J\left(\frac{RE}{R}\right)^2\left(1 - 5SL^2\right)\right)UNIT(\overline{R}) + 2\,SL\,J\left(\frac{RE}{R}\right)^2\overline{UZ}\right]$$

$$\overline{VI} = \overline{TEM} + \frac{\overline{DELV}}{2} + DT\,\frac{\overline{G}}{2}$$

Fig. 5-14 "Average-g" Navigation

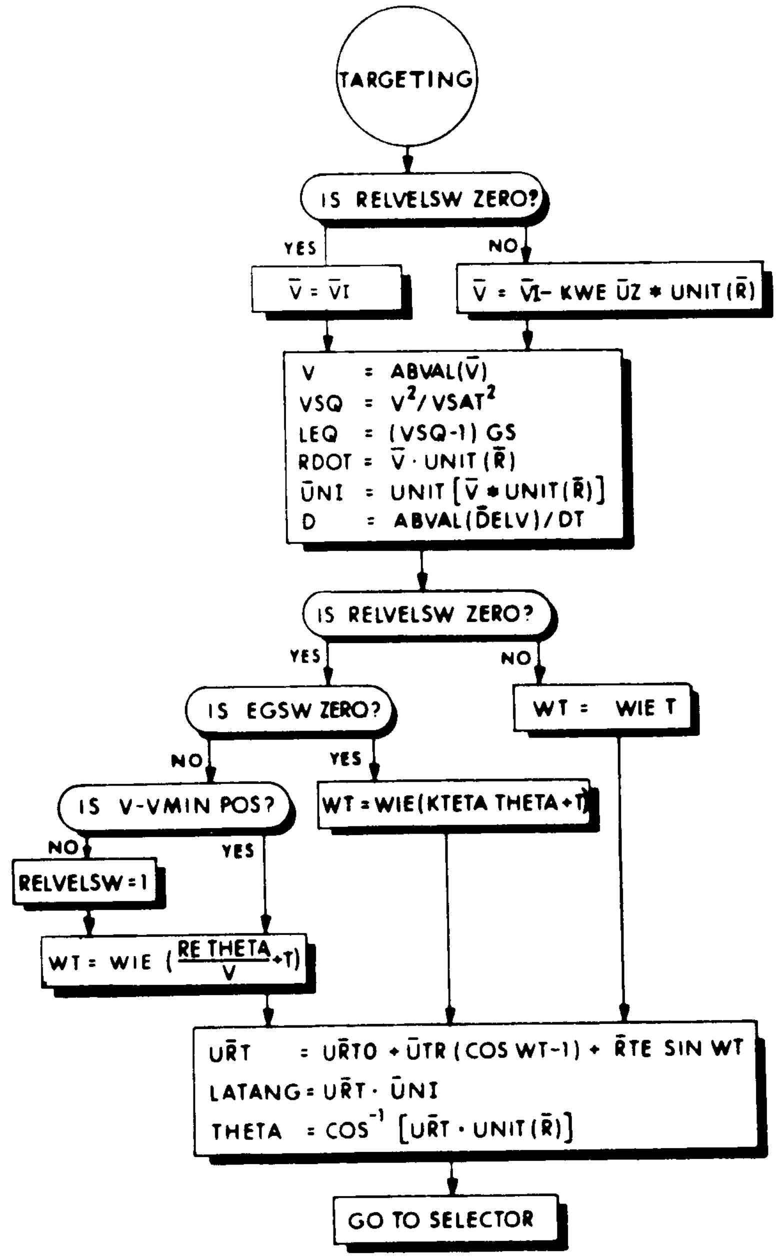


Fig. 5-15 Targeting

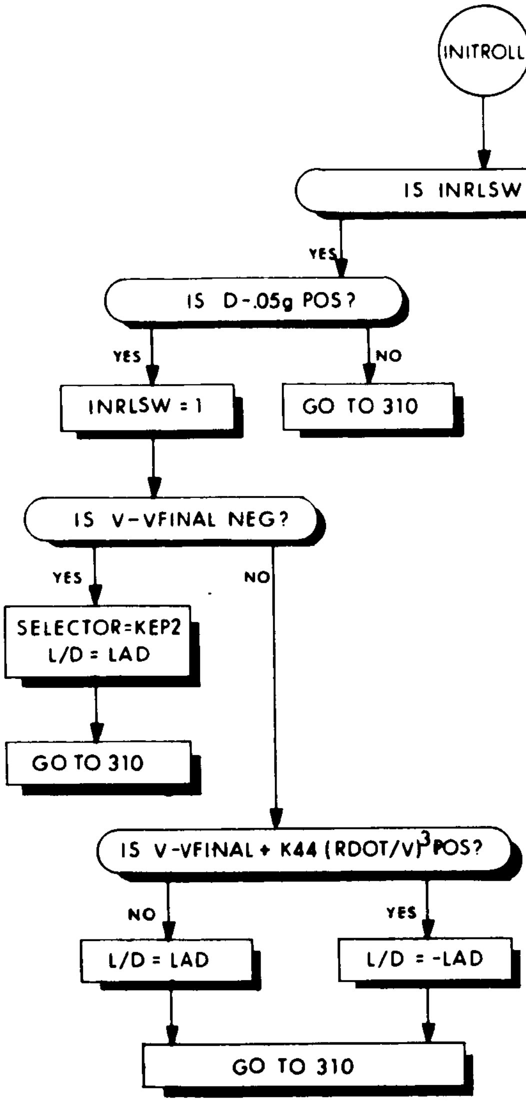


Fig. 5-16 Initial Roll

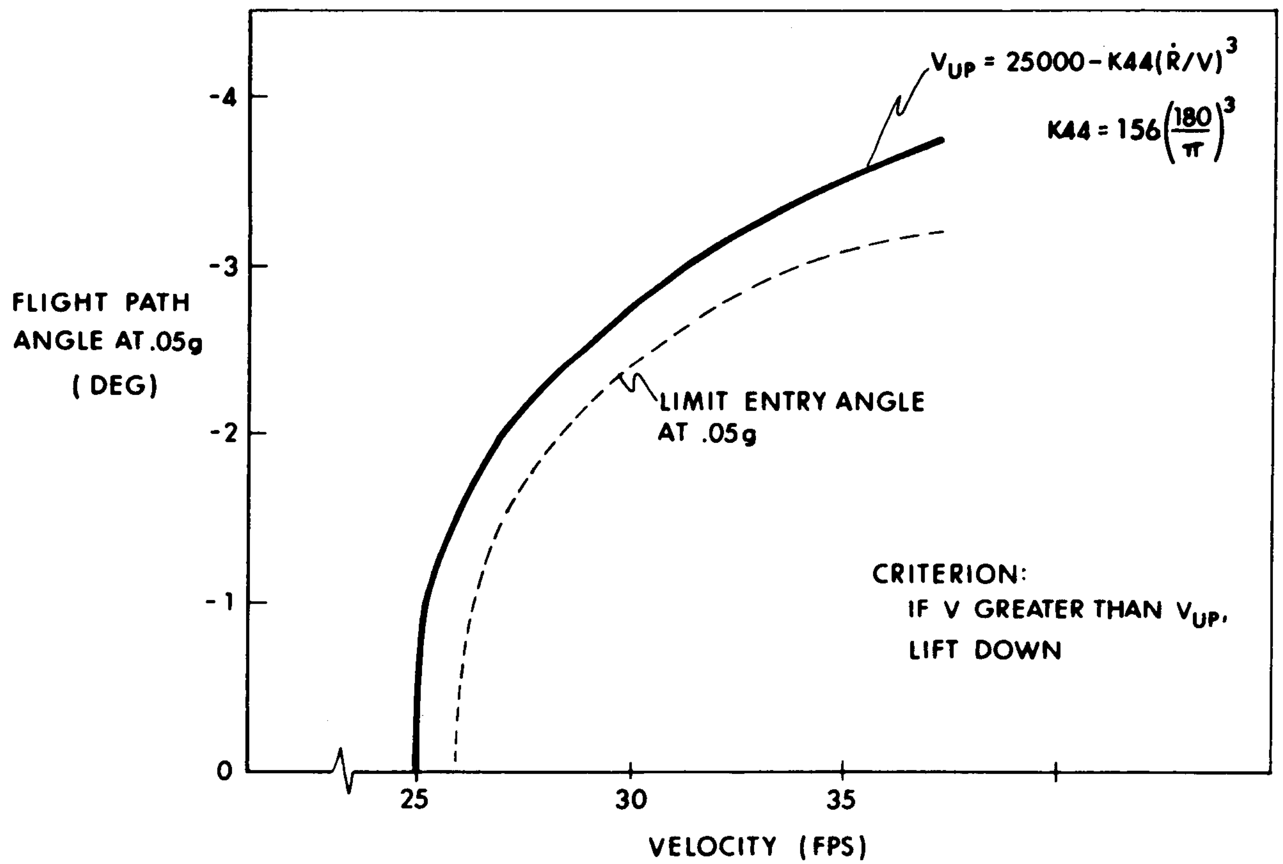


Fig. 5-17 Criterion for Up- or Down-Lift

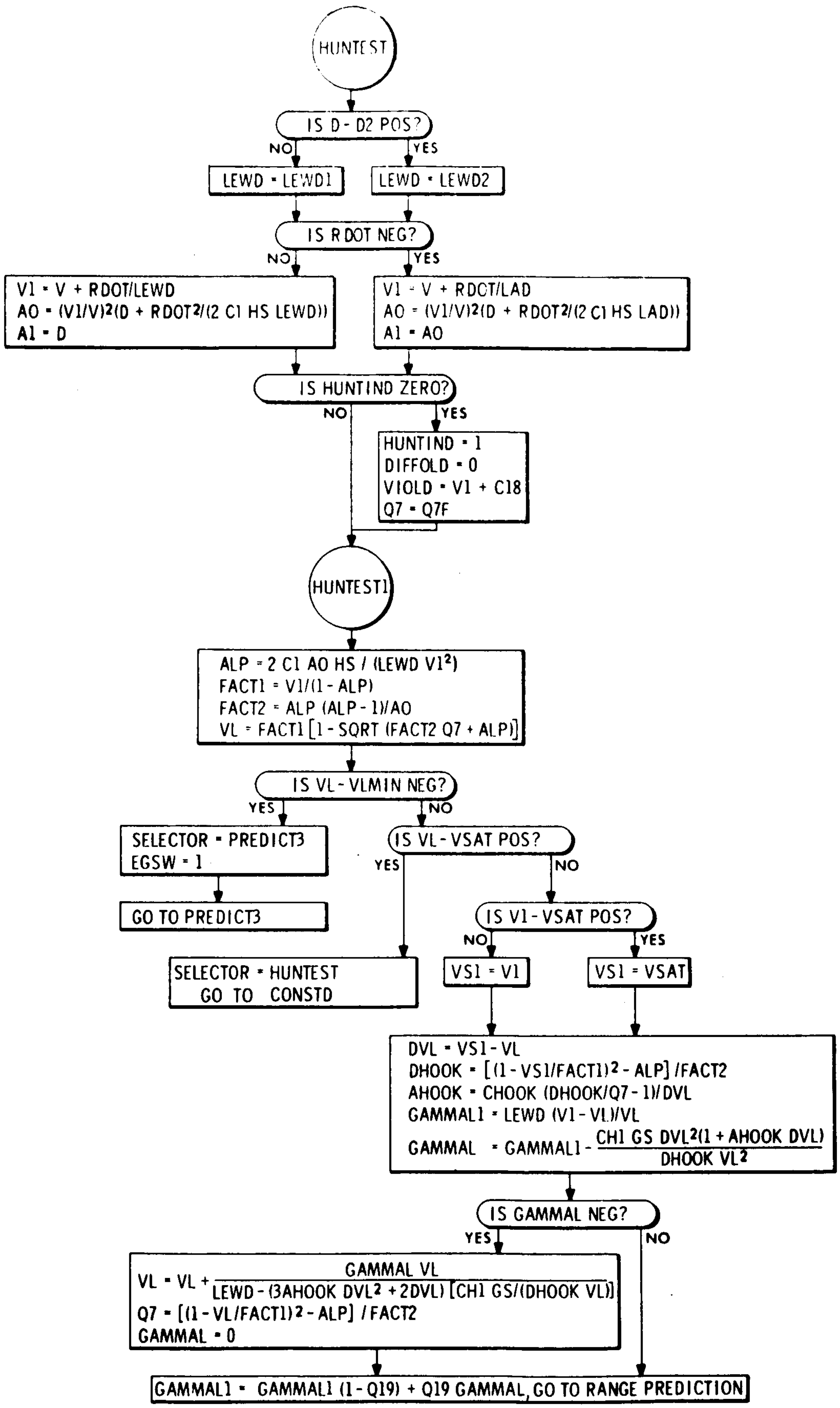


Fig. 5-18 Huntest

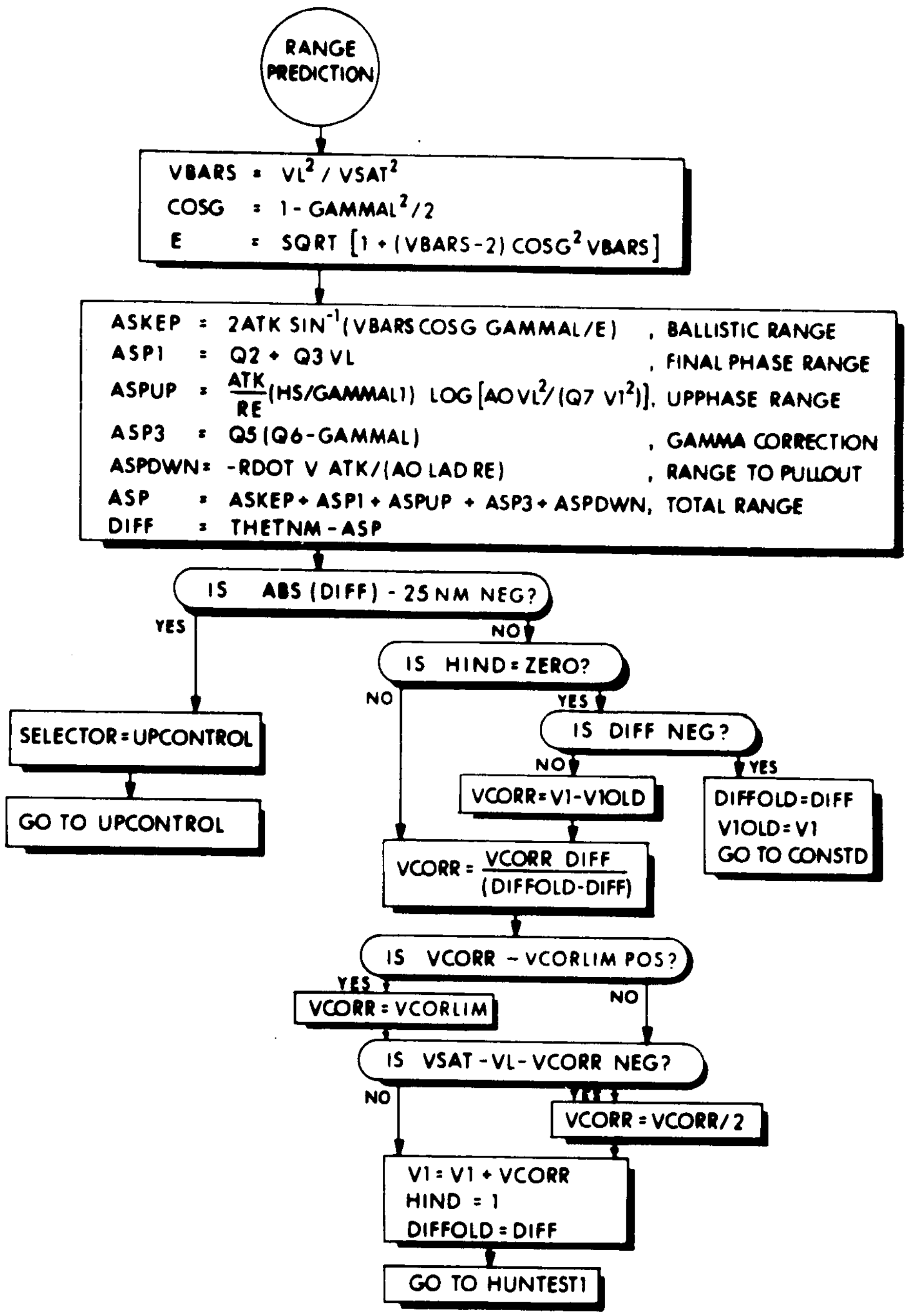


Fig. 5-19 Range Prediction

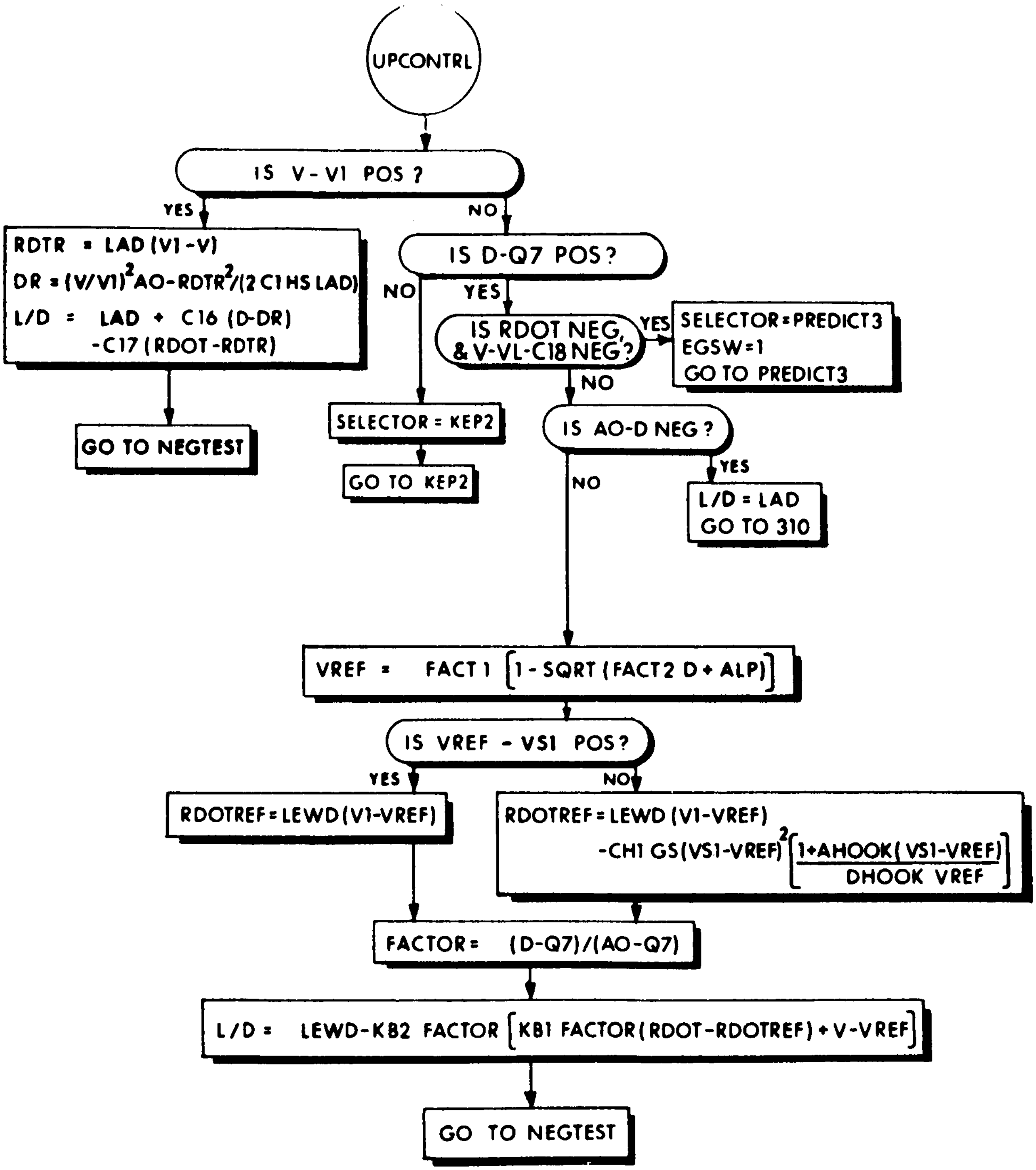


Fig. 5-20 Upcontrol

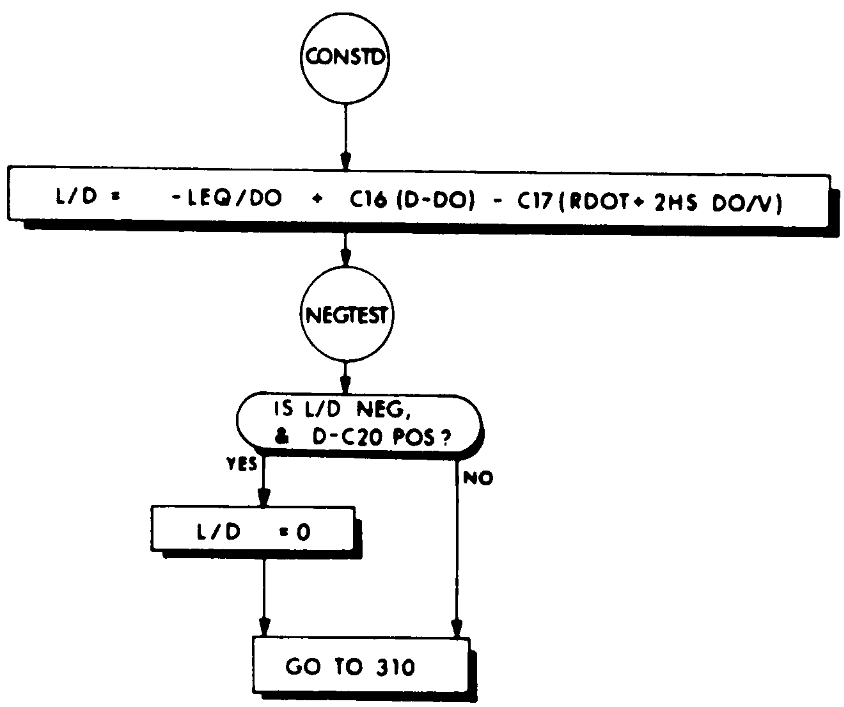


Fig. 5-21 Constant Drag Control

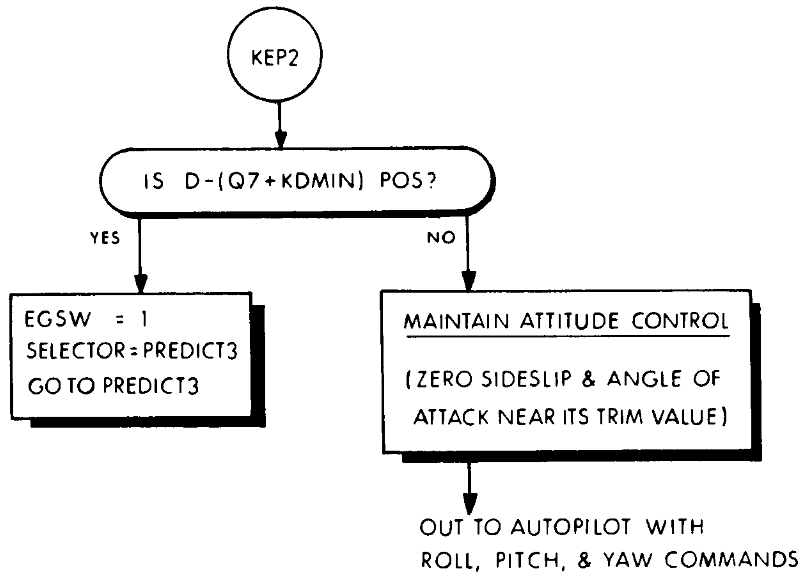


Fig. 5-22 Ballistic Phase

ATTITUDE CONTROL PHASE

Calculates commanded gimbal angles (OGC, MGC, IGC) by computing desired orientation of Nav Base with respect to relative velocity vector.

$\overline{UVA}$ = UNIT ($\bar{V}$-KWE $\overline{UZ}$ * UNIT ($\bar{R}$))

$\overline{UYA}$ = UNIT ($\overline{UVA}$ * $\bar{R}$)

$\overline{UNA}$ = UNIT ($\overline{UYA}$ * $\overline{UVA}$)

$\overline{UBY}$ = $\overline{UYA}$ COS (ROLLC) + $\overline{UNA}$ SIN (ROLLC)

$\overline{UBX}$ = -UNIT ($\overline{UBY}$ * $\overline{UVA}$) SIN (13) - $\overline{UVA}$ COS (13)

$\overline{UBZ}$ = $\overline{UBX}$ * $\overline{UBY}$

Call CALGTA with ($\overline{UBX}$, $\overline{UBY}$, $\overline{UBZ}$)
Return with (OGC, IGC, MGC).

