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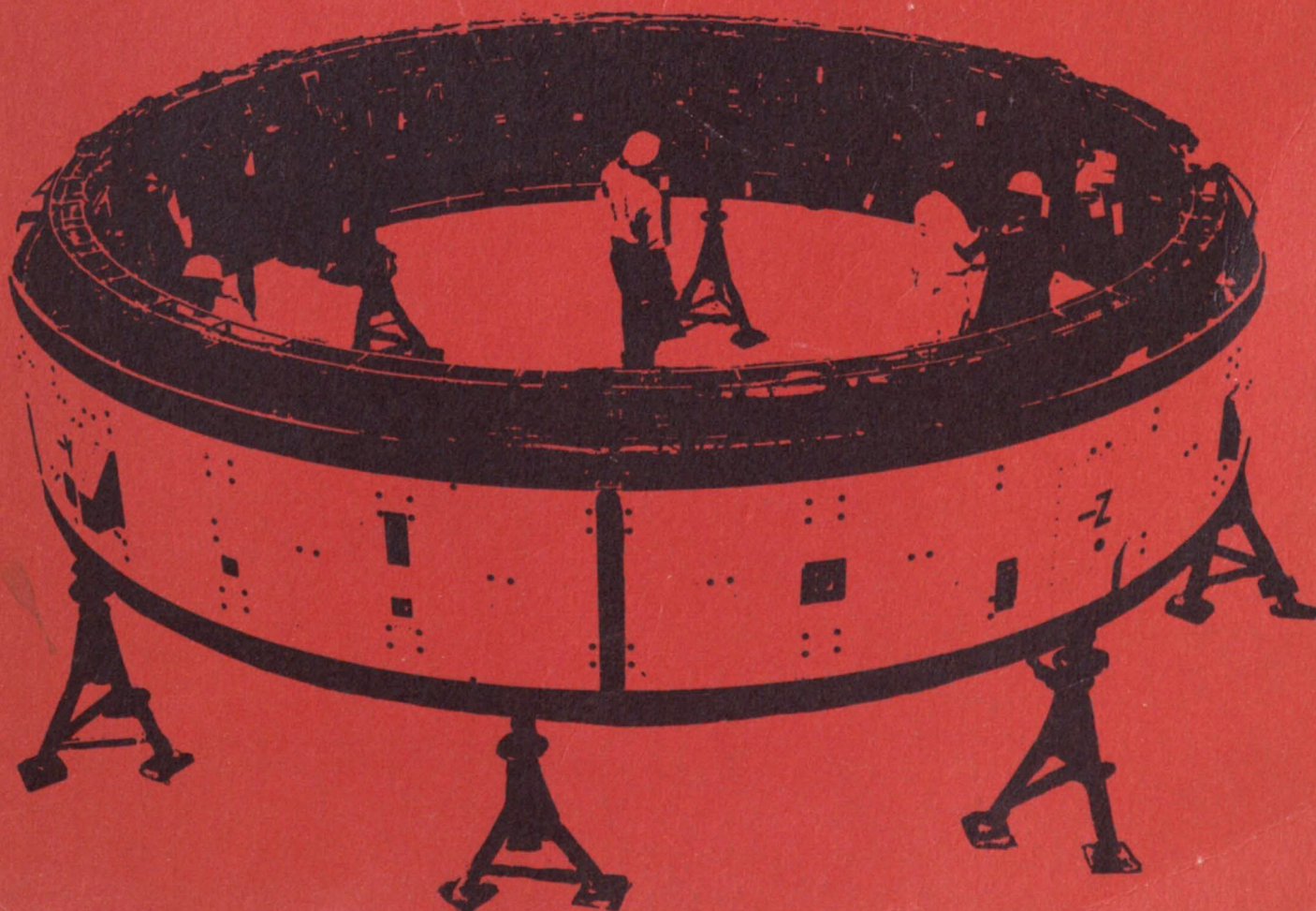
Saturn IB/V - Instrument Unit

LVDC Equation Defining Document
for the
AS-501 Flight Program

F J HUDSON JR
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Prepared for the

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Huntsville, Alabama

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AS-501 Flight Program**

25 February 1966

Classification and Content Approval

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Program Office Approval

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IBM Space Systems Center, Huntsville, Alabama

FOREWORD

This document has been prepared in two parts. The first part (Sections 1 through 18) will be maintained as an active document by updating it with change forms. The second part (Appendices A through E) will not be updated.

Sections 1 through 18 contain the specification for the flight computer program. These sections, as updated by subsequent change forms, will reflect the current status of the AS-501 Flight Program Specification.

The appendices contain information from simulation studies. The results in the appendices are not part of the actual specification, but do support it and indicate the flight program performance to be expected when this specification is met.

1. INTRODUCTION

The Apollo-Saturn 501 flight is the initial mission of the Saturn V launch vehicle. The nominal mission profile calls for two revolutions in a circular parking orbit at 185 kilometers altitude, followed by one revolution in an elliptical waiting orbit of four hour period, and reentry.

This document defines the LVDC flight program for the mission. The flight program is defined as that program which controls the LVDC from liftoff minus 8 seconds (guidance reference release - when control of the computer is transferred from the ground to the flight routines) until the end of the mission.

The LVDC performs seven primary functions during the mission: navigation, guidance, attitude control, event sequencing, data management, ground command processing, and hardware evaluation. The flight program, as it relates to each of these areas, is defined and discussed; general flow diagrams of the flight program are presented. The initial value and the range of each important variable of the flight program are given as an aid to scaling of the program.

In order to verify that the present form of the program is suitable for the AS-501 mission, simulation studies have been made. A summary of the results obtained from simulation studies is presented in the appendices of this document.

The primary mission objectives which are related to LVDC/LVDA operations are:

- a. Demonstrate the S-II stage propulsion system, including programmed mixture ratio shift and the propellant utilization system, and determine performance parameters.
- b. Demonstrate the capability of the S-IVB auxiliary propulsion system to maintain attitude control and perform required maneuvers during S-IVB powered flight and coast periods.
- c. Demonstrate the launch vehicle control/guidance system during S-IC, S-II and S-IVB powered flight, achieve guidance cutoff and evaluate system accuracy.
- d. Demonstrate launch vehicle sequencing system.
- e. Demonstrate dual-plane separation of S-II from S-IC.
- f. Demonstrate the S-IVB stage restart capability.

- g. Demonstrate separation of S-IVB from S-II.
- h. Monitor performance of the Emergency Detection System in an open loop configuration.
- i. Demonstrate the mission support capability required for launch and mission operations (including a special tracking, telemetry, and communications system) extending to large post injection altitudes.
- j. Verify pre-launch and launch support equipment compatibility with launch vehicle and spacecraft systems.
- k. Determine in-flight launch vehicle internal environment.

SA-501 is an unmanned flight mission. The following is a description of the nominal mission. S-IC stage ignition occurs at T - 6 seconds, but vehicle holddown arms prevent liftoff until sea-level thrust has been achieved. At liftoff (T + 0), a control release device mounted on the holddown arms will provide for a "soft" release during the first six inches of vertical travel and, at T plus 12 seconds, the vehicle will execute a tilt-over/roll maneuver to a downrange trajectory of 72° East of North. During the S-IC powered flight, the SA-501 will be under programmed autopilot control with open loop guidance. The engine shutdown sequence will be initiated by signals from the propellant level sensors. For a nominal trajectory, this sequence will begin at approximately T plus 142 seconds. When the thrust level decreases to 10 percent of nominal value, a linear shaped cutting charge will separate the S-IC stage from the rest of the vehicle. Eight retrorockets on the S-IC provide retrograde acceleration for positive separation of the S-IC stage from the vehicle. The expended S-IC stage will impact 590 km (320 n. m.) downrange.

At S-IC stage separation, eight ullage rockets on the S-II stage will ignite and burn for 3.7 seconds to provide for propellant settling. Following a coast period of about 3.5 seconds, the S-II main engines will ignite. Thirty seconds after S-IC separation, the forward ring of the S-II interstage is jettisoned. Thirty-five seconds after S-IC separation, the Launch Escape System is jettisoned. S-II powered flight will last for approximately 370 seconds during which time guidance and steering commands will be generated by the LVDC.

S-II stage engine shutdown, as with the S-IC, is initiated by propellant level sensors. Stage separation is effected by activation of a Mild Detonating Fuse (MDF) located on the separation plane of the S-II/S-IVB interstage. Four retrorockets located in the S-IVB interstage provide for positive separation of the S-II stage and S-IVB interstage as a unit. The S-II stage/S-IVB interstage will impact 4190 km (2260 n. m.) downrange.

The SA-501 mission plan requires that the space vehicle be inserted into a 185 km (100 n. m.) near-circular parking orbit, followed by insertion into an elliptical waiting

orbit, followed by insertion into an elliptical waiting orbit after one to three, nominally two, parking orbits. This dual-orbit requirement will be achieved by two separate S-IVB boost periods.

The first boost period will insert the space vehicle into the parking orbit. To initiate the sequence, two ullage rocket engines will provide for propellant settling, followed by S-IVB ignition approximately 3 seconds after S-II separation. After about 172 seconds of boost, S-IVB cutoff occurs and the space vehicle will have achieved the parking orbit, and will remain in this orbit for the specified number of revolutions around the earth. During this time, vehicle guidance will be updated and mission data will be reviewed to confirm that conditions are satisfactory for continuation of the mission.

For the second boost phase, the S-IVB engine will be re-ignited while positioned close to Cape Kennedy (preceded by ignition of the 72-pound ullage engines for chilldown and propellant settling). After a boost period of about five minutes, the space vehicle will be inserted into the high elliptical waiting orbit. Following S-IVB engine cutoff, the S-IVB/IU will separate from the Apollo spacecraft, concluding the Saturn V launch vehicle portion of the flight mission.

2. GENERAL DESCRIPTION OF THE FLIGHT PROGRAM

The LVDC flight program may be divided into five parts for the purpose of discussion: the powered flight major loop, the orbital flight program, the minor loop, interrupts, and telemetry. The powered flight major loop contains guidance and navigation calculations, time-keeping, and all other repetitive functions which do not occur on an interrupt basis. The orbital flight program consists of an executive routine concerned with IU equipment evaluation during orbit and a telemetry time-sharing routine to be employed while the vehicle is over receiving stations. In addition, in the orbital flight program, all navigation, guidance, and time-keeping computations are carried out on an interrupt basis keyed to the minor loop interrupt. The minor loop contains the control system computations and accelerometer sampling. Since the minor loop is involved with vehicle control, minor loop computations must be executed at 25 times per second during the powered phase of flight. However, in earth orbit, only a rate of 10 executions per second is required for satisfactory vehicle control.

The flight program is designed to operate in either the powered flight mode or the orbital flight mode. The first transition from powered flight to orbital flight occurs at first S-IVB cutoff, approximately 690 seconds after liftoff. Transition from orbital to powered flight occurs just prior to the second ignition of the S-IVB stage, at 11,500 seconds after liftoff for the nominal case of 2 orbits. The second transition from powered flight to orbital flight occurs at second S-IVB cutoff, approximately 325 seconds after restart of the J2 engine.

The average execution time for any given major loop in powered flight, complete with minor loop computation and interrupt processing, is called the nominal computation cycle for that mode. The computation cycle is not fixed for two reasons. First, the various flight modes of the flight program have different computation cycle lengths. Second, even in a given flight mode, the uncertainties of discrete and interrupt processing and the variety of possible paths in the loop preclude a fixed computation cycle length. Even though the exact length of any given computation cycle is not predictable, the longest nominal computation cycle in boost should be less than two seconds. In orbit, the computation cycle will be approximately one second for guidance and eight seconds for navigation. For the second S-IVB burn (out of orbit flight), the computation cycle will be approximately two seconds in length.

The flight program is shown in two stages of detail in this document: a general flow diagram and a "word flow" diagram. Figure 2.0, the major loop general flow diagram, shows the most general form of the major loop computations. The processing depicted in these blocks is explained in more detail in the remainder of this document. Figure 2.1 is designed to show the relationship of the various parts of the powered flight major loop and the orbital flight program. The minor loop and other interrupts

Tactical Process Design

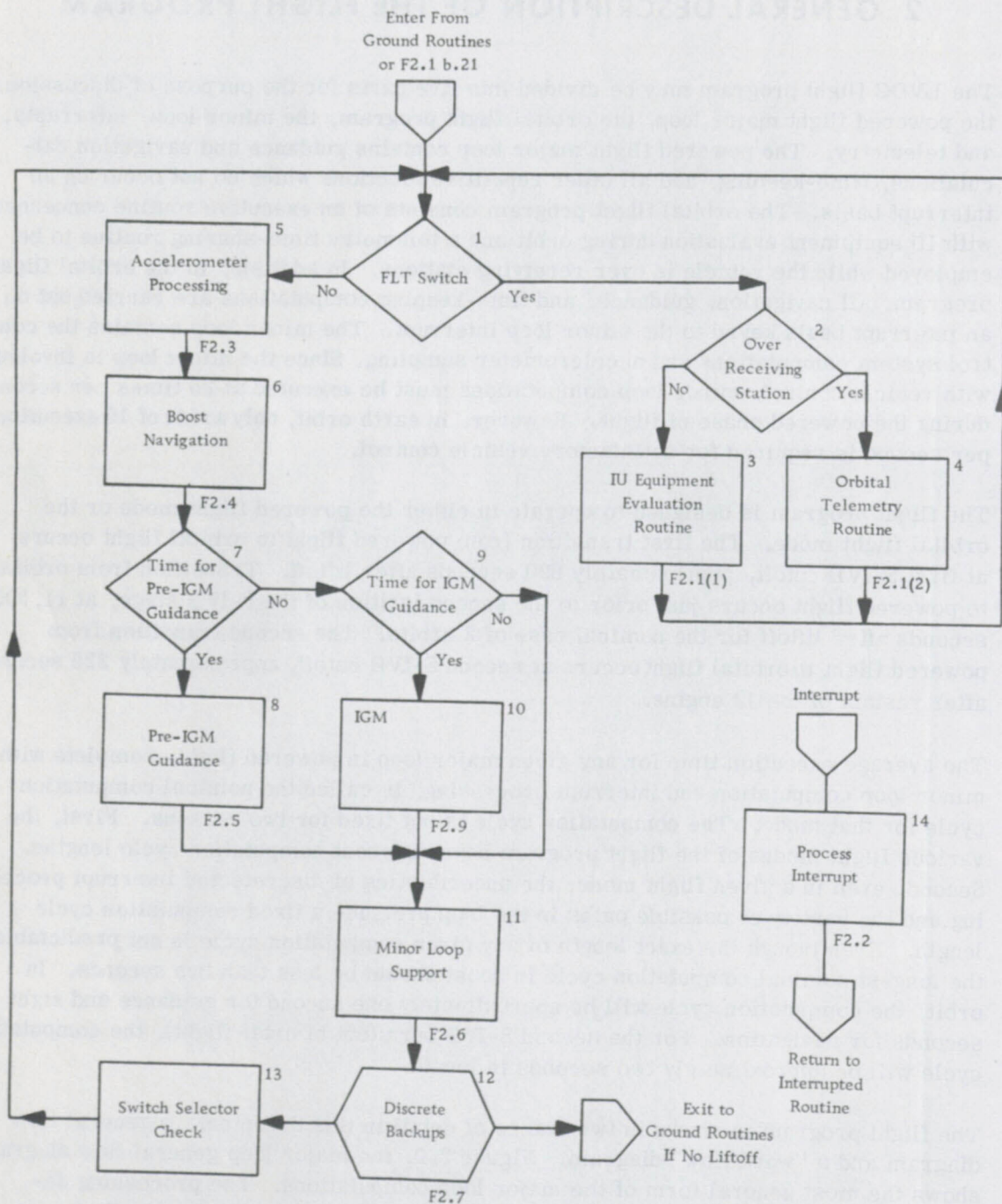


Figure 2.0 Major Loop General Flow

Tactical Process Design

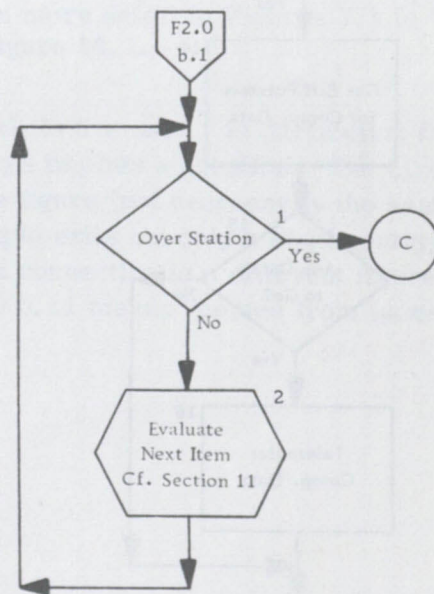


Figure 2.1 Orbital Flight Program (Sheet 1 of 2)
(This sheet is box 2 and 3 of Figure 2.0)

Tactical Process Design

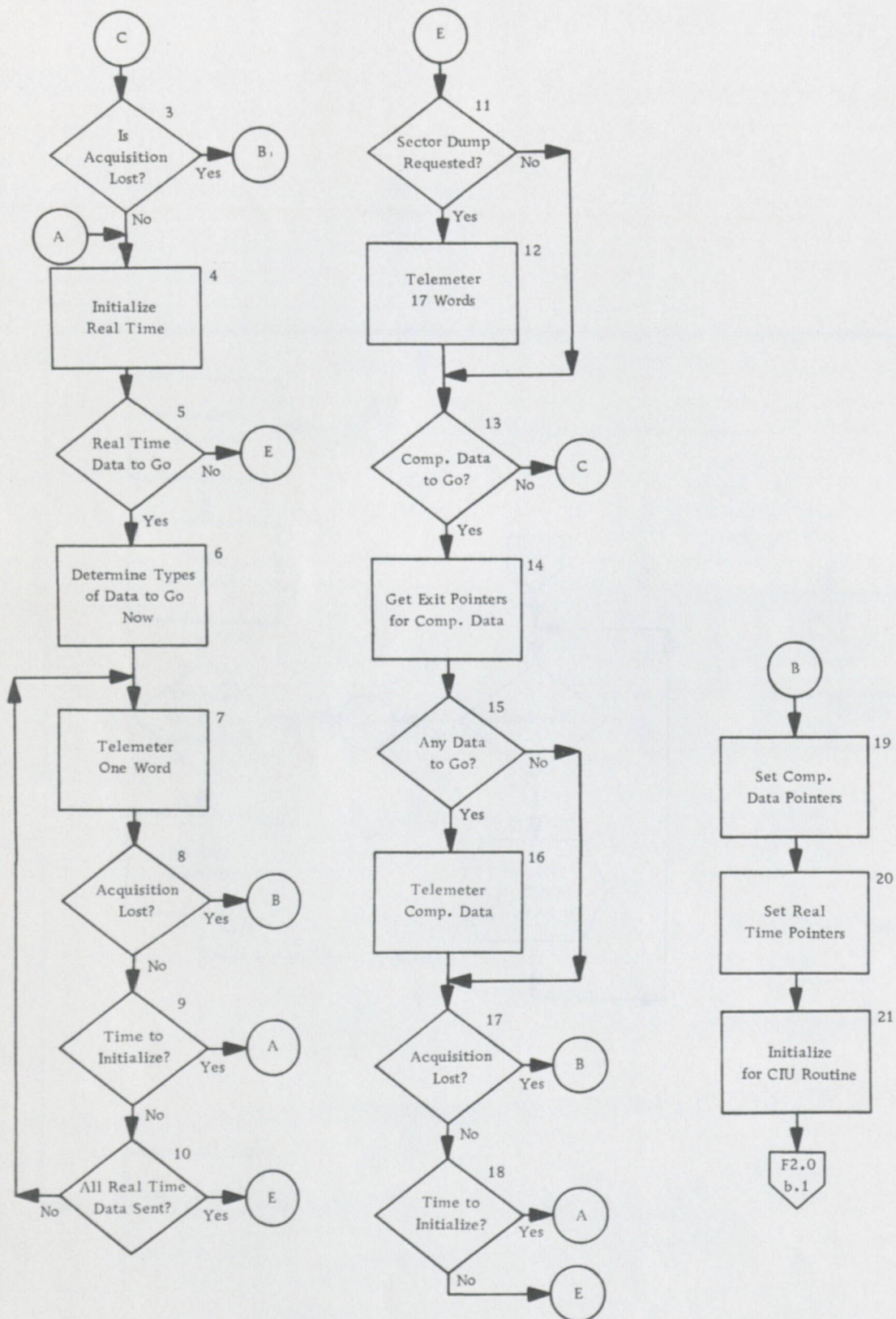


Figure 2.1 Orbital Flight Program (Sheet 2 of 2)
(This sheet is block 4 of Figure 2.0)

are shown in Figure 2.2. These interrupts can occur at any time by interrupting the major loop or the orbital flight program. The interrupt register is then decoded and the program switched to the appropriate interrupt subroutine.

