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DOWNGRADED AT 3 YEAR INTERVALS:
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DOD DIR 5200.10

C 65-4103

CLASSIFICATION CHANGE
To UNCLASSIFIED
By authority of GDS - EO 11652
Changed by L Shirley Date 12/31/72
Classified Document Master Control Station, NASA
Scientific and Technical Information Facility

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE AND NAVIGATION

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TYPE I DOCUMENT
APPROVED BY NASA

[redacted]

R-477
(Unclassified Title)

GUIDANCE AND NAVIGATION SYSTEM OPERATIONS PLAN APOLLO MISSION 202

January 1965

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ACKNOWLEDGMENT

This report was prepared under DSR Project 55-191, sponsored by the Manned Spacecraft Center of the National Aeronautics and Space Administration through Contract NAS 9-153.

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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 202.

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:

(1) Trajectory uncertainties due to G&N component errors (Error Analysis)
(2) Trajectory deviations due to spacecraft performance variations and launch vehicle cut-off dispersions (Performance Analysis)
(3) G&N instrumentation (PCM telemetry and on-board recording) exclusive of AGC DOWNLINK
(4) External tracking data

Revisions to this plan which reflect changes in information items (1) through (4) will not require approval of the NASA CCB.

1.3 Preliminary Data

Unapproved data are printed in red.

*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 originated 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 Test Objectives

2.1.1 Spacecraft Test Objectives which require proper operation of G&N System:

1) Evaluate the thermal performance of the CM heat shield ablator during a high heat load, long duration entry.
2) Demonstrate CM adequacy for manned entry from low earth orbit.
3) Determine nominal mode separation characteristics of the CSM from the SIVB and the CM from the SM.
4) Demonstrate multiple SPS restart (after the second major burn, two 3 second burns with 10 second intervals between burns are required).
5) Determine performance of CSM systems: G&N, SCS, ECS (pressure and temperature control), EPS, RCS and Telecommunications.

2.1.2 Detailed G&N Test Objectives

1) Evaluate performance of the following integrated G&N/Spacecraft modes of operation:
   a. Boost Monitor
   b. Thrust Vector Control
   c. Orbit Attitude Control
   d. Lift Vector Control
   e. Unmanned Spacecraft Control
2) Determine accuracy of G&N system in computation of spacecraft position and velocity during all mission phases.

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 function interface between the AGC and the MCP is complex and its description is deferred until Section 3. 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 Clear Lake Mission Control Center (CLMCC) 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 CLMCC with the capability to enter the AGC with any instruction or data which can be entered by the crew via the DSKY keyboard. It is specifically planned to use this link to provide the AGC with several discrete commands for contingencies. This link will also be used to update the orbit parameters in erasable memory with more accurate data if it is available from ground tracking.

2.2.3 Guidance Errors

The performance of the G&N system for mission 202 has been estimated assuming that no navigation data is inserted via the AGC UPLINK.

The most significant G&N error is that error in the critical path angle at entry which is estimated to be 0.165 degree on a one sigma basis. The next most significant error is manifested in the CEP at splash which is estimated to be 15.6 n.m.

A complete breakdown of G&N errors is given in Section 6.

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 define programming requirements, in Section 3.

The reference trajectory is defined in Section 5 in sufficient detail to satisfy MIT's requirements for development of guidance equations, spacecraft control logic and determination of flight environment.

Section 9 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.

The overall mission profile is illustrated in Fig. 5-1 and Table 5-1 and might well be examined at this point.

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 Y and Z 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 point downrange at an azimuth of 105 degrees East of True North. Initial azimuth is determined by tracking a ground target with the G&N Sextant prior to closeout at -11 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 first SPS burn cut-off.

2.3.2 SI Boost

The boost trajectory is described in Fig. 5-2. Upon receipt of the LIFT OFF signal from the Saturn I.U. the AGC will command the CDUs to the time history of gimbal angles associated with the nominal SI attitude polynomials. The CDU outputs will then represent vehicle attitude errors and will be displayed on the FDAI and telemetered to the ground. This SI attitude monitor is a required element of the launch vehicle malfunction detection scheme, and, in association with computed position and velocity, constitute the Boost Monitor data provided by the G&N system during this period.

2.3.3 Staging, Coast and SIVB Boost

The G&N system will not have the capability to control the SIVB. During this period the G&N system will monitor IMU gimbal angles to detect tumbling and will compute the free fall time to entry interface altitude (300,000 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 Aborts from SIVB Boost

Aborts from the boost phase are mechanized in the same way as manned flight aborts whenever possible. G&N control of CSM aborts from SIVB boost is enabled by the MCP 2 seconds after start of the MCP SIVB/CSM Separation sequence. Upon receipt of the SIVB/CSM SEPARATION signal from the spacecraft the AGC determines a sequence of events using the control logic given in Section 3. Briefly, the sequence of events is derived from three tests:

A. Has the AGC received the ABORT signal from the ground via the UPLINK?

B. Do the spacecraft body rates exceed the tumbling threshold?

C. Does the free-fall time to entry interface altitude fall below the abort T_f criterion of 160 seconds?

For NO ABORT and NO TUMBLING, the AGC commands a normal separation and SPS burn to the nominal First Burn aim point as described more fully below.

If the ABORT signal is received and there is NO TUMBLING, the AGC commands an abort separation sequence followed by an SPS abort burn to the downrange Atlantic Recovery Point. Landing area control capability is illustrated on Fig. 5-1 which shows a continuous recovery area and the selected downrange Atlantic Recovery Point. This downrange point is the splash point obtained if, after a nominal SIVB cut-off and separation sequence, the SPS is fired for 7 seconds in the trajectory plane with the spacecraft X axis 35 degrees above the visible horizon and the CM is oriented for full up lift during the entry phase. The G&N system will control the thrust and lift vectors to achieve this splash point with the constraints, (1) that the spacecraft X axis be directed 35 degrees above the visible horizon during thrusting and (2) that the entry point - splash point separation provide CM lift sufficiently positive to reduce entry g's below a level acceptable for human tolerance. A 10 g limit is incorporated in the entry program also to minimize excessive g loads.

If the abort occurs too early in the boost phase or at an "unsafe" flight path angle, the selected downrange Atlantic Recovery Point cannot be reached because either (1) there is insufficient fuel in the SM tanks, or (2) the booster cut-off conditions are such that the spacecraft would dip into the atmosphere while thrusting. These two conditions are avoided by test C which is mechanized as an interrupt. If the free-fall time falls below 160 seconds so that test C results in a NO answer, the AGC will command engine shutdown and a CSM attitude maneuver to the CM/SM separation attitude.

When the free fall time to entry interface altitude falls below 75 seconds the AGC will command CM/SM SEPARATION and CM orientation to the aerodynamic trim attitude. The lift vector will be up during the entry phase. Note that "early" aborts result in splash points within the continuous recovery area.

If TUMBLING is detected, the AGC will start the SPS 2.5 seconds after separation. This will result in stabilization by the SCS rate loops, and SPS cutoff by the AGC when it senses that spacecraft body rates have dropped below the tumbling threshold. Following SPS shutdown the AGC will estimate the maneuver time, T_M, required to orient to the abort SPS burn attitude (X axis 35 degrees above the visible horizon). If the free-fall time to entry interface altitude is greater than $T_M + 160$, the AGC will command the CSM to the abort SPS burn attitude, command engine on at T_M and guide to the downrange Atlantic Recovery area. Again as in the non-tumbling abort case the engine will be shutdown if free-fall time drops below 160 seconds. If after tumbling arrest burn shutdown the free-fall time is less than $T_M + 160$, the AGC will command the CSM to the CM/SM SEPARATION attitude. Abort area control is illustrated in Fig. 9-4.

2.3.5 CSM/SIVB Separation

There are two CSM/SIVB separation sequences, a normal sequence and an abort sequence used if tumbling or the abort signal is present. In the normal sequence the SPS is ignited by the AGC a fixed time delay of 12.7 seconds after it receives the CSM/SIVB SEPARATION signal. This time delay permits the RCS ullage thrust to build up enough separation distance to prevent the SPS from damaging the SIVB or upsetting its attitude. On the other hand the time delay is not so long as to cause an unjustified ΔV penalty. After separation the AGC computes the initial SPS thrust attitude and commands the required attitude maneuver. If the spacecraft is not completely oriented at the end of the fixed time delay, the SPS is started anyway and orientation is completed during the first few seconds of the burn. Only when large rates and/or large negative pitch attitude dispersions exist at SIVB cut-off will the fixed time delay be too short to permit completion of spacecraft orientation before SPS ignition.

In the abort separation sequence, the SPS is ignited by the AGC a time delay of 2.5 seconds after it receives the CSM/SIVB SEPARATION signal. This time delay is made as short as possible to minimize the probability of CSM-SIVB re-contact or loss of IMU reference in the tumbling case and to get the CSM away from the SIVB as quickly as possible in any abort case.

2.3.6 SPS First Burn

First burn thrust will be controlled by the G&N system to achieve the reference trajectory major axis and eccentricity at cut-off. The trajectory plane at cut-off will include the Pacific Recovery Point at nominal splash time. The nominal attitude, flight path angle and altitude histories are given by Fig. 9-1. Section 9 also contains tables which show the effects of CSM performance variations and launch vehicle cutoff dispersions. The steer law used in this maneuver is given in Section 4, where are found all the CSM guidance equations for Mission 202. It will be noted that the universal cross product steering law for Apollo is used whenever possible, specifically, for this mission, in all cases except tumbling arrest and the short third and fourth burns.

2.3.7 Coast Phase, First Burn Cut-off to Second Burn Ignition

Following first burn cut-off the AGC will compute and command a spacecraft attitude maneuver to align the X-axis to the local vertical, nose down, and the Y-axis to a fixed angle of 0 degrees from the angular momentum vector $\underline{R} * \underline{V}$. Simultaneously the AGC will establish the second burn ignition point by a process of precision numerical integration.

When the inner gimbal angle reaches   degrees the AGC will command FDAI ALIGN for 10 seconds thereby resetting the backup attitude reference to correct for its accumulated drift error. The CSM attitude during this interval will be within 1 degree of a pre-determined attitude with respect to the IMU stable member.

After a time interval of 2006 secs. from first burn cut-off the vehicle attitude in tracking the local vertical will come closest, in the nominal case, to the second burn ignition attitude. At this time the local vertical mode will be terminated and the AGC will command the vehicle to the second burn ignition attitude, which it will hold inertially until ignition.

2.3.8 Second, Third and Fourth SPS Burns

Second burn ignition occurs after a fixed time delay of 3041 seconds from first burn cut-off. The AGC will command + X TRANSLATION 30 seconds before ignition to provide ullage. Thrust is controlled by the G&N system to achieve the reference trajectory major axis and eccentricity at cut-off, and a trajectory plane which includes the Pacific Recovery Point at nominal splash time.

Second burn is terminated by the AGC six seconds before the required velocity is attained. The spacecraft attitude at this time will be held until fourth burn cutoff. During second burn the G&N attitude error signal will develop a bias proportional to the c.g. shift from the engine gimbal trim position set in prior to second burn ignition. After second burn cutoff the

CDUs will be moved off from their position at cutoff by a stored estimate of this bias in order to minimize the attitude transient after engine shutdown.

The AGC will start and shutdown the SPS on a time basis so that the last two burns are each of 3 seconds duration and so that the two short coast periods are each of 10 seconds duration. The AGC will control the + X TRANSLATION signal so that the RCS will provide ullage thrust as well as attitude control during the 10 second coast periods. Note that the SCS disables +X translation during SPS firing.

The nominal attitude, flight path angle and altitude histories are given by Fig. 9-2. Figure 9-3 shows the slant range, azimuth and elevation to the CSM from the Carnarvon tracking station. Tables in Section 9 show the effects of CSM performance variations and launch vehicle cut off dispersions.

2.3.9 Pre-Entry Sequence

The fourth burn cutoff attitude is held until the free-fall time to entry interface altitude drops below the normal T_f criterion of 160 seconds, when the G&N system will start pitching the spacecraft up to the CM/SM separation attitude (+ X axis up in the trajectory plane and tipped forward in the direction of motion 60 degrees above the velocity vector. When the free-fall time drops below 75 seconds the AGC will command CM/SM SEPARATION. After a 5 second time delay to allow for separation and stabilization, the G&N system will start orienting the CM to the entry attitude. The CM will then be at the aerodynamic trim angle of attack with roll angle for down lift.

2.3.10 Entry

The velocity and critical flight path angle at entry are directly controlled by the G&N system during the second, third and fourth burns. The nominal entry trajectory provided by the guidance equations is illustrated in Fig. 9-4. The entry guidance equations, which are given in Section 4, are designed to provide a trajectory which will satisfy heat shield test objectives while controlling the roll angle so as to splash at the designated Pacific Recovery Point.

3. LOGIC AND TIMELINE FOR SPACECRAFT AND MISSION CONTROL

3.1 Interfaces, Ground Commands and Constraints

3.1.1 G&N Interface with Spacecraft

The following interfaces will be effective on Mission 202/AF 011/ AGE 017:

3.1.1.1 AGC Outputs to MCP

This interface is documented in ICD No. MH01-01200-216 and provides the following signals:

(1) G&N ATTITUDE CONTROL MODE SELECT

(2) G&N ENTRY MODE SELECT

(3) G&N ΔV MODE SELECT

(4) +X TRANSLATION ON/OFF

There is a requirement for this command (over and above the translation requirement) to provide for termination of Direct Ullage mode.

At SIVB/CSM Separation the AGC must command "+X TRANSLATION ON" to key the MCP to terminate the "SIVB/ CSM Separate" command to the MESC, which in turn deactivates the MESC-controlled "DIRECT ULLAGE" command. The MESC will not terminate direct ullage earlier than 3.5 sec after receipt of "SIVB/CSM Separate" nor continue it longer than 12 sec regardless of whether the SIVB/CSM Separate command is terminated or not.

(5) CM/SM SEPARATION COMMAND

(6) FDAI ALIGN

This signal will be initiated and held for 10 seconds soon after orientation to SPS second burn attitude when the IMU gimbal angles are near prescribed values. This will result in FDAI ALIGN when the spacecraft is within 1-1/2 degrees of a prescribed inertial orientation.

(7) T/C ANTENNA SWITCH

The AGC has the capability to switch the T/C Antennas although the requirements for this function have not yet been defined and thus not incorporporated in AGC programming.

(8) G&N FAIL INDICATION

This signal is generated by the AGC based upon its assessment of certain functions with the G&N. The AGC generated G&N FAIL INDICATION will be an "OR" of the following normal Block I FAIL indices;

IMU FAIL - an "OR" of IG servo error
MG servo error
OG servo error
3200 CPS loss
wheel supply loss

ACCEL FAIL - an "OR" of
x PIPA error
y PIPA error
z PIPA error

CDU FAIL - an "OR" of CDU 25.6 KC supply
CDU Motor excit. loss
Inner CDU error
Middle CDU error
Outer CDU error

Each of these three FAIL signals (IMU, ACCEL, CDU) are subject to AGC program processing as there are certain phases of normal G&N operation where the FAIL parameters will exceed FAIL thresholds, thus requiring AGC inhibition of FAIL indication. The G&N FAIL circuitry will be scanned for evidence of failure every 480 ms.

As is apparent from the FAIL parameters the G&N FAIL INDICATION signal is basically a monitor of the inertial subsystem and not of the AGC. Thus, confirmation of an AGC failure must be made by the ground by examination of the DIGITAL DOWNLINK.

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 ATTITUDE CONTROL MODE. The attitude reference becomes the BMAG's. 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 once to retransfer S/C control to G&N, however, this command must come from the ground.

(9) .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. 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 0.05G indication is not used within the re-entry program, however, so should this function be backed up by a redundant CM sensor or by the UDL signal, no AGC confusion should result.

(10) 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. The MCP does this sequentially and therefore the AGC must terminate this command only once after 1st SPS burn, (to select trim position for 2nd burn) and once after 2nd SPS burn (to select trim position for 3rd burning). The trim position for the 1st burn is selected by MCP upon keying from the SIVB/CSM Separate Command. The 3rd burn trim position is also satisfactory for the 4th burn.

(11) SPARE

This is a relay identical to those used in (1) through (10) and is identically wired to the MIT/NAA interface.

3.1.1.1.1 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. Presently the arming logic for the G&N/MCP interface is as shown in Fig. 3-1.

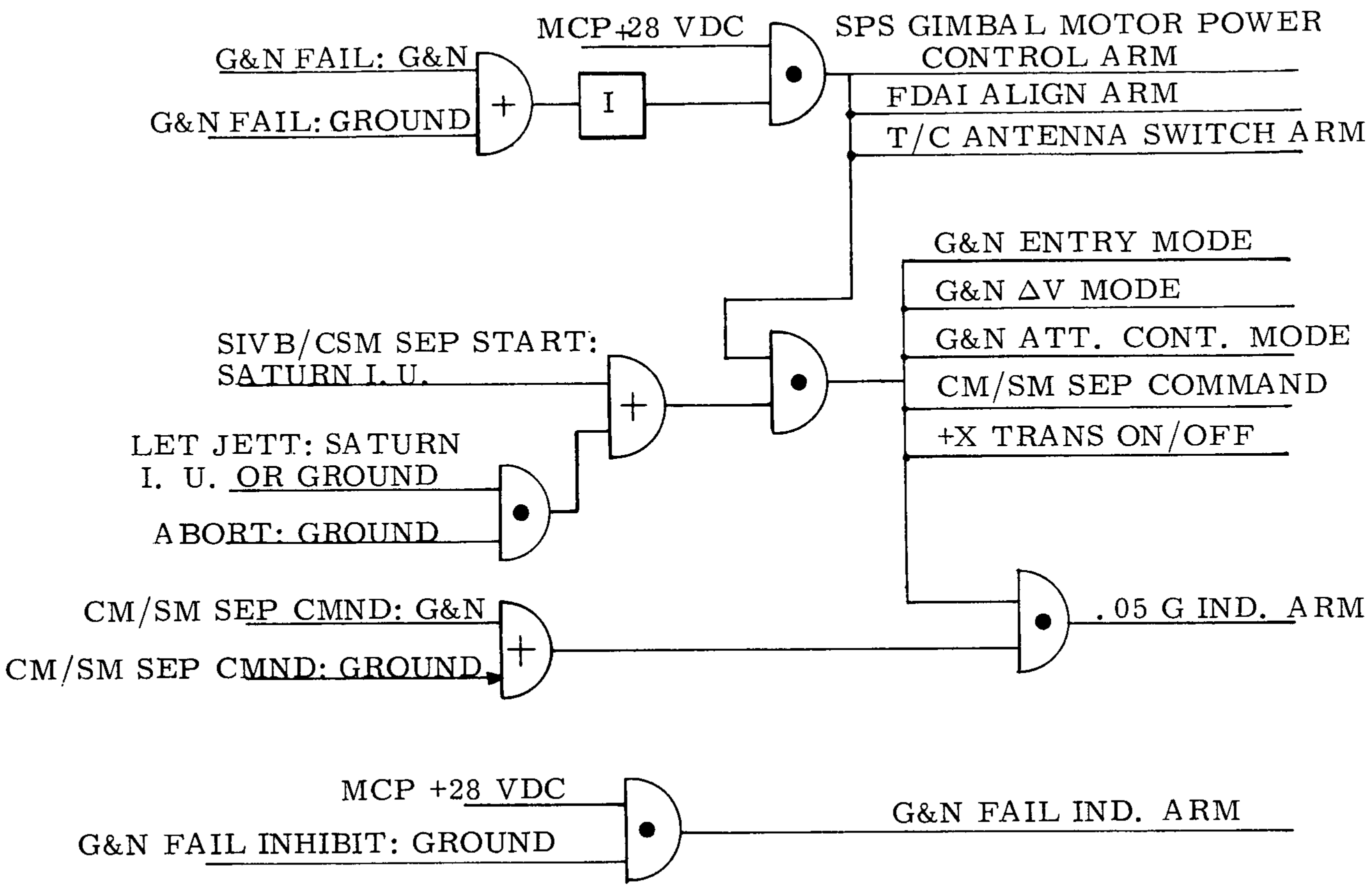


Fig. 3-1 Arming Logic for G&N/MCP Interface

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

3.1.1.2 Additional Interfaces

Pertinent G&N electrical signal interfaces with other S/C subsystems are described in detail in the ICD's below.

ICD. NO.	TITLE	SIGNALS INCLUDED
MH01-01024-416	Attitude Error Signals	Pitch Error (Body & Body Offset) Yaw Error (Body) Yaw Error (Body Offset) Roll Error (Body) Roll Error (Body Offset) Error Signal Reference (all signals go from G&N to SCS)
MH01-01025-416	Total Attitude Signals	SIN AIG COS AIG SIN AMG COS AMG SIN AOG COS AOG Attitude Signal Reference (all signals go from G&N to SCS)
MH01-01038-216	Engine On Signal to SCS	Engine ON/OFF (AGC command to SCS system - not via MCP)
MH01-01026-216	Central Timing Equipment Synch. Pulse	AGC synch. pulse to PCM telemetry system
MH01-01028-216	G&N DATA Transmission to Operational PCM Telemetry Equipment	G&N analog data and AGC serial digital data (AGC Downlink) to PCM (Includes flight recorder data).
MH01-01036-200	ACE Uplink/Spacecraft Digital Up-Data Link to AGC	Coded data input to AGC from ground
MH01-01278-216	Launch Vehicle to G&N Interfaces (Block I Series 100)	1. Liftoff 2. Guidance Reference Release
MH01-01280-216	Vehicle Separation Signals to AGC (Block I Series 100)	1. CSM/SIVB Separate

3.1.2 Ground Commands

3.1.2.1 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) ABORT INDICATION (required for abort logic as described earlier)

(2) LIFT-OFF (backup to discrete input)

(3) SIVB/CSM SEPARATION (backup to discrete input)

(4) G&N ATTITUDE CONTROL MODE SELECT

(5) G&N ΔV MODE SELECT

(6) G&N ENTRY MODE SELECT

(7) +X TRANSLATION ON/OFF

(8) GIMBAL MOTOR POWER ON/OFF

(inputs (4) - (8) will cause the AGC to issue these commands to the MCP)

(9) Position and Velocity data (provides ground capability to update navigation data in the AGC).

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

All information 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.) The rate of transmission is 1 K bits/sec. allowing for slightly over 9 keyboard characters per sec. 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 ($1C\bar{C}C$).

3.1.2.2 Discrete Real Time Commands to MCP

The following list details the real-time commands planned for support of the Apollo 202 Mission. This list is restricted to commands for the Command/Service Module Systems and is exclusive of commands to the SIVB and AGC Uplink commands:

1. Abort (Also Backup for SIVB/CSM Separation Start)
2. LET Jettison Start-Backup to onboard command from S-IVB.
3. Thrust off- Turn off SPS engine; backup to onboard command in case of malfunction.
4. Thrust On - Turns on SPS engine; backup to onboard command in case of malfunction.
5. CM/SM Separation - Backup to onboard command from the G&N.
6. Lifting Entry - Necessary for no-roll entry in the SCS entry mode.
7. G&N Failure - Backup to G&N function.
8. G&N Failure Inhibit - Reset G&N failure.
9. Roll Rate Gyro Backup - Switches roll BMAG to rate mode and uses this gyro for roll rate data.
10. Yaw Rate Gyro Backup - Switches yaw BMAG to rate mode and uses this gyro for yaw data.
11. Pitch Rate Gyro Backup - Switches pitch BMAG to rate mode and uses this gyro for pitch rate data.
12. Roll A and C Channel Disable - Disables the automatic A and C RCS roll channels.
13. Roll B and D Channel Disable - Disables the automatic B and D RCS roll channels.
14. Pitch Channel Disable - Disables the automatic pitch RCS channels.
15. Yaw Channel Disable - Disables the automatic yaw RCS channels.
16. -Direct rotation + pitch
17. -Direct rotation - pitch
18. -Direct rotation + yaw
19. -Direct rotation - yaw
20. -Direct rotation + roll
21. -Direct rotation - roll

22-23. SM Quad A Propellant Off/On.

24-25. SM Quad B Propellant Off/On.

26-27. SM Quad C Propellant Off/On.

28-29. SM Quad D Propellant Off/On.

30-31. CM System A Propellant Off/On.

32-33. CM System B Propellant Off/On.

34. Direct Ullage (Also sets SCS ΔV mode)

35-37. Fuel Cell Purge (cell #1 - cell #3)

38. FDAI align

39-40. T/C Antenna Switch (-Z, +Z)

41. UDL/S-Band Comm. Switch

42-45. Cryogenic Heater Fan Switch (0_2#1, 0_2#2 H_2#1, H_2#2)

Commands 12-21 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; abort, thrust off, thrust on, G&N Failure Inhibit, G&N Fail, Direct Ullage.

Abort: As discussed above, this abort command may be accompanied by an abort command to the AGC via AGC Uplink.

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 10 seconds exit from thrust vector control and hold attitude until the free-fall interrupt occurs.

Thrust On: AGC Engine On logic presently includes a monitor of ΔV to ensure engine ignition. This monitor continues for 10 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 calculations.

G&N Failure: This command is a ground backup for the G&N originated command. As all control of the vehicle by G&N is thereby inhibited, the resulting confusion of the AGC (it has no knowledge of the ground command) is interesting but irrelevant.

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 control loss.

G&N Failure Inhibit: This command overrides the G&N FAIL signal.

3.1.3 Backup Control Systems Constraints on G&N Operation

3.1.3.1 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 systime. As the SCS system is presently designed, the BMAG's 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, attitude changes over 17° might occur.

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 at rates beyond which the backup attitude reference system can maintain its reference, the G&N will limit its command rate to the CSM.

3.1.3.2 Backup Entry Control

During the pre-entry coast the G&N system must orient the CM for aerodynamic trim and lift vector down. Then, in the event of G&N FAIL INDICATION, the MCP/SCS will hold this attitude until it senses a prescribed "g" level at which time it will command a continuous roll angular velocity.

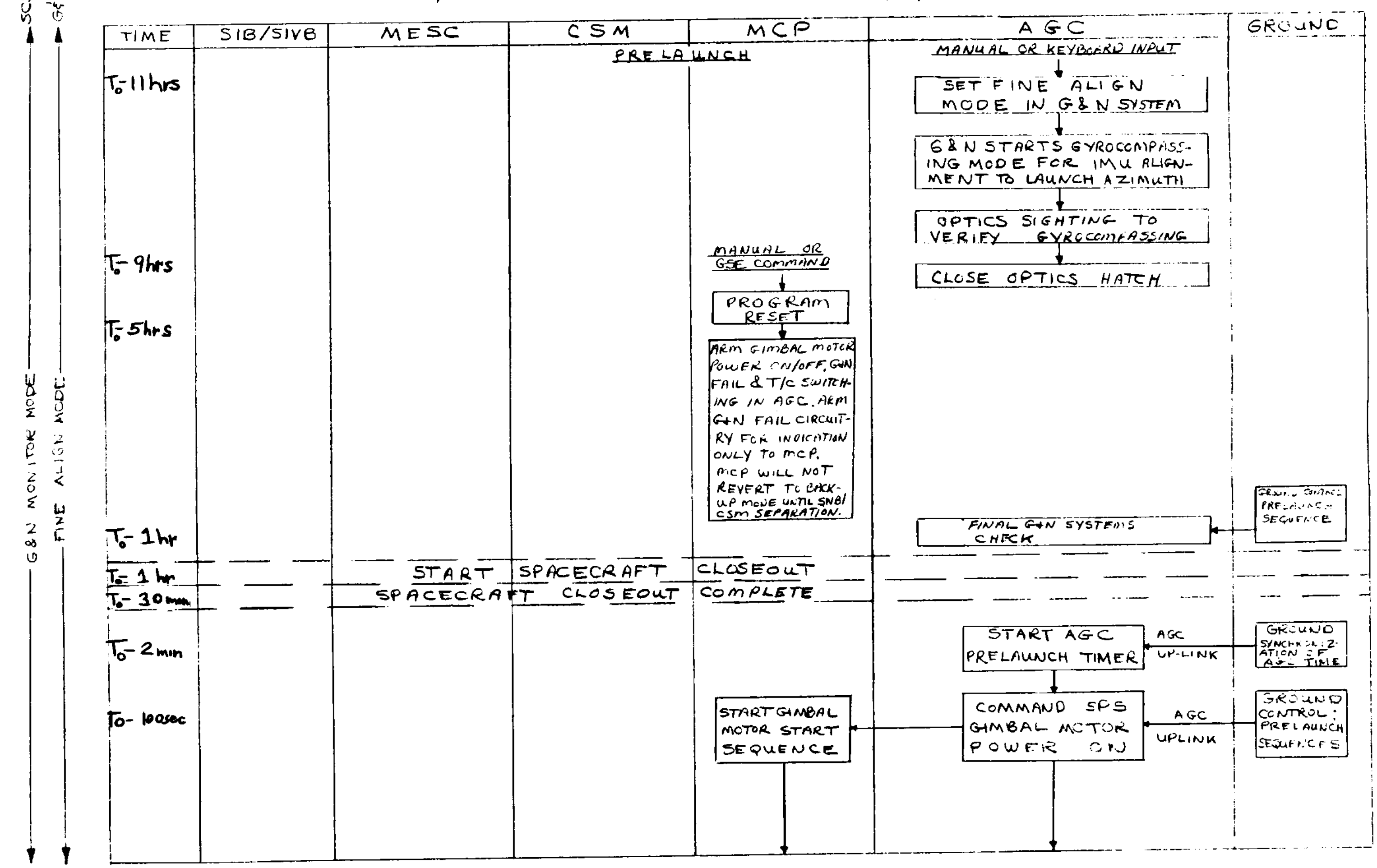
3.2 Normal and Abort Mission Logic

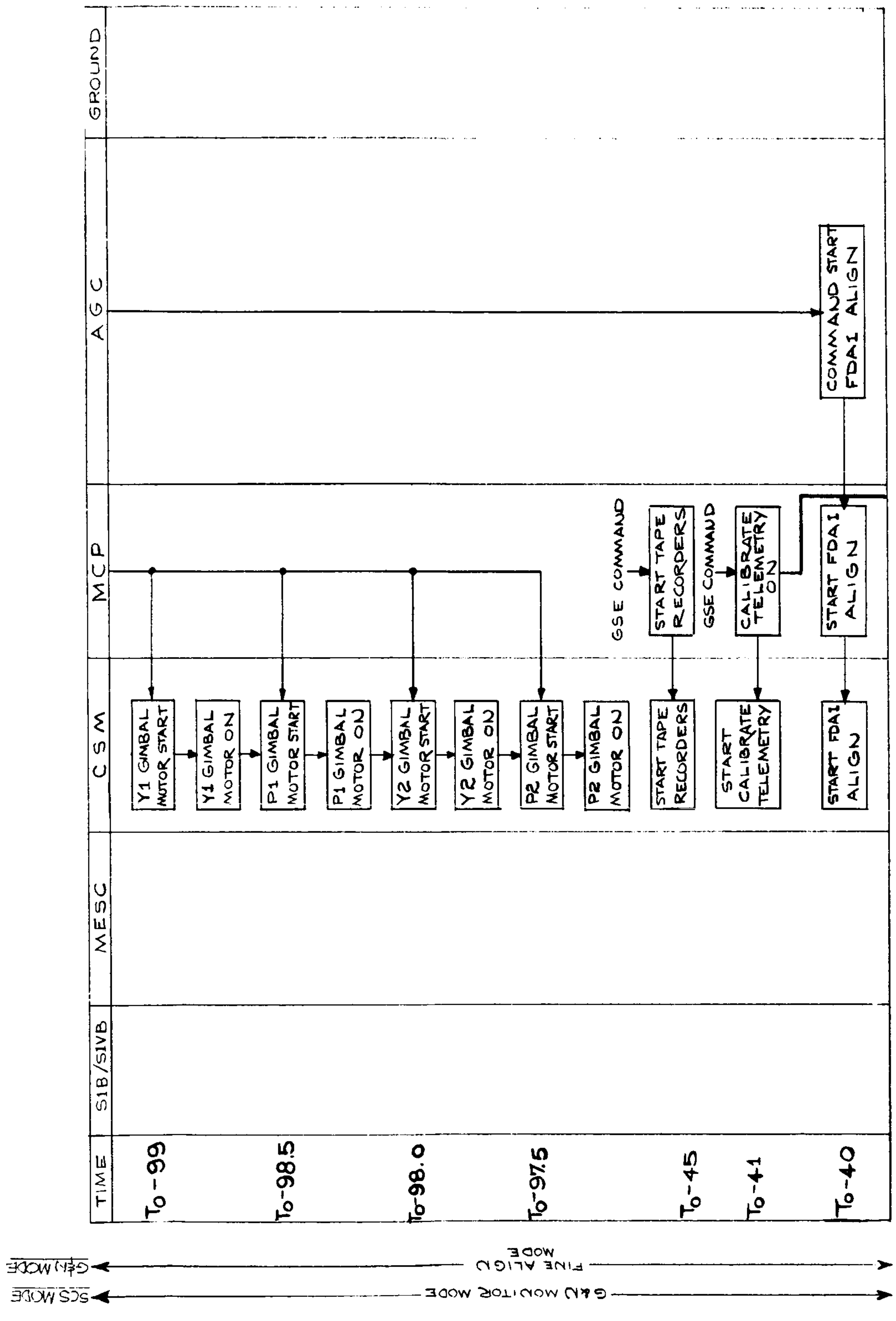
The following pages describe the timeline and logic for AGC control of the spacecraft.

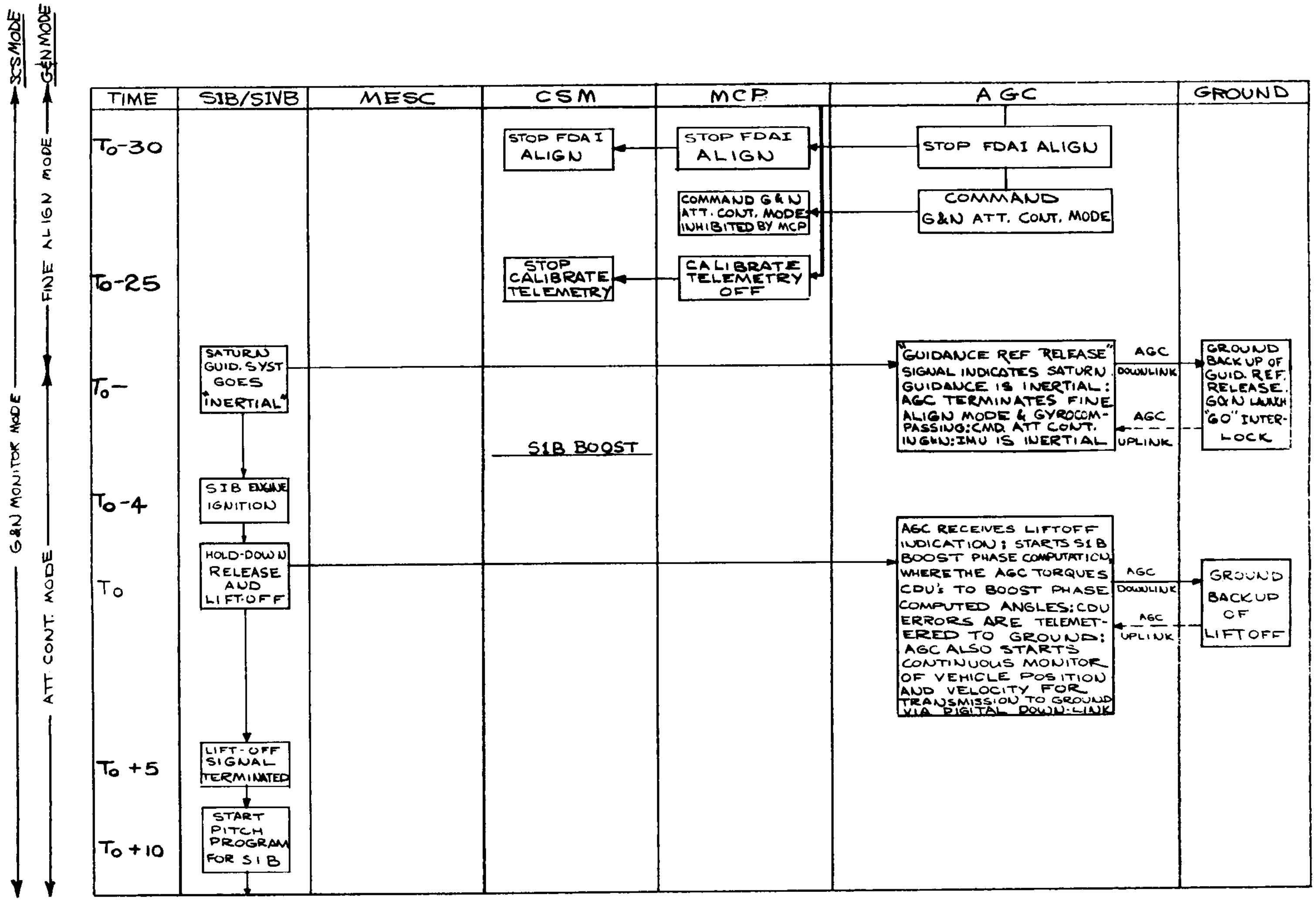
3.2.1 Normal Sequence of Events

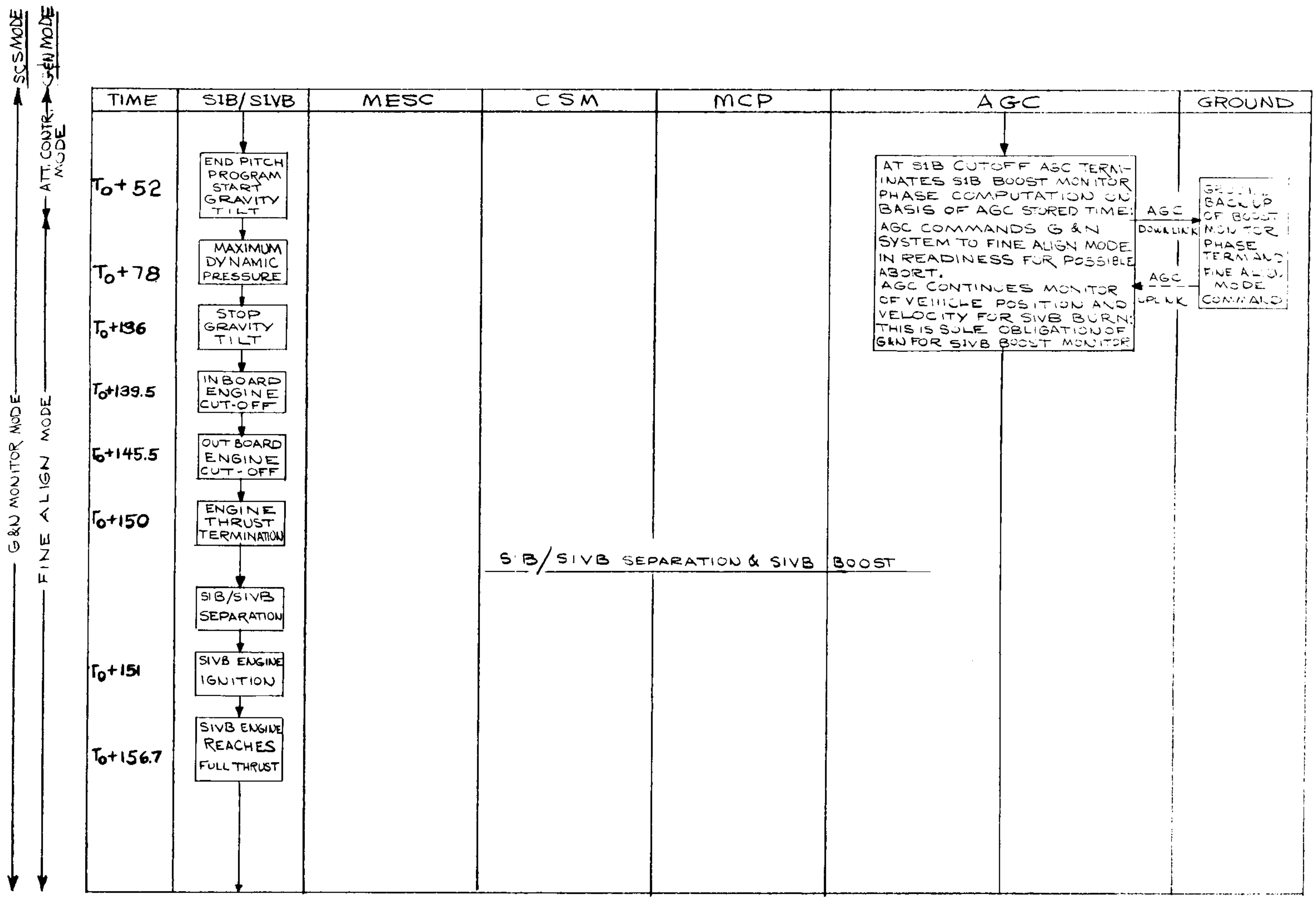
3.2.2 AGC Program Logic

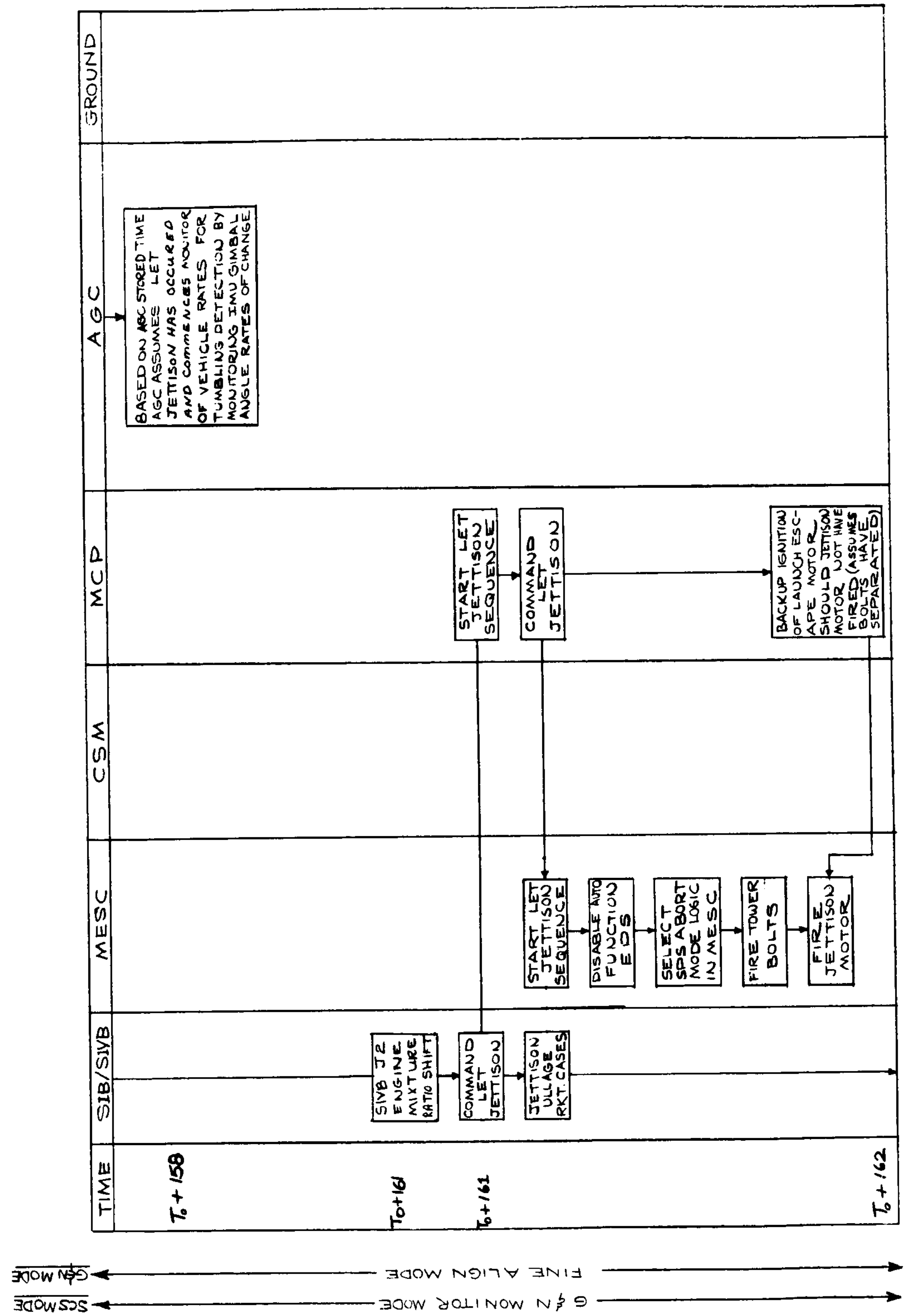
NORMAL SEQUENCE OF EVENTS - MISSION 202
S/C 011 MISSION CONTROL PROGRAMMER / G&N

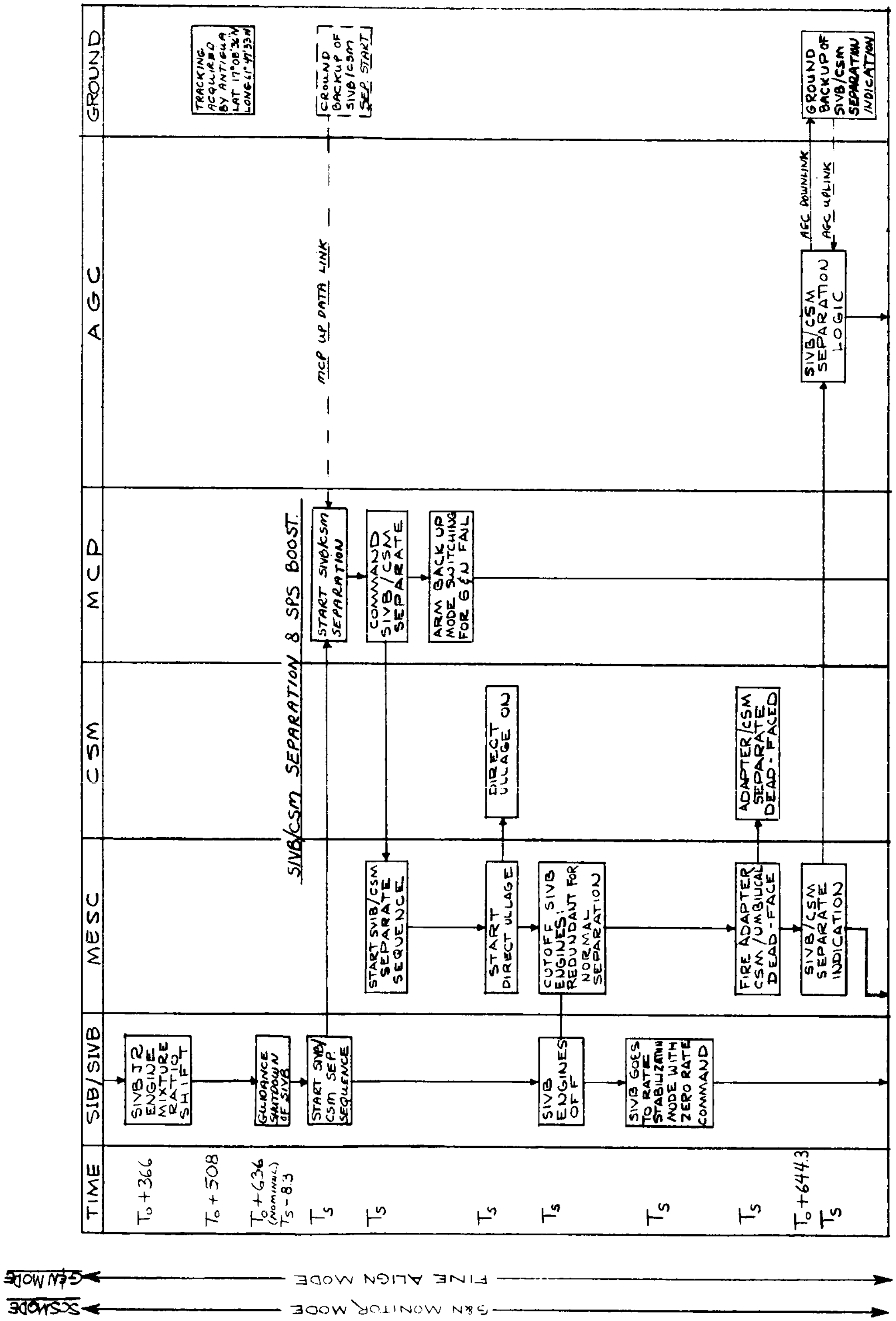


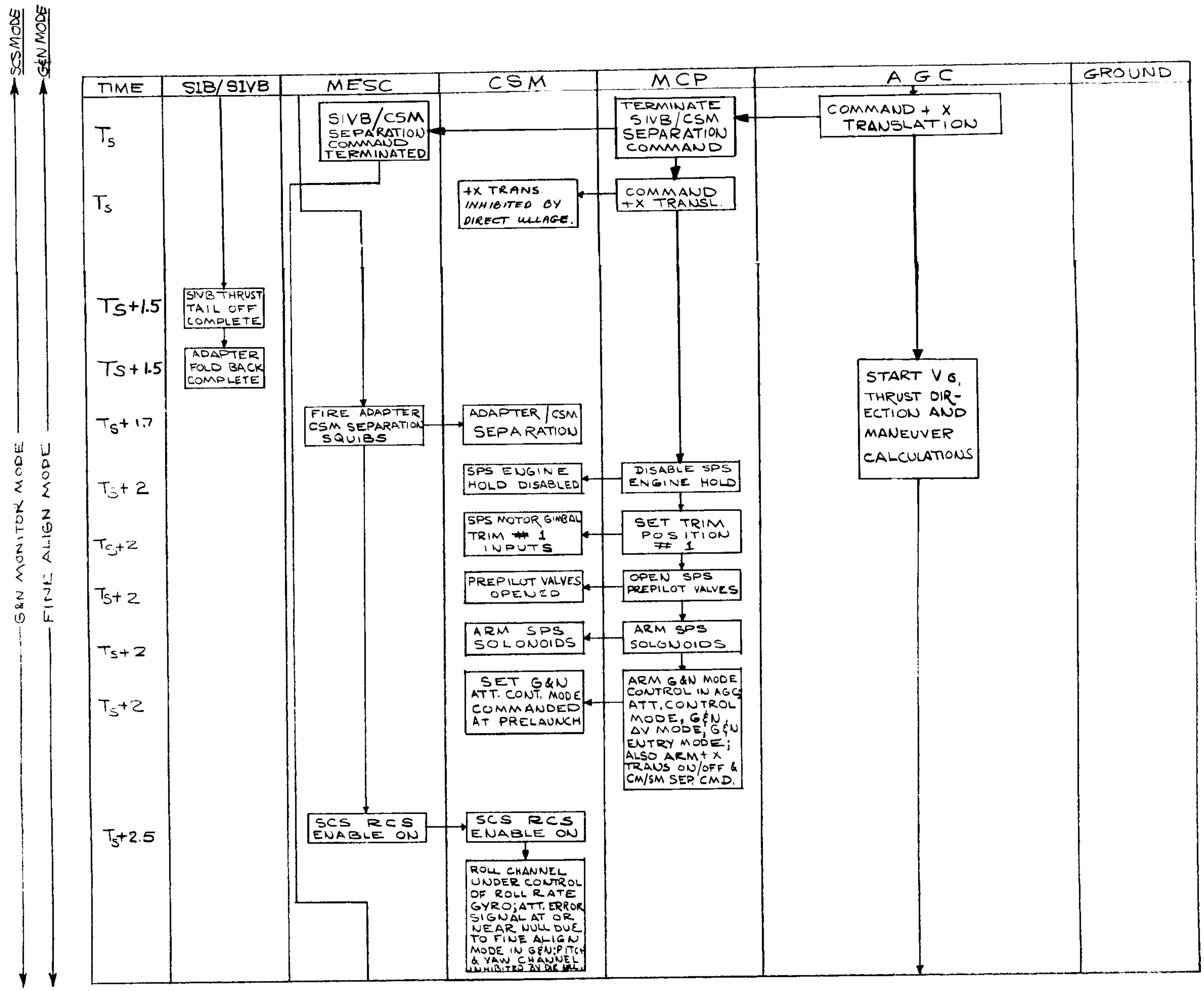

GROUND
A G C
M C P
C S M
M E S C
S1B/S1VB
TIME
COMMAND START FDAI ALIGN
GSE COMMAND
START TAPE RECORDERS
GSE COMMAND
CALIBRATE TELEMETRY ON
START FDAI ALIGN
Y1 GIMBAL MOTOR START
Y1 GIMBAL MOTOR ON
P1 GIMBAL MOTOR START
P1 GIMBAL MOTOR ON
Y2 GIMBAL MOTOR START
Y2 GIMBAL MOTOR ON
P2 GIMBAL MOTOR START
P2 GIMBAL MOTOR ON
START TAPE RECORDERS
START CALIBRATE TELEMETRY
START FDAI ALIGN
To-99
To-98.5
To-98.0
To-97.5
To-45
To-41
To-40
G&N MODE
FINE ALIGN MODE
SCS MODE
G&N MONITOR MODE