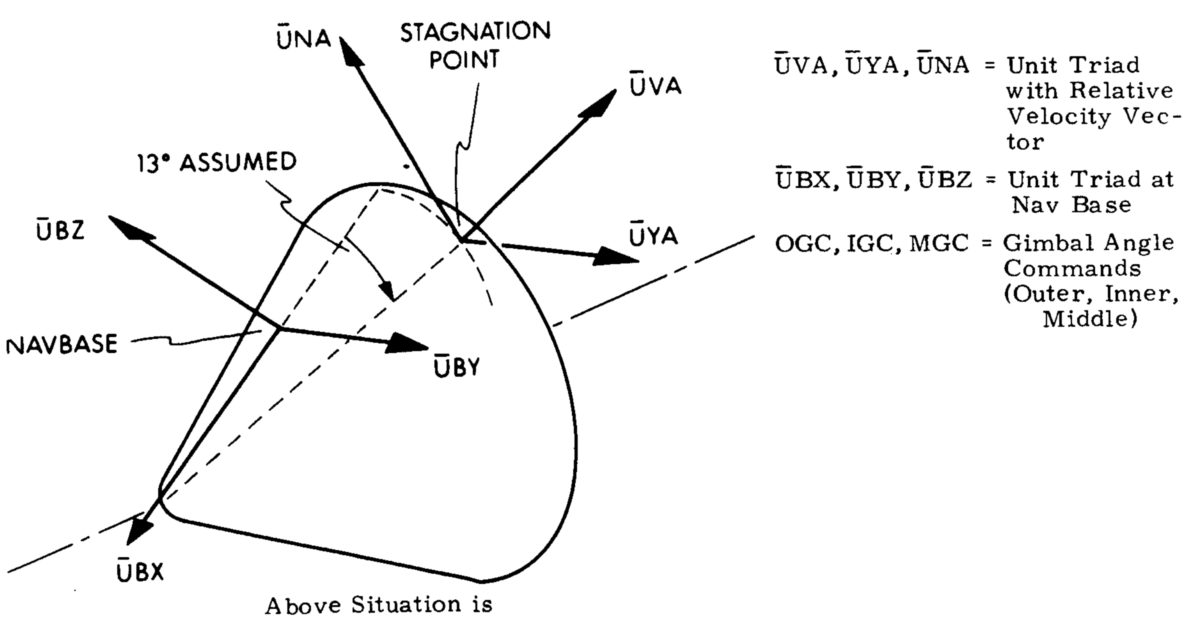


Fig. 5-23

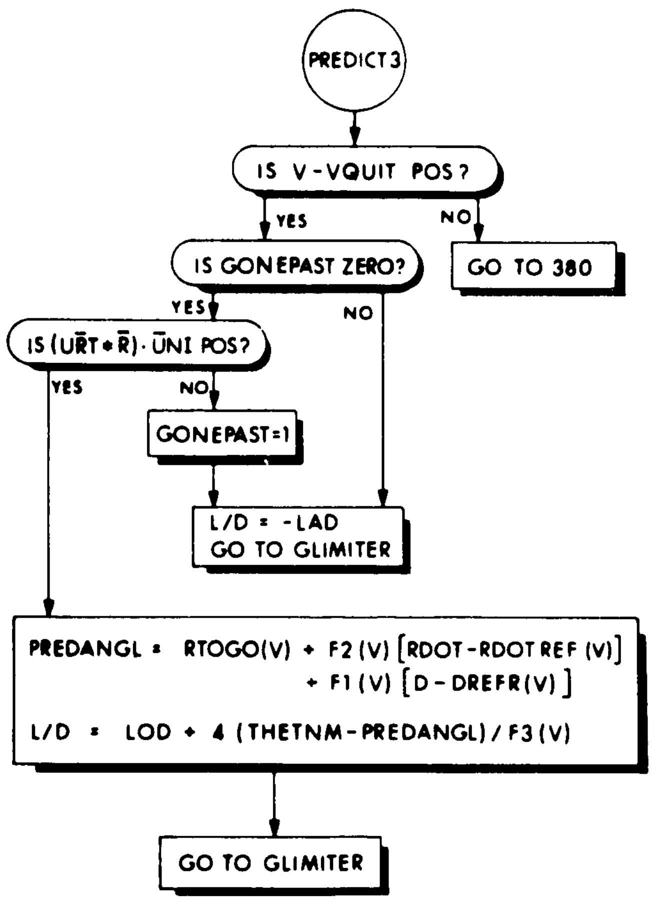


Fig. 5-24 Final Phase

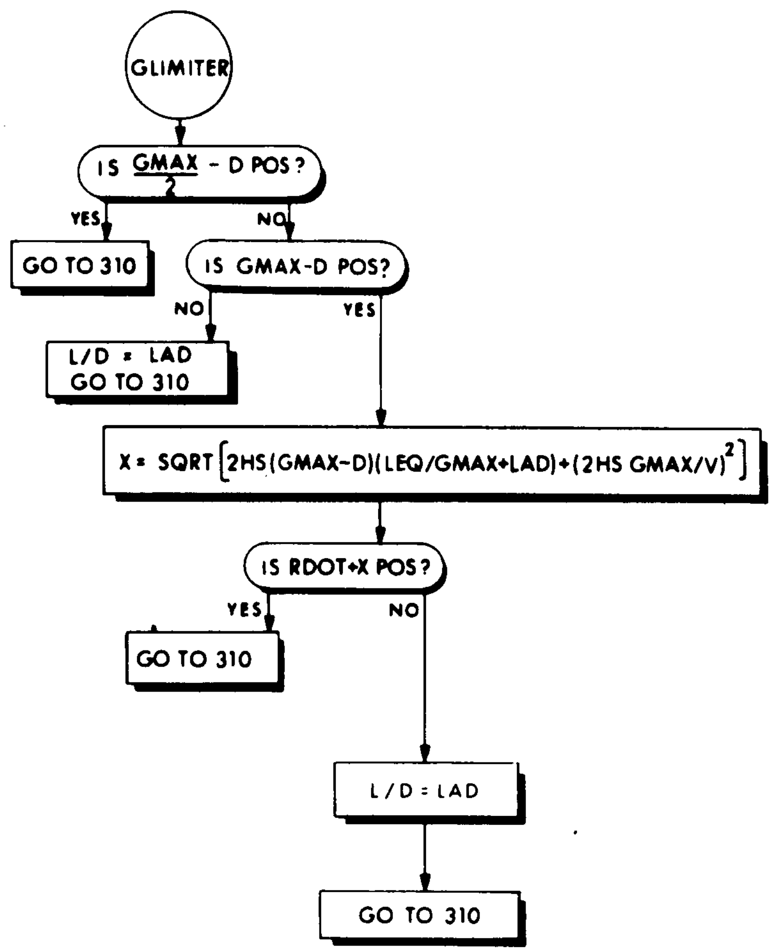


Fig. 5-25 G-limiter

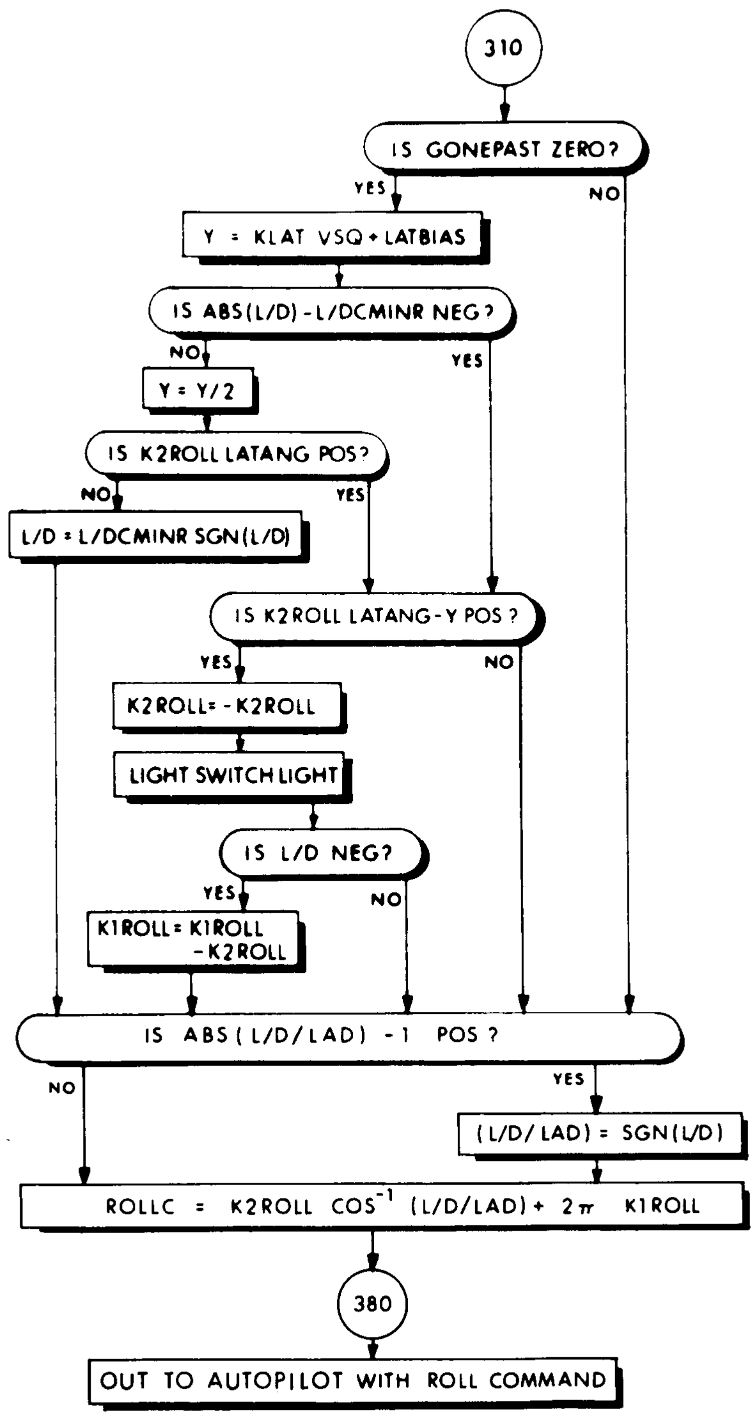


Fig. 5-26 Lateral Logic

VREF FPS	RDOTREF FPS	DREFR FPSS	DR/DRDOT F2 NM/FPS	DR/DA F1 NM/FPSS	RTOGO NM	DR/DL/D F3 NM
0	-331	34.1	0	-.02695	0	1
337	-331	34.1	0	-.02695	0	1
1080	-693	42.6	.002591	-.03629	2.7	6.44 x 2
2103	-719	60.	.003582	-.05551	8.9	10.91 x 2
3922	-694	81.5	.007039	-.09034	22.1	21.64 x 2
6295	-609	93.9	.01446	-.1410	46.3	48.35 x 2
8531	-493	98.5	.02479	-.1978	75.4	93.72 x 2
10101	-416	102.3	.03391	-.2372	99.9	141.1 x 2
14014	-352	118.7	.06139	-.3305	170.9	329.4
15951	-416	125.2	.07683	-.3605	210.3	465.5
18357	-566	120.4	.09982	-.4956	266.8	682.7
20829	-781	95.4	.1335	-.6483	344.3	980.5
23090	-927	28.1	.2175	-2.021	504.8	1385
23500	-820	6.4	.3046	-3.354	643.0	1508
35000	-820	6.4	.3046	-3.364	643.0	1508

Fig. 5-27 Final Phase Reference

VARIABLE	DESCRIPTION	MAXIMUM VALUE	COMPUTER NAME
$\overline{\text{URTO}}$	INITIAL TARGET VECTOR	2 (UNIT VECTOR)	= RTINIT
$\overline{\text{UZ}}$	UNIT VECTOR NORTH	2	= (UZ) OR UNITW
$\overline{\text{V}}$	VELOCITY VECTOR	2 VSAT	= (V)
$\overline{\text{R}}$	POSITION VECTOR	2 EXP 29 METERS	= RN
$\overline{\text{VI}}$	INERTIAL VELOCITY	128 M/CENTISEC	= VPIP
$\overline{\text{RTE}}$	VECTOR EAST AT INITIAL TARGET	2	= RTEAST
$\overline{\text{UTR}}$	NORMAL TO RTE AND UZ	2	= RTNORM
$\overline{\text{URT}}$	TARGET VECTOR	2	= (RT)
$\overline{\text{UNI}}$	UNIT NORMAL TO TRAJECTORY PLANE	2	
$\overline{\text{DELV}}$	INTEGRATED ACCEL. FROM PIPAS	5.85 16384 CM/S	
$\overline{\text{G}}$	GRAVITY VECTOR	1/32 M/CS/CS	= GRAVITY
A0	INITIAL DRAG FOR UPCONTRL	805 FPSS	FPSS=FT/SEC/SEC
AHOOKDV	TERM IN GAMMAL CALC. = AHOOK DVL	805/16 VSAT FPS FPSS	
ALP	CONST FOR UPCONTRL	1	
ASKEP	KEPLER RANGE	21600 NM	NM = NAUTICAL MILE
ASP1	FINAL PHASE RANGE	21600 NM	
ASPUP	UP-RANGE	21600 NM	
ASP3	GAMMA CORRECTION	21600 NM	
ASPDWN	RANGE DOWN TO PULL-UP	21600 NM	
ASP	PREDICTED RANGE	21600 NM	
COSG	COSINE(GAMMAL)	2	= COSG/2
D	TOTAL ACCELERATION	805 FPSS	
D0	CONTROLLED CONST. DRAG	805 FPSS	
DHOOK	TERM IN GAMMAL COMPUTATION	805 FPSS	
DIFF	THETNM-ASP (RANGE DIFFERENCE)	21600/16 NM	
DIFFOLD	PREVIOUS VALUE OF DIFF	21600/16 NM	
DR	REFERENCE DRAG FOR DOWNCONTROL	805 FPSS	
DREFR	REFERENCE DRAG	805 FPSS	
DVL	VS1-VL	2 VSAT	
E	ECCENTRICITY	4	
F1	DRANGE/D DRAG (FINAL PHASE)	2700/805	
F2	DRANGE/D RDOT (FINAL PHASE)	2700/2VS NM/FPS	
F3	DRANGE/D (L/D)	2700 NM	
FACT1	CONST FOR UPCONTRL	2 VSAT	
FACT2	CONST FOR UPCONTRL	1	
FACTOR	USED IN UPCONTRL	1	
GAMMAL	FLIGHT PATH ANGLE AT VL	1 RADIAN	
GAMMAL1	SIMPLE FORM OF GAMMAL	1 RADIAN	

Fig. 5-28 Computer Variables

VARIABLE	DESCRIPTION	MAXIMUM VALUE	COMPUTER NAME
K1ROLL	INDICATOR FOR ROLL SWITCH		
K2ROLL	INDICATOR FOR ROLL SWITCH		
LATANG	LATERAL RANGE	4 RADIANS	
LEQ	EXCESS C.F. OVER GRAV=(VSQ-1)GS	128.8 FPSS	
L/D	DESIRED LIFT TO DRAG RATIO (VERTICAL PLANE)		
PREDANGL	PREDICTED RANGE (FINAL PHASE)	2700 NM	
Q7	MINIMUM DRAG FOR UPCONTROL	805 FPSS	
RDOT	ALTITUDE RATE	2 VSAT	
RDOTREF	REFERENCE RDOT FOR UPCONTROL	2 VSAT	
RDTR	REFERENCE RDOT FOR DOWNCONT	2 VSAT	
ROLLC	ROLL COMMAND	8 REVOLUTIONS	
RTOGO	RANGE TO GO (FINAL PHASE)	2700 NM	
SL	SINE OF LATITUDE	1	
T	TIME	16384 SEC	= TENTRY
THETA	DESIRED RANGE (RADIANS)	2 PI RADIANS	= THETAH
THETNM	DESIRED RANGE (NM)	21600 NM	
V	VELOCITY MAGNITUDE	2 VSAT	
V1	INITIAL VELOCITY FOR UPCONTROL	2 VSAT	
V1OLD	PREVIOUS VALUE OF V1	2 VSAT	
VCORR	VELOCITY CORRECTION FOR UPCONTROL	2 VSAT	
VL	EXIT VELOCITY FOR UPCONTROL	2 VSAT	
VREF	REFERENCE VELOCITY FOR UPCONTROL	2 VSAT	
VS1	VSAT OR V1, WHICHEVER IS SMALLER	2 VSAT	
VBARS	$VL^2/VSAT^2$	4	
VSQ	NORMALISED VEL. SQUARED = $V^2/VSAT^2$	4	= VSQUARE
WT	EARTH RATE TIMES TIME	1 REVOLUTION	= WIE (DTEAROT)
X	INTERMEDIATE VARIABLE IN G-LIMITER		
Y	LATERAL MISS LIMIT	4 RADIANS	

Fig. 5-28a Computer Variables (cont'd)

EXTRA COMPUTER ERASABLE LOCATIONS NOT SHOWN ON FLOW CHARTS

VARIABLE	DESCRIPTION	MAXIMUM VALUE
C/DO	SCALED RECIPROCAL OF DO	
GOTOADDR	ADDRESS SELECTED BY SEQUENCER	
XPIPBUF	BUFFER TO STORE X PIPA COUNTS	
YPIPBUF	BUFFER TO STORE Y PIPA COUNTS	
ZPIPBUF	BUFFER TO STORE Z PIPA COUNTS	
PIPCTR	COUNTS PASSES THRU PIPA READ ROUTINE	
JJ	INDEX IN FINAL PHASE TABLE LOOK-UP	
M1	INDEX IN FINAL PHASE TABLE LOOK-UP	
GRAD	INTERPOLATION FACTOR IN FINAL PHASE	
FX	DRANGE/D L/D = F3	2700 NM
FX + 1	AREF	805 FPSS
FX + 2	RTOGO	2700 NM
FX + 3	RDOTREF	VSAT/4
FX + 4	DRANGE/D RDOT = F2	21600/2VS NM/FPS
FX + 5	DRANGE/D DRAG = F1	2700/805 NM/FPSS
UNITV	UNIT V VECTOR	2
UNITR	UNIT R VECTOR	2
TEM1B	TEMPORARY LOCATION	

SWITCHES

(6)	GONEPAST	INDICATES OVERSHOOT OF TARGET
(7)	RELVELSW	RELATIVE VELOCITY SWITCH
(8	EGSW	FINAL PHASE SWITCH
(9)	HUNTIND	INITIAL PASS THRU HUNTEST
(10)	HIND	INDICATES ITERATION IN HUNTEST
(11)	INRLSW	INDICATES INIT ROLL ATTITUDE SET

Fig. 5-28b Computer Variables (cont'd)

CONSTANTS AND GAINS		VALUE		
C1	FACTOR IN ALP COMPUTATION	1.25		
C16	CONSTD GAIN ON DRAG	.01		
C17	CONSTD GAIN ON RDOT	.001		
C18	BIAS VEL. FOR FINAL PHASE START	500	FPS	
C19	MINIMUM CONST DRAG	130	FPSS	
C20	MAX DRAG FOR DOWN-LIFT	175	FPSS	
CHOCK	FACTOR IN AHOCK COMPUTATION	.25		
CH1	FACTOR IN GAMMAL COMPUTATION	.75		
DCMAX	MAX CONST DRAG	175	FPSS	
DT	COMPUTATION CYCLE TIME INTERVAL	2	SEC.	
GMAX	MAXIMUM ACCELERATION	322	FPSS	(10 G-S)
KAFIX	DRAG TO ROLL UP IF DOWN INITIALLY (=KAT)	64.4	FPSS	
KB1	OPTIMIZED UPCONTROL GAIN	3.4		
KB2	OPTIMIZED UPCONTROL GAIN	.0034		
KDMIN	INCREMENT ON Q7 TO DETECT END OF KEPLER PHASE	.5	FPSS	
KLAT	LATERAL SWITCH GAIN	.0125		
KTETA	TIME OF FLIGHT CONSTANT	1000		
K44	GAIN USED IN INITIAL ROLL SECTION	29342068	FPS	
LAD	MAX L/D (MIN ACTUAL VEHICLE L/D)	.3		
LATBIAS	LATERAL SWITCH BIAS TERM	.4	NM	
L/DCMINR	LAD COS(15 DEG)	.2895		
LEWD1	NOMINAL UPCONTROL L/D	.1		
LEWD2	UPCONTROL L/D HIGH DRAG CASES	.2		
LOD	FINAL PHASE L/D	.18		
Q2	FINAL PHASE RANGE - 23500 Q3	-1002	NM	
Q3	FINAL PHASE DRANGE/D V	.07	NM/FPS	
Q5	FINAL PHASE DRANGE/ D GAMMA	7050	NM/RAD	
Q6	FINAL PHASE INITIAL FLIGHT PATH ANGLE	.0349	RAD	
Q7F	MIN DRAG FOR UPCONTROL	6	FPSS	
Q7MIN	MIN VALUE FOR Q7 IN FACTOR CALCULATION	35	FPSS	
Q19	FACTOR IN GAMMAL1 CALCULATION	.2		
VFINAL	VELOCITY TO START FINAL PHASE ON INITIAL ENTRY	25000	FPS	
VLMIN	MINIMUM VL	18000	FPS	
VMIN	VELOCITY TO SWITCH TO RELATIVE VEL	VSAT/2		
VRCONTRL	RDOT TO START INTO HUNTEST	700	FPS	
VCORLIM	MAX VALUE OF VCORR	1000	FPS	
25NM	TOLERANCE TO STOP RANGE ITERATION	25	NM	
VQUIT	VELOCITY TO STOP STEERING	1000	FPS	

CONVERSION FACTORS AND SCALING CONSTANTS			
ATK	ANGLE IN RAD TO NM	3437.7468	NM/RAD
GS	NOMINAL G VALUE FOR SCALING	32.2	FPSS
HS	ATMOSPHERE SCALE HEIGHT	28500	FT
J	GRAVITY HARMONIC COEFFICIENT	.00162345	
KWE	EQUATORIAL EARTH RATE	1546.70168	FPS
MUE	EARTH GRAVITATIONAL CONSTANT	3.986032233 E 14	CUBIC M/ SEC SEC
RE	EARTH RADIUS	21202900	FT
VSAT	SATELLITE VELOCITY AT RE	25766.1973	FPS
WIE	EARTH RATE	.0000729211505	RAD/SEC

Fig. 5-29 Constants, Gains and Conversion Factors

6. MISSION AND VEHICLE DATA

6.1 Scope

Section 6 is a summary of all Flight 501 mission and vehicle data that have an impact on AGC programming. Data have been collected under the following headings:

Section 6.2 Mission Data. Establishes the outlines of the mission in terms of trajectories, profiles, etc. Includes performance figures for Saturn boost phase inasmuch as they affect conditions pertaining at take-over of control by G&N system.

Section 6.3 Memory Data. Contains all mission- and vehicle-dependent data that are, in one form or another, written directly into the memory of the AGC. In a wired-memory computer, such as the AGC, the very limited erasable section is intended primarily for storage of computational variables. An attempt has been made to consign those mission parameters that do not change during flight to the fixed section of the memory.

Section 6.4 Vehicle Data. Contains information that will mainly affect simulations and rope verification and will not, with only one or two exceptions, appear directly in the AGC program.

Section 6.5 Physical Constants. These definitions will be used in AGC programs and verification work.

Numerical data are presented in the most convenient and widely accepted units. The AGC is, however, programmed in the metric set of kilogram, meter, and centisecond (10^{-2} sec). Conversion to other sets of units is done by use of the factors defined in Section 6.5.2.

Points on the surface of the earth are defined in terms of geodetic latitude and longitude, referred to the Fischer ellipsoid of 1960, and of geocentric radius.

It is pointed out that not all items of numerical data included in this section are to be found in the memory explicitly as defined. They are often rescaled, changed in units, or combined with other data for storage in the most convenient and/or economical fashion.

6.2 Mission Data

6.2.1 Mission Trajectories

"AS-501 Spacecraft Reference Trajectory"	
TRW Systems 3902-H002-RC000	1 November 1965
Nominal Mission Profile	See Fig. 6.1 and Fig. 6.2
Major Events During Mission	See Table 6.1
Nominal Saturn Boost Profile	See Figs. 6.3 and 6.4

6.2.2 Nominal SIVB Separation Attitude Conditions

Roll rate	0°/sec
Pitch rate	0°/sec
Yaw rate	0°/sec

6.2.3 3σ Dispersions from Nominal Attitude at SIVB Separation

x-axis attitude dispersion	2°
y-axis attitude dispersion	2°
z-axis attitude dispersion	2°
Roll rate residual	0.2°/sec
Pitch rate residual	0.2°/sec
Yaw rate residual	0.2°/sec

6.2.4 SIVB Engine-Off Transient

Vacuum Thrust Decay	not available
Tail-Off Impulse	not available

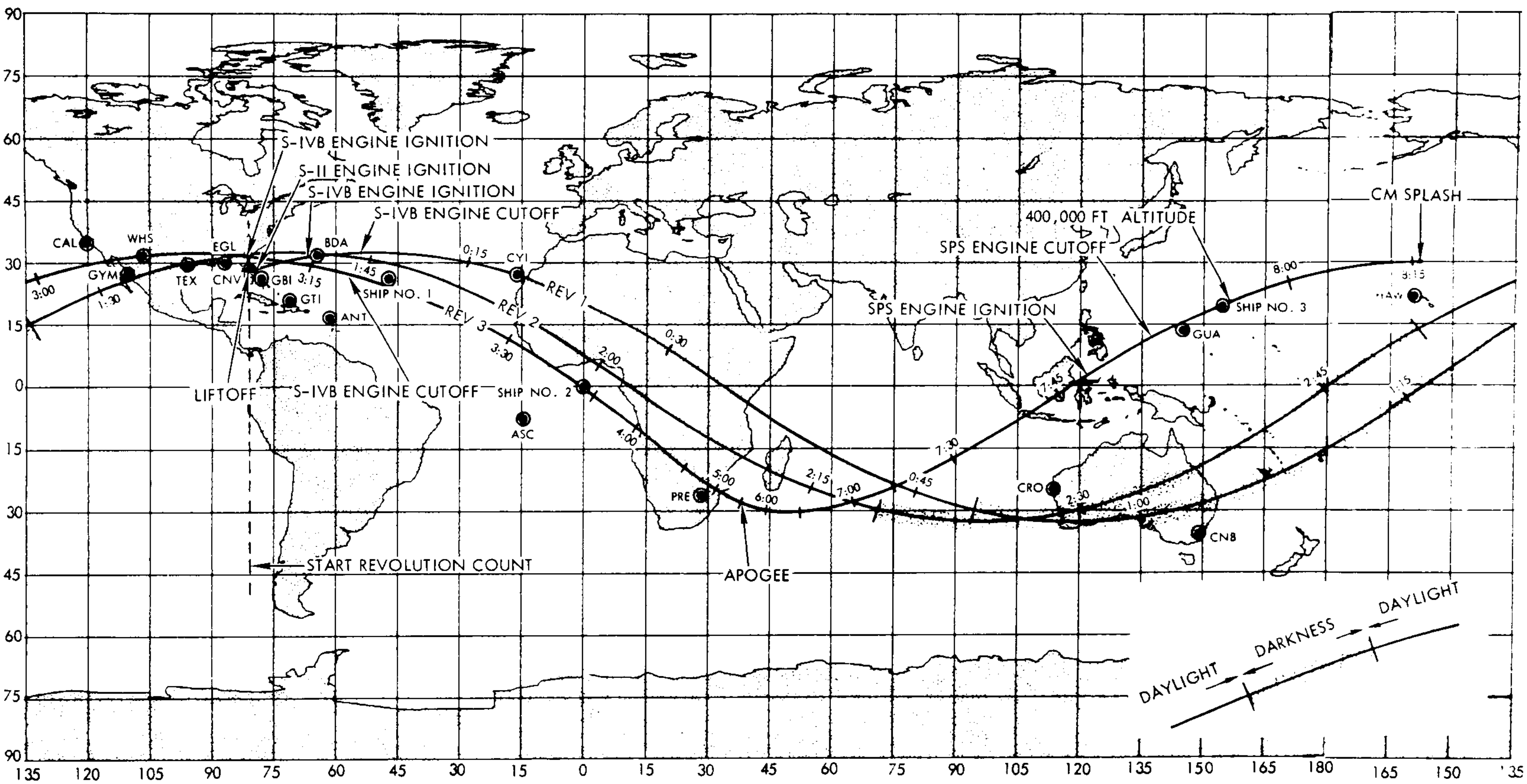


Figure 6-1. Ground Track

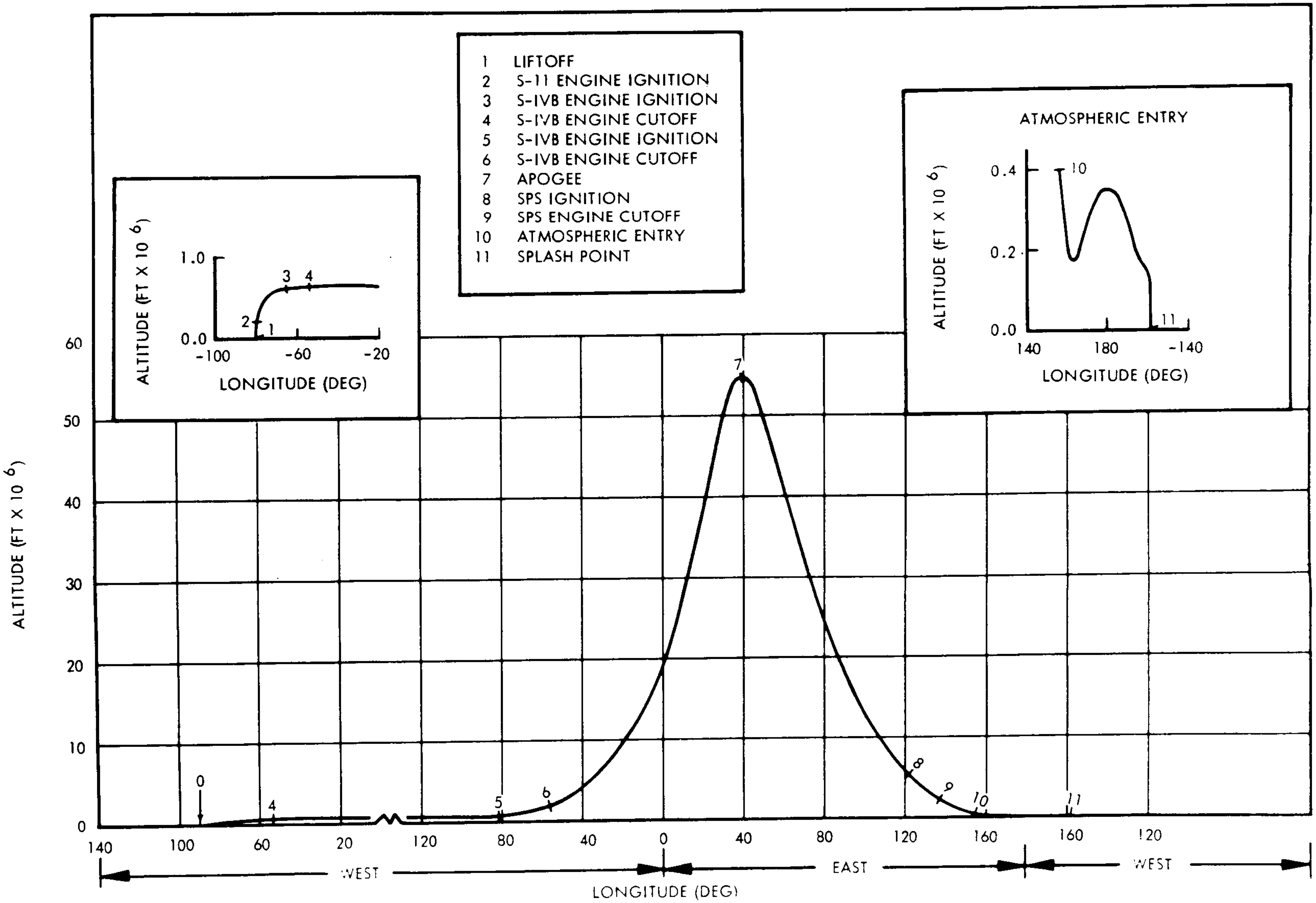


Figure 6-2. Altitude-Longitude History

Table 6.1

Major 501 Mission Events

Event	Time from Liftoff (hr/min/sec)	Altitude (ft)	Geodetic Latitude (deg)	Longitude (deg)	Inertial Velocity (fps)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
Liftoff	0/0/0	-16,021	28.648 N	80.635 W	1,340	0.0	90.0
Max Q	0/1/12						
SIC Cutoff	0/2/28.85	175,914	28.871 N	79.846 W	8,845	19.678	75.324
LET JET	0/3/03.85	269,751	29.078 N	79.088 W	9,340	15.127	75.541
SII Cutoff	0/8/30.69	584,290	31.687 N	66.126 W	22,170	1.047	81.286
SIVB Cutoff #1	0/11/21.08	607,609	32.709 N	54.173 W	25,574	0.001	87.931
SIVB Ign #2	3/11/27.05	642,742	31.909 N	81.753 W	25,573	0.016	97.852
SIVB Cutoff #2	3/17/07.28	1,937,072	27.412 N	56.769 W	30,653	15.544	103.427
CSM Sep	3/47/07.28	22,065,637	3.29 S	3.781 E	19,030	34.425	120.010
Apogee	5/35/42.57	54,669,128	28.486 S	39.056 E	8,928	0.0	100.771
Update	7/28/27.8						
SPS Ign	7/48/27.8	5,339,370	2.412 N	121.712 E	27,919	-23.028	59.93
SPS Cutoff	7/53/2.56	2,265,769	11.56 N	136.904 E	34,836	-17.929	61.925
CM/SM Sep	7/54/2.56	1,663,178	13.912 N	141.239 E	35,299	-15.409	62.932
Entry (400,000ft)	7/57/02.67	400,000	20.927 N	156.263 E	36,333	-7.13	67.67
Splash	8/17/41.96	0.0	30.232 N	158.359 W	1,320	-1.137	90.003
Entry 400,000 ft (No SPS)	7/58/04	400,000	21.138 N	156.562 E	32,067	-9.20	67.87
Splash (No SPS)	8/09/56	0.0	24.668 N	166.431 E	---	---	