Discrete processing is a part of the flight program which is not shown in Figure 2.1. This topic is discussed in Section 12. Telemetry and data compression are also parts of the flight program and are discussed in detail in Sections 15 and 16, where specific quantities to be telemetered and compressed are listed. A description is also included for the Flight Test Routine (pseudo flight and simulated flight).

Figures 2.3 through 2.11 are an expansion of Figure 2.0 into "word flow" diagrams. These figures are designed to be a word description of the important parts of the flight program. They are shown here in connected form in order to provide a clearer picture of how all the sections fit together. Similar word flow diagrams (corresponding to Figure 2.2) are found in the minor loop and interrupt sections (Sections 10 and 13) where more details are exhibited to aid in understanding these interrupt operations. IGM (block 10) is shown in more detail in Figures 7.1 to 7.4. Discrete backups (block 12) are shown in figure 14.1.

Standard flowcharting symbols are used. In particular; the diamond represents a logical decision, and always implies a question. The circle represents a connection to another circle in the same figure (not necessarily the same sheet) bearing the same letter; there may be multiple exits but only a single entry for a given letter. The "home plate" represents a connection to a different figure, the figure and block numbers are given, e.g. F2.0 b.11 means "comes from (goes to) block 11 of Figure 2.0."

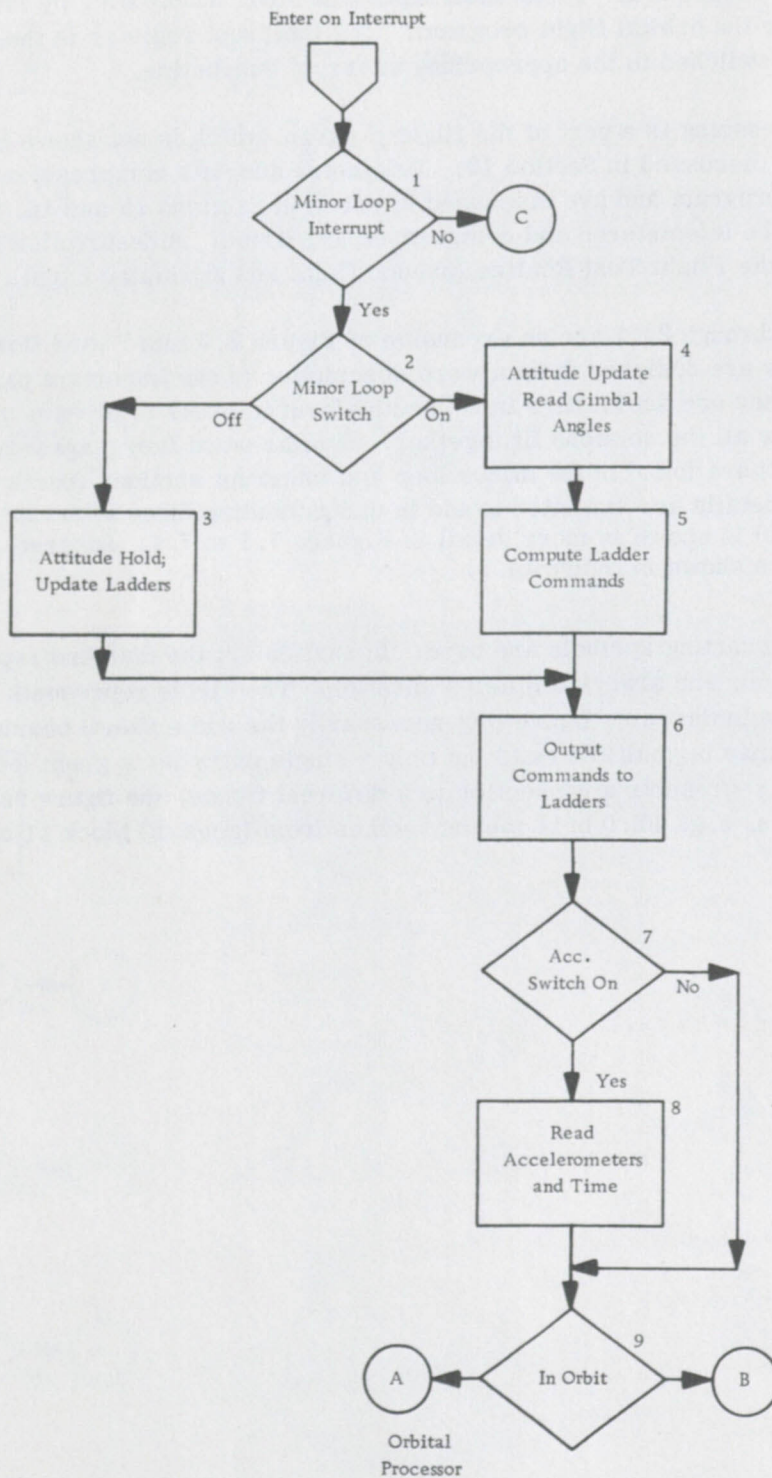


Figure 2.2 Interrupt Processing (Sheet 1 of 3)

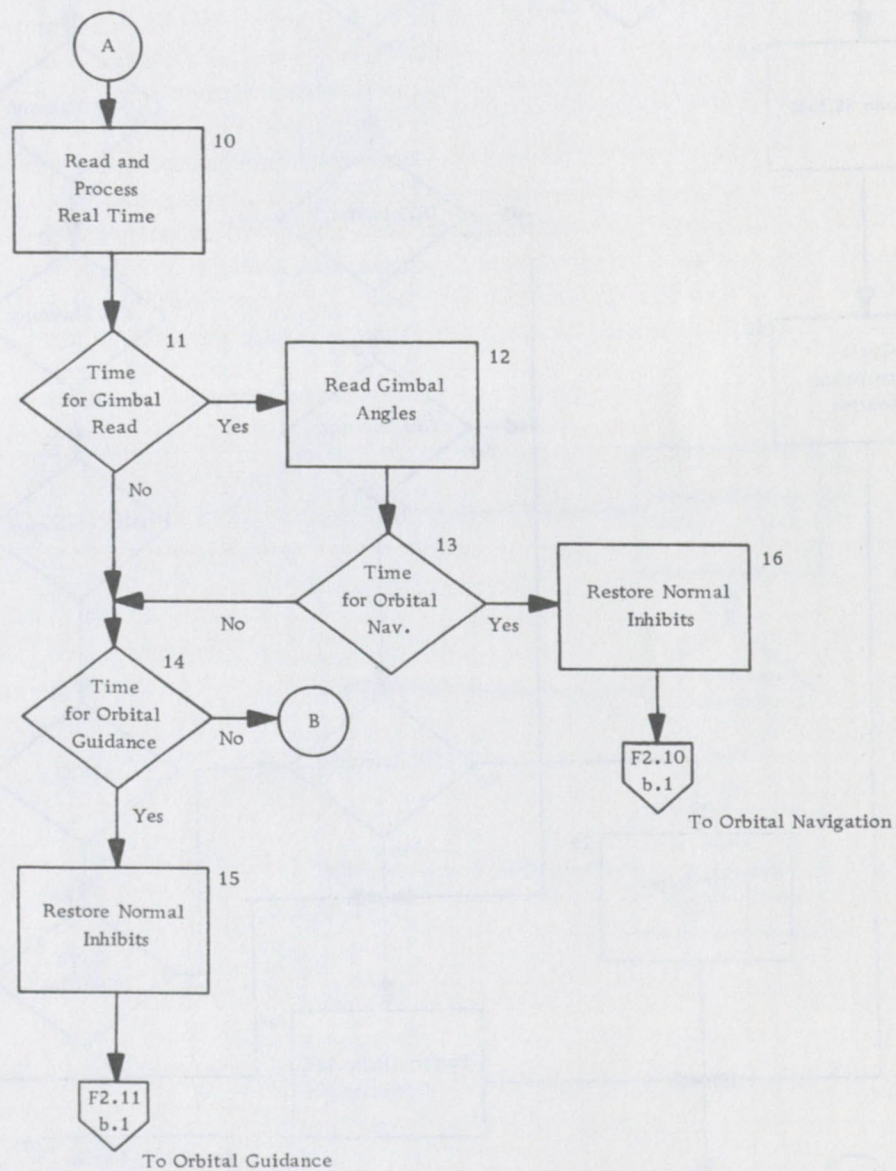


Figure 2.2 Interrupt Processing (Sheet 2 of 3)

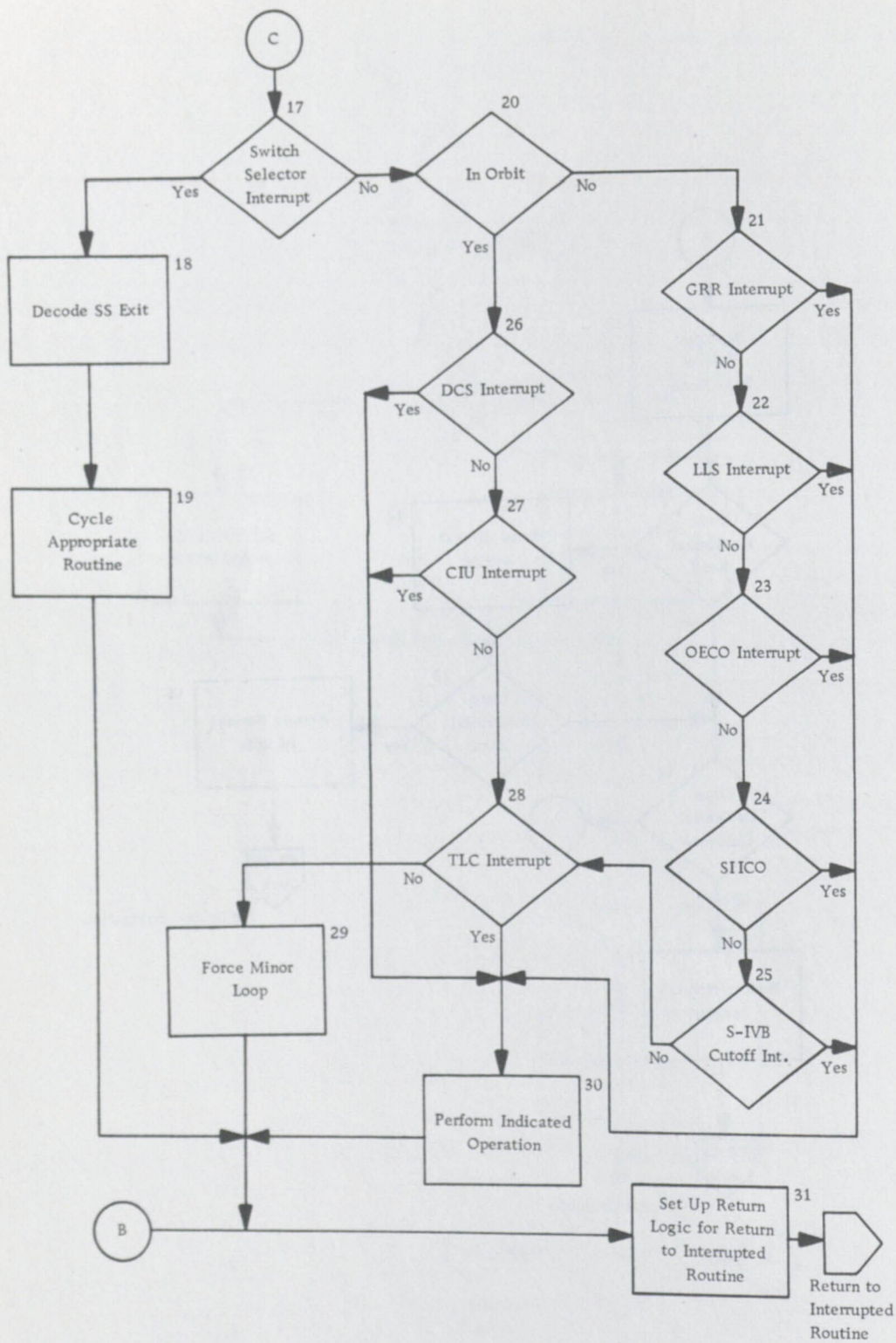


Figure 2.2 Interrupt Processing (Sheet 3 of 3)

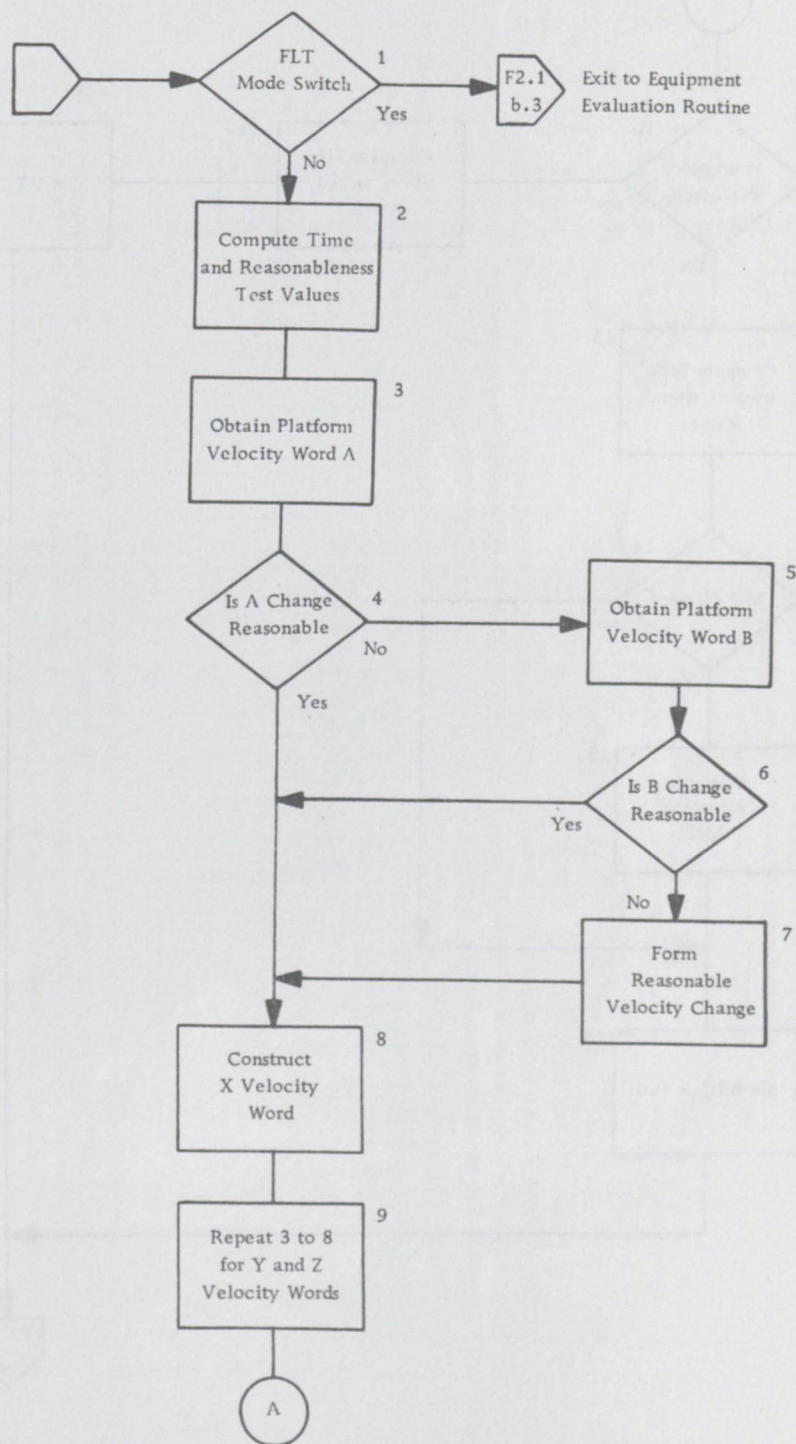


Figure 2.3 Accelerometer Processing (Sheet 1 of 2)
(This figure is box 1 and 5 of Figure 2.0)