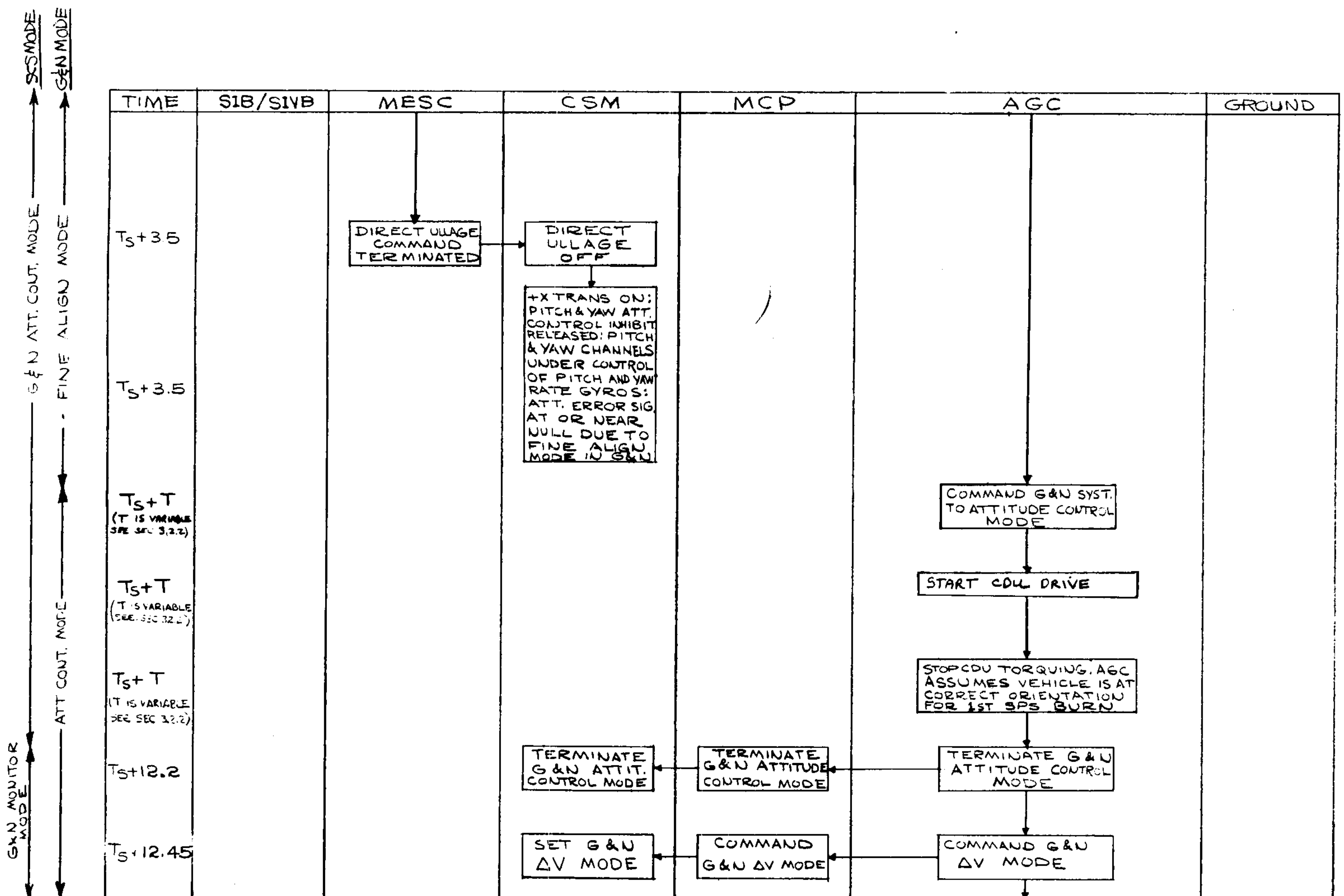

SCS MODE
G&N MODE
FINE ALIGN MODE
ATT. CONT. MODE
G&N MONITOR MODE
TIME
S1B/SIVB
MESC
CSM
MCP
AGC
GROUND
To-30
To-25
To-
To-4
To
To +5
To +10
STOP FDAI ALIGN
STOP FDAI ALIGN
STOP FDAI ALIGN
COMMAND G&N ATT. CONT. MODE
COMMAND G&N ATT. CONT. MODE INHIBITED BY MCP
STOP CALIBRATE TELEMETRY
CALIBRATE TELEMETRY OFF
SATURN GUID. SYST GOES "INERTIAL"
"GUIDANCE REF RELEASE" SIGNAL INDICATES SATURN GUIDANCE IS INERTIAL: AGC TERMINATES FINE ALIGN MODE & GYROCOMPASSING: CMD. ATT CONT. IN G&N: IMU IS INERTIAL
AGC DOWNLINK
AGC UPLINK
GROUND BACK UP OF GUID. REF. RELEASE. G&N LAUNCH "GO" INTERLOCK
S1B BOOST
S1B ENGINE IGNITION
HOLD-DOWN RELEASE AND LIFT-OFF
AGC RECEIVES LIFTOFF INDICATION; STARTS S1B BOOST PHASE COMPUTATION, WHERE THE AGC TORQUES CDU's TO BOOST PHASE COMPUTED ANGLES; CDU ERRORS ARE TELEMETERED TO GROUND; AGC ALSO STARTS CONTINUOUS MONITOR OF VEHICLE POSITION AND VELOCITY FOR TRANSMISSION TO GROUND VIA DIGITAL DOWN-LINK
AGC DOWNLINK
AGC UPLINK
GROUND BACKUP OF LIFTOFF
LIFT-OFF SIGNAL TERMINATED
START PITCH PROGRAM FOR S1B

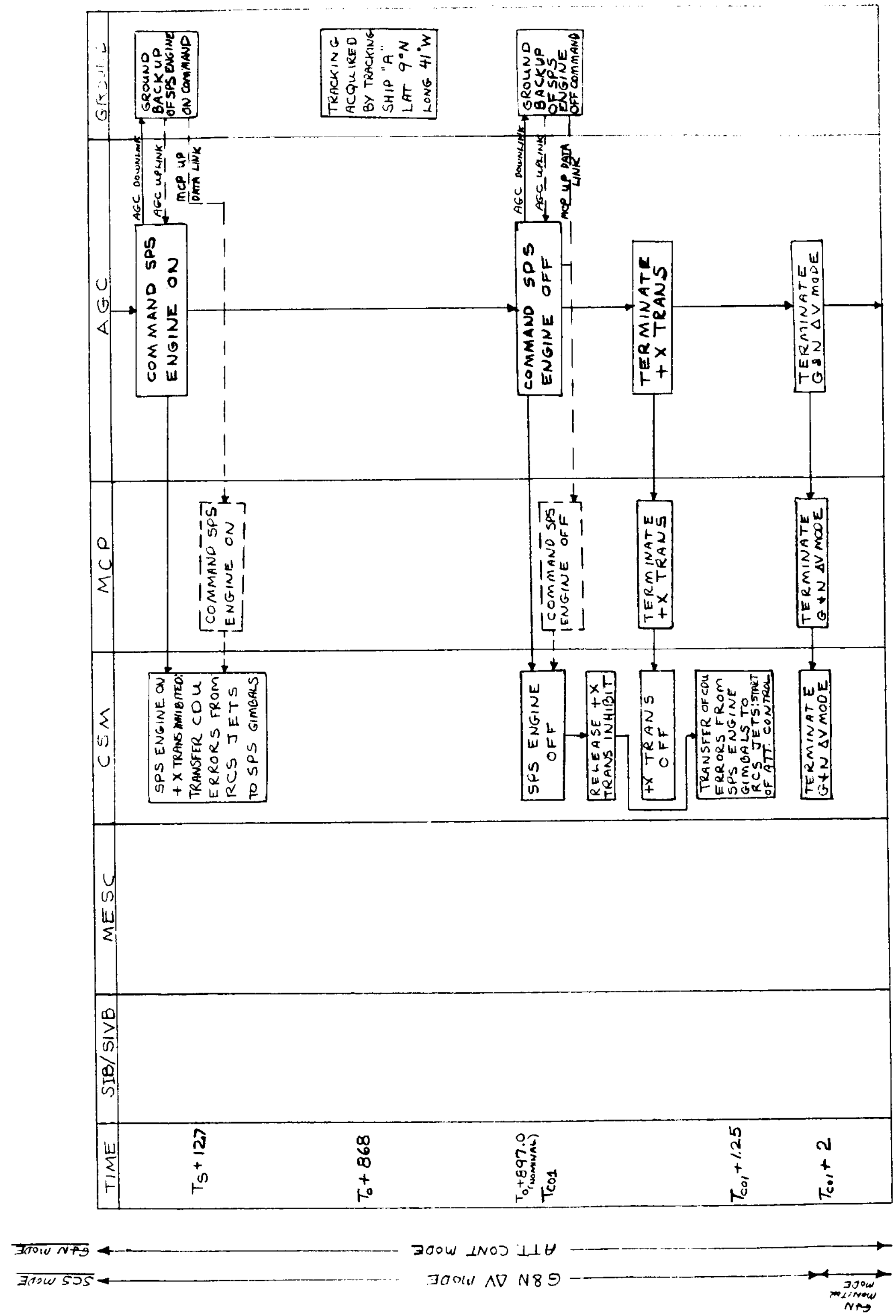

TIME
S1B/SIVB
MESC
CSM
MCP
AGC
GROUND
T_0+52
T_0+78
T_0+136
T_0+139.5
T_0+145.5
T_0+150
T_0+151
T_0+156.7
END PITCH PROGRAM START GRAVITY TILT
MAXIMUM DYNAMIC PRESSURE
STOP GRAVITY TILT
INBOARD ENGINE CUT-OFF
OUT BOARD ENGINE CUT-OFF
ENGINE THRUST TERMINATION
SIB/SIVB SEPARATION
SIVB ENGINE IGNITION
SIVB ENGINE REACHES FULL THRUST
SIB/SIVB SEPARATION & SIVB BOOST
AT SIB CUTOFF AGC TERMINATES SIB BOOST MONITOR PHASE COMPUTATION ON BASIS OF AGC STORED TIME: AGC COMMANDS G & N SYSTEM TO FINE ALIGN MODE IN READINESS FOR POSSIBLE ABORT. AGC CONTINUES MONITOR OF VEHICLE POSITION AND VELOCITY FOR SIVB BURN: THIS IS SOLE OBLIGATION OF G&N FOR SIVB BOOST MONITOR
AGC DOWNLINK
AGC UPLINK
BACKUP
PHASE
MODE
SCS MODE
G&N MONITOR MODE
GEN MODE
ATT. CONTR. MODE
FINE ALIGN MODE

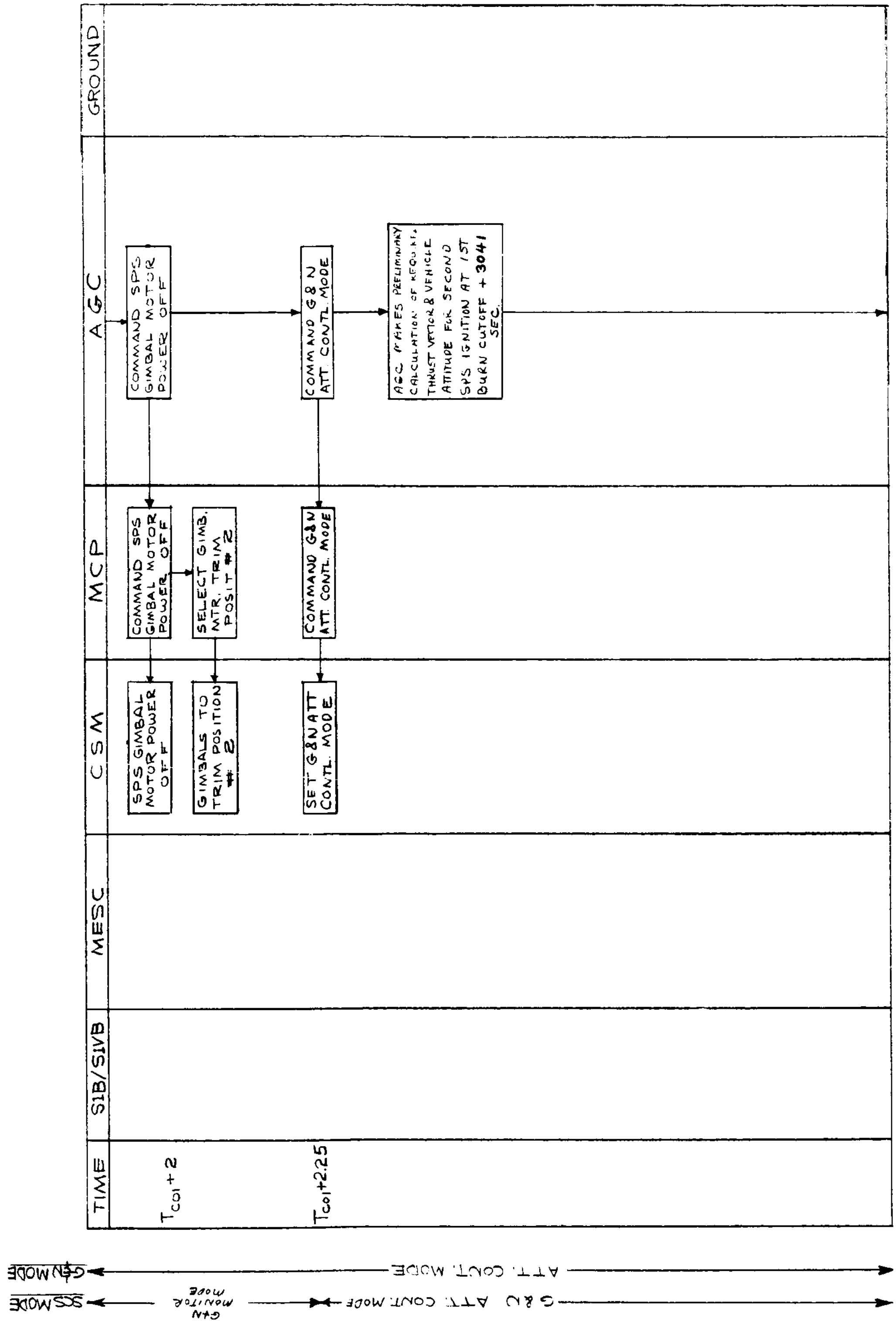

GROUND
AGC
BASED ON AGC STORED TIME AGC ASSUMES LET JETTISON HAS OCCURED AND COMMENCES MONITOR OF VEHICLE RATES FOR TUMBLING DETECTION BY MONITORING IMU GIMBAL ANGLE RATES OF CHANGE
MCP
START LET JETTISON SEQUENCE
COMMAND LET JETTISON
BACKUP IGNITION OF LAUNCH ESCAPE MOTOR SHOULD JETTISON MOTOR NOT HAVE FIRED (ASSUMES BOLTS HAVE SEPARATED)
CSM
MESC
START LET JETTISON SEQUENCE
DISABLE AUTO FUNCTION EDS
SELECT SPS ABORT MODE LOGIC IN MESC
FIRE TOWER BOLTS
FIRE JETTISON MOTOR
SIB/SIVB
SIVB J2 ENGINE MIXTURE RATIO SHIFT
COMMAND LET JETTISON
JETTISON ULLAGE RKT. CASES
TIME
T0 + 158
T0+161
T0+161
T0 + 162
G&N MODE
FINE ALIGN MODE
SCS MODE
G&N MONITOR MODE

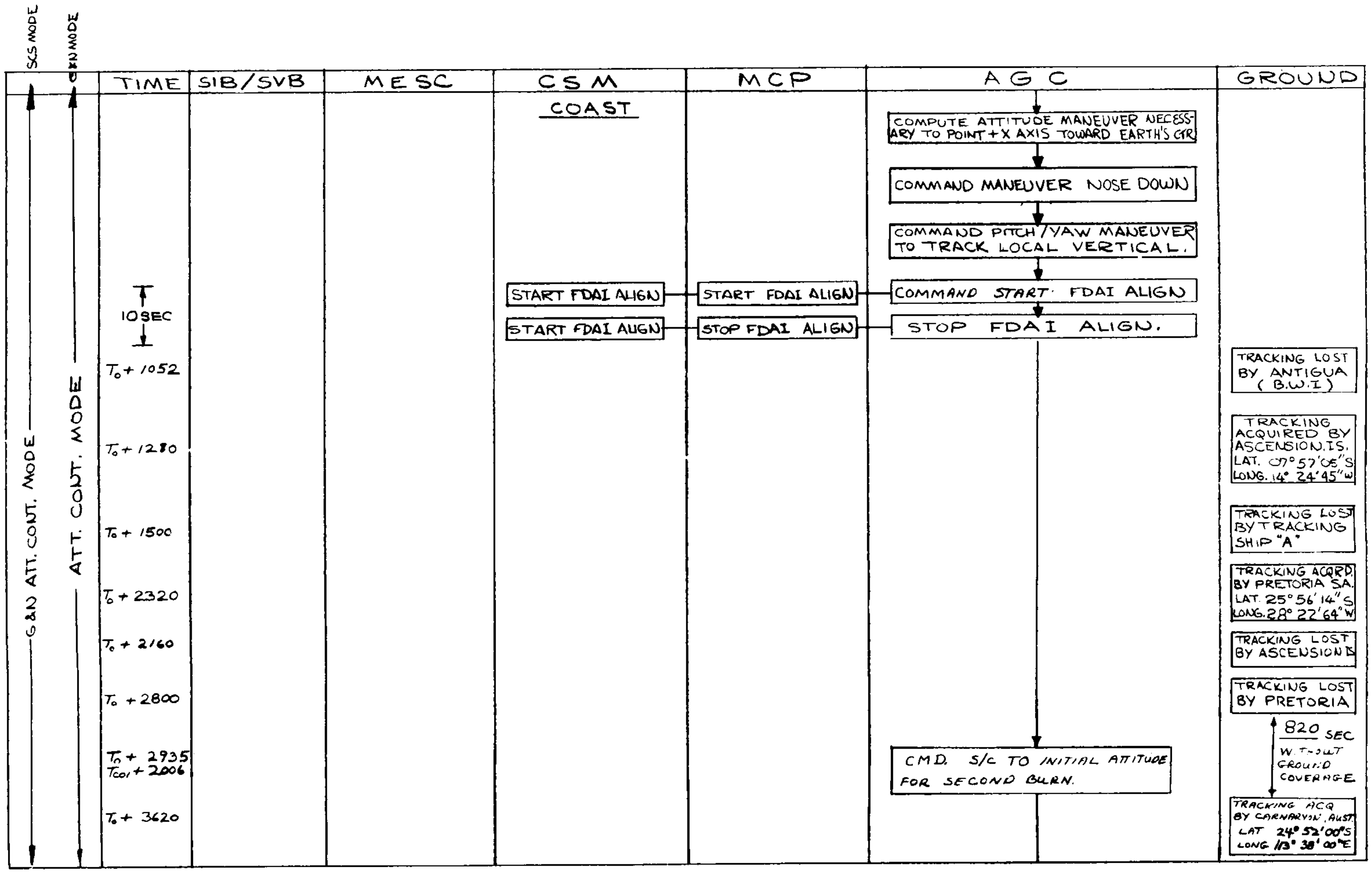

TIME
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
SIVB/CSM SEPARATION & SPS BOOST.
$T_0 + 366$
$T_0 + 508$
$T_0 + 636$ (NOMINAL)
$T_S - 8.3$
T_S
$T_0 + 6443$
SIVB J2 ENGINE MIXTURE RATIO SHIFT
GUIDANCE SHUTDOWN OF SIVB
START SIVB/CSM SEP SEQUENCE
SIVB ENGINES OFF
SIVB GOES TO RATE STABILIZATION MODE WITH ZERO RATE COMMAND
START SIVB/CSM SEPARATE SEQUENCE
START DIRECT ULLAGE
CUTOFF SIVB ENGINES; REDUNDANT FOR NORMAL SEPARATION
FIRE ADAPTER CSM/UMBILICAL DEAD-FACE
SIVB/CSM SEPARATE INDICATION
DIRECT ULLAGE ON
ADAPTER/CSM SEPARATE DEAD-FACED
START SIVB/CSM SEPARATION
COMMAND SIVB/CSM SEPARATE
ARM BACK UP MODE SWITCHING FOR G&N FAIL
MCP UP DATA LINK
SIVB/CSM SEPARATION LOGIC
AGC DOWNLINK
AGC UPLINK
TRACKING ACQUIRED BY ANTIGUA LAT 17°08'36"N LONG 61°47'33"W
GROUND BACKUP OF SIVB/CSM SEP START
GROUND BACKUP OF SIVB/CSM SEPARATION INDICATION
FINE ALIGN MODE
G&N MODE
S&N MONITOR MODE
SCS MODE

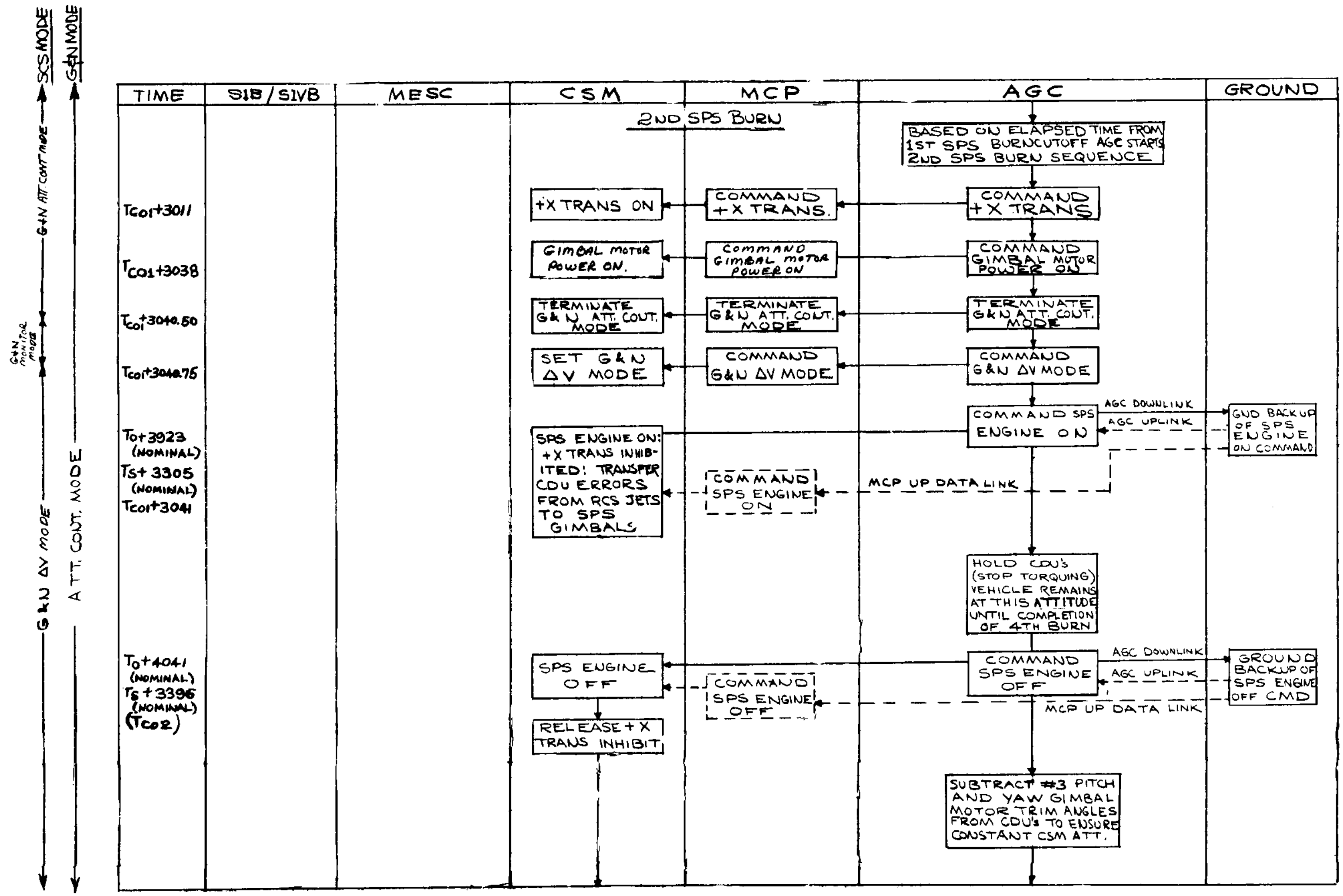

TIME
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
COMMAND + X TRANSLATION
TERMINATE SIVB/CSM SEPARATION COMMAND
SIVB/CSM SEPARATION COMMAND TERMINATED
COMMAND +X TRANSL.
+X TRANS. INHIBITED BY DIRECT ULLAGE.
SIVB THRUST TAIL OFF COMPLETE
ADAPTER FOLD BACK COMPLETE
START V G, THRUST DIR-ECTION AND MANEUVER CALCULATIONS
FIRE ADAPTER CSM SEPARATION SQUIBS
ADAPTER/CSM SEPARATION
DISABLE SPS ENGINE HOLD
SPS ENGINE HOLD DISABLED
SET TRIM POSITION # 1
SPS MOTOR GIMBAL TRIM # 1 INPUTS
OPEN SPS PREPILOT VALVES
PREPILOT VALVES OPENED
ARM SPS SOLONOIDS
ARM SPS SOLONOIDS
ARM G&N MODE CONTROL IN AGC ATT. CONTROL MODE, G&N ΔV MODE, G&N ENTRY MODE; ALSO ARM +X TRANS ON/OFF & CM/SM SEP. CMD.
SET G&N ATT. CONT. MODE COMMANDED AT PRELAUNCH
SCS RCS ENABLE ON
SCS RCS ENABLE ON
ROLL CHANNEL UNDER CONTROL OF ROLL RATE GYRO; ATT. ERROR SIGNAL AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N; PITCH & YAW CHANNEL
Ts
Ts
Ts+1.5
Ts+1.5
Ts+1.7
Ts+2
Ts+2
Ts+2
Ts+2
Ts+2
Ts+2.5
SCS MODE
G&N MODE
G&N MONITOR MODE
FINE ALIGN MODE


S&C MODE
G&N MODE
G&N ATT. CONT. MODE
FINE ALIGN MODE
ATT CONT. MODE
G&N MONITOR MODE
TIME
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
Ts+3.5
Ts+3.5
Ts+T (T IS VARIABLE SEE SEC 3.2.2)
Ts+T (T IS VARIABLE SEE SEC 3.2.2)
Ts+T (T IS VARIABLE SEE SEC 3.2.2)
Ts+12.2
Ts+12.45
DIRECT ULLAGE COMMAND TERMINATED
DIRECT ULLAGE OFF
+X TRANS ON: PITCH & YAW ATT. CONTROL INHIBIT RELEASED: PITCH & YAW CHANNELS UNDER CONTROL OF PITCH AND YAW RATE GYROS: ATT. ERROR SIG AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N
COMMAND G&N SYST. TO ATTITUDE CONTROL MODE
START CDU DRIVE
STOP CDU TORQUING. AGC ASSUMES VEHICLE IS AT CORRECT ORIENTATION FOR 1ST SPS BURN
TERMINATE G&N ATTITUDE CONTROL MODE
TERMINATE G&N ATTITUDE CONTROL MODE
TERMINATE G&N ATTIT. CONTROL MODE
COMMAND G&N ΔV MODE
COMMAND G&N ΔV MODE
SET G&N ΔV MODE

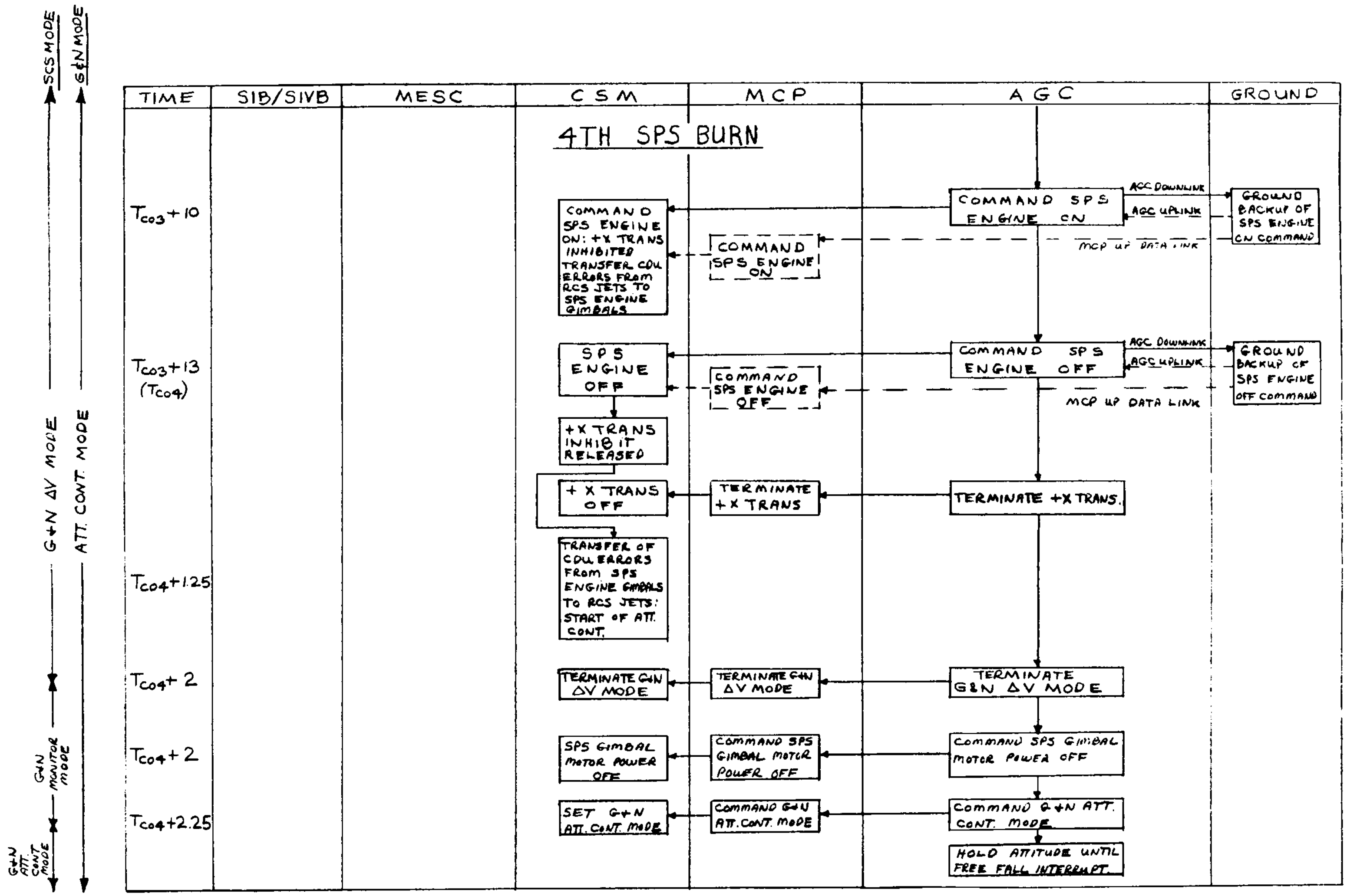

GROUND
AGC
MCP
CSM
MESC
SIB/SIVB
TIME
GROUND BACKUP OF SPS ENGINE ON COMMAND
TRACKING ACQUIRED BY TRACKING SHIP "A" LAT 9°N LONG 41°W
GROUND BACKUP OF SPS ENGINE OFF COMMAND
AGC DOWNLINK
AGC UPLINK
MCP UP DATA LINK
COMMAND SPS ENGINE ON
COMMAND SPS ENGINE OFF
TERMINATE +X TRANS
TERMINATE G&N ΔV MODE
COMMAND SPS ENGINE ON
COMMAND SPS ENGINE OFF
TERMINATE +X TRANS
TERMINATE G&N ΔV MODE
SPS ENGINE ON +X TRANS INHIBITED TRANSFER CDU ERRORS FROM RCS JETS TO SPS GIMBALS
SPS ENGINE OFF
RELEASE +X TRANS INHIBIT
+X TRANS OFF
TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS; START OF ATT. CONTROL
TERMINATE G&N ΔV MODE
$T_S + 127$
$T_0 + 868$
$T_0 + 897.0$ (NOMINAL) T_{C01}
$T_{C01} + 1.25$
$T_{C01} + 2$
ATT CONT MODE
G&N MODE
G&N ΔV MODE
SCS MODE
G&N MONITOR MODE

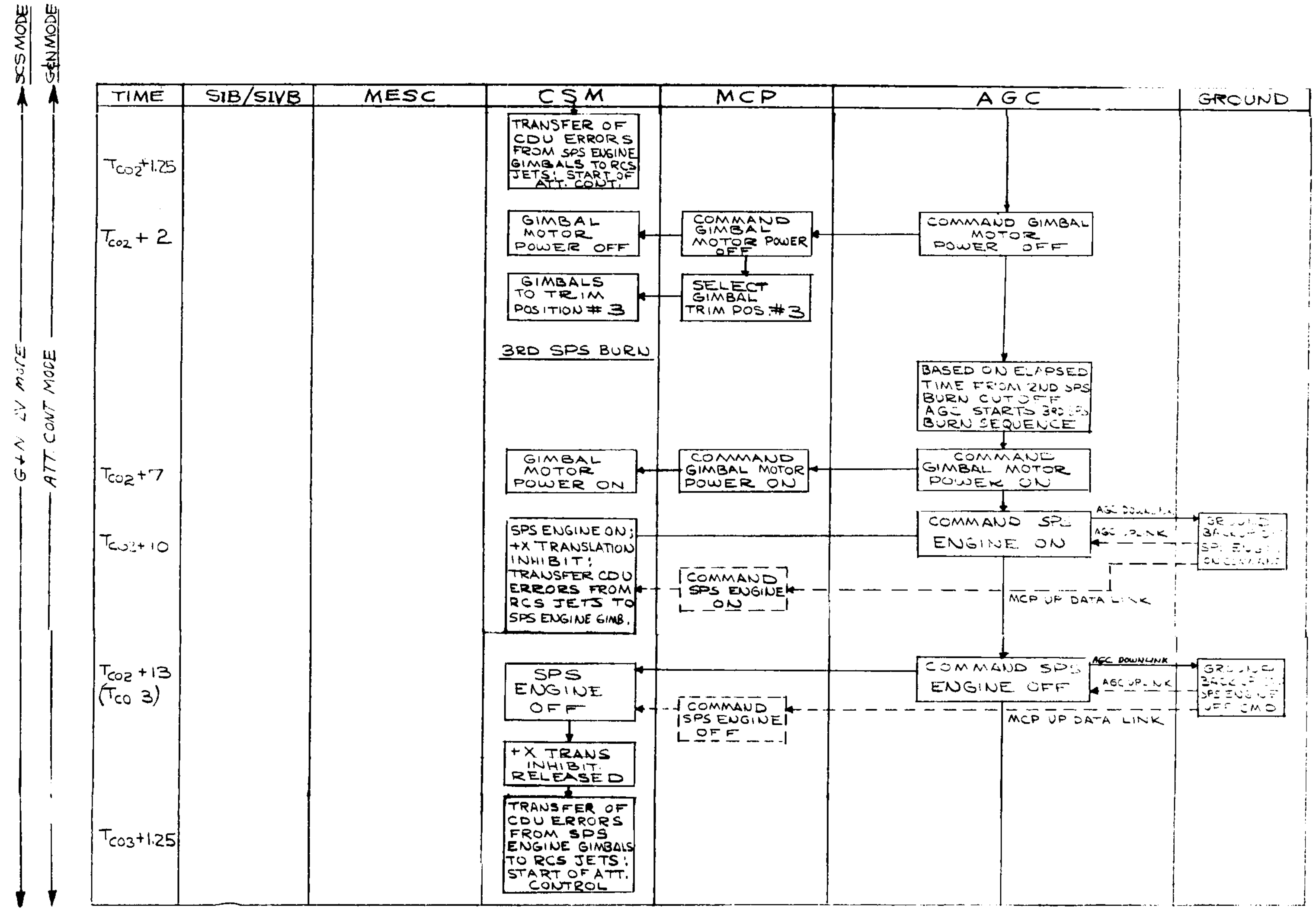

GROUND
AGC
MCP
CSM
MESC
S1B/S1VB
TIME
COMMAND SPS GIMBAL MOTOR POWER OFF
COMMAND G&N ATT. CONTL. MODE
AGC MAKES PRELIMINARY CALCULATION OF REQUIRED THRUST VECTOR & VEHICLE ATTITUDE FOR SECOND SPS IGNITION AT 1ST BURN CUTOFF + 3041 SEC.
COMMAND SPS GIMBAL MOTOR POWER OFF
SELECT GIMB. MTR. TRIM POSIT #2
COMMAND G&N ATT. CONTL. MODE
SPS GIMBAL MOTOR POWER OFF
GIMBALS TO TRIM POSITION #2
SET G&N ATT CONTL. MODE
$T_{CO1}+2$
$T_{CO1}+2.25$
G&N MODE
ATT. CONT. MODE
SCS MODE
G&N MONITOR MODE
G&N ATT. CONT MODE

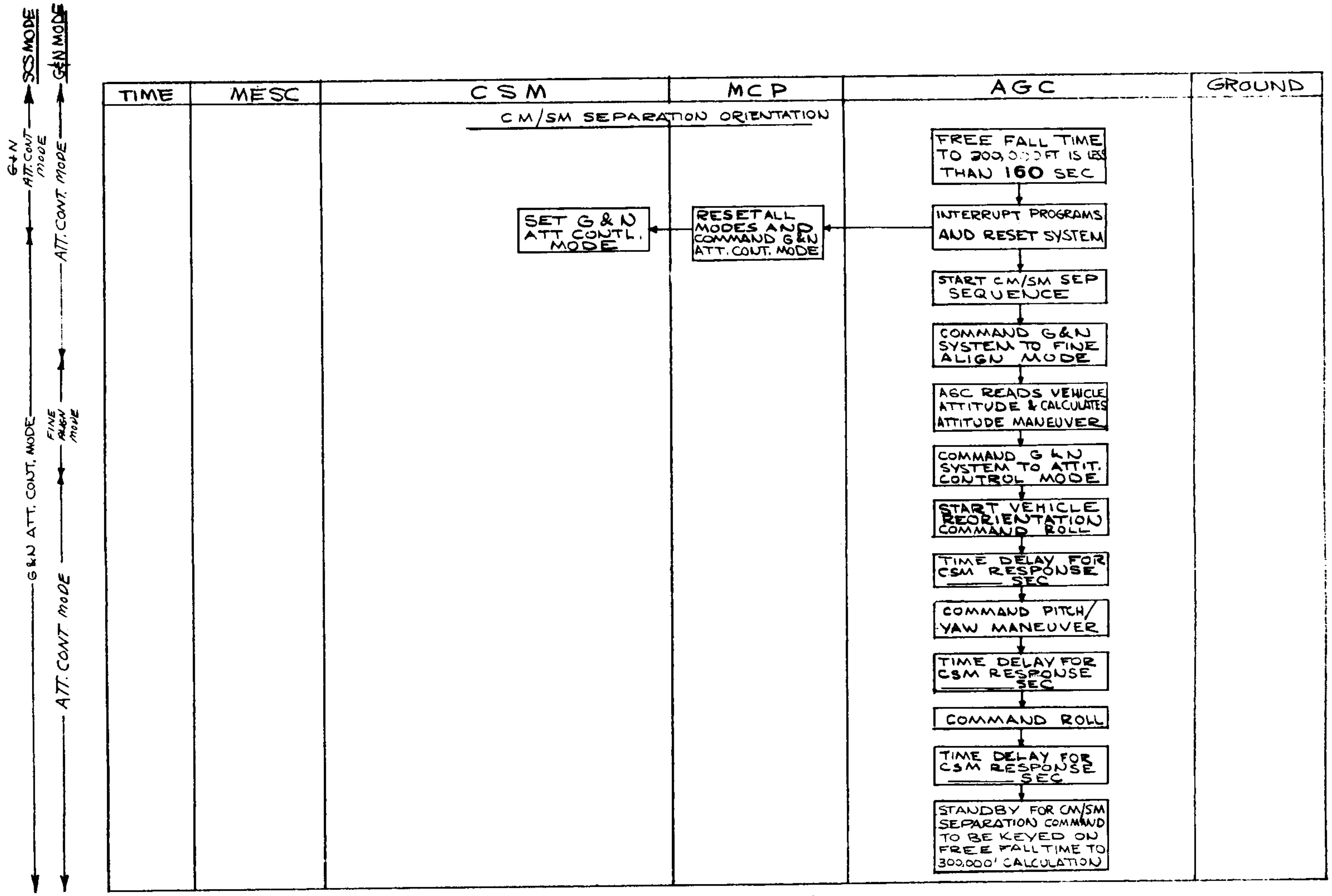

SCS MODE
G&N MODE
TIME
SIB/SVB
MESC
CSM
MCP
AGC
GROUND
COAST
COMPUTE ATTITUDE MANEUVER NECESSARY TO POINT +X AXIS TOWARD EARTH'S CTR
COMMAND MANEUVER NOSE DOWN
COMMAND PITCH/YAW MANEUVER TO TRACK LOCAL VERTICAL.
START FDAI ALIGN
START FDAI ALIGN
COMMAND START FDAI ALIGN
START FDAI ALIGN
STOP FDAI ALIGN
STOP FDAI ALIGN.
10 SEC
To + 1052
TRACKING LOST BY ANTIGUA (B.W.I)
To + 1280
TRACKING ACQUIRED BY ASCENSION.IS. LAT. 07° 57' 05" S LONG. 14° 24' 45" W
To + 1500
TRACKING LOST BY TRACKING SHIP "A"
To + 2320
TRACKING ACQRD. BY PRETORIA S.A. LAT. 25° 56' 14" S LONG. 28° 22' 64" W
To + 2160
TRACKING LOST BY ASCENSION IS
To + 2800
TRACKING LOST BY PRETORIA
820 SEC W/OUT GROUND COVERAGE
To + 2935
Tco1 + 2006
CMD. S/C TO INITIAL ATTITUDE FOR SECOND BURN.
To + 3620
TRACKING ACQ BY CARNARVON, AUST LAT 24° 52' 00" S LONG 113° 38' 00" E
G&N ATT. CONT. MODE
ATT. CONT. MODE

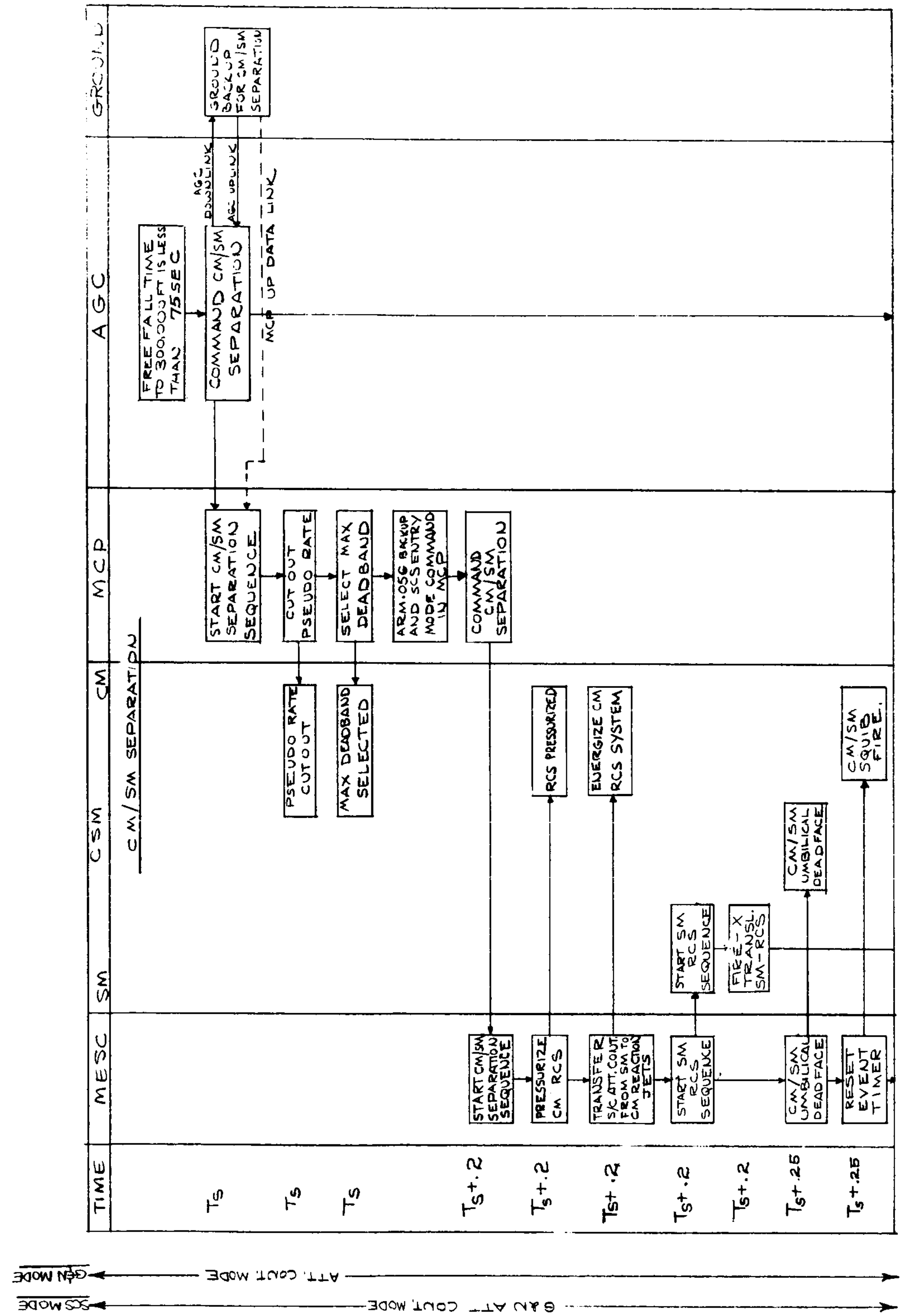


TIME
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
2ND SPS BURN
BASED ON ELAPSED TIME FROM 1ST SPS BURNCUTOFF AGC STARTS 2ND SPS BURN SEQUENCE
Tco1+3011
+X TRANS ON
COMMAND +X TRANS.
COMMAND +X TRANS
Tco1+3038
GIMBAL MOTOR POWER ON.
COMMAND GIMBAL MOTOR POWER ON
COMMAND GIMBAL MOTOR POWER ON
Tco1+3040.50
TERMINATE G&N ATT. CONT. MODE
TERMINATE G&N ATT. CONT. MODE
TERMINATE G&N ATT. CONT. MODE
Tco1+3040.75
SET G&N ΔV MODE
COMMAND G&N ΔV MODE
COMMAND G&N ΔV MODE
To+3923 (NOMINAL)
Ts+3305 (NOMINAL)
Tco1+3041
SPS ENGINE ON: +X TRANS INHIBITED: TRANSFER CDU ERRORS FROM RCS JETS TO SPS GIMBALS
COMMAND SPS ENGINE ON
COMMAND SPS ENGINE ON
MCP UP DATA LINK
AGC DOWNLINK
AGC UPLINK
GND BACKUP OF SPS ENGINE ON COMMAND
HOLD CDU'S (STOP TORQUING) VEHICLE REMAINS AT THIS ATTITUDE UNTIL COMPLETION OF 4TH BURN
To+4041 (NOMINAL)
Ts+3396 (NOMINAL)
(Tco2)
SPS ENGINE OFF
COMMAND SPS ENGINE OFF
COMMAND SPS ENGINE OFF
AGC DOWNLINK
AGC UPLINK
MCP UP DATA LINK
GROUND BACKUP OF SPS ENGINE OFF CMD
RELEASE +X TRANS INHIBIT
SUBTRACT #3 PITCH AND YAW GIMBAL MOTOR TRIM ANGLES FROM CDU's TO ENSURE CONSTANT CSM ATT.
SCS MODE
G&N ATT CONT MODE
G&N MONITOR MODE
G&N ΔV MODE
G&N MODE
ATT. CONT. MODE