Notes: Altitude from liftoff to parking orbit insertion is measured above an earth having a mean radius of 20,925,739 feet. From insertion to splash, altitude is measured above the reference ellipsoid.

These data are for a single SPS burn trajectory, since the trajectory with two SPS burns is not yet available.

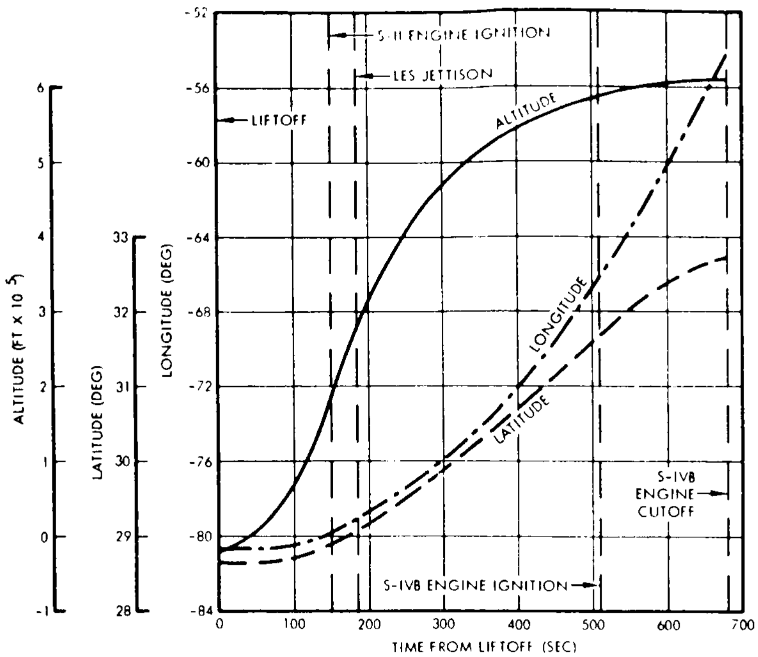


Figure 6-3. Saturn V Ascent to Orbit/Altitude, Latitude, and Longitude

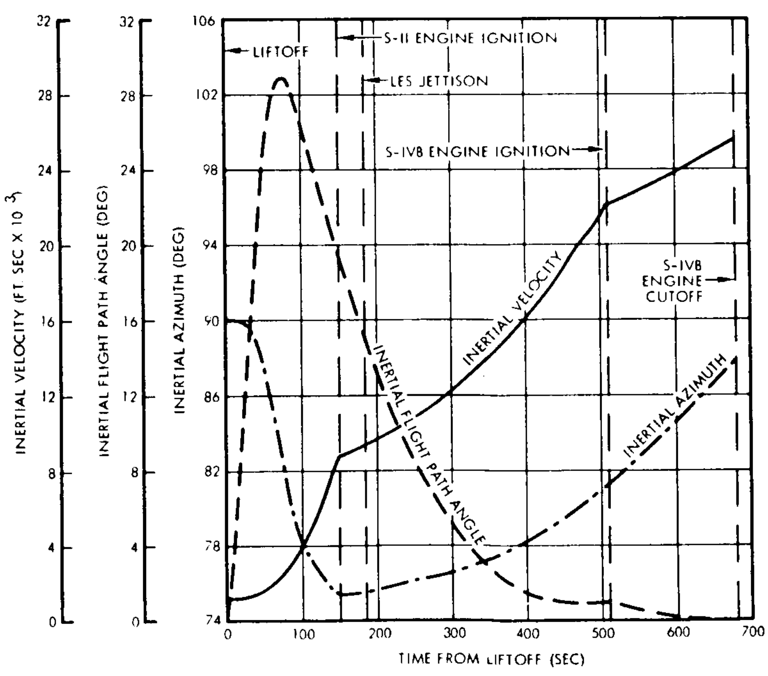


Figure 6-4. Saturn V Ascent to Orbit/Inertial Velocity, Flight Path Angle, and Azimuth

6.3 Memory Data

6.3.1 Prelaunch

	Memory Type	Value
Launch Pad #39A: Latitude	F	28°38'50.92" N
Longitude	F	80°38'8.07" W
Altitude of G&N above ellipsoid	F	Not available
Inertial reference plane (IMU) azimuth	F	Not available
Optical target 1		
Azimuth	F	Not available
Elevation	F	Not available
Optical target 2		
Azimuth	F	Not available
Elevation	F	Not available
Latitude of local vertical at launch pad	F	Not available

6.3.2 Saturn Boost

	Memory Type	Value
(Interval: Lift-off-LET jettison assumed complete		183.0 sec)
Interval: Lift-off to start of roll maneuver	E	12.0 sec
Interval: Duration of roll maneuver	E	Not available
(Interval: Lift-off to start of Pitch maneuver		Not available)
Interval: Duration of Pitch Maneuver	E	Not available
Roll maneuver: Rotation about inertial vertical	E	Not available
Roll maneuver rate (constant)	E	Not available

	Memory Type	Value
Pitch polynomial[1] coefficient A_0	E	Not available
A_1	E	Not available
A_2	E	Not available
A_3	E	Not available
A_4	E	Not available
A_5	E	Not available
A_6	E	Not available

Note 1. Form of pitch polynomial is:

$$\theta = \sum_{n=0}^{6} A_n t^n$$

where θ = angle between inertial horizontal at launch and vehicle X-axis, in degrees

t = Time in secs ($t = 0$ at 10 secs after Lift-off)

6.3.3 Attitude Maneuvers

	Memory Type	Value
Limit: commanded S/C angular rate:		
Roll (CSM)	F	7.2°/sec
Roll (CM only)	F	15°/sec
Pitch, Yaw (CSM, CM)	F	4°/sec
Interval between attitude updates	F	0.5 sec
Interval for stabilization after maneuver	F	5.0 sec

6.3.3.1 Cold-Soak Attitude

The desired cold soak attitude of the CSM is defined for the AGC via four angles in erasable memory. The angles are (1) RA, apparent right ascension of the sun; (2) D, declination of the sun; (3) A_z, Azimuth about the solar vector; (4) ψ, orientation of the solar vector in the CSM X - Z plane.

The defining rotations are shown in Figures 6-5 through 6-7.

The angles RA and D define the solar vector in ECI co-ordinates and are extracted for any day from the American Ephemeris and Nautical Almanac.

The angles A_z and ψ define the orientation of the CSM with respect to the solar vector and will be selected in accordance with gimbal lock and communications constraints.

The four angles are a function of the launch time.

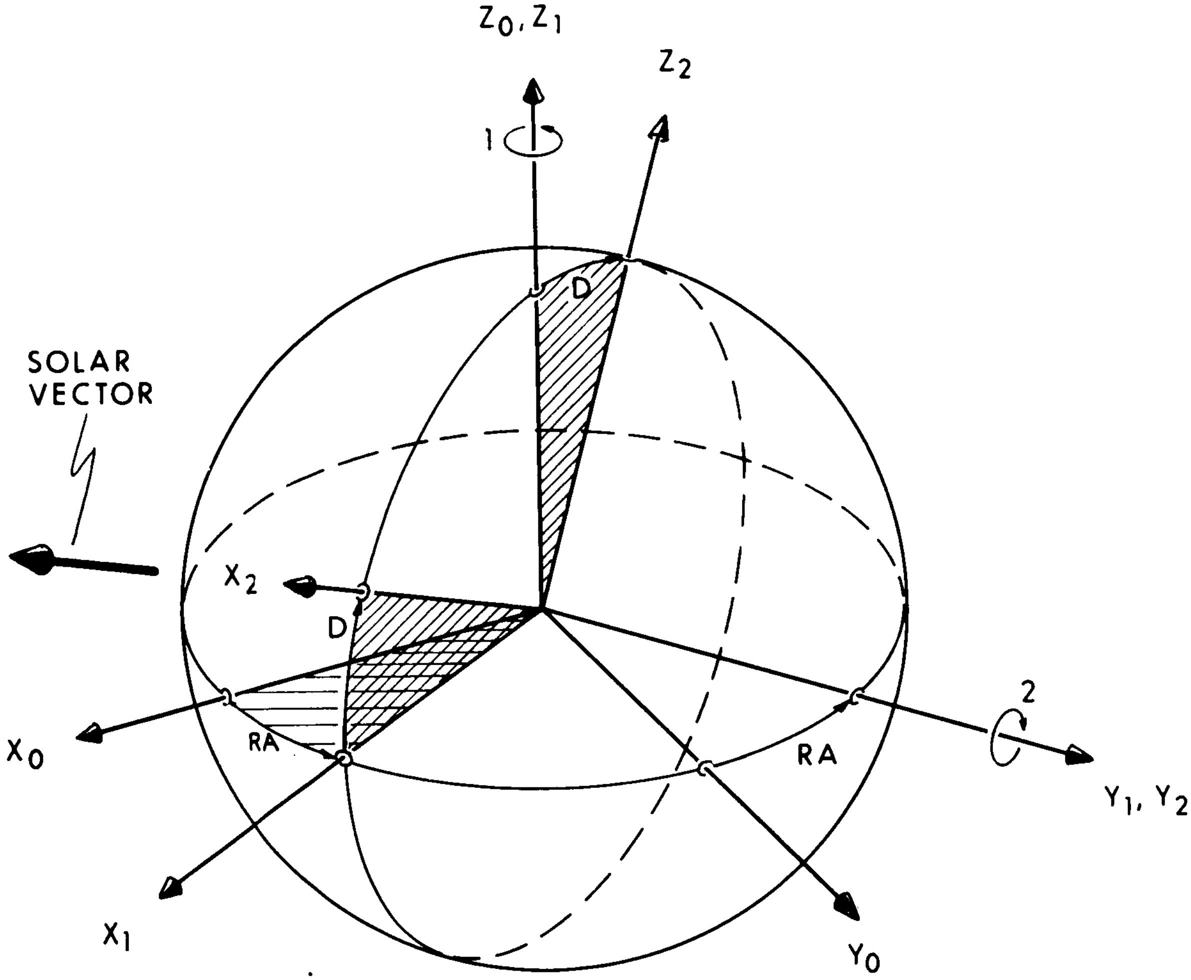
RA Right Ascension--available for particular date from American Ephemeris and Nautical Almanac. This angle is measured as positive rotation about polar axis.

D Declination--also available from Almanac. This angle is measured as a negative rotation about the Y-axis.

A_z Azimuth--selected to satisfy gimbal lock and communication constraints. This angle is measured as a negative rotation about the sun vector.

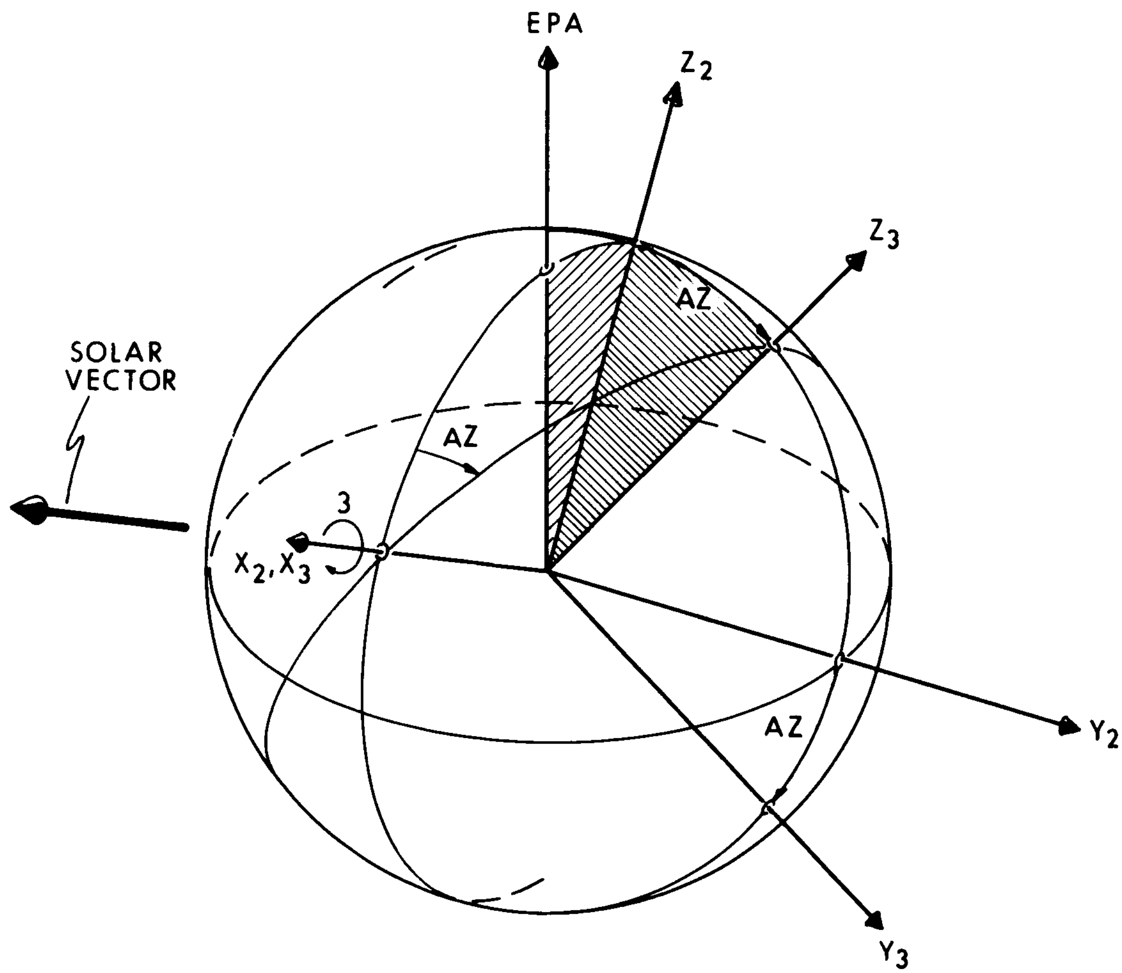
ψ Psi -- also to satisfy mission constraints. This angle is measured as a negative rotation about the $Y_{s/c}$ axis.

	Memory Type	Value
Right Ascension	E	not yet determined
Declination	E	not yet determined
Azimuth	E	not yet determined
Psi	E	not yet determined



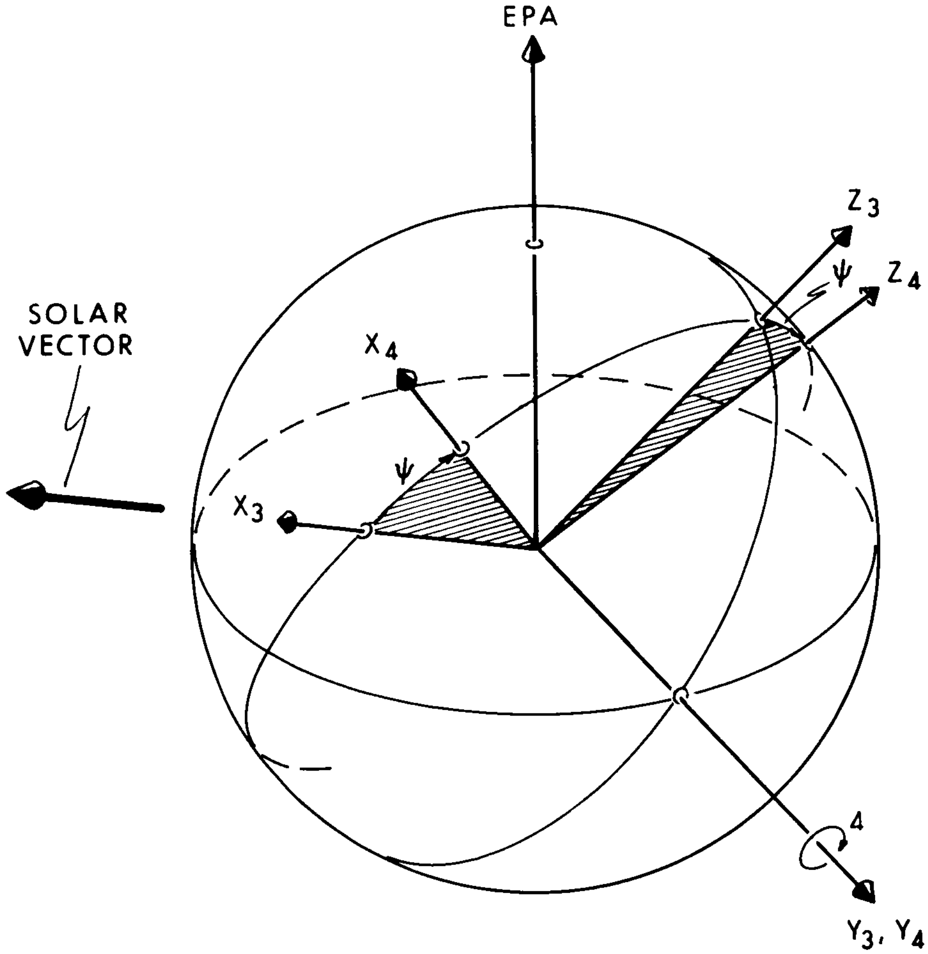
(X_0, Y_0, Z_0) DEFINE ECI COORDINATES
(X_1, Y_1, Z_1) RESULTS FROM ROTATION OF RA ABOUT Z_0
(X_2, Y_2, Z_2) RESULTS FROM ROTATION OF D ABOUT $-Y_1$

Fig. 6-5



(X_3, Y_3, Z_3) RESULTS FROM ROTATING OF A_Z ABOUT $-X_2$

Fig. 6-6



(X_4, Y_4, Z_4) RESULTS FROM ROTATION OF ψ ABOUT $-Y_3$

Fig. 6-7

6.3.4 TVC (nominal mission)

	Memory Type	Value
CSM c.g. displacement in X-Y plane*	F	Not determined
CSM c.g. displacement in X-Z plane*	F	Not determined
Minimum ΔV criterion for thrust monitor	F	1 ft/s/s
Interval for thrust monitor	F	20 sec
Interval between steering updates	F	2 sec
Steer law gain (K_1)	F	0.125
Steer law integrator loop gain (K_2)	F	0.010
Integrator saturation limit	F	1.0°
Steer law coefficient (c)	F	1.0
Maximum interval: freeze CDU's to engine off command:	F	Not determined
Interval: between SCS mode change commands	F	0.25 sec
Interval: Gimbal motor power on to Engine start	F	12.0 sec
Interval: Engine off to Gimbal motor power off	F	7.0 sec
Interval: Engine off to ΔV mode off	F	10.5 sec
Maximum interval: Receipt of SIVB/CSM separation signal to receipt of uplink abort	F	1.7 sec
Interval: mean effective SPS tailoff duration	F	0.39 sec
SPS Burn aim point criteria:		
First SPS Burn		
semilatus rectum(p)	E	3.28465×10^7 ft
eccentricity (e)	E	0.59473
Second SPS Burn		
semilatus rectum (p)	E	4.19693×10^7 ft.
eccentricity (e)	E	0.99913

* Separate values needed for each SPS burn

6.3.5 Entry (Normal Mission)

	Symbol	Memory Type	Value
CSM attitude for CM/SM separation			
X-axis above the velocity vector by:		F	60^{o}
(Y-axis along momentum vector ($R \times V$), Z-axis above velocity $\overline{\text{vector}}$)			
CM Pacific pre-entry attitude:			
X-axis above velocity vector by:		F	157.24^{o}
(Y-axis opposite momentum vector ($R \times V$), Z-axis above velocity $\overline{\text{vector}}$. A lift vector up attitude)			
Trim angle of attack		F	22.76^{o}
Interval: CM/SM separation to start of maneuver		F	20 sec
Pacific recovery point:			
Latitude:		E	30.232^{o} N
Longitude:		E	158.359^{o} W
Entry Constants and Gains			
Factor in ALP computation	C1	F	1.25
Constd gain on drag	C16	F	.01
Constd gain on RDOT	C17	F	.001
Bias vel. for final phase start	C18	F	500 fps
Minimum const drag	C19	F	130 fpss
Max drag for down-lift	C20	F	175 fpss
Factor in AHOOK computation	CHOOK	F	.25
Factor in GAMMAL computation	CH1	F	.75
Max const drag	DOMAX	F	175 fpss
Computation cycle time interval	DT	F	2 sec
Maximum acceleration	GMAX	F	322 fpss (10 g-s)
Drag to roll up if down initially (=KAT)	KAFIX	F	64.4 fpss
Optimized upcontrol gain	KB1	F	3.4
Optimized upcontrol gain	KB2	F	.0034
Increment on Q7 to detect end of Kepler phase	KDMIN	F	0.5 fpss
Lateral switch gain	KLAT	F	.0125
Time of flight constant	KTETA	F	1000
Max L/D (Min actual vehicle L/D)	LAD	F	.3

	Symbol	Memory Type	Value
LAD cos (15 deg)	L/DCMINR	F	.2895
Upcontrol L/D	LEWD	F	.2
Final Phase L/D	LOD	F	.18
Final phase range - 23500 Q3	Q2	F	-1002 nm
Final phase DRange/D V	Q3	F	0.07 nm/fps
Final phase DRange/D GAMMA	Q5	F	7050 nm/rad
Final phase initial flight path angle	Q6	F	0.0349 rad
Min drag for upcontrol	Q7F	F	6 fpss
Minimum VL	VLMIN	F	18000 fps
Velocity to switch to relative vel	VMIN	F	VSAT/2
RDOT to start into HUNTEST	VRCONTRL	F	700 fps
Max value of VCORR	VCORLIM	F	1000 fps
Tolerance to stop range iteration	25NM	F	25 nm
Lateral switch bias term	LATBIAS	F	0.4 nm
Velocity to stop steering	VQUIT	F	1000 fps
Initial Attitude gain	K44	F	236
Velocity to start final phase on INITENTRY	VFINAL	F	25,000 fps
Entry Conversion Factors and Scaling Constants			
Angle in RAD to NM	ATK	F	3437.7468 nm/rad
Nominal G value for scaling	GS	F	32.2 fpss
Atmospheric Scale height	HS	F	28,500 ft
Earth radius	RE	F	21,202,900 ft
Satellite velocity at RE	VSAT	F	25,766.1973 fps
Earth Rate	W	F	$72.9211504 \times 10^{-6}$ rad/sec
Earth Equatorial Rate	KWE	F	1546.70168 fps

6.4 Vehicle Data

6.4.1 CSM Data

Spacecraft Launch Configuration	See Figure 6.8
Mass Properties Data at Launch	See Table 6.2
Mass Properties Data of Expendable Items	Not available
Center of Gravity X-location vs. usable propellant weight	See Figure 6.9
Center of Gravity Y-location vs. usable propellant weight	See Figure 6.10
Center of Gravity Z-location vs. usable propellant weight	See Figure 6.11
Roll Moment of Inertia I_{xx} vs. usable propellant weight	See Figure 6.12
Pitch Moment of Inertia I_{yy} vs. usable propellant weight	See Figure 6.13
Yaw Moment of Inertia I_{zz} vs. usable propellant weight	See Figure 6.14
Product of Inertia I_{xy} vs. usable propellant weight	See Figure 6.15
Product of Inertia I_{xz} vs. usable propellant weight	See Figure 6.16
Product of Inertia I_{yz} vs. usable propellant weight	See Figure 6.17
RCS Thruster Moment Arm	7.1 feet
Fuel Equivalent Slosh Mass	Not available
Oxidizer Equivalent Slosh Mass	Not available
Fuel Mass C.G. X-location	Not available
Oxidizer Mass C.G. X-location	Not available
Fuel Mass Natural Frequency	Not available
Oxidizer Mass Natural Frequency	Not available
Fuel Mass Damping Ratio	Not available
Oxidizer Mass Damping Ratio	Not available