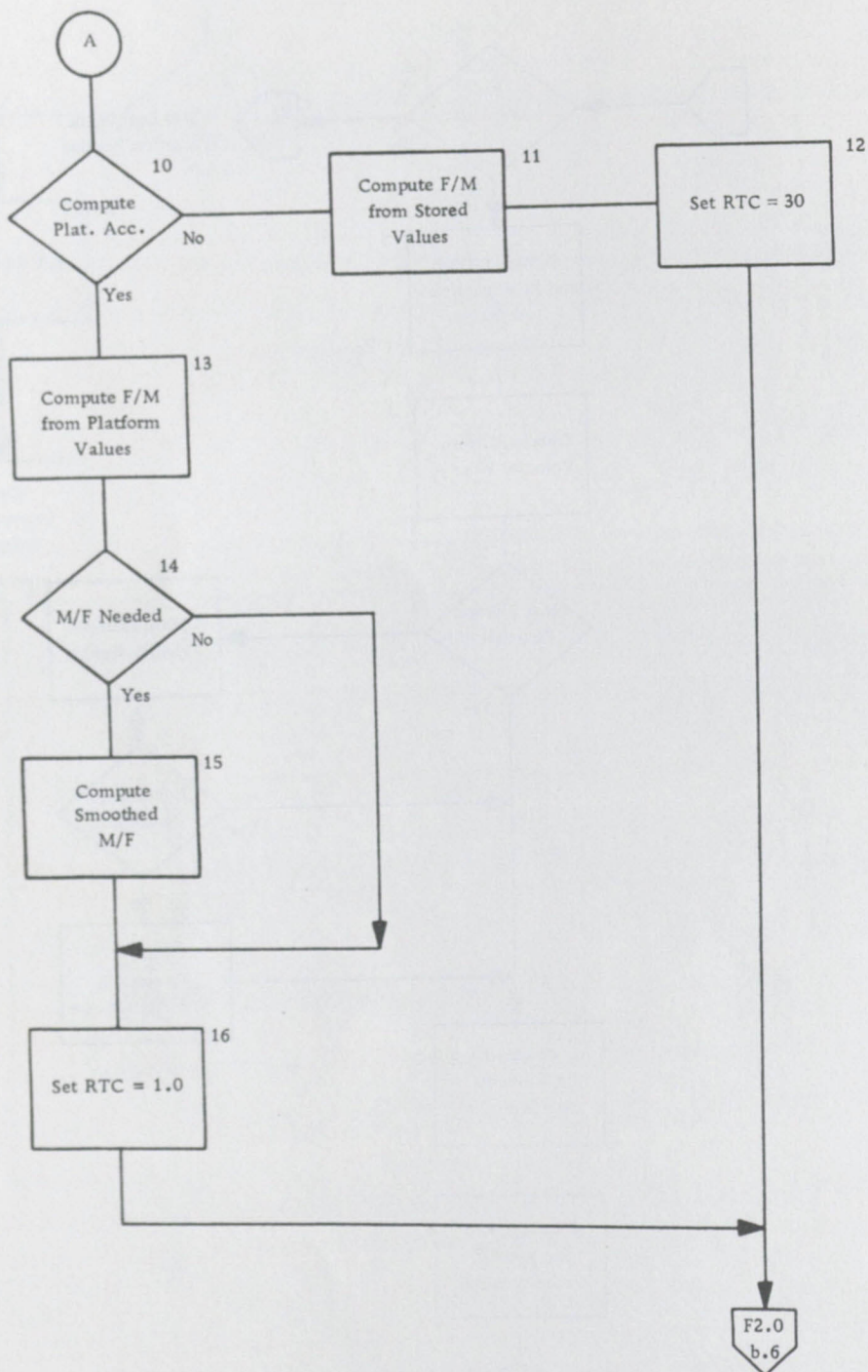


Figure 2.3 Accelerometer Processing (Sheet 2 of 2)

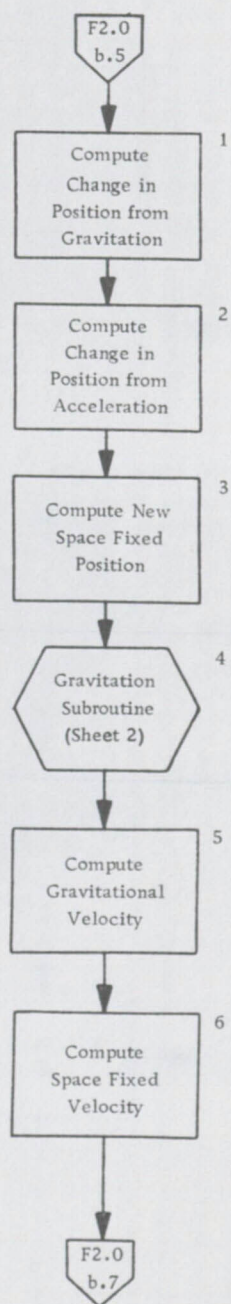


Figure 2.4 Boost Navigation (Sheet 1 of 2)
(This is block 6 of Figure 2.0)

Enter Gravitation Subroutine

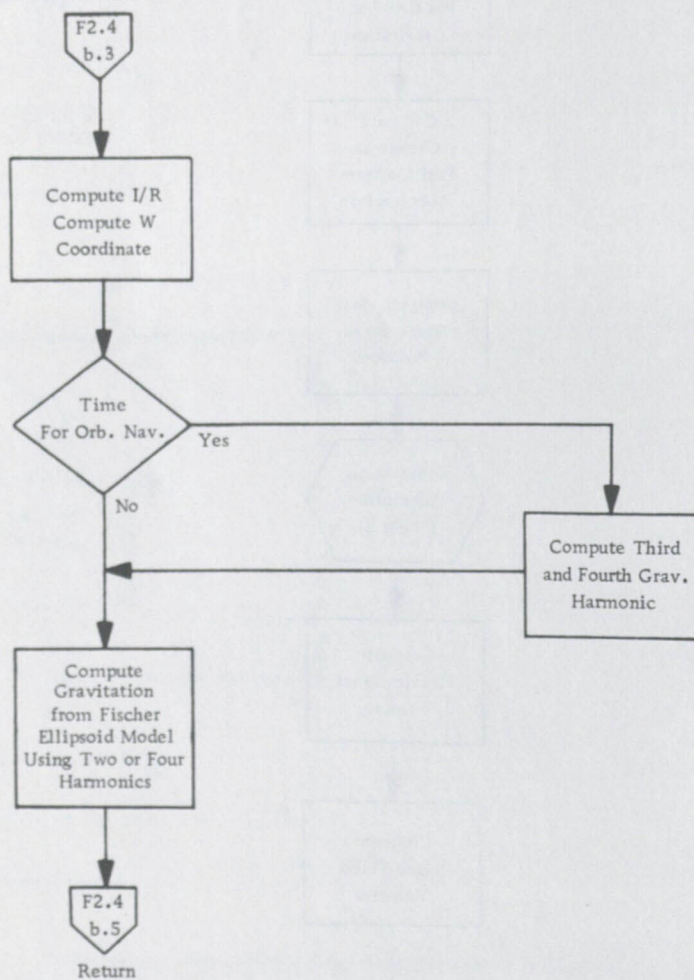


Figure 2.4 Boost Navigation (Sheet 2 of 2)
(This sheet is block 4 of sheet 1.)

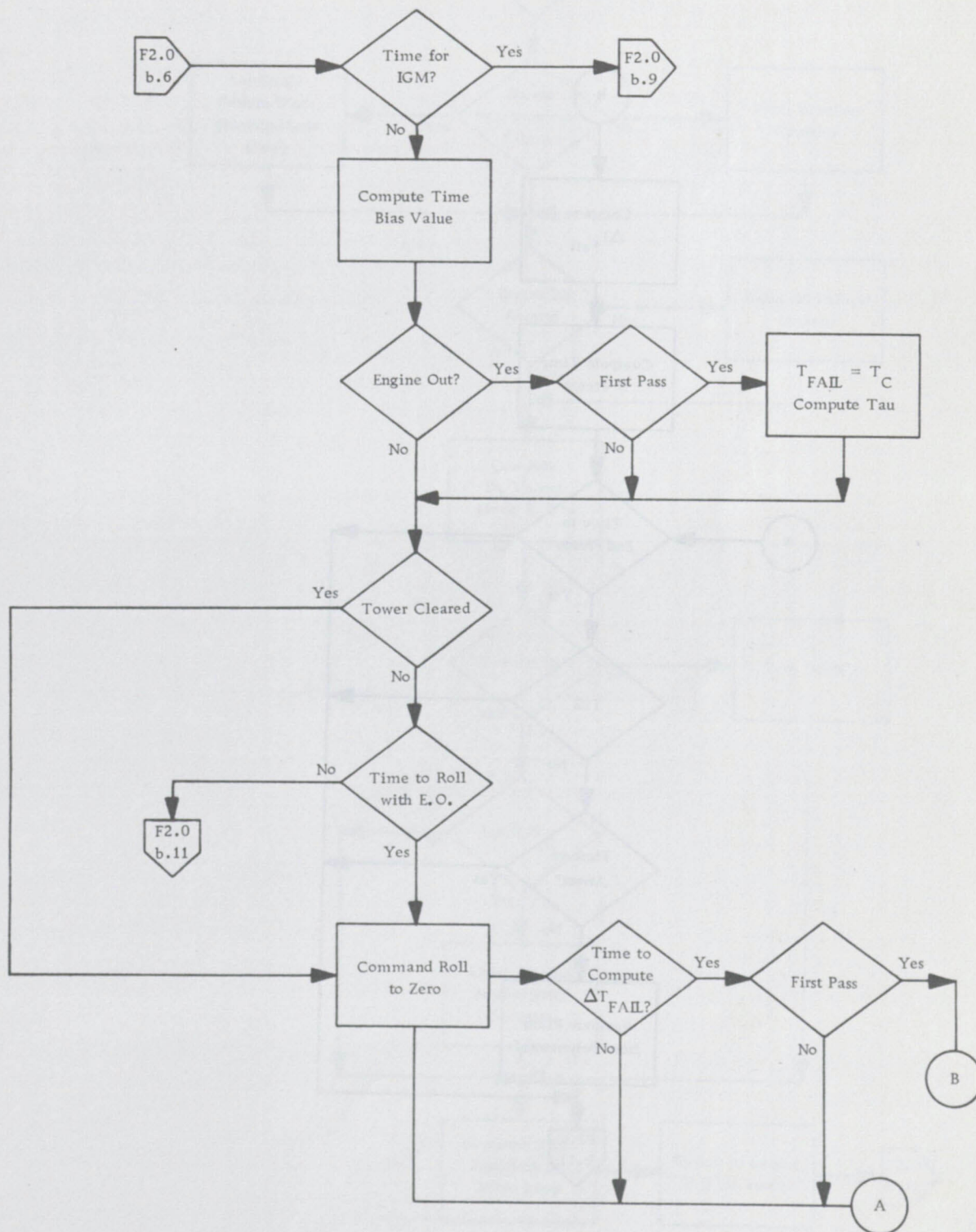


Figure 2.5 Pre-IGM (Sheet 1 of 2)
(This Figure is blocks 7 and 8 of Figure 2.0)

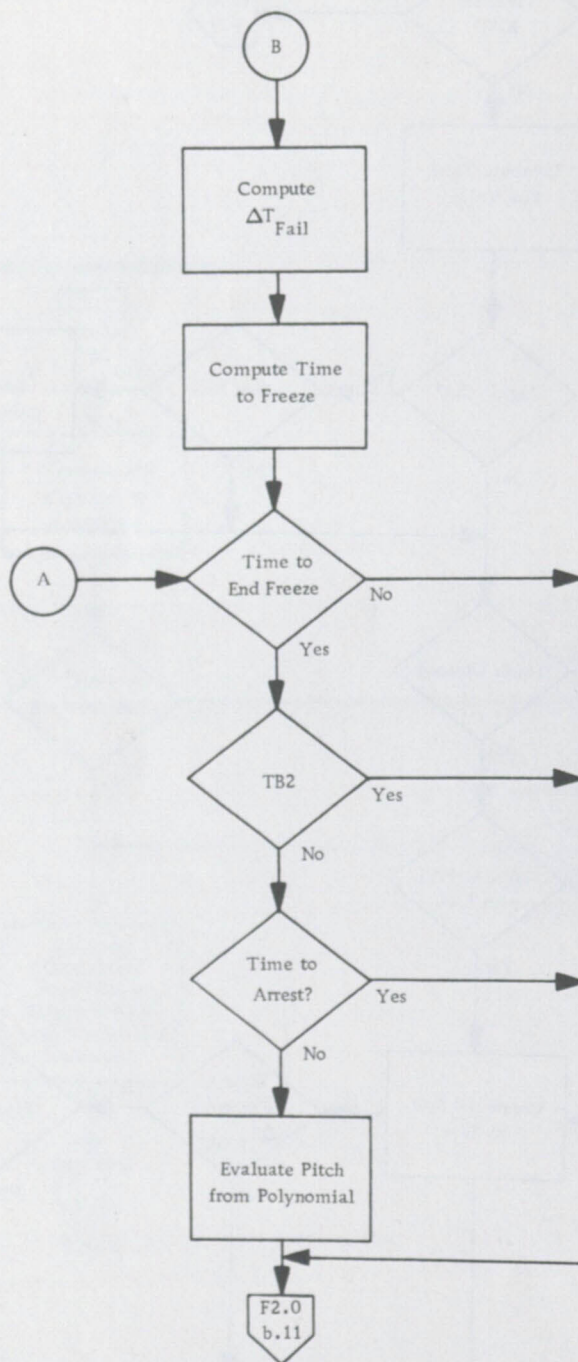


Figure 2.5 Pre-IGM (Sheet 2 of 2)

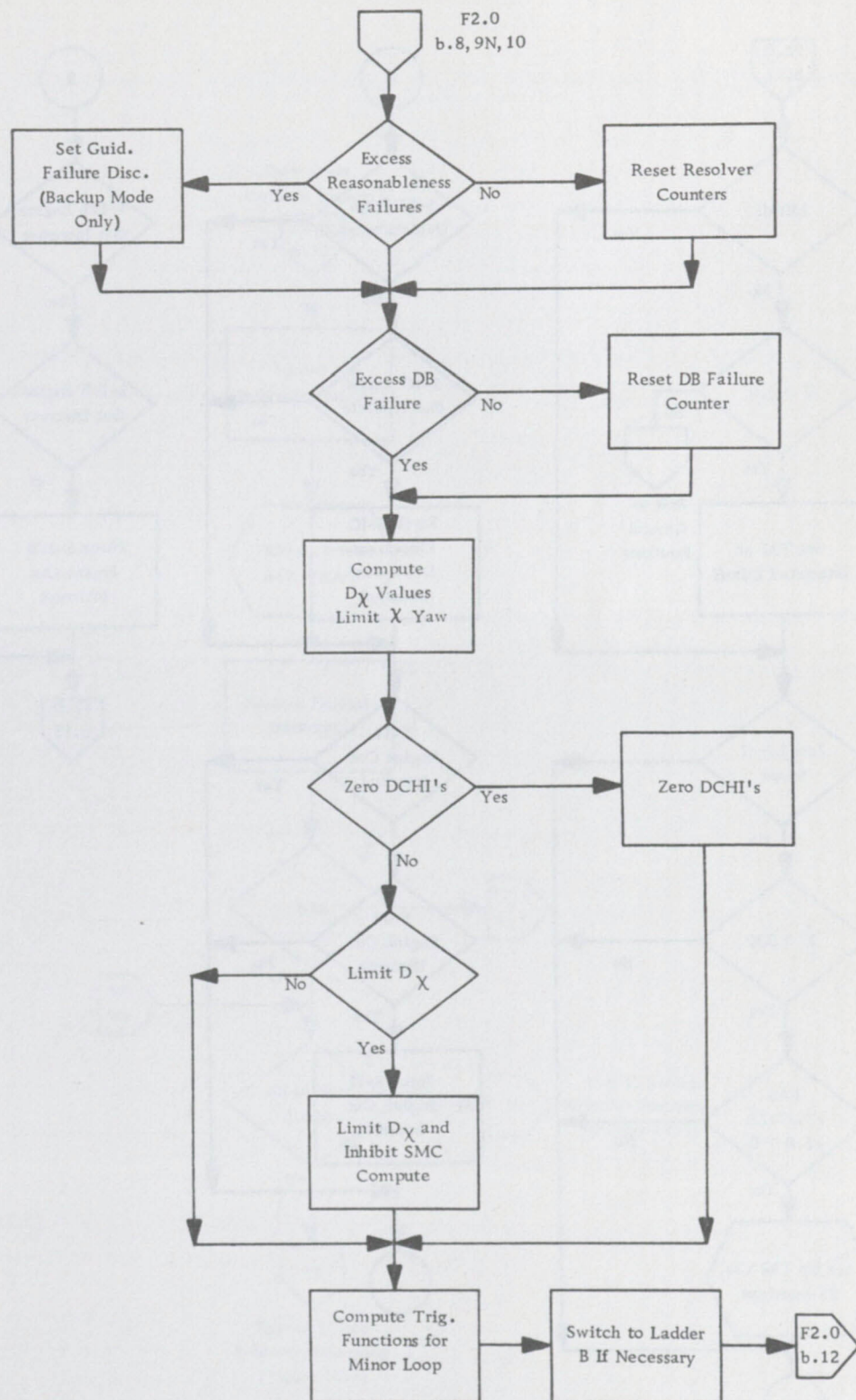


Figure 2.6 Minor Loop Support
(This Figure is block 11 of Figure 2.0)

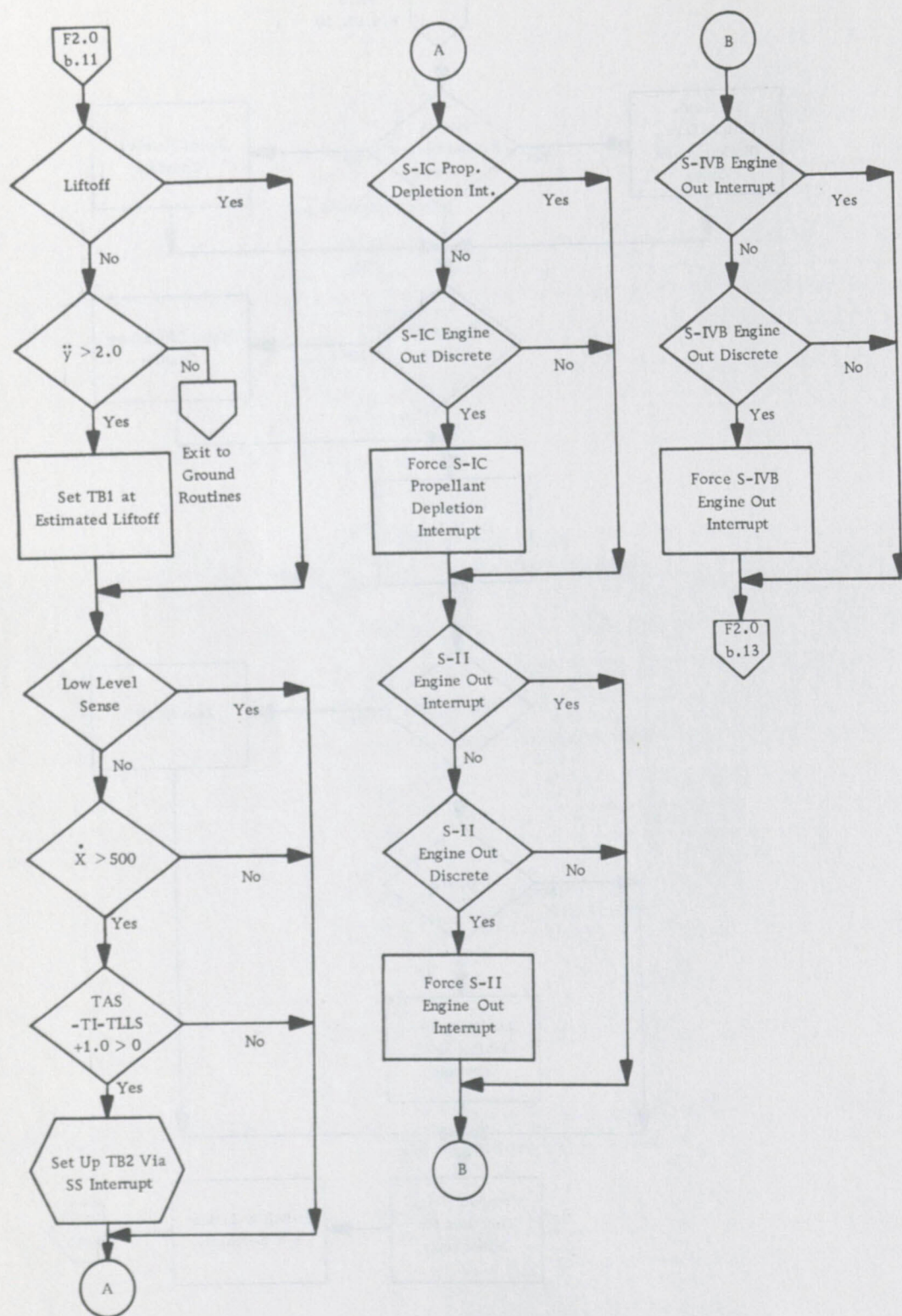


Figure 2.7 Discrete Backups
(This Figure is block 12 of Figure 2.0)