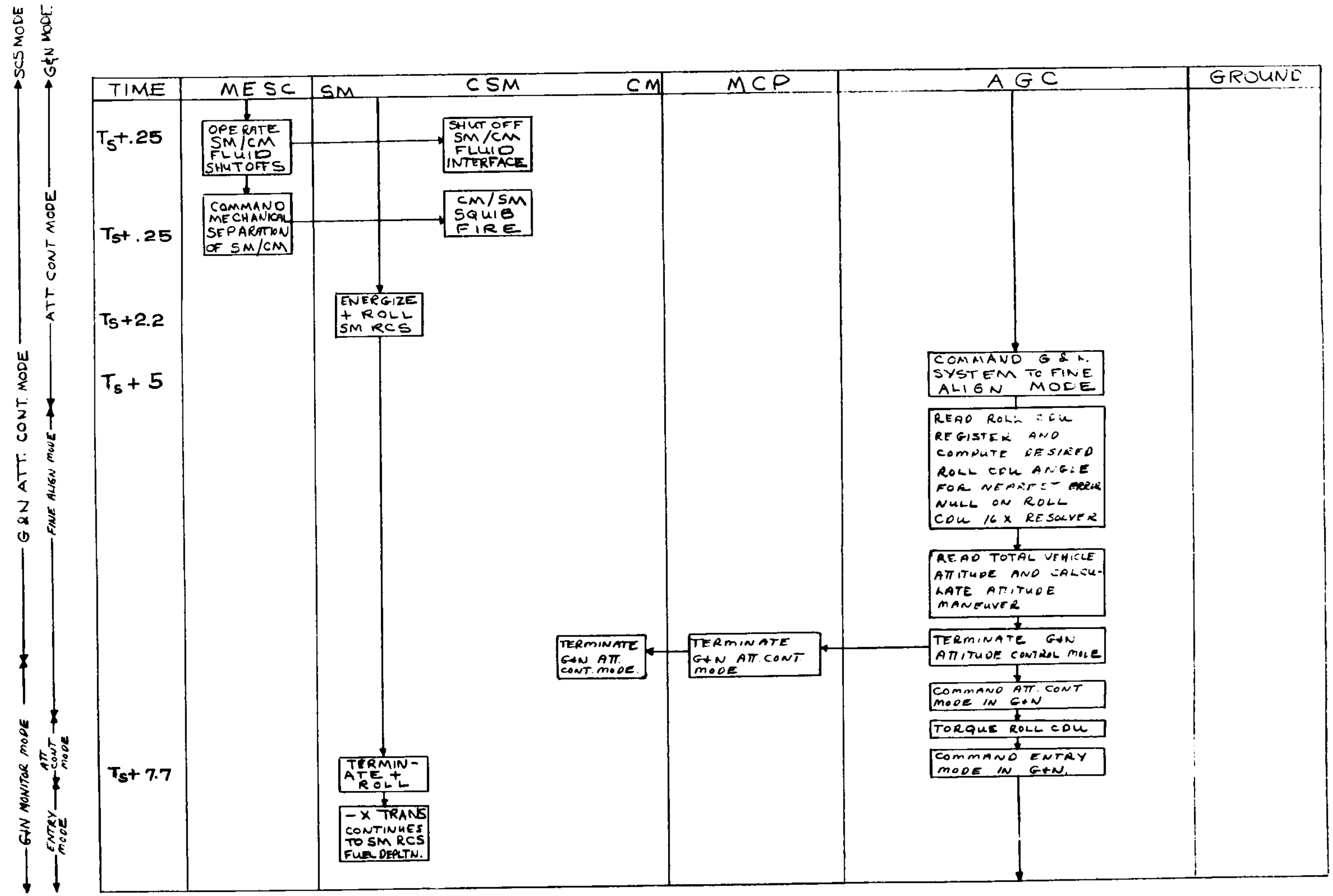

TIME
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
4TH SPS BURN
Tco3+10
Tco3+13
(Tco4)
Tco4+1.25
Tco4+2
Tco4+2
Tco4+2.25
COMMAND SPS ENGINE ON
AGC DOWNLINK
AGC UPLINK
MCP UP DATA LINK
GROUND BACKUP OF SPS ENGINE ON COMMAND
COMMAND SPS ENGINE ON
COMMAND SPS ENGINE ON: +X TRANS INHIBITED TRANSFER COU ERRORS FROM RCS JETS TO SPS ENGINE GIMBALS
COMMAND SPS ENGINE OFF
GROUND BACKUP OF SPS ENGINE OFF COMMAND
COMMAND SPS ENGINE OFF
SPS ENGINE OFF
+X TRANS INHIBIT RELEASED
TERMINATE +X TRANS.
TERMINATE +X TRANS
+ X TRANS OFF
TRANSFER OF COU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS: START OF ATT. CONT.
TERMINATE G&N ΔV MODE
TERMINATE G+N ΔV MODE
TERMINATE G+N ΔV MODE
COMMAND SPS GIMBAL MOTOR POWER OFF
COMMAND SPS GIMBAL MOTOR POWER OFF
SPS GIMBAL MOTOR POWER OFF
COMMAND G+N ATT. CONT. MODE
COMMAND G+N ATT. CONT. MODE
SET G+N ATT. CONT. MODE
HOLD ATTITUDE UNTIL FREE FALL INTERRUPT.
SCS MODE
G+N ΔV MODE
G+N MONITOR MODE
G+N ATT. CONT. MODE
G+N MODE
ATT. CONT. MODE

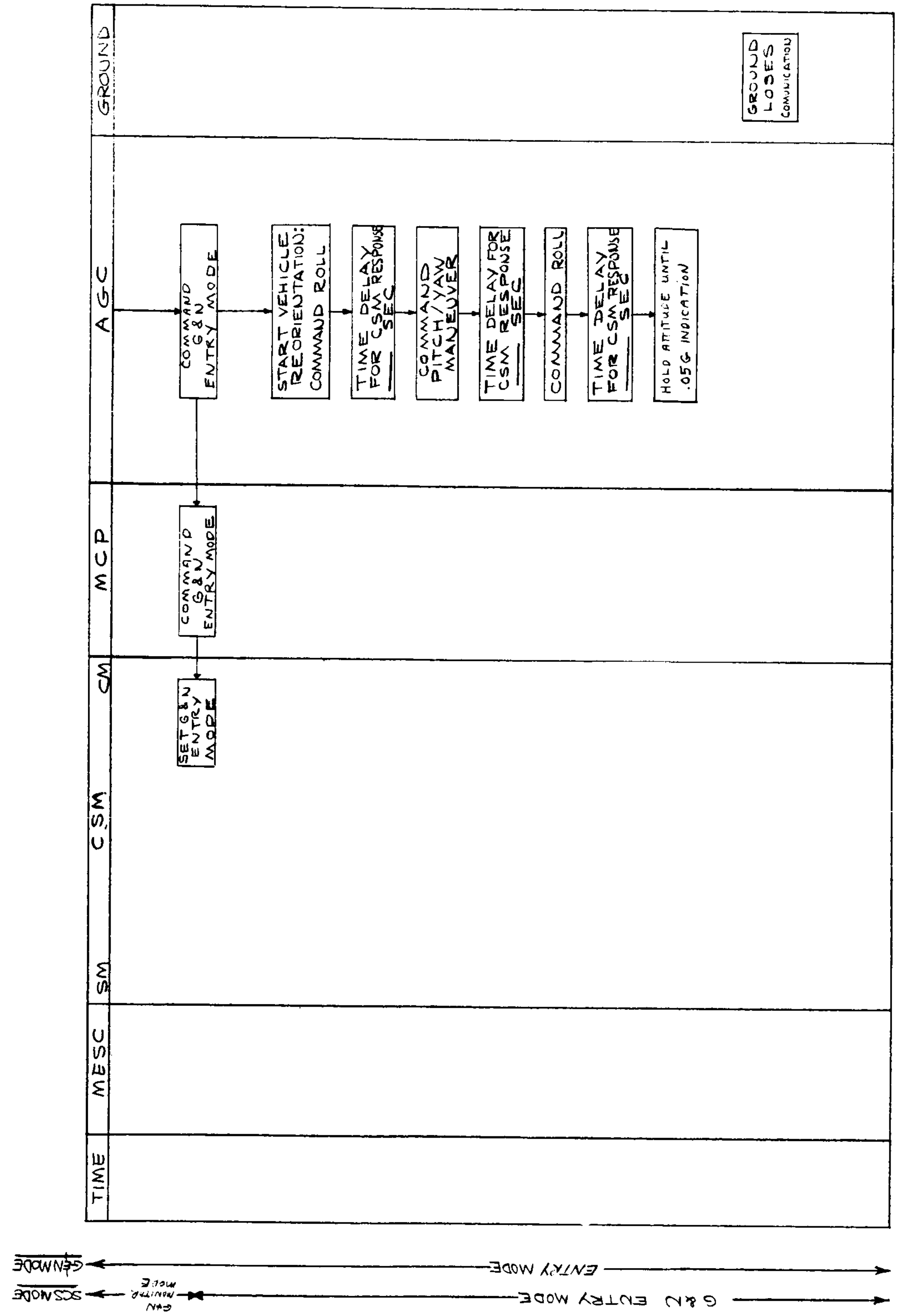

TIME
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
Tco2+1.25
Tco2 + 2
Tco2+7
Tco2+10
Tco2 +13 (Tco 3)
Tco3+1.25
TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS; START OF ATT. CONT.
GIMBAL MOTOR POWER OFF
GIMBALS TO TRIM POSITION #3
3RD SPS BURN
GIMBAL MOTOR POWER ON
SPS ENGINE ON; +X TRANSLATION INHIBIT; TRANSFER CDU ERRORS FROM RCS JETS TO SPS ENGINE GIMB.
SPS ENGINE OFF
+X TRANS INHIBIT RELEASED
TRANSFER OF CDU ERRORS FROM SPS ENGINE GIMBALS TO RCS JETS; START OF ATT. CONTROL
COMMAND GIMBAL MOTOR POWER OFF
SELECT GIMBAL TRIM POS #3
COMMAND GIMBAL MOTOR POWER ON
COMMAND SPS ENGINE ON
COMMAND SPS ENGINE OFF
COMMAND GIMBAL MOTOR POWER OFF
BASED ON ELAPSED TIME FROM 2ND SPS BURN CUTOFF AGC STARTS 3RD SPS BURN SEQUENCE
COMMAND GIMBAL MOTOR POWER ON
COMMAND SPS ENGINE ON
COMMAND SPS ENGINE OFF
MCP UP DATA LINK
AGC DOWNLINK
AGC UPLINK
SCS MODE
G&N MODE
G&N ΔV MODE
ATT. CONT MODE

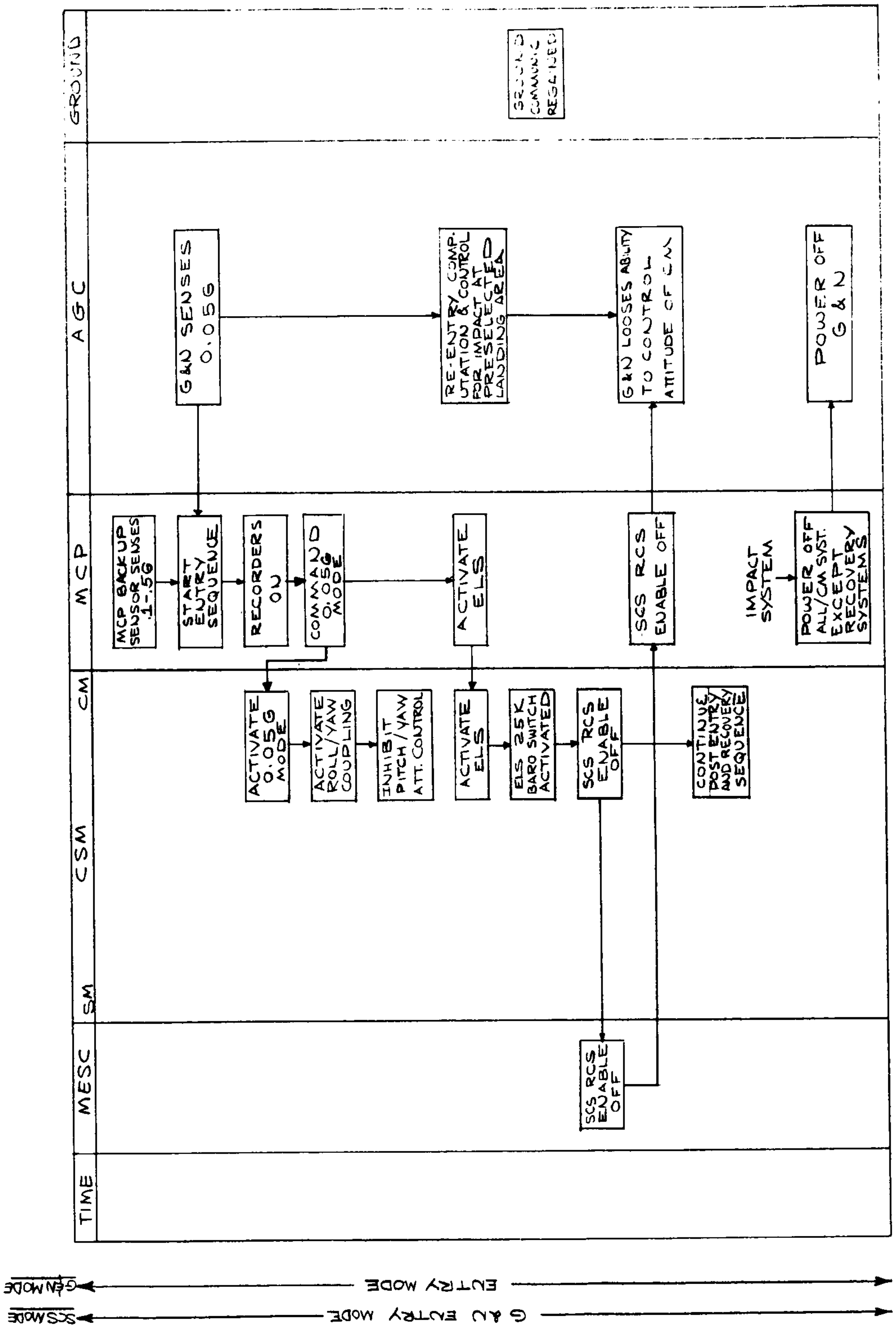

SCS MODE
G&N MODE
G+N ATT. CONT MODE
G&N ATT. CONT. MODE
ATT. CONT. MODE
FINE ALIGN MODE
ATT. CONT MODE
TIME
MESC
CSM
MCP
AGC
GROUND
CM/SM SEPARATION ORIENTATION
FREE FALL TIME TO 300,000 FT IS LESS THAN 160 SEC
INTERRUPT PROGRAMS AND RESET SYSTEM
RESET ALL MODES AND COMMAND G&N ATT. CONT. MODE
SET G & N ATT CONTL. MODE
START CM/SM SEP SEQUENCE
COMMAND G&N SYSTEM TO FINE ALIGN MODE
AGC READS VEHICLE ATTITUDE & CALCULATES ATTITUDE MANEUVER
COMMAND G & N SYSTEM TO ATTIT. CONTROL MODE
START VEHICLE REORIENTATION COMMAND ROLL
TIME DELAY FOR CSM RESPONSE SEC
COMMAND PITCH/ YAW MANEUVER
TIME DELAY FOR CSM RESPONSE SEC
COMMAND ROLL
TIME DELAY FOR CSM RESPONSE SEC
STANDBY FOR CM/SM SEPARATION COMMAND TO BE KEYED ON FREE FALL TIME TO 300,000' CALCULATION



TIME
MESC
SM
CSM
CM
MCP
AGC
GROUND
CM/SM SEPARATION
FREE FALL TIME TO 300,000 FT IS LESS THAN 75 SEC
COMMAND CM/SM SEPARATION
AGC DOWNLINK
AGC UPLINK
GROUND BACKUP FOR CM/SM SEPARATION
MCP UP DATA LINK
START CM/SM SEPARATION SEQUENCE
CUT OUT PSEUDO RATE
SELECT MAX DEADBAND
ARM .05G BACKUP AND SCS ENTRY MODE COMMAND IN MCP
COMMAND CM/SM SEPARATION
PSEUDO RATE CUT OUT
MAX DEADBAND SELECTED
RCS PRESSURIZED
ENERGIZE CM RCS SYSTEM
CM/SM SQUIB FIRE
CM/SM UMBILICAL DEADFACE
START SM RCS SEQUENCE
FIRE -X TRANSL. SM-RCS
START CM/SM SEPARATION SEQUENCE
PRESSURIZE CM RCS
TRANSFER S/C ATT. CONT. FROM SM TO CM REACTION JETS
START SM RCS SEQUENCE
CM/SM UMBILICAL DEADFACE
RESET EVENT TIMER
Ts
Ts
Ts
Ts+.2
Ts+.2
Ts+.2
Ts+.2
Ts+.2
Ts+.25
Ts+.25
ATT. CONT. MODE
GEN MODE
G&N ATT. CONT. MODE
SCS MODE


TIME
MESC
SM
CSM
CM
MCP
AGC
GROUND
Ts+.25
Ts+.25
Ts+2.2
Ts+5
Ts+7.7
OPERATE SM/CM FLUID SHUTOFFS
COMMAND MECHANICAL SEPARATION OF SM/CM
SHUT OFF SM/CM FLUID INTERFACE
CM/SM SQUIB FIRE
ENERGIZE + ROLL SM RCS
TERMINATE + ROLL
-X TRANS CONTINUES TO SM RCS FUEL DEPLTN.
COMMAND G&N SYSTEM TO FINE ALIGN MODE
READ TOTAL VEHICLE ATTITUDE AND CALCULATE ATTITUDE MANEUVER
TERMINATE G+N ATTITUDE CONTROL MODE
COMMAND ATT. CONT MODE IN G+N
TORQUE ROLL CDU
COMMAND ENTRY MODE IN G+N.
TERMINATE G+N ATT. CONT MODE
TERMINATE G+N ATT. CONT. MODE.
SCS MODE
G&N ATT. CONT. MODE
G+N MONITOR MODE
G&N MODE
ATT CONT MODE
FINE ALIGN MODE
ATT CONT MODE
ENTRY MODE


GROUND
GROUND LOSES COMMUNICATION
AGC
COMMAND G&N ENTRY MODE
START VEHICLE REORIENTATION: COMMAND ROLL
TIME DELAY FOR CSM RESPONSE SEC
COMMAND PITCH/YAW MANEUVER
TIME DELAY FOR CSM RESPONSE SEC
COMMAND ROLL
TIME DELAY FOR CSM RESPONSE SEC
HOLD ATTITUDE UNTIL .05G INDICATION
MCP
COMMAND G&N ENTRY MODE
CM
SET G&N ENTRY MODE
CSM
SM
MESC
TIME
G&N MODE
ENTRY MODE
SCS MODE
G&N MONITOR MODE
G&N ENTRY MODE


GROUND
AGC
MCP
CM
CSM
SM
MESC
TIME
G&N SENSES 0.05G
RE-ENTRY COMPUTATION & CONTROL FOR IMPACT AT PRESELECTED LANDING AREA
G&N LOOSES ABILITY TO CONTROL ATTITUDE OF CM
POWER OFF G & N
MCP BACKUP SENSOR SENSES .1-.5G
START ENTRY SEQUENCE
RECORDERS ON
COMMAND 0.05G MODE
ACTIVATE ELS
SCS RCS ENABLE OFF
IMPACT SYSTEM
POWER OFF ALL/CM SYST. EXCEPT RECOVERY SYSTEMS
ACTIVATE 0.05G MODE
ACTIVATE ROLL/YAW COUPLING
INHIBIT PITCH/YAW ATT. CONTROL
ACTIVATE ELS
ELS 25K BARO SWITCH ACTIVATED
SCS RCS ENABLE OFF
CONTINUE POST ENTRY AND RECOVERY SEQUENCE
SCS RCS ENABLE OFF
G&N MODE
ENTRY MODE
SCS MODE
G&N ENTRY MODE

3.2.2 AGC Program Logic, Mission 202

The following diagrams illustrate the AGC logic for Mission 202. Each group of logical decisions and/or computations enclosed within a dotted line represents a routine. Routines marked * are performed at a specified time under AGC waitlist control. Such routines cannot be interrupted by an other AGC activity and will run to completion.

The terminology used is defined as follows:

Call - Cause a specified routine (an AGC "waitlist task") to be started at a specific time. Waitlist tasks are designated * (a task called once at a specified time) or ** (a task which, once called, continues until terminated)

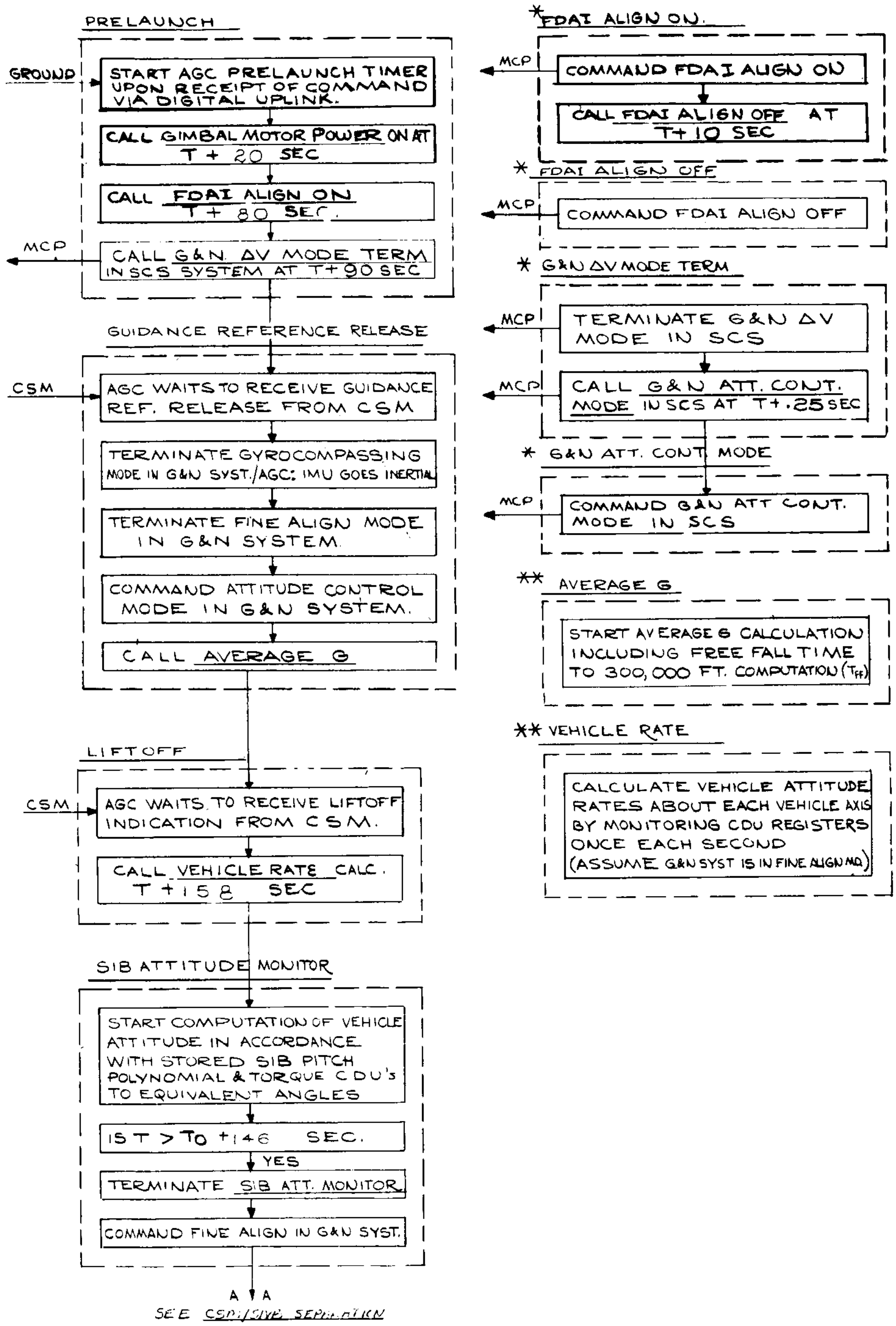
Go To - Branch to another part of the program without return

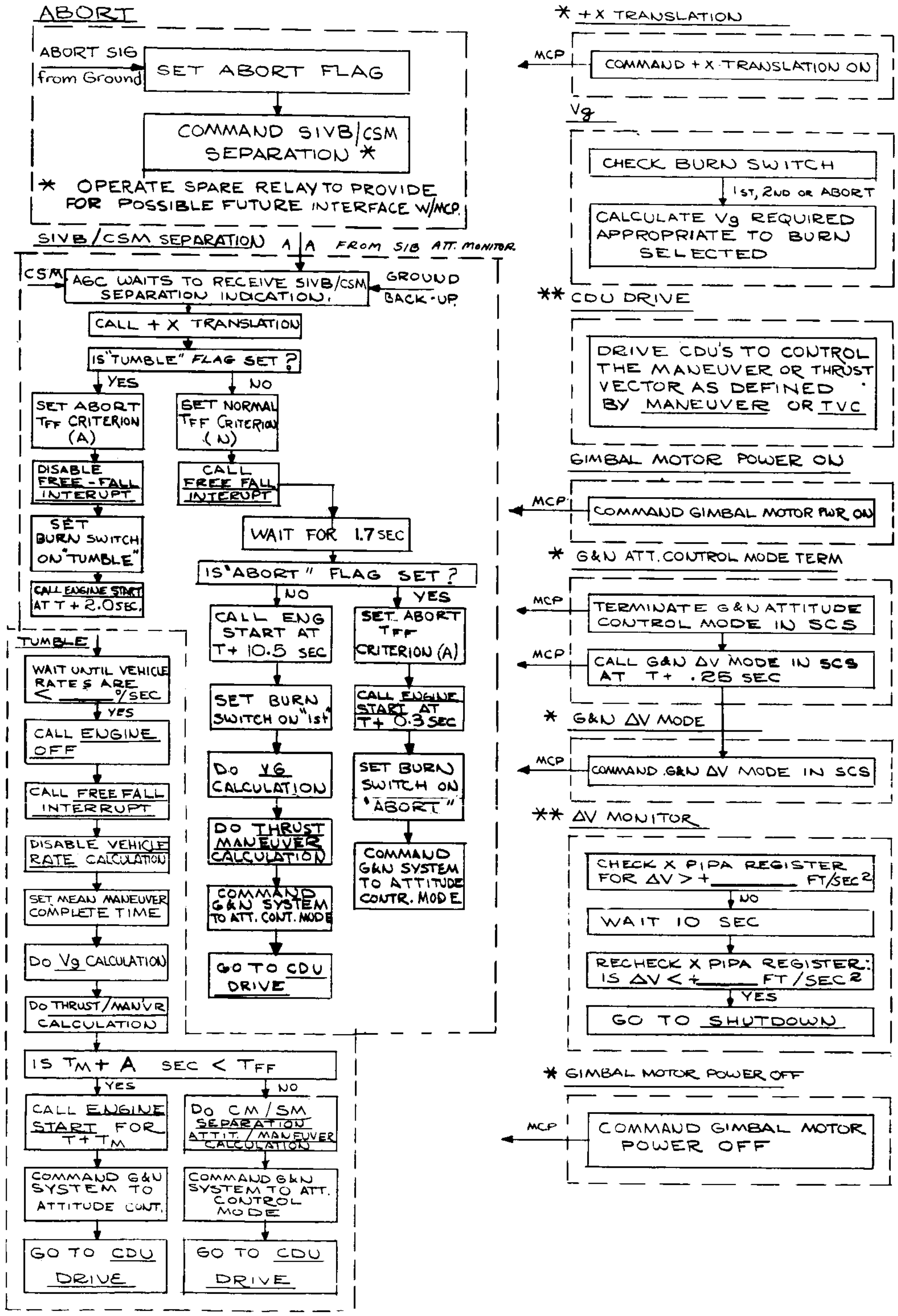
Do - Branch to a routine with a return to the next operation in sequence.

Set - A permanent change of state of a flag or register valid until being reset.

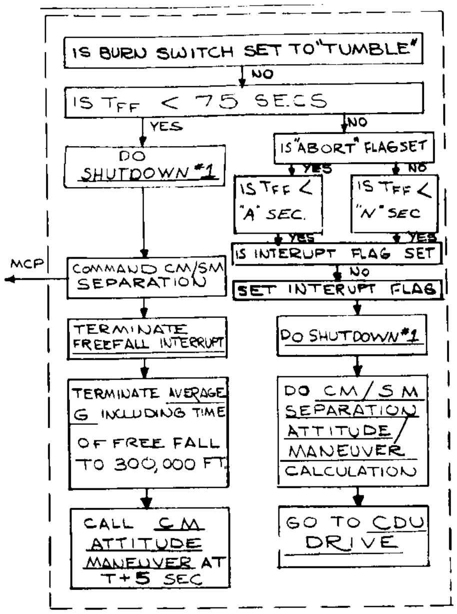
T - Present time.

Store - Store indicated quantity in erasable for future reference.

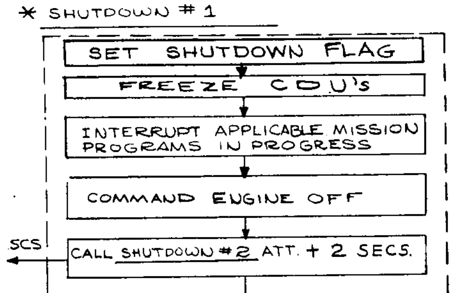

PRELAUNCH
GROUND
START AGC PRELAUNCH TIMER UPON RECEIPT OF COMMAND VIA DIGITAL UPLINK.
CALL GIMBAL MOTOR POWER ON AT T + 20 SEC
CALL FDAI ALIGN ON T + 80 SEC.
MCP
CALL G&N ΔV MODE TERM IN SCS SYSTEM AT T+90 SEC
GUIDANCE REFERENCE RELEASE
CSM
AGC WAITS TO RECEIVE GUIDANCE REF. RELEASE FROM CSM
TERMINATE GYROCOMPASSING MODE IN G&N SYST./AGC; IMU GOES INERTIAL
TERMINATE FINE ALIGN MODE IN G&N SYSTEM.
COMMAND ATTITUDE CONTROL MODE IN G&N SYSTEM.
CALL AVERAGE G
LIFTOFF
CSM
AGC WAITS TO RECEIVE LIFTOFF INDICATION FROM CSM.
CALL VEHICLE RATE CALC. T + 158 SEC
SIB ATTITUDE MONITOR
START COMPUTATION OF VEHICLE ATTITUDE IN ACCORDANCE WITH STORED SIB PITCH POLYNOMIAL & TORQUE CDU's TO EQUIVALENT ANGLES
IS T > To +146 SEC.
YES
TERMINATE SIB ATT. MONITOR
COMMAND FINE ALIGN IN G&N SYST.
A A
*FDAI ALIGN ON.
MCP
COMMAND FDAI ALIGN ON
CALL FDAI ALIGN OFF AT T+10 SEC
* FDAI ALIGN OFF
MCP
COMMAND FDAI ALIGN OFF
* G&N ΔV MODE TERM
MCP
TERMINATE G&N ΔV MODE IN SCS
MCP
CALL G&N ATT. CONT. MODE IN SCS AT T+.25 SEC
* G&N ATT. CONT. MODE
MCP
COMMAND G&N ATT CONT. MODE IN SCS
** AVERAGE G
START AVERAGE G CALCULATION INCLUDING FREE FALL TIME TO 300,000 FT. COMPUTATION (T_{FF})
** VEHICLE RATE
CALCULATE VEHICLE ATTITUDE RATES ABOUT EACH VEHICLE AXIS BY MONITORING CDU REGISTERS ONCE EACH SECOND (ASSUME G&N SYST IS IN FINE ALIGN MO)


ABORT
ABORT SIG from Ground
SET ABORT FLAG
COMMAND SIVB/CSM SEPARATION *
* OPERATE SPARE RELAY TO PROVIDE FOR POSSIBLE FUTURE INTERFACE W/MCP.
SIVB/CSM SEPARATION
A
A FROM S/B ATT. MONITOR.
CSM
AGC WAITS TO RECEIVE SIVB/CSM SEPARATION INDICATION.
GROUND BACK-UP
CALL +X TRANSLATION
IS "TUMBLE" FLAG SET ?
YES
NO
SET ABORT TFF CRITERION (A)
SET NORMAL TFF CRITERION (N)
DISABLE FREE-FALL INTERUPT
CALL FREE FALL INTERUPT
SET BURN SWITCH ON "TUMBLE"
WAIT FOR 1.7 SEC
CALL ENGINE START AT T + 2.0 SEC.
IS "ABORT" FLAG SET ?
NO
YES
CALL ENG START AT T+ 10.5 SEC
SET ABORT TFF CRITERION (A)
SET BURN SWITCH ON "1st"
CALL ENGINE START AT T+ 0.3 SEC
DO VG CALCULATION
SET BURN SWITCH ON "ABORT"
DO THRUST MANEUVER CALCULATION
COMMAND G&N SYSTEM TO ATTITUDE CONTR. MODE
COMMAND G&N SYSTEM TO ATT. CONT. MODE
GO TO CDU DRIVE
TUMBLE
WAIT UNTIL VEHICLE RATES ARE < ___ °/SEC
YES
CALL ENGINE OFF
CALL FREE FALL INTERUPT
DISABLE VEHICLE RATE CALCULATION
SET MEAN MANEUVER COMPLETE TIME
DO Vg CALCULATION
DO THRUST/MANVR CALCULATION
IS TM + A SEC < TFF
YES
NO
CALL ENGINE START FOR T+TM
DO CM/SM SEPARATION ATTIT. / MANEUVER CALCULATION
COMMAND G&N SYSTEM TO ATTITUDE CONT.
COMMAND G&N SYSTEM TO ATT. CONTROL MODE
GO TO CDU DRIVE
GO TO CDU DRIVE
* +X TRANSLATION
MCP
COMMAND +X TRANSLATION ON
Vg
CHECK BURN SWITCH
1st, 2nd or ABORT
CALCULATE Vg REQUIRED APPROPRIATE TO BURN SELECTED
** CDU DRIVE
DRIVE CDU'S TO CONTROL THE MANEUVER OR THRUST VECTOR AS DEFINED BY MANEUVER OR TVC
GIMBAL MOTOR POWER ON
MCP
COMMAND GIMBAL MOTOR PWR ON
* G&N ATT. CONTROL MODE TERM
MCP
TERMINATE G&N ATTITUDE CONTROL MODE IN SCS
MCP
CALL G&N ΔV MODE IN SCS AT T+ .25 SEC
* G&N ΔV MODE
MCP
COMMAND G&N ΔV MODE IN SCS
** ΔV MONITOR
CHECK X PIPA REGISTER FOR ΔV > + ________ FT/SEC²
NO
WAIT 10 SEC
RECHECK X PIPA REGISTER: IS ΔV < + ________ FT/SEC²
YES
GO TO SHUTDOWN
* GIMBAL MOTOR POWER OFF
MCP
COMMAND GIMBAL MOTOR POWER OFF

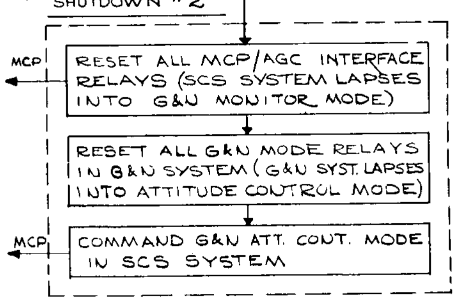
** FREEFALL INTERRUPT



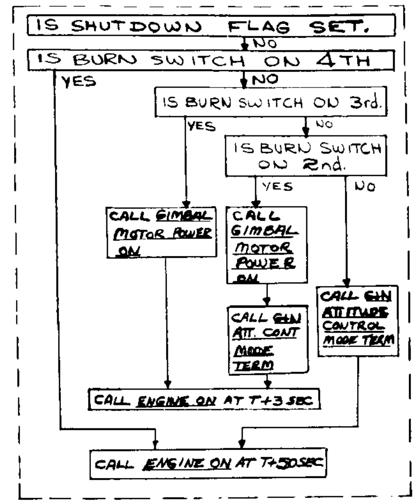
* SHUTDOWN # 1



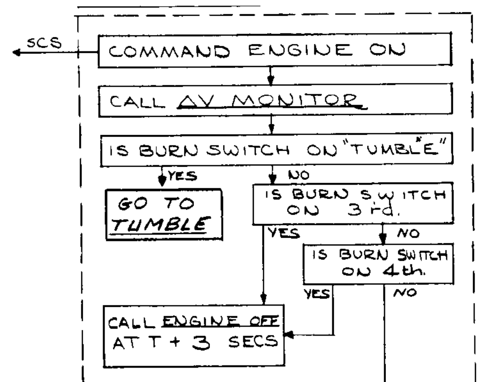
* SHUTDOWN #2



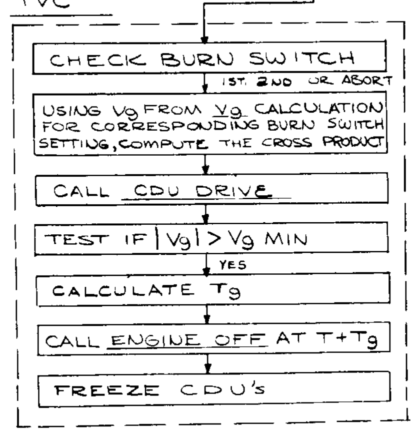
* ENGINE START

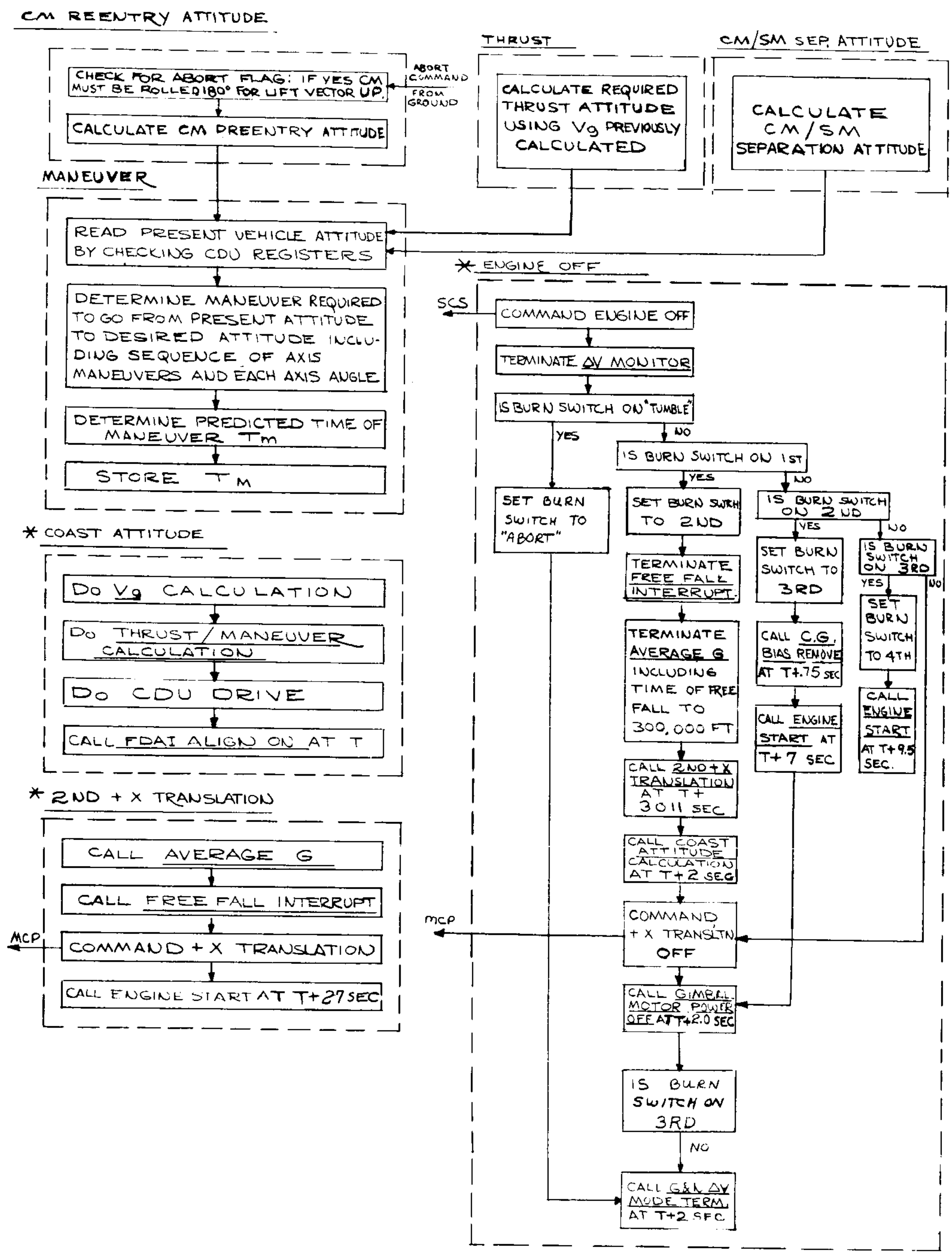


* ENGINE ON

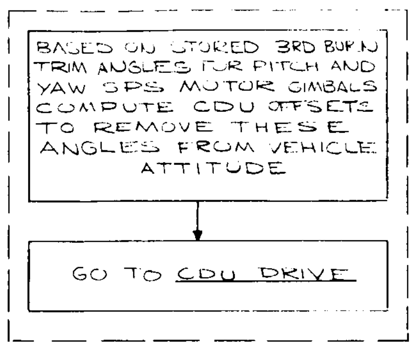


TVC

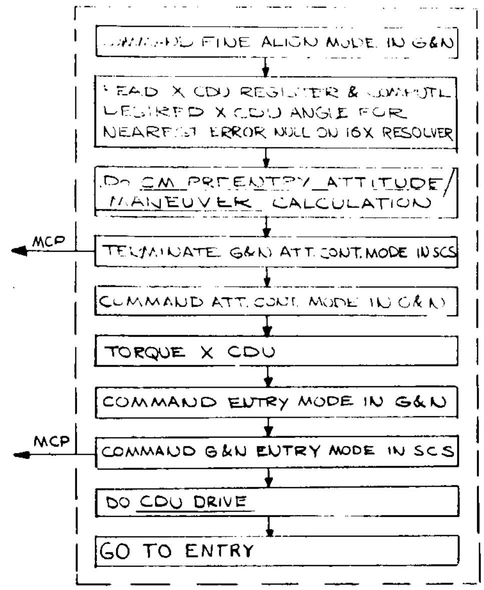



CM REENTRY ATTITUDE
CHECK FOR ABORT FLAG: IF YES CM MUST BE ROLLED 180° FOR LIFT VECTOR UP
ABORT COMMAND FROM GROUND
CALCULATE CM PREENTRY ATTITUDE
THRUST
CALCULATE REQUIRED THRUST ATTITUDE USING Vg PREVIOUSLY CALCULATED
CM/SM SEP. ATTITUDE
CALCULATE CM/SM SEPARATION ATTITUDE
MANEUVER
READ PRESENT VEHICLE ATTITUDE BY CHECKING CDU REGISTERS
DETERMINE MANEUVER REQUIRED TO GO FROM PRESENT ATTITUDE TO DESIRED ATTITUDE INCLUDING SEQUENCE OF AXIS MANEUVERS AND EACH AXIS ANGLE
DETERMINE PREDICTED TIME OF MANEUVER Tm
STORE TM
* COAST ATTITUDE
DO Vg CALCULATION
DO THRUST/MANEUVER CALCULATION
DO CDU DRIVE
CALL FDAI ALIGN ON AT T
* 2ND + X TRANSLATION
CALL AVERAGE G
CALL FREE FALL INTERRUPT
MCP
COMMAND + X TRANSLATION
CALL ENGINE START AT T+27 SEC
* ENGINE OFF
SCS
COMMAND ENGINE OFF
TERMINATE ΔV MONITOR
IS BURN SWITCH ON "TUMBLE"
YES
NO
IS BURN SWITCH ON 1ST
SET BURN SWITCH TO "ABORT"
SET BURN SWITCH TO 2ND
IS BURN SWITCH ON 2ND
SET BURN SWITCH TO 3RD
IS BURN SWITCH ON 3RD
SET BURN SWITCH TO 4TH
TERMINATE FREE FALL INTERRUPT
TERMINATE AVERAGE G INCLUDING TIME OF FREE FALL TO 300,000 FT
CALL C.G. BIAS REMOVE AT T+.75 SEC
CALL ENGINE START AT T+7 SEC
CALL ENGINE START AT T+9.5 SEC.
CALL 2ND + X TRANSLATION AT T+ 30.11 SEC
CALL COAST ATTITUDE CALCULATION AT T+2 SEC
MCP
COMMAND + X TRANSLTN OFF
CALL GIMBAL MOTOR POWER OFF AT T+2.0 SEC
IS BURN SWITCH ON 3RD
NO
CALL G&N ΔV MODE TERM. AT T+2 SEC

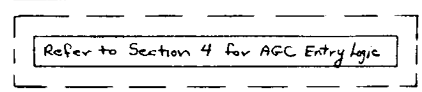
* C.G. BIAS REMOVE



* CM ATTITUDE MANEUVER



ENTRY



4. GUIDANCE EQUATIONS FOR CSM

4.1 Powered Flight Guidance Scheme

The guidance scheme for Mission 202 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

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

Differentiation of both sides yields

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

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

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

where

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

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

$$\underline{a}_{T_D} * \underline{v}_g = c\underline{b} * \underline{v}_g \tag{6}$$

where c is a constant scalar.

*Indicates vector cross product

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

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

where

$$\underline{\dot{m}} = c\underline{b} - \underline{a}_T \tag{8}$$

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 as the steering command.

Once a required velocity $\underline{v}_r$ is defined satisfactorily, the procedure for the generation of the steering command $\underline{\omega}_c$ 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.

4.2 Nominal Mission

4.2.1 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 major axis a, and eccentricity e). The values used are

	First Burn	Second Burn
a	2.22806×10^7	2.82776×10^7
e	0.102415	0.252865

These numbers correspond to the trajectory described in Section 5. The value of c in Eq. (6) is 1.

The required velocity can be written as

$$\underline{v}_r = \underline{i}_r\ v_{rad} + i_H\ v_H \tag{9}$$

where

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

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

$$p = a(1 - e^2) \qquad (12)$$

$$\underline{i}_r = \frac{\underline{r}}{|\underline{r}|} \qquad (13)$$

and

$$\underline{i}_H = \text{UNIT}\ (\underline{i}_N * \underline{i}_r) \qquad (14)$$

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

4.2.2 Yaw Steering

Plane control during the nominal mission is achieved by specifying the normal ($\underline{i}_N$) to the required plane appearing in Eq. (14). The required trajectory plane is defined to be the plane containing the present position vector ($\underline{r}$) and the landing site vector ($\underline{r}_{LS}$; 14.9N, 165.6E) at the nominal time (5090 sec) of landing and is given by

$$\underline{i}_N = \text{UNIT}\ (\underline{r} * \underline{r}_{LS})\ \text{Sign}\left[(\underline{r} * \underline{r}_{LS}) \cdot \underline{i}_w\right] \qquad (15)$$

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. (9) and (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.