6.4.2 SPS Engine Data

Mass*	
Inertia (IY = IZ = IR)*	
Hinge to c.g. radius*	
Maximum start and shutdown Transients	See Figure 6.18
Mean thrust-off impulse	8,400 lb-sec
Displacement, thrust vector from engine gimbal axes intersection	<0.125 inch
Misalignment, thrust vector from engine mount plane normal	<0.5 degrees
SPS Engine Performance	See Table 6.3

* Mod II actuator model not available

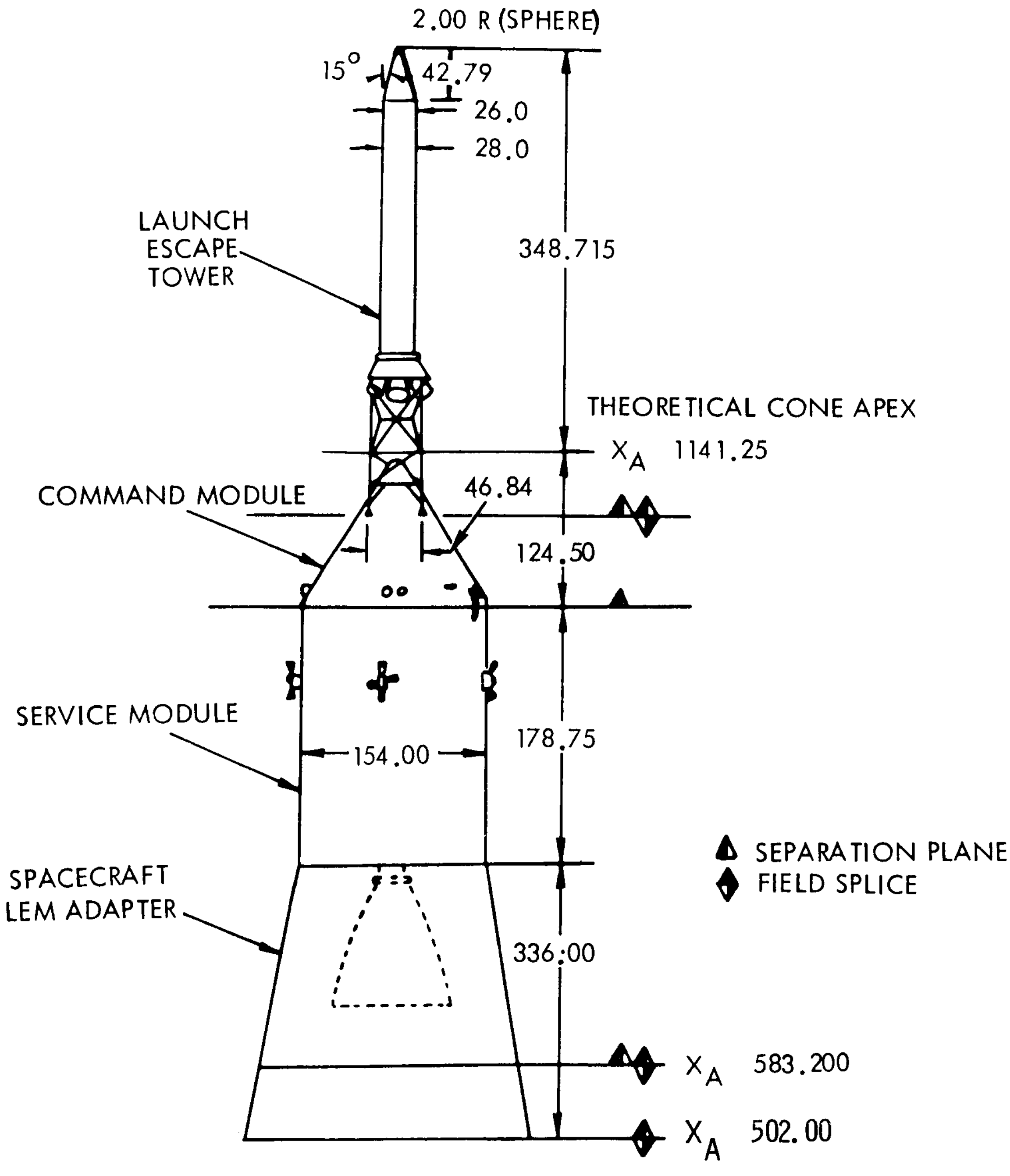


Figure 6.8 CSM Reference Dimensions

Table 6-2. CSM 017 Spacecraft Mass Properties Summary at Launch--Mission 501

Item	Weight (lb)	Center of Gravity[1] (inches)			Moment of Inertia[2] (slug-ft^2)			Product of Inertia[2] (slug-ft^2)		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
Command Module	11,000.0	1043.3	-0.2	6.3	4,949.9	4,364.8	4,057.6	15.2	278.7	30.5
Service Module-less prop.	10,200.0	909.6	0.8	-1.3	6,618.0	10,619.0	10,377.0	286.6	-502.0	-609.2
SLA attachment ring	62.0	837.1	0.0	-1.8	93.0	48.0	46.0	-	-	-
CSM - less propellant	21,262.0	978.6	0.3	2.6	11,729.0	26,737.0	26,090.0	-61.0	525.0	-588.0
SM propellant	28,000.0									
CSM - with propellant	49,262.0									
Launch Escape Sub-system	8,200.0	1298.4	0.0	0.0	571.0	21,482.0	21,484.0	-0.1	72.4	20.9
Adapter	3,738.0	643.4	0.7	-2.4	9,338.0	12,566.0	12,289.0	6.1	-74.4	-10.6
LEM Simulated Article	32,000.0									

NOTES: (1) Centers of gravity are in the Apollo Spacecraft Reference System

(2) Moments and products of inertia are about the center of gravity

[redacted]

Table 6.3 Apollo CSM Propulsion Performance Summary

	Vacuum Specific Impulse I_{sp} (sec)	Vacuum Thrust Per Engine F (lb)	Vacuum Propellant Flow Rate Per Engine $\dot{\omega}$ (lb/sec)	Nozzle Expansion Ratio $\epsilon = A_e/A_t$
SPS (steady state)	$311.2 \pm 2.1 (3\sigma)$	$21,400 \pm 400 (3\sigma)$	68.766	62.5/1

NOTE: The SPS propellant loading presented in Table 6.2 is available as usable propellant plus retained propellant and performance reserves. Three hundred and fifty pounds of propellant will be retained in the propellant retention devices as unusable propellant. Performance reserves should be based on 3σ tolerances presented above. Loading tolerances, M/R tolerances, residuals and trapped propellant are accounted for in the SM inert weight.

[redacted]

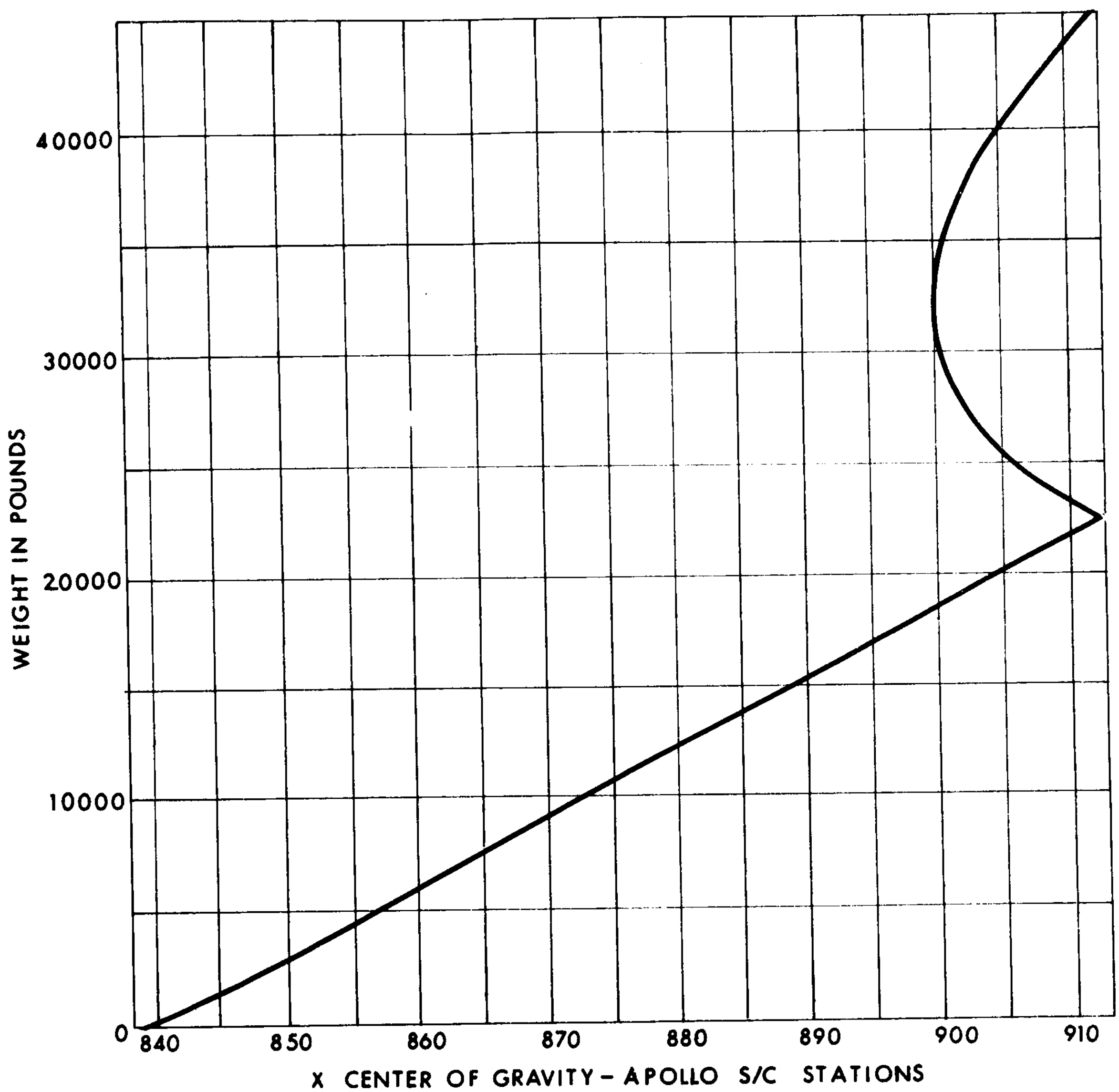


Fig. 6-9 Center of Gravity X-location vs. Usable Propellant Weight

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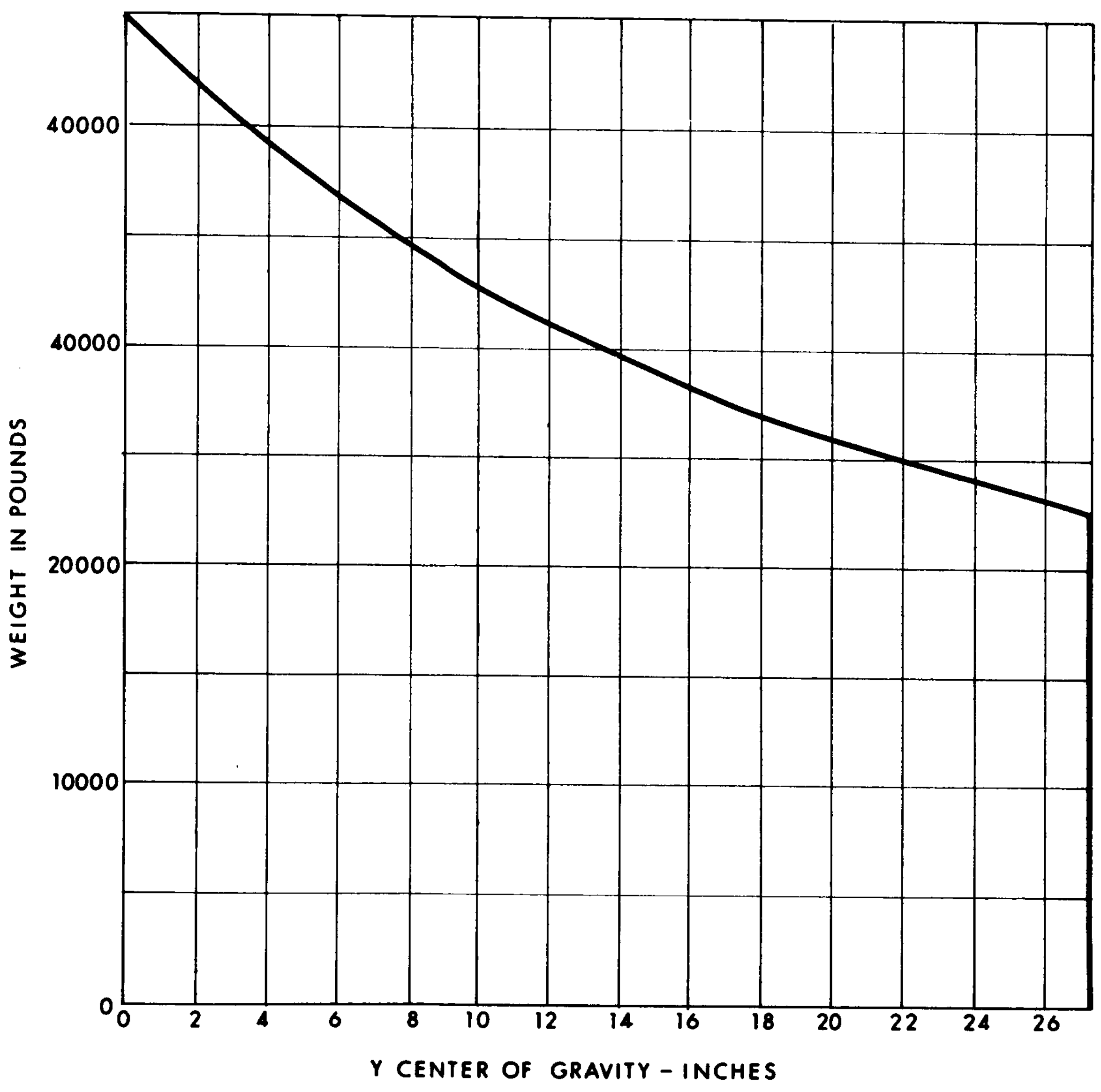

Fig. 6-10 Center of Gravity Y-location vs. Usable Propellant Weight

[redacted]

[redacted]

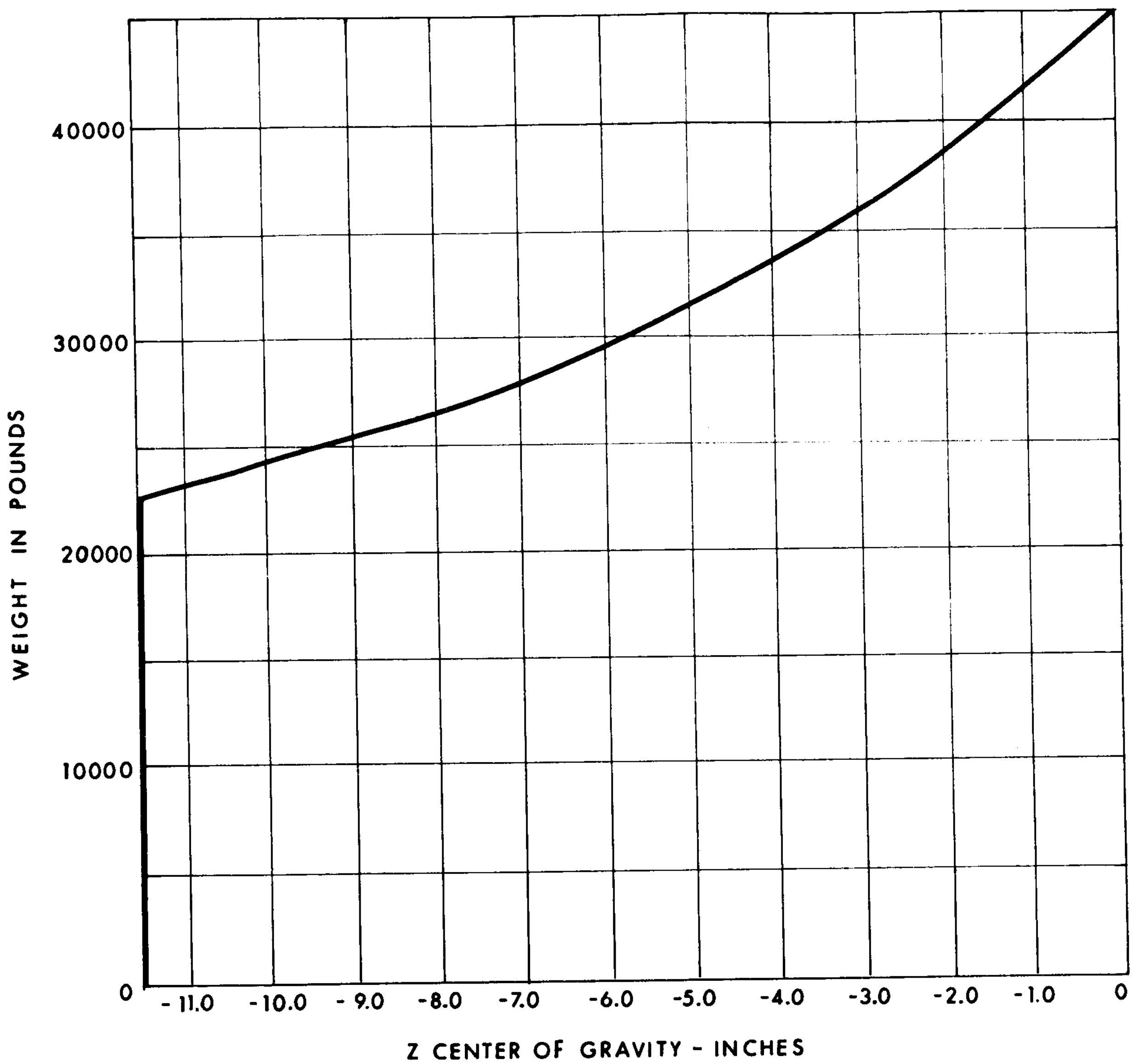

Fig. 6-11 Center of Gravity Z-location vs. Usable Propellant Weight

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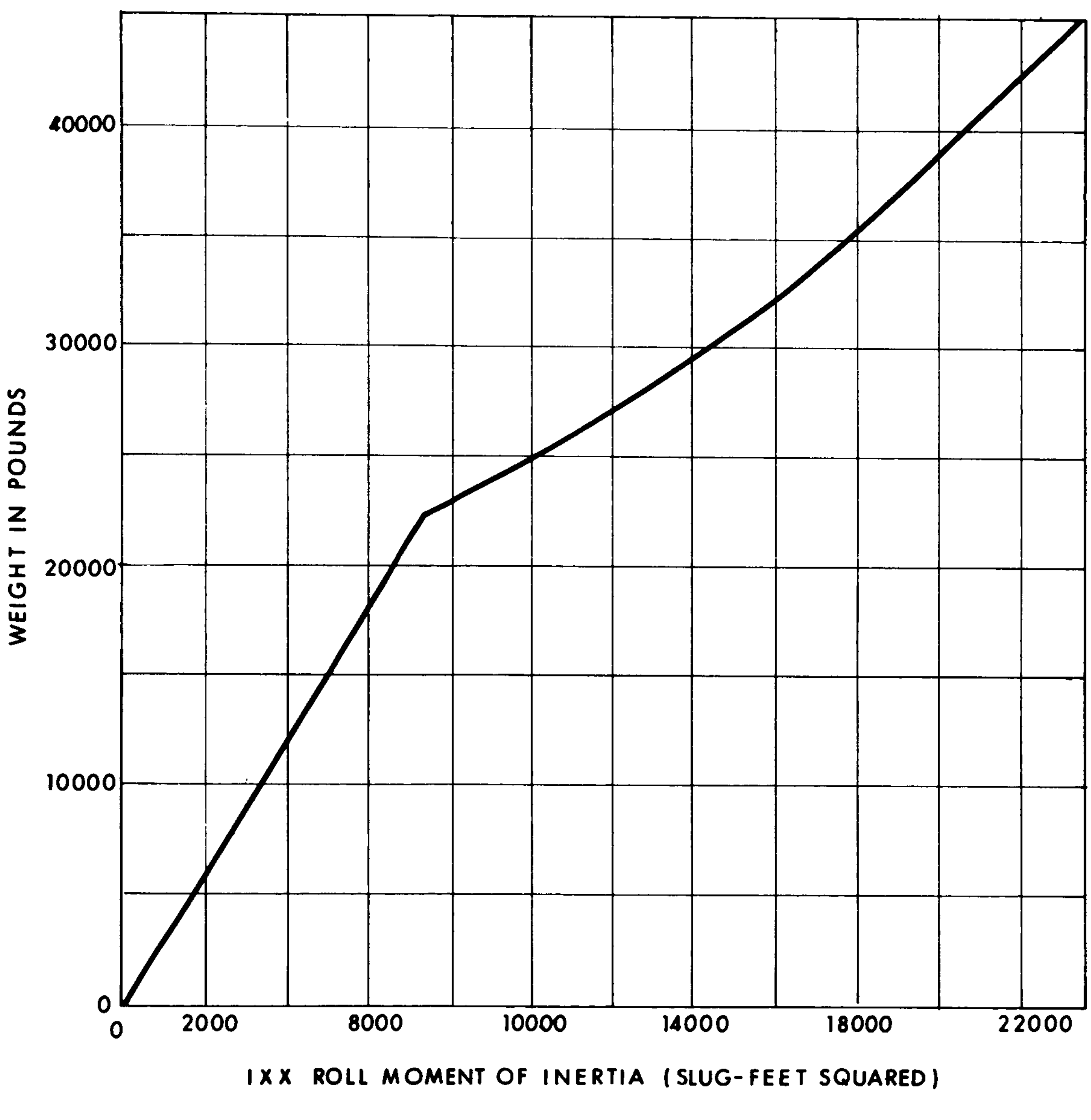

Fig. 6-12 I_{XX} Roll Moment of Inertia vs. Usable Propellant Weight

[redacted]

[redacted]

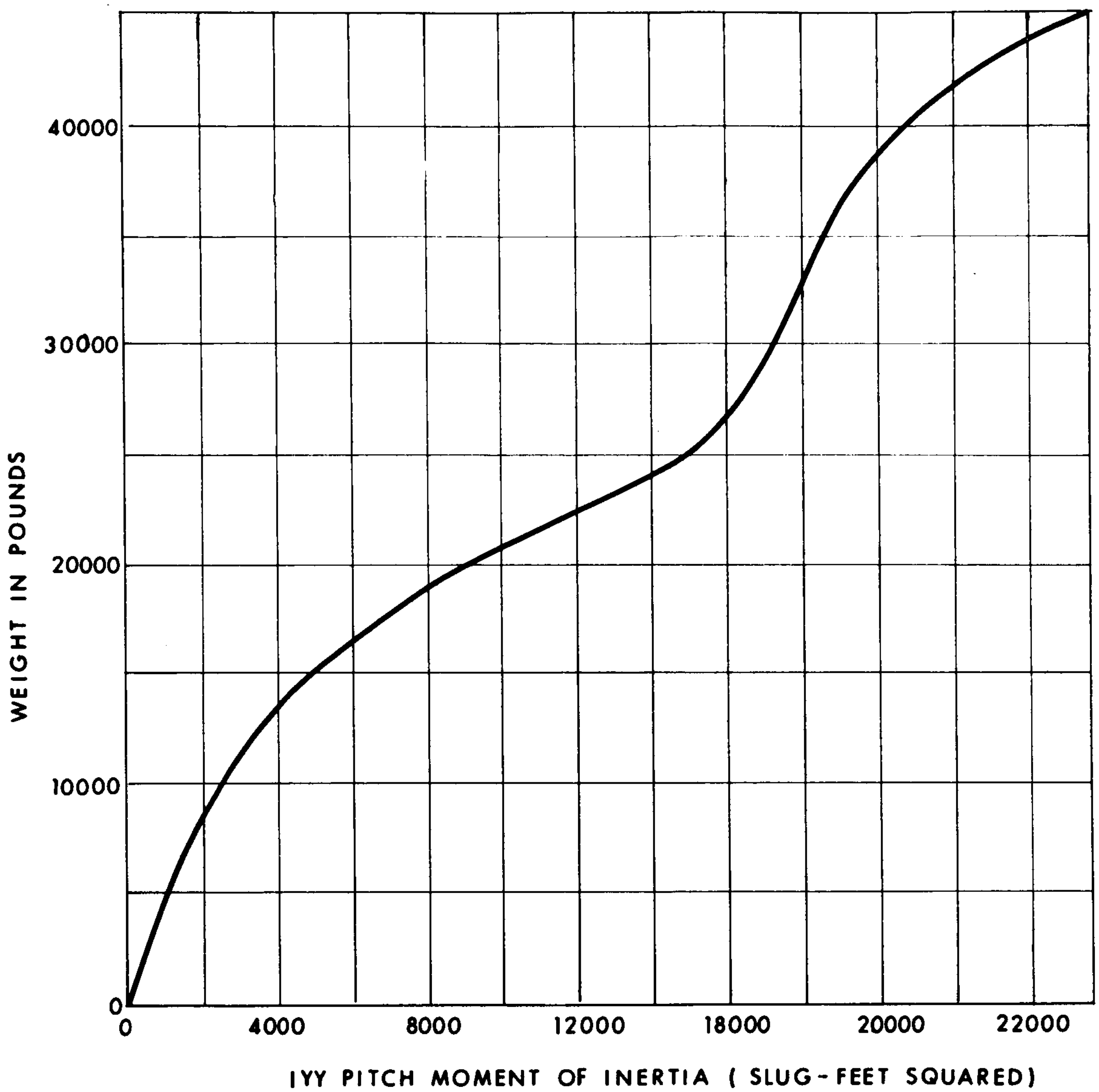

Fig. 6-13 I_{YY} Pitch Moment of Inertia vs. Usable Propellant Weight

[redacted]