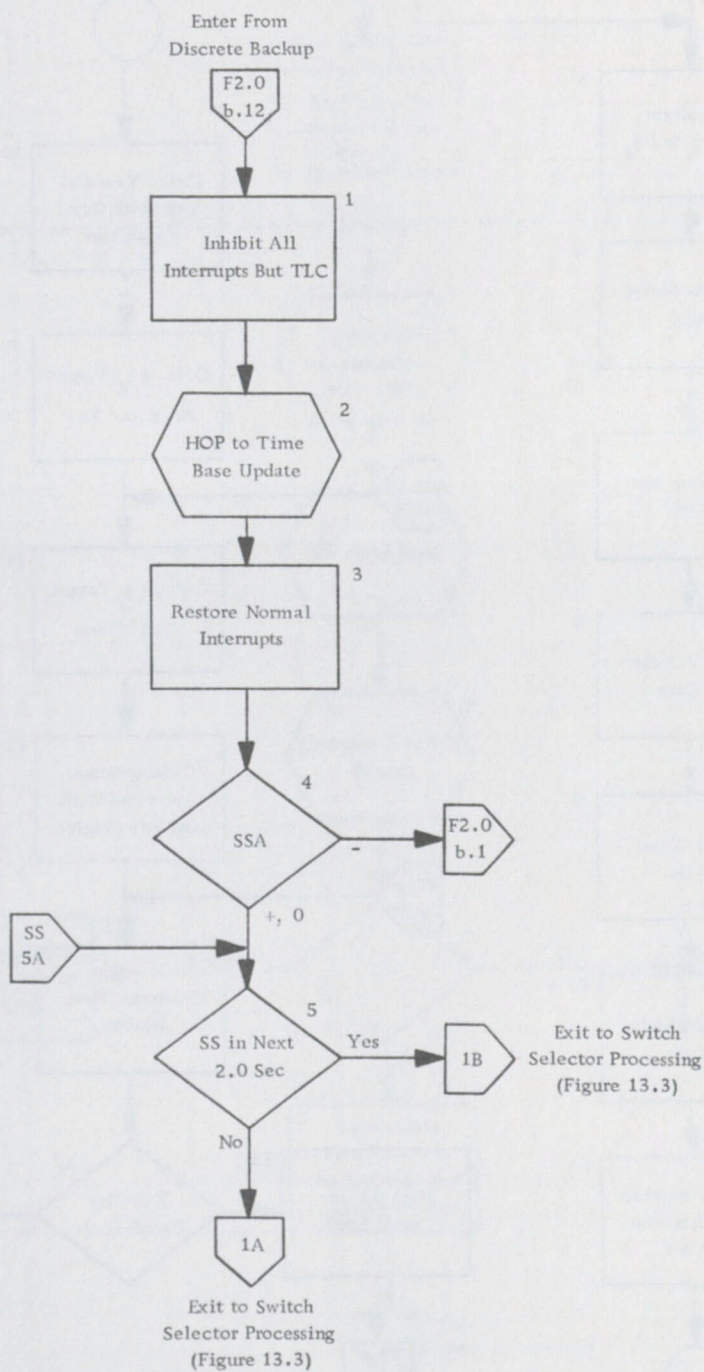


Figure 2.8 Boost Switch Selector Check
(This Figure is block 13 of Figure 2.0)

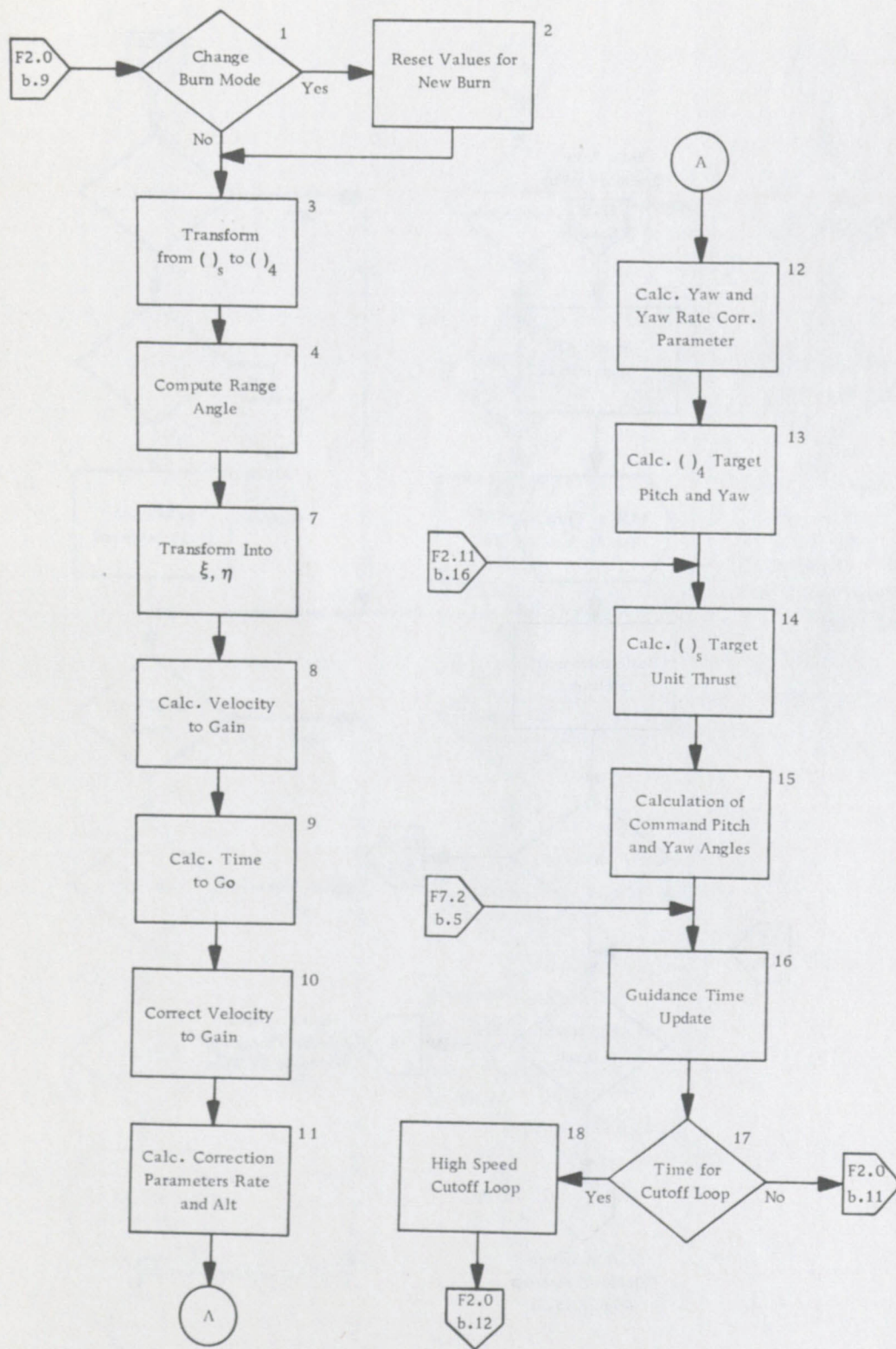


Figure 2.9 IGM
(This Figure is block 10 of Figure 2.0)

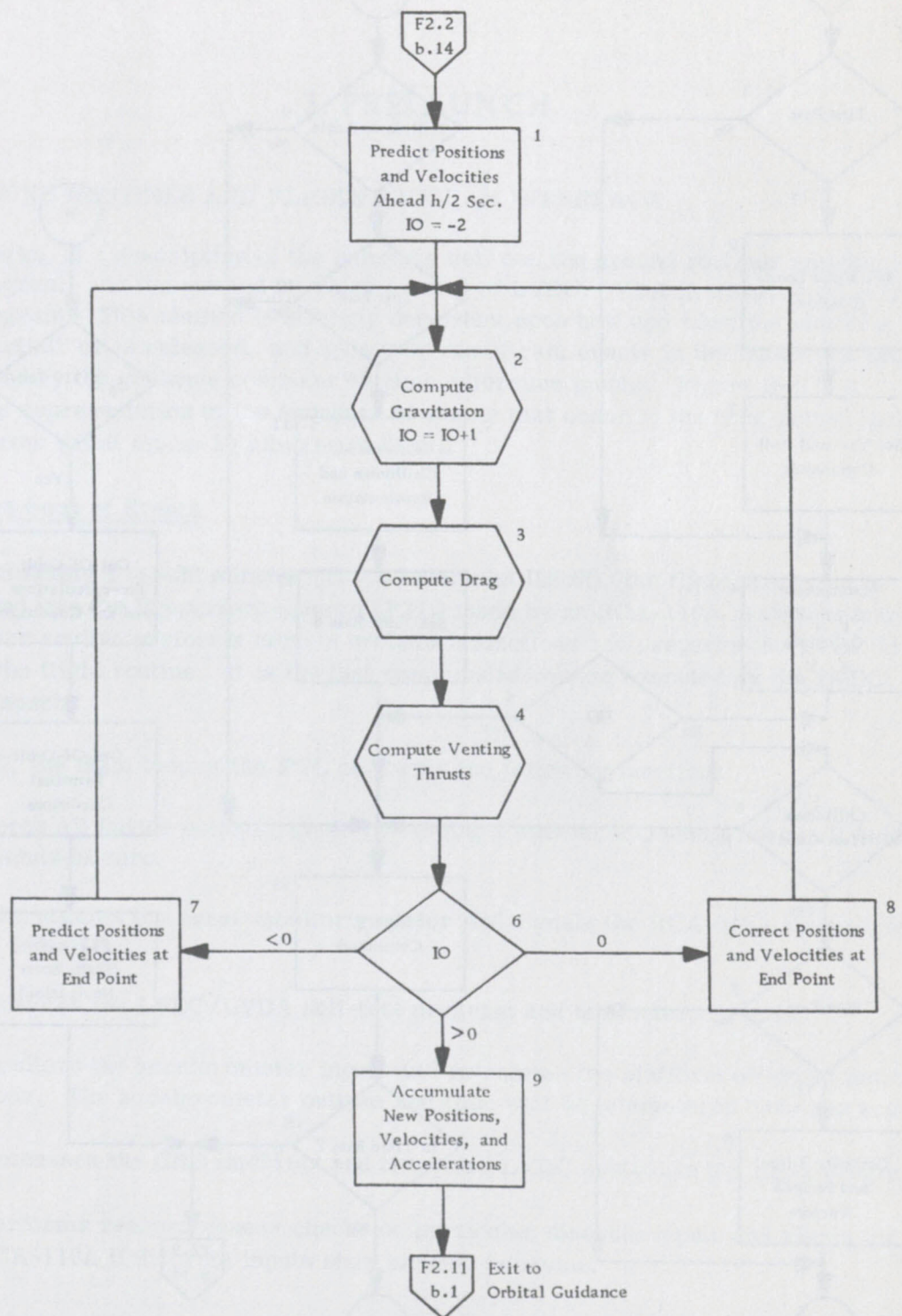


Figure 2.10 Orbital Navigation

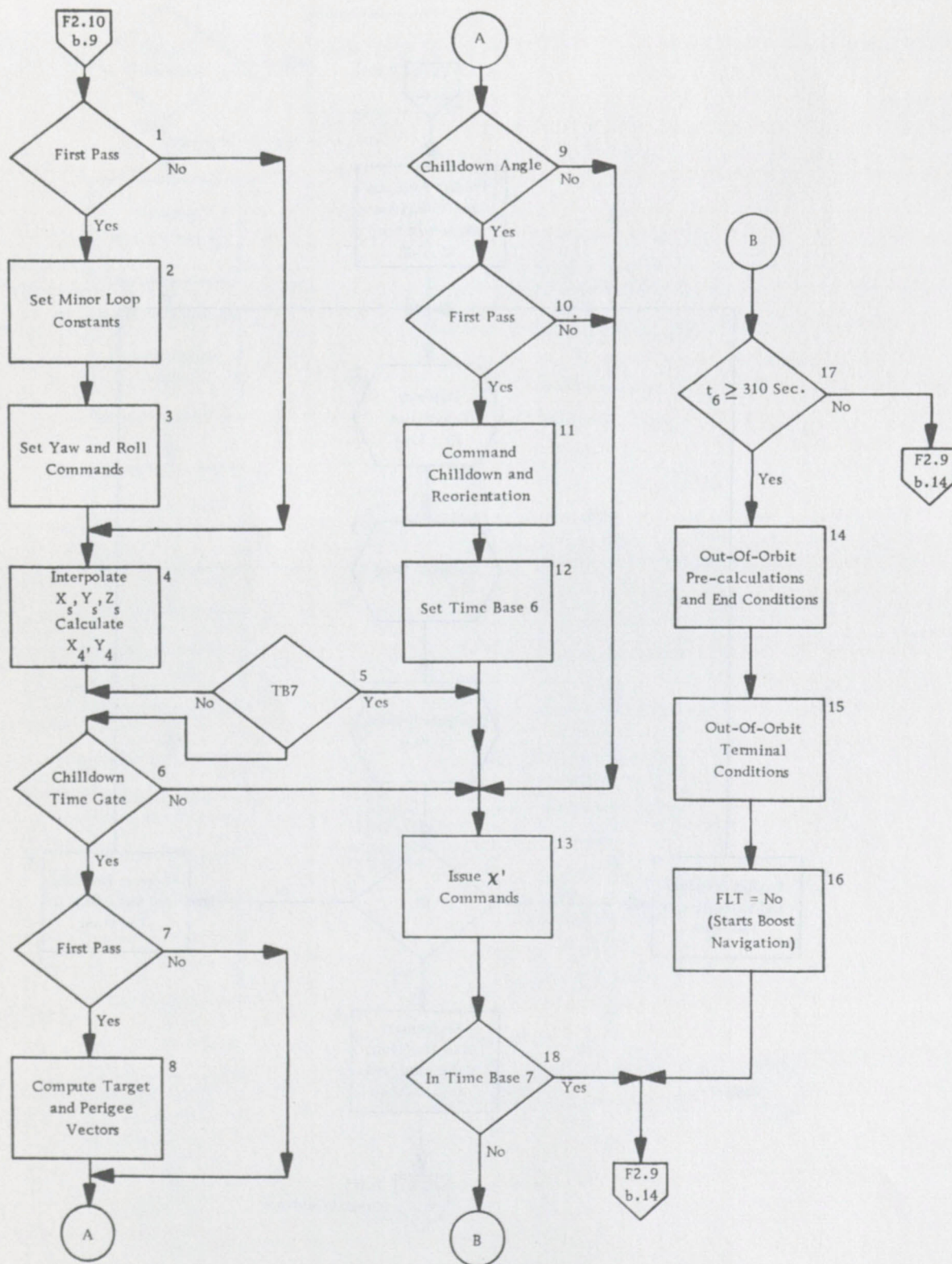


Figure 2.11 Orbital Guidance and Restart

3. PRELAUNCH

3.1 GROUND ROUTINES AND FLIGHT PROGRAM INTERFACE

The following is a description of the interface between the ground routines and the flight program, and the method by which control of LVDC/LVDA is transferred to the flight program. This method is strongly dependent upon how and when the platform "goes inertial" or is released, and upon what significant events in the launch sequence can be used by the guidance computer as time reference points. Figure 3-1 is a schematic representation of the sequence of events that occur in the time period that extends from liftoff minus 20 minutes to liftoff.

3.1.1 Sequence of Events

At approximately $T = -20$ minutes ($T = 0$ is time of liftoff), the flight computer is commanded into the Prepare-to-Launch (PTL) mode by an RCA-110A mode command. This ground routine performs certain prelaunch functions and prepares the LVDC for entering the flight routine. It is the last commanded routine executed by the LVDC prior to launch.

In general, the main loop of the PTL performs the following functions:

- a. Keeps all ladder outputs zeroed by issuing a special PIO which keeps all ladder outputs at zero.
- b. Interrogates the error monitor register and signals the RCA-110A if an error is detected.
- c. Executes the LVDC/LVDA self-test program and telemeters results.
- d. Monitors the accelerometer inputs and calculates the platform off-level indications. The accelerometer outputs and time will be telemetered once per second.
- e. Processes the GRR interrupt and transfers LVDC control to the flight program.
- f. Performs reasonableness checks on particular discrete inputs and alerts the RCA-110A if discrete inputs show unusual behavior.
- g. Samples platform gimbal angles and telemeters both backup and fine gimbal angles six times per second.

At 153 seconds prior to liftoff, the automatic launch sequence is started. This occurrence is not communicated to the LVDC.

At approximately $T = -13$ seconds, a discrete originating in the launch sequencer, called Guidance Reference Release Alert (GRR), will be sent to the LVDC. This input does not influence the PTL routine. When the GRR interrupt is sent to the LVDC, the PTL routine transfers control of the LVDC to the flight program. This event marks the point at which the ground routines relinquish control to the flight program.

3.1.2 Azimuth Laying Program

The Azimuth Laying Program is executed in the RCA-110A Automatic Ground Control System Computer (AGCSC). It is used to position the ST-124M platform to the desired firing azimuth. This program has two modes, manual and automatic. The manual mode is used in fixed azimuth launches and the automatic mode is used for variable azimuth launches. SA501 will use the manual mode.