4.2.3 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 12.7 seconds after receipt of SIV-B/CSM separation signal, the second burn 3041 seconds after first burn cutoff, the third burn 10 seconds after second burn cutoff and the fourth burn 10 seconds after third burn cutoff.

4.2.4 Engine Cutoff

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

$$T_g = |\underline{v}_g| / |\underline{a}_T| \tag{16}$$

The accuracy of T_g increases as $T_g \to 0$, because as $|\underline{v}_g| \to 0, |\underline{b}| \to 0$.

For the first burn, when T_g falls, for the first time, below the computational repetitive interval of Δt, the clock is set to turn off the engine T_g seconds later. The second burn is turned off the moment T_g falls below 6 seconds for the first time.

In the third and fourth burns the engine is turned off 3 seconds after ignition.

4.3 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 the 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. 4.1).

4.3.1 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,

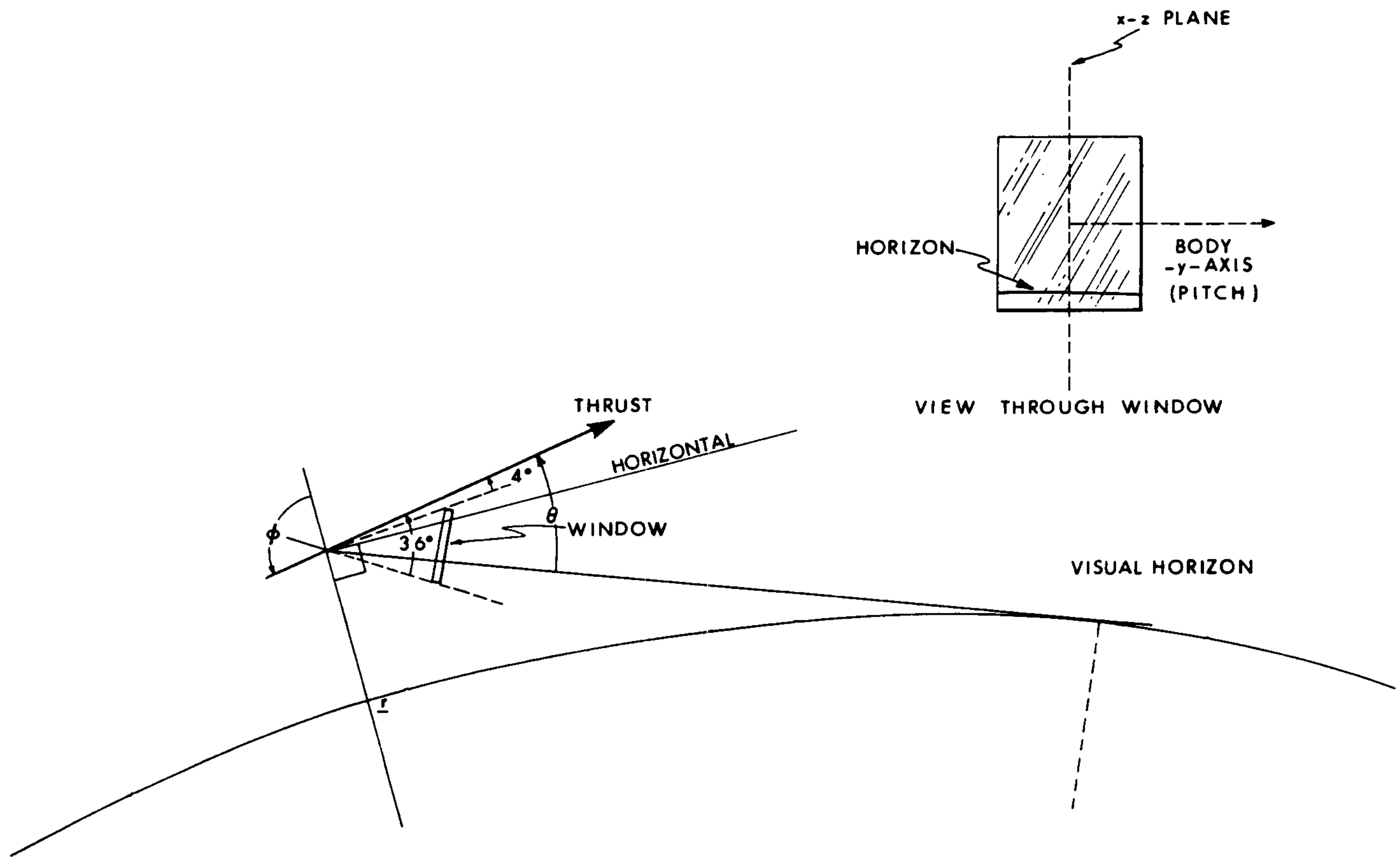


Fig. 4-1 Window Geometry

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 (300,000 ft) corresponding to a free fall from the present position. Then we can write

$$x = \cot\left(\frac{\theta_f}{2}\right) \quad (17)$$

$$= \frac{r_e \cot \gamma + r \cot \gamma_e}{r_e - r} \quad (18)$$

and

$$\sin \theta_f = \frac{2x}{x^2 + 1} \quad (19)$$

$$\cos \theta_f = \frac{x^2 - 1}{x^2 + 1} \quad (20)$$

where

$$\cot \gamma = \frac{\underline{v} \cdot \underline{i}_r}{\underline{v} \cdot \underline{i}_H} \quad (21)$$

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

$$\underline{i}_H' = \underline{i}_p * \underline{i}_r \quad (23)$$

$$\underline{i}_p = \text{UNIT } (\underline{r} * \underline{v}) \quad (24)$$

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

r_e is the radius at 300,000 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

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

Now, let $\underline{r}_T$ be the desired entry point (target vector). The error d can be written as

$$d = \left| \underline{r}_T - \underline{r}_e \right| \tag{26}$$

The target vector is the inertial position of 14.3926°N latitude and 313° longitude at 975 seconds from lift-off. This choice corresponds to minimum plane change for aborts at 617.4 seconds from the nominal boost trajectory.

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

$$\dot{d} = \frac{\Delta d}{\Delta t} \tag{27}$$

$$\cong \left| \underline{r}_{e_n} - \underline{r}_{e_{n-1}} \right| / \Delta t \tag{28}$$

where the subscript n denotes the nth computational repetition

Observing that $d/\dot{d}$ is a measure of the time to cutoff (T_g) and that T_g according to Eq. (16) is $|\underline{v}_g| / |\underline{a}_T|$ in the general scheme, the magnitude of $\underline{v}_g$ is defined as

$$|\underline{v}_g| = \frac{d}{\dot{d}} |\underline{a}_T| \tag{29}$$

or

$$|\underline{v}_g| = \frac{d}{\Delta d} |\underline{\Delta v}| \tag{30}$$

where $\underline{\Delta v}$ is the velocity increment measured with the accelerometers in the interval Δt.

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

$$\underline{a}_{T_D} * \underline{v}_g = 0 \tag{31}$$

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 4-1 shows the geometry of the spacecraft window. The angle ϕ between the thrust and $\underline{r}$ is given by

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

where θ is the specified angle (35°) to the horizon and R_{vh} is the radius to the visual horizon.

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

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

4.3.2 Yaw and Roll Steering

The development of Eq. (33) is based on $\underline{i}_r$ and $\underline{i}_{H'}$ which are both in the present trajectory plane according to Eq. (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 $\underline{r}$ and the target vector (See Section 4.3.1) $\underline{r}_T$ be defined by

$$\underline{i}_N = \text{UNIT}\,(\underline{r} * \underline{r}_T)\ \text{Sign}\ [(\underline{r} * \underline{r}_T)\cdot \underline{i}_w] \qquad (34)$$

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. 4-2).

$$\Delta v_N = |v|\,(\underline{i}_p * \underline{i}_N)\cdot \underline{i}_r \qquad (35)$$

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

$$\underline{a}_N = \underline{i}_p \frac{\Delta v_N}{T_g + \delta} \qquad (36)$$

where δ is a small scalar (5 seconds). In order to prevent large yaw rate commands, a limit of 5 ft/sec² is imposed on $|\underline{a}_{N_n} - \underline{a}_{N_{n-1}}|$.

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

$$\underline{v}_g = \underline{i}_T \frac{d}{\Delta d} |\Delta v| \tag{37}$$

where

$$\underline{i}_T = \left[\text{UNIT} \quad - \underline{i}_r \cos\phi + \text{UNIT}\,(i_{H'}\, a_T + \underline{a}_n) \sin\phi \right] \tag{38}$$

and a_T is the magnitude of the thrust acceleration.

The required velocity is given by

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

where $\underline{v}_g$ is given by Eq. (37). With the required velocity so computed and with c = 0, the same steering (Eq. 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. 4-1) This is achieved by generating a roll command ($\underline{\omega}_R$) from

$$\underline{\omega}_R = -(\underline{i}_R \quad \underline{i}_{pitch})\ \underline{i}_{roll} \tag{39a}$$

The negative sign is the result of the desired orientation in which the spacecraft $\underline{z}$ - axis is pointed up.

The roll rate command is added to the rate command generated from Eq. (7). Note that the roll rate computed according to Eq. (39a) must not be commanded unless the spacecraft z-axis is within 90° of local vertical.

4.3.3 Engine Ignition

In the case of a non-tumbling abort the engine is ignited 2.5 secs after receipt of the SIV-B/CSM separation signal.

If tumbling has been detected by the time the separation signal is received, the engine is ignited 2.5 secs later and is shut down when tumbling has been arrested. If the capability of landing area control

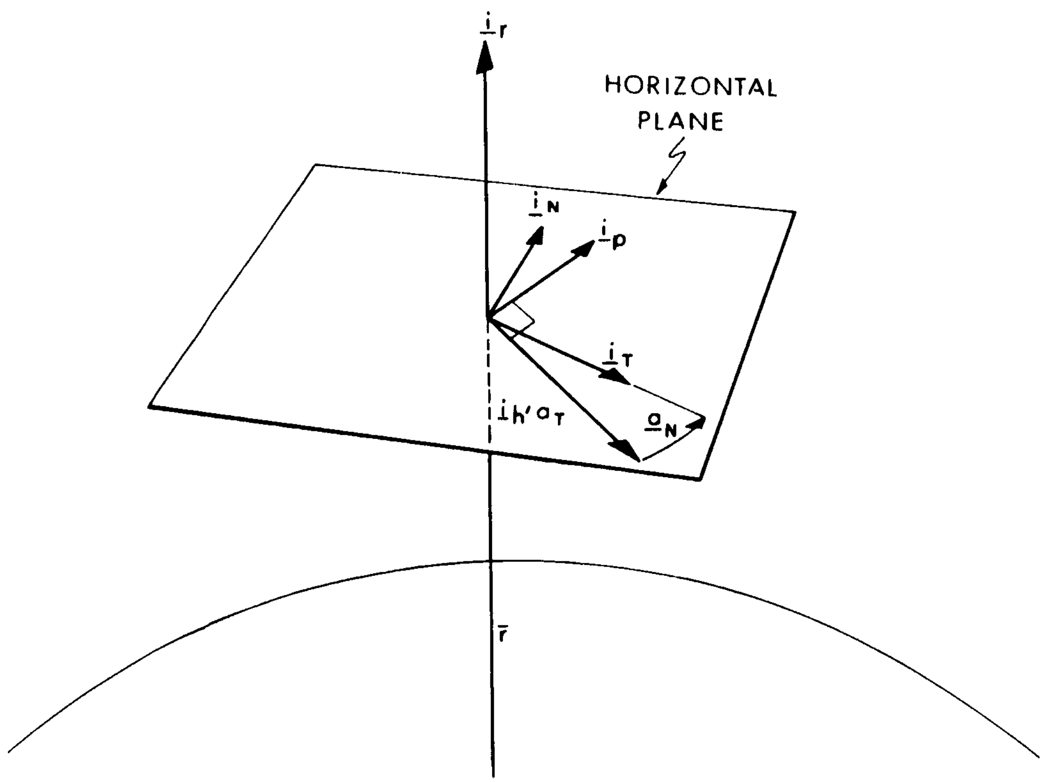


Fig. 4-2 Computation of $\underline{a}_n$ and $\underline{i}_t$

exists, the engine is re-ignited after a time interval calculated to be sufficient to orient to the desired initial thrust direction.

4.3.4 Engine Cutoff

When T_g falls below Δt, 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 $T_g < \Delta t$.

a) Free-fall time to 300,000ft is below 160seconds

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

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

It should be pointed out that the estimate of T_g is very poor in the early part of the burn for long burns. Hence its value at ignition cannot be used in back-up systems.

4.4 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. 4-3. The computational blocks are common to all powered flight maneuvers except the computation of $\underline{v}_r$ described in the preceeding sections.

4.4.1 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

$$\underline{g}_n = \frac{\mu}{r_n^2} \underline{i}_{r_n} \tag{46}$$

$$\underline{v}_n = \underline{v}_{n-1} + \frac{\underline{g}_{n-1} + \underline{g}_n}{2} \Delta t + \underline{\Delta v} \tag{47}$$

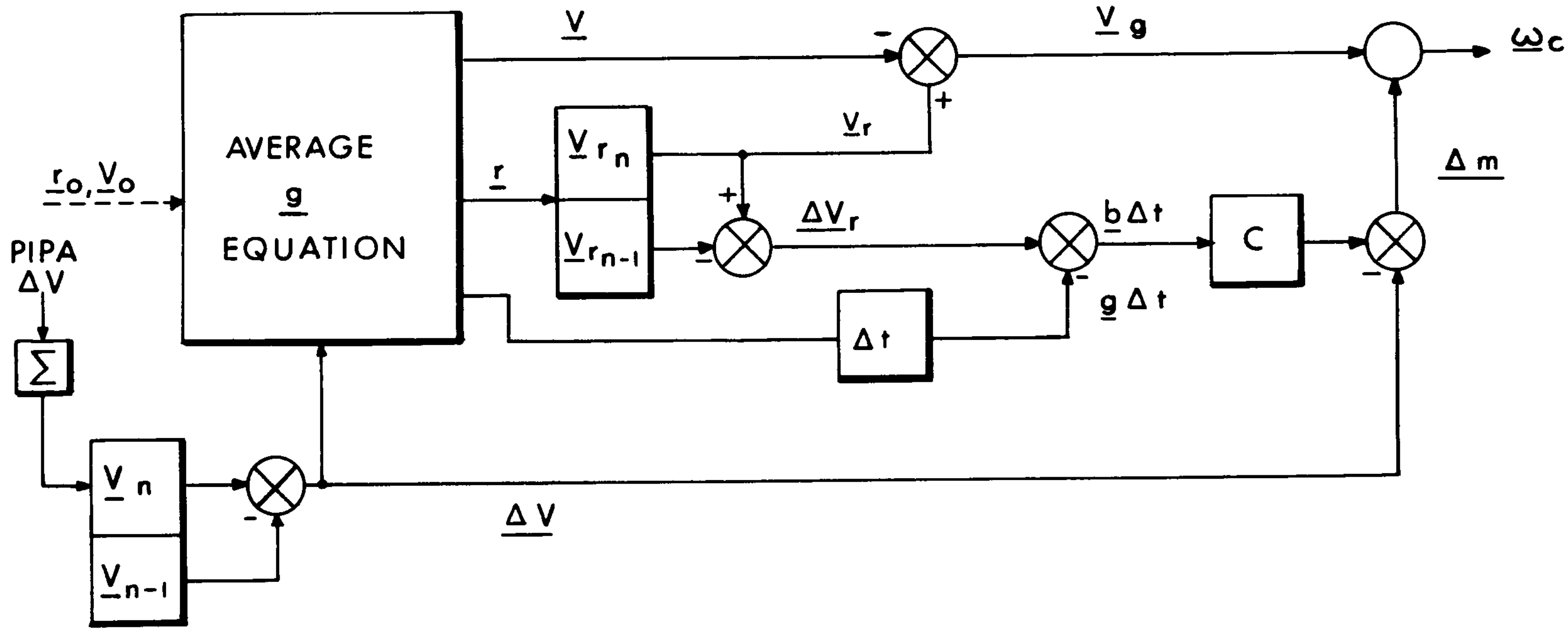


Fig. 4-3 Block Diagram of AGC Guidance Computations

and

$$\underline{r}_n = \underline{r}_{n-1} + \Delta t \left(\underline{v}_{n-1} + \underline{g}_{n-1} \frac{\Delta t}{2} + \frac{\Delta \underline{v}}{2} \right) \tag{48}$$

where the subscript n denotes the nth computational repetition.

4.4.2 Steering Command

The vector $\underline{b}$ was defined in Eq. (5) as

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

In the AGC (as shown in Fig. 4-3), the increment ($\underline{b}\,\Delta t$) is computed as

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

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

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

where

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

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

4.4.3 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.

4.5 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. 4-3.

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

$$\underline{i}_T = \text{UNIT}\,(c\underline{b} + (q - \underline{i}_g \cdot c\underline{b})\,\underline{i}_g \qquad (53)$$

where

$$\underline{i}_g = \text{UNIT}\,(\underline{v}_g) \qquad (54)$$

$$q = (a_T{}^2 - (cb)^2 + (\underline{i}_g \cdot c\underline{b})^2)^{1/2} \qquad (55)$$

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

Once $\underline{i}_T$ is computed from Eq. (53), the vehicle is oriented prior to arrival at the ignition point such that the thrust axis is along $\underline{i}_T$.

4.6 Entry Mode

Included in this section is a set of flow charts that describe the logic and equations that control the entry vehicle. Figure 4.4 shows the overall picture of the sequence of operations during entry. Each block in Figure 4.4 is described in detail in subsequent charts. Table 4-1 defines symbols which represent computed variables stored in erasable memory. The value and definition of constants is given in Section 5.

Every pass through the entry equations, which is now anticipated to be once every 2 seconds, is begun with the section called navigation. (See Figure 4.5). This integrates to determine the vehicles new position and velocity vector. This sub-routine is used by other phases than entry and will probably be operated during all of flight 202.

Next, the targeting is done. This updates the desired landing site position vector and computes some quantities based on the vehicles position and velocity and the position of the landing site. (See Figure 4.6).

The next sequence of calculations is dependent upon the phase of the entry trajectory that is currently being flown. First is the initial roll angle computation. (See Figure 4.7). This merely adjusts the initial roll angle (180° for flight 202 is now planned) and tests when to start the next phase.

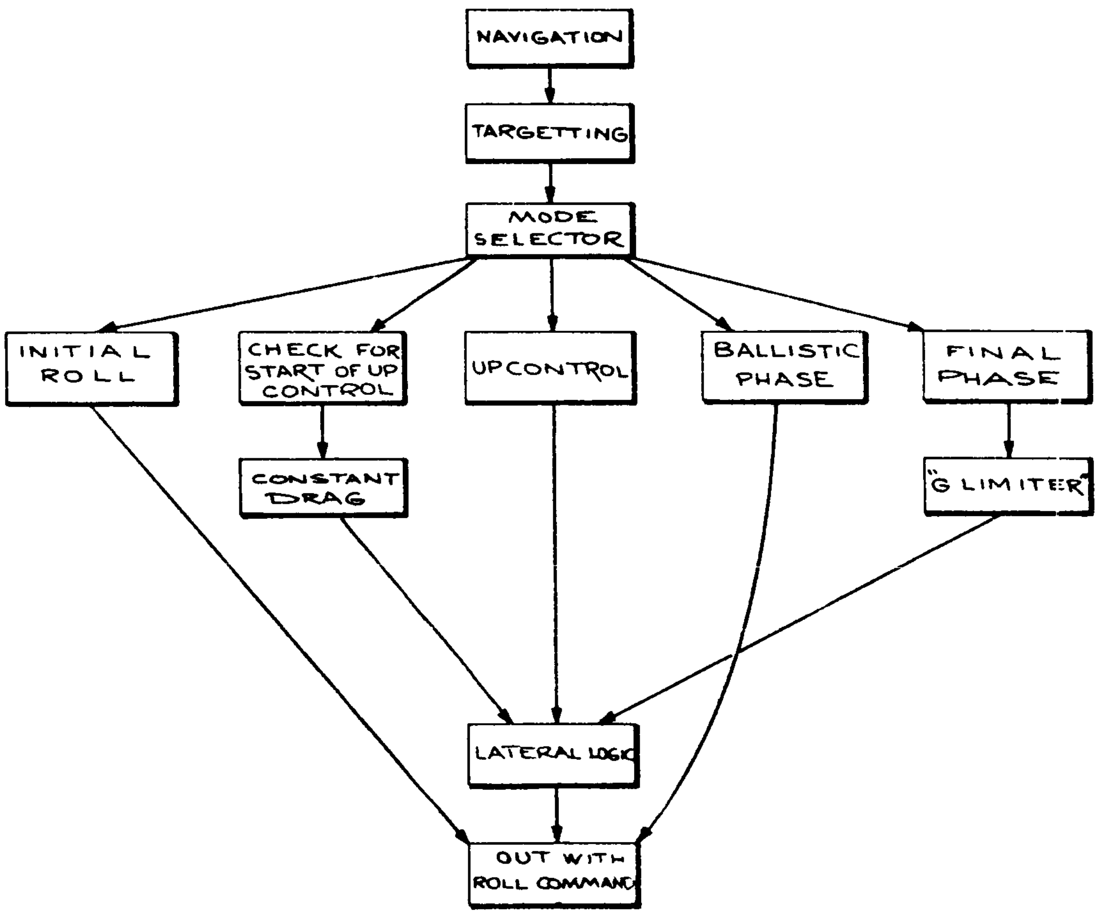


Fig. 4-4 Re-Entry Steering

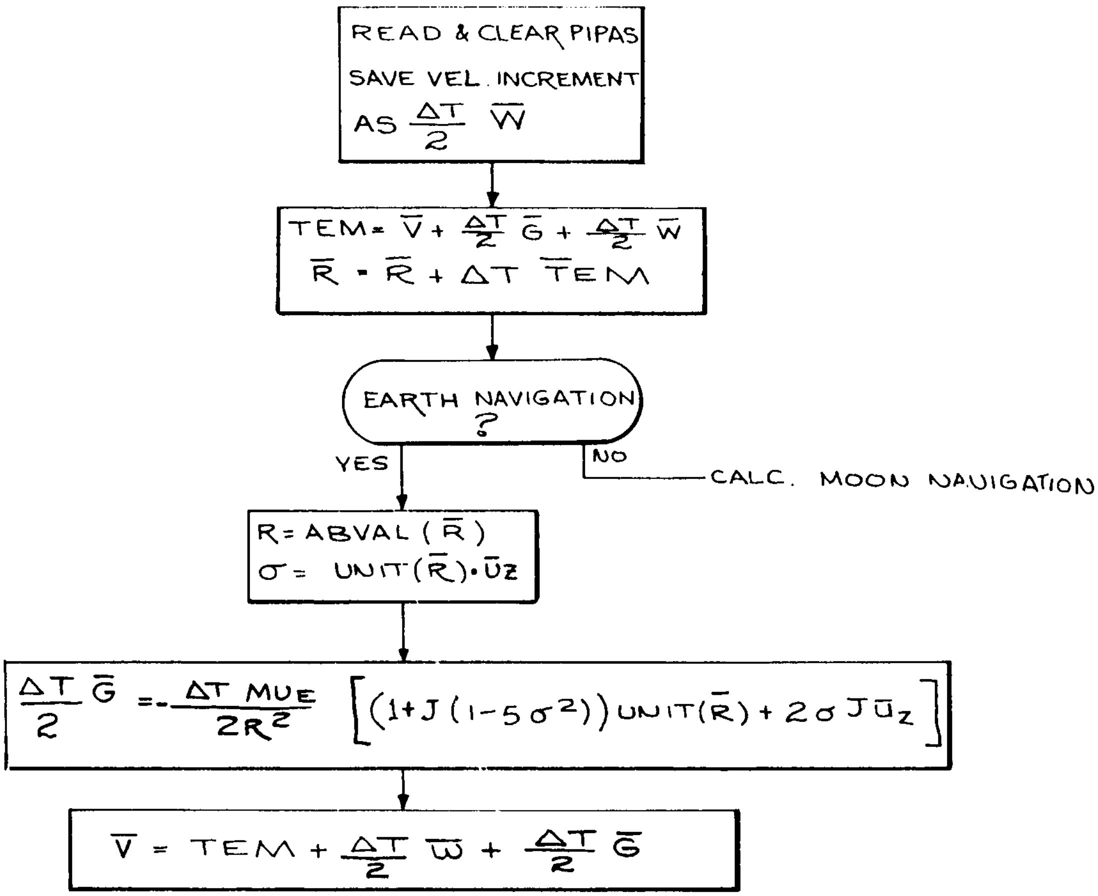


Fig. 4-5 Re-Entry Steering - Navigation

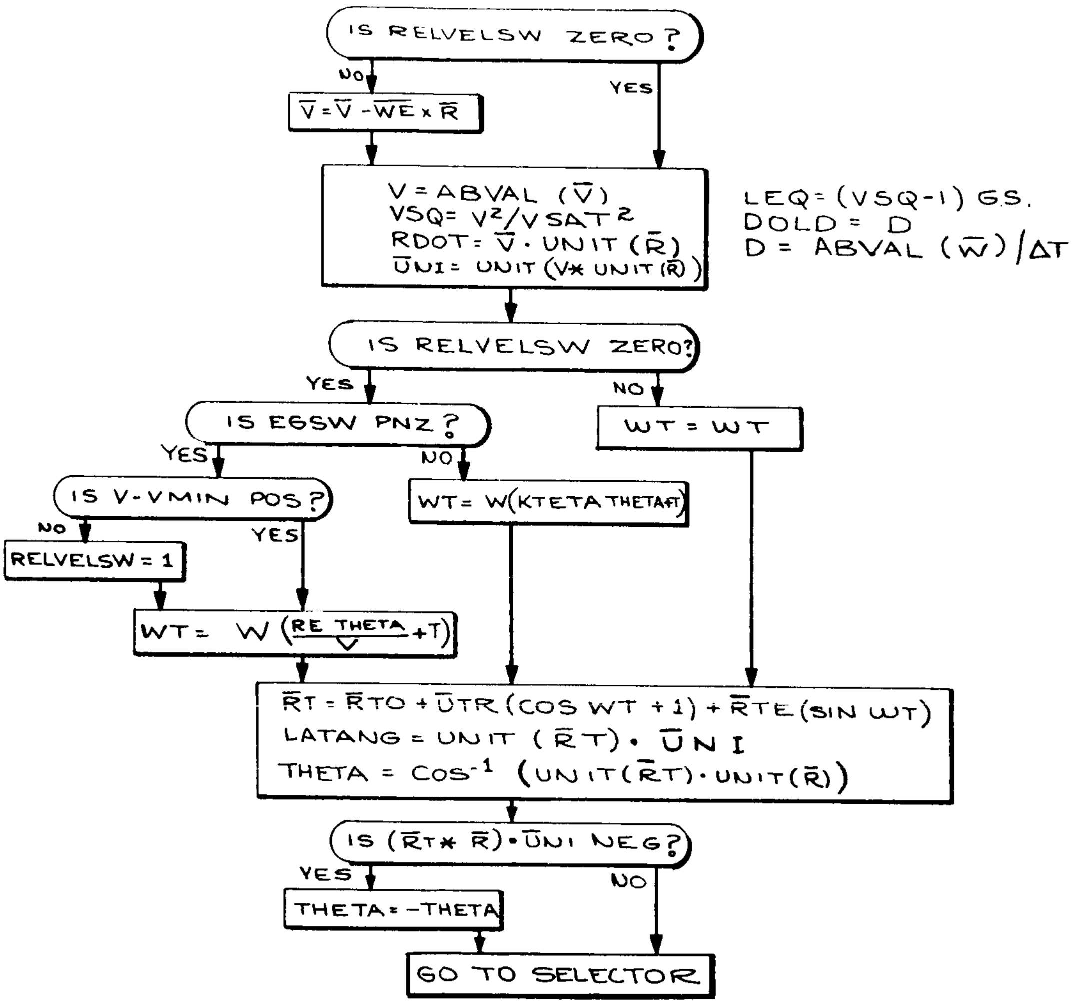


Fig. 4-6 Re-Entry Steering - Targetting

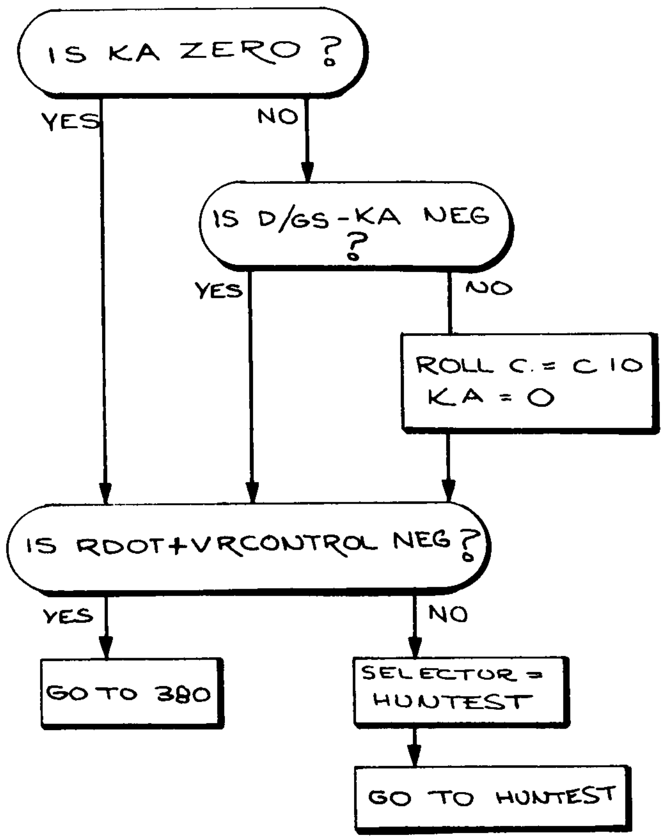


Fig. 4-7 Re-Entry Steering - Initial Roll

The next phase maintains a constant drag trajectory while testing to see if it is time to go into the up-control phase. The testing is presented in Figures 4.8 and 4.9. The constant drag equations are given in Figure 4.10. The other phases (up-control, ballistic and final) are listed in Figure 4.11, 4.12 and 4.13. The final phase is accomplished by a stored reference trajectory. Its characteristics as well as the steering gains are stored as shown in Figure 4.14. The routine that prevents excessive acceleration build-up (G limiter) is given in Figure 4.15. And finally, the section that does the lateral logic calculations and computes the commanded roll angle is shown in Figure 4.16.

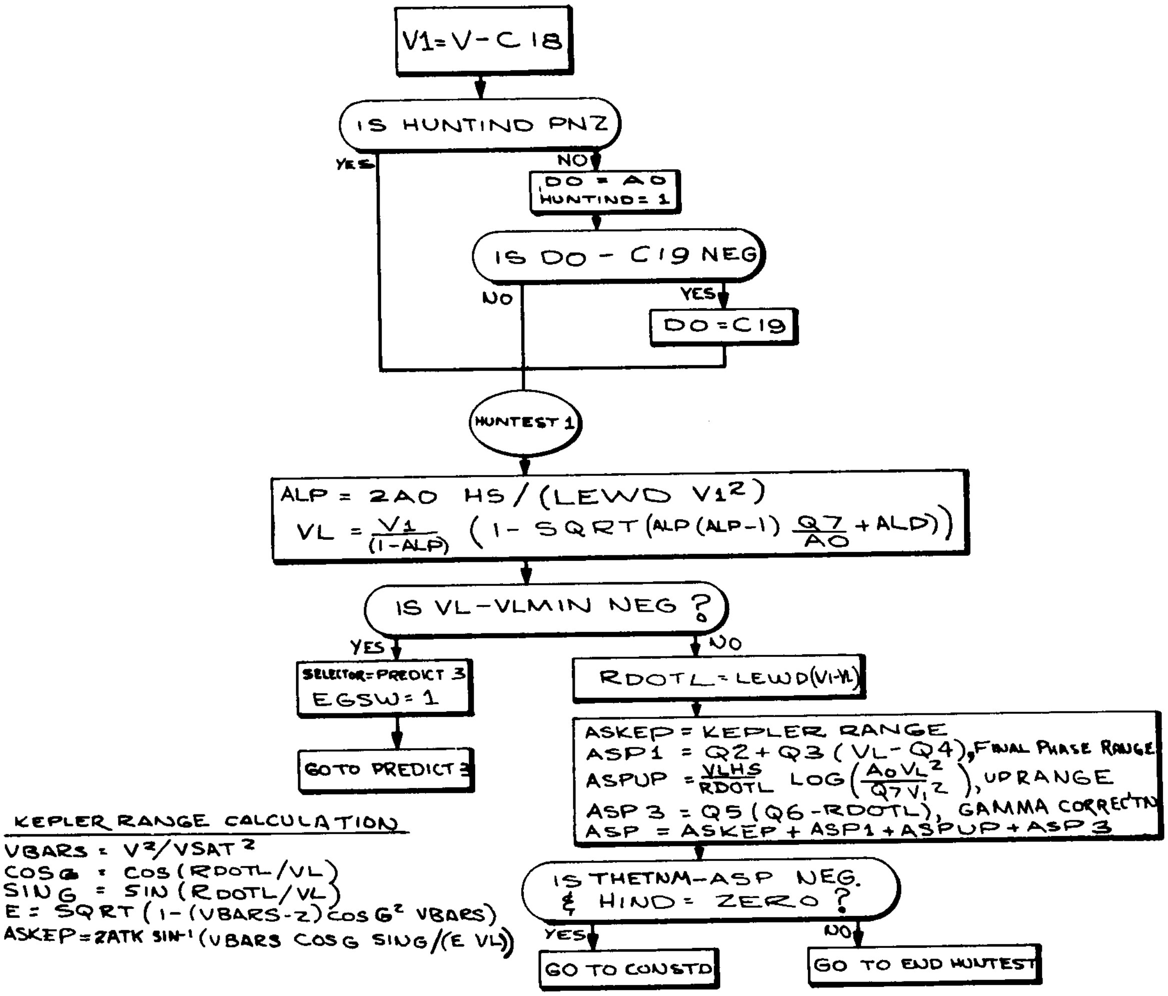


Fig. 4-8 Re-Entry Steering - Huntest

Fig. 4-9 Re-Entry Steering - End Huntest

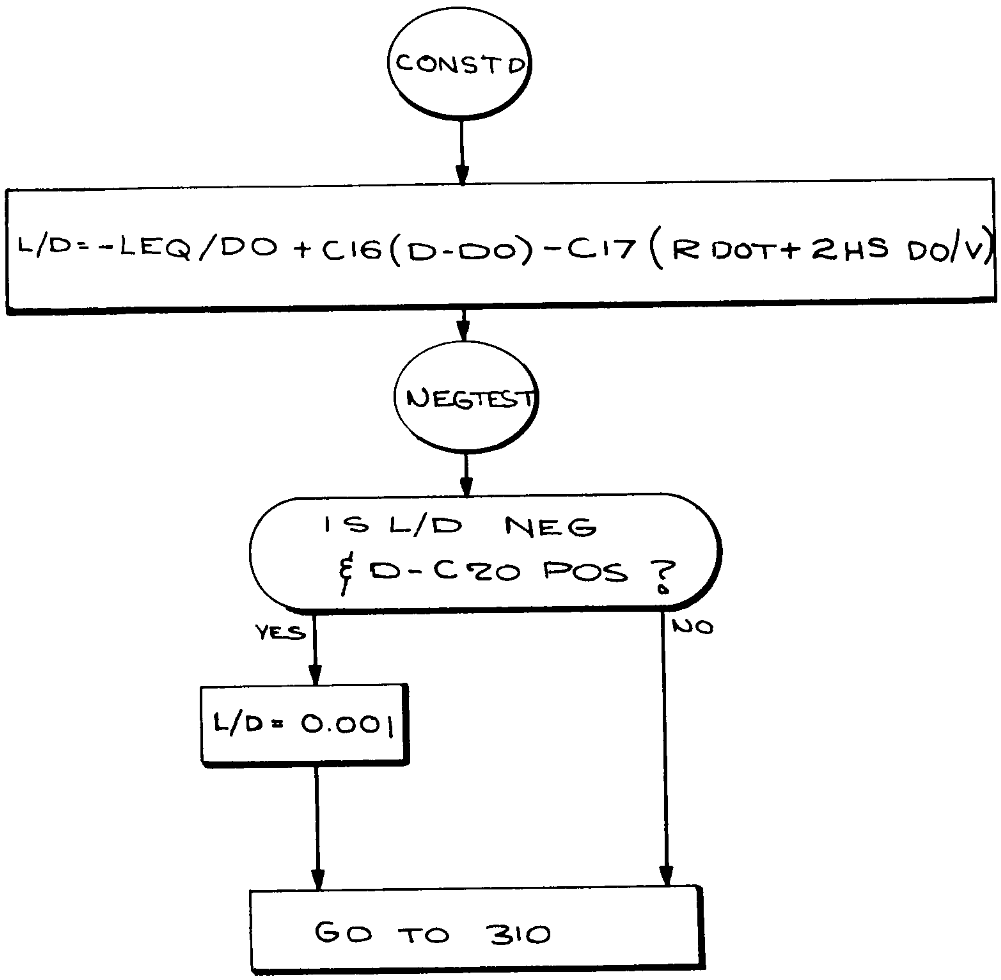


Fig. 4-10 Re-Entry Steering - CONSTD

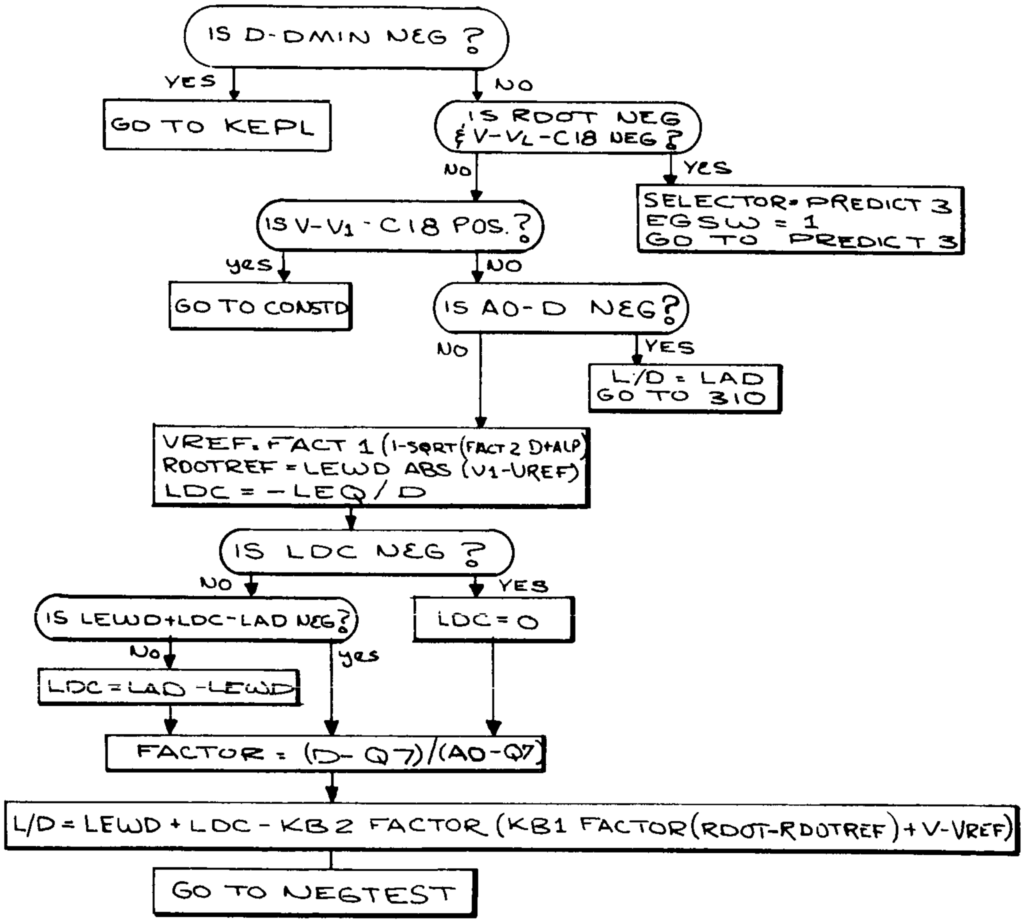


Fig. 4-11 Re-Entry Steering - UP CONTRL

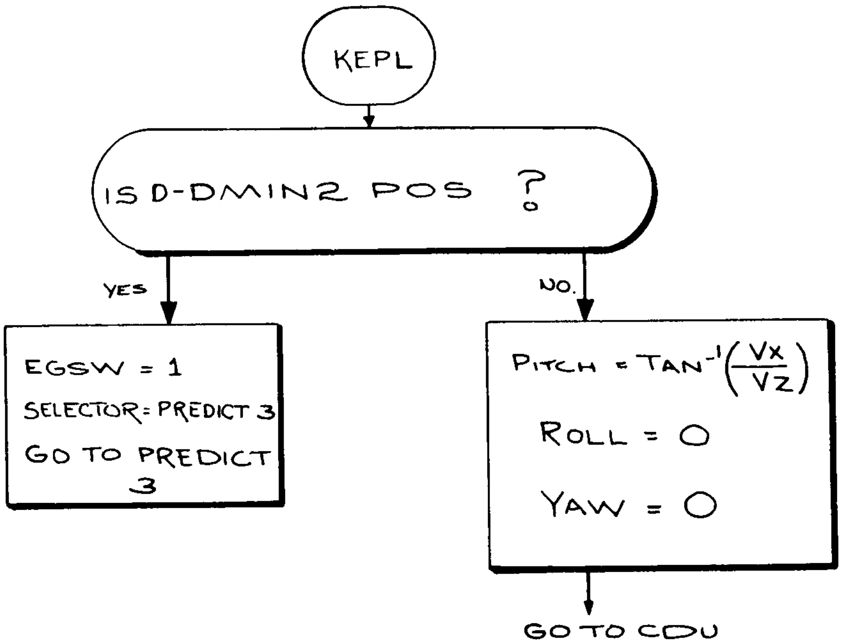


Fig. 4-12 Re-Entry Steering - Ballistic

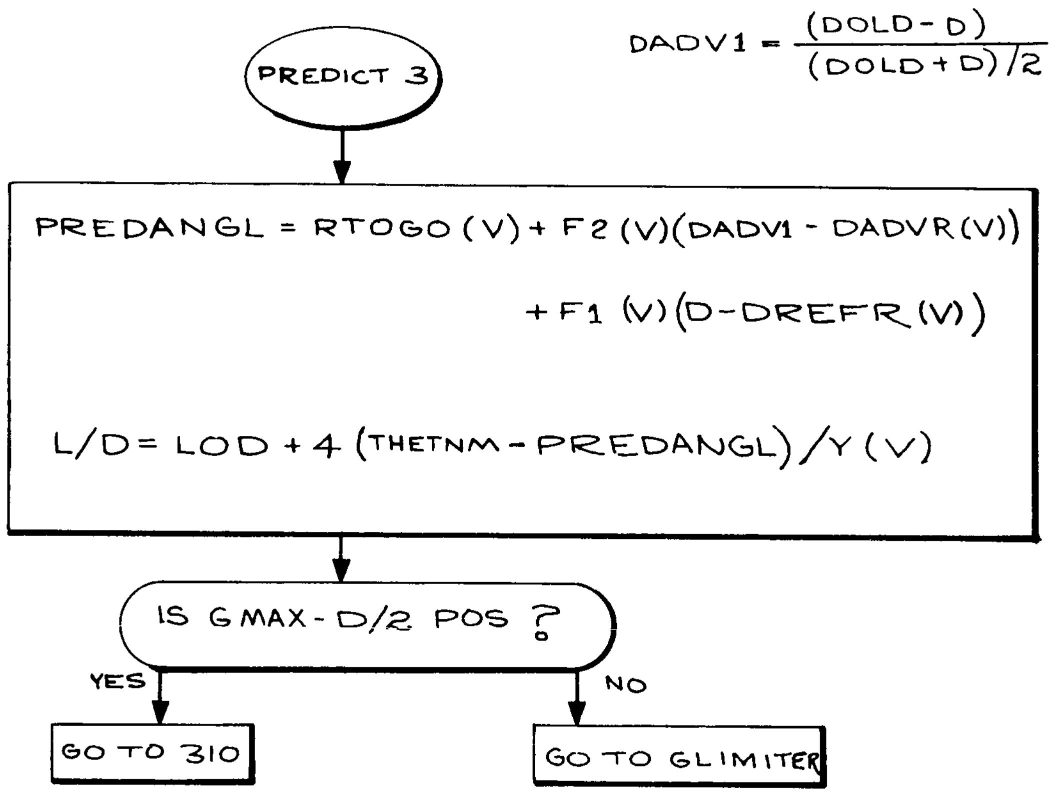


Fig. 4-13 Re-Entry Steering - Predict 3

FINAL PHASE REFERENCE

VREF FT/SEC	DA/DV (100/SEC)	AREF FT/SEC^2	DR/DAPR NM/SEC	DR/DA NM/FT/SEC	RTOGO NM	DR/DL/D NM
0	5.255	38.7	0	-.03959	0	.05
620	5.255	38.7	13.6	-.03959	0	.05
1080	1.487	42.6	57.4	-.04232	2	2.177
2103	1.668	60.0	78.86	-.05625	8	6.772
3922	.9431	81.5	160.9	-.09033	21	17.69
6295	.3095	93.9	343.5	-.1411	45	45.52
8531	.1925	98.5	607.9	-.198	74	90.0
10101	.2971	102.3	847.4	-.2374	98	137.4
14014	.4855	118.7	1699	-.3308	169	325.9
15951	.2103	125.2	2119	-.3607	209	462.1
18357	-.4966	120.4	3146	-.4959	265	679.6
20829	-1.56	95.4	3860	-.6486	343	977.6
23090	-3.85	28.1	4963	-2.022	503	1403
23500	-5.293	6.4	5485	-7.572	641	1505
30000	-5.293	6.4	5485	-7.572	641	1505

Fig. 4-14 Final Phase Reference

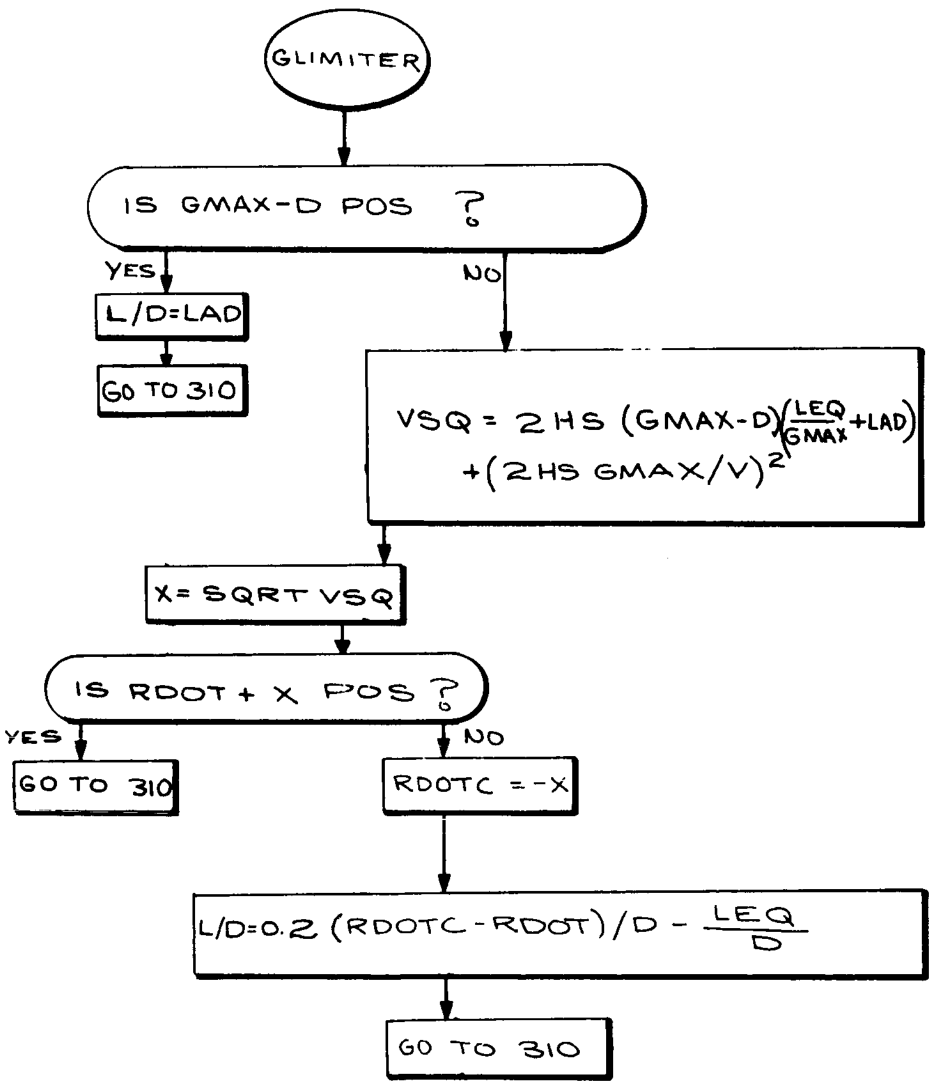


Fig. 4-15 Re-Entry Steering - GLIMITER

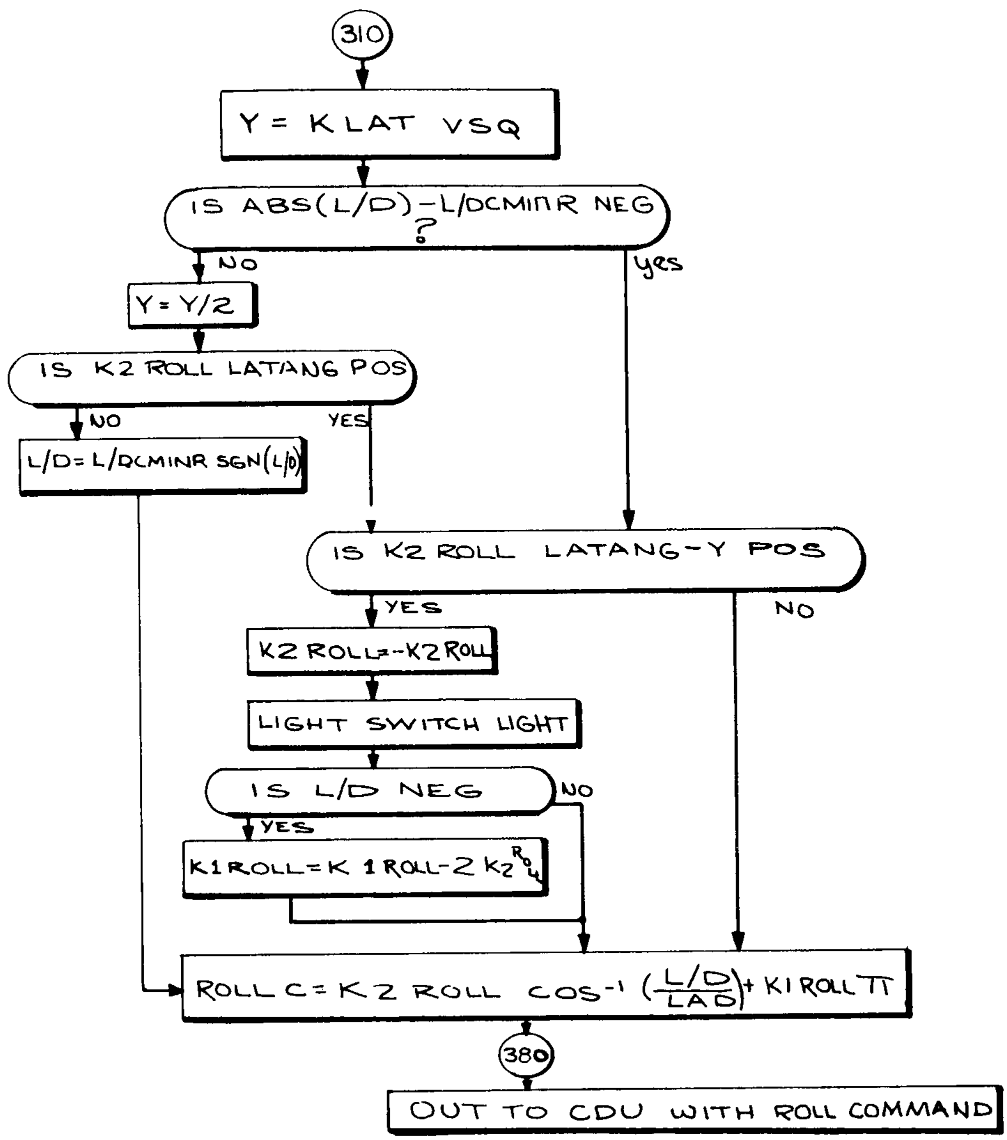


Fig. 4-16 Re-Entry Steering - Lateral Logic

TABLE 4-1

VARIABLES FOR RE-ENTRY CONTROL

$\overline{RTO}$	INITIAL TARGET VECTOR
$\overline{UZ}$	UNIT VECTOR NORTH
$\overline{V}$	VELOCITY VECTOR
$\overline{R}$	POSITION VECTOR
$\overline{RTE}$	VECTOR EAST AT INITIAL TARGET
$\overline{UTR}$	NORMAL TO $\overline{RTE}$ AND $\overline{UZ}$
$\overline{WE}$	EARTH RATE VECTOR
$\overline{RT}$	TARGET VECTOR
$\overline{UNI}$	UNIT NORMAL TO TRAJECTORY PLANE
A0	INITIAL DRAG FOR UPCONTRL
ALP	CONST FOR UPCONTRL
ASKEP	KEPLER RANGE
ASP1	FINAL PHASE RANGE
ASPUP	UPRANGE
ASP3	GAMMA CORRECTION
ASP	PREDICTED RANGE = ASKEP+ASP1+ASPUP+ASP3
D	TOTAL ACCELERATION
D0	CONTROLLED CONST DRAG
DADV1	D DRAG/DV=APRIME (FINAL PHASE)
DADVR	REFERENCE D DRAG/DV (FINAL PHASE)
DREF	REFERENCE DRAG
E	ECCENTRICITY
F1	DRANGE/D DRAG (FINAL PHASE)
F2	DRANGE/DAPRIME (FINAL PHASE)
FACT1	CONST FOR UPCONTRL
FACT2	CONST FOR UPCONTRL
FACTOR	USED IN UPCONTRL
K1ROLL	INDICATOR FOR ROLL SWITCH (0)
K2ROLL	INDICATOR FOR ROLL SWITCH (1)
LATANG	LATERAL RANGE
LEQ	EXCESS C.F. OVER GRAV =(VSQ-1)GS
LDC	L/D CORRECTION FOR UPCONTRL
LV	D RANGE/DV
PREDANGL	PREDICTED RANGE (FINAL PHASE)
RDOT	ALTITUDE RATE
RDOTREF	REFERENCE RDOT FOR UPCONTRL
ROLLC	ROLL COMMAND
RDOTL	EXIT RDOT FOR UPCONTRL
RTOGO	RANGE TO GO (FINAL PHASE)
T	TIME
THETA	DESIRED RANGE (RADIANS)
THETNM	DESIRED RANGE (NM)
VCORR	VELOCITY CORRECTION FOR UPCONTRL
V	VELOCITY MAGNITUDE
V1	INITIAL VELOCITY FOR UPCONTRL
VL	EXIT VELOCITY FOR UPCONTRL
VREF	REFERENCE VELOCITY FOR UPCONTRL
VBARS	$VL^2/VSAT^2$
VSQ	NORMALISED VELOCITY SQUARED = $V^2/VSAT^2$
WT	EARTH RATE X TIME
Y	D RANGE/D(L/D)
HUNTIND	SWITCH TO SELECT CONST D LEVEL(0)
HIND	SWITCH TO ITERATE IN HUNTEST (0)
RELVELSW	REL VELOCITY SWITCH (0)
EGSW	SWITCH (0)

5. MISSION AND VEHICLE DATA

5.1 Scope

Section 5 is a summary of all Flight 202 mission and vehicle data that have an impact on AGC programming. Data have been collected under the following headings:

Section 5.2 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 5.3 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. Some exceptions have had to be made in the case of the Saturn boost polynomials and SPS aim-point criteria, since these will not be available until shortly before the flight.