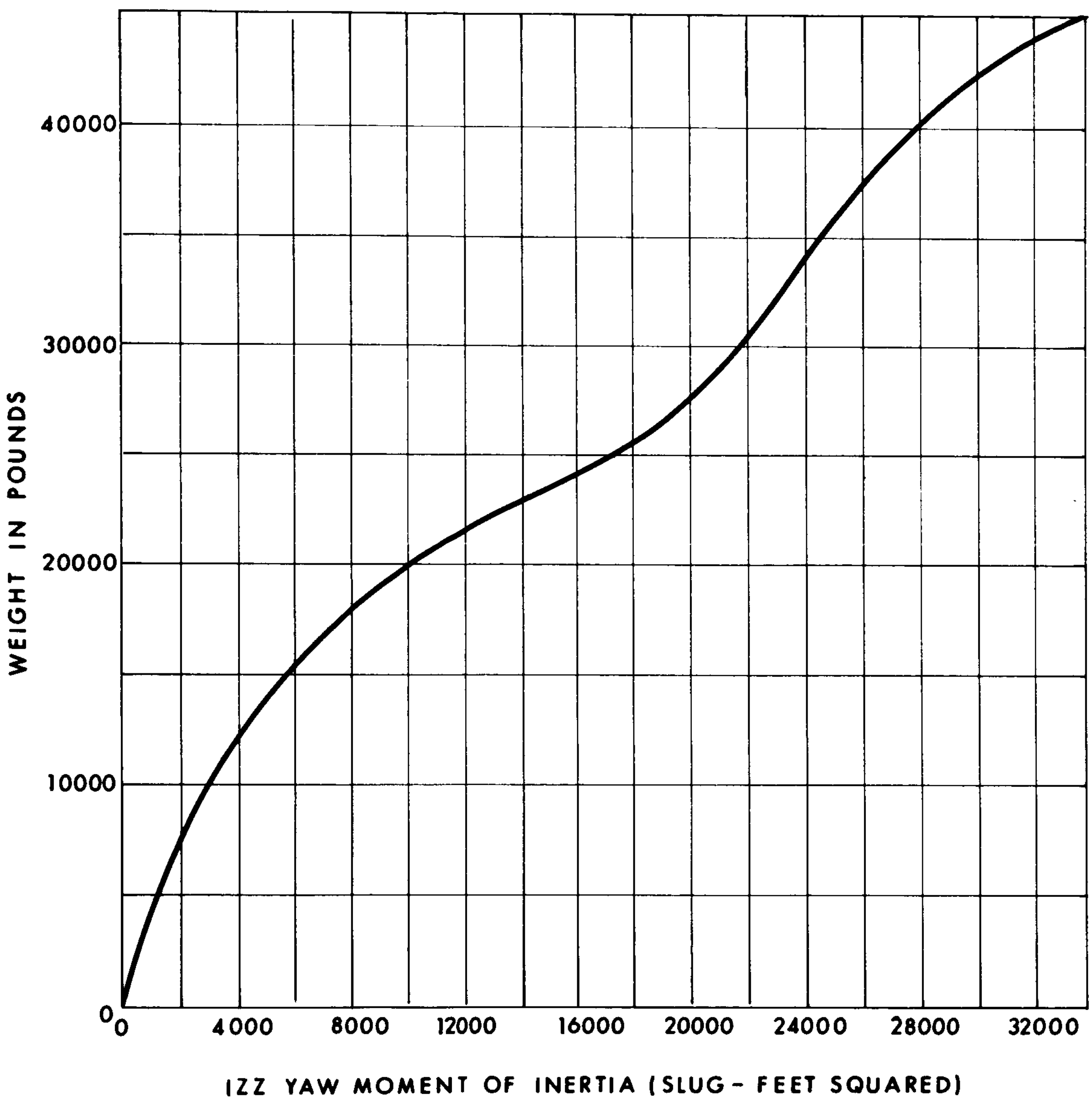

Fig. 6-14 I_{ZZ} Yaw Moment of Inertial vs. Usable Propellant Weight

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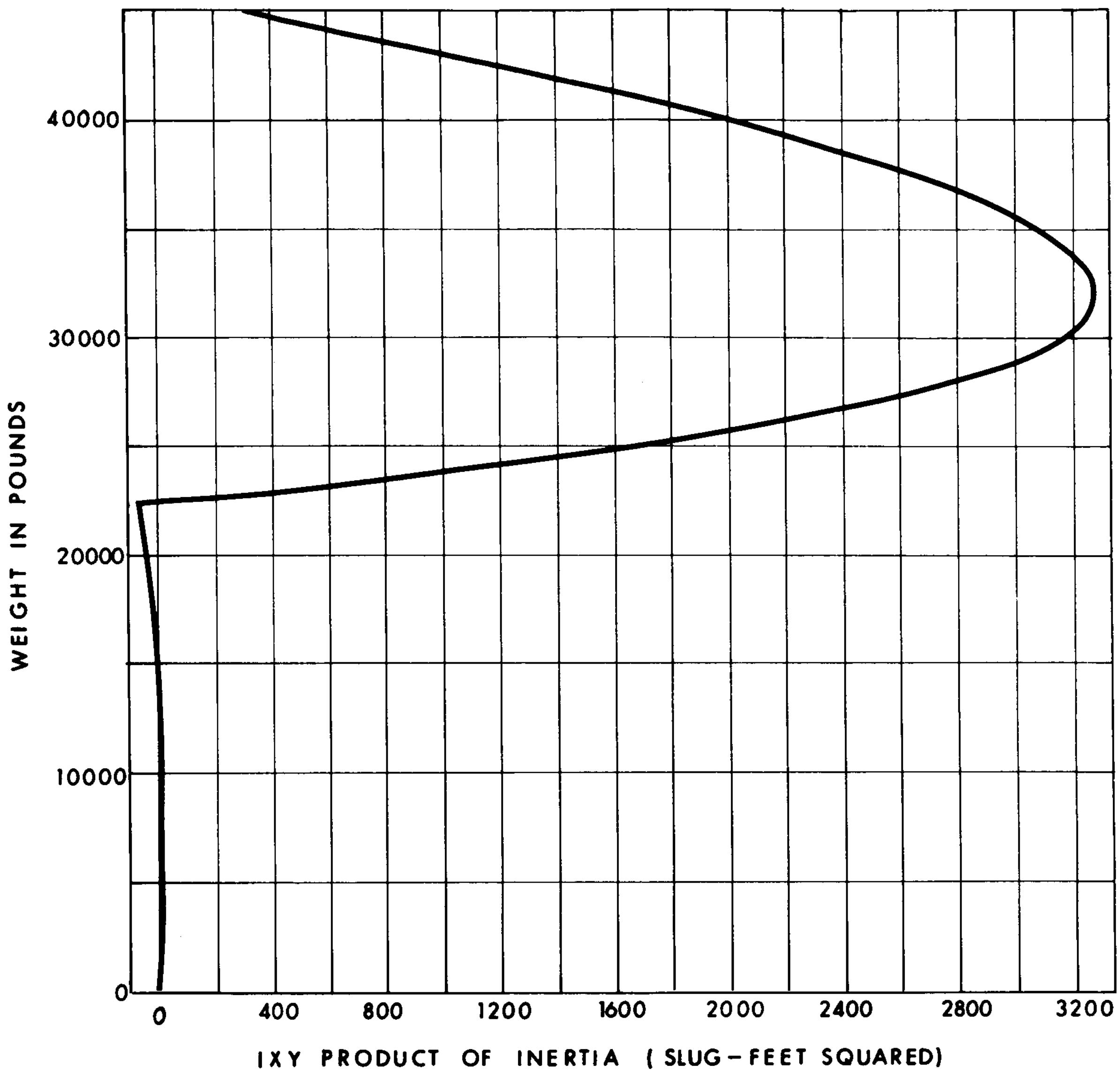

Fig. 6-15 I_{XY} Product of Inertia vs. Usable Propellant Weight

[redacted]

[redacted]

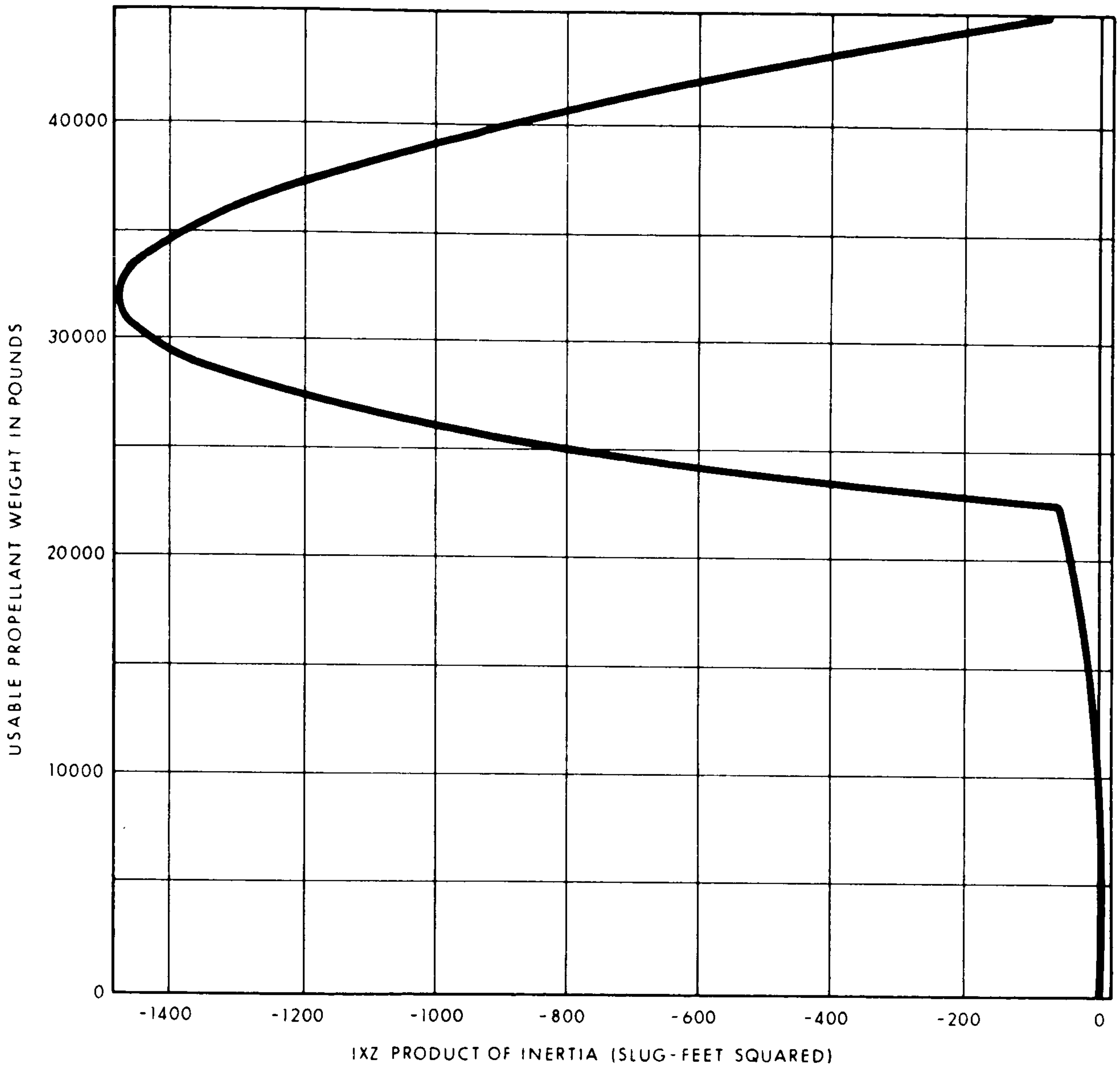

Fig. 6-16 I_{XZ} Product of Inertia vs. Usable Propellant Weight

[redacted]

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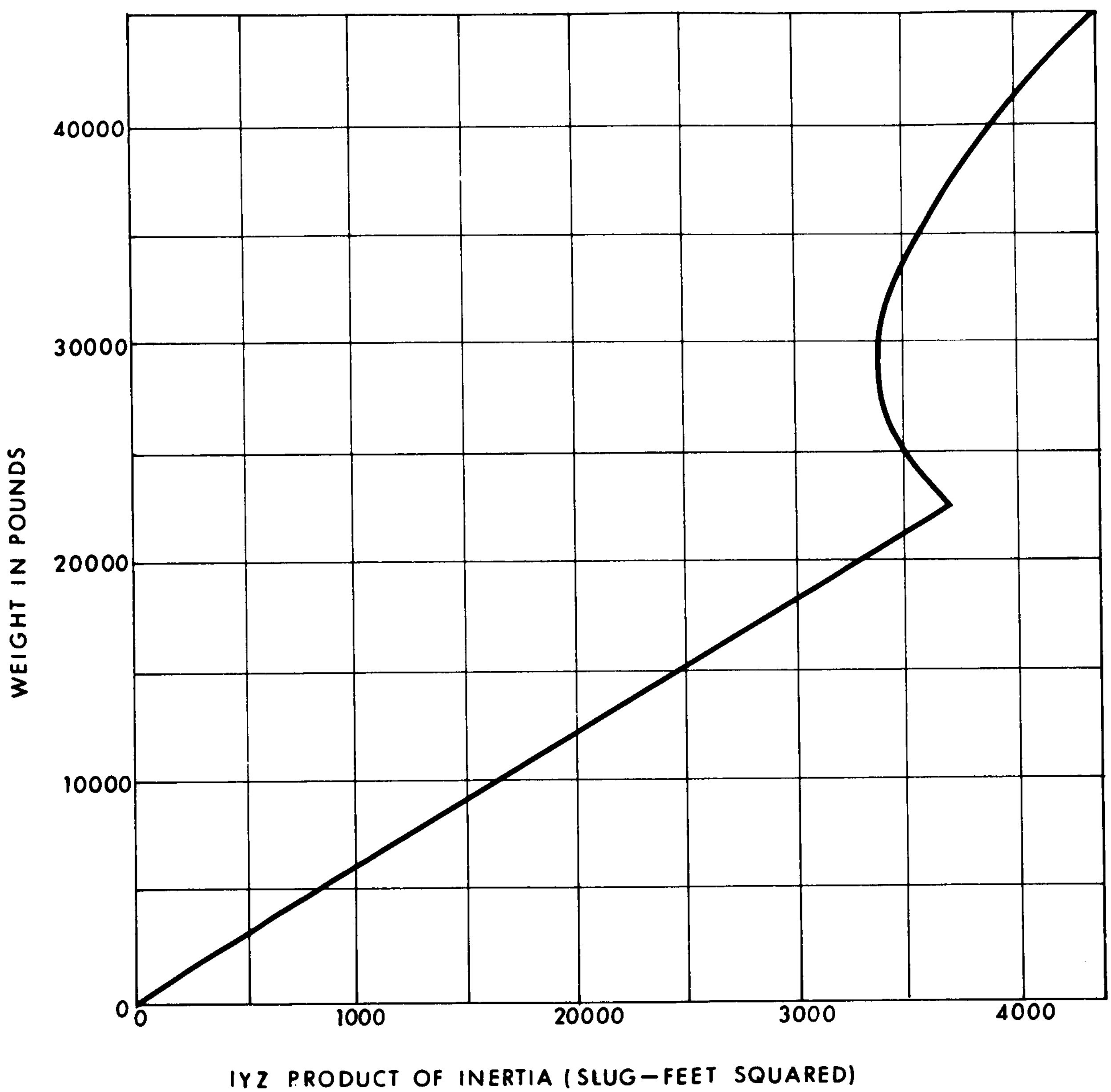

Fig. 6-17 I_{YZ} Product of Inertia vs. Usable Propellant Weight

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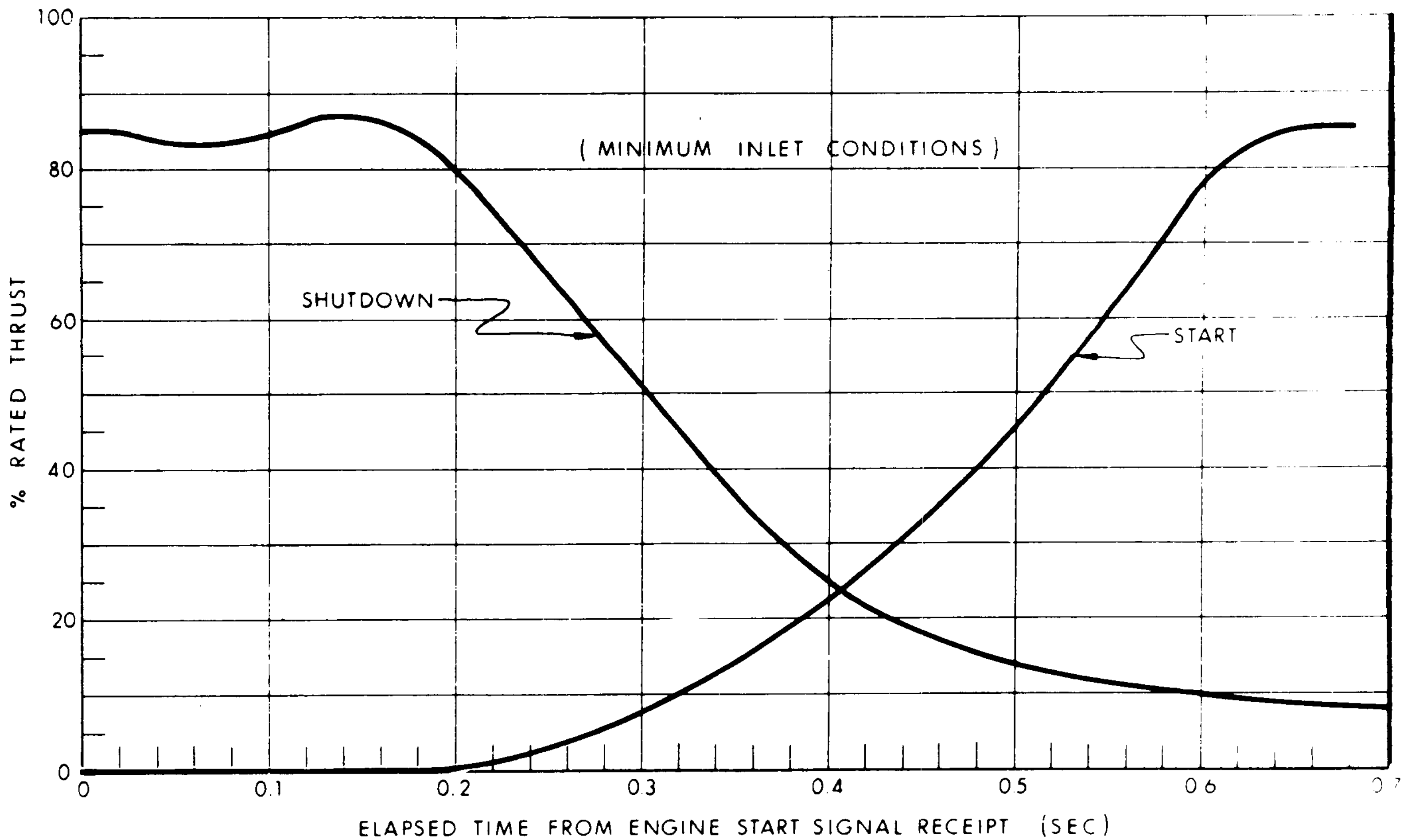

Fig. 6.18 SPS Engine Start and Shutdown Transients

6.4.3 TVC Autopilot Data

TVC Autopilot Data	Symbol	Pitch (Y)	Yaw (Z)	Units
Configuration	Defined in Fig. 6.19			
Attitude error gain	KA	1.00		rad/rad
Attitude rate gain	KR	0.500		rad/rad/sec
Rate command limit	L	0.140 (effectively 16°/sec)		rad
Att. rate filter lead time constant	τ_1	0.125		sec
Att. rate filter lag time constant	τ_2	0.042		sec
Forward filter gain	KE	1.50		
Commanded position breakpoint	LMP(1)	0.105		rad(6°)
Commanded position limit	LMP(2)	0.227		rad(13°)
Clutch servo amplifier gain*	KS			
Clutch servo amp. lead time const.	τ_3	0.025		sec
Clutch servo amp. lag time const.	τ_4	0.029		sec
Clutch servo current limit*	LMI			
Clutch gain	KC	3,530		lb/amp
Actuator moment arm*	RA			
Clutch lead time constant	τ_5	0.022		sec
Clutch lag time constant	τ_6	0.029		sec
Total actuator load inertia*	JT			
Actuator load time constant*	WA			
Actuator load natural frequency*	WB			
Actuator load damping ratio*	ζ			
Engine rate limit	LMR	0.300		rad/sec
Engine position limit (pitch)	LMY	±0.105		rad(±6°)
Engine position limit (yaw)	LMZ		+0.192 / -0.052	rad($^{+11.0^{\circ}}_{-\ 3.0^{\circ}}$)
Position feedback gain*	KD			
Position pickoff frequency	WD	63.0	46.2	
Rate feedback gain*	KG			
Rate pickoff frequency	WC	48.1	40.0	rad/sec

* Mod II actuator model not available

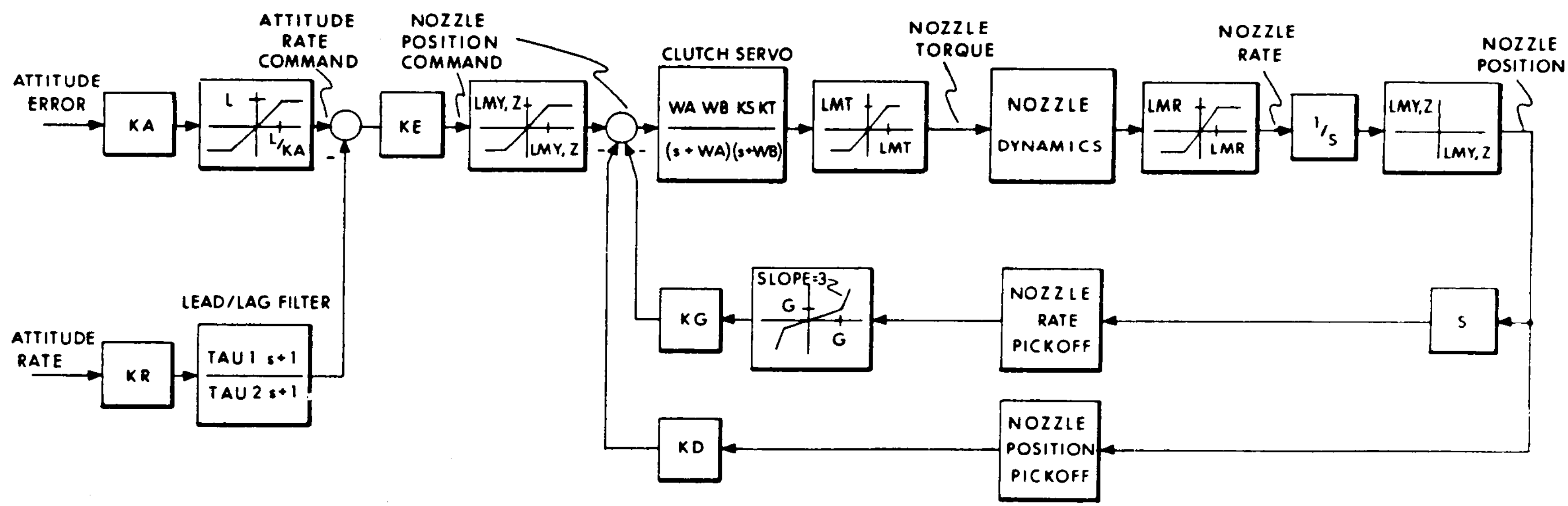

Figure 6-7. TVC Autopilot Block Diagram

6.4.4 RCS Autopilot Data

			Att. Cont.	TVC	Pre-05g		Entry	
Configuration: see Fig. 6.20			Roll, Pitch, Yaw	Roll	Roll, Pitch,	Yaw	Roll	Pitch, Yaw
Attitude error deadband	D	Degrees	0	0	4.0		4.0	---(1)
Attitude error gain	GA	Deg/sec per deg	1.0	1.0	0.2		0.2	---(1)
Rate command limiter	E	Deg/sec	---(2)	---(2)	1.9^3	0.7^4	1.9^3	---(1)
Rate Gain	GR	n.d.	1.0	1.0	0.1		0.1	
Roll-to-yaw coupling angle	ALPHA	Degrees	---	---	---		22^o	
Filter gain	K	Deg/sec	---	---	---		---	
Filter Time constant	τ_f	sec	---	---	---		---	
Switch Deadband	A	Deg/sec	0.2	0.2	0.2		0.2	
	B	Deg/sec	A-0.007	A-0.007	A-0.007		A-0.007	

NOTES

1. Pitch, yaw attitude error channels open-circuited during entry.
2. Effective attitude rate limit set by saturation of electronics at approximately 9.3^o/sec. Commanded rates will be limited to 4^o/sec (pitch, yaw), 7.2^o/sec (CSM-roll), 15^o/sec (CM only-roll).
3. Effective attitude rate limit (roll): 17^o/sec
4. Effective attitude rate limit (pitch, yaw): 5^o/sec

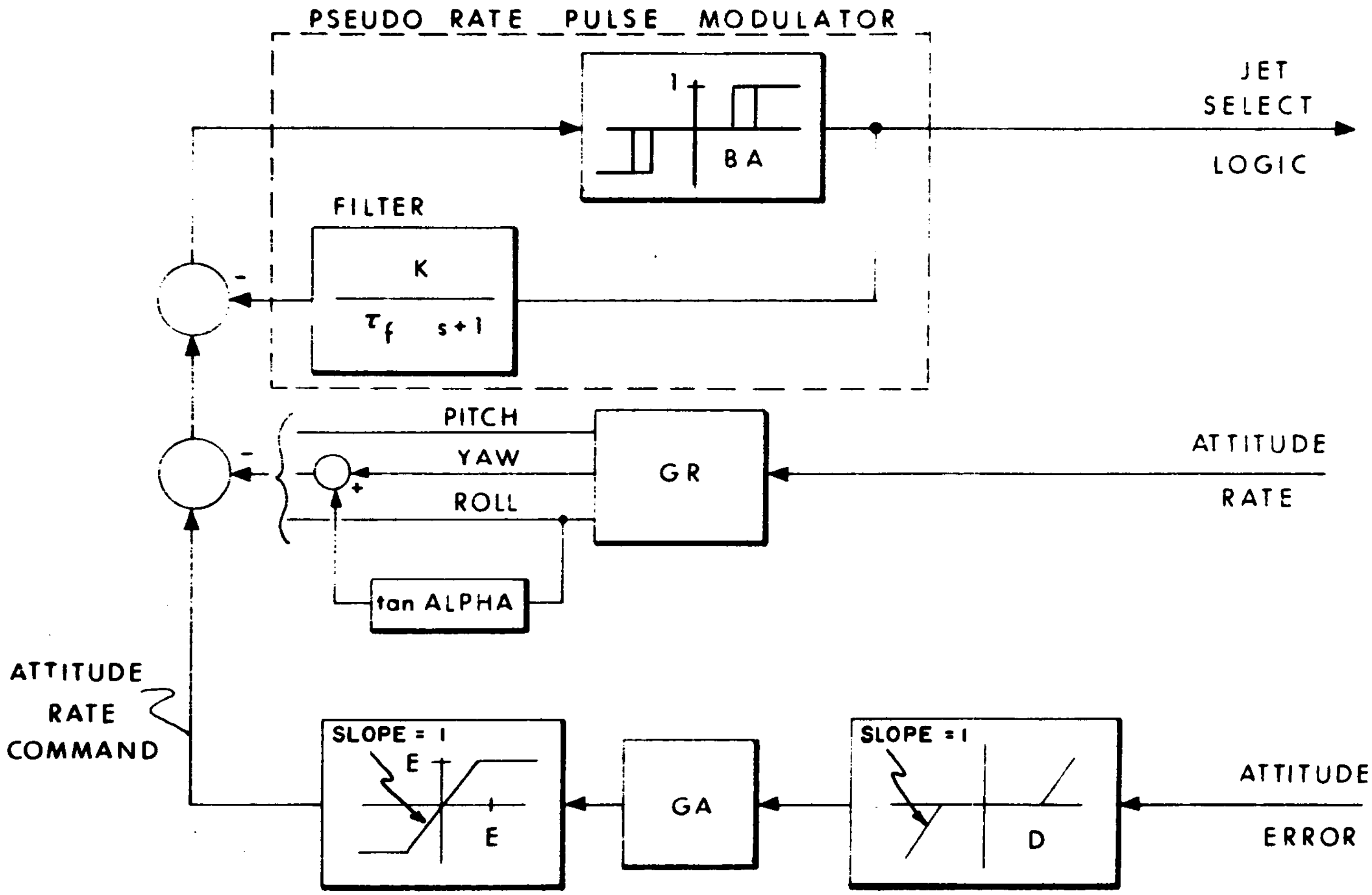

Fig. 6.20 RCS Autopilot Block Diagram.