3.1.2.1 Manual Mode

At approximately $T - 20$ minutes the azimuth laying program will be called into execution at the AGCSC. The following initial conditions will be verified.

- a. Platform on
- b. Inertial Prism acquisition
- c. Moving Prism acquisition
- d. Dual Prism align on.

If all of the above conditions are satisfied, a reading of the Azimuth Encoder will be made and stored. This is the azimuth encoder offset. Dual prism align is then turned off. The theodolite azimuth is entered through the console keyboard. Next, the desired firing azimuth is entered. This value can be either positive or negative but is measured relative to the theodolite azimuth rather than north. The value entered is converted to an encoder value. To this is algebraically added the encoder offset. The platform is then driven until the Azimuth Encoder Readout matches exactly the computed azimuth encoder value. Using the theodolite azimuth, a firing azimuth for the LVDC is computed and stored in permanent core memory of the AGCSC. This value can be used to verify the pre-stored firing azimuth in the LVDC at any time prior to launch.

The azimuth laying program can be recalled and executed at any time after initial execution. If this is done, however, all initial conditions are waived and any firing azimuth value entered on the console is algebraically added to the platform's present position.

Monitoring of the platform gimbal angles exists at the Block House Computer (BHC) up until T -8 seconds. Any drift of the azimuth encoder greater than one binary bit (5 arc seconds) will be corrected by automatically recalling and executing a section of the azimuth laying program. Corrections will be made up until T -5 minutes. Any encoder drift after this time will result only in an error message display. The azimuth laying program will not be recalled and executed.

3.1.2.2 Automatic Mode (not required for AS-501)

The program will operate in essentially the same manner as in the manual mode. Initial start conditions and the entering of the theodolite azimuth are identical. When the request to enter a firing azimuth is made, the absence of a firing azimuth entered on the keyboard signals the program that the automatic mode is to be used. The program will first request that the file number for the correct table of azimuths sorted on magnetic tape be entered. This table of azimuths will be for the correct day and time of launch. The tables consist of a set of launch azimuths; each one minute apart in time and covers the range safety spectrum, i.e., 72 to 108 degrees. Along with each azimuth there will be two corresponding targeting parameters: the inclination angle and the descending node.

As soon as the program receives the file number, the corresponding table will be read in from the tape.

By using the Count Down Clock (CDC) and the Eastern Standard Time Clock (EST) the precise second of Guidance Reference Release (GRR), which occurs at T-8 seconds, can be determined. The azimuth, which is closest to GRR in time, is obtained from the table. By use of first order interpolation the azimuth can be obtained to an accuracy of one arc second. This same procedure is used to obtain the angle of inclination and the descending node. These three values, along with time (EST), are stored into permanent core to be transmitted to the LVDC at some later time by another program. The platform is positioned to the firing azimuth, and the program is exited.

Monitoring exists as in the manual mode with one notable exception. Upon resumption of the countdown after a hold, the azimuth laying program will automatically be recalled and a new azimuth along with its parameters will be computed. Since this condition will not exist between T-5 minutes and launch, any hold after T-5 minutes must be recycled beyond T-5 minutes so that a new azimuth can be computed.

3.1.3 Entry into the Flight Program and Initialization

GRR marks the beginning of the navigation calculations. The platform from this point on is "inertial" or untorqued. When the GRR interrupt is received, the computer reads time and sets time base zero, T_0 . The accelerometers and gimbal angles are sampled

and stored as initial values for the accelerometer sampling routine and the minor loop. The accelerometer readings and time are telemetered, and the initialization routine is entered. Finally, a code is telemetered which indicates that the LVDC has entered the flight program. Entry to the flight program is made from the GRR processing via the interrupt processing routine.

In the period between GRR and liftoff, the LVDC initializes all flight variables, performs navigation calculations, and processes the minor loops. This period is equivalent to a low thrust burn. At $T = -6$ seconds, the engines are ignited. At $T = 0$, liftoff occurs, and the time base for first-stage steering and discrete outputs is begun (T_1). Indication of liftoff is given to the LVDC by a discrete input for which the LVDC checks every 10 ms after GRR. The test is initiated by a switch selector counter interrupt and when it is received, the testing is discontinued.

From GRR to liftoff, the LVDC also processes a liftoff backup routine. This is designed to detect liftoff if it occurs. Figure 3.2 shows this routine.

Table 3-1 lists both the initial values which are precomputed and those which are calculated after GRR. The launch site dependent quantities are precomputed and loaded as fixed constants. The quantities time (EST), azimuth (A), inclination (i), and difference in the longitude of the descending node and the launch point (λ) are identified with targeting data, and will change if mission requirements are altered.

RCA-110A

T = -20 mins.		T = -153 secs.	T = -13	T = -8
---------------	--	----------------	---------	--------

Issue Prepare-to-Launch Mode Command	Execute Azimuth Laying Program	Start Launch Sequencer (Input)	Guidance Reference Release Alert (Input)	Guidance Reference Release (Input)
--------------------------------------	--------------------------------	--------------------------------	--	------------------------------------

LVDC

T = -20 mins.		T = -153 secs.	T = -13	T = -8		T = 0
---------------	--	----------------	---------	--------	--	-------

Guidance Computer Enters Prepare-to-Launch Mode			Guidance Reference Release Alert (Input)	Guidance Reference Release (Input)		Liftoff Discrete
---	--	--	--	------------------------------------	--	------------------

Launch Sequencer

		T = -153 secs.	T = -13	T = -8	T = -6	T = 0
--	--	----------------	---------	--------	--------	-------

	Start Launch Sequencer	Guidance Reference Release Alert (Output)	Guidance Reference Release (Output)	Engine Ignition	Liftoff
--	------------------------	---	-------------------------------------	-----------------	---------

Figure 3-1 Sequence of Events

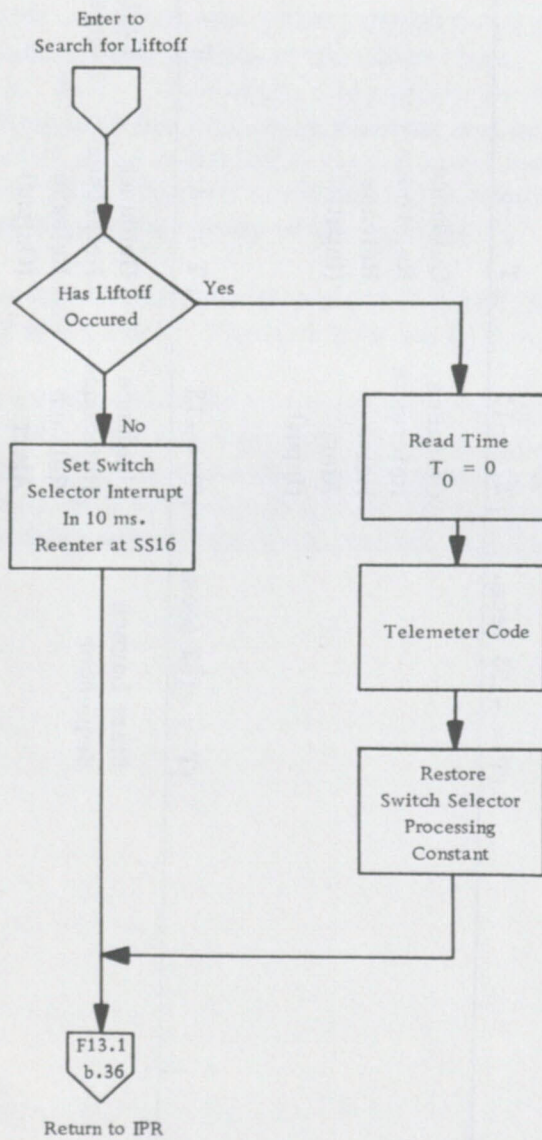


Figure 3.2 Liftoff Search

TABLE 3-1

INITIALIZATION EQUATIONS

1. Definitions

1.1 \emptyset is geodetic latitude1.2 \emptyset' is geocentric latitude. It may be calculated from

$$\emptyset' = \tan^{-1} \left[\frac{b^2}{a^2} \cdot \tan \emptyset \right] \quad \text{where}$$

b is the earth's polar radius and

a is earth's equatorial radius

1.3 A is firing azimuth measured positively eastward from north

1.4 i is inclination of target orbit plane

1.5 $\emptyset_N = \emptyset_D - \emptyset_L$ is the difference in longitude of the launch meridian (\emptyset_L) and the descending node (\emptyset_D) of the target orbit. It is positive measured eastward from the launch site.1.6 R_0 is the length of the geocentric radius vector to center of the I U

1.7 r is the distance from center of the Instrument Unit to the geodetic radius which is displaced in the launch meridian plane to pass through the center of the earth. r may be calculated from the relation.

$$r = R_0 \sin (\emptyset - \emptyset')$$

1.8 FIN1AZ is azimuth of fin 1.

1.9 Ω_e is angular velocity of the earth

TABLE 3-1 (Continued)

INITIALIZATION EQUATIONS

1.10 G matrix transforms from ()_S to ()₄ coordinate system

$$G = \begin{bmatrix} G_1 & G_2 & G_3 \\ G_4 & G_5 & G_6 \\ G_7 & G_8 & G_9 \end{bmatrix}$$

1.11 EST is Eastern Standard Time measured from midnight of the launch day.

2. Precomputed values:

2.1 r (See definition)

2.2 R_0 (See definition)

2.3 $(R_0 \Omega_E \cos \theta')$ (See definition)

2.4 $Y_S = R_0 \cos (\theta - \theta')$

2.5 $\dot{Y}_S = 0$

2.6 $S\theta = \sin \theta$ (See definition of θ)

2.7 $C\theta = \cos \theta$

2.8 A

2.9 i

2.10 θ_N

2.11 EST

TABLE 3.1 (Continued)

INITIALIZATION EQUATIONS

3. Initialization computed in LVDC

3.1 G matrix

The G matrix computation is shown in Table 7.1. The recomputation for out-of-orbit is shown in Table 7.4.

3.2 Initial position

$$3.2.1 \quad X_S = -r \cos A$$

$$3.2.2. \quad Y_S = R_0 \cos (\theta - \theta')$$

$$3.2.3 \quad Z_S = r \sin A$$

3.3 Initial velocity

$$3.3.1 \quad \dot{X}_S = R_0 \Omega_E \cos \theta' \sin A$$

$$3.3.2 \quad \dot{Y}_S = 0$$

$$3.3.3 \quad \dot{Z}_S = (R_0 \Omega_E \cos \theta') \cos A$$

3.4 Initial gravitational values

Computed by using the gravitational subroutine for boost. See Section 3.2.

3.5 Initial roll command

$$ROL\ OLD = A - FIN1AZ$$

4. ACCELEROMETER PROCESSING

The accelerometer processing word flow diagram is found in Figure 2.3. This part of the program has two main objectives: to accumulate velocity as measured by the platform, and to detect velocity measurement errors through the "reasonableness" tests. The velocity construction computations are indicated in Blocks 3, 5, 7, and 8, while the reasonableness test is shown in Blocks 2, 4, and 6. Blocks 10 to 16 establish constants to be used in the reasonableness tests. The quantity F/M is computed from platform velocities except during those portions of the flight when such computation may be unusually noisy. During those portions, F/M is computed from appropriate stored constants. A smoothed value of M/F is computed in this section for use in IGM when needed.

4.1 FORMATION OF THE VELOCITY WORD

The accelerometer optisyn readings are accumulated in delay lines in the LVDA in increments of 0.05 m/sec. The LVDC will perform a PIO operation during one program-selected minor loop per computation cycle in order to obtain the platform velocity word. The LVDA receives the redundant optisyn readings separately. The velocity word received by the LVDC contains both optisyn pulse counts, and has the following bit configuration: AAAAAAAAAAASSBBBBBBBBBBBBBB, where A stands for the A optisyn value, B for the B optisyn reading, and S is a spare bit. The LVDC program must separate this word into A and B words, scale the A word, compute the difference between the current A word and the past A word, and assign the proper sign to the difference. This process need not be repeated for the B word unless the A word fails the "reasonableness" test described in the following paragraph. If the velocity increment is found to be reasonable, this increment is added to the past value of the platform velocity word to form the updated value of that quantity. This process must be carried out for all three platform axes, X, Y, and Z.

4.2 REASONABLENESS TESTS

The "reasonableness" test is designed to detect gross errors in the formation of the velocity word. These errors could occur at any point in the system between the actual accelerometers and the LVDC. The reasonableness test will not correct the cause of the error, but will prevent such gross errors from causing correspondingly large errors in guidance and navigation quantities. The reasonableness test also serves as a program switch which selects the second (B) velocity channel in the event of a failure of the first (A).

The reasonableness test depends upon the calculation of an expected platform velocity change. This expected change (E_C) is obtained by an approximate resolution of F/M through the measured gimbal angles. The particular value of F/M used is normally that which was computed during the last computation cycle from the differentiation of platform velocity components. However, during periods of the flight in which the F/M computations may be unusually noisy, preset constants are used in place of computed values of F/M to obtain expected changes. Once the expected changes have been computed, the reasonableness test can be made. A platform velocity change is judged reasonable if it falls within a band of $\pm 50\%$ of the expected change, enlarged by a reasonableness test constant (R_{TC}). That is, ΔV is reasonable if:

for $E_C \geq 0$,

$$0.5E_C - R_{TC} \leq \Delta V \leq 1.5E_C + R_{TC}$$

or for $E_C < 0$,

$$1.5E_C - R_{TC} \leq \Delta V \leq 0.5E_C + R_{TC}$$

Figure 4.1 shows this test. R_{TC} is normally 1.0, its large value is 30.

The R_{TC} serves two purposes: its normal value provides leeway in the test when E_C is near zero, and its large value provides a large safety margin during portions of the flight in which F/M computations may be questionable. Should both A and B readings fail the reasonableness test, an appropriate velocity change is computed from current gimbal angles, time, and prestored values of thrust, mass, and mass flow rate.

In Blocks 10, 11, and 12 of Figure 2.3, R_{TC} is selected and F/M is computed or set constant in various flight modes. Specifically, F/M is computed at all times during boost except from S-IC IEEO to 3 seconds past S-II ignition, and from S-II cutoff until 3 seconds past S-IVB ignition. The value of F/M is assumed zero in non-powered flight, and computation of it begins again 3 seconds after S-IVB reignition. Whenever F/M is computed, R_{TC} is set to the normal value, and whenever F/M is set, R_{TC} is set to its large value.

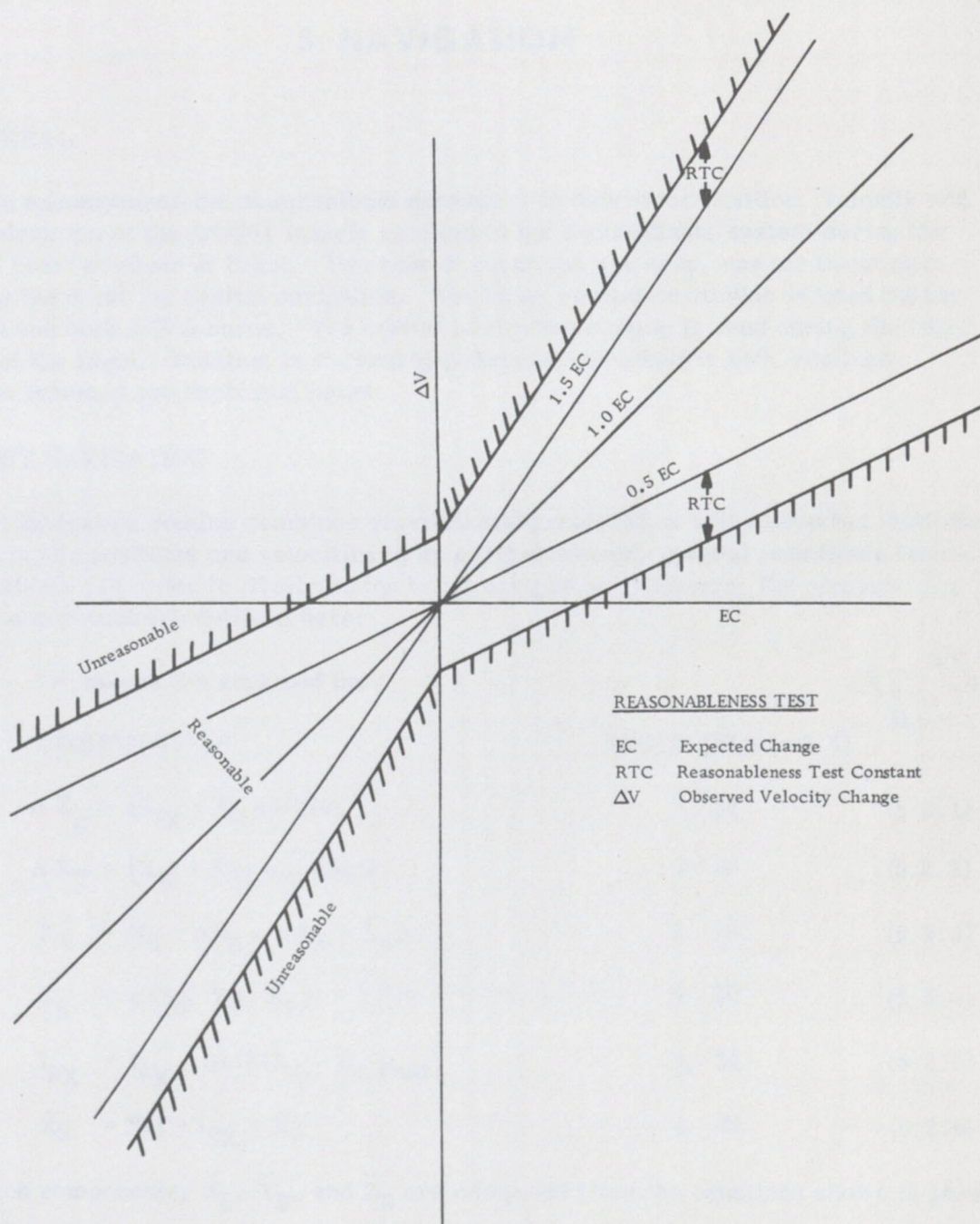


Figure 4.1

5. NAVIGATION

5.1 GENERAL

Navigation encompasses the computations necessary to determine position, velocity and total acceleration of the AS-501 vehicle relative to the S-coordinate system during the boost and coast portions of flight. Two sets of equations are used, one for boost navigation and the other for orbital navigation. The boost navigation routine is used during S-IC burn and both S-IVB burns. The orbital navigation routine is used during the other portions of the flight. Position is carried to precision and a half in both routines. These two schemes are explained below.