Section 5.4 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 5.5 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 5.5.2.

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

5.2 Mission Data

5.2.1 Mission Trajectories

Reference trajectory (Saturn boost, SPS1, coast, SPS2)	not available[1]
Reference entry trajectory (Pre-05g to touch-down)	not available[1]
Nominal mission profile	see Fig. 5.1
Major events during nominal mission	see Table 5.1
Nominal Saturn boost profile	see Fig. 5.2

Note 1. No official trajectories issued. All dependent data in this report are derived from MSC SA-202 optimum trajectory dated September 1964, and an undated entry reference trajectory communicated on 11 November 1964.

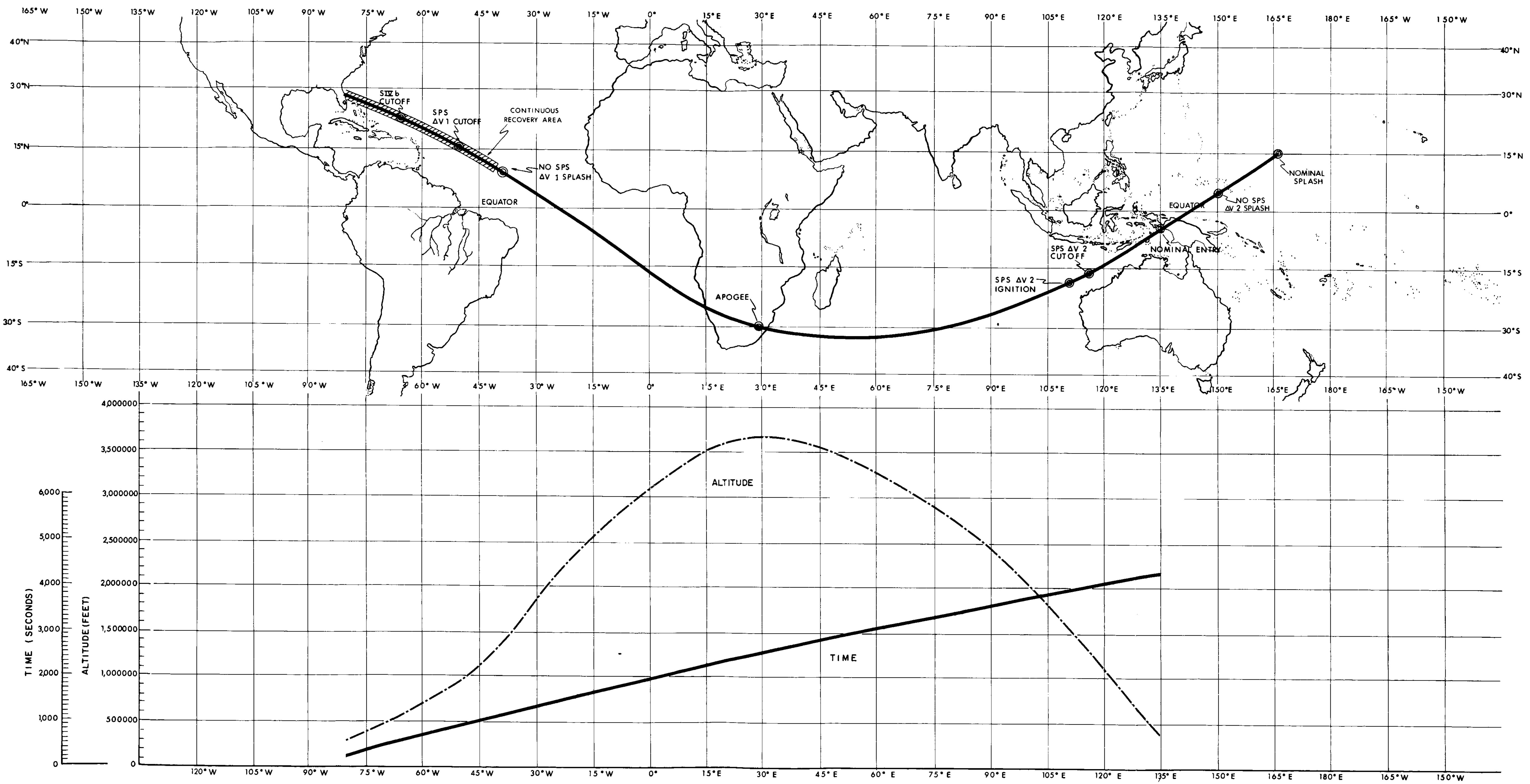


FIG. 5-1 MISSION 202 PROFILE

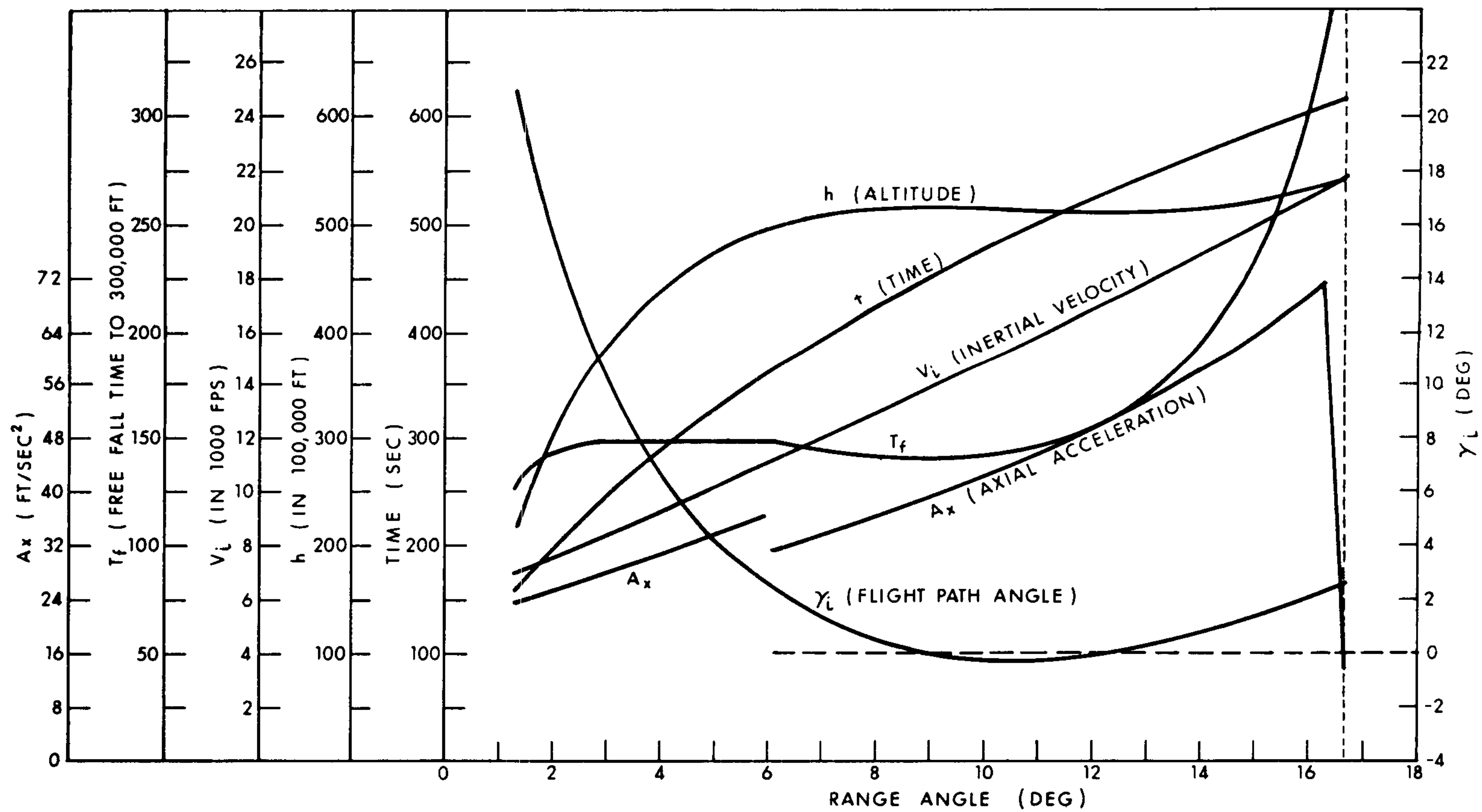


Fig. 5-2 Saturn Boost Trajectory Profile

TABLE 5-1. MAJOR EVENTS, MISSION 202

EVENT	t (sec)	V_i (fps)	i (deg)	AZ	ALT.	N. GEOD. LAT. (deg)	E. LONG	WEIGHT
Lift-off	0	0	0	90.00	0	28.53	279.42	1,322,530
SIB c/o	145.5	7,022	24.02	102.43	175,508	28.23	279.98	434,058
SIVB Ign.	151	6,953	22.80	102.49	190,757	28.21	280.06	320,240
LES Jett	161	7,037	21.01	102.66	216,802	28.17	280.21	306,928
SIVB c/o	617.4	21,848	2.635	112.05	544,569	23.43	294.61	83,099
SPS Ign.	628.4*	21,834	2.395	112.31	554,893	23.20	295.18	45,701
SPS c/o	882.0	25,632	5.77	117.70	918,950	16.46	309.35	27,956
Apogee	2528.	22,713	-0.006	105.89	3,606,674	-27.99	29.56	27,956
Ullage	3893.4	24,837	-5.80	64.61	1,620,500	-19.95	109.25	27,942
SPS Ign.	3923.4	24,923	-5.82	63.99	1,543,640	-19.24	110.95	27,942
SPS c/o	4014.	27,739	-7.67	62.18	1,243,966	-16.26	116.48	21,589
SPS Ign.	4024.	27,647	-7.53		1,218,301	-16.15	116.63	21,589
SPS c/o	4027.	27,751	-7.56		1,207,390	-16.05	116.82	21,379
SPS Ign.	4037.	27,789	-7.44		1,171,147	-15.72	117.43	21,379
SPS c/0	4039.6**	27,878	-7.46		1,161,917	-15.60	117.59	21,200
Entry	4319.6	28,690	-3.51		397,603	- 5.16	134.85	
End of Entry	5087.6	1,791			49,613	14.9	165.6	
End of Entry for No SPS ΔV	1469.4					9.25	320.6	
End of Entry for No SPS ΔV_2	4977.					4.7	148.4	

* Data from this time on is from MIT 202 performance simulations

** Fourth Burn cutoff due to propellant depletion in this simulation

5.2.2 Nominal SIVB Separation Attitude Conditions

X-axis in plane of maneuver, forward of local vertical by	67.20°
(Y-axis along momentum vector $\underline{R} * \underline{V}$	
Z-axis above local horizontal)	
Roll rate	0°/sec
Pitch rate	0°/sec
Yaw rate	0°/sec

5.2.3 3σ Dispersions from Nominal 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

5.2.4 SIVB Engine-off Transient

Decay time 100%-10%	not available
Decay time 10%-0%	not available
Tail-off impulse 100%-10%	not available
Tail-off impulse 10%-0%	not available

5.3 Memory Data

5.3.1 Prelaunch

		Memory Type	Value
Launch position:	Latitude	F	28.53253° N
	Longitude	F	279.41701°E
	Radius	F	6,373,305.2 meters
Inertial reference plane (IMU) azimuth		F	105.0000° E of N

5.3.2 Saturn Boost

	Memory Type	Value
Roll polynomial coefficient (s)	E	not available
Pitch polynomial coefficient(s)	E	not available
Heading polynomial coefficient(s)	E	not available
Interval: Lift-off-SI attitude monitor terminate	F	150 sec
Interval: Lift-off-LET jetison assumed complete	F	171 sec

5.3.3 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 (CSM)	F	1 sec
(CM only)	F	0.5 sec
Interval for stabilization after maneuver		
(CSM)	F	6 sec
(CM)	F	3 sec

5.3.4 TVC (Normal mission)

	Memory Type	Value
CSM c.g. displacement in X-Y plane: (SPS 1)	F	6.60° [1]
CSM c.g. displacement in X-Y plane: (SPS 2)	F	3.35° [1]
CSM c.g. displacement in X-Y plane: (SPS 3)	F	0.30° [1]
CSM c.g. displacement in X-Z plane: (SPS 1)	F	2.25° [1]
CSM c.g. displacement in X-Z plane: (SPS 2)	F	0.60° [1]
CSM c.g. displacement in X-Z plane: (SPS 3)	F	-0.70° [1]
Mass loss rate of SPS engine	F	2.175 slug/sec
Initial mass of CSM + propellants	F	1,428 slugs
Tailoff impulse (mean) of SPS engine	F	8,400 lb-sec
Minimum ΔV criterion for thrust monitor	F	1 ft/s/s
Interval for thrust monitor	F	10 sec
Interval between steering updates	F	1 sec
Steer law gain	F	0.25
Steer law velocity bias	F	160 ft/sec
Steer law coefficient (C)	F	1.0
Interval: freeze CDUs to engine-off command	F	1.8 sec
Interval: SIVB/CSM Sep. - SPS 1 ignition	F	12.7 sec
Interval: SPS 1 cut-off - SPS 2 ignition	E	3041 sec
Interval: SPS 2, 3 cut-off - SPS 3, 4 ignition	F	10 sec

Note 1: Figures derived from data in Section 5.4.1 using weight data in Table 5-1.

		Memory Type	Value
Interval:	SPS 3, 4 ignition - SPS 3, 4 cut-off	F	3 sec
Interval:	+ X translation - SPS 2 ignition	F	30 sec
Interval:	between SCS mode change commands	F	0.25 sec
Interval:	Gimbal mot. power ON - Engine start	F	2 sec
SPS 1	aim-point criteria		
	Semi-major axis	E	2.22806×10^7 ft
	Eccentricity	E	0.102415
SPS 2	aim-point criteria:		
	Semi-major axis	E	2.82776×10^7 ft
	Eccentricity	E	0.252865
Interval:	Lift-off - touch down. (Nominal mission)	E	5090 sec

5.3.5 Entry (Normal mission)

	Symbol	Memory Type	Value
CSM attitude for SM/CM Separation:			
X-axis above velocity vector by		F	60^o
(Y-axis along monentum vector ($\underline{R} * \underline{V}$),			
Z-axis above velocity vector)			
CM Pacific pre-entry attitude:			
X-axis below velocity vector by		F	160^o
(Y-axis along momentum vector ($\underline{R} * \underline{V}$),			
Z-axis below velocity vectory. A lift-vector down attitude)			
Trim angle of attack		F	20^o
Interval: SM/CM Sep. - start maneuver		F	5 sec
Pacific recovery point: Latitude		E	14.000^oN
Longitude		E	165.600^oE
Constant on ALP	C1	F	1.25
Initial shaping roll	C10	F	0
Constant drag gain (on drag)	C16	F	0.01
Constant drag gain (on RDOT)	C17	F	0.0002
Lead velocity for up control start	C18	F	500 ft/s
Minimum constant drag	C19	F	35 ft/s/s
Minimum D for lift up	C20	F	200 ft/s/s
Minimum drag to start Kepler	DMIN	F	6 ft/s/s
Minimum drag to end Kepler	DMIN2	F	6.5 ft/s/s
G-limit	GMAX	F	10g
Minimum drag for lift up if down	KA	F	0.2g
Up control gain, optimized	KB3	F	0.0034
Up control gain, optimized	KB4	F	3.4
Lateral switch gain	KLAT	F	0.0075
Time of flight calculation gain	KTETA	F	1,500

	Symbol	Memory Type	Value
Max L/D	LAD	F	0.3
LAD cos (15^{o})	L/DCMINR	F	0.2895
Up control L/D	LEWD	F	0.1
Final phase L/D	LOD	F	0.18
Final phase range	Q2	F	641 n.m.
Final phase dR/dV	Q3	F	0.07 n.m/ft/s
Final phase initial velocity	Q4	F	23,500 ft/s
Final phase dR/dRDOT	Q5	F	0.3 n.m/ft/s
Final phase initial RDOT	Q6	F	820 ft/s
Minimum drag for up control	Q7	F	6 ft/s/s
Minimum RDOT to close loop	VRCONTRL	F	700 ft/s
Minimum VL	VLMIN	F	18,000 ft/s
Normalization factor, acceleration	GS	F	32.2 ft/s/s
Atmosphere Scale Height	HS	F	28,500 ft
Normalization factor, velocity	VSAT	F	25,766.197 ft/sec
Nominal earth's radius (entry only)	RE	F	21,202,909 ft

5.3.6 TVC (Abort)

	Symbol	Memory Type	Value
Criterion for tumbling detection		F	not available
Interval: SIVB/CSM Sep. - SPS ignition (tumbling and abort)		F	2.5 sec
Interval: Time-to-go bias		F	5 sec
Interval: between steering updates		F	2 sec
Thrust attitude:			
X-axis above visual horizon by		F	35°
(Y-axis normal to local vertical,			
Z-axis above local horizontal)			
Limit: commanded change in yaw acceleration		F	5 ft/s/s
Abort aim-point: Latitude		E	14.3926°N
Longitude		E	313.0000°E
Interval: Lift-off - abort aim-point			
(Abort from nominal mission (See Section 4.0))		E	975 sec
Mean geo-centric radius of visual horizon	R_{vh}	F	not available

5.3.7 Entry (Abort)

	Memory Type	Value
CM Atlantic pre-entry attitude:		
X-axis above velocity vector by	F	160°
(Y-axis along neg. momentum vector ($\underline{V}$*$\underline{R}$)		
Z-axis above velocity vector		
A lift-vector up attitude)		
Atlantic recovery point: Latitude	E	not available
Longitude	E	not available

5.3.8 Free-fall time (T_f) monitor

	Memory Type	Value
Entry interface altitude	F	300, 000 ft
Abort T_f criterion (A) to start orientation to CM/SM Separation Attitude	F	160 sec
Normal T_f criterion (N) to start orientation to CM/SM Separation Attitude	F	160 sec
Interval: min T_f to start CM/SM Separation	F	75 sec
Interval: between T_f updates	F	1 sec

5.4 Vehicle Data

5.4.1 CSM Data

Weight empty	MS	21,200 lbs
Weight of initial fuel load	ML	24,500 lbs
Variation of principal inertia with mass	IXX	Defined in Fig. 5.4
Variation of principal inertia with mass	IYY	Defined in Fig. 5.5
Variation of principal inertia with mass	IZZ	Defined in Fig. 5.6
Variation of product of inertia with mass	IXY	Defined in Fig. 5.7
Variation of product of inertia with mass	IYZ	Defined in Fig. 5.8
Variation of product of inertia with mass	IZX	Defined in Fig. 5.9
Variation of C.G. X-location[2] with mass	CGX	Defined in Figs. 5.10, 5.11
Variation of C.G. Y-location[2] with mass	CGY	Defined in Figs. 5.12, 5.13
Variation of C.G. Z-location[2] with mass	CGZ	Defined in Figs. 5.14, 5.15
Fuel equivalent slosh mass	MF	14.3 slugs
Oxidizer equivalent slosh mass	MO	44.6 slugs
Fuel mass C.G. X-location	RF	958 ins. (Apollo Ref.)
Oxidizer mass C.G. X-location	RO	966 ins. (Apollo Ref.)
Fuel mass natural frequency	WF	4.07[1] rad/sec
Fuel mass damping ratio	ZF	.005
Oxidizer mass natural frequency	WO	3.82[1] rad/sec
Oxidizer mass damping ratio	ZO	.005
RCS thruster moment arm	LT	7.1 feet
Engine hinge point location	LE	833 ins. (Apollo Ref.)
Spacecraft Launch Configuration		See Fig. 5-3

NOTE: 1. Data corresponds to initial thrust acceleration of 20.9 ft/sec^2 and the relation $(W^2 a_T)_t = (W^2 a_T)_{initial}$ is assumed.