6.4.5 RCS Reaction Jet Data

Item	Units	Value SM	Value CM
Configuration			
Nominal vacuum thrust	lb	See Table 6.5	See Table 6.4
Specific impulse (steady)	sec	See Table 6.5	See Table 6.4
Minimum impulse	lb-sec	See Table 6.5	See Table 6.4
Thrust rise lag	millisec	< 12.5	< 13.0
Thrust rise time constant	millisec	2.0 (exp)	2.0 (linear)
Duration, minimum impulse electrical signal	millisec	18.0 ± 4.0	18.0 ± 4.0
Engine cant angle	deg	10.0	

Table 6.4. Command Module Reaction Control System Performance Summary

	Vacuum Specific Impulse I_{sp} (sec)	Vacuum Thrust Per Engine F (lb)	Vacuum Propellant Flow Rate Per Engine $\dot{\omega}$ (lb/sec)	Nozzle Expansion Ratio $\epsilon = A_e/A_t$
CM/RCS (steady state)	274 ± 9.9 (3σ)	93.3 ± 3.45 (3σ)	0.341	9.0/1

NOTE: The CM/RCS minimum impulse is 1.5 ± .5 (3σ) lb-sec per engine. CM/RCS propellant capacity is 270 pounds of which 225 pounds are available for maneuvering and performance reserves.

M/R tolerances, loading tolerances, residual and trapped fuel are accounted for in the unusable propellant.

[redacted]

Table 6.5 Apollo CSM Reaction Control System Performance Summary

	Vacuum Specific Impulse I_{sp} (sec)	Vacuum Thrust Per Engine F (lb)	Vacuum Propellant Flow Rate Per Engine $\dot{\omega}$ (lb/sec)	Nozzle Expansion Ratio $\epsilon = A_e/A_t$
SM/RCS (steady state)*	$280 {+10 \atop -4} (3\sigma)$	$100 \pm 2.5 (3\sigma)$	0.357	40.0/1
SM/RCS (steady state) **	$275 \pm 7 (3\sigma)$	$100 \pm 2.5 (3\sigma)$	0.364	40.0/1

* Data applicable for burns $\leqq 5$ sec.

** Data applicable for burns > 5 sec.

The minimum impulse provided by the SM/RCS is $0.75 \pm 0.15 (3\sigma)$ lb-sec per engine.

The SM/RCS propellant capacity is 838 pounds of which 790 pounds are availavle for maneuvering and performance reserves. M/R tolerances, loading tolerances, residual and trapped fuel are accounted for in the unusable propellant.

[redacted]

6.4.6 CM Data

Control Weight	11,000 lb	
Principal inertia (I_{xx})	4949.9 slug-ft^2	
Principal inertia (I_{yy})	4364.8 slug-ft^2	
Principal inertia (I_{zz})	4057.6 slug-ft^2	
Product of inertias (I_{xy})	15.2 slug-ft^2	From Table 6.2
Product of inertias (I_{yz})	30.5 slug-ft^2	
Product of inertias (I_{xz})	278.7 slug-ft^2	
CG X-location	1043.3 inch	
CG Y-location	-0.2 inch	
CG Z-location	6.3 inches	
Aerodynamic reference area	129.35 square feet	
Aerodynamic reference diameter	154.0 inches	
Aerodynamic coefficients	see: Table 6.6	
Variation of coefficients with Mach number	see: Fig. 6.21 and 6.22	

Table 6.6. Apollo Command Module Aerodynamic Coefficients at Trim Angle of Attack Versus Mach Number for the Command Module with Protuberances

Mach Number	α*Trim (deg)	$C_{L_{Trim}}$ (deg)	$C_{D_{Trim}}$ (deg)	L/D_{Trim} (deg)
0.4	168.14	0.2435	0.8642	0.2817
0.7	165.78	0.2149	0.9501	0.2262
0.9	161.45	0.3076	1.0485	0.2933
1.1	156.47	0.4530	1.1885	0.3812
1.2	155.05	0.4924	1.2156	0.4051
1.35	154.27	0.5395	1.2820	0.4208
1.65	153.66	0.5410	1.2791	0.4230
2.0	153.38	0.5248	1.2748	0.4117
2.4	153.97	0.4993	1.2355	0.4041
3.0	155.04	0.4871	1.2117	0.4020
5.0	157.24	0.4269	1.2280	0.3477
25.0	157.24	0.4269	1.2280	0.3477

*Measured from + X-axis

NOTES: (1) Coefficients are for a moment center located at:

$$X_{cg} = 1,043.3 \text{ in.}; \; Y_{cg} = -0.2 \text{ in.}; \; Z_{cg} = 6.3 \text{ in.}$$

(2) Heat shield cant = 0.465 degree

(3) Coefficient accuracies are:

$$L/D_{Trim} = \pm 0.03; \; C_{L_{Trim}} = \pm 0.025; \; C_{D_{Trim}} = \pm 0.04$$

where: C_L is normal to the air velocity vector, positive in the upward direction and C_D is tangent to and directed opposite to the air velocity vector.

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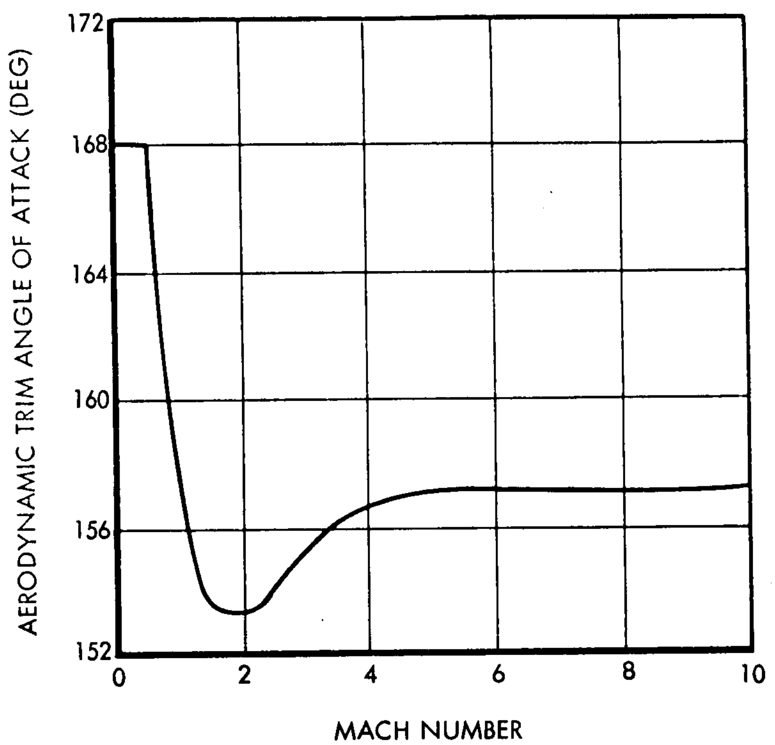

Figure 6.21 Command Module Aerodynamic Trim Angle of Attack

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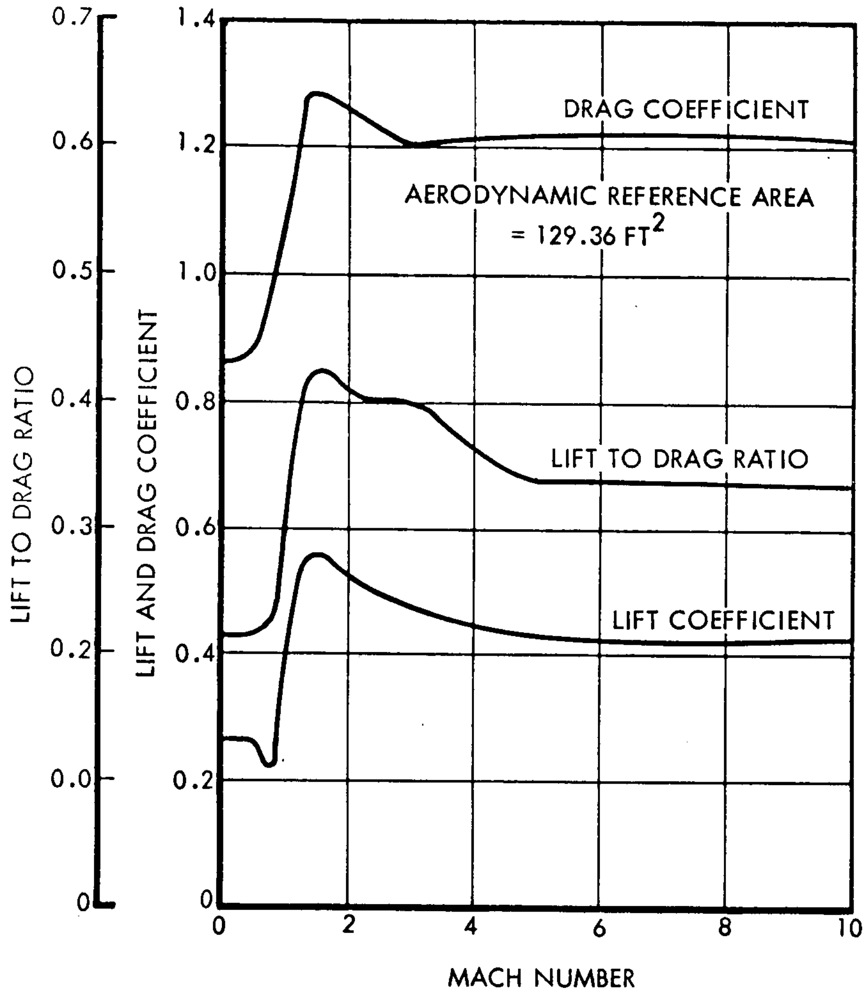


Figure 6.22 Command Module Aerodynamic Trim Lift and Drag Coefficients

6.5 Physical constants

6.5.1 Geophysical constants

	Symbol	Value
Earth's gravitation constant	MUE	$3.986\ 032\ 233 \times 10^{14}$ meters^3/sec^2
Gravity potential harmonic coeff.	J	1.62345×10^{-3}
	H	-0.575×10^{-5}
	D	0.7875×10^{-5}
Earth's mean equatorial radius	RE	$6.378\ 165 \times 10^6$ meters
Earth's sidereal rate	WIE	$7.292\ 115\ 05 \times 10^{-5}$ radians/sec
Reference ellipsoid		Fischer, 1960

6.5.2 Conversion Factors

	Multiply by
International feet to meters	0.304 8
Pounds to newtons	4.448 221 530
Slugs to kilograms	14.593 902 680
Nautical miles to kilometers	1.852
Statute miles to kilometers	1.609 344 000
Slugs to pounds (g)	32.174 048 000 ft/s/s

[redacted]

7. G & N ERROR ANALYSIS

7.1 Introduction

The results of a revised G & N error study for the 501 mission are presented herein. Primarily, this study considered the effects of IMU component uncertainties on actual trajectory uncertainties for three cases. These are:

a) Navigational update 20 minutes before injection burn ignition (2nd S IV B burn). Referred to as update 1A in tables.

b) Navigational update 5 minutes before injection burn ignition. Referred to as update 1B in tables.

c) Navigational update 20 minutes before 2nd SPS burn ignition (30 minutes before spacecraft reaches 400,000 - ft altitude on the coast ellipse). Referred to as update 2 in tables.

Simulation of the state vector or navigational R, V updates included the effects of tracking uncertainties. Updating does not apply to the IMU Stable Member alignment, since the SM is not realigned during the 501 flight.

The no-updating case was not considered in this error study, although it had been covered in the preliminary report issued in January 1966. Further, the conditions attending the first two cases above differ somewhat from those for the preliminary report. These conditions are described in some detail in section 7.3.

This study did not consider the effects of Saturn guidance errors or of boost trajectory perturbations on errors at SIVB cutoff.

The error studies assumed a prelaunch Stable Member orientation as shown in Fig. 7.1. That is, X_{SM} is up along the local vertical at launch instant, while Z_{SM} is horizontal down-range at the nominal azimuth. This orientation is different from that assumed for the preliminary error study, where X_{SM} was horizontal down-range and Z_{SM} was vertical down at launch instant.

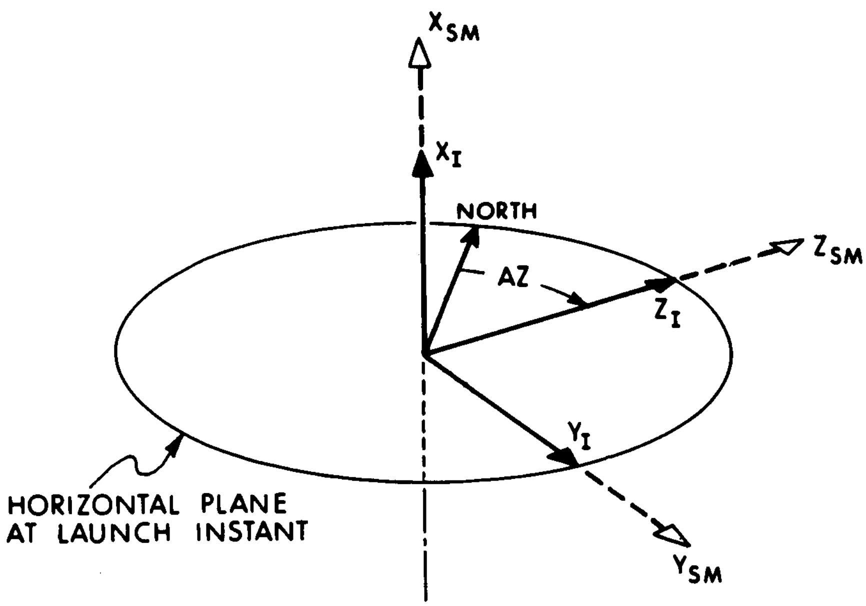
Block 1 IMU uncertainties were assumed for these studies. These were the same as those assumed for the preliminary study with two important exceptions, an accelerometer bias uncertainty of 0.4 cm/sec^2 and an accelerometer scale factor uncertainty of 150 PPM were used for the present report, whereas the smaller uncertainties of 0.2 cm/sec^2 and 100 PPM, respectively, had been used in the earlier report.

7.2 Significant Results of Error Study

The most important data required from the studies were the effects of IMU uncertainties for the three update cases on:

1) Computed free-fall time of flight to 400,000-foot altitude,

[redacted]



X_I, Y_I, Z_I - LAUNCH INERTIAL AXES

X_{SM}, Y_{SM}, Z_{SM} - IMU STABLE MEMBER AXES

Note: NOMINAL AZIMUTH IS 72°.

Fig. 7.1 Coordinate Axes for 501 Launch Configuration

2) Flight path angle uncertainty at reentry start (400,000-foot altitude),

3) CEP at reentry end.

Table 7.1 gives these data in summary form. All uncertainties are due to the combined effect of 1 σ Block I IMU uncertainties and 1 σ tracking update uncertainties.

TABLE 7.1

SUMMARY

Uncertainty Variable	Event	Update Timing: 20 mins before Injection Ignition (Upd. 1A)	5 mins before Injection Ignition (Upd. 1B)	20 mins before 2nd SPS Ignition (Upd. 2)
Uncertainty in computed Free-fall Time of Flight to 400,000-ft altitude	Injection burn cutoff	131 sec	98 sec	-----
	1st SPS burn cutoff	178 sec	168 sec	-----
	20 mins before 2nd SPS burn ignition	183 sec	172 sec	0.15 sec
	10 mins before 2nd SPS burn ignition	188 sec	177 sec	0.17 sec
Flight Path Angle Uncertainty, (U) γ_{AA}	Reentry Start (400,000 ft. alt.)	(32.6 mr)	49.8 mr	2.1 mr
CEP	Reentry End (25,000 ft. alt.)	444 nm	405 nm	7.7 nm

The reader should see Section 7.7 (and Fig. 7.2) on the definition used for flight path angle uncertainty. Data given here are for (U) γ_{AA}. The uncertainty figure for Update 1A case is parenthesized, since it represents an incomplete rss because the perturbed trajectory due to ACBZ has a perigee higher than the 400,000-ft altitude, making it impossible to compute (U) γ_{AA} for this particular IMU uncertainty.

7.3 Navigational Update Conditions and Uncertainties

For the preliminary error studies it had been assumed that the AGC would not receive acceleration information from the accelerometers during free-fall periods. Accelerometer bias would then have no effect on AGC inputs. However, since then the decision has been made to use AGC programming similar to that for the 202 mission. For the 202 mission the AGC was left sensitive to accelerometer outputs from SIVB cutoff to 1st SPS burn ignition. Correspondingly, for the 501 mission the AGC will now receive acceleration data from the accelerometers from 1st SIVB cut-off through the entire parking orbit and from 2nd SIVB burn (injection burn) cutoff for 30 minutes free fall to 1st SPS burn ignition. The AGC will have the accelerometer biases as inputs during those two free-fall periods.

Leaving the AGC sensitive to accelerometer bias during the extended parking orbit results in large uncertainties in position and velocity by the time of injection burn ignition. Because of this, a navigational update before injection burn ignition is now provided for.

Two updating times before injection burn ignition, one 20 minutes before and the other 5 minutes before, were used in the error studies. At update times the uncertainties in position and velocity were reduced to those represented by the tracking update uncertainties.

There will also be provision for a 2nd navigational update. This will take place 20 minutes before the 2nd SPS burn ignition (or approximately 30 minutes free-fall away from 400,000-ft altitude). This is also the important time for AGC computation of the free-fall time of flight to this altitude. Another time that free-fall time is computed is 10 minutes before 2nd SPS burn ignition. For both times, if the 2nd navigational update has been made, the computed free-fall time of flight will be affected only by tracking update uncertainties.

The navigational updates would be performed on the basis of orbit computations made using observations by the MSFN (Manned Space Flight Network). The tracking-station-computed position and velocity vectors would be subject to uncertainties because of noise and bias in tracking measurements.

In this IMU error study, simulation of tracking update uncertainties was based on data available in MSC Internal Note No. 66-FM-46, "Error Analysis of MSFN Tracking Data for AS-501" by P. T. Pixley and M. L. Alexander. Tracking uncertainty covariance matrices for times just before injection burn ignition and the 2nd SPS burn ignition were available in this report. The one-sigma position and velocity uncertainties for the three update times relative to local vertical axes were as follows:

	Position Uncertainty (in nautical miles)			Velocity Uncertainty (in ft/sec)		
	Alt.	Track	Range	Alt.	Track	Range
20 min before Inject. Burn Ignit	0.12	0.05	0.39	2.7	0.6	0.5
5 min before Inject. Burn Ignit.	0.10	0.04	0.41	2.6	0.6	0.4
20 min before 2nd SPS Ignit.	0.02	0.07	0.08	0.3	0.6	0.1

In the error tables, after updating time, the uncertainties include the effects of both navigational update and IMU uncertainties.

7.4 Error Table Description

At the end of this section error tables are given summarizing the results of these studies.

Table 7.2 summarizes the RSS flight uncertainties caused by one sigma Block I IMU component uncertainties at important times during the mission for the three update cases previously described. Abbreviations for these cases are as follows:

[redacted]

Table 7.2 Summary of 501 Flight Uncertainties

Event	Update	RSS Position Uncert. (n. miles)			RSS Velocity Uncert. (ft/sec)			Flight Path Angle Uncert. $(U)\gamma_{AI}$	Azim. Uncert. $(U)A_Z$	$(U)T_{ff}$
		Alt.	Track	Range	Alt.	Track	Range	(mr)	(mr)	(sec)
Earth Launch	None	0	0	0	0	0	0	0	2.4	----
SIVB Cutoff	None	0.95	3.51	0.40	18.8	54.3	5.8	0.73	2.1	----
20 min before Injection Ignition	1A Now	0.12	0.05	0.39	2.7	0.6	0.5	0.11	0.02	----
5 min before Injection Ignition	1B Now	0.10	0.04	0.41	2.6	0.6	0.4	0.11	0.02	----
Injection Ignition	1A 1B	1.90 0.15	1.31 0.11	1.65 0.41	25.8 4.9	11.0 3.9	14.2 3.9	0.91 0.16	0.4 0.2	---- ----
Injection Cutoff	1A 1B	3.28 0.54	1.98 0.66	3.07 0.74	41.6 15.1	29.5 28.4	26.1 17.3	1.11 0.47	1.0 0.2	131 98
SPS1 Cutoff	1A 1B	15.7 10.3	8.9 8.4	24.0 9.4	87.8 57.7	21.4 25.6	66.0 35.9	3.31 2.52	3.3 1.7	178 168
20 min before SPS2 Ignition	1A 1B 2 Now	342.1 312.8 0.02	3.8 4.1 0.07	471.0 412.0 0.08	1,429 1,270 0.34	17.6 24.3 0.56	92.8 88.5 0.13	14.8 10.2 0.002	1.1 1.5 0.03	183 172 0.15
10 min before SPS2 Ignition	1A 1B 2	358.7 329.1 0.03	4.6 4.1 0.07	579.9 514.4 0.08	2,138 1,912 0.38	15.3 24.3 0.55	96.0 89.3 0.13	30.1 22.1 0.003	0.8 1.2 0.03	188 177 0.17
SPS2 Ignition	1A 1B 2	310.5 286.8 0.04	5.1 4.7 0.10	748.4 673.0 0.09	3,485 3,136 0.51	12.5 22.0 0.45	131.6 137.9 0.12	63.6 49.4 0.006	0.5 0.9 0.02	---- ---- ----
Reentry Start (at 400,000 ft)	1A 1B 2	82.6 80.0 1.3	3.8 4.1 1.4	906.2 822.9 0.3	4,835 4,372 23	40.8 40.5 22.5	182.2 193.3 3.8	(32.6)*† 49.7* 2.1*	1.1 1.1 0.6	---- ---- CEP nm
Reentry End (at 24,000 ft)	1A 1B 2	149.3 140.0 8.4	22.1 21.2 11.0	728.6 667.2 2.1	--- --- ---	--- --- ---	--- --- ---	--- --- ---	--- --- ---	444 405 7.7

*Data given at reentry start are for $(U)\gamma_{AA}$ and not $(U)\gamma_{AI}$. See Section 7.7.

†For update 1A case the perturbed trajectory due to ACBZ has a perigee higher than 400,000-ft altitude. The figure of 32.6 mr for $(U)\gamma_{AA}$ is RSS for all other uncertainties except ACBZ.

[redacted]

Update 1A : Update 20 mins. before injection burn ignition.

Update 1B : Update 5 mins. before injection burn ignition.

Update 2 : Update 20 mins. before 2nd SPS burn ignition.

In Table 7.2 the rss uncertainty in free-fall time-of-flight to 400,000-ft altitude is also given where applicable.

Tables 7.3 through 7.9 are detailed error tables showing how the individual IMU uncertainties contribute to the overall position and velocity uncertainties for three critical times during the 501 flight. These times are: 1) SPS1 cutoff, 2) 20 minutes before 2nd SPS burn ignition, and 3) Reentry start (at 400,000-ft altitude). Separate tables are given for the various update cases.

Tables 7.10 through 7.13 are detailed error tables that show the effect of IMU uncertainties on uncertainty in computed free-fall time of flight (T_{ff}) to 400,000-ft altitude for two critical times during the 501 flight. These times are: 1) SPS1 cutoff, and 2) 20 min before 2nd SPS burn ignition. Separate tables are given for the various update cases, and for both positive and negative IMU uncertainties. In those tables "RSS" stands for RSS of T_{ff} uncertainties with positive IMU uncertainties while "RSN" stands for RSS with negative IMU uncertainties.

Tables 7.14 through 7.16 are detailed error tables showing the effect of IMU uncertainties in flight path angle uncertainty at reentry start for the three update cases. The reader should refer to Sect. 7.7 for flight path angle uncertainty definitions.

Finally, Table 7.17 gives data on IMU Stable Member misalignments and drifts throughout the flight.

7.5 IMU Errors and Uncertainties

The AGC will be able to provide compensation for the measured average values of the following IMU component errors:

1) accelerometer bias error,
2) accelerometer scale factor error,
3) gyro bias drift,
4) gyro input axis acceleration sensitive drift, and
5) gyro spin reference axis acceleration sensitive drift.

Since the average IMU errors will be compensated by means of AGC programs during prelaunch and in flight, it is the actual unpredictable deviations from the measured average errors that constitute the IMU component uncertainties.

The Block I IMU error uncertainties (see also MEI No. 1015000-Part I) for the present error studies are as follows:

[redacted]

Block I One-Sigma IMU Error Uncertainties

	Input Axis			
	X	Y	Z	Units
Accelerometer bias (ACB)	0.40	0.40	0.40	cm/sec^2
Accelerometer scale factor (SFE)	150	150	150	PPM
Accelerometer nonlinearity (NC)	10	10	10	$\mu g/g^2$
Gyro bias drift (BD)	2	2	2	meru
Gyro input axis accel. sens. drift (ADIA)	8	8	8	meru/g
Gyro spin axis accel. sens. drift (ADSRA)	5	5	5	meru/g
Gyro acceleration squared sens. drift	0.3	0.3	0.3	$meru/g^2$
Accelerometer I. A. misalignments				
Non-orthogonality X to Z	0.14	-	-	mr
Non-orthogonality X to Y	0.14	-	-	mr
Y about X_{SM}	-	0.10	-	mr
Gyro I. A. misalignment				
About SRA	0.50	0.50	0.50	mr
About OA	0.50	0.50	0.50	mr

It is important to note that some IMU uncertainties affect both the pre-launch alignment of the Stable Member and the in-flight computation of position and velocity. These include: accelerometer bias, gyro bias drift, and IA and SRA acceleration sensitive drift. Since pre-launch and in-flight IMU uncertainties are assumed correlated, their effects are summed in the error computation.

The Stable Member azimuth alignment uncertainty is affected primarily by the effect of Z and Y gyro drift rate uncertainty on the gyro-compassing loop during pre-launch alignment. Table 7.14 shows that the overall rss azimuth alignment uncertainty due to all gyro drift uncertainties is 2.35 milliradians.

7.6 Stable Member Orientation

The orientation of the IMU Stable Member axes (X_{SM}, Y_{SM}, Z_{SM}) relative to launch inertial axes (X_I, Y_I, Z_I) are shown in Fig. 7.1. The X, Y, Z accelerometer and gyro input axes are colinear with corresponding Stable Member axes. The launch inertial axis Z_I, is in the horizontal plane of launch instant and oriented at the nominal launch azimuth of 72^o from north. The X_I - Z_I plane will be the initial pitch plane as well as initial reference trajectory plane.

The Stable Member is not realigned during flight. Note that the SM orientation shown in Fig. 7.1 is different from that assumed for the preliminary error studies where X_{SM} was aligned parallel to Z_I and Z_{SM} was parallel to $-X_I$.

[redacted]

7.7 Flight Path Angle and Altitude Rate Uncertainty Definitions

Fig. 7.2 defines the three flight path angle uncertainties, (U) γ_{AI}, (U) γ_{AIN} and (U) γ_{AA}. Data for (U) γ_{AA} are given only for reentry start (at 400,000-ft altitude) in the summary tables, 7.1 and 7.2, since the flight path angle uncertainty with the spacecraft actually at 400,000-ft altitude is the desired parameter. For all other times during the 501, flight data are given for (U) γ_{AI}.