5.2 BOOST NAVIGATION

The boost navigation routine combines gravitational acceleration with measured platform data to compute positions and velocities in an earth-centered, inertial coordinate frame (the S-system). In order to illustrate the boost navigation procedure, the computations for the X component are outlined here:

"=" means "is replaced by"

COMPUTATION

BLOCK (Figure 2.4)

$$\Delta X_g = [I_{gX} + \ddot{X}_g \Delta t / 2] \Delta t \quad 1 \quad 27 \quad (5.2.1)$$

$$\Delta X_T = [\dot{X}_M + \dot{X}_M \text{ Past}] \Delta t / 2 \quad 2 \quad 28 \quad (5.2.2)$$

$$X_S = X_S + \Delta X_g + \Delta X_T + \dot{X}_O \Delta t \quad 3 \quad 29 \quad (5.2.3)$$

$$\ddot{X}_g = g(X_S, Y_S, Z_S) \quad (\text{See Section 5.4.1}) \quad 4 \quad 30 \quad (5.2.4)$$

$$I_{gX} = I_{gX} + \Delta t / 2 (\ddot{X}_g + \ddot{X}_g \text{ Past}) \quad 5 \quad 31 \quad (5.2.5)$$

$$\dot{X}_S = \dot{X}_M + I_{gX} + \dot{X}_O \quad 6 \quad 32 \quad (5.2.6)$$

Gravitation components, \ddot{X}_g , \ddot{Y}_g , and \ddot{Z}_g are computed from the equations shown in paragraph 5.3.1.

5.3 ORBITAL NAVIGATION

5.3.1 Introduction

The orbital navigation computations are carried out in an indirect fashion, making use of mathematical models of the earth, its atmosphere, and the vehicle to approximate the effects of the physical world on the vehicle. Certain simplifying assumptions are made with regard to the drag model and the rotation of the earth's atmosphere (See Section 5.4).

The accelerations are calculated using the following equations:

$$\begin{aligned}\ddot{X}_S &= \ddot{X}_g + \ddot{X}_D + \ddot{X}_V \\ \ddot{Y}_S &= \ddot{Y}_g + \ddot{Y}_D + \ddot{Y}_V \\ \ddot{Z}_S &= \ddot{Z}_g + \ddot{Z}_D + \ddot{Z}_V\end{aligned}\tag{5.3.1}$$

where \ddot{X}_S is the total acceleration in the space-fixed X-direction, caused by gravitation, \ddot{X}_g , atmospheric drag component, \ddot{X}_D , and venting force component, \ddot{X}_V . These equations are integrated numerically to obtain position and velocity of the vehicle at any time. The models for drag and venting are discussed in Section 5.4.

5.2.2 Numerical Integration Scheme

The integration method selected is a modified Scarborough routine, a third-order scheme which is similar to Runge-Kutta formulae. The method is self-starting, which facilitates the inclusion of venting accelerations. The actual integration is carried out in two basic steps. First, values of position and velocity at the midpoint of the next 8-second integration interval are predicted. Total acceleration of the vehicle due to gravitation, drag, and venting can now be computed based on these midpoint positions and velocity values. Next, an extrapolation is made to the end of the integration interval to predict position and velocity. The total acceleration is then computed using these values. Finally, the end-point position, velocity, and acceleration are calculated by modifying (correcting) the predicted end-point values. Values for position and velocity valid during the 8-second period between integrations are interpolated assuming a constant velocity over the interval. The equations used to carry out the integration are given below:

$$\begin{aligned}X(t+4) &= X(t) + 4\dot{X}(t) + 8\ddot{X}(t) \\ \dot{X}(t+4) &= \dot{X}(t) + 4\ddot{X}(t) \\ \ddot{X}_1(t+4) &= f[t+4, X(t+4), \dot{X}(t+4)]\end{aligned}\tag{5.3.2}$$

where f is the function of equation 5.3.1.

$$\begin{aligned} X_p(t+8) &= X(t) + 8\dot{X}(t) + 32\ddot{X}_1(t+4) \\ X_p(t+8) &= \dot{X}(t+4) + 8\ddot{X}_1(t+4) \end{aligned} \quad (5.3.3)$$

$$\ddot{X}_p(t+8) = f[t+8, X_p(t+8), \dot{X}_p(t+8)]$$

$$\begin{aligned} X(t+8) &= X(t) + 8\dot{X}(t) + \frac{32}{3} [\ddot{X}(t) + 2\ddot{X}_1(t+4)] \\ \dot{X}(t+8) &= \dot{X}(t) + \frac{4}{3} [X(t) + 4\ddot{X}_1(t+4) + \ddot{X}_p(t+8)] \\ \ddot{X}(t+8) &= f[t+8, X(t+8), \dot{X}(t+8)] \end{aligned} \quad (5.3.4)$$

The equations used for integration of the Y and Z components are identical to those given above for the X component.

Truncation (method) error in position is on the order of 2 meters after 5 orbits. Cf. LVDC Equation Defining Documents AS-203, Section 5 and AS-204, Appendix D.

5.4 MATHEMATICAL MODELS

5.4.1 Gravitation Model

The equations characterizing the gravitation model are shown in Figure 19.3, the gravitation subroutine. The equations are also given below:

$$W = -X_S \cos \theta \cos A - Y_S \sin \theta + Z_S \cos \theta \sin A$$

$$S = -\frac{GM}{R^3} \left\{ 1 + J \left(\frac{a_e}{R} \right)^2 \left[1 - 5 \left(\frac{W}{R} \right)^2 \right] + S_{34} \right\}, \quad (5.4.1)$$

where

$$S_{34} = H \left(\frac{a_e}{R} \right)^3 \left(\frac{W}{R} \right) \left[3 - 7 \left(\frac{W}{R} \right)^2 \right] + \frac{D}{7} \left(\frac{a_e}{R} \right)^4 \left[3 - 42 \left(\frac{W}{R} \right)^2 + 63 \left(\frac{W}{R} \right)^4 \right]$$

and

$$P = \frac{GM}{R^2} \left\{ \left(\frac{a_e}{R} \right)^2 2J \frac{W}{R} + P_{34} \right\} \quad (5.4.2)$$

where

$$P_{34} = \frac{H}{5} \left(\frac{a_e}{R} \right) \left[15 \left(\frac{W}{R} \right)^2 - 3 \right] + \frac{D}{7} \left(\frac{a_e}{R} \right)^2 \left(\frac{W}{R} \right) \left[12 - 28 \left(\frac{W}{R} \right)^2 \right].$$

Using these quantities, acceleration is computed as follows:

$$\ddot{X}_g = X \cdot S - P \cos \emptyset \cos A$$

$$\ddot{Y}_g = Y \cdot S - P \sin \emptyset$$

$$\ddot{Z}_g = Z \cdot S + P \cos \emptyset \sin A$$

where

\emptyset = geodetic latitude of launch site,

A = firing azimuth,

$$GM = 0.3986032 \times 10^6 \text{ Km}^3/\text{sec}^2, *$$

$$a_e = 0.6378165 \times 10^7 \text{ meters}, *$$

$$J = 0.162345 \times 10^{-2}, *$$

The evaluation of gravitation, using these equations, is a three-step process. The first step computes the W component of the vehicle position in the UVW coordinate system. In the second step, the gravitational acceleration is computed from a zonal harmonic expansion of the earth potential. The third step transforms the gravitational components back into the navigation coordinate system.

The gravitation model used in current studies (and recommended for use in the LVDC) evaluates only the round earth and first oblateness terms during boost. This is accomplished by setting the terms P_{34} and S_{34} in equations (5.4.2) to zero during boost. The accuracy of the navigation routine is not seriously degraded by neglecting all but the first two terms in the potential expansion. In orbit, however, where periods of several hours are involved, two additional terms of the expansion must be considered. This is done by computing the quantities, S_{34} and P_{34} , shown in equations (5.4.1) and (5.4.2).

5.4.2 Atmospheric Drag Model

The onboard drag model assumes the form

$$D = -1/2 \rho C_D \frac{A}{M} V_R^2 \quad (5.4.4)$$

*From JPL Technical Report No. 32-604, adopted by the NASA Standard Constants Committee.

which is the total drag acceleration for a convex body of mass M with average presentation area A , traveling through a medium of density ρ , with relative speed V_R . For the onboard scheme, the following constants were prescribed:

$$C_D = 2.18$$

$$A = 40 \text{ m}^2$$

$$M = 123,207 \text{ Kg after first S-IVB burn, } = 56,731 \text{ Kg after second.}$$

The density is obtained through the use of a polynomial approximation to the PRA 63 Earth Atmosphere Model. This is,

That is,

$$\rho = \bar{a}_0 + \bar{a}_1 h + \bar{a}_2 h^2 + \bar{a}_3 h^3 + \bar{a}_4 h^4 + \bar{a}_5 h^5, \quad (5.4.5)$$

where h is the altitude of the vehicle over an oblate earth. The quantity h is computed according to

$$h = R \left[1 - \frac{a_e}{\left(U^2 + V^2 + \left(\frac{W a_e}{b} \right)^2 \right)^{1/2}} \right] \quad (5.4.6)$$

where the constants in equations 5.4.4 and 5.4.5 are initialized in the Appendix E.
ables, Section 19. Thus, the components of the drag accelerations become:

$$\begin{aligned} \ddot{X}_D &= -1/2 \rho \quad C_D (A/M) V_R \cdot \dot{X}_R \\ \ddot{Y}_D &= -1/2 \rho \quad C_D (A/M) V_R \cdot \dot{Y}_R \\ \ddot{Z}_D &= -1/2 \rho \quad C_D (A/M) V_R \cdot \dot{Z}_R \end{aligned} \quad (5.4.7)$$

where $\bar{V}_R = (\dot{X}_R, \dot{Y}_R, \dot{Z}_R)$ is the velocity of the vehicle relative to the atmosphere which is assumed rotating at velocity $\bar{\omega}_e$, the earth's rate of rotation.

5.4.3 Venting Effects

In the AS-501 mission, numerous programmable vents are anticipated. In particular, Table 5.1 contains a list of typical worst case venting thrust magnitudes (in newtons) relative to the body fixed X Y Z - coordinate system, and the on-off times for these vents.

In the flight program, the platform gimbal angles will be sampled every four seconds for use in resolving the vent accelerations from the body-fixed system into the space

TABLE 5.1

TYPICAL WORST-CASE VENTING THRUST MAGNITUDES

VENT	TIME ON (SECONDS)	TIME OFF (SECONDS)	FORCE (NEWTONS)
Fuel Tank Relief Valve	93	96	2050
	146	149	2050
	206	203	2050
	254	257	2050
	308	311	2050
	360	363	2050
Fuel Tank Continuous Vent	0.0	3600	49.2
	3601	14,400	123.0
LOX Tank Relief Valve	2100	2103	615
	4320	4323	615
	8300	8303	615

fixed X_S Y_S Z_S system. Thus, if $B(t)$ is the time varying matrix which transforms body coordinates into the space fixed coordinates X_S , Y_S , Z_S , then the instantaneous vent accelerations in the space-fixed system are computed according to:

$$\begin{pmatrix} \ddot{X}_V \\ \ddot{Y}_V \\ \ddot{Z}_V \end{pmatrix} = B(t) \begin{pmatrix} V_{ZB/M} \\ V_{YB/M} \\ V_{XB/M} \end{pmatrix} \quad (5.4.8)$$

and the instantaneous venting accelerations are then added to accelerations due to gravitation and drag to complete the mathematical model.

It would be a suitable alternative to return to boost navigation during the venting periods. The flight program initialization will be written so that this alternative could be easily adopted.

6. GUIDANCE PRIOR TO IGM

Guidance prior to IGM deals with the method of generating commands (χ angles) during the time from guidance reference release (GRR) to initiation of IGM. The guidance flow diagram for this time period is depicted in Figure 2.5. The basic scheme is a time-tilt profile. If an S-IC engine fails from 6 seconds into the S-IC stage, parameters are modified to insure corrections of burn time, mass flow, etc.

For this flight, a -18° roll offset is present at liftoff. This is because fin 1 has an azimuth of 90° at liftoff whereas the desired position for fin 1 is in the direction of the firing azimuth (72°). After liftoff, the vehicle is maintained vertical and the roll attitude is held constant (-18°) until the tower is cleared. At an altitude of 137 meters, roll is commanded to zero. In the event of an accelerometer failure, a time backup is provided. After this command, χ_X and χ_Y remain zero and χ_Z is computed by the Reduced Load Chi Freeze Guidance method. A fourth-order time polynomial, obtained from a least-square curve fit of the nominal baseline chi versus time, is used to determine the commanded steering angle (rate limiting of the χ 's prevents the commanded χ_Y and χ_Z change from exceeding one degree per second; this keeps the rate change within safe bounds). The curve fit is a fourth-degree polynomial of the form

$$\chi_Z = A_1 + B_1 T_R + C_1 T_R^2 + D_1 T_R^3 + E_1 T_R^4 - 90^\circ$$

$$T_R = T_C - \Delta T_{\text{FAIL}} + 4.0$$

where the coefficients A_1 , B_1 , C_1 , D_1 and E_1 are defined in Table 7.1; χ_Z is expressed in degrees for the table values of the coefficients. T_R includes a 4.0 second bias.

The failure of an engine is compensated for by freezing the steering angle for a specific time. The specific time varies with the time of engine failure. For the AS-501 mission the freeze period, ΔT_{FAIL} , is calculated as follows (T_C = clock time measured from liftoff):

$$0 < T_{\text{FAIL}} < t_2$$

$$t_2 \leq T_{\text{FAIL}} < t_4$$

$$t_4 \leq T_{\text{FAIL}} < t_5$$

$$t_5 \leq T_{\text{FAIL}}$$

$$\Delta T_{\text{FAIL}} = t_3$$

$$\Delta T_{\text{FAIL}} = B_{11} T_{\text{FAIL}} + B_{12}$$

$$\Delta T_{\text{FAIL}} = B_{21} T_{\text{FAIL}} + B_{22}$$

$$\Delta T_{\text{FAIL}} = 0$$

where B_{ij} coefficients are mission dependent constants, cf Table 7.1. When the freeze period is completed, the original x_Z versus time profile is resumed with a time bias equal to ΔT_{FAIL} .

Tilt arrest occurs at CECO of the S-IC. A time backup is provided in the event that the signal is not received. The tilt arrest varies with the time of engine failure. Compensation for this is made in the equation used to calculate T_{ar} . After tilt arrest x_Y and x_X remain zero and x_Z remains frozen until the initiation of IGM.

TABLE 7.1

$$A_1 = 8.6690087 \times 10^1 \text{ deg}$$

$$B_1 = 5.2805826 \times 10^{-1} \text{ deg/sec}$$

$$C_1 = -2.5657166 \times 10^{-2} \text{ deg/sec}^2$$

$$D_1 = 2.0822663 \times 10^{-4} \text{ deg/sec}^3$$

$$E_1 = -5.3473700 \times 10^{-6} \text{ deg/sec}^4$$

$$B_{11} = -0.62$$

$$B_{12} = 40.90$$

$$B_{21} = -0.36111$$

$$B_{22} = 29.25$$

$$t_1 = 12$$

$$t_2 = 20$$

$$t_3 = 36$$

$$t_4 = 45$$

$$t_5 = 81$$

$$t_6 = 0$$

7. ITERATIVE GUIDANCE MODE (IGM)

7.1 GENERAL

IGM is an optimum guidance scheme based on the flat earth optimum steering function derived using the calculus of variations. This thrust vector steering function ($x = a + bt$), although only an approximate result for a flat earth, is implemented in an iterative manner in both pitch and yaw planes of motion. Thus, the S-IVB is guided to meet desired end conditions in near optimal fashion. Simulation studies have indicated that burn time and end conditions attained by IGM compare favorably with those attained by solving exactly the two-point boundary value problem using a Pontryagin minimum fuel trajectory program.

A detailed description of the method used to implement the flat earth steering scheme can be found in the Aero-Astroynamics Laboratory Document MTP-AERO-63-49 and in "Guidance Equations for Saturn V, AS-501", R-AERO-DAG-39-65, August 15, 1965. These two documents have served as the fundamental references for all of the IGM studies for the AS-501 mission.

IGM will be implemented in two phases for this flight. The first phase will guide the vehicle in pitch and yaw for the powered portion of flight from a fixed time after S-IC outboard engine cutoff to the first cutoff of the S-IVB stage at injection into parking orbit. The second phase will guide the S-IVB stage from parking orbit into waiting orbit. The first phase, boost to parking orbit, is discussed in section 7.2 below. The second phase, out of parking orbit, is discussed in sections 7.3 and 7.4 below. Although there are two phases for IGM, most of the equations and logic of IGM will be the same.

7.2 BOOST TO PARKING ORBIT

31
307
→ 358
Approximately 31 seconds after S-II ignition, IGM is started. At 307 ± 30 seconds after S-II ignition there is a propellant mixture ratio change from 5.5 to 4.7. At 358 seconds after S-II ignition, S-II thrust terminates and separation occurs. After separation there is a coast period of 2 seconds. The S-IVB is then ignited and burns for approximately 165 seconds. IGM will inject the S-IVB stage into a 185.2 km (100 nautical miles) circular earth parking orbit.

The basic IGM equations are listed in Table 7.1. The general functional relationships of IGM are shown in the word flow chart, Figure 7.1. Greater detail for blocks 1 and 2 of Figure 7.1 is given in Figure 7.2, Burn Mode Initialization Logic. The guidance time update process is shown in Figure 7.3. Figure 7.4 details a block of Figure 7.1.

TABLE 7.1

A. The calculation and format of the G matrix follows:

$$[G] = \begin{bmatrix} G_1 & G_2 & G_3 \\ G_4 & G_5 & G_6 \\ G_7 & G_8 & G_9 \end{bmatrix}$$

$$G_1 = \cos i \cdot \cos \theta_N \cdot \sin A_Z + \cos i \cdot \sin \theta_N \cdot \cos A_Z \cdot \sin \phi_L \\ - \sin i \cdot \cos A_Z \cdot \cos \phi_L$$

$$G_2 = -\cos i \cdot \sin \theta_N \cdot \cos \phi_L - \sin i \cdot \sin \phi_L$$

$$G_3 = \cos i \cdot \cos \theta_N \cdot \cos A_Z - \cos i \cdot \sin \theta_N \cdot \sin A_Z \cdot \sin \phi_L \\ + \sin i \cdot \sin A_Z \cdot \cos \phi_L$$

$$G_4 = \sin \theta_N \cdot \sin A_Z - \cos \theta_N \cdot \cos A_Z \cdot \sin \phi_L$$

$$G_5 = \cos \theta_N \cdot \cos \phi_L$$

$$G_6 = \sin \theta_N \cdot \cos A_Z + \cos \theta_N \cdot \sin A_Z \cdot \sin \phi_L$$

$$G_7 = -\sin i \cdot \cos \theta_N \cdot \sin A_Z - \sin i \cdot \sin \theta_N \cdot \cos A_Z \cdot \sin \phi_L \\ - \cos i \cdot \cos A_Z \cdot \cos \phi_L$$

$$G_8 = \sin i \cdot \sin \theta_N \cdot \cos \phi_L - \cos i \cdot \sin \phi_L$$

$$G_9 = -\sin i \cdot \cos \theta_N \cdot \cos A_Z + \sin i \cdot \sin \theta_N \cdot \sin A_Z \cdot \sin \phi_L \\ + \cos i \cdot \sin A_Z \cdot \cos \phi_L$$

TABLE 7.1 (Continued)

A_z	=	initial aiming azimuth
i	=	inclination of the desired parking orbit
θ_N	=	difference between launch longitude and longitude of descending node of desired parking orbit.
ϕ_L	=	latitude of launch site.