2. Angles given as positive rotations of (engine hinge-point to c.g.) line about positive CSM Y and Z axes.

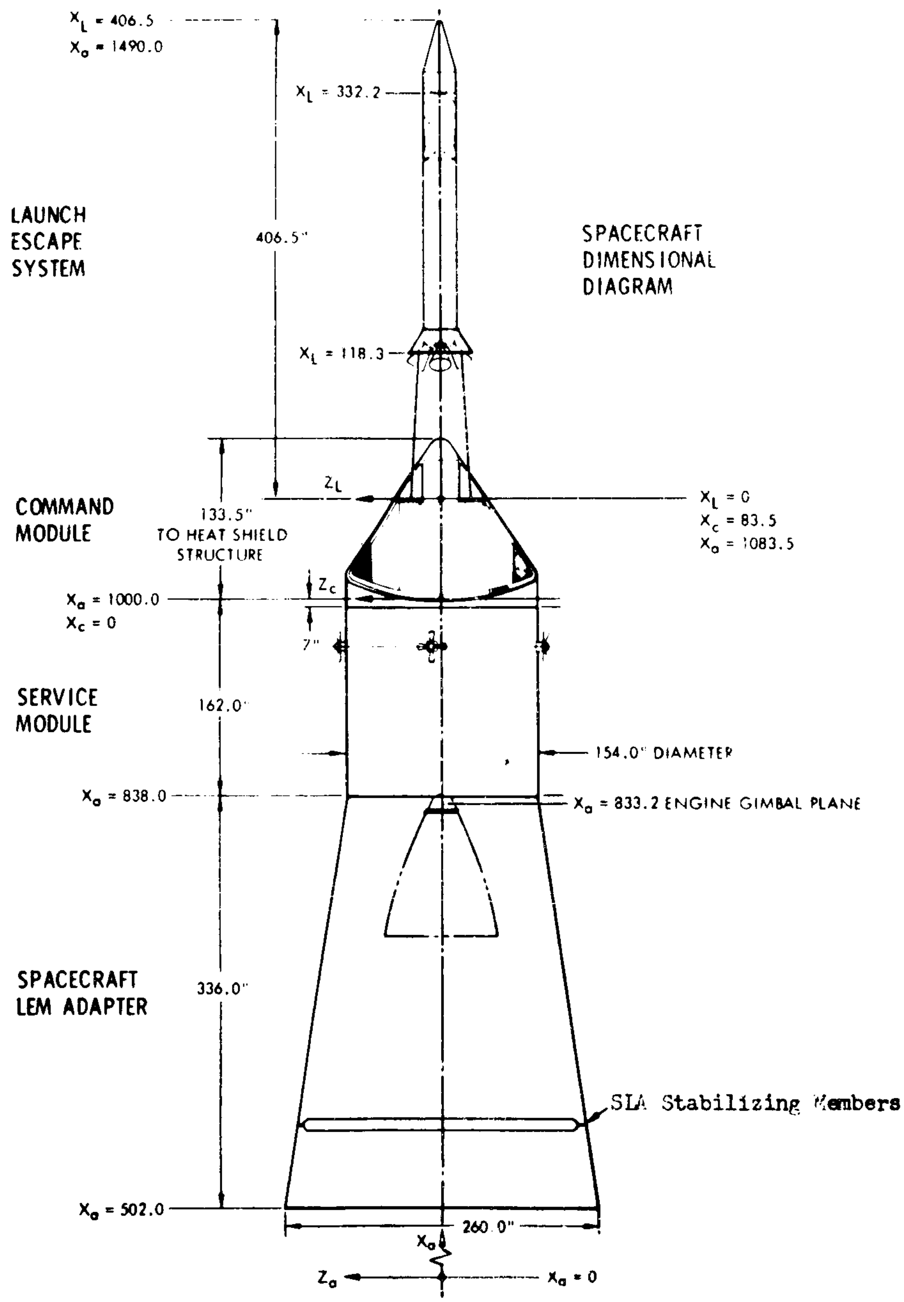


Fig. 5-3 CSM Launch Configuration

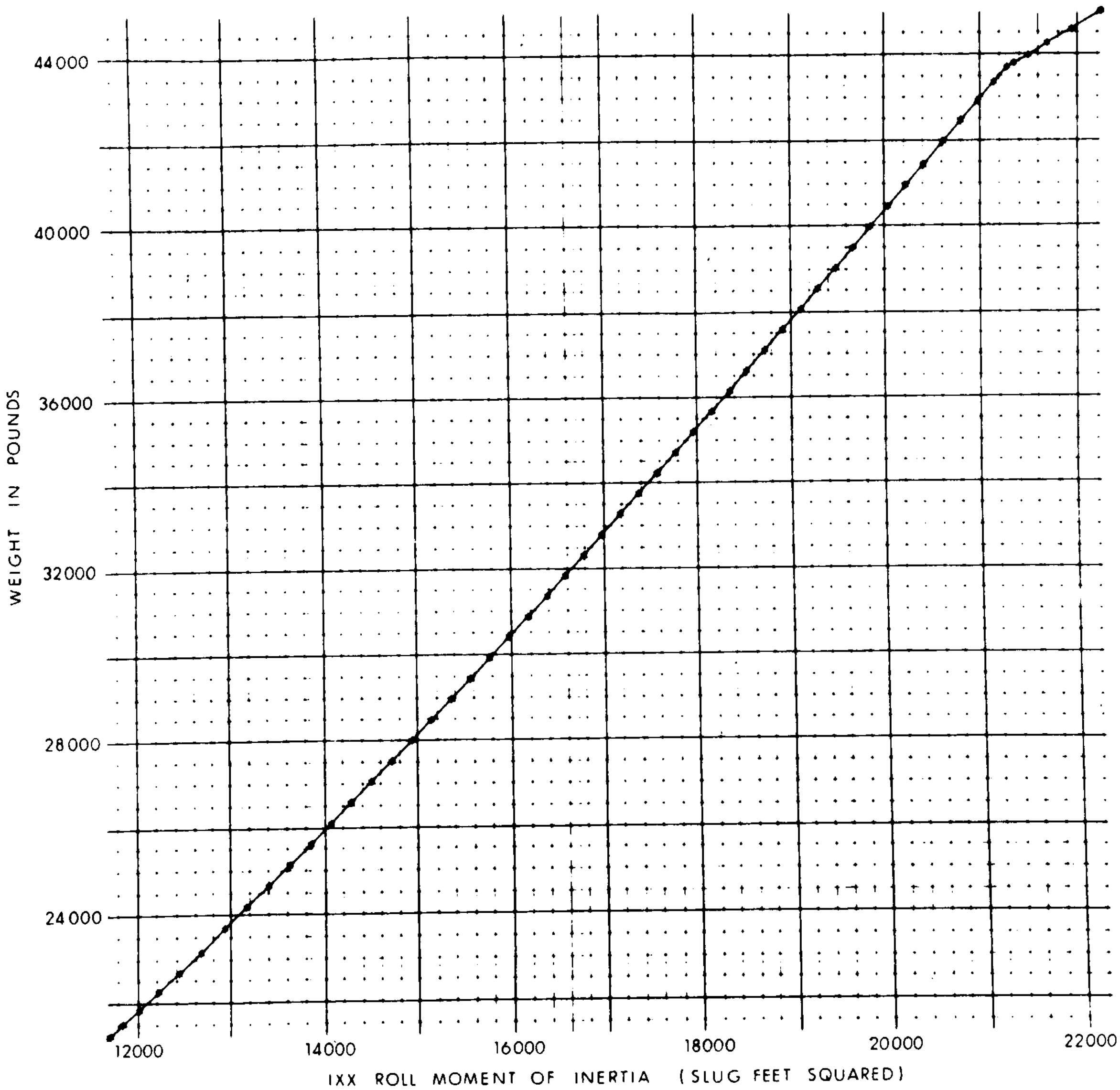


Fig. 5-4 IXX Moment of Inertia against CSM Weight

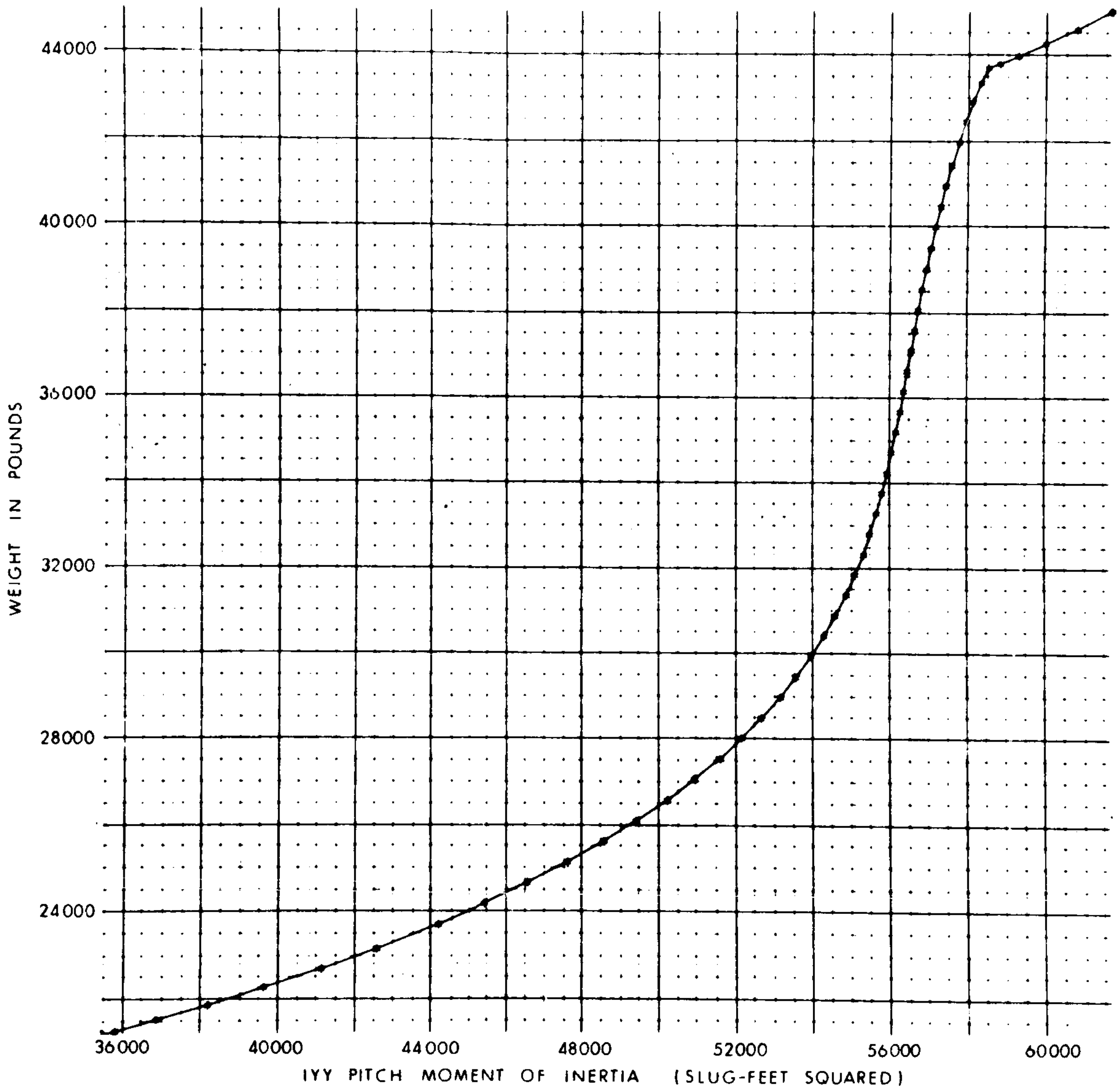


Fig. 5-5 IYY Moment of Inertia against CSM Weight

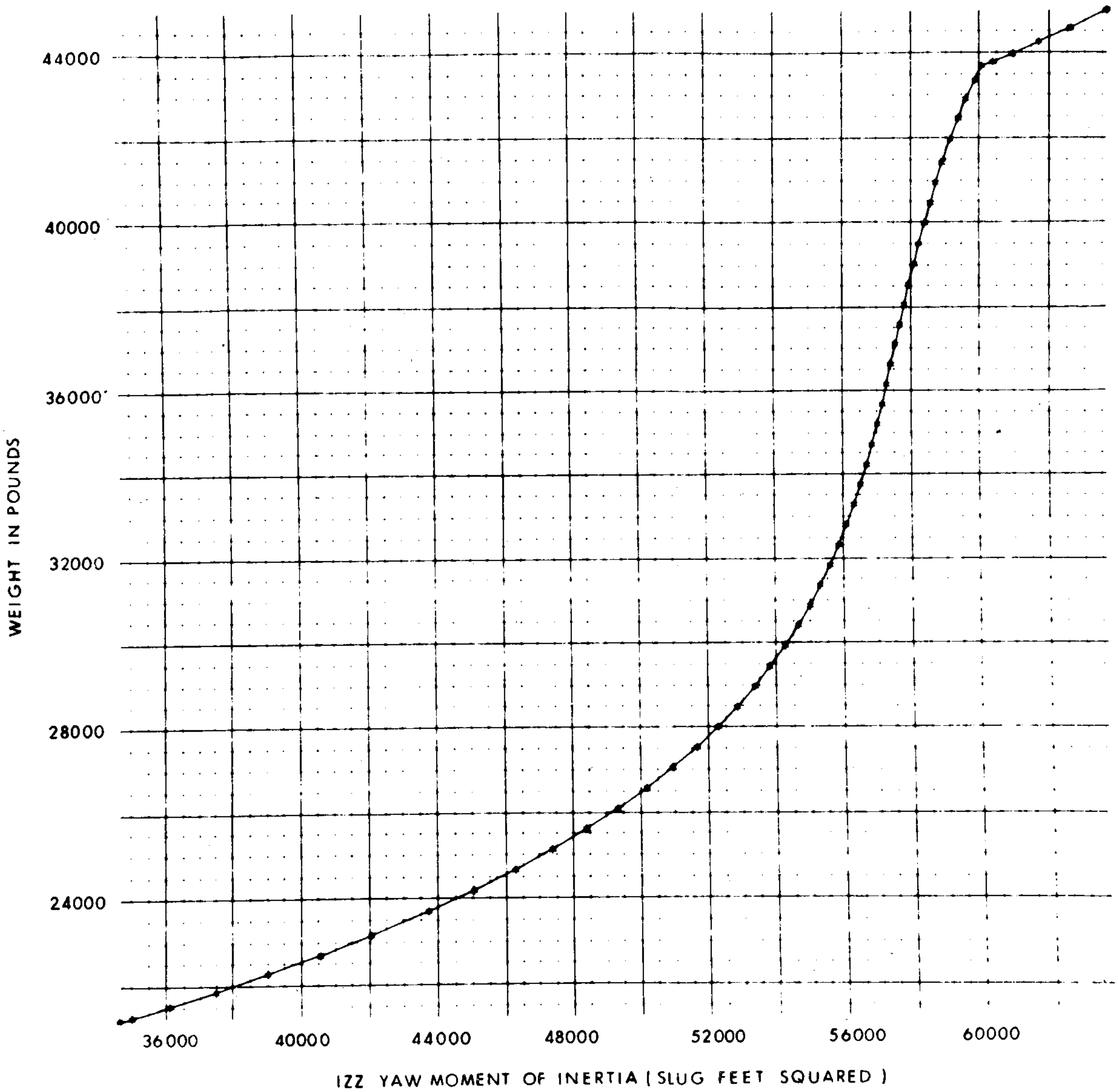


Fig. 5-6 IZZ Moment of Inertia against CSM Weight

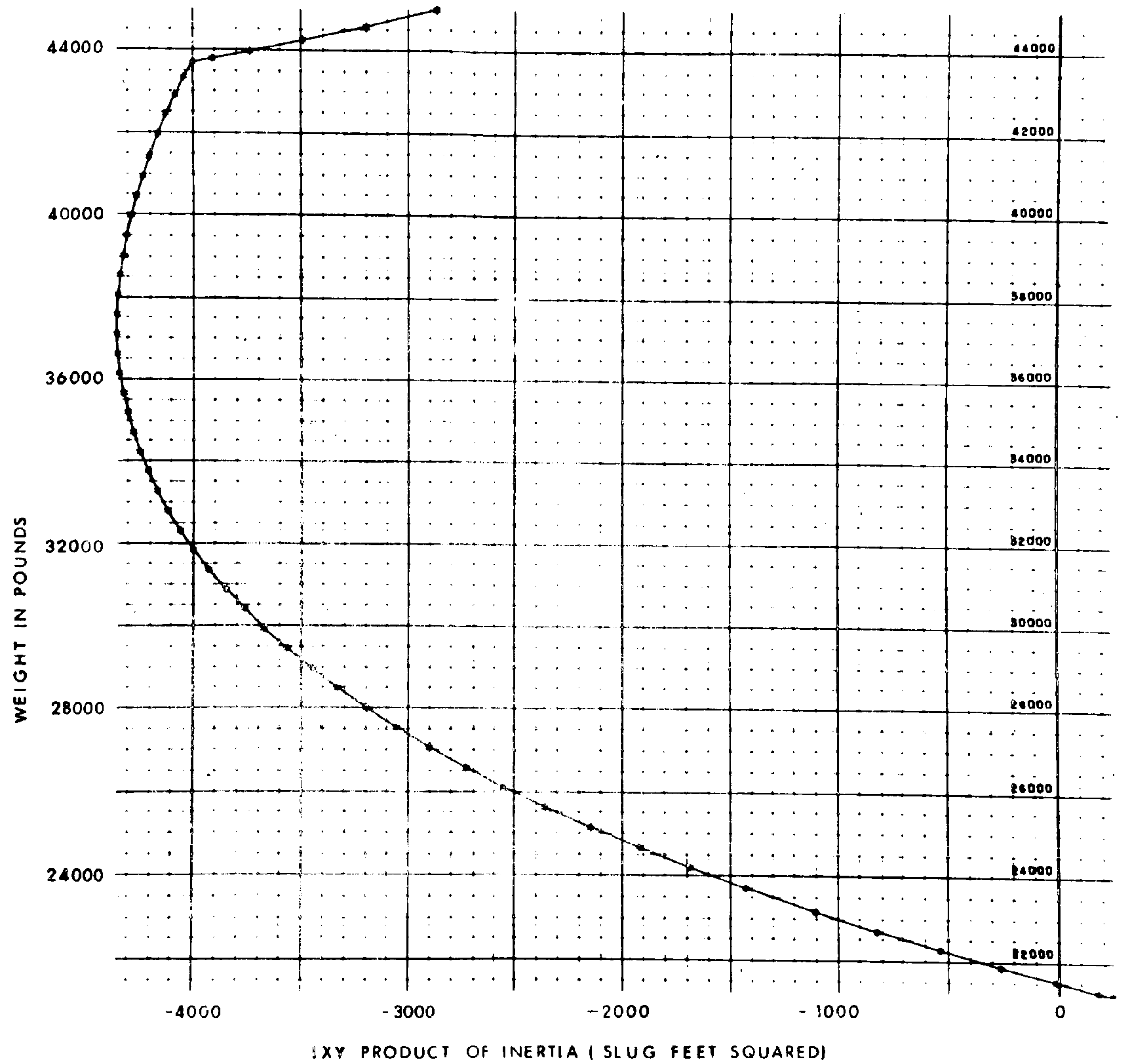


Fig. 5-7 IXY Product of Inertia against CSM Weight

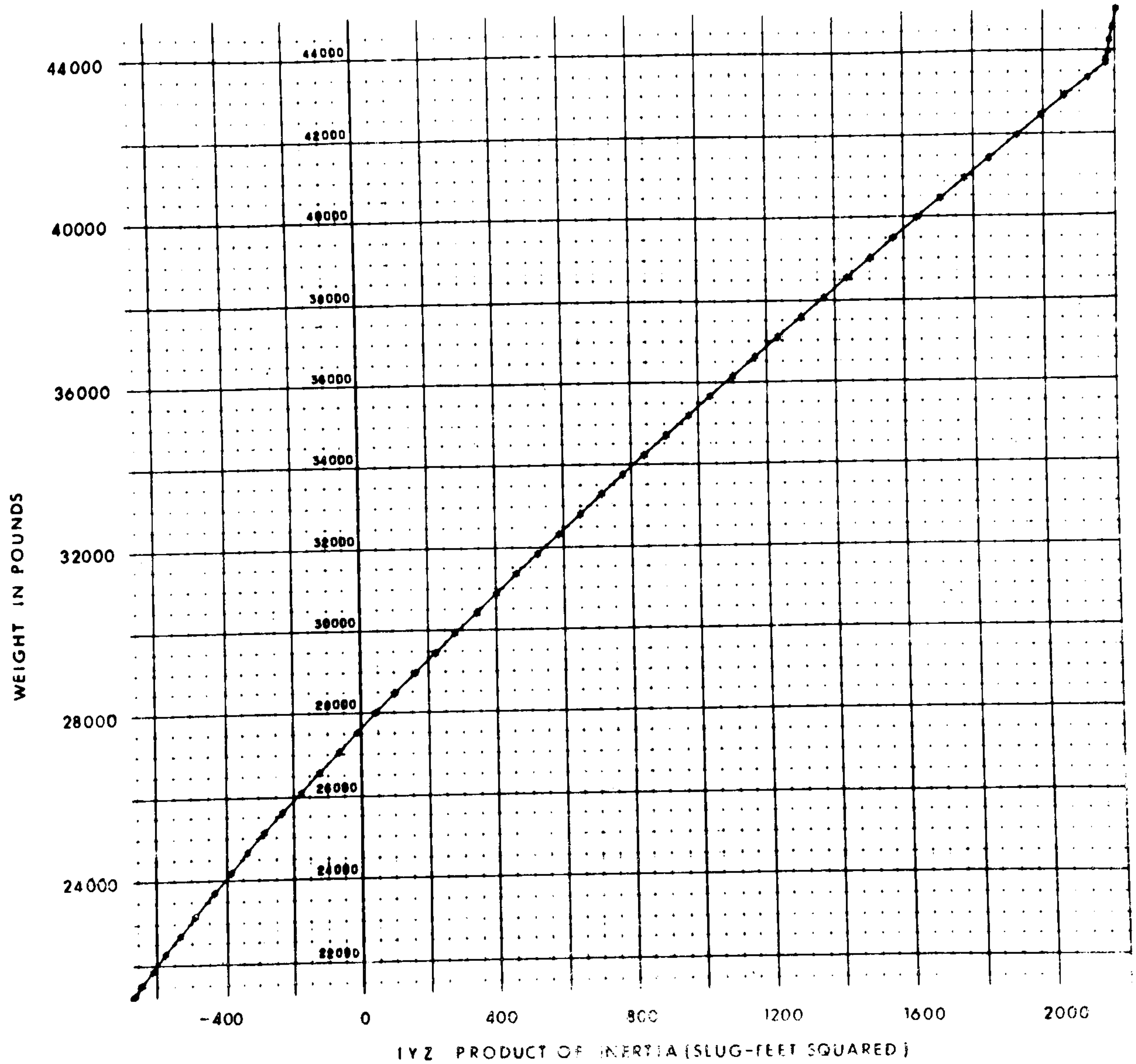


Fig. 5-8 IYZ Product of Inertia against CSM Weight

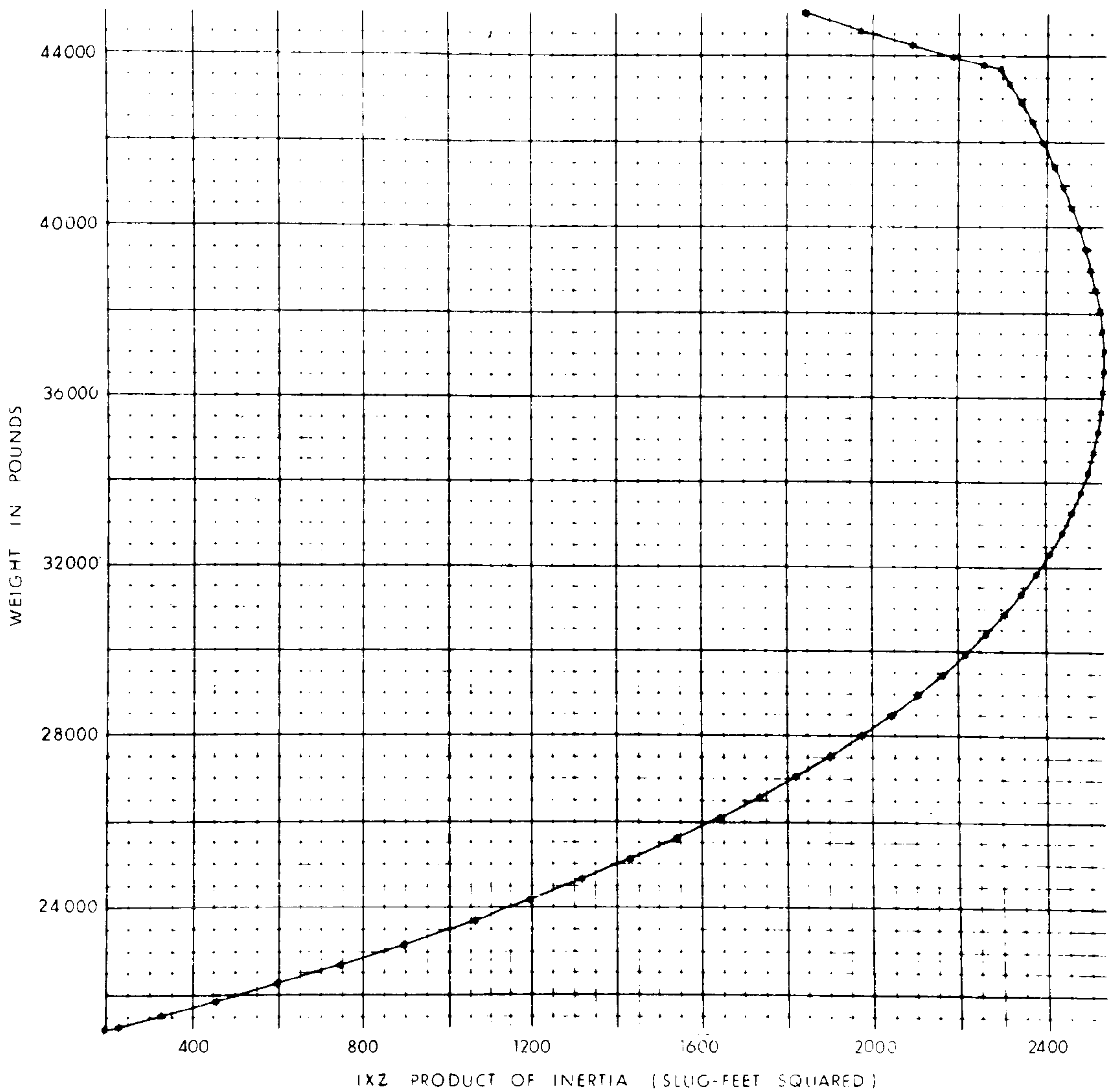


Fig. 5-9 IXZ Product of Inertia against CSM Weight

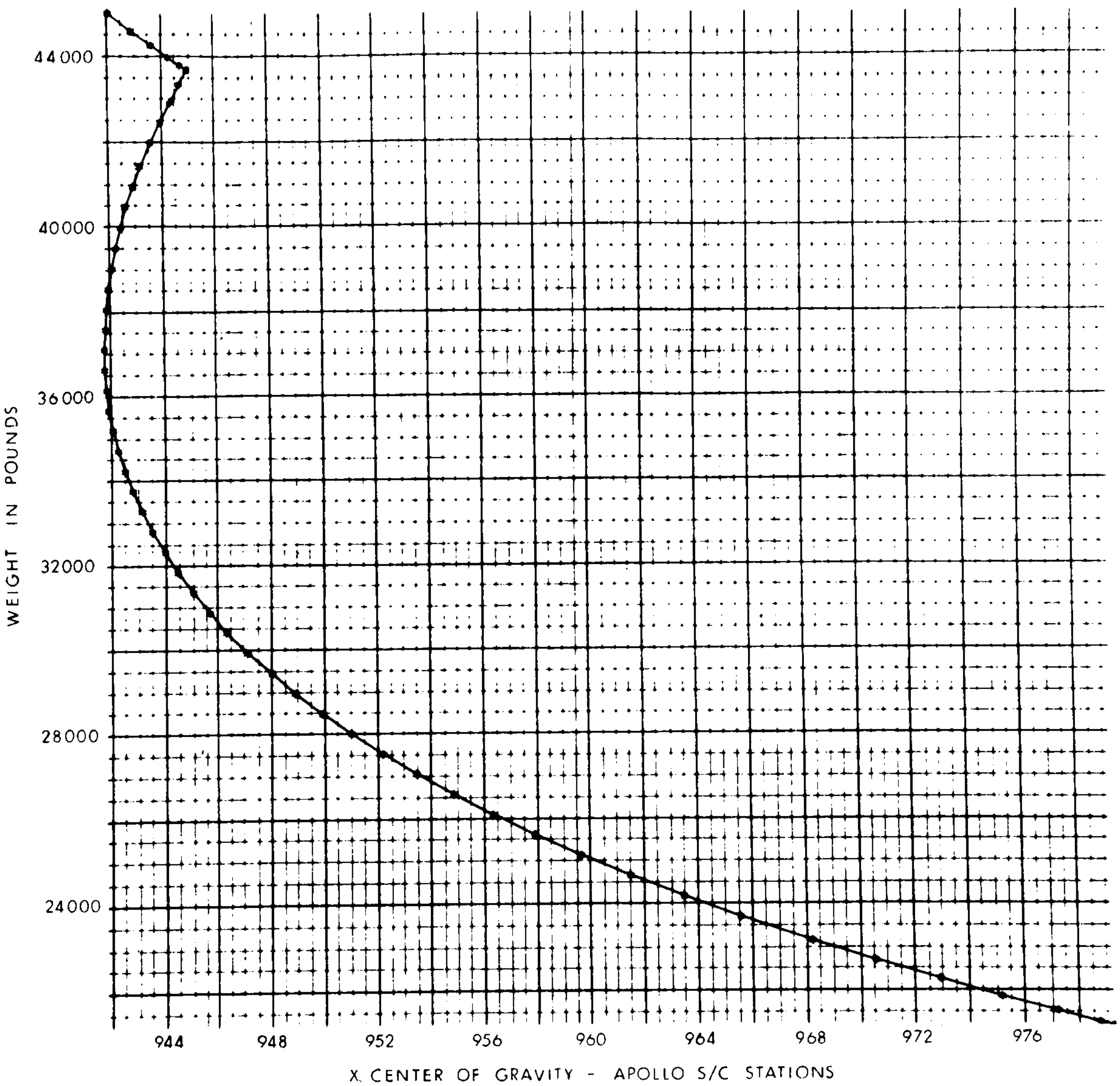


Fig. 5-10 C. g. X-Axis Coordinate against CSM Weight

[redacted]

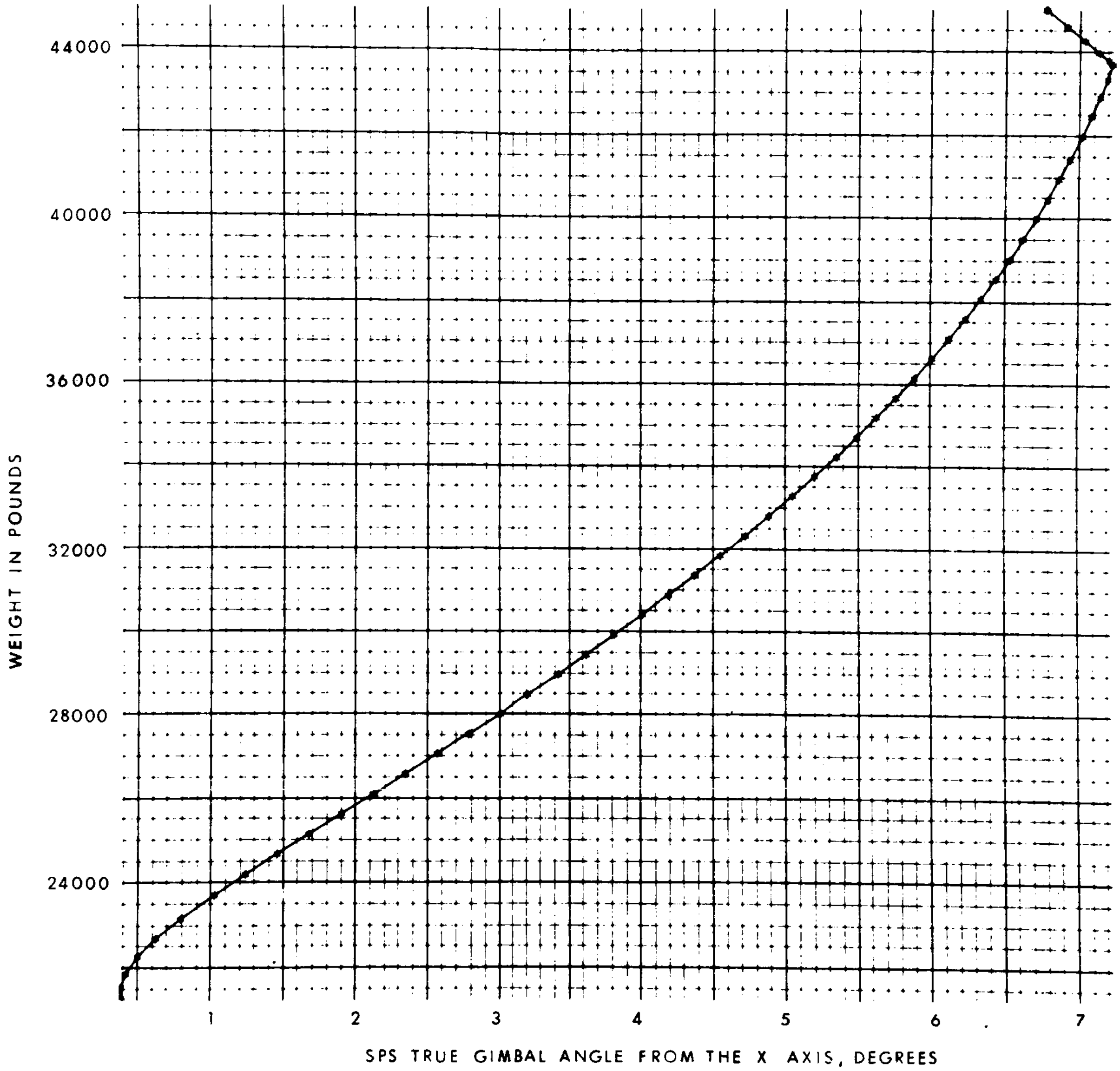


Fig. 5-11 SPS True Gimbal Angle from X-Axis against CSM Weight.

[redacted]

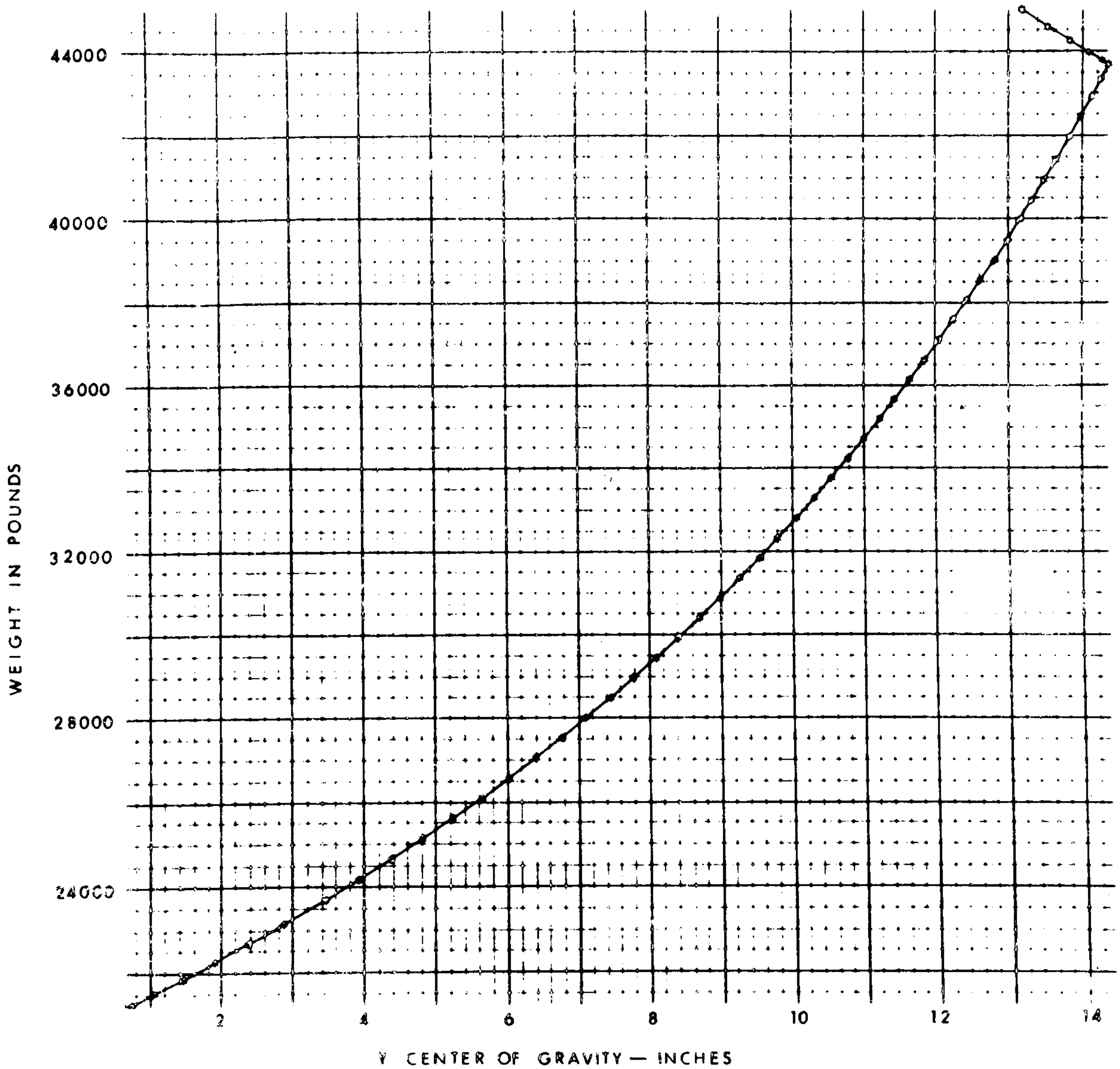


Fig. 5-12 C.g. Y-Axis Coordinate against CSM Weight

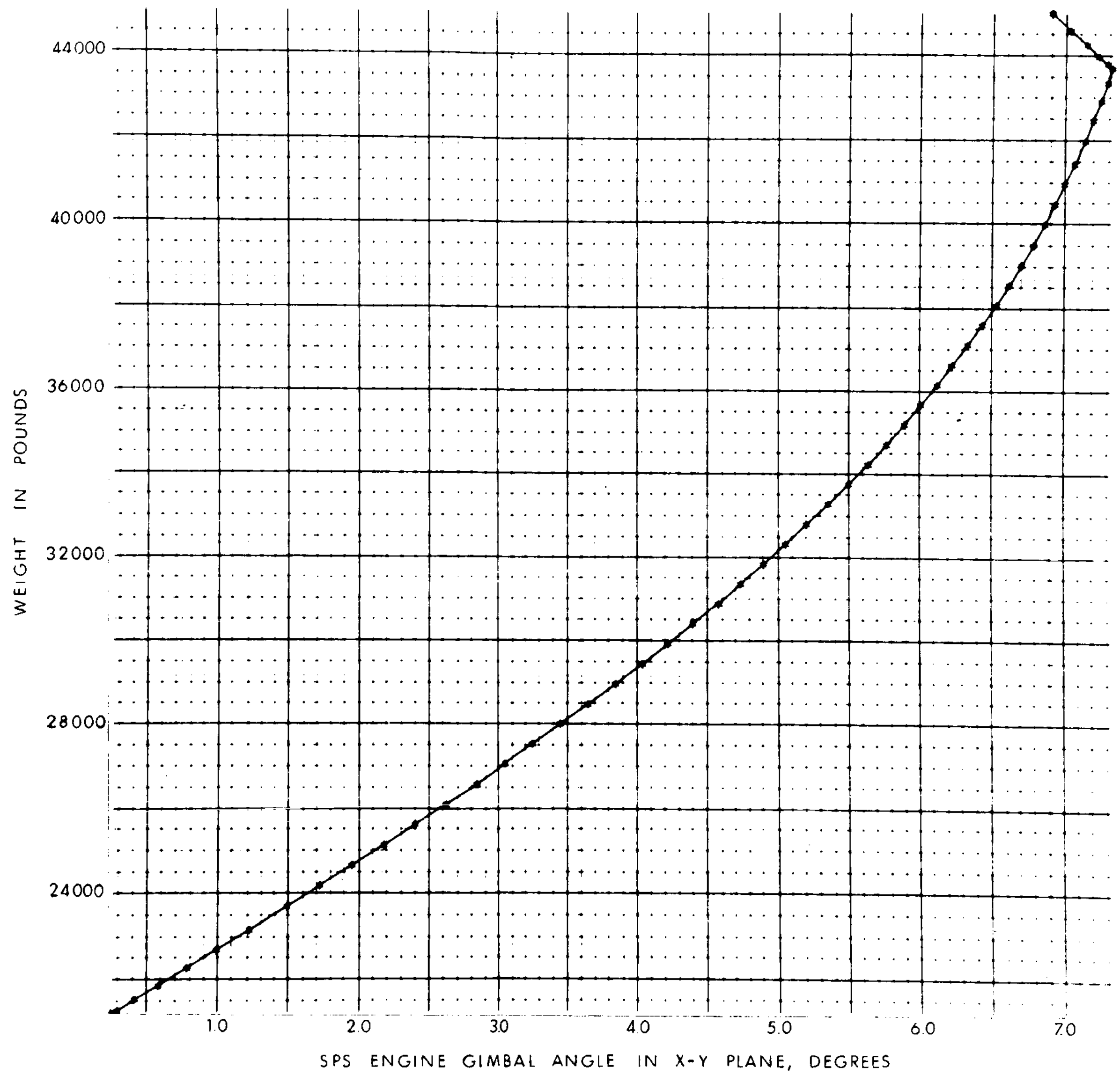


Fig. 5-13 SPS Gimbal Angle in X-Y Plane against CSM Weight.

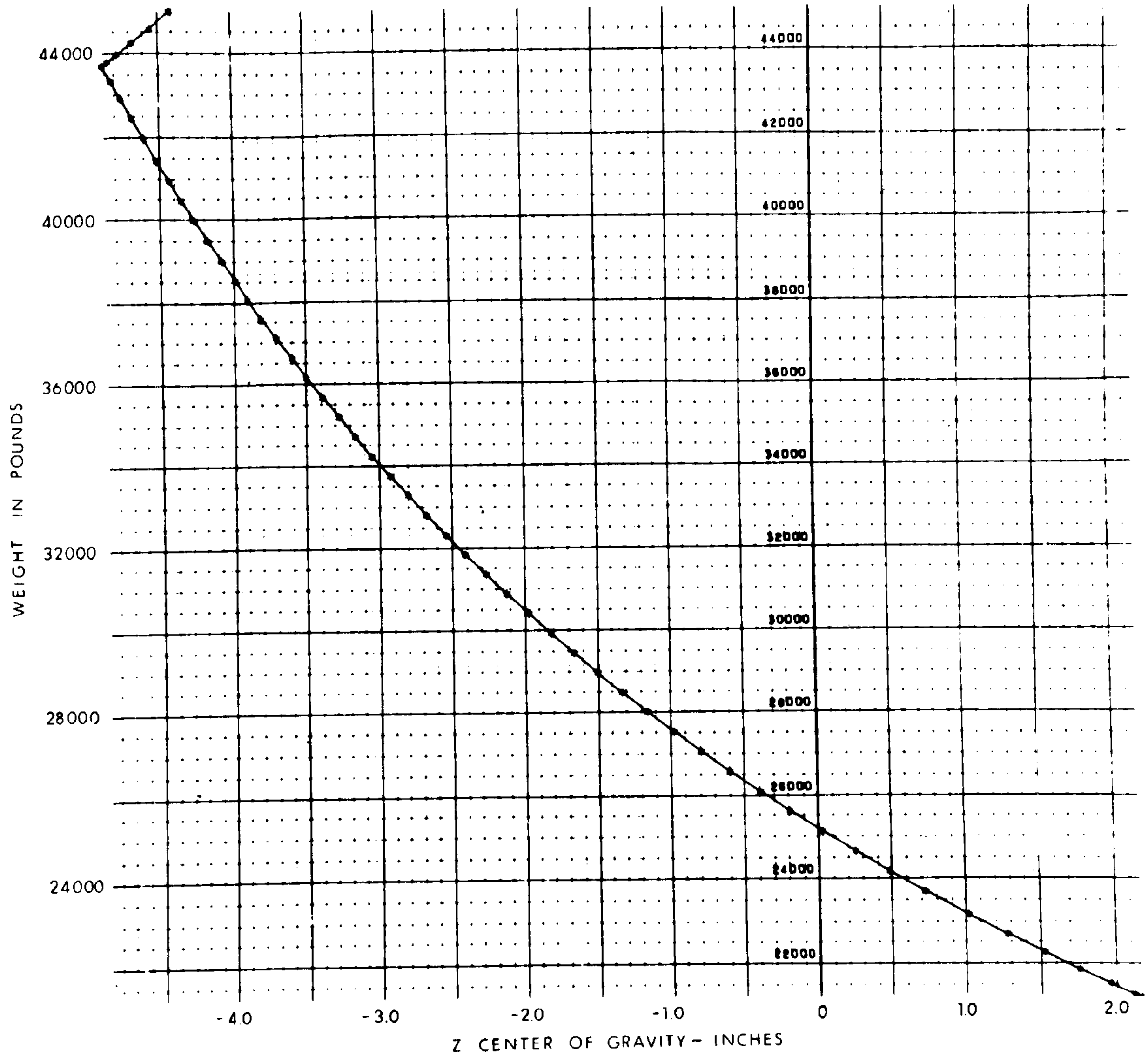


Fig. 5-14 C. g. Z-Axis Coordinate against CSM Weight

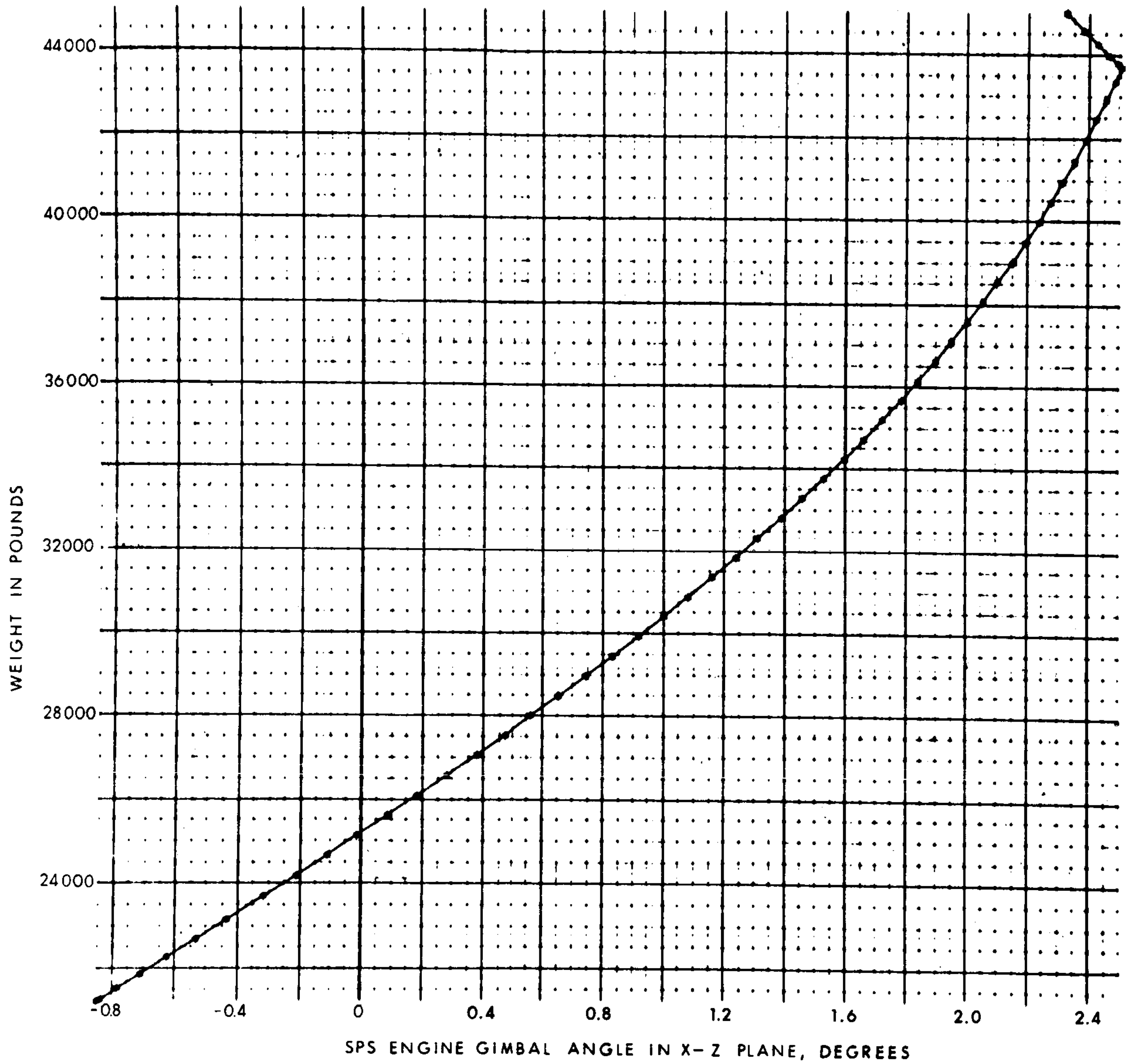


Fig. 5-15 SPS Gimbal Angle in X-Z Plane against CSM Weight.

5.4.2 SPS Engine Data

Item	Symbol	Value
Mass	ME	20 slugs
Inertia (IY = IZ = IR)	IR	213 slug ft^2
Hinge to c.g. radius	LE	8.0 inches
Vacuum thrust	TF	2.19×10^4 lbs (± 1% after 30 sec) ($^{+10\%}_{-1\%}$ after 750 sec)
Specific impulse	ISP	318.7 sec (3σ value after 750 sec)
Maximum start and shutdown transients		See Fig. 5.16
Mean thrust-off impulse		8,400 lb-sec
Displacement, thrust vector from engine gimbal axes intersection		<0.125 inches
Misalignment, thrust vector from engine mount plane normal		<0.5 deg.

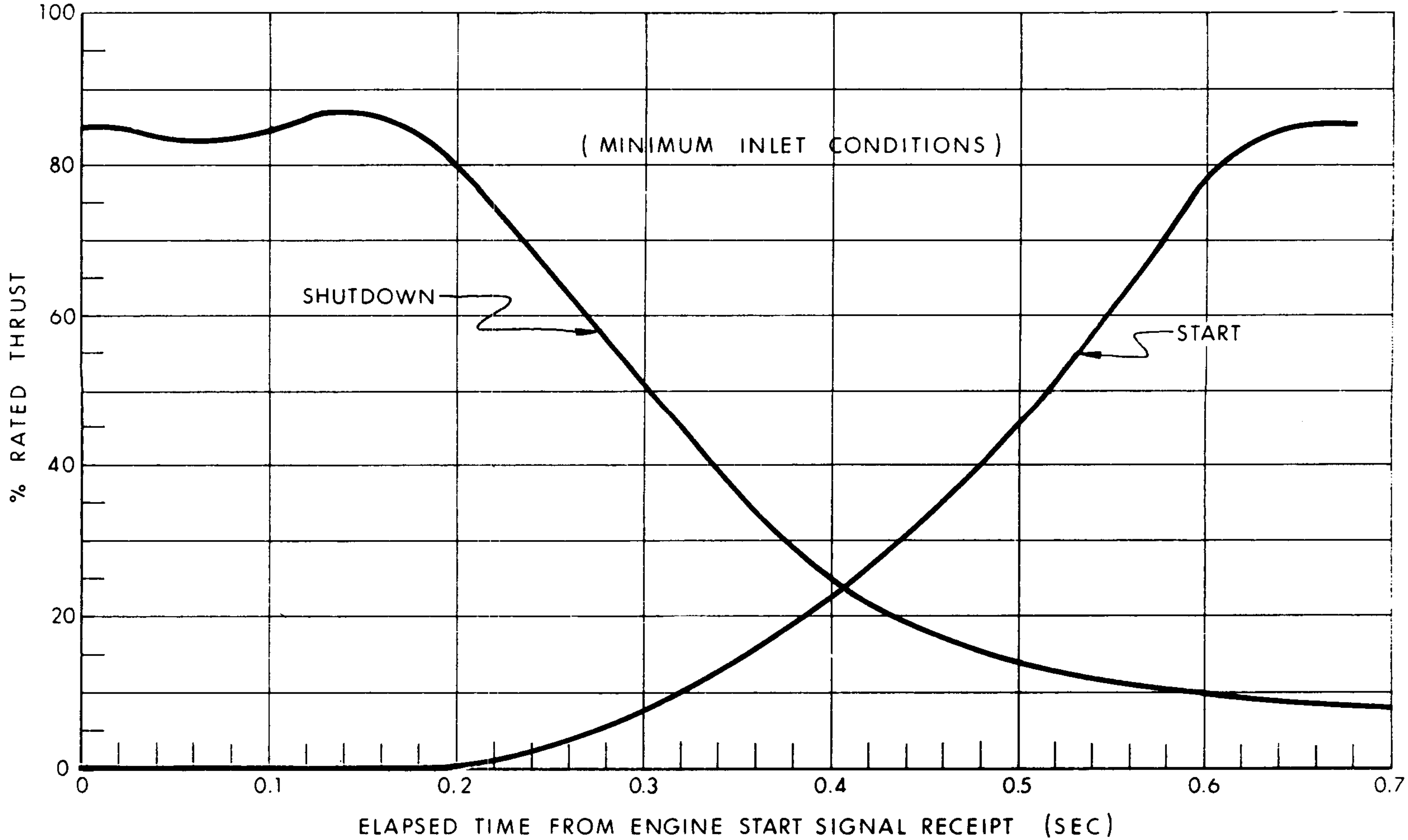


Fig. 5-16 SPS Engine Start and Shutdown Transients

5.4.3 TVC Autopilot Data

TVC Autopilot Data	Symbol	Pitch (Y)	Yaw (Z)	Units
Configuration	Defined in Fig. 5.17			
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		rads(6°)
Commanded position limit	LMP(2)	0.227		rads(13°)
Clutch servo amplifier gain	KS	20.0		Amps/rad
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	0.600		Amps
Clutch gain	KC	3,530		lbs/amp
Actuator moment arm	RA	1.00	1.05	feet
Clutch lead time constant	τ_5	0.022		sec
Clutch lag time constant	τ_6	0.029		sec
Total actuator load inertia	JT	281	287	slug-ft^2
Actuator load time constant	τ_7	0.150	0.154	rad/sec
Actuator load natural frequency	WB	104	81.7	rad/sec
Actuator load damping ratio	ζ	0.104	0.137	
Engine rate limit	LMR	0.300		rad/sec
Engine position limit (pitch)	LMY	±0.105		rad($\pm 6^{\circ}$)
Engine position limit (yaw)	LMZ		+0.218 -0.078	rad($^{+12.5^{\circ}}_{-4.5^{\circ}}$)
Position feedback gain	KD	1.00		rads/ft/sec
Position pickoff frequency	WD	63.0	46.2	
Rate feedback gain	KG	0.090		rads/ft
Rate pickoff frequency	WC	48,1	40.0	rads/sec

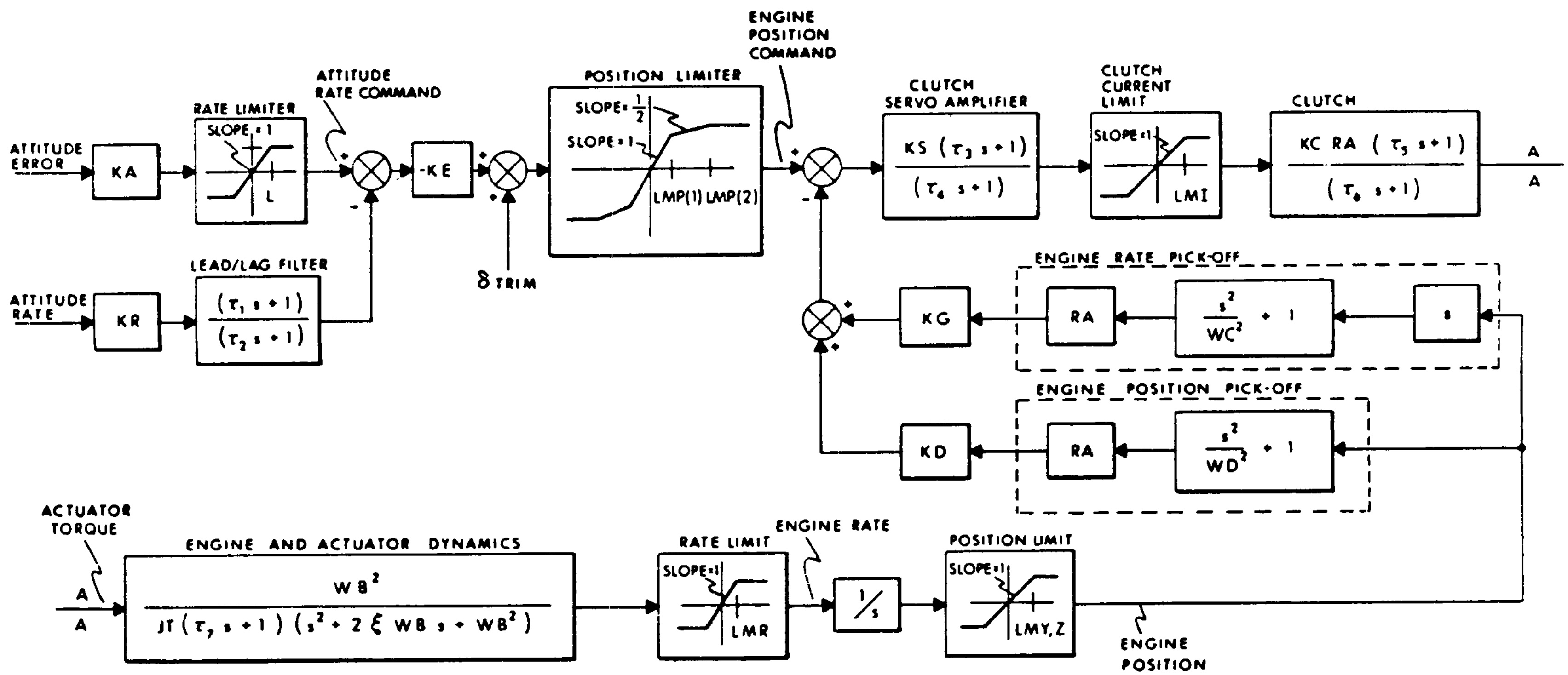


Fig. 5-17 TVC Autopilot Block Diagram

5.4.4 RCS Autopilot Data

			Att. Cont.	TVC	Pre-05g		Entry	
Configuration: see Fig. 5-18			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	---3	---3	1.9^4	0.7^5	1.9^4	---(1)
Rate Gain	GR	n.d.	1.0	1.0	0.1		0.1	
Roll-to-yaw coupling angle	ALPHA	Degrees	---	---	---		33	
Filter gain	K	Deg/sec	1.0	1.0	--(2)		--(2)	
Filter Time constant	τ_f	sec	1.0	1.0	--(2)		--(2)	
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. Filter feedback open-circuited during entry.
3. 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)
4. Effective attitude rate limit (roll): 17^o/sec
5. Effective attitude rate limit (pitch, yaw): 5^o/sec

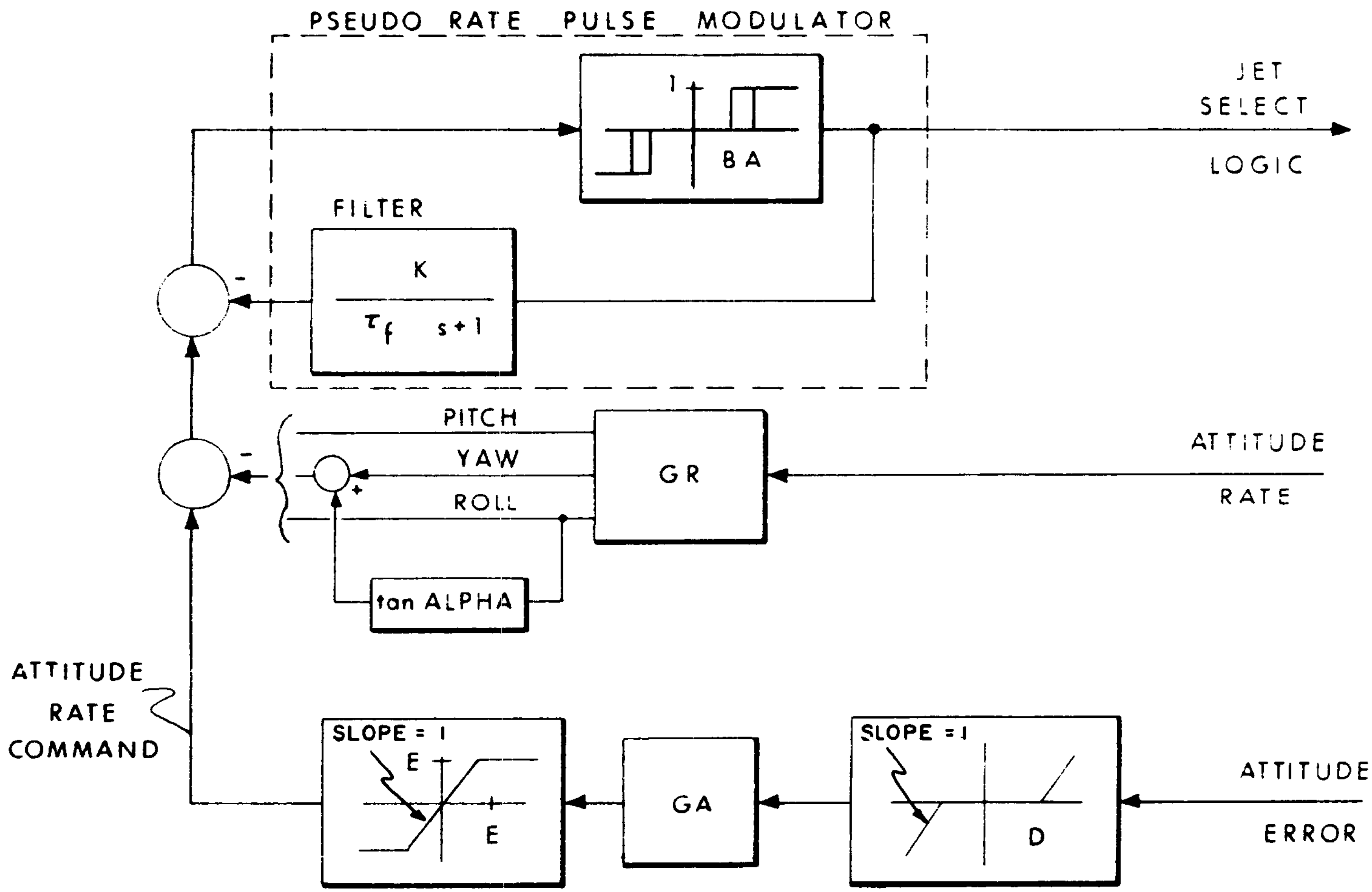


Fig. 5-18 RCS Autopilot Block Diagram

Item	Units	Value SM	Value CM
5. 4. 5 RCS Reaction Jet Data			
Configuration		(see Fig. 5. 19)	(see Fig. 5. 20)
Nominal vacuum thrust	lbs	100 ± 5	91 ± 3
Specific impulse (steady)	secs	300 ± 5	270 ± 4
Minimum impulse	lb-sec	0. 5 ± 0. 1	2. 0 ± 0. 3
Thrust rise lag	millisec	<12. 5	<13. 0
Thrust rise time constant	millisec	2. 0 (exp)	2. 0 (linear)
Thrust decay lag	millisec	<6. 0	<4. 0
Thrust decay time constant	millisec	2. 0 (exp)	5. 0 (linear)
Duration, minimum impulse electrical signal	millisec	18. 0±4. 0	18. 0±4. 0

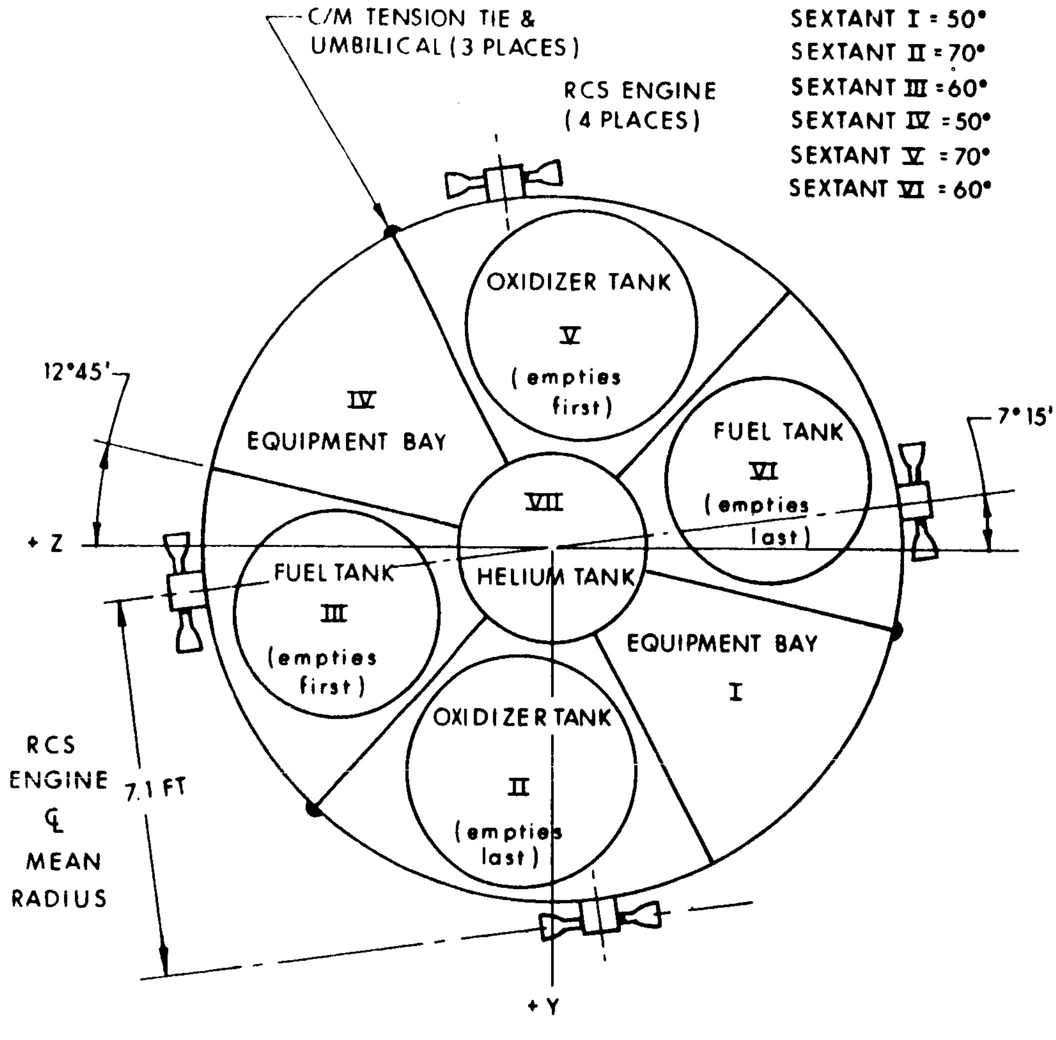


Fig. 5-19 (1) CSM Reaction Jet Positions

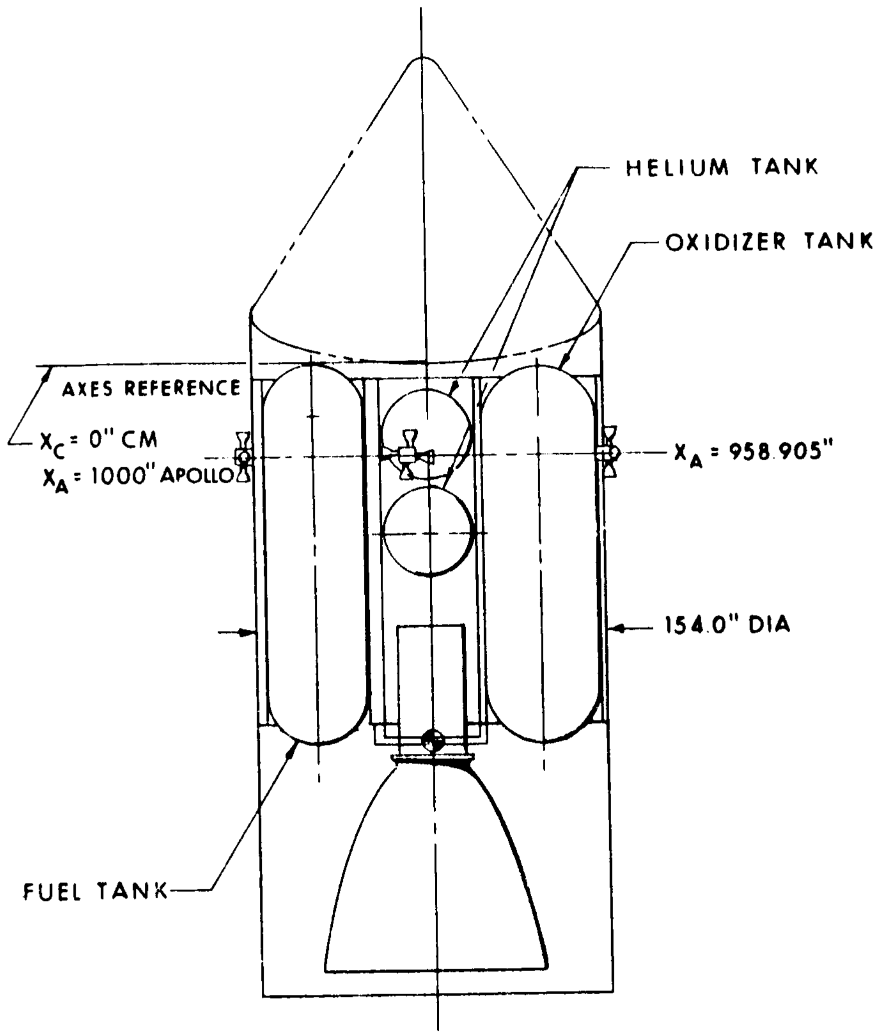
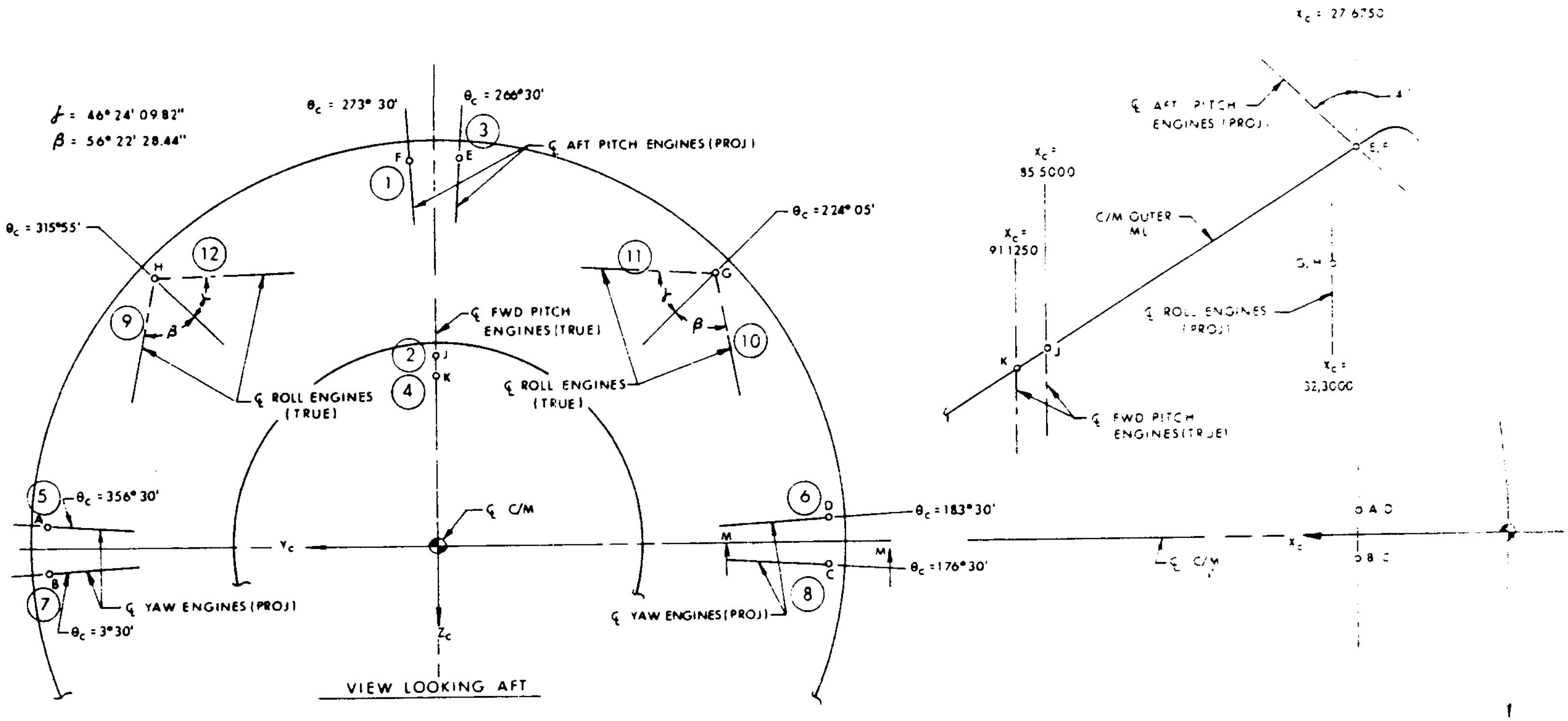