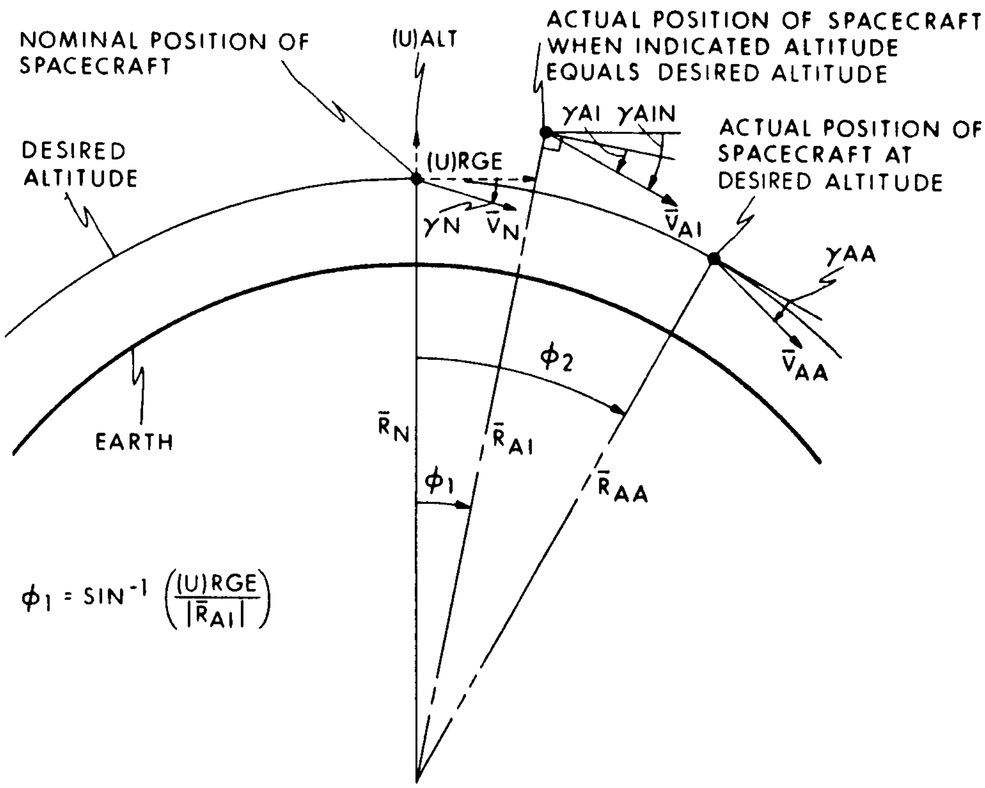
As the range angle uncertainty, (U) Rge/R, increases (as it will for prolonged, non-updated orbital missions, since (U) Rge is unbounded), the uncertainty, (U) γ_{AIN}, will increase correspondingly, since γ_{AIN} is measured relative to the nominal horizontal axis. The uncertainty, (U) γ_{AI}, is the more useful figure. In the previous report data had, however, been given only for (U) γ_{AIN}. In this report data are given for (U) γ_{AI}, with the exception of reentry start where the data are for (U) γ_{AA}.

Data in all error tables for RSS position and velocity uncertainties are given relative to nominal local vertical axes (see Fig. 7.2). These data may be used to compute (U) γ_{AIN}. Unless appropriate transformations are made, (U) γ_{AI} can not be computed from the above data.

7.8 Error Computation Procedure

Position and velocity uncertainties given in the tables were computed as follows. Approximate error equations were derived for the effect of each IMU component error on trajectory position and velocity. The 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 error equations took into account the effect of the IMU errors on gravity vector computation. The computations program incorporating the error equations require nominal trajectory acceleration and position vectors (relative to fixed inertial axes) as inputs at discrete time intervals. The nominal trajectory itself was generated in a separate program. At significant events, such as SIVB cutoff, detailed error printouts were made giving the position and velocity uncertainties due to each IMU uncertainty relative to nominal local vertical axes.

The uncertainties in computed free-fall time of flight were calculated by perturbing the equation for T_{ff} (see IL-SFA Memo No. 28-65 by R. Bairnsfather) with the position and velocity uncertainties due to each IMU component uncertainty.



Flight Path Angle and Velocity Uncertainty Equations

$(U)\gamma_{AIN} = \gamma_{AIN} - \gamma_N$

$(U)\gamma_{AI} = \gamma_{AI} - \gamma_N$ $\qquad$ $(U)V_{AI} = V_{AI} - V_N$

$(U)\gamma_{AA} = \gamma_{AA} - \gamma_N$ $\qquad$ $(U)V_{AA} = V_{AA} - V_N$

Altitude Rate Uncertainty Equations

$(U)\dot{Alt}_{AIN} = V_{AI} \sin\gamma_{AIN} - V_N \sin\gamma_N \cong (\bar{V}_{AI} - \bar{V}_N) \cdot \bar{R}_N / R_N$

$(U)\dot{Alt}_{AI} = V_{AI} \sin\gamma_{AI} - V_N \sin\gamma_N$

$(U)\dot{Alt}_{AA} = V_{AA} \sin\gamma_{AA} - V_N \sin\gamma_N$

Note that γ_{AIN} is measured with respect to the same nominal horizontal axis as γ_N, while γ_{AI} and γ_{AA} are measured with respect to their particular local horizontal axes.

Fig. 7-2 Flight Path Angles

Table 7.3 RMS Uncertainties at 1st SPS Burn Cutoff (Update 1A)

POSITION AND VELOCITY UNCERTAINTIES ALONG LOCAL VERTICAL AXES AT TIME FROM LCH.= 3 HR.48 MIN.47.280 SEC (13727.281 SEC)

UNCERT. SOURCE	ONE SIGMA UNCERTAINTY	POSITION UNCERTAINTIES IN FEET (REL. TO NOM. AXES) ALT.	TRACK	RANGE	VELOCITY UNCERTAINTIES IN FT/SEC (REL. TO NOM. AXES) ALT.	TRACK	RANGE
INITIAL S.M. MLMS. (UNCORREL.) ABOUT LAUNCH INERTIAL AXES							
XI	0.500 MR	-3738.3	-6183.0	4287.0	-3.302	-1.475	1.999
YI	0.060 MR	-770.9	-76.8	-379.8	-0.475	-0.015	-0.044
ZI	0.060 MR	-298.6	-19.1	-229.1	-0.184	-0.048	-0.041
ACCEL.INPUT AXIS MLMS.							
MXTOY	0.141 MR	-688.8	-80.8	-546.4	-0.433	-0.021	-0.106
MXTOZ	0.141 MR	-1537.3	-179.3	-1196.9	-0.925	-0.042	-0.190
MYABTX	0.100 MR	235.4	-1206.2	-18.8	0.169	-0.286	-0.037
ACCEL.BIAS							
ACBXINIT		0.0	0.0	0.0	0.000	0.000	0.000
ACBXFLGT	0.400 CM/S.SQ	8217.6	5162.1	93968.9	-3.270	1.842	33.854
ACBXCOMB		8217.6	5162.1	93968.9	-3.270	1.842	33.854
ACBYINIT		-2030.1	-130.4	-1557.6	-1.254	-0.331	-0.282
ACBYFLGT	0.400 CM/S.SQ	7041.7	-36881.9	-19.5	5.985	-18.295	-0.714
ACBYCOMB		5011.5	-37012.3	-1577.1	4.730	-18.626	-0.996
ACBZINIT		5241.3	522.4	2582.0	3.230	0.107	0.302
ACBZFLGT	0.400 CM/S.SQ	-91109.6	-1650.5	106174.1	-85.449	-0.958	55.191
ACBZCOMB		-85868.3	-1128.1	108756.2	-82.218	-0.850	55.493
ACCEL.SCALE FACTOR							
SFEX	150 PPM	-8.8	4.1	110.5	-0.093	-0.010	-0.033
SFEZ	150 PPM	-3239.0	-101.2	2875.5	-2.689	-0.024	1.390
ACCEL.SQ.IND.UNCERT.							
NCXX	10 MG/GSQ	29.1	3.4	23.5	0.019	0.001	0.005
NCZZ	10 MG/GSQ	-188.4	-6.0	165.8	-0.159	-0.001	0.084
GYRO BIAS DRIFT							
BDXINIT		-1090.4	-1803.5	1250.4	-0.963	-0.430	0.583
BDXFLGT	2.0 MERU	-12758.0	-21141.3	14632.8	-11.290	-4.929	6.826
BDXCOMB		-13848.4	-22945.3	15883.3	-12.254	-5.359	7.409
BDYINIT		-5257.2	-8695.3	6028.9	-4.645	-2.074	2.811
BDYFLGT	2.0 MERU	-21784.8	-2184.2	-10985.5	-13.226	-0.432	-1.354
BDYCOMB		-27042.1	-10879.5	-4956.5	-17.871	-2.506	1.457
BDZINIT		-16180.2	-26761.5	18555.3	-14.295	-6.385	8.654
BDZFLGT	2.0 MERU	-8488.4	-646.8	-6521.0	-5.236	-1.528	-1.185
BDZCOMB		-24668.6	-27408.5	12034.3	-19.532	-7.913	7.468
GYRO ACC.SENS.DRIFT							
ADIAXCOMB	8.0 MERU/G	-5953.7	-9882.2	6831.8	-5.259	-2.370	3.186
ADSAYCOMB	5.0 MERU/G	3890.5	414.2	2439.3	2.296	0.083	0.423
ADIAZCOMB	8.0 MERU/G	-2579.6	-503.3	-2007.7	-1.594	-0.546	-0.377
RSS UNCERT.(FT AND FT/SEC)		95305.3	54152.5	145491.5	87.744	21.376	55.999
RSS UNCERT.(N.MI.AND FT/SEC)		15.685	8.912	23.944	87.744	21.376	55.999
RSS UNCERT.(N.MI.AND FT/SEC) (INCL.TKG.UPDATE UNCERT.)		15.687	8.913	23.963	87.801	21.377	56.011

Table 7.4 RMS Uncertainties at 1st SPS Burn Cutoff (Update 1B)

POSITION AND VELOCITY UNCERTAINTIES ALONG LOCAL VERTICAL AXES AT TIME FROM LCH.= 3 HR.48 MIN.47.280 SEC (13727.281 SEC)

UNCERT. SOURCE	ONE SIGMA UNCERTAINTY	POSITION UNCERTAINTIES IN FEET (REL. TO NOM. AXES) ALT.	TRACK	RANGE	VELOCITY UNCERTAINTIES IN FT/SEC (REL. TO NOM. AXES) ALT.	TRACK	RANGE
INITIAL S.M. MLMS. (UNCORREL.) ABOUT LAUNCH INERTIAL AXES							
XI	0.500 MR	-3738.3	-6183.0	4287.0	-3.302	-1.475	1.999
YI	0.060 MR	-770.9	-76.8	-379.8	-0.475	-0.015	-0.044
ZI	0.060 MR	-298.6	-19.1	-229.1	-0.184	-0.048	-0.041
ACCEL.INPUT AXIS MLMS.							
MXTOY	0.141 MR	-688.8	-80.8	-546.4	-0.433	-0.021	-0.106
MXTOZ	0.141 MR	-1537.3	-179.3	-1196.9	-0.925	-0.042	-0.190
MYABTX	0.100 MR	235.4	-1206.2	-18.8	0.169	-0.286	-0.037
ACCEL.BIAS							
ACBXINIT		0.0	0.0	0.0	0.000	0.000	0.000
ACBXFLGT	0.400 CM/S.SQ	26436.6	3397.9	24640.3	25.278	2.420	15.273
ACBXCOMB		26436.6	3397.9	24640.3	25.278	2.420	15.273
ACBYINIT		-2030.1	-130.4	-1557.6	-1.254	-0.331	-0.282
ACBYFLGT	0.400 CM/S.SQ	5353.9	-32114.8	99.9	5.221	-23.000	-0.107
ACBYCOMB		3323.7	-32245.2	-1457.7	3.966	-23.331	-0.390
ACBZINIT		5241.3	522.4	2582.0	3.230	0.107	0.302
ACBZFLGT	0.400 CM/S.SQ	-45440.4	-1779.1	43196.3	-45.211	-1.285	30.088
ACBZCOMB		-40199.1	-1256.6	45778.4	-41.980	-1.177	30.390
ACCEL.SCALE FACTOR							
SFEX	150 PPM	-8.8	4.1	110.5	-0.093	-0.010	-0.033
SFEZ	150 PPM	-3239.0	-101.2	2875.5	-2.689	-0.024	1.390
ACCEL.SQ.IND.UNCERT.							
NCXX	10 MG/GSQ	29.1	3.4	23.5	0.019	0.001	0.005
NCZZ	10 MG/GSQ	-188.4	-6.0	165.8	-0.159	-0.001	0.084
GYRO BIAS DRIFT							
BDXINIT		-1090.4	-1803.5	1250.4	-0.963	-0.430	0.583
BDXFLGT	2.0 MERU	-12758.0	-21141.8	14632.8	-11.290	-4.929	6.826
BDXCOMB		-13848.4	-22945.3	15883.3	-12.254	-5.359	7.409
BDYINIT		-5257.2	-8695.3	6028.9	-4.645	-2.074	2.811
BDYFLGT	2.0 MERU	-21784.8	-2184.2	-10985.5	-13.226	-0.432	-1.354
BDYCOMB		-27042.1	-10879.6	-4956.5	-17.871	-2.506	1.457
BDZINIT		-16180.2	-26761.6	18555.3	-14.295	-6.385	8.654
BDZFLGT	2.0 MERU	-8488.4	-646.8	-6521.0	-5.236	-1.528	-1.185
BDZCOMB		-24668.6	-27408.5	12034.3	-19.532	-7.913	7.468
GYRO ACC.SENS.DRIFT							
ADIAXCOMB	8.0 MERU/G	-5953.7	-9882.2	6831.8	-5.259	-2.370	3.186
ADSAYCOMB	5.0 MERU/G	3890.5	414.2	2439.3	2.296	0.083	0.423
ADIAZCOMB	8.0 MERU/G	-2579.6	-503.3	-2007.7	-1.594	-0.546	-0.377
RSS UNCERT.(FT AND FT/SEC)		62793.3	50868.0	56675.8	57.647	25.641	35.865
RSS UNCERT.(N.MI.AND FT/SEC)		10.334	8.371	9.327	57.647	25.641	35.865
RSS UNCERT.(N.MI.AND FT/SEC) (INCL.TKG.UPDATE UNCERT.)		10.338	8.372	9.374	57.734	25.642	35.887

Table 7.5 RMS Uncertainties at 20 mins. before 2nd SPS Ignition (Update 1A)

POSITION AND VELOCITY UNCERTAINTIES ALONG LOCAL VERTICAL AXES AT TIME FROM LCH.= 7 HR,28 MIN,27.800 SEC (26907.802 SEC)

UNCERT. SOURCE	ONE SIGMA UNCERTAINTY	POSITION UNCERTAINTIES IN FEET (REL. TO NOM. AXES) ALT.	TRACK	RANGE	VELOCITY UNCERTAINTIES IN FT/SEC (REL. TO NOM. AXES) ALT.	TRACK	RANGE
INITIAL S.M. MLMS. (UNCORREL.) ABOUT LAUNCH INERTIAL AXES							
XI	0.500 MR	-66311.3	3797.3	96179.5	-47.521	0.691	0.365
YI	0.060 MR	-24129.8	52.0	31380.8	-15.982	0.005	1.020
ZI	0.060 MR	-10186.4	-75.4	13185.7	-6.718	0.058	0.451
ACCEL.INPUT AXIS MLMS.							
MXTOY	0.141 MR	-24015.8	44.3	31046.9	-15.824	0.012	1.073
MXTOZ	0.141 MR	-51125.9	110.4	66361.8	-33.767	0.019	2.232
MYABTX	0.100 MR	6221.5	742.7	-8338.3	4.207	0.133	-0.204
ACCEL.BIAS							
ACBXINIT		0.0	0.0	0.0	0.000	0.000	0.000
ACBXFLGT	0.400 CM/S.SQ	1180201.1	-1962.6	-1393058.3	729.635	-1.352	-85.411
ACBXCOMB		1180201.1	-1962.6	-1393058.3	729.635	-1.352	-85.411
ACBYINIT		-69248.6	-513.1	89638.0	-45.670	0.395	3.067
ACBYFLGT	0.400 CM/S.SQ	221805.4	3891.5	-294890.0	149.114	16.168	-7.928
ACBYCOMB		152556.7	3378.4	-205252.0	103.444	16.563	-4.860
ACBZINIT		164037.5	-354.1	-213330.6	108.649	-0.037	-6.938
ACBZFLGT	0.400 CM/S.SQ	-1529312.5	-102.4	2292704.6	-1117.999	0.901	-6.023
ACBZCOMB		-1365275.0	-456.5	2079374.0	-1009.350	0.864	-12.961
ACCEL.SCALE FACTOR							
SFEX	150 PPM	-3341.6	-24.8	4021.9	-2.132	0.013	0.195
SFEZ	150 PPM	-64781.1	62.3	91101.4	-45.423	0.011	1.032
ACCEL.SQ.IND.UNCERT.							
NCXX	10 MG/GSQ	1066.1	-1.6	-1372.7	0.700	-0.000	-0.048
NCZZ	10 MG/GSQ	-3737.0	3.0	5299.3	-2.632	0.001	0.051
GYRO BIAS DRIFT							
BDXINIT		-19342.0	1107.6	28054.0	-13.861	0.201	0.106
BDXFLGT	2.0 MERU	-226660.9	13212.4	328753.2	-162.430	2.216	1.254
BDXCOMB		-246003.0	14320.1	356807.2	-176.291	2.417	1.360
BDYINIT		-93255.3	5340.3	135259.6	-66.831	0.971	0.514
BDYFLGT	2.0 MERU	-680214.9	1517.6	883858.9	-450.299	0.130	28.923
BDYCOMB		-773470.3	6858.0	1019118.5	-517.130	1.102	29.437
BDZINIT		-287010.4	16435.9	416286.3	-205.685	2.990	1.582
BDZFLGT	2.0 MERU	-289526.2	-2316.9	374724.6	-190.930	1.815	12.834
BDZCOMB		-576536.7	14118.9	791011.0	-396.615	4.806	14.417
GYRO ACC.SENS.DRIFT							
ADIAXCOMB	8.0 MERU/G	-105531.9	6044.9	153082.4	-75.635	1.120	0.577
ADSAYCOMB	5.0 MERU/G	125986.0	-284.7	-162881.3	83.107	-0.026	-5.556
ADIAZCOMB	8.0 MERU/G	-88625.1	-533.3	114616.3	-58.416	0.597	3.947
RSS UNCERT.(FT AND FT/SEC)		2078193.7	22762.8	2861077.4	1428.226	17.584	92.838
RSS UNCERT.(N.MI.AND FT/SEC)		342.026	3.749	470.872	1428.226	17.584	92.838
RSS UNCERT.(N.MI.AND FT/SEC) (INCL.TKG.UPDATE UNCERT.)		342.149	3.750	471.040	1428.751	17.585	92.844

[redacted]

Table 7.6 RMS Uncertainties at 20 mins. before 2nd SPS Ignition (Update 1B)

POSITION AND VELOCITY UNCERTAINTIES ALONG LOCAL VERTICAL AXES AT TIME FROM LCH.= 7 HR.28 MIN.27.800 SEC (26907.802 SEC)

UNCERT. SOURCE	ONE SIGMA UNCERTAINTY	POSITION UNCERTAINTIES IN FEET (REL. TO NOM. AXES) ALT.	TRACK	RANGE	VELOCITY UNCERTAINTIES IN FT/SEC (REL. TO NOM. AXES) ALT.	TRACK	RANGE
INITIAL S.M. MLMS. (UNCORREL.) ABOUT LAUNCH INERTIAL AXES							
XI	0.500 MR	-66311.3	3797.3	96179.5	-47.521	0.691	0.365
YI	0.060 MR	-24129.8	52.0	31380.8	-15.982	0.005	1.020
ZI	0.060 MR	-10186.4	-75.4	13185.7	-6.718	0.058	0.451
ACCEL.INPUT AXIS MLMS.							
MXTOY	0.141 MR	-24015.8	44.3	31046.9	-15.824	0.012	1.073
MXTOZ	0.141 MR	-51125.9	110.4	66361.8	-33.767	0.019	2.232
MYABTX	0.100 MR	6221.5	742.7	-8338.3	4.207	0.133	-0.204
ACCEL.BIAS							
ACBXINIT		0.0	0.0	0.0	0.000	0.000	0.000
ACBXFLGT	0.400 CM/S.SQ	1486509.3	1093.3	-1852416.1	959.611	-2.421	-79.816
ACBXCOMB		1486509.3	1093.3	-1852416.1	959.611	-2.421	-79.816
ACBYINIT		-69248.6	-513.1	89638.0	-45.670	0.395	3.067
ACBYFLGT	0.400 CM/S.SQ	198583.5	-10579.6	-260851.8	132.500	23.048	-7.783
ACBYCOMB		129334.8	-11092.7	-171213.8	86.830	23.443	-4.715
ACBZINIT		164037.5	-354.1	-213330.6	108.649	-0.037	-6.938
ACBZFLGT	0.400 CM/S.SQ	-751233.7	-608.8	1172638.4	-560.914	1.291	-10.446
ACBZCOMB		-587196.1	-962.9	959307.7	-452.265	1.254	-17.384
ACCEL.SCALE FACTOR							
SFEX	150 PPM	-3341.6	-24.8	4021.9	-2.132	0.013	0.195
SFEZ	150 PPM	-64781.1	62.3	91101.4	-45.423	0.011	1.032
ACCEL.SQ.IND.UNCERT.							
NCXX	10 MG/GSQ	1066.1	-1.6	-1372.7	0.700	-0.000	-0.048
NCZZ	10 MG/GSQ	-3737.0	3.0	5299.3	-2.632	0.001	0.051
GYRO BIAS DRIFT							
BDXINIT		-19342.0	1107.6	28054.0	-13.861	0.201	0.106
BDXFLGT	2.0 MERU	-226660.9	13212.4	328753.2	-162.430	2.216	1.254
BDXCOMB		-246003.0	14320.1	356807.2	-176.291	2.417	1.360
BDYINIT		-93255.3	5340.3	135259.6	-66.831	0.971	0.514
BDYFLGT	2.0 MERU	-680214.9	1517.6	883858.9	-450.299	0.130	28.923
BDYCOMB		-773470.3	6858.0	1019118.5	-517.130	1.102	29.437
BDZINIT		-287010.4	16435.9	416286.3	-205.685	2.990	1.582
BDZFLGT	2.0 MERU	-289526.2	-2316.9	374724.6	-190.930	1.815	12.834
BDZCOMB		-576536.7	14118.9	791011.0	-396.615	4.806	14.417
GYRO ACC.SENS.DRIFT							
ADIAXCOMB	8.0 MERU/G	-105531.9	6044.9	153082.4	-75.635	1.120	0.577
ADSAYCOMB	5.0 MERU/G	125986.0	-284.7	-162881.3	83.107	-0.026	-5.556
ADIAZCOMB	8.0 MERU/G	-88625.1	-533.3	114616.3	-58.416	0.597	3.947
RSS UNCERT.(FT AND FT/SEC)		1900000.5	25075.0	2502051.0	1269.216	24.276	88.472
RSS UNCERT.(N.MI.AND FT/SEC)		312.699	4.126	411.784	1269.216	24.276	88.472
RSS UNCERT.(N.MI.AND FT/SEC) (INCL.TKG.UPDATE UNCERT.)		312.833	4.127	411.976	1269.808	24.276	88.478

[redacted]

Table 7.7 RMS Uncertainties at Reentry Start (Update 1A)

POSITION AND VELOCITY UNCERTAINTIES ALONG LOCAL VERTICAL AXES AT TIME FROM LCH.= 7 HR,57 MIN, 2.670 SEC (28622.672 SEC)

UNCERT. SOURCE	ONE SIGMA UNCERTAINTY	POSITION UNCERTAINTIES IN FEET (REL. TO NOM. AXES) ALT.	TRACK	RANGE	VELOCITY UNCERTAINTIES IN FT/SEC (REL. TO NOM. AXES) ALT.	TRACK	RANGE
INITIAL S.M. MLMS. (UNCORREL.) ABOUT LAUNCH INERTIAL AXES							
XI	0.500 MR	-15470.2	1658.2	178124.6	-158.176	-5.291	4.657
YI	0.060 MR	-6090.5	-18.5	63332.9	-55.113	-0.080	2.395
ZI	0.060 MR	-2605.5	20.0	26691.0	-23.326	0.046	1.004
ACCEL.INPUT AXIS MLMS.							
MXTOY	0.141 MR	-6150.3	-3.9	62912.4	-54.974	-0.051	2.375
MXTOZ	0.141 MR	-12781.8	-31.3	134015.0	-116.429	-0.178	5.004
MYABTX	0.100 MR	1530.5	350.4	-16414.8	14.360	-1.033	-0.540
ACCEL.BIAS							
ACBXINIT		0.0	0.0	0.0	0.000	0.000	0.000
ACBXFLGT	0.400 CM/S.SQ	323683.2	-622.3	-3036720.1	2626.046	2.481	-141.265
ACBXCOMB		323683.2	-622.3	-3036720.1	2626.046	2.481	-141.265
ACBYINIT		-17713.0	136.2	181449.1	-158.578	0.316	6.826
ACBYFLGT	0.400 CM/S.SQ	55392.6	21431.7	-584342.8	512.190	-6.847	-20.227
ACBYCOMB		37679.5	21568.0	-402893.6	353.612	-6.530	-13.401
ACBZINIT		41404.2	125.9	-430544.9	374.665	0.548	-16.287
ACBZFLGT	0.400 CM/S.SQ	-330158.7	-1486.2	4126063.5	-3662.898	-0.972	82.182
ACBZCOMB		-288754.5	-1360.3	3695518.5	-3288.233	-0.423	65.894
ACCEL.SCALE FACTOR							
SFEX	150 PPM	-986.6	0.2	8721.0	-7.614	0.016	0.451
SFEZ	150 PPM	-15542.9	-77.0	172662.0	-152.666	-0.120	4.498
ACCEL.SQ.IND.UNCERT.							
NCXX	10 MG/GSQ	275.5	0.0	-2791.5	2.441	0.001	-0.107
NCZZ	10 MG/GSQ	-881.4	-3.7	9975.6	-8.820	-0.005	0.258
GYRO BIAS DRIFT							
BDXINIT		-4512.4	483.6	51956.2	-46.137	-1.543	1.358
BDXFLGT	2.0 MERU	-53327.6	1446.7	608772.5	-542.041	-28.893	15.764
BDXCOMB		-57840.0	1930.4	660728.7	-588.178	-30.437	17.122
BDYINIT		-21756.2	2332.0	250501.0	-222.447	-7.441	6.549
BDYFLGT	2.0 MERU	-167448.8	-958.0	1785552.6	-1539.820	-3.418	68.544
BDYCOMB		-189205.0	1374.0	2036053.7	-1762.267	-10.860	75.094
BDZINIT		-66958.7	7177.3	770963.0	-684.622	-22.904	20.158
BDZFLGT	2.0 MERU	-73803.4	574.7	758645.7	-662.174	1.188	28.602
BDZCOMB		-140762.1	7752.1	1529608.8	-1346.796	-21.715	48.761
GYRO ACC.SENS.DRIFT							
ADIAXCOMB	8.0 MERU/G	-24612.3	2717.8	283486.6	-251.723	-8.289	7.411
ADSAYCOMB	5.0 MERU/G	31826.7	108.1	-330312.5	286.763	0.472	-12.736
ADIAZCOMB	8.0 MERU/G	-22684.6	341.8	232190.6	-202.870	0.291	8.766
RSS UNCERT.(FT AND FT/SEC)		501401.9	23316.4	5504180.1	4832.767	40.764	182.108
RSS UNCERT.(N.MI.AND FT/SEC)		82.520	3.837	905.871	4832.767	40.764	182.108
RSS UNCERT.(N.MI.AND FT/SEC) (INCL.TKG.UPDATE UNCERT.)		82.554	3.837	906.201	4834.559	40.786	182.190

Table 7.8 RMS Uncertainties at Reentry Start (Update 1B)

POSITION AND VELOCITY UNCERTAINTIES ALONG LOCAL VERTICAL AXES AT TIME FROM LCH.= 7 HR,57 MIN, 2.670 SEC (28622.672 SEC)