B. Rotations into X_4, Y_4, Z_4 system using G matrix:

$$\begin{bmatrix} X_4 \\ Y_4 \\ Z_4 \end{bmatrix} = [G] \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} ;$$

$$\begin{bmatrix} \dot{X}_4 \\ \dot{Y}_4 \\ \dot{Z}_4 \end{bmatrix} = [G] \begin{bmatrix} \dot{X}_S \\ \dot{Y}_S \\ \dot{Z}_S \end{bmatrix} ;$$

$$\begin{bmatrix} \ddot{X}_{g4} \\ \ddot{Y}_{g4} \\ \ddot{Z}_{g4} \end{bmatrix} = [G] \begin{bmatrix} \ddot{X}_{gS} \\ \ddot{Y}_{gS} \\ \ddot{Z}_{gS} \end{bmatrix} .$$

C. Calculation of terminal range angle ϕ_T measured in the orbit plane, from the descending node clockwise to the point of injection.

$$1. \quad L_1 = V_{EX1} \ln (\tau_1 / (\tau_1 - T_1))$$

$$2. \quad J_1 = L_1 \tau_1 - V_{EX1} T_1$$

TABLE 7.1 (Continued)

3. $S_1 = L_1 T_1 - J_1$
4. $L_2 = V_{EX2} \ln (\tau_2 / (\tau_2 - T_2))$
5. $J_2 = L_2 \tau_2 - V_{EX2} T_2$
6. $S_2 = L_2 T_2 - J_2$
7. $L_{12} = L_1 + L_2$
8. $J_{12} = J_1 + J_2 + L_2 T_1$
9. $S_{12} = S_1 - J_2 + L_{12} (T_2 + T_C)$
10. $T_{1C} = T_1 + T_2 + T_C$
11. $T'_T = T_{1C} + T'_3$
12. $L'_3 = V_{EX3} \ln (\tau_3 / (\tau_3 - T'_3))$
13. $J'_3 = L'_3 \tau_3 - V_{EX3} T'_3$
14. $L'_Y = L_{12} + L'_3$
15. $D_2 = VT'_T - J'_3 + L'_Y T'_3 - [R_{OV}/V_{EX3}] [(\tau_1 - T_1) L_1 + (\tau_2 - T_2) L_2 + (\tau_3 - T'_3) L'_3] [L'_Y + V - V_T]$
16. $\phi_T = \tan^{-1} (X_4/Y_4) + (1/\eta_T) (S_{12} + D_2) \cos \theta_T/\pi$

TABLE 7.1 (Continued)

D. Calculation of position, velocity and gravitation in the injection coordinate system.

$$\begin{bmatrix} \phi_T \end{bmatrix} = \begin{bmatrix} \cos \phi_T & -\sin \phi_T & 0 \\ \sin \phi_T & \cos \phi_T & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \phi_T \end{bmatrix} \begin{bmatrix} X_4 \\ Y_4 \\ Z_4 \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \dot{\xi} \\ \dot{\eta} \\ \dot{\zeta} \end{bmatrix} = \begin{bmatrix} \phi_T \end{bmatrix} \begin{bmatrix} \dot{X}_4 \\ \dot{Y}_4 \\ \dot{Z}_4 \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \ddot{\xi}_g \\ \ddot{\eta}_g \\ \ddot{\zeta}_g \end{bmatrix} = \begin{bmatrix} \phi_T \end{bmatrix} \begin{bmatrix} \ddot{X}_{g4} \\ \ddot{Y}_{g4} \\ \ddot{Z}_{g4} \end{bmatrix} \quad (4)$$

E. Calculation of velocities to be gained in the injection coordinate system.

$$\begin{bmatrix} \ddot{\xi}_g^* \\ \ddot{\eta}_g^* \\ \ddot{\zeta}_g^* \end{bmatrix} = 1/2 \begin{bmatrix} \ddot{\xi}_{gT} \\ \ddot{\eta}_{gT} \\ \ddot{\zeta}_{gT} \end{bmatrix} + \begin{bmatrix} \ddot{\xi}_g \\ \ddot{\eta}_g \\ \ddot{\zeta}_g \end{bmatrix} \quad (1)$$

TABLE 7.1 (Continued)

$$\dot{\Delta} \xi' = \dot{\xi}_T - \dot{\xi} - \ddot{\xi}_g^* T'_T \quad (2)$$

$$\dot{\Delta} \eta' = \dot{\eta}_T - \dot{\eta} - \ddot{\eta}_g^* T'_T \quad (3)$$

$$\dot{\Delta} \zeta' = \dot{\zeta}_T - \dot{\zeta} - \ddot{\zeta}_g^* T'_T \quad (4)$$

F. Calculation of "time-to-go" (T_3)

$$\Delta L_3 = \left[\frac{((\dot{\Delta} \xi')^2 + (\dot{\Delta} \eta')^2 + (\dot{\Delta} \zeta')^2)}{L_{Y'}} - L_{Y'} \right] / 2 \quad (1)$$

$$\Delta T_3 = \Delta L_3 \frac{(\tau_3 - T'_3)}{V_{EX3}} \quad (2)$$

$$T_3 = T'_3 + \Delta T_3 \quad (3)$$

$$T_T = T'_T + \Delta T_3 \quad (4)$$

G. Correction of velocities to be gained.

$$\dot{\Delta} \xi = \dot{\Delta} \xi' - \ddot{\xi}_g^* \Delta T_3 \quad (1)$$

$$\dot{\Delta} \eta = \dot{\Delta} \eta' - \ddot{\eta}_g^* \Delta T_3 \quad (2)$$

$$\dot{\Delta} \zeta = \dot{\Delta} \zeta' - \ddot{\zeta}_g^* \Delta T_3 \quad (3)$$

TABLE 7.1 (Continued)

H. Calculation of desired pitch and yaw steering angles based on current velocity deficiency.

$$L_3 = L'_3 + \Delta L_3 \quad (1)$$

$$L_Y = L_{12} + L_3 \quad (2)$$

$$\tilde{\chi}_Y = \sin^{-1} \frac{\dot{\Delta \zeta}}{L_Y} \quad (3)$$

$$\tilde{\chi}_P = \tan^{-1} \frac{\dot{\Delta \eta}}{\Delta \xi} \quad (4)$$

I. Calculation of parameters for rate and attitude corrections.

$$Q_1 = S_1 \tau_1 - (V_{EX1} T_1^2)/2 \quad (1)$$

$$P_1 = J_1 \tau_1 - (V_{EX1} T_1^2)/2 \quad (2)$$

$$U_1 = Q_1 \tau_1 - (V_{EX1} T_1^3)/6 \quad (3)$$

$$Q_2 = S_2 \tau_2 - (V_{EX2} T_2^2)/2 \quad (4)$$

$$P_2 = J_2 \tau_2 - (V_{EX2} T_2^2)/2 \quad (5)$$

$$U_2 = Q_2 \tau_2 - (V_{EX2} T_2^3)/6 \quad (6)$$

$$Q_{12} = Q_1 + Q_2 + S_2 T_1 + J_1 T_2 \quad (7)$$

$$P_{12} = P_1 + P_2 + T_1 (2J_2 + L_2 T_1) \quad (8)$$

TABLE 7.1 (Continued)

$$U_{12} = U_1 + U_2 + T_1 (2Q_2 + S_2 T_1) + T_2 P_1 \quad (9)$$

$$J_3 = J'_3 + \Delta L_3 T_3 \quad (10)$$

$$S_3 = L_3 T_3 - J_3 \quad (11)$$

$$Q_3 = S_3 \tau_3 - (V_{EX3} T_3^2)/2 \quad (12)$$

$$P_3 = J_3 (\tau_3 + 2T_{1C}) - (V_{EX3} T_3^2)/2 \quad (13)$$

$$U_3 = Q_3 (\tau_3 + 2T_{1C}) - (V_{EX3} T_3^3)/6 \quad (14)$$

J. Calculation of altitude correction term for yaw (K_3) and yaw rate (K_4) terms.

$$J_Y = J_{12} + J_3 + L_3 T_{1C} \quad (1)$$

$$S_Y = S_{12} - J_3 + L_Y T_3 \quad (2)$$

$$Q_Y = Q_{12} + Q_3 + S_3 T_{1C} + (T_C + T_3) J_{12} \quad (3)$$

$$K_Y = L_Y/J_Y \quad (4)$$

$$D_Y = S_Y - K_Y Q_Y \quad (5)$$

$$\Delta \zeta = \zeta + \dot{\zeta} T_T + \ddot{\zeta}_Y T_T^2/2 + S_Y \sin \tilde{\chi}_Y \quad (6)$$

$$K'_3 = \Delta \zeta / (D_Y \cos \tilde{\chi}_Y) \quad (7)$$

TABLE 7.1 (Continued)

$$K_3 = K'_3 (1 - (K'_3)^2 \cdot T_{RY})/\pi \quad (8)$$

$$K_4 = K_Y K_3 \quad (9)$$

K. Calculation of altitude correction terms for pitch (K_1) and pitch rate (K_2)

$$L_P = L_Y \cos \tilde{\chi}_Y \quad (1)$$

$$C_2 = \cos \tilde{\chi}_Y + K_3 \sin \tilde{\chi}_Y \quad (2)$$

$$C_4 = K_4 \sin \tilde{\chi}_Y \quad (3)$$

$$J_P = J_Y C_2 - C_4 (P_{12} + P_3 + T_{1C}^2 L_3) \quad (4)$$

$$S_P = S_Y C_2 - C_4 Q_Y \quad (5)$$

$$Q_P = Q_Y C_2 - C_4 [U_{12} + U_3 + T_{1C}^2 S_3 + (T_3 + T_C) P_{12}] \quad (6)$$

$$K_P = L_P/J_P \quad (7)$$

$$D_P = S_P - K_P Q_P \quad (8)$$

$$\Delta \eta = \eta - \eta_T + \dot{\eta} T_T + (\ddot{\eta}_g^* T_T^2)/2 = S_P \sin \tilde{\chi}_P \quad (9)$$

$$K'_1 = \Delta \eta / (D_P \cos \tilde{\chi}_P) \quad (10)$$

$$K_1 = K'_1 (1 - [K'_1]^2 T_{RP})/\pi \quad (11)$$

$$K_2 = K_P K_1 \quad (12)$$

TABLE 7.1 (Continued)

L. Calculation of pitch and yaw in the X_4, Y_4, Z_4 coordinate system.

$$\dot{Y} = \tilde{x}_Y - K_3 + K_4 (TOT + \Delta t) \quad (1)$$

$$x'_P = \tilde{x}_P - K_1 + K_2 (TOT + \Delta t) - \phi_T - 1/2 \quad (2)$$

M. Rotation of Unit Thrust Vector into X_S, Y_S, Z_S system.

$$\begin{bmatrix} X'_S \\ Y'_S \\ Z'_S \end{bmatrix} = [G]^{-1} \begin{bmatrix} -\sin x'_P \cdot \cos x_Y \\ \cos x'_Z \cdot \cos x_Y \\ \sin x'_Y \end{bmatrix}$$

N. Calculation of command pitch and yaw angles.

$$x_Z = \tan^{-1} \left[\frac{-X'_S}{Y_S} \right] \quad (1)$$

$$x_X = \tan^{-1} \left(\frac{Z'_S}{\sqrt{1 - Z'^2_S}} \right) \quad (2)$$

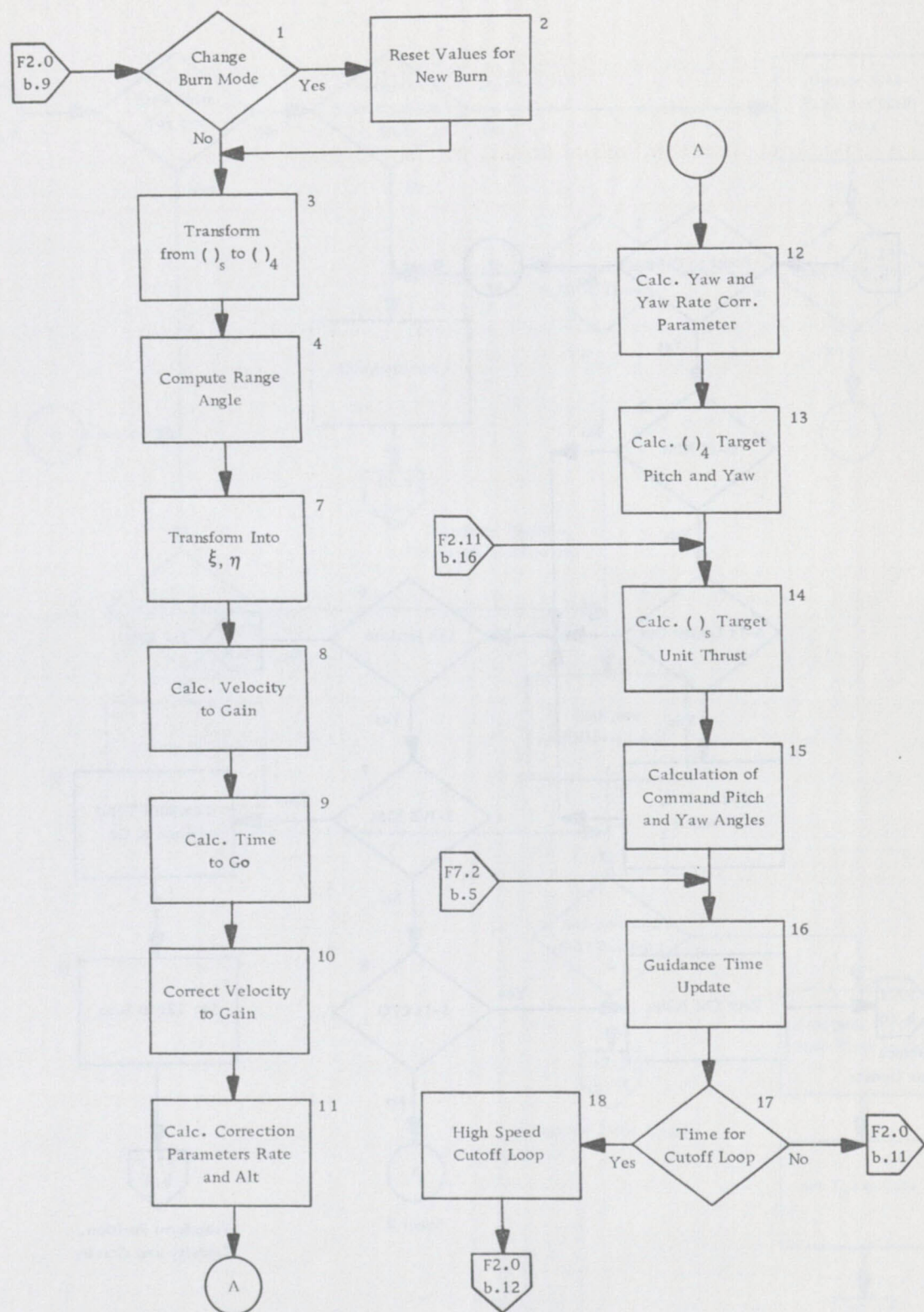


Figure 7.1 General IGM

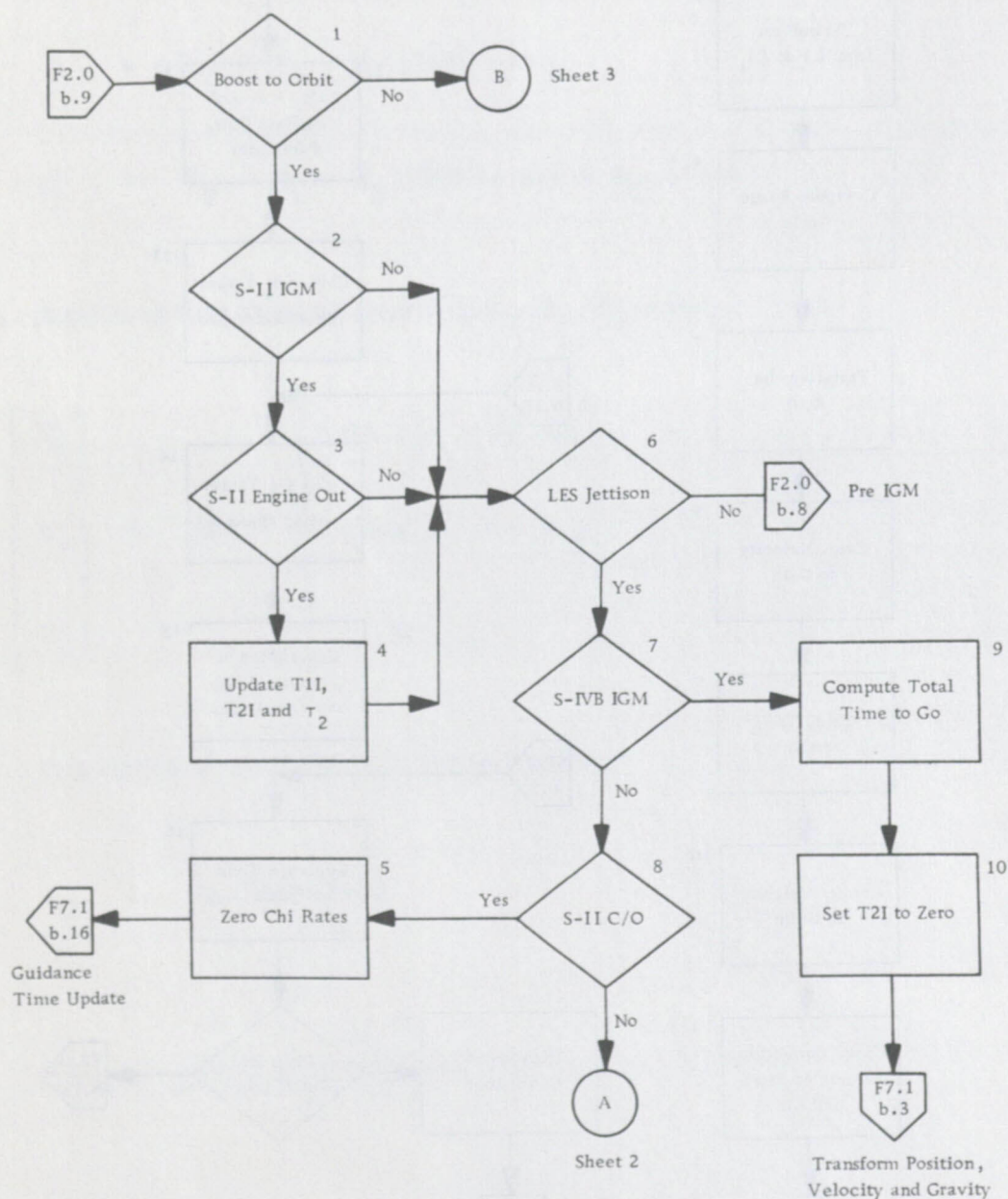


Figure 7.2 Burn Mode Initialization Logic (Sheet 1 of 3)
(This figure is blocks 1 and 2 of Figure 7.1)