Fig. 5-19 (2) CSM Reaction Jet Positions

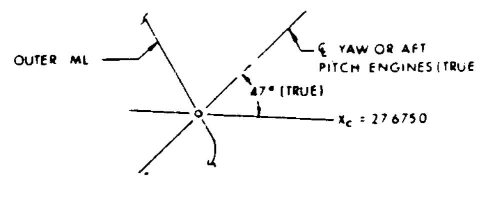


	X_c	Y_c	Z_c	R_c
A	27.6750	72.2846	- 4.4211	72.4197
B	27.6750	72.2846	4.4211	72.4197
C	27.6750	-72.2846	4.4211	72.4197
D	27.6750	-72.2846	- 4.4211	72.4197
E	27.6750	- 4.4211	- 72.2846	72.4197
F	27.6750	4.4211	- 72.2846	72.4197
(1)G	32.3000	- 51.9826	- 50.3454	72.3661
(1)H	32.3000	51.9826	- 50.3454	72.3661
J	85.5000	0	- 35.5483	35.5483
K	91.1250	0	- 31.9616	31.9616

NOTES (1) NOT ON OUTER ML — INTERS PT OF ℄ ROLL ENGINES

(2) ALL LINEAR MEASUREMENTS IN INCHES

(3) JET NUMBERING SUGGESTED BY MIT



SECTION M-M

(TYPICAL RADIAL SECTION THRU ℄ YAW OR AFT PITCH ENGINES)

Fig. 5-20 CM Reaction Jet Positions

5.4.6 CM Data

Control Weight	11,000 lbs	
Principal inertia (IXX)	5065.0 slug-ft^2	
Principal inertia (IYY)	4491.3 slug-ft^2	
Principal inertia (IZZ)	3973.5 slug-ft^2	
Product of inertias (IXY)	-1.7 slug-ft^2	
Product of inertias (IYZ)	-43.5 slug-ft^2	
Product of inertias (IXZ)	-291.8 slug-ft^2	
CG X-location	43.4 inches	from CM origin = S/C sta. 1000
CG Y-location	0.5 inches	
CG Z-location	5.3 inches	
Aerodynamic reference area	129.4 square feet	
Aerodynamic reference diameter	154.0 inches	
Aerodynamic coefficients	see: Table (5.2), Fig. (5.21)	
Variation of coefficients with Mach number	see: Fig. (5.22)	

Table 5.2

Aerodynamic Coefficients Against Angle of Attack
for the Command Module with Protuberances

α, deg.	C_M	C_N	C_A	C_L	C_D	L/D
140.465	0.03282	0.13187	-0.99218	0.52987	0.84915	0.62400
145.465	0.02686	0.10490	-1.10571	0.54042	0.97033	0.55695
150.465	0.01851	0.07990	-1.20796	0.52595	1.09038	0.48236
155.465	0.00779	0.06223	-1.29105	0.47950	1.20032	0.39947
160.465	-0.00268	0.05562	-1.36511	0.40405	1.30513	0.30958
165.465	-0.01411	0.04354	-1.42967	0.31666	1.39484	0.22702
170.465	-0.02601	0.01772	-1.47186	0.22634	1.45446	0.15562
175.465	-0.03708	-0.00144	-1.50081	0.12010	1.49600	0.08082

NOTES:
1. Above Table for Mach 10.0
2. Coefficients for Moment Center at

$X_{c.g.}$ = 1043.1 inches

$Y_{c.g.}$ = 0.0 inches

$Z_{c.g.}$ = 5.4 inches

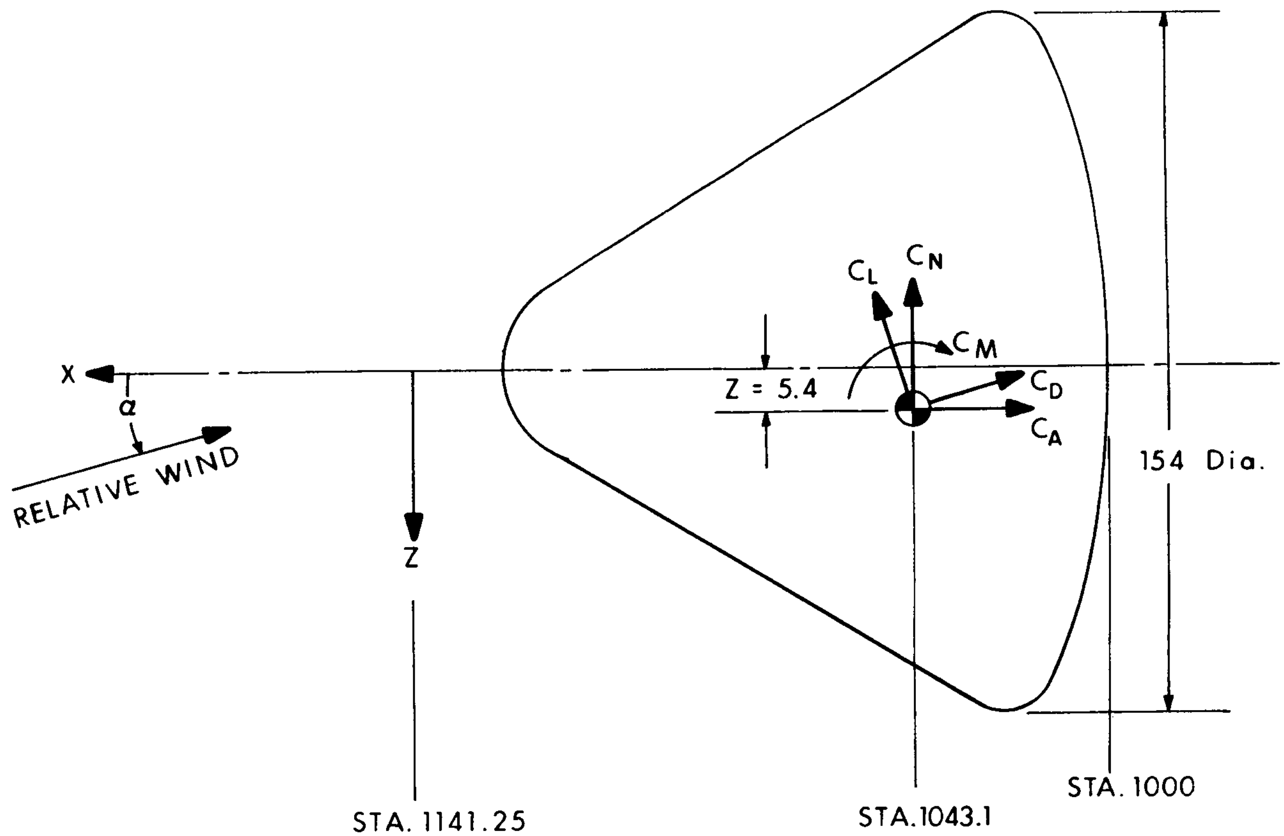
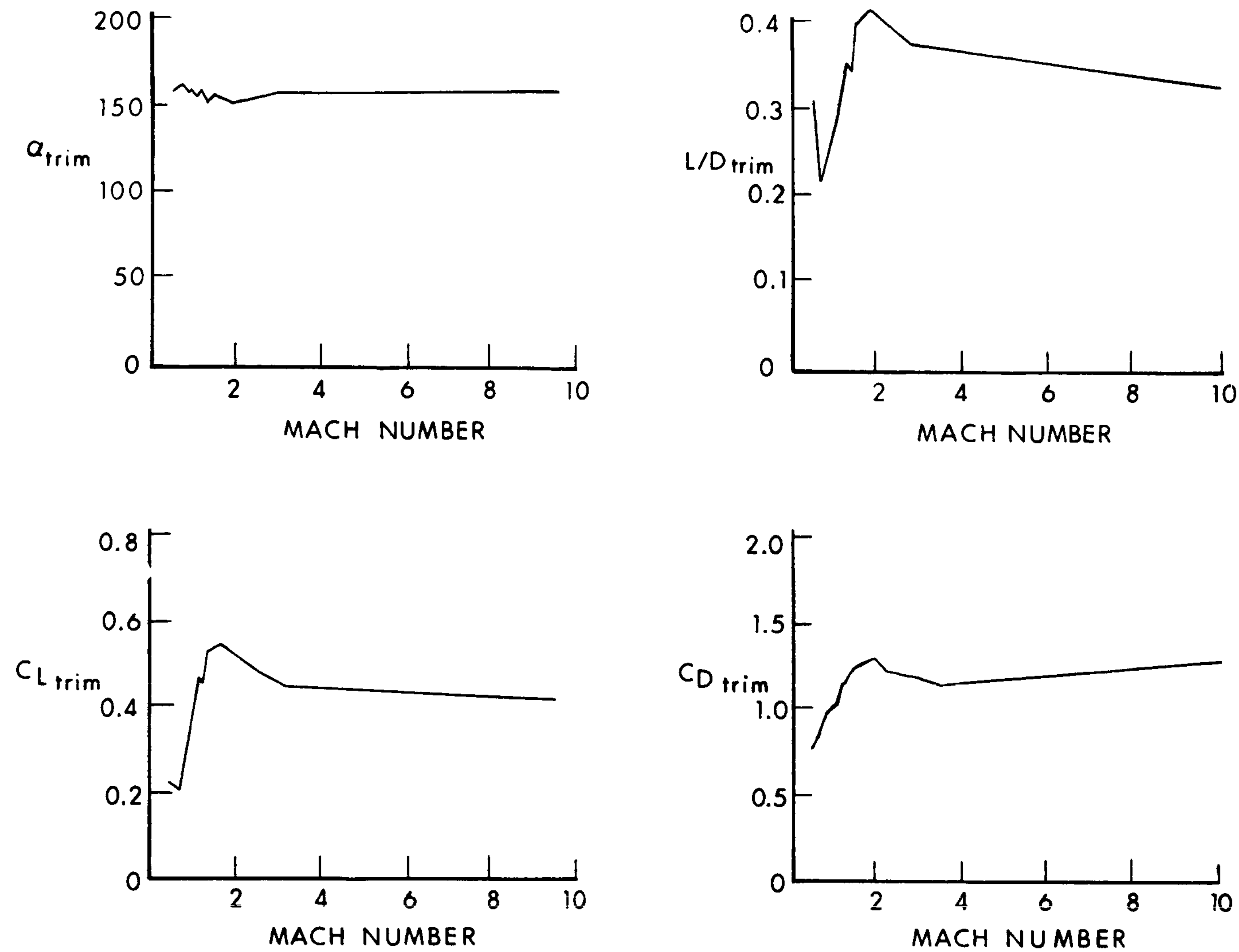


Fig. 5-21 CM Axis System and Reference Center of Gravity



NOTE: COEFFICIENTS FOR MOMENT CENTER AT.

$X_{c.g.}$ = 1043.1 ins

$Y_{c.g.}$ = 0.0 ins

$Z_{c.g.}$ = 5.4 ins

Fig. 5-22 Experimental Trim Values for Block I CM with External Protruberances

5.5 Physical constants

5.5.1 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	$7.292\ 106\ 35 \times 10^{-5}$ radians/sec
Reference ellipsoid		Fischer, 1960

5.5.2 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

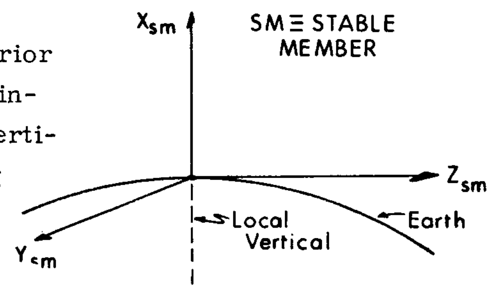
6. G&N ERROR ANALYSIS

This section provides the results of G&N Error Analysis. Table 6-1 summarizes the one-sigma total error at each major event time and breaks these down into the contributions of IMU errors accumulated during each powered phase. Tables 6-2 through 6-16 break down each line of Table 6-1 into the contributions of each IMU sensor error term.

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

Entry γ_i (one sigma)	:	0.165 degree
Entry V_i (one sigma)	:	18.0 feet per second
CEP at Pacific Recovery Point:		15.6 nautical miles

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



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

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

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

4) No realignment of the Stable Member was assumed.

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

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

7) "Initial S.M. Alignment Errors" includes only the uncorrelated alignment errors. They do not include the alignment errors due to accelerometer bias errors. The azimuth alignment error (about X_{SM}) is affected principally by by Z gyro drift effect on the gyro-compassing loop. Since there are other contributing factors to azimuth misalignment, this alignment error has been assumed to be statistically independent of Z gyro drift.

8) The position and velocity errors given in the tables for the various IMU sensor error terms are indication errors. No steering error was assumed. The indication errors in position and velocity were computed separately for each sensor error term using an array of error equations and the input position and acceleration trajectory data. These equations take into account the effect of the platform error on the gravity vector computation. For each trajectory run the position and velocity errors due to each platform error are computed simultaneously and printed in a summary table for all trajectory events of interest.

TABLE 6-1

202 TRAJECTORY ERRORS

Event	Time from start (mins)	Type of Error	Position Error (n. miles)			Velocity Error (ft/sec)		
			Alt.	Track	Range	Alt.	Track	Range
SIVB Cutoff	10.3	1) Total Indication Error	0.34	3.07	0.17	9.2	72.1	4.2
SPS 1st Burn Cutoff	14.7	1) Total Indication Error	0.75	6.35	0.53	13.5	79.5	7.7
		2) Effect of IMU Errors during SPS 1st Burn	0.06	0.34	0.05	3.3	17.7	2.3
Coast Apogee	42.2	1) Total Indication Error	2.68	11.14	5.84	33.8	46.2	12.2
		2) Effect of IMU Errors during SPS 1st Burn	0.74	2.72	1.16	7.3	3.6	3.1
Coast End End (SPS 2nd Burn Ignition)	65.4	1) Total Indication Error	3.84	5.35	11.36	70.3	73.5	16.1
		2) Effect of IMU Errors during SPS 1st Burn	1.46	0.08	2.99	20.0	17.1	6.2
SPS 2nd Burn Cutoff	67.0	1) Total Indication Error	3.78	6.51	11.80	73.2	74.1	17.7
		2) Effect of IMU Errors during SPS 1st & 2nd Burns	1.46	0.39	3.20	20.7	22.1	7.7
		3) Effect of IMU errors during SPS 2nd Burn	0.02	0.05	0.01	3.1	6.1	1.6
Entry Start	72.0	1) Total Indication Error	3.17	9.70	13.20	82.5	53.5	18.0
		2) Effect of IMU Errors during SPS 1st & 2nd Burns	1.24	1.43	3.93	24.3	19.8	7.5
		3) Effect of IMU Errors during SPS 2nd Burn	0.20	0.34	0.04	3.9	5.6	0.6
Entry End (at altitude of 50,000 ft)		1) Total Indication Error	4.76	12.06	14.43	116.0	38.7	28.6
		2) Effect of IMU Errors during SPS 1st & 2nd Burns & Entry	2.25	3.60	4.92	56.1	50.3	11.9
		3) Effect of IMU Error during SPS 2nd Burn & Entry	1.07	1.64	0.62	36.8	49.0	9.7
		4) Effect of IMU Errors during Entry only	1.70	1.66	0.31	45.3	48.9	7.80

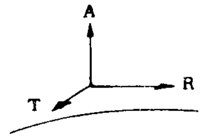
Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		-18,580			-71.61	
		$A_{(SM)YI}$		0.04 mr	153		- 283	0.75		-0.73
		$A_{(SM)ZI}$		0.07 mr		403			0.89	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	557		- 157	2.34		-0.61
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	-1,316		369	-4.65		1.18
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		- 1,194			- 3.69	
			Eff on Init Mlm			1,173			2.60	
			Combined Eff			- 21			- 1.09	
		ACBZ	Direct effect	0.2 cm/sec^2	- 359		-1,142	-1.24		-3.52
			Eff on Init Mlm		- 779		1,441	-3.83		3.73
			Combined Eff		-1,138		299	-5.07		0.21
	Scale Factor Error	SFEX		87 PPM	- 573		159	-1.62		0.38
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	- 134		- 430	-0.56		-1.65
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	- 95		26	-0.24		0.05
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	- 21		- 68	-0.09		-0.27
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		- 333			- 1.97	
		BDY	Direct effect	3.6 meru	281		- 302	1.86		-1.29
		BDZ	Direct effect	3.6 meru		213			0.74	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		- 1,594			-7.71	
		ADSRAY		10.5 meru /g	- 692		642	-4.95		3.19
		ADIAZ		15 meru /g		608			2.47	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g^2		- 162			-0.71	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g^2	94		- 88	0.65		-0.42
		$A^2A_{(IA)(IA)Z}$		1 meru/g^2		58			0.23	
Root Sum Square Error (in ft and ft/sec)					2,069	18,667	1,028	9.20	72.12	4.16
Root Sum Square Error (in n. mi. and ft/sec)					0.34	3.07	0.17	9.2	72.1	4.2

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Table 6-2 Total Indication Errors at SIVB Cutoff

Error (A, T, R)				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		-38,364			-78.85	
		$A_{(SM)YI}$		0.04 mr	240		-558	0.83		-0.92
		$A_{(SM)ZI}$		0.07 mr		622			0.75	
ACCELEROMETER	Accel. IA Nonorthog-onality	X to Y		0.1 mr						
		X to Z		0.1 mr	1,160		-671	3.12		-1.47
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	-2,598		1,491	-6.97		3.24
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		-2,307			-4.72	
			Eff on Init Mlm			1,812			2.20	
			Combined Eff			-495			-2.52	
		ACBZ	Direct effect	0.2 cm/sec^2	-1,412		-1,893	-3.61		-3.79
			Eff on Init Mlm		-1,224		2,844	-4.22		4.67
			Combined Eff		-2,636		951	-7.83		0.88
	Scale Factor Error	SFEX		87 PPM	-962		539	-2.07		0.82
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	-563		-762	-1.44		-1.54
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-152		84	-0.31		0.11
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-89		-120	-0.22		-0.22
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		-938			-2.73	
		BDY	Direct effect	3.6 meru	685		-894	2.55		-2.26
		BDZ	Direct effect	3.6 meru		411			0.77	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		-3,816			-9.27	
		ADSRAY		10.5 meru/g	-1,842		2,174	-6.92		5.96
		ADIAZ		15 meru/g		1,294			2.71	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 $meru/g^2$		-363			-0.82	
		$A^2D_{(SRA)(SRA)Y}$		1 $meru/g^2$	245		-290	0.91		-0.78
		$A^2A_{(IA)(IA)Z}$		1 $meru/g^2$		122			0.25	
Root Sum Square Error (in ft and ft/sec)					4,506	38,600	3,224	13.50	79.54	7.66
Root Sum Square Error (in n. mi. and ft/sec)					0.75	6.35	0.53	13.5	79.5	7.7

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Table 6-3 Total Indication Errors at SPS 1st Burn Cutoff

Error (A, R, T axes)				RMS Error	Final Position Error in Local Axes (in feet): Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec): Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		-2,041			-17.46	
		$A_{(SM)YI}$		0.04 mr	17		- 15	-0.15		-0.13
		$A_{(SM)ZI}$		0.07 mr		6			0.05	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	49		- 31	0.42		0.27
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec²	-180		115	-1.44		0.90
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec²		-210			- 1.64	
			Eff on Init Mlm			19			0.15	
			Combined Eff			-191			- 1.49	
		ACBZ	Direct effect	0.2 cm/sec²	-116		-176	-0.93		-1.37
			Eff on Init Mlm		- 89		79	-0.78		0.67
			Combined Eff		-205		- 97	-1.71		-0.70
	Scale Factor Error	SFEX		87 PPM	- 7		4	-0.06		0.03
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	- 27		- 41	-0.24		-0.35
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g²	0		0	0		0
		NCYY		10 μg/g²		0			0	
		NCZZ		10 μg/g²	- 2		- 3	-0.02		-0.02
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		- 107			-0.98	
		BDY	Direct effect	3.6 meru	82		- 73	0.77		-0.66
		BDZ	Direct effect	3.6 meru		17			0.14	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		- 290			-2.51	
		ADSRAY		10.5 meru /g	-237		210	-2.16		1.84
		ADIAZ		15 meru /g		71			0.58	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g²		- 23			-0.20	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g²	31		- 28	0.28		-0.24
		$A^2A_{(IA)(IA)Z}$		1 meru/g²		7			0.05	
Root Sum Square Error (in ft and ft/sec)					376	2,074	276	3.25	17.74	2.32
Root Sum Square Error (in n.mi. and ft/sec)					0.06	0.34	0.05	3.3	17.7	2.3

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Table 6-4 Effect of IMU Errors during SPS 1st Burn at SPS 1st Burn Cutoff

Error (A, T, R)				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(E)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		32,300			72.86	
		$A_{(SM)YI}$		0.04 mr	- 2,715		3,804	- 4.62		2.01
		$A_{(SM)ZI}$		0.07 mr		- 573			- 0.67	
ACCELEROMETER	Accel. IA Nonorthog-onality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 58		-10,813	9.70		1.26
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	- 57		24,562	-22.12		- 2.70
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		1,945			4.36	
			Eff on Init Mlm			- 1,669			- 1.95	
			Combined Eff			276			2.41	
		ACBZ	Direct effect	0.2 cm/sec^2	-25,226		71,298	-75.49		14.70
			Eff on Init Mlm		13,843		-19,396	23.57		-10.27
			Combined Eff		-11,383		51,893	-51.92		4.43
	Scale Factor Error	SFEX		87 PPM	- 1,455		10,356	-10.18		0.07
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	-10,167		28,677	-30.37		5.93
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	288		1,683	- 1.69		0.05
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	- 1,508		4,290	- 4.54		0.88
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		714			2.57	
		BDY	Direct effect	3.6 meru	- 5,996		4,750	- 7.23		4.77
		BDZ	Direct effect	3.6 meru		- 354			- 0.71	
	Acceler-ation Sensitive Drift	ADIAX		15 meru/g		3,080			8.64	
		ADSRAY		10.5 meru /g	15,515		-10,670	17.39		-12.47
		ADIAZ		15 meru /g		- 1,085			- 2.51	
	Acceler-ation Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g^2		300			0.76	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g^2	- 2,010		1,361	- 2.23		1.62
		$A^2A_{(IA)(IA)Z}$		1 meru/g^2		- 102			- 0.23	
Root Sum Square Error (in ft and ft/sec)					23,320	32,485	69,050	70.32	73.51	16.06
Root Sum Square Error (in n. mi. and ft/sec)					3.84	5.35	11.36	70.3	73.5	16.1

Table 6-5 Total Indication Errors at Coast End (SPS 2nd Burn Ignition)

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(E)X_{Io}$		0 ft	0	0	0	0	0	0
		$(E)Y_{Io}$		0 ft						
		$(E)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(E)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		478			16.83	
		$A_{(SM)YI}$		0.04 mr	- 432		377	- 0.58		0.33
		$A_{(SM)ZI}$		0.07 mr		- 2			- 0.05	
ACCELEROMETER	Accel. IA Nonorthog-onality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 763		132	- 0.58		0.63
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	2,515		- 278	1.78		-2.09
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		64			1.58	
			Eff on Init Mlm			- 6			- 0.14	
			Combined Eff			58			1.44	
		ACBZ	Direct effect	0.2 cm/sec^2	-7,204		18,366	-19.86		4.43
			Eff on Init Mlm		2,204		- 1,922	2.98		-1.68
			Combined Eff		-5,000		16,444	-16.88		2.75
	Scale Factor Error	SFEX		87 PPM	97		- 11	0.07		-0.08
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	-1,841		4,679	- 5.06		1.13
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	1		0	0		0
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	- 129		328	- 0.36		0.08
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		20			0.94	
		BDY	Direct effect	3.6 meru	-2,191		1,932	- 2.98		1.67
		BDZ	Direct effect	3.6 meru		- 4			- 0.14	
	Acceler-ation Sensitive Drift	ADIAX		15 meru/g		66			2.42	
		ADSRAY		10.5 meru /g	6,142		- 5,393	8.34		-4.67
		ADIAZ		15 meru /g		- 19			- 0.56	
	Acceler-ation Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 $meru/g^2$		5			0.19	
		$A^2D_{(SRA)(SRA)Y}$		1 $meru/g^2$	- 789		690	- 1.07		0.60
		$A^2A_{(IA)(IA)Z}$		1 $meru/g^2$		- 2			- 0.05	
Root Sum Square Error (in ft and ft/sec)					8,893	492	18,180	19.96	17.10	6.24
Root Sum Square Error (in n.mi. and ft/sec)					1.46	0.08	2.99	20.0	17.1	6.2

Table 6-6 Effect of IMU Errors during SPS 1st Burn at Coast End (SPS 2nd Burn Ignition)

Category	Group	Error		RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		-39,336			73.40	
		$A_{(SM)YI}$		0.04 mr	- 2,720		4,309	- 4.96		2.12
		$A_{(SM)ZI}$		0.07 mr		- 626			- 0.43	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 323		-10,663	9.92		1.40
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	574		24,235	-21.87		- 3.52
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		2,322			3.47	
			Eff on Init Mlm			- 1,824			- 1.24	
			Combined Eff			498			2.23	
		ACBZ	Direct effect	0.2 cm/sec^2	-24,424		75,517	-79.58		15.03
			Eff on Init Mlm		13,866		-21,971	25.28		-10.79
			Combined Eff		-10,558		53,546	-54.30		4.24
	Scale Factor Error	SFEX		87 PPM	- 1,268		10,506	-10.34		- 0.15
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	- 9,855		30,364	-32.23		5.75
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	- 260		1,723	- 1.74		0.03
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	- 1.460		4,541	- 4.80		0.87
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		1,022			3.88	
		BDY	Direct effect	3.6 meru	- 6,019		5,964	- 5.58		6.31
		BDZ	Direct effect	3.6 meru		- 304			1.87	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		3,926			8.98	
		ADSRAY		10.5 meru /g	15,864		-13,705	18.29		-13.86
		ADIAZ		15 meru /g		- 1,222			- 0.27	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 $meru/g^2$		373			0.78	
		$A^2D_{(SRA)(SRA)Y}$		1 $meru/g^2$	- 2,055		1,755	- 2.35		1.80
		$A^2A_{(IA)(IA)Z}$		1 $meru/g^2$		- 115			- 0.03	
Root Sum Square Error (in ft and ft/sec)					22,982	39,576	71,726	73.17	74.11	17.70
Root Sum Square Error (in n. mi. and ft/sec)					3.78	6.51	11.30	73.2	74.1	17.7

Table 6-7 Total Indication Errors at SPS 2nd Burn Cutoff

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		-2,318			21.56	
		$A_{(SM)YI}$		0.04 mr	- 440		461	- 0.55		0.40
		$A_{(SM)ZI}$		0.07 mr		1			0.12	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 796		279	- 0.59		0.60
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	2,670		- 794	2.69		-2.59
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		185			0.93	
			Eff on Init Mlm			3			0.35	
			Combined Eff			188			1.28	
		ACBZ	Direct effect	0.2 cm/sec^2	-7,022		19,619	-20.76		4.95
			Eff on Init Mlm		2,245		- 2,352	2.82		-2.03
			Combined Eff		-4,777		17,262	-17.94		2.92
	Scale Factor Error	SFEX		87 PPM	110		- 36	0.26		-0.20
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	-1,802		4,988	- 5.45		1.03
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	2		- 1	0.02		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	- 126		350	- 0.37		0.08
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		175			2.35	
		BDY	Direct effect	3.6 meru	-2,136		2,407	- 0.75		3.09
		BDZ	Direct effect	3.6 meru		97			2.39	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		332			3.17	
		ADSRAY		10.5 meru /g	6,249		- 6,592	7.81		-5.71
		ADIAZ		15 meru /g		24			1.55	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g^2		26			0.25	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g^2	- 803		845	- 1.00		0.73
		$A^2A_{(IA)(IA)Z}$		1 meru/g^2		2			0.14	
Root Sum Square Error (in ft and ft/sec)					8,870	2,359	19,472	20.66	22.14	7.73
Root Sum Square Error (in n. mi. and ft/sec)					1.46	0.39	3.20	20.7	22.1	7.7

Table 6-8 Effect of IMU Errors during SPS 1st and 2nd Burn at SPS 2nd Burn Cutoff

Effect of IMU Errors during SPS 2nd Burn at SPS 2nd Burn Cutoff

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		227			4.88	
		$A_{(SM)YI}$		0.04 mr	5		2	0.10		0.05
		$A_{(SM)ZI}$		0.07 mr		8			0.17	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr	5		-3	0.11		-0.07
		X to Z		0.1 mr						
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	25		-17	0.53		-0.35
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		-30			-0.63	
			Eff on Init Mlm			23			0.49	
			Combined Eff			-7			-0.14	
		ACBZ	Direct effect	0.2 cm/sec^2	17		25	0.35		0.53
			Eff on Init Mlm		-23		-12	-0.51		-0.26
			Combined Eff		-6		13	-0.16		0.27
	Scale Factor Error	SFEX		87 PPM	8		-5	0.18		-0.12
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	-3		-5	-0.07		-0.10
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	1		0	0.02		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	0		0	0		0
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		65			1.42	
		BDY	Direct effect	3.6 meru	118		60	2.58		1.33
		BDZ	Direct effect	3.6 meru		115			2.52	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		35			0.77	
		ADSRAY		10.5 meru/g	-70		-35	-1.51		-0.77
		ADIAZ		15 meru/g		97			2.10	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g^2		3			0.06	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g^2	9		4	0.19		0.10
		$A^2A_{(IA)(IA)Z}$		1 meru/g^2		9			0.19	
Root Sum Square Error (in ft and ft/sec)					140	282	73	3.06	6.11	1.61
Root Sum Square Error (in n. mi. and ft/sec)					0.02	0.05	0.01	3.1	6.1	1.6

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Table 6-9 Effect of IMU Errors during SPS 2nd Burn at SPS 2nd Burn Cutoff

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		58,534			52.86	
		$A_{(SM)YI}$		0.04 mr	- 2,400		5,968	- 6.26		2.17
		$A_{(SM)ZI}$		0.07 mr		- 714			- 0.15	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 1,351		- 9,853	9.84		1.80
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	3,063		22,286	-21.93		- 4.62
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		3,201			2.31	
			Eff on Init Mlm			- 2,079			- 0.43	
			Combined Eff			1,122			1.88	
		ACBZ	Direct effect	0.2 cm/sec^2	-18,174		88,387	-91.67		14.40
			Eff on Init Mlm		12,230		-30,427	31.94		-11.06
			Combined Eff		- 5,944		57,956	-59.73		3.34
	Scale Factor Error	SFEX		87 PPM	- 348		10,745	-11.12		- 0.37
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	- 7,444		35,501	-37.25		5.63
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	- 117		1,803	- 1.89		0.01
		NCYY		$10\ \mu g/g^2$		0			0	
		NCZZ		$10\ \mu g/g^2$	- 1,092		5,304	- 5.53		0.84
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		2,102			3.23	
		BDY	Direct effect	3.6 meru	- 4,917		9,940	- 7.84		5.61
		BDZ	Direct effect	3.6 meru		262			1.87	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		6,330			6.83	
		ADSRAY		10.5 meru /g	15,079		-24,114	25.69		- 14.57
		ADIAZ		15 meru /g		- 1,227			0.25	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$1\ meru/g^2$		578			0.58	
		$A^2D_{(SRA)(SRA)Y}$		$1\ meru/g^2$	- 1,955		3,104	- 3.31		1.89
		$A^2A_{(IA)(IA)Z}$		$1\ meru/g^2$		- 117			0.02	
Root Sum Square Error (in ft and ft/sec)					19,231	58,944	80,193	82.52	53.48	18.03
Root Sum Square Error (in n. mi. and ft/sec)					3.17	9.70	13.20	82.5	53.5	18.0

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Table 6-10 Total Indication Errors at Entry Start

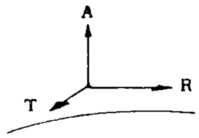
Error 				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		8,514			19.27	
		$A_{(SM)YI}$		0.04 mr	- 400		748	- 0.75		0.40
		$A_{(SM)ZI}$		0.07 mr		37			0.11	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr	- 827		793	- 1.01		0.69
		X to Z		0.1 mr						
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	$0.2\ cm/sec^2$	2,971		- 2,778	3.94		-3.15
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	$0.2\ cm/sec^2$		448			0.80	
			Eff on Init Mlm			107			0.33	
			Combined Eff			555			1.13	
		ACBZ	Direct effect	$0.2\ cm/sec^2$	-5,334		23,528	-24.05		4.73
			Eff on Init Mlm		2,037		- 3,816	3.82		-2.05
			Combined Eff		-3,297		19,712	-20.23		2.68
	Scale Factor Error	SFEX		87 PPM	154		- 160	0.28		-0.27
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	-1,448		5,947	- 6.40		1.07
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	5		- 6	0.01		-0.02
		NCYY		$10\ \mu g/g^2$		0			0	
		NCZZ		$10\ \mu g/g^2$	- 98		420	- 0.44		0.08
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		855			2.13	
		BDY	Direct effect	3.6 meru	-1,179		3,867	- 1.12		2.14
		BDZ	Direct effect	3.6 meru		793			2.20	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		1,243			2.83	
		ADSRAY		10.5 meru /g	5,633		-10,670	10.56		-5.70
		ADIAZ		15 meru /g		477			1.44	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$1\ meru/g^2$		97			0.22	
		$A^2D_{(SRA)(SRA)Y}$		$1\ meru/g^2$	- 725		1,369	- 1.36		0.73
		$A^2A_{(IA)(IA)Z}$		$1\ meru/g^2$		42			0.13	
Root Sum Square Error (in ft and ft/sec)					7,513	8,715	23,880	24.25	19.81	7.53
Root Sum Square Error (in n. mi. and ft/sec)					1.24	1.43	3.93	24.3	19.8	7.5

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Table 6-11 Effect of IMU Errors during SPS 1st and 2nd Burns at Entry Start

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		1,648			4.49	
		$A_{(SM)YI}$		0.04 mr	40		3	0.13		0.01
		$A_{(SM)ZI}$		0.07 mr		57			0.16	
ACCELEROMETER	Accel. IA Nonorthog-onality	X to Y		0.1 mr						
		X to Z		0.1 mr	29		- 39	0.09		-0.11
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	134		-180	0.44		-0.50
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		- 214			-0.58	
			Eff on Init Mlm			166			0.45	
			Combined Eff			- 48			-0.13	
		ACBZ	Direct effect	0.2 cm/sec^2	189		118	0.59		0.31
			Eff on Init Mlm		- 205		- 13	-0.66		-0.03
			Combined Eff		- 16		105	-0.07		0.28
	Scale Factor Error	SFEX		87 PPM	44		- 60	0.14		-0.17
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	- 35		- 22	-0.11		-0.06
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	4		- 5	0.01		-0.02
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	2		1	0.01		0
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		477			1.30	
		BDY	Direct effect	3.6 meru	1,048		67	3.35		0.13
		BDZ	Direct effect	3.6 meru		850			2.32	
	Acceler-ation Sensitive Drift	ADIAX		15 meru/g		260			0.71	
		ADSRAY		10.5 meru /g	- 612		- 39	-1.95		-0.07
		ADIAZ		15 meru /g		708			1.93	
	Acceler-ation Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g^2		20			0.05	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g^2	78		5	0.25		0.01
		$A^2A_{(IA)(IA)Z}$		1 meru/g^2		63			0.17	
Root Sum Square Error (in ft and ft/sec)					1,226	2,060	234	3.92	5.61	0.63
Root Sum Square Error (in n. mi. and ft/sec)					0.20	0.34	0.04	3.9	5.6	0.6

Table 6-12 Effect of IMU Errors during SPS 2nd Burn at Re-entry Start

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		72,198			1.86	
		$A_{(SM)YI}$		0.04 mr	- 3.317		8,430	- 11.06		- 1.21
		$A_{(SM)ZI}$		0.07 mr		- 953			- 1.13	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 903		- 6,514	7.39		3.77
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec²	1,757		12,345	- 17.64		-15.00
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec²		1,631			- 6.11	
			Eff on Init Mlm			- 2,778			- 3.30	
			Combined Eff			- 1,147			- 9.41	
		ACBZ	Direct effect	0.2 cm/sec²	-23,933		100,229	-111.25		-25.28
			Eff on Init Mlm		16,909		-42,983	56.39		6.18
			Combined Eff		- 7,023		57,246	- 54.86		-19.10
	Scale Factor Error	SFEX		87 PPM	- 1,298		10,112	- 11.47		- 1.82
		SFEY		87 PPM		0			0	
		SFEZ		87 PPM	-11,211		40,671	- 49.22		- 9.56
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g²	- 320		1,570	- 2.18		- 1.25
		NCYY		10 μg/g²		0			0	
		NCZZ		10 μg/g²	- 1,599		6,039	- 7.05		- 1.47
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		4,307			10.09	
		BDY	Direct effect	3.6 meru	-12,100		14,663	- 52.03		- 7.86
		BDZ	Direct effect	3.6 meru		- 6,270			-31.00	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		8,174			- 2.86	
		ADSRAY		10.5 meru /g	22,045		-41,880	65.19		3.16
		ADIAZ		15 meru /g		- 5,670			-18.14	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g²		843			1.08	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g²	- 2,896		5,400	- 8.81		0.56
		$A^2A_{(IA)(IA)Z}$		1 meru/g²		- 558			- 1.99	
Root Sum Square Error (in ft and ft/sec)					28,923	73,302	87,695	116.03	38.73	28.61
Root Sum Square Error (in n.mi. and ft/sec)					4.78	12.06	14.43	116.0	38.7	28.6

Table 6-13 Total Indication Errors at Entry End (at 50,000 ft Alt).

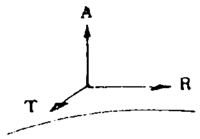
Error 				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		20,284			31.15	
		$A_{(SM)YI}$		0.04 mr	- 720		1,195	- 2.54		- 0.26
		$A_{(SM)ZI}$		0.07 mr		- 336			- 1.72	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 1,148		1,781	- 2.58		- 0.61
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	$0.2\ cm/sec^2$	3,777		- 8,881	8.05		- 5.38
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	$0.2\ cm/sec^2$		- 1,003			- 4.30	
			Eff on Init Mlm			- 980			- 5.00	
			Combined Eff			- 1,983			- 9.30	
		ACBZ	Direct effect	$0.2\ cm/sec^2$	- 4,766		27,117	-24.54		- 7.11
			Eff on Init Mlm		3,673		- 6,092	12.95		1.31
			Combined Eff		- 1,093		21,025	-11.59		- 5.80
	Scale Factor Error	SFEX		87 PPM	262		74	0.76		2.03
		SFEY		87 PPM		- 51			- 0.07	
		SFEZ		87 PPM	- 2,300		7,140	- 9.43		- 1.37
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	- 12		- 154	- 0.08		- 0.67
		NCYY		$10\ \mu g/g^2$		4			- 0.02	
		NCZZ		$10\ \mu g/g^2$	- 122		493	- 0.47		- 0.12
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		2,844			10.67	
		BDY	Direct effect	3.6 meru	- 7,370		4,180	-39.52		- 7.59
		BDZ	Direct effect	3.6 meru		- 5,740			-31.32	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		2,510			- 0.23	
		ADSRAY		10.5 meru /g	10,148		-16,954	35.33		32.58
		ADIAZ		15 meru /g		- 3,870			-19.11	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$1\ meru/g^2$		323			1.34	
		$A^2D_{(SRA)(SRA)Y}$		$1\ meru/g^2$	- 1,352		2,169	- 4.94		- 0.57
		$A^2A_{(IA)(IA)Z}$		$1\ meru/g^2$		- 391			- 2.08	
Root Sum Square Error (in ft and ft/sec)					13,665	21,867	29,873	56.08	50.27	11.91
Root Sum Square Error (in n. mi. and ft/sec)					2.25	3.60	4.92	56.1	50.3	11.9

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Table 6-14 Effect of IMU Errors during SPS 1st and 2nd Burns and Entry End (Alt. of 50,000 ft)

Error (axes A, T, R)				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		6,435			29.17	
		$A_{(SM)YI}$		0.04 mr	- 112		- 89	- 0.94		-0.24
		$A_{(SM)ZI}$		0.07 mr		- 296			- 1.71	
ACCELEROMETER	Accel. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	19		- 205	- 0.03		-0.83
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec²	- 78		-2,431	- 0.25		-4.58
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec²		-2,306			- 4.46	
			Eff on Init Mlm			- 863			- 4.98	
			Combined Eff			-3,169			- 9.44	
		ACBZ	Direct effect	0.2 cm/sec²	3,246		- 610	8.44		-1.12
			Eff on Init Mlm		571		454	4.77		1.22
			Combined Eff		3,817		- 156	13.21		0.10
	Scale Factor Error	SFEX		87 PPM	113		323	0.44		2.06
		SFEY		87 PPM		- 51			- 0.07	
		SFEZ		87 PPM	- 250		62	- 1.02		0.15
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g²	- 14		- 151	- 0.06		-0.67
		NCYY		10 μg/g²		- 4			- 0.02	
		NCZZ		10 μg/g²	23		- 4	0.12		-0.02
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		2,070			10.55	
		BDY	Direct effect	3.6 meru	-4,283		-2,344	-31.37		-7.49
		BDZ	Direct effect	3.6 meru		-5,626			-31.31	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		523			- 0.52	
		ADSRAY		10.5 meru/g	1,500		1,315	12.51		3.00
		ADIAZ		15 meru/g		3,408			19.05	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g²		166			1.32	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g²	- 241		- 177	- 2.01		-0.54
		$A^2A_{(IA)(IA)Z}$		1 meru/g²		- 349			- 2.07	
Root Sum Square Error (in ft and ft/sec)					6,492	9,977	3,783	36.77	49.03	9.69
Root Sum Square Error (in n. mi. and ft/sec)					1.07	1.64	0.62	36.8	49.0	9.7

Table 6-15 Effect of IMU Errors during SPS 2nd Burn and Entry at Entry End (50,000 ft alt)

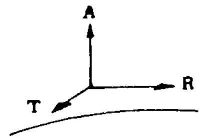
Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
Init. Cond. Matrix Diag. Term. Errors	Position	$(F)X_{Io}$		0 ft	0	0	0	0	0	0
		$(F)Y_{Io}$		0 ft						
		$(F)Z_{Io}$		0 ft						
	Velocity	$(F)V_{XIo}$		0 ft/sec						
		$(F)V_{YIo}$		0 ft/sec						
		$(F)V_{ZIo}$		0 ft/sec						
Stable Member	Initial S. M. Alignment Errors	$A_{(SM)XI}$		3.6 mr		2,493			28.14	
		$A_{(SM)YI}$		0.04 mr	- 284		11	- 1.25		-0.16
		$A_{(SM)ZI}$		0.07 mr		- 433			- 1.75	
ACCELEROMETER	Accel.. IA Nonorthogonality	X to Y		0.1 mr						
		X to Z		0.1 mr	- 10		- 69	- 0.11		-0.78
		Y to Z		0.1 mr						
	Bias Error	ACBX	Direct effect	0.2 cm/sec^2	- 212		- 1,795	- 0.63		-4.31
			Eff on Init Mlm							
			Combined Eff							
		ACBY	Direct effect	0.2 cm/sec^2		- 1,797			- 4.33	
			Eff on Init Mlm			- 1,261			- 5.09	
			Combined Eff			- 3,058			- 9.42	
		ACBZ	Direct effect	0.2 cm/sec^2	2,201		- 316	6.57		-0.77
			Eff on Init Mlm		1,446		- 55	6.39		0.83
			Combined Eff		3,647		- 371	12.96		0.06
	Scale Factor Error	SFEX		87 PPM	69		535	0.31		2.15
		SFEY		87 PPM		- 51			- 0.07	
		SFEZ		87 PPM	- 55		7	- 0.67		0.09
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g^2	- 18		- 132	- 0.09		-0.66
		NCYY		10 μg/g^2		- 4			- 0.02	
		NCZZ		10 μg/g^2	13		- 2	0.11		-0.01
GYRO	Bias Drift	BDX	Direct effect	3.6 meru		928			10.25	
		BDY	Direct effect	3.6 meru	- 8,757		254	-39.66		-5.50
		BDZ	Direct effect	3.6 meru		- 7,662			-31.84	
	Acceleration Sensitive Drift	ADIAX		15 meru/g		- 100			- 0.68	
		ADSRAY		10.5 meru /g	4,107		- 201	17.34		1.84
		ADIAZ		15 meru /g		- 5,103			-19.49	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		1 meru/g^2		120			1.30	
		$A^2D_{(SRA)(SRA)Y}$		1 meru/g^2	- 572		16	- 2.63		-0.39
		$A^2A_{(IA)(IA)Z}$		1 meru/g^2		- 500			- 2.11	
Root Sum Square Error (in ft and ft/sec)					10,359	10,069	1,942	45.30	48.88	7.80
Root Sum Square Error (in n. mi. and ft/sec)					1.70	1.66	0.31	45.3	48.9	7.80

Table 6-16 Effect of IMU Errors during Entry only at Entry End (50,000 ft Alt)

7. G&N CONFIGURATION

System 017 will be the G&N system for Mission 202. It is a Block I series 50 system with one modification; the wiring of the 11 spare relays in the main DSKY to the MCP to provide the AGC/MCP signal interface (refer ICD #MH01-01200-216) described in Section 3.

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's capabilities for Mission 202.

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 apparaent 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 - Addition of automatic star tracker, photometer and minor servo modifications.

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

Block I series 50 is basically the Block I series 100 system less the automatic star tracker and the photometer.

8. INSTRUMENTATION

8.1 G&N Instrumentation

The inflight information from G&N is available in three distinct forms: PCM telemetry of the AGC DIGITAL DOWNLINK, (PCMD); PCM telemetry of low band-width G&N measurements, (PCM +, PCM, PCME); and on-board recording of high band-width G&N measurements (TR).

The PCM telemetry of the AGC DIGITAL DOWNLINK has been clearly defined at the MIT/NAA interface as 50 words of 40 bits each per second. The particular format of this DOWNLINK is AGC program variable and can remain under MIT's control without having interface repercussion (see 8.1.1).

The PCM telemetry of the low band-width measurement and the on-board recording of the high band-width measurements have been defined by NASA in "NASA Program Apollo Working Paper 1141, Apollo SC Measurement Requirements, Apollo Mission A-202, Spacecraft 001" dated November 11, 1964 (see 8.1.2).

8.1.1 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 202 all further discussion will use the 50 words/sec rate.

The digital downlink format is controlled by an AGC program which loads the next word to be transmitted into register OUT4. The program has an established priority (see Fig. 8-1). This program is entered on an interrupt caused by an "endpulse" from the telemetry system. Relay words have the highest priority and will be sent down on the next telemetry word. These relay words contain the state of all latching DSKY relays and therefore indicate displays (display word) and mode status of the G&N and MCP/SCS. Relay words for flight 202 are listed below.

The maximum rate for relay words is 1 word/120 msec. If a relay command has occurred, a relay word is loaded into OUT4 and the AGC returns to whatever program it was in before the interrupt. In a similar way, if no relay word is used, the AGC checks to see if an "input character word" has been received (manual keyboard entry, mark, or uplink). The maximum rate of input character words could occur due to uplink words; this rate is 1 keyboard character/110 msec (see section 3.1.2.1). If no relay or input word is indicated, the AGC checks to see if an ID word is required (there is an ID word for every block of 4 data words). If no relay, input, or ID word is sent, the AGC will load OUT4 with the next data word to be sent. A list of the data words which will be used for flight 202 is also listed below.