UNCERT. SOURCE	ONE SIGMA UNCERTAINTY	POSITION UNCERTAINTIES IN FEET (REL. TO NOM. AXES) ALT.	TRACK	RANGE	VELOCITY UNCERTAINTIES IN FT/SEC (REL. TO NOM. AXES) ALT.	TRACK	RANGE
INITIAL S.M. MLMS. (UNCORREL.) ABOUT LAUNCH INERTIAL AXES							
XI	0.500 MR	-15470.2	1658.2	178124.6	-158.176	-5.291	4.657
YI	0.060 MR	-6090.5	-18.5	63332.9	-55.113	-0.080	2.395
ZI	0.060 MR	-2605.5	20.0	26691.0	-23.326	0.046	1.004
ACCEL.INPUT AXIS MLMS.							
MXTOY	0.141 MR	-6150.3	-3.9	62912.4	-54.974	-0.051	2.375
MXTOZ	0.141 MR	-12781.8	-31.3	134015.0	-116.429	-0.178	5.004
MYABTX	0.100 MR	1530.5	350.4	-16414.8	14.360	-1.033	-0.540
ACCEL.BIAS							
ACBXINIT		0.0	0.0	0.0	0.000	0.000	0.000
ACBXFLGT	0.400 CM/S.SQ	403382.3	-64.1	-3877571.7	3382.190	0.252	-168.713
ACBXCOMB		403382.3	-64.1	-3877571.7	3382.190	0.252	-168.713
ACBYINIT		-17713.0	136.2	181449.1	-158.578	0.316	6.826
ACBYFLGT	0.400 CM/S.SQ	50405.8	23507.9	-522177.9	457.259	4.438	-18.907
ACBYCOMB		32692.7	23644.2	-340728.8	298.680	4.755	-12.081
ACBZINIT		41404.2	125.9	-430544.9	374.665	0.548	-16.287
ACBZFLGT	0.400 CM/S.SQ	-142416.7	58.2	2033346.3	-1805.319	-0.167	21.112
ACBZCOMB		-101012.4	184.1	1602801.4	-1430.654	0.381	4.825
ACCEL.SCALE FACTOR							
SFEX	150 PPM	-986.6	0.2	8721.0	-7.614	0.016	0.451
SFEZ	150 PPM	-15542.9	-77.0	172662.0	-152.666	-0.120	4.498
ACCEL.SQ.IND.UNCERT.							
NCXX	10 MG/GSQ	275.5	0.0	-2791.5	2.441	0.001	-0.107
NCZZ	10 MG/GSQ	-881.4	-3.7	9975.6	-8.820	-0.005	0.258
GYRO BIAS DRIFT							
BDXINIT		-4512.4	483.6	51956.2	-46.137	-1.543	1.358
BDXFLGT	2.0 MERU	-53327.6	1446.7	608772.5	-542.041	-28.893	15.764
BDXCOMB		-57840.0	1930.4	660728.7	-588.178	-30.437	17.122
BDYINIT		-21756.2	2332.0	250501.0	-222.447	-7.441	6.549
BDYFLGT	2.0 MERU	-167448.8	-958.0	1785552.6	-1539.820	-3.418	68.544
BDYCOMB		-189205.0	1374.0	2036053.7	-1762.267	-10.860	75.094
BDZINIT		-66958.7	7177.3	770963.0	-684.622	-22.904	20.158
BDZFLGT	2.0 MERU	-73803.4	574.7	758645.7	-662.174	1.188	28.602
BDZCOMB		-140762.1	7752.1	1529608.8	-1346.796	-21.715	48.761
GYRO ACC.SENS.DRIFT							
ADIAXCOMB	8.0 MERU/G	-24612.3	2717.8	283486.6	-251.723	-8.289	7.411
ADSAYCOMB	5.0 MERU/G	31826.7	108.1	-330312.5	286.763	0.472	-12.736
ADIAZCOMB	8.0 MERU/G	-22684.6	341.8	232190.6	-202.870	0.291	8.766
RSS UNCERT.(FT AND FT/SEC)		485616.9	25205.6	4997577.3	4370.033	40.462	193.182
RSS UNCERT.(N.MI.AND FT/SEC)		79.922	4.148	822.495	4370.033	40.462	193.182
RSS UNCERT.(N.MI.AND FT/SEC) (INCL.TKG.UPDATE UNCERT.)		79.958	4.148	822.859	4372.015	40.464	193.259

Table 7.9 RMS Uncertainties at Reentry Start (Update 2)

POSITION AND VELOCITY UNCERTAINTIES ALONG LOCAL VERTICAL AXES AT TIME FROM LCH.= 7 HR.57 MIN. 2.670 SEC (28622.672 SEC)

UNCERT. SOURCE	ONE SIGMA UNCERTAINTY	POSITION UNCERTAINTIES IN FEET (REL. TO NOM. AXES) ALT.	TRACK	RANGE	VELOCITY UNCERTAINTIES IN FT/SEC (REL. TO NOM. AXES) ALT.	TRACK	RANGE
INITIAL S.M. MLMS. (UNCORREL.) ABOUT LAUNCH INERTIAL AXES							
XI	0.500 MR	-95.4	-858.1	-14.1	-0.288	-2.198	-0.030
YI	0.060 MR	110.1	-10.6	10.7	0.333	-0.027	0.019
ZI	0.060 MR	6.7	-3.0	0.6	0.020	-0.006	0.001
ACCEL.INPUT AXIS MLMS.							
MXTOY	0.141 MR	16.4	-1.6	1.2	0.049	-0.004	0.002
MXTOZ	0.141 MR	260.5	-25.2	19.6	0.789	-0.064	0.034
MYABTX	0.100 MR	-20.5	-171.0	8.1	-0.062	-0.438	0.022
ACCEL.BIAS							
ACBXINIT		0.0	0.0	0.0	0.000	0.000	0.000
ACBXFLGT	0.400 CM/S.SQ	-1416.2	137.0	-104.4	-4.187	0.339	-0.165
ACBXCOMB		-1416.2	137.0	-104.4	-4.187	0.339	-0.165
ACBYINIT		45.5	-20.6	4.3	0.138	-0.044	0.008
ACBYFLGT	0.400 CM/S.SQ	-158.0	-1310.2	62.6	-0.472	-3.245	0.166
ACBYCOMB		-112.4	-1330.9	66.9	-0.333	-3.290	0.174
ACBZINIT		-749.0	72.0	-73.0	-2.269	0.185	-0.132
ACBZFLGT	0.400 CM/S.SQ	178.7	-72.5	-1328.1	0.618	-0.179	-3.322
ACBZCOMB		-570.3	-0.4	-1401.2	-1.650	0.005	-3.455
ACCEL.SCALE FACTOR							
SFEX	150 PPM	6.4	-0.6	0.4	0.016	-0.001	0.000
SFEZ	150 PPM	34.4	-14.2	-259.7	0.121	-0.036	-0.671
ACCEL.SQ.IND.UNCERT.							
NCXX	10 MG/GSQ	0.0	0.0	0.0	-0.000	0.000	0.000
NCZZ	10 MG/GSQ	1.2	-0.5	-9.3	0.004	-0.001	-0.025
GYRO BIAS DRIFT							
BDXINIT		-27.8	-250.3	-4.1	-0.084	-0.641	-0.008
BDXFLGT	2.0 MERU	-786.8	-7075.9	-116.5	-2.381	-18.139	-0.250
BDXCOMB		-814.6	-7326.2	-120.6	-2.465	-18.780	-0.259
BDYINIT		-134.2	-1206.7	-19.8	-0.405	-3.091	-0.042
BDYFLGT	2.0 MERU	7571.4	-728.5	738.0	22.947	-1.872	1.344
BDYCOMB		7437.2	-1935.3	718.2	22.541	-4.963	1.301
BDZINIT		-413.0	-3714.1	-61.1	-1.249	-9.514	-0.131
BDZFLGT	2.0 MERU	460.8	-208.1	44.2	1.404	-0.454	0.081
BDZCOMB		47.8	-3922.2	-16.9	0.154	-9.968	-0.049
GYRO ACC.SENS.DRIFT							
ADIAXCOMB	8.0 MERU/G	-146.0	-1313.4	-21.6	-0.441	-3.364	-0.046
ADSAYCOMB	5.0 MERU/G	-734.4	-70.7	-71.4	-2.240	-0.183	-0.132
ADIAZCOMB	8.0 MERU/G	71.6	-31.5	6.8	0.219	-0.069	0.012
RSS UNCERT.(FT AND FT/SEC)		7681.0	8780.5	1607.3	23.256	22.452	3.772
RSS UNCERT.(N.MI.AND FT/SEC)		1.264	1.445	0.264	23.256	22.452	3.772
RSS UNCERT.(N.MI.AND FT/SEC) (INCL.TKG.UPDATE UNCERT.)		1.264	1.449	0.286	23.266	22.454	3.776

Table 7.10 RMS Computed T_{ff} Uncertainties at 1st SPS Burn Cutoff (Update 1A)

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR POSITIVE ERRORS (SECS)

MLMXI-	5.428	MZTOX -	1.925	ACBXI	0.000	ACBYI -	6.081	ACBZI	14.453	SFEX-	0.133	NCXX	0.279 SEC.
MLMYI-	1.939	MZTOY -	4.292	ACBXF	107.373	ACBYF	19.383	ACBZF-	123.547	SFEY-	0.190	NCYY	0.194 SEC.
MLMZI-	0.709	MYABTZ	0.726	ACBXT	107.539	ACBYT	13.476	ACBZT-	109.082	SFEZ-	5.381	NCZZ-	0.133 SEC.
BDXI-	1.638	BDYI-	7.892	BDZI-	24.245	ADIAXT-	8.745	ADSAX-	0.038	ADIXX	0.109		
BDXF-	19.156	BDYF-	59.774	BDZF-	25.408	ADSAYT	11.309	ADIAY	1.038	ADSYY-	0.487	RSS	177.220 SEC.
BDXT-	20.600	BDYT-	67.430	BDZT-	49.407	ADIAZT-	7.601	ADSAZ	0.488	ADIZZ-	0.105	RSN	178.971 SEC.

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR NEGATIVE ERRORS (SECS)

MLMXI	5.805	MZTOX	2.295	ACBXI	0.000	ACBYI -	6.081	ACBZI	14.453	SFEX	0.503	NCXX	0.091 SEC.
MLMYI	2.309	MZTOY	4.664	ACBXF	107.373	ACBYF	19.383	ACBZF-	123.547	SFEY	0.560	NCYY	0.175 SEC.
MLMZI	1.079	MYABTZ-	0.355	ACBXT-	105.736	ACBYT -	12.976	ACBZT	112.718	SFEZ	5.755	NCZZ	0.503 SEC.
BDXI-	1.638	BDYI-	7.892	BDZI-	24.245	ADIAXT	9.133	ADSAX	0.408	ADIXX	0.260		
BDXF-	19.156	BDYF-	59.774	BDZF-	25.408	ADSAYT-	10.928	ADIAY-	0.668	ADSYY	0.857	RSS	177.220 SEC.
BDXT	21.071	BDYT	68.222	BDZT	50.088	ADIAZT	7.977	ADSAZ-	0.118	ADIZZ	0.475	RSN	178.971 SEC.

Table 7.11 RMS Computed T_{ff} Uncertainties at 1st SPS Burn Cutoff (Update 1B)

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR POSITIVE ERRORS (SECS)

MLMXI-	5.428	MZTOX -	1.925	ACBXI	0.000	ACBYI -	6.081	ACBZI	14.453	SFEX-	0.133	NCXX	0.279 SEC.
MLMYI-	1.939	MZTOY -	4.292	ACBXF	135.590	ACBYF	17.510	ACBZF-	57.408	SFEY-	0.190	NCYY	0.194 SEC.
MLMZI-	0.709	MYABTZ	0.726	ACBXT	135.751	ACBYT	11.603	ACBZT-	42.859	SFEZ-	5.381	NCZZ-	0.133 SEC.
BDXI-	1.638	BDYI-	7.892	BDZI-	24.245	ADIAXT-	8.745	ADSAX-	0.038	ADIXX	0.109		
BDXF-	19.156	BDYF-	59.774	BDZF-	25.408	ADSAYT	11.309	ADIAY	1.038	ADSYY-	0.487	RSS	167.814 SEC.
BDXT-	20.600	BDYT-	67.430	BDZT-	49.407	ADIAZT-	7.601	ADSAZ	0.488	ADIZZ-	0.105	RSN	167.069 SEC.

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR NEGATIVE ERRORS (SECS)

MLMXI	5.805	MZTOX	2.295	ACBXI	0.000	ACBYI -	6.081	ACBZI	14.453	SFEX	0.503	NCXX	0.091 SEC.
MLMYI	2.309	MZTOY	4.664	ACBXF	135.590	ACBYF	17.510	ACBZF-	57.408	SFEY	0.560	NCYY	0.175 SEC.
MLMZI	1.079	MYABTZ-	0.355	ACBXT-	133.662	ACBYT -	11.078	ACBZT	44.122	SFEZ	5.755	NCZZ	0.503 SEC.
BDXI-	1.638	BDYI-	7.892	BDZI-	24.245	ADIAXT	9.133	ADSAX	0.408	ADIXX	0.260		
BDXF-	19.156	BDYF-	59.774	BDZF-	25.408	ADSAYT-	10.928	ADIAY-	0.668	ADSYY	0.857	RSS	167.814 SEC.
BDXT	21.071	BDYT	68.222	BDZT	50.088	ADIAZT	7.977	ADSAZ-	0.118	ADIZZ	0.475	RSN	167.069 SEC.

Table 7.12 RMS Computed T_{ff} Uncertainties at 20 mins. before 2nd SPS Ignition (Update 1A)

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR POSITIVE ERRORS (SECS)

MLMXI-	5.299	MZTOX -	1.852	ACBXI	0.000	ACBYI -	6.021	ACBZI	14.801	SFEX-	0.066	NCXX	0.347 SEC.
MLMYI-	1.866	MZTOY -	4.195	ACBXF	123.019	ACBYF	19.992	ACBZF-	83.707	SFEY-	0.122	NCYY	0.262 SEC.
MLMZI-	0.641	MYABTZ	0.795	ACBXT	123.369	ACBYT	13.822	ACBZT-	76.919	SFEZ-	5.257	NCZZ-	0.065 SEC.
BDXI-	1.632	BDYI-	7.762	BDZI-	23.008	ADIAXT-	8.517	ADSAX	0.029	ADIXX	0.177		
BDXF-	18.385	BDYF-	53.890	BDZF-	24.352	ADSAYT	11.591	ADIAY	1.108	ADSYY-	0.419	RSS	166.179 SEC.
BDXT-	19.641	BDYT-	59.610	BDZT-	44.754	ADIAZT-	7.442	ADSAZ	0.556	ADIZZ-	0.037	RSN	197.949 SEC.

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR NEGATIVE ERRORS (SECS)

MLMXI	5.945	MZTOX	2.373	ACBXI	0.000	ACBYI -	6.021	ACBZI	14.801	SFEX	0.572	NCXX	0.158 SEC.
MLMYI	2.387	MZTOY	4.770	ACBXF	123.019	ACBYF	19.992	ACBZF-	83.707	SFEY	0.628	NCYY	0.243 SEC.
MLMZI	1.150	MYABTZ-	0.288	ACBXT-	91.164	ACBYT -	12.658	ACBZT	144.877	SFEZ	5.890	NCZZ	0.571 SEC.
BDXI-	1.632	BDYI-	7.762	BDZI-	23.008	ADIAXT	9.378	ADSAX	0.477	ADIXX	0.328		
BDXF-	18.385	BDYF-	53.890	BDZF-	24.352	ADSAYT-	10.670	ADIAY-	0.600	ADSYY	0.926	RSS	166.179 SEC.
BDXT	22.076	BDYT	76.432	BDZT	54.927	ADIAZT	8.153	ADSAZ-	0.050	ADIZZ	0.543	RSN	197.949 SEC.

Table 7.13 RMS Computed T_{ff} Uncertainties at 20 mins. before 2nd SPS Ignition (Update 1B)

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR POSITIVE ERRORS (SECS)

MLMXI-	5.299	MZTOX -	1.852	ACBXI	0.000	ACBYI -	6.021	ACBZI	14.801	SFEX-	0.066	NCXX	0.347 SEC.
MLMYI-	1.866	MZTOY -	4.195	ACBXF	164.397	ACBYF	17.962	ACBZF-	47.625	SFEY-	0.122	NCYY	0.262 SEC.
MLMZI-	0.641	MYABTZ	0.795	ACBXT	164.776	ACBYT	11.838	ACBZT-	36.459	SFEZ-	5.257	NCZZ-	0.065 SEC.
BDXI-	1.632	BDYI-	7.762	BDZI-	23.008	ADIAXT-	8.517	ADSAX	0.029	ADIXX	0.177		
BDXF-	18.385	BDYF-	53.890	BDZF-	24.352	ADSAYT	11.591	ADIAY	1.108	ADSYY-	0.419	RSS	186.838 SEC.
BDXT-	19.641	BDYT-	59.610	BDZT-	44.754	ADIAZT-	7.442	ADSAZ	0.556	ADIZZ-	0.037	RSN	154.665 SEC.

UNCERTAINTIES IN TIME OF FLIGHT COMPUTATION FOR NEGATIVE ERRORS (SECS)

MLMXI	5.945	MZTOX	2.373	ACBXI	0.000	ACBYI -	6.021	ACBZI	14.801	SFEX	0.572	NCXX	0.158 SEC.
MLMYI	2.387	MZTOY	4.770	ACBXF	164.397	ACBYF	17.962	ACBZF-	47.625	SFEY	0.628	NCYY	0.243 SEC.
MLMZI	1.150	MYABTZ-	0.268	ACBXT-	107.428	ACBYT -	10.868	ACBZT	50.391	SFEZ	5.890	NCZZ	0.571 SEC.
BDXI-	1.632	BDYI-	7.762	BDZI-	23.008	ADIAXT	9.378	ADSAX	0.477	ADIXX	0.328		
BDXF-	18.385	BDYF-	53.890	BDZF-	24.352	ADSAYT-	10.670	ADIAY-	0.600	ADSYY	0.926	RSS	186.838 SEC.
BDXT	22.076	BDYT	76.432	BDZT	54.927	ADIAZT	8.153	ADSAZ-	0.050	ADIZZ	0.543	RSN	154.665 SEC.

Table 7.14 RMS Flight Path Angle Uncertainties at Reentry Start (Update 1A)

UNCERTAINTIES IN FLIGHT PATH ANGLE RELATIVE TO ACTUAL AXES AT NOMINAL TIME (EG1) (U) γ_{AI}

MLMXI	4.060	MZTOX	1.459	ACBXI	0.000	ACBYI	4.214	ACBZI-	9.961	SFEX	0.202	NCXX-	0.064	MR.
MLMYI	1.475	MZTOY	3.129	ACBXF-	67.374	ACBYF -	13.383	ACBZF	96.132	SFEY	0.262	NCYY-	0.006	MR.
MLMZI	0.618	MYABTZ-	0.379	ACBXT-	67.374	ACBYT -	9.237	ACBZT	85.763	SFEZ	3.953	NCZZ	0.227	MR.
BDXI	1.182	BDYI	5.715	BDZI	17.691	ADIAXT	6.470	ADSAX	0.161	ADIXX	0.054			
BDXF	13.906	BDYF	42.724	BDZF	17.766	ADSAYT-	7.672	ADIAY-	0.584	ADSYY	0.466	RSS	126.591	MR.
BDXT	15.104	BDYT	48.616	BDZT	35.722	ADIAZT	5.397	ADSAZ-	0.208	ADIZZ	0.200	RSS	7.253	DEG.

UNCERTAINTIES IN FLIGHT PATH ANGLE RELATIVE TO ACTUAL AXES AT DESIRED ALTITUDE (EG2) (U) γ_{AA}

MLMXI	1.237	MZTOX	0.315	ACBXI	0.000	ACBYI	0.967	ACBZI-	1.796	SFEX	0.017	NCXX-	0.012	MR.
MLMYI	0.342	MZTOY	0.773	ACBXF	14.510	ACBYF -	2.244	ACBZF-	3302.244	SFEY	0.061	NCYY-	0.001	MR.
MLMZI	0.131	MYABTZ-	0.092	ACBXT	14.510	ACBYT -	1.810	ACBZT	3300.000	SFEZ	1.110	NCZZ	0.063	MR.
BDXI	0.343	BDYI	1.788	BDZI	6.621	ADIAXT	2.051	ADSAX	0.046	ADIXX	0.015			
BDXF	4.822	BDYF	19.330	BDZF	5.246	ADSAYT-	1.469	ADIAY-	0.128	ADSYY	0.106	RSS	3300.161	MR.
BDXT	5.341	BDYT	23.993	BDZT	15.281	ADIAZT	1.265	ADSAZ-	0.042	ADIZZ	0.042	RSS	189.085	DEG.

NOTE: Figure "3300" indicates that this figure cannot be computed, since perturbed trajectory due to ACBZ has perigee higher than 400,000 ft (desired altitude).

Table 7.15 RMS Flight Path Angle Uncertainties at Reentry Start (Update 1B)

UNCERTAINTIES IN FLIGHT PATH ANGLE RELATIVE TO ACTUAL AXES AT NOMINAL TIME (EG1) (U) γ_{AI}

MLMXI	4.060	MZTOX	1.459	ACBXI	0.000	ACBYI	4.214	ACBZI-	9.961	SFEX	0.202	NCXX-	0.064	MR.
MLMYI	1.475	MZTOY	3.129	ACBXF-	83.625	ACBYF -	11.984	ACBZF	46.868	SFEY	0.262	NCYY-	0.006	MR.
MLMZI	0.618	MYABTZ-	0.379	ACBXT-	83.625	ACBYT -	7.831	ACBZT	36.561	SFEZ	3.953	NCZZ	0.227	MR.
BDXI	1.182	BDYI	5.715	BDZI	17.691	ADIAXT	6.470	ADSAX	0.161	ADIXX	0.054			
BDXF	13.906	BDYF	42.724	BDZF	17.766	ADSAYT-	7.672	ADIAY-	0.584	ADSYY	0.466	RSS	111.519	MR.
BDXT	15.104	BDYT	48.616	BDZT	35.722	ADIAZT	5.397	ADSAZ-	0.208	ADIZZ	0.200	RSS	6.389	DEG.

UNCERTAINTIES IN FLIGHT PATH ANGLE RELATIVE TO ACTUAL AXES AT DESIRED ALTITUDE (EG2) (U) γ_{AA}

MLMXI	1.237	MZTOX	0.315	ACBXI	0.000	ACBYI	0.967	ACBZI-	1.796	SFEX	0.017	NCXX-	0.012	MR.
MLMYI	0.342	MZTOY	0.773	ACBXF	30.512	ACBYF -	1.934	ACBZF	34.139	SFEY	0.061	NCYY-	0.001	MR.
MLMZI	0.131	MYABTZ-	0.092	ACBXT	30.512	ACBYT -	1.443	ACBZT	26.261	SFEZ	1.110	NCZZ	0.063	MR.
BDXI	0.343	BDYI	1.788	BDZI	6.621	ADIAXT	2.051	ADSAX	0.046	ADIXX	0.015			
BDXF	4.822	BDYF	19.330	BDZF	5.246	ADSAYT-	1.469	ADIAY-	0.128	ADSYY	0.106	RSS	49.720	MR.
BDXT	5.341	BDYT	23.993	BDZT	15.281	ADIAZT	1.265	ADSAZ-	0.042	ADIZZ	0.042	RSS	2.848	DEG.

[redacted]

Table 7.16 RMS Flight Path Angle Uncertainties at Reentry Start (Update 2)

UNCERTAINTIES IN FLIGHT PATH ANGLE RELATIVE TO ACTUAL AXES AT NOMINAL TIME (EG1) (U) γ_{AI}

MLMXI-	0.008	MZTOX	0.001	ACBXI	0.000	ACBYI	0.004	ACBZI-	0.065	SFEX	0.000	NCXX	0.000	MR.
MLMYI	0.009	MZTOY	0.022	ACBXF-	0.119	ACBYF -	0.009	ACBZF-	0.056	SFEY	0.000	NCYY	0.000	MR.
MLMZI	0.000	MYABTZ-	0.001	ACBXT-	0.119	ACBYT -	0.005	ACBZT-	0.122	SFEZ-	0.011	NCZZ-	0.000	MR.
BDXI -	0.002	BDYI -	0.012	BDZI-	0.037	ADIAXT-	0.013	ADSAX-	0.000	ADIXX-	0.000			
BDXF -	0.071	BDYF	0.665	BDZF	0.040	ADSAYT-	0.064	ADIAY-	0.011	ADSYY	0.003	RSS	0.683	MR.
BDXT -	0.073	BDYT	0.653	BDZT	0.003	ADIAZT	0.006	ADSAZ-	0.000	ADIZZ	0.000	RSS	0.039	DEG.

UNCERTAINTIES IN FLIGHT PATH ANGLE RELATIVE TO ACTUAL AXES AT DESIRED ALTITUDE (EG2) (U) γ_{AA}

MLMXI-	0.026	MZTOX	0.004	ACBXI	0.000	ACBYI	0.012	ACBZI-	0.206	SFEX	0.001	NCXX	0.000	MR.
MLMYI	0.030	MZTOY	0.071	ACBXF-	0.384	ACBYF -	0.038	ACBZF-	0.023	SFEY	0.000	NCYY	0.000	MR.
MLMZI	0.001	MYABTZ-	0.005	ACBXT-	0.384	ACBYT -	0.026	ACBZT-	0.229	SFEZ-	0.004	NCZZ-	0.000	MR.
BDXI -	0.007	BDYI -	0.037	BDZI-	0.114	ADIAXT-	0.040	ADSAX-	0.002	ADIXX-	0.000			
BDXF -	0.218	BDYF	2.101	BDZF	0.127	ADSAYT-	0.202	ADIAY-	0.036	ADSYY	0.011	RSS	2.135	MR.
BDXT -	0.225	BDYT	2.063	BDZT	0.012	ADIAZT	0.019	ADSAZ-	0.001	ADIZZ	0.000	RSS	0.122	DEG.

[redacted]

Table 7.17 Stable Member Drift Angles and Misalignments

Event	Misalignment About Launch Inertial Axes (millirad)			Misalignment About Local Vertical Axes (millirad)		
	X_I	Y_I	Z_I	Alt.	Track	Range
RSS initial S. M. misalignment at earth launch	2.35	0.41	0.41	----	----	----
Stable Member RSS Drift Angles						
At SIVB cutoff	0.21	0.30	0.47	0.28	0.30	0.43
At injection burn cutoff	1.74	1.77	1.83	1.82	1.77	1.76
At 1st SPS burn cutoff	2.02	2.04	2.10	2.05	2.04	2.06
20 mins before 2nd SPS burn ignition	3.93	3.95	3.97	3.97	3.95	3.93
At 2nd SPS burn ignition	4.11	4.12	4.15	4.13	4.12	4.13
At reentry start (400,000 ft)	4.18	4.20	4.24	4.18	4.20	4.24
Overall RSS Stable Member Misalignments						
At SIVB cutoff	2.41	0.51	0.62	2.19	0.51	1.18
At injection burn cutoff	2.97	1.82	1.88	2.14	1.84	2.78
At 1st SPS burn cutoff	3.14	2.08	2.14	2.73	2.10	2.63
20 mins before 2nd SPS burn ignition	4.61	3.97	4.00	4.00	3.98	4.60
At 2nd SPS burn ignition	4.76	4.14	4.17	4.46	4.15	4.48
At reentry start (400,000 ft)	4.83	4.22	4.26	4.81	4.23	4.26

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