While it is theoretically possible to get almost 18 relay and input character words/sec leaving only 32 words/sec for both ID and data words, it is estimated that the AGC will average at least 32 data words/sec and 8 ID words/sec.

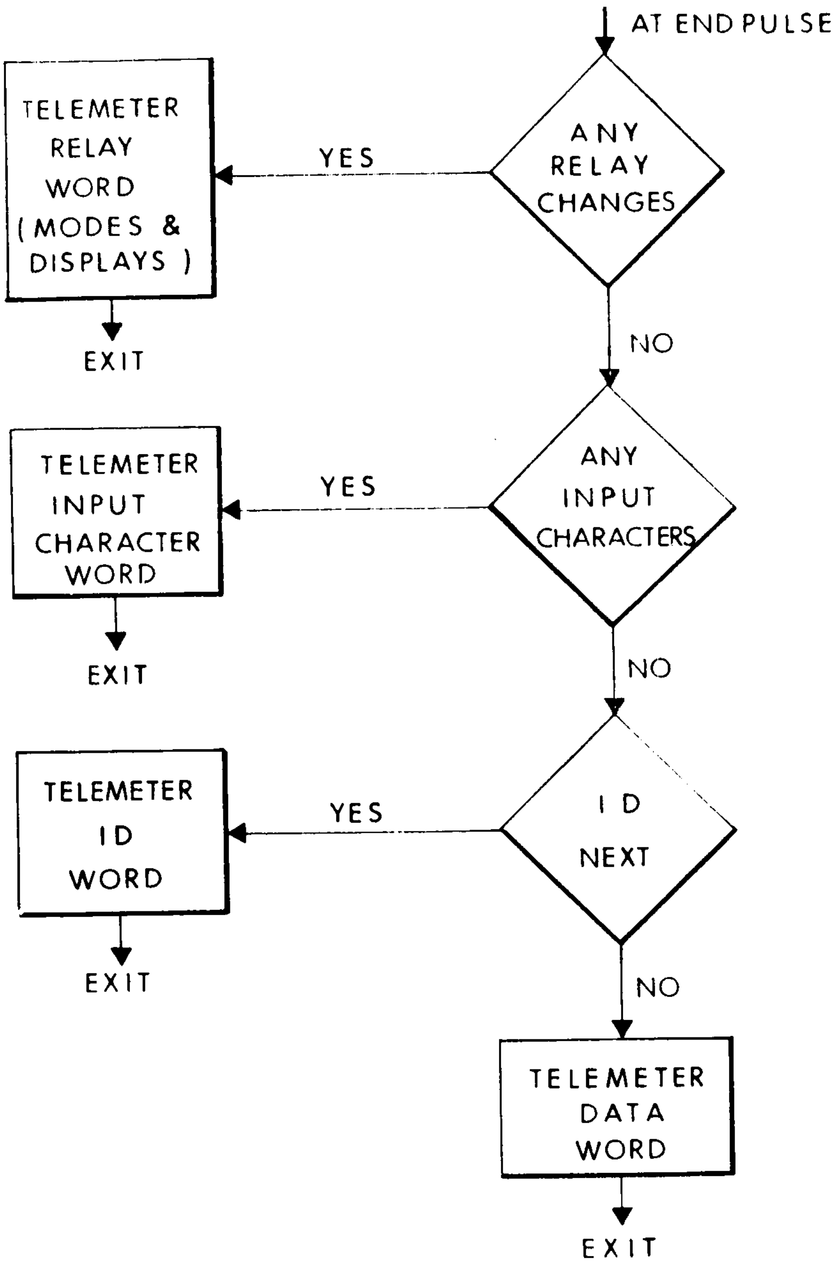


Fig. 8-1 AGC Downlink Transmission Logic

RELAY WORDS

A. Display Words

Item	Remark
Vg_x Vg_y Vg_z	three components of velocity-to-be-gained during powered flight
T_{ff}	free-fall time to 300,000 ft when calculated
W_x W_y W_z	Spacecraft Body Rates when calculated

B. Other Relay Commands

Item	Remark
1. G/N ATT CONTROL SELECT G/N ΔV MODE SELECT G/N ENTRY MODE SELECT CM/SM SEP COMMAND +X TRANSLATION ON/OFF G/N FAIL INDICATION .05 G INDICATION GIMBAL MOTOR POWER ON/OFF FDAI ALIGN T/C ANTENNA SWITCH	MCP/SCS Modes
2. ZERO ENCODE COARSE ALIGN LOCK CDU FINE ALIGN RE-ENTRY ATT CONTR ZERO OPT. CDU's	G&N Modes
3. CDU ZERO LIGHT CDU FAIL LIGHT PIPA FAIL LIGHT IMU FAIL LIGHT OR OF ALL ALARMS COND LAMP TEST	FAILURE & WARNING LIGHTS

DATA WORDS

This list is comprised of three groups: Group I is transmitted throughout the flight; group II is transmitted only in non-powered flight; and group III is transmitted only in powered flight.

Point Measured	Remarks
Group I	
Time I	AGC Timing Register
Time II	AGC Timing Register
IN0	Contains keyboard characters, mark, block uplink, inhibit upsinc
IN2	Four lowest order time bits, CDU, PIPA, and IMU Fail and Parity Alarm, Lift Off, Guid Release, SIVB Separate,
IN3	Zero CDU encoders, lock CDU, fine align, re-entry, OPT modes 2 & 3, star present, zero OPT, Coarse align, ATT SW and TRN SW, Sextant On, OR OF C1-C33
OUT1	Engine on; block end pulse; ID word; RUPT trap reset; T/M, program, and program check fail alarms, key release, and computer activity
Position & Velocity	Six double precision words (12 words in all)
Group II	
3 actual CDU counters	Used to monitor platform alignment
Group III	
PIPA	Contents of the three PIP accumulation registers
CDU's (actual and desired)	6 AGC registers which give actual and desired CDU angles

8.1.2 G&N PCM Telemetry (exclusive of DIGITAL DOWNLINK) and On-Board Recording for Mission #202

OPERATIONAL

CG0001	V	Computer Digital Data	PCMD	50 S/S	(See 8.1.1)
CG1101	V	-28 VDC Supply	PCM+	1	
CG1110	V	2.5 VDC TM Bias	PCM+	1	
CG1503	X	IMU +28 VDC Operate	PCME	10	
CG1513	X	IMU +28 VDC Standby	PCME	10	
CG1523	X	AGC +28 VDC	PCME	10	

OPERATIONAL (Cont'd)

CG1533	X	OPTX +28 VDC	PCME	10
CG2110	V	IGA Torque Motor Input	PCM	10
CG2112	V	IGA IX Res Output, sine, inphase	PCM	10
CG2113	V	IGA IX Res Output, cos, inphase	PCM	10
CG2117	V	IGA Servo Error, inphase	PCM	100
CG2140	V	MGA Torque Motor Input	PCM	10
CG2142	V	MGA IX Resolver Output, sine inphase	PCM	10
CG2143	V	MGA IX Resolver Output, cos, inphase	PCM	10
CG2147	V	MGA Servo Error in Phase	PCM	100
CG2167	V	OGA Servo Error in Phase	PCM	1
CG2170	V	OGA Torque Motor Input	PCM	10
CG2172	V	OGA IX Resolver Output, sine inphase	PCM	10
CG2173	V	OGA IX Resolver Output, cos, inphase	PCM	10
CG2177	V	OGA Servo Error, in Phase	PCM	100
CG2206	V	IGA CDU IX Res Error, in phase	PCM	1
CG2236	V	MGA CDU IX Res Error, in phase	PCM	1
CG2264	V	OGA CDU 16X Res Error, in phase	PCM+	10
CG2266	V	OGA CDU IX Res Error, in phase	PCM	1
CG2300	T	PIPA Temp.	PCM+	1
CG2301	T	IRIG Temp.	PCM+	1
CG2302	C	IMU Heater Current	PCM+	1
CG2303	C	IMU Blower Current	PCM+	1
CG3102	V	SXT Trun Motor Drive in phase	PCM	10
CG3112	V	SXT Shaft Motor Drive, in phase	PCM	10
CG3200	V	Trun CDU Motor Drive in phase	PCM	10
CG3209	V	OPTX Direct Trunnion Contlr, in phase	PCM	10
CG3220	V	Shaft CDU Motor Drive in phase	PCM	10
CG3229	V	OPTX Direct Shaft Contlr in phase	PCM	10

OPERATIONAL (Cont'd)

CG4300	T	AGC Temp.	PCM	10
CG5000	X	PIPA FAIL	PCME	10
CG5001	X	IMU FAIL	PCME	10
CG5002	X	CDU FAIL	PCME	10
CG5003	X	Gimbal Lock Warning	PCME	10
CG5005	X	Error Detect	PCME	10
CG5006	X	IMU Temp. Light	PCME	10
CG5007	X	Zero Encoder Light	PCME	10
CG5008	X	IMU Delay Light	PCME	10
CG5020	X	AGC Alarm #1 (Program)	PCME	10
CG5021	X	AGC Alarm #2 (AGC Activity)	PCME	10
CG5022	X	AGC Alarm #3 (T/M)	PCME	10
CG5023	X	AGC Alarm #4 (PROG CHK FAIL)	PCME	10
CG5024	X	AGC Alarm #5 (Scalar FAIL)	PCME	10
CG5025	X	AGC Alarm #6 (Parity FAIL)	PCME	10
CG5026	X	AGC Alarm #7 (Counter FAIL)	PCME	10
CG5027	X	AGC Alarm #8 (Key Release)	PCME	10
CG5028	X	AGC Alarm #9 (RUPT Lock)	PCME	10
CG5029	X	AGC Alarm #10 (TC Trap)	PCME	10
CG5030	X	Computer Power Fail Light	PCME	10
CG6000	P	IMU Pressure	PCM	1

FLIGHT QUALIFICATION

CG2010	V	X PIPA SG. Output, inphase	TR	2000 cps.
CG2030	V	Y PIPA SG. Output, inphase	TR	2000 cps.
CG2050	V	Z PIPA SG. Output, inphase	TR	2000 cps.
CG6001	D	NAV Base Roll Vibration	TR	2000 cps.
CG6002	D	NAV Base Pitch Vibration	TR	2000 cps.
CG6003	D	NAV Base Yaw Vibration	TR	2000 cps.

8.2 External Data Requirements

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

8.2.1 Navigation Data via the Uplink

No requirement for this data is made at this time.

8.2.2 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 8-1. Subsequent revisions of this plan will reflect more realistic requirements.

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

This requirement is given by Table 8-2, which is derived from the total indication error expected in the position and velocity data telmetered to the ground via the AGC DOWNLINK.

TABLE 8-1

EXTERNAL TRACKING DATA REQUIREMENTS
TO SUPPORT POST FLIGHT ANALYSIS OF G&N

Three orthogonal components of position and velocity are required in IMU coordinates at one second intervals during each powered phase. The required accuracies are given in this table in local vertical coordinates.

Phase	one sigma Position Error (ft)			one sigma Velocity Error (fps)		
	Alt.	Track	Range	Alt.	Track	Range
S-IB Boost	200	1900	100	0.9	7.2	0.4
1st SPS Burn	40	210	30	0.3	1.8	0.2
2nd, 3rd, 4th SPS Burns	10	30	10	0.3	0.6	0.2
Entry	1100	1000	200	4.6	4.9	0.8

TABLE 8-2

EXTERNAL TRACKING DATA REQUIREMENTS
TO PROVIDE REAL-TIME MONITOR OF G&N

Three orthogonal components of position and velocity are required in IMU coordinates at one second intervals during each powered phase. The required accuracies are given in this table in local vertical coordinates.

	one sigma Position Error (ft)			one sigma Velocity Error (fps)		
	Alt.	Track	Range	Alt.	Track	Range
S-IB Boost	200	1900	100	0.9	7.2	0.4
1st SPS Burn	400	3900	300	1.4	8.0	0.8
2nd, 3rd, 4th SPS Burns	2300	4000	7200	7.3	7.4	1.8
Entry	2900	7300	8800	11.6	3.9	2.9

9. G&N Performance Analysis

This section presents brief summaries of the performance of those phases of the 202 mission that are under G&N control. The data (in Figs. 9-1, 9-2, 9-3, 9-4, 9-5, and 9-6) has been derived from point mass studies using the Saturn Boost phase of the trajectory referenced in Section 5.

The data in the Tables 9-1 through 9-8 present performance data derived by perturbing the nominal mission with the dispersions listed on the following page.

The affects of these dispersions are demonstrated in the tables as follows:

Table 9-1	Time, latitude, longitude, altitude, velocity, flight path angle and range (central angle from SIVB cut-off point) at the start of the first SPS burn.
Table 9-2	Same as Table 9-1 at the end of the first SPS burn, plus fuel remaining and burn time.
Table 9-3	Time latitude, longitude, altitude, velocity flight path angle, R, A, and E from Carnarvon at the start of the second SPS burn.
Table 9-4	Same as Table 9-3 at the end of the second SPS burn.
Table 9-5	Same as Table 9-3 at the final cut off.
Table 9-6	Time latitude, longitude, altitude, velocity flight path angle at entry after fourth burn or fuel depletion.
Table 9-7	Velocity and flight path angle at entry without the two short burns.
Table 9-8	Same as Table 9-6 after the first burn only.

The radar at Carnarvon was taken to be at 24.867S latitude and 113.63E longitude at a radius of 20,913,669 feet.

The latitude and longitude at entry in Table 9-7 above will be practically the same as Table 9-6 above.

Fig. 9-6 shows the track during the nominal second SPS burn and the two short burns. The ignition point and final cut off points of extreme cases are also shown. It should be observed that

a) The maximum westerly dispersion at ignition is about 0.5° longitude.

b) The dispersion in track (213036) cannot be rectified by modification of the second ignition logic.

Any downrange dispersion at SIVB cut-off will move the entire trajectory downrange by the amount of dispersion.

List of Dispersions

Mac Run	Dispersions
210066	617.4 sec, + 200'/sec inertial velocity
210067	617.4 sec, + 40'/sec inertial velocity
210068	617.4 sec, -40'/sec inertial velocity
210069	617.4 sec, + 3000 ft altitude
210070	617.4 sec, - 3000 ft altitude
210071	617.4 sec, + 0.5° flight path angle
210072	617.4 sec, - 0.5° flight path angle
210073	617.4 sec, + 3 sec I_{sp}
210074	617.4 sec, -3 sec I_{sp}
210075	617.4 sec, + 660 lbs thrust
210076	617.4 sec, -660 lbs thrust
210077	617.4 sec, + 500 lbs weight
210078	617.4 sec, - 500 lbs weight
210890	600 sec, + 30,000 ft. altitude -2° flight path angle -3 sec I_{sp} - 660 lbs thrust + 500 lbs weight
210891	600 sec, negative of above
211683	617.4 sec, nominal
213036	617.4 sec, +1° azimuth -1.63 southern latitude

NOTE:

1. Nominal I_{sp} was increased by 3 seconds over the November figure.

2. All cases have an 11 second coast between SIVB time indicated and SPS 1 ignition.

3. Altitude is in feet
Velocity is in ft/sec
All angles are in degrees
Time is in seconds; total time is measured from lift-off
Range from Carnarvon is slant range in n. m.
Radius of earth used in 20,925,738 feet.
The coast time used is 3041 seconds
Precision integration was used during coast

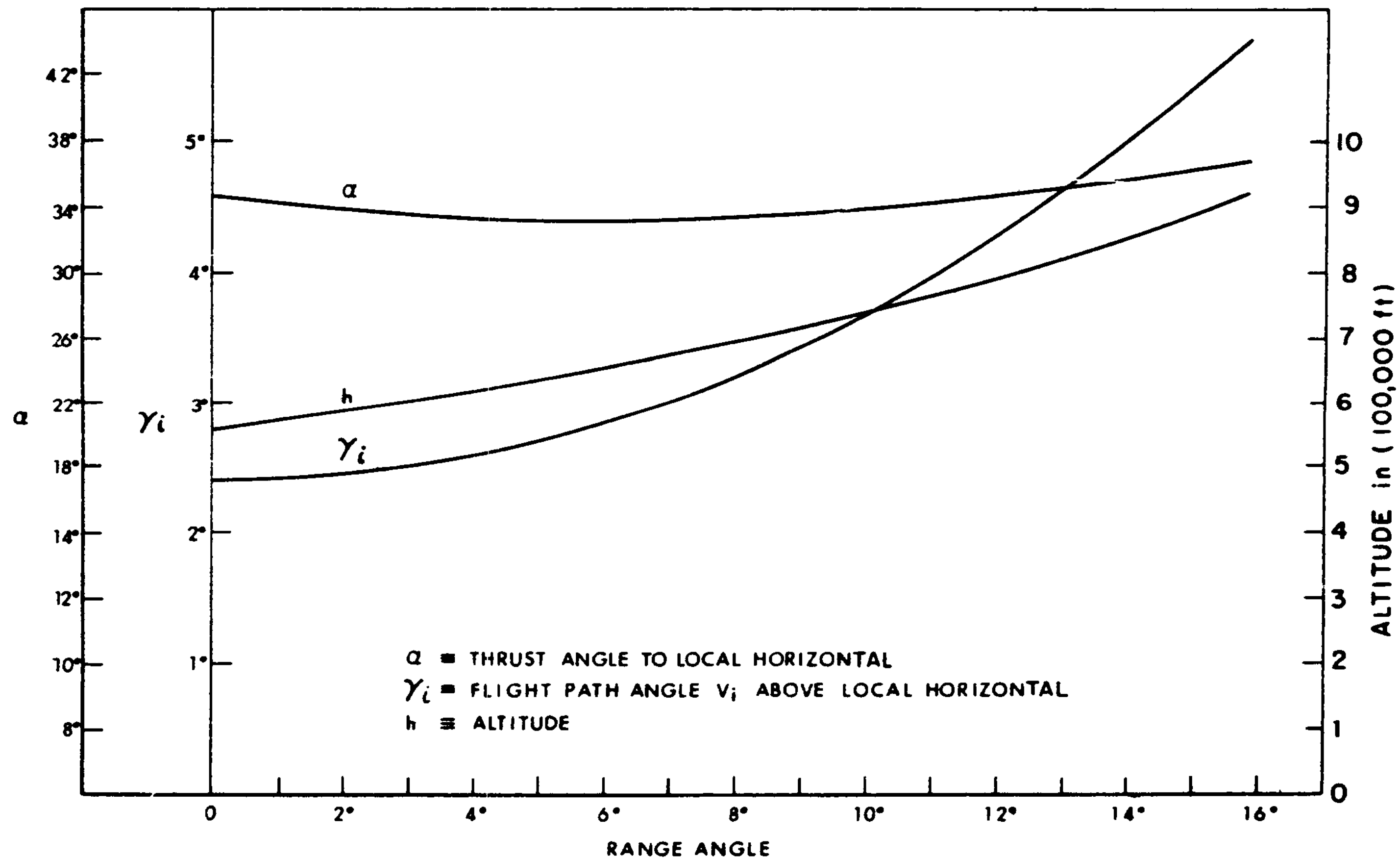


Fig. 9-1 Mission 202 First Burn Trajectory

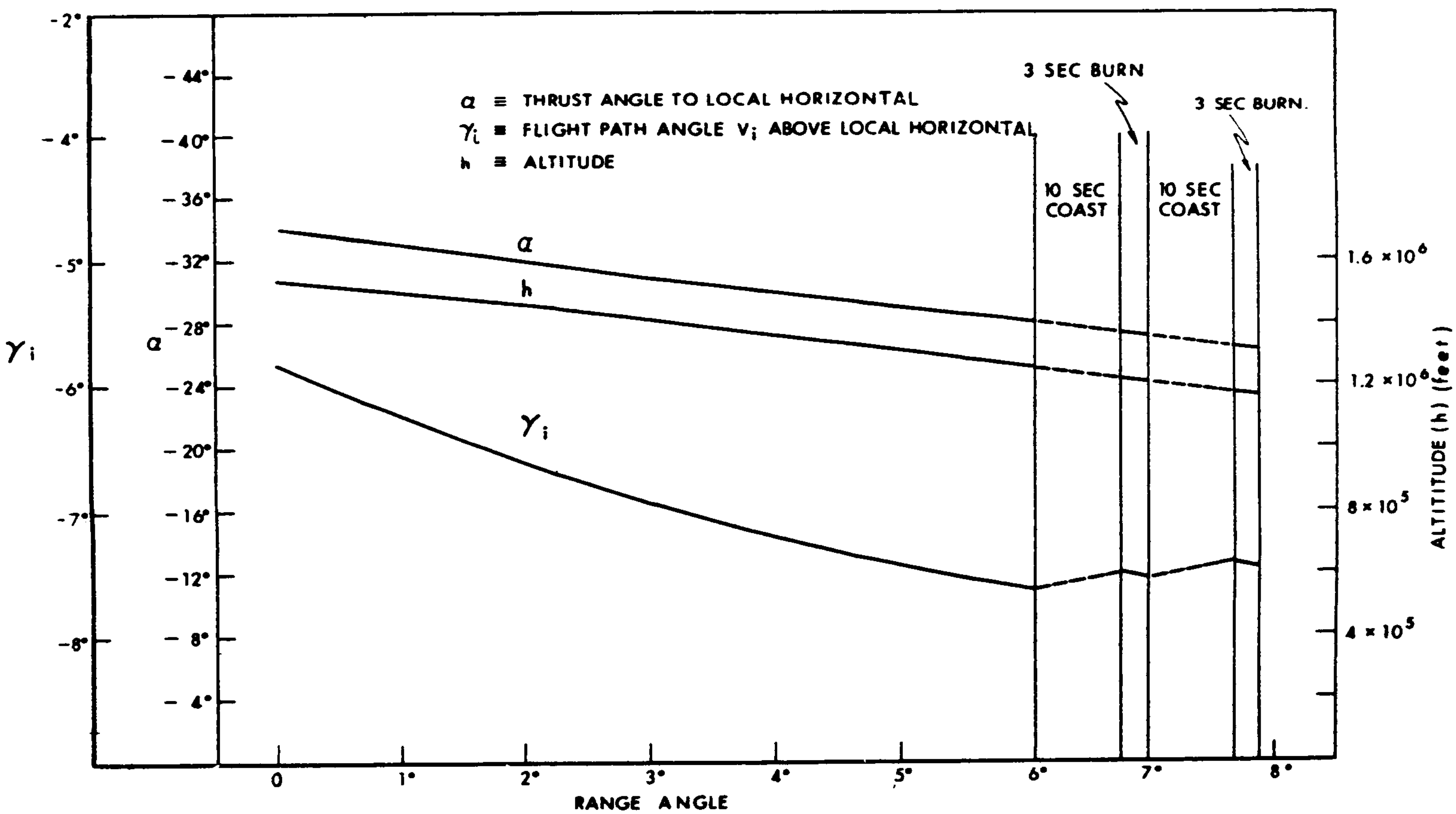


Fig. 9-2 Second, Third and Fourth Burn Trajectory

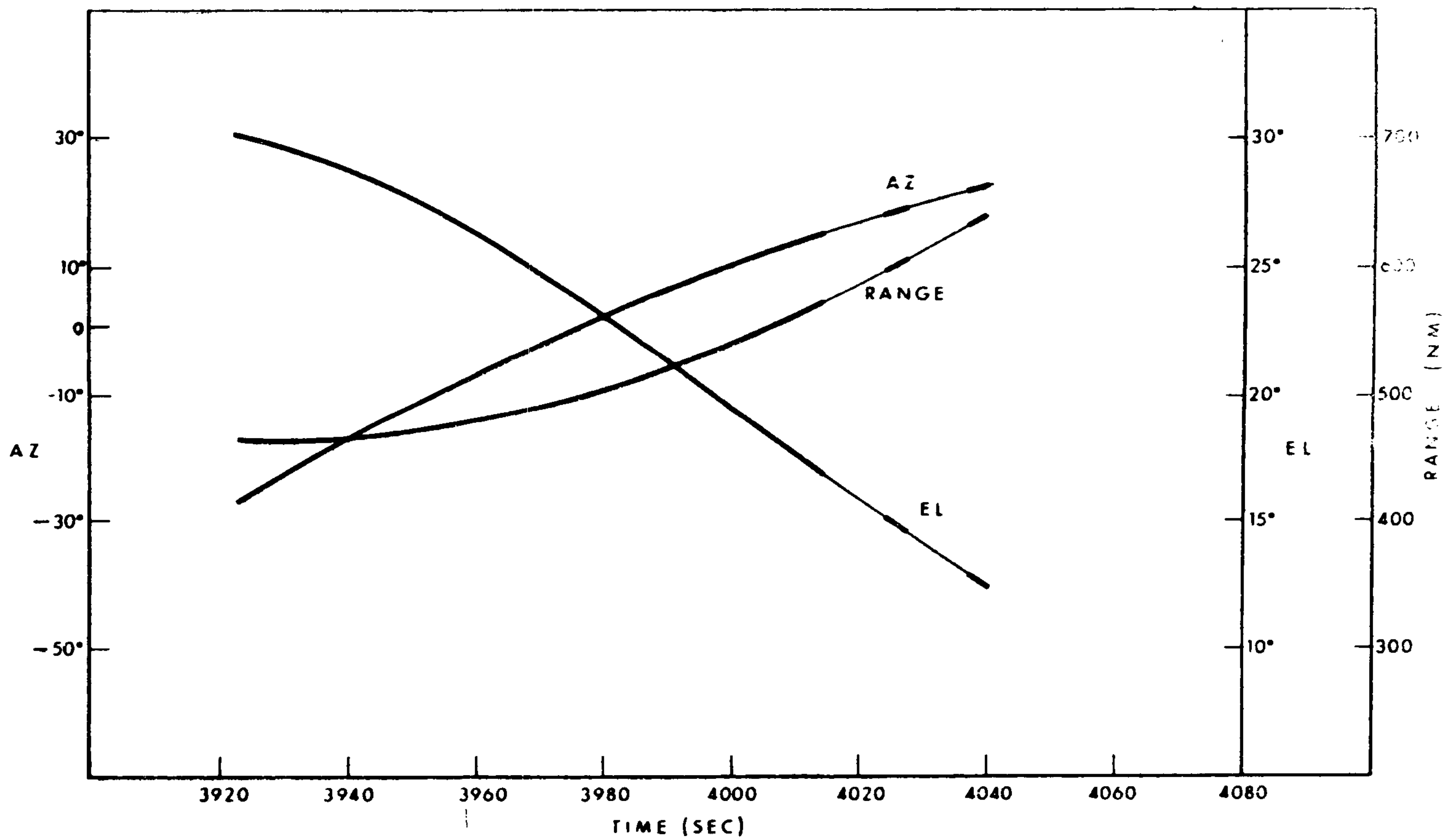


Fig. 9-3 Slant Range, Azimuth, and Elevation from Carnarvan during 2nd, 3rd, and 4th SPS Burns.

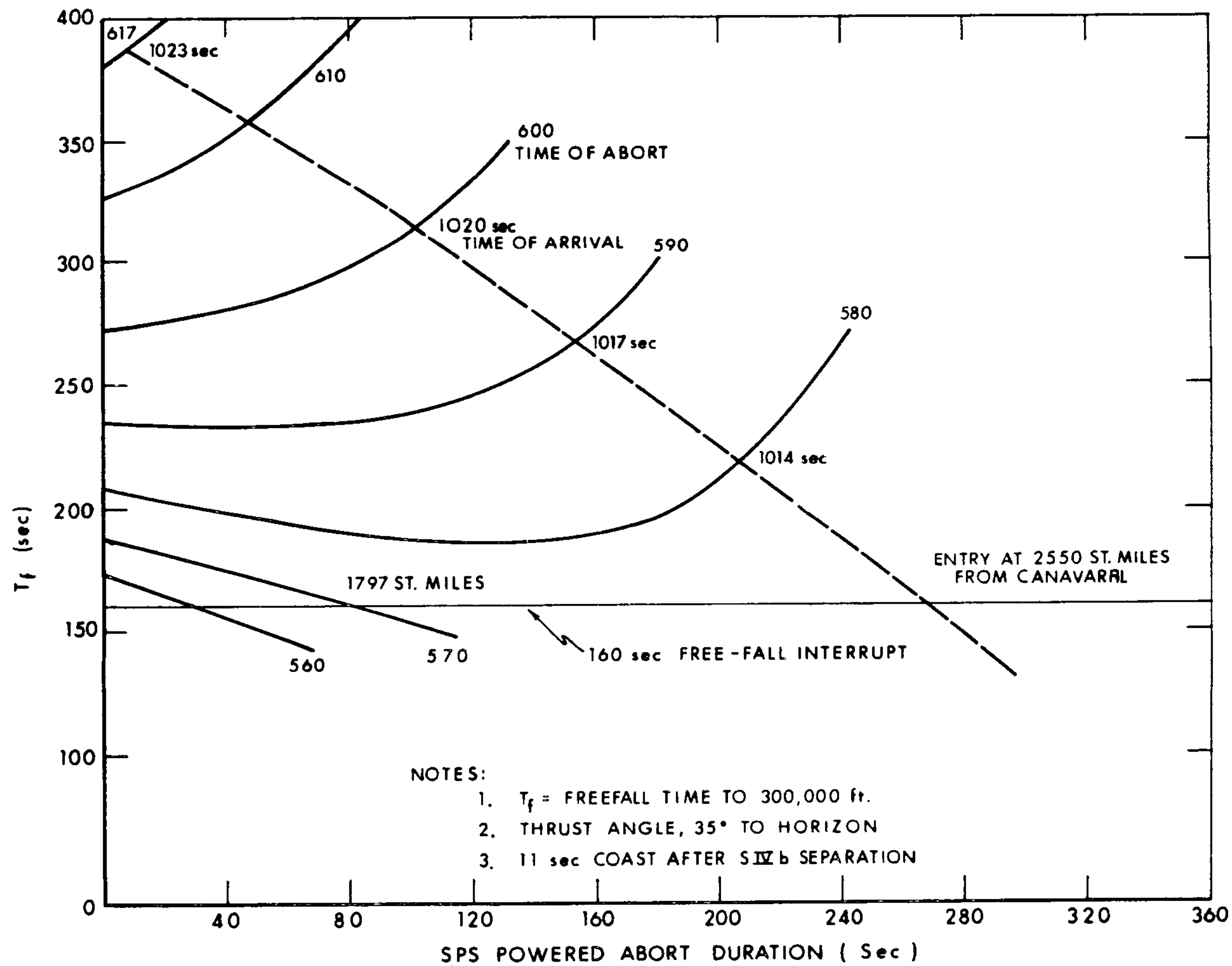


Fig. 9-4 Area Control Capability for Aborts During Saturn Boost

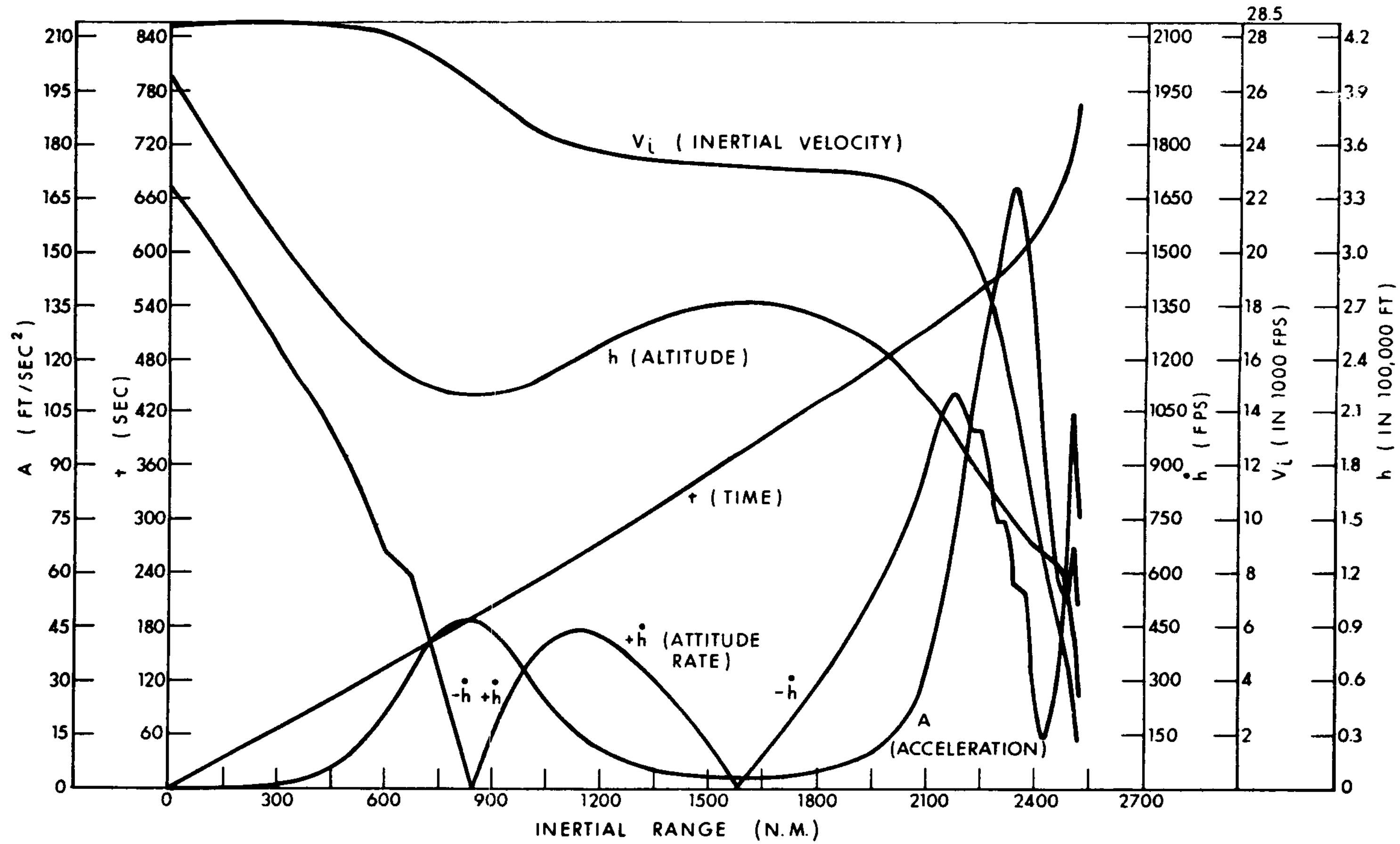


Fig. 9-5 Mission 202 Guided Entry Trajectory

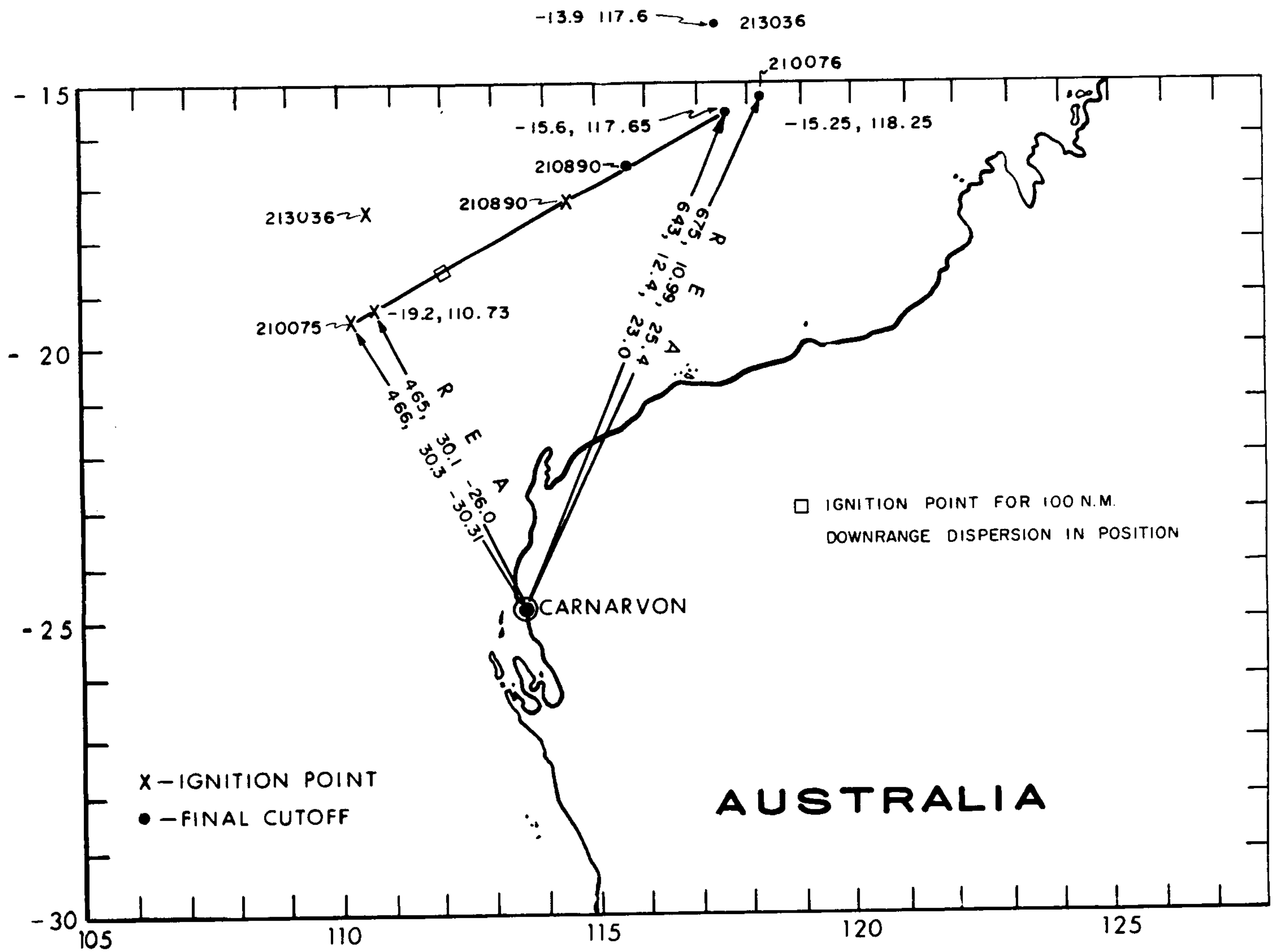


Fig. 9-6 SPS Second Burn Dispersions

Table 9-1

SPS First Burn Ignition

Mac Run	Ignition Time	Lat.	Long.	Arc.	Alt.	V	γ
210066	628.4	23.20	295.19	0.646	555239	22034	2.41
210067	628.4	23.20	295.18	0.641	555138	21874	2.40
210068	628.4	23.20	295.18	0.639	555088	21794	2.39
210069	628.4	23.20	295.18	0.640	558114	21834	2.40
210070	628.4	23.20	295.18	0.640	552113	21834	2.39
210071	628.4	23.20	295.18	0.640	557207	21831	2.90
210072	628.4	23.20	295.18	0.640	553019	21837	1.90
210073	628.4	23.20	295.18	0.640	555113	21834	2.40
to	Same						
210078							
210890	611.0	23.58	294.22	0.607	559265	20715	-4.20
210891	611.0	23.58	294.22	0.607	515147	20692	3.58
211683	628.4	23.20	295.18	0.640	555113	21834	2.40
213036	628.4	21.56	295.17	0.640	555113	21834	2.40

Table 9-2

SPS First Burn Cut Off

Mac Run	Burn Time	Lat.	Long.	Arc	Alt.	V	γ	Fuel Left
210066	244.94	16.68	308.97	15.997	914031	25638	5.77	7525
210067	252,33	16.49	309.30	16.392	918982	25632	5.77	7012
210068	256.00	16.40	309.47	16.586	921243	25629	5.77	6758
210069	254.04	16.45	309.37	16.477	923082	25627	5.77	6894
210070	254.31	16.44	309.39	16.501	917178	25634	5.77	6876
210071	250.00	16.58	309.13	16.197	945703	25601	5.78	7174
210072	258.59	16.30	309.65	16.799	893486	25661	5.76	6578
210073	254.75	16.43	309.41	16.525	921056	25630	5.77	7011
210074	253.59	16.47	309.35	16.452	919192	25632	5.77	6757
210075	245.92	16.68	308.95	15.980	910220	25642	5.77	6943
210076	263.01	16.20	309.85	17.033	930580	25619	5.77	6822
210077	257.27	16.36	309.55	16.680	923819	25626	5.77	7169
210078	251.08	16.54	309.22	16.298	916432	25635	5.79	6599
210890	340.15	14.57	312.77	21.479	752820	25824	5.67	1418
210891	285.16	16.30	309.66	17.833	959525	25585	5.79	4333
211683	254.17	16.45	309.38	16.489	920130	25631	5.77	6884
213036	255.68	14.75	309.29	16.581	921928	25629	5.77	6780

Table 9-3

SPS Second Burn Ignition

Mac Run	Time	Lat.	Long.	Alt.	V	γ	Range (nm)	Elev.	Azimuth
							From Carnarvon		
210066	3914.3	-19.42	110.31	1545371	24920	-5.83	465.1	30.27	-30.20
210067	3921.7	-19.25	110.65	1540221	24925	-5.83	464.6	30.18	-26.86
210068	3925.4	-19.16	110.82	1537872	24928	-5.83	464.9	30.10	-25.22
210069	3923.4	-19.21	110.72	1536144	24930	-5.83	464.4	30.09	-26.18
210070	3923.7	-19.20	110.75	1541913	24923	-5.83	465.0	30.18	-25.89
210071	3919.4	-19.35	110.44	1514190	24955	-5.84	462.1	29.75	-28.95
210072	3928.0	-19.05	111.05	1564895	24898	-5.82	468.4	30.46	-22.94
210073	3924.1	-19.19	110.77	1538141	24928	-5.83	464.7	30.12	-25.74
210074	3923.0	-19.22	110.70	1539997	24926	-5.83	464.7	30.16	-26.35
210075	3915.3	-19.42	110.30	1549110	24915	-5.83	465.5	30.32	-30.33
210076	3932.4	-18.97	111.20	1528456	24938	-5.83	465.9	29.77	-21.48
210077	3926.7	-19.12	110.90	1535303	24931	-5.83	464.9	30.03	-24.43
210078	3920.5	-19.29	110.57	1542763	24922	-5.83	464.8	30.22	-27.65
210890	3992.1	-17.28	114.54	1699460	24747	-5.77	551.8	26.82	6.61
210891	3937.2	-19.08	110.97	1500239	24970	-5.84	462.2	29.39	-23.73
211683	3923.6	-19.21	110.73	1539027	24927	-5.83	464.7	30.14	-26.04
213036	3925.1	-17.40	110.67	1534096	24932	-5.83	533.6	23.34	-20.97

Table 9-4

SPS Second Burn Cut Off

Mac Run	Burn Time	Time	Lat.	Long.	Alt.	V	γ	From Carnarvon Range	From Carnarvon Elev.	From Carnarvon Azimuth
210066	94	4008.3	-16.59	115.81	1250376	27624	-7.64	563.5	17.33	14.38
210067	92	4013.7	-16.48	116.03	1251680	27615	-7.64	573.1	16.89	15.52
210068	91	4016.4	-16.42	116.13	1252555	27610	-7.64	577.8	16.68	16.06
210069	91	4014.4	-16.47	116.04	1251168	27599	-7.62	573.5	16.86	15.57
210070	91	4014.7	-16.46	116.06	1256700	27592	-7.64	575.0	16.89	15.70
210071	92	4011.4	-16.58	115.83	1226923	27640	-7.56	563.0	16.92	14.48
210072	91	4019.0	-16.31	116.35	1278291	27585	-7.72	589.1	16.62	17.16
210073	92	4016.4	-16.42	116.14	1249716	27615	-7.63	577.9	16.63	16.11
210074	91	4014.0	-16.48	116.02	1254557	27610	-7.65	572.9	16.95	15.48
210075	89	4004.3	-16.76	115.50	1269437	27586	-7.69	552.1	18.27	12.64
210076	94	4026.4	-16.12	116.68	1234429	27635	-7.58	601.7	15.28	18.79
210077	92	4018.7	-16.34	116.27	1247262	27607	-7.62	583.5	16.32	16.77
210078	91	4011.5	-16.55	115.89	1256943	27618	-7.66	567.5	17.26	14.79
210890	20.89	4013.0	-16.67	115.68	1643339	25352	-6.53	589.0	23.28	13.63
210891	61.27	3998.4	-17.27	114.52	1315852	26950	-7.35	518.81	21.05	6.47
211683	91	4014.6	-16.46	116.05	1253933	27595	-7.63	574.2	16.88	15.64
213036	91	4016.1	-14.76	115.98	1248948	27613	-7.63	668.8	12.85	12.85

Table 9-5

Final Cut Off Conditions

								From Carnarvon		
Mac Run	Burn Time	Time	Lat.	Long.	Alt.	V	γ	Range	Elev.	Azimuth
210066	100	4034.3	-15.74	117.42	1155966	27904	-7.45	631.2	12.78	22.05
210067	98	4039.7	-15.62	117.63	1157306	27898	-7.45	642.1	12.40	22.90
210068	97	4042.4	-15.56	117.73	1158195	27894	-7.46	647.5	12.22	23.31
210069	97	4040.4	-15.61	117.63	1157013	27882	-7.44	642.6	12.38	22.93
210070	97	4040.7	-15.60	117.66	1162358	27875	-7.46	644.2	12.41	23.03
210071	98	4037.4	-15.71	117.44	1133495	27921	-7.37	631.2	12.42	22.12
210072	94.92	4042.9	-15.51	117.81	1190537	27797	-7.52	653.6	12.50	23.63
210073	98	4042.1	-15.55	117.74	1155440	27897	-7.45	647.7	12.17	23.34
210074	96.57	4039.6	-15.63	117.59	1161644	27874	-7.46	640.7	12.52	22.76
210075	95	4030.3	-15.90	117.10	1174504	27875	-7.51	617.3	13.63	20.71
210076	100	4052.4	-15.25	118.28	1140699	27913	-7.39	675.1	10.99	25.39
210077	96.24	4042.9	-15.54	117.76	1159533	27828	-7.41	649.0	12.18	23.42
210078	97	4037.5	-15.69	117.49	1162261	27903	-7.48	635.6	12.72	22.35
211683	97	4040.6	-15.60	117.65	1159684	27878	-7.45	643.4	12.39	22.98

Table 9-6

Final Entry Conditions

							At 400, 000 ft. Altitude	
Mac Run	Time	Lat.	Long.	Alt.	V	γ	V	γ
210066	4314	-5. 26	134. 7	394160	28711	-3. 47	28702	-3. 49
210067	4320	-5. 13	134. 9	394943	28706	-3. 48	28698	-3. 50
210068	4322	-5. 07	135. 0	395452	28703	-3. 49	28695	-3. 50
210069	4320	-5. 13	134. 9	395282	28690	-3. 49	28682	-3. 50
210070	4321	-5. 12	134. 9	397910	28686	-3. 52	28680	-3. 50
210071	4307	-5. 63	134. 1	400988	28699	-3. 53	28697	-3. 50
210072	4333	-4. 67	135. 6	395489	28642	-3. 51	28634	-3. 52
210073	4322	-5. 06	134. 0	394113	28705	-3. 48	28695	-3. 50
210074	4320	-5. 16	134. 9	397455	28690	-3. 51	28684	-3. 50
210075	4310	-5. 46	134. 4	403404	28693	-3. 56	28693	-3. 50
210076	4323	-5. 10	134. 9	403655	28695	-3. 56	28696	-3. 50
210077	4323	-5. 07	135. 0	398082	28637	-3. 54	28632	-3. 52
210078	4317	-5. 21	134. 8	396989	28715	-3. 50	28708	-3. 49
210890	4484	-5. 26	141. 8	403303	26749	-4. 79	26748	-4. 75
210891	4332	-5. 35	134. 5	403340	27941	-3. 93	27940	-3. 88
211683	4321	-5. 13	135. 0	396594	28688	-3. 50	28681	-3. 50
213036	4322	-3. 84	135. 0	393717	28704	-3. 48	28695	-3. 50

Table 9-7

Entry Conditions (400, 000 ft) After Second Burn
(no short burns)

Mac Run	V	γ
210066	28497	-3.57
210067	28518	-3.57
210068	28514	-3.57
210069	28502	-3.57
210070	28501	-3.57
210071	28518	-3.57
210072	28515	-3.56
210073	28516	-3.57
210074	28516	-3.57
210075	28508	-3.57
210076	28520	-3.57
210077	28506	-3.57
210078	28526	-3.56
211683	28501	-3.57
213036	28514	-3.57

Table 9-8

Entry Conditions After First Burn
(No Second Burn)

Mac Run	Time	Lat.	Long.	Alt.	V	γ
210066	4364	-4.76	135.3	399677	26241	-5.34
210067	4371	-4.58	135.6	397107	26244	-5.34
210068	4374	-4.48	135.7	394821	26246	-5.34
210069	4372	-4.54	135.6	393152	26248	-5.34
210070	4373	-4.53	135.7	398742	26242	-5.34
210071	4358	-5.04	134.9	396344	26245	-5.34
210072	4387	-4.02	136.4	396602	26244	-5.34
210073	4373	-4.51	135.7	395084	26246	-5.34
210074	4372	-4.55	135.6	396887	26244	-5.34
210075	4367	-4.70	135.4	398418	26242	-5.34
210076	4381	-4.24	136.1	385683	26257	-5.33
210077	4376	-4.43	135.8	392327	26249	-5.34
210078	4369	-4.64	135.5	399577	26241	-5.34
211683	4373	-4.53	134.7	395945	26245	-5.34
213036	4374	-3.24	135.7	390864	26251	-5.34

The entry conditions at 400,000 feet are 26237 ft/sec 5.34° for all cases.

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