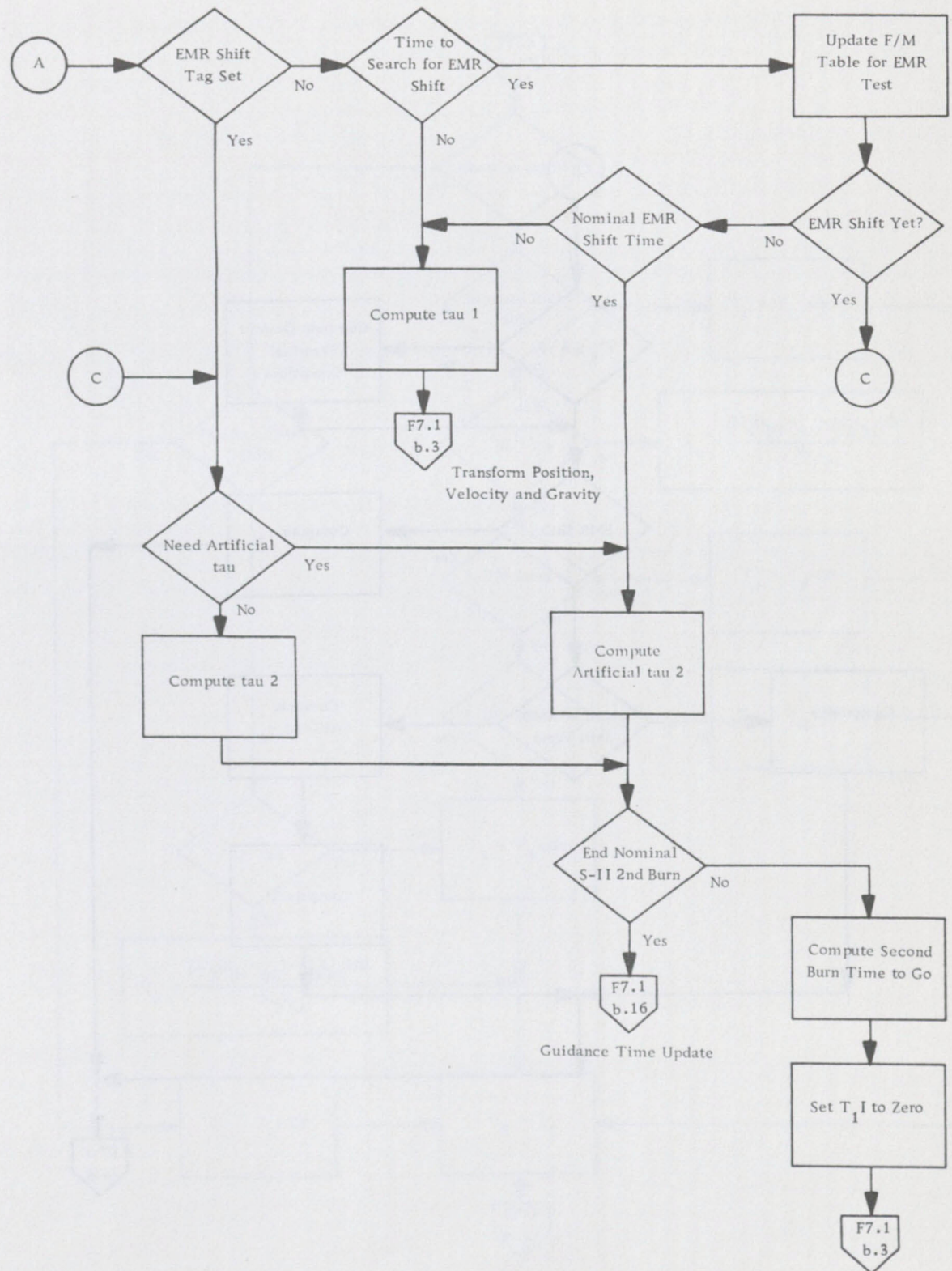


Figure 7.2 Burn Mode Initialization Logic (Sheet 2 of 3)

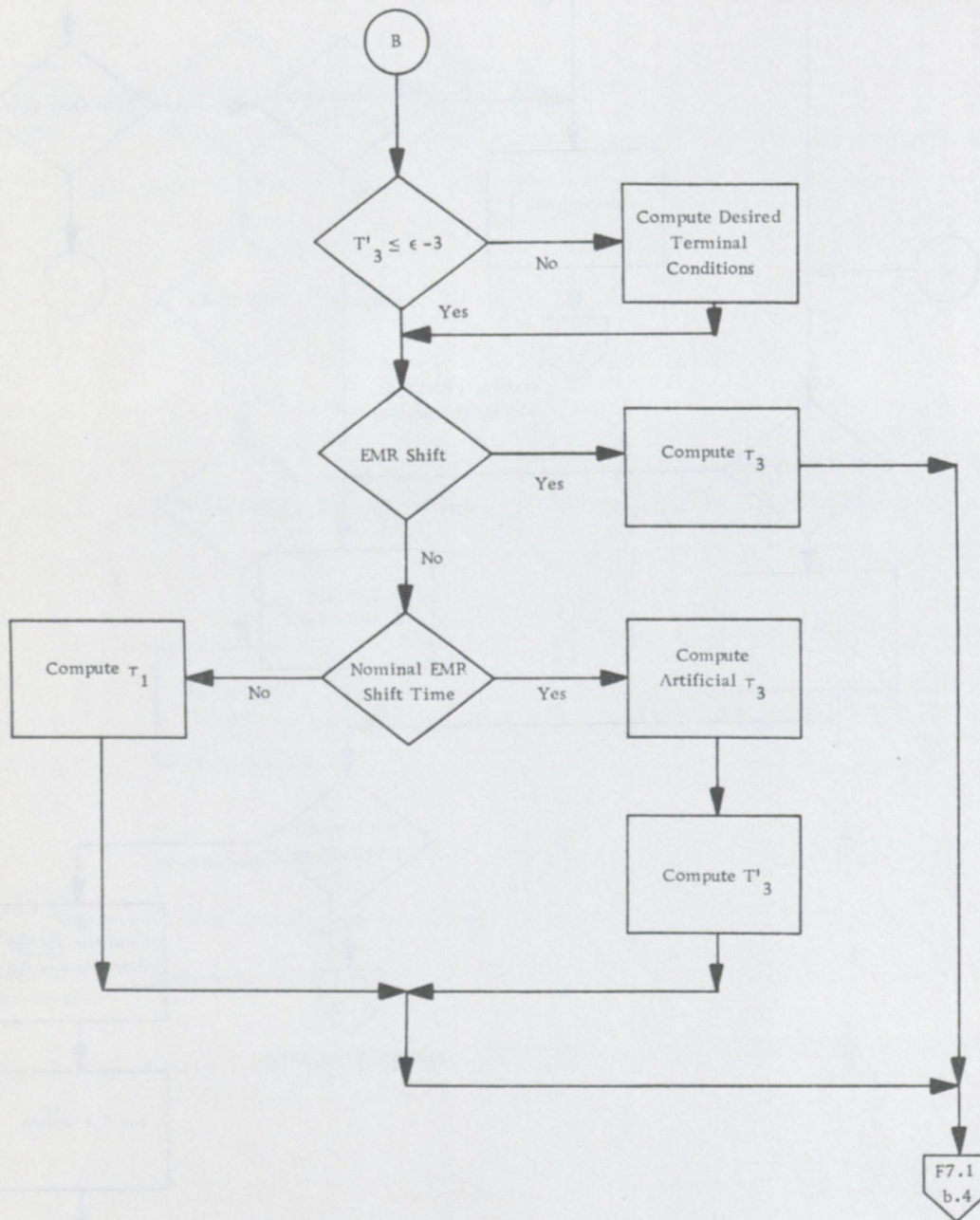


Figure 7.2 Burn Mode Initialization Logic (Sheet 3 of 3)

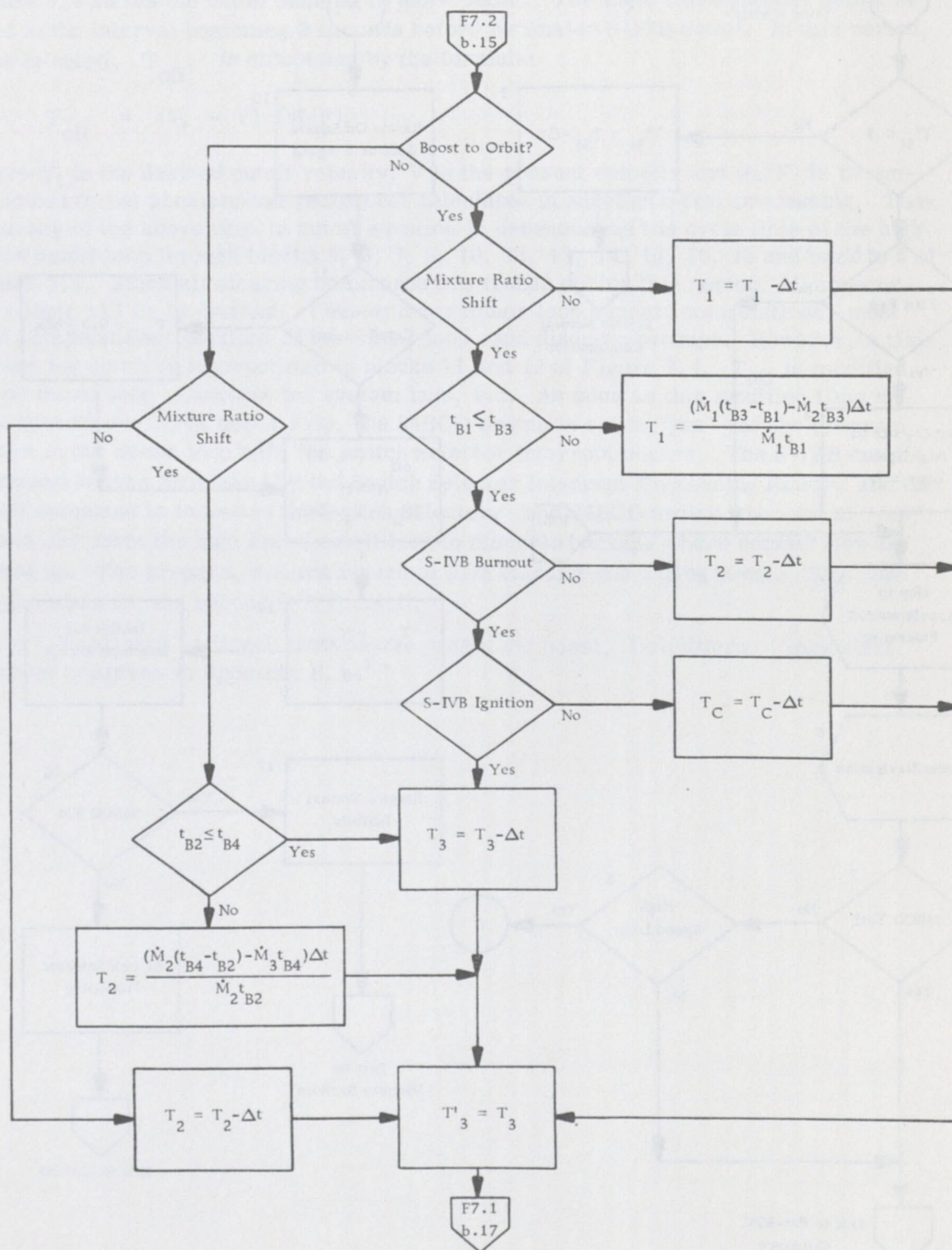


Figure 7.3 Guidance Time Update (This figure is block 16 of Figure 7.1)

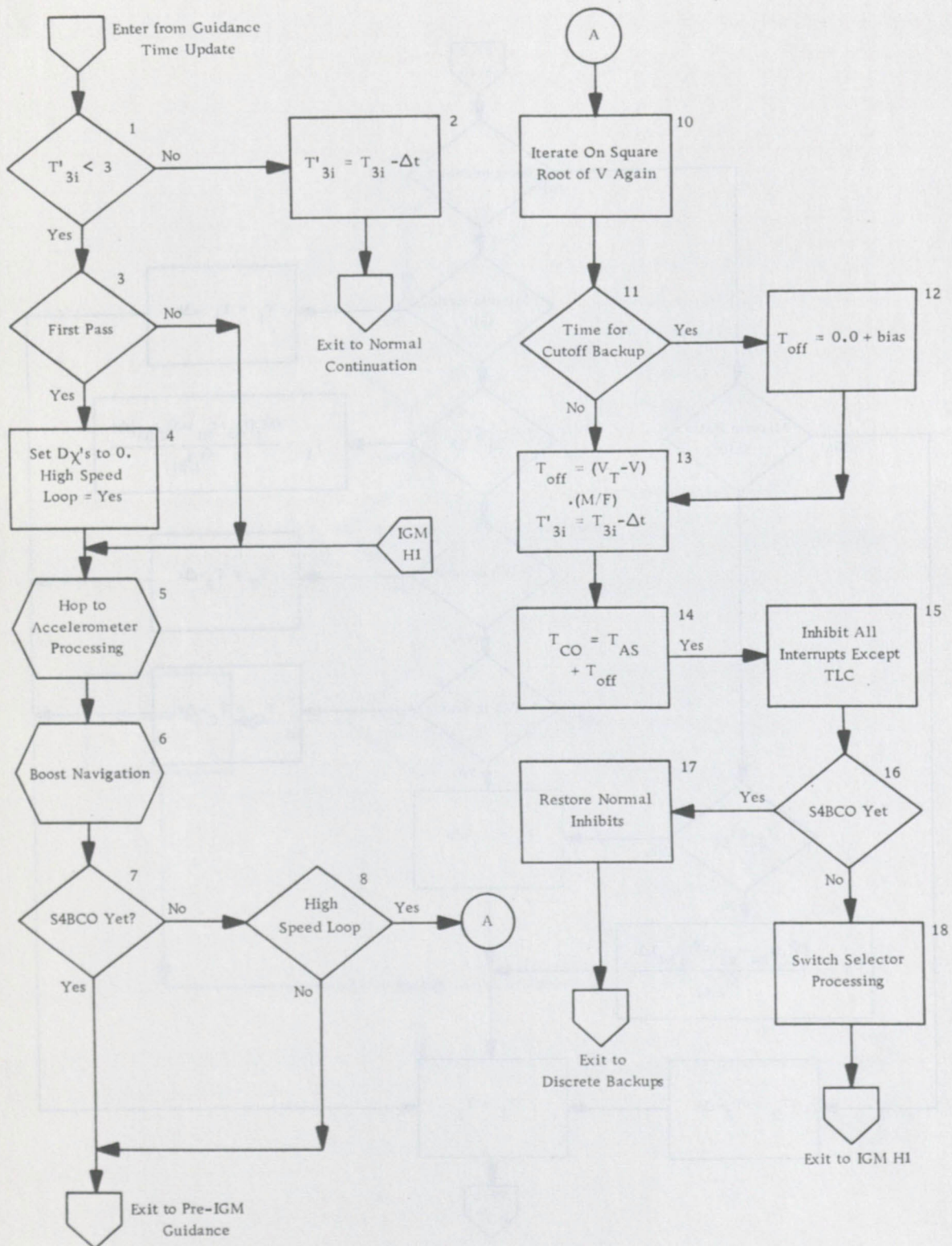


Figure 7.4 High Speed Cutoff Loop (This is block 18 of Figure 7.1)

Figure 7.4 shows the cutoff scheme in more detail. The logic and equations shown are used in the interval beginning 2 seconds before estimated S-IVB cutoff. In this period, time to cutoff, T_{off} , is calculated by the formula:

$$T_{\text{off}} = (V_t - V) (M/F),$$

where V_t is the desired cutoff velocity, V is the present velocity and (M/F) is the unsmoothed thrust acceleration reciprocal calculated in accelerometer processing. The accuracy of the above time to cutoff equation is dependent on the cycle time of the high speed cutoff loop through blocks 5, 6, 7, 8, 10, 11, 13, 14, 15, 16, 18 and back to 5 of Figure 7.4. Since all steering commands are frozen during this period, all unnecessary logic will be by-passed. This includes minor loop support computations, most IGM computations, portions of the minor loop, and discrete backups. However, a time backup for cutoff is incorporated in blocks 11 and 12 of Figure 7.4. T_{off} is modified in the minor loop to account for system lags, etc. As soon as this modified time is less than 60 ms in the minor loop, the S4BCO switch is set to "yes" and the program delays in the minor loop until the switch selector interrupt occurs. The S-IVB cutoff command is then processed by the Switch Selector Interrupt Processing Routine and the cutoff command is issued to the Switch Selector. The S4BCO switch when set to "yes" allows exit from the high speed cutoff loop to discrete backups where normal flow is picked up. The program will not return to IGM calculations during boost. This path is also taken for the second S-IVB cutoff.

Table 7.2 contains variables that may be preset for boost. Definitions of important symbols are given in Appendix E.

TABLE 7.2

IGM Boost to Parking Orbit Preset Variables (Values will be
found in Range of Variables Section)

1. \dot{M}_1	14. T_C
2. \dot{M}_2	15. T'_3
3. R_T	16. τ_2
4. V_T	17. τ_3
5. θ_T	18. Δt
6. $\sin \phi_L$	19. t_{B1}
7. $\cos \phi_L$	20. t_{B3}
8. T_{RP}	21. \dot{x}_{PL}
9. R_{OV}	22. \dot{x}_{YL}
10. T_{RY}	23. V_{EX1}
11. μ	24. V_{EX2}
12. T_1	25. V_{EX3}
13. T_2	

7.3 OUT-OF-ORBIT

The guidance equations for the second S-IVB burn, which takes the vehicle from the parking orbit to the waiting orbit, are the same as those used during boost except that the end conditions are recalculated each cycle as a function of the range angle. Injection takes place on an ellipse specified at ignition time, but the point of injection onto the ellipse varies with range angle.

Table 7.3 gives the equations which are used in the modification of the end conditions. The flow chart, Figure 7.2, shows a test to establish whether the burn in process is the out-of-orbit case. If so, the computations for end conditions are executed.

The next section describes the computation defining the injection ellipse. The constants e , p , K_5 and α appearing in the equations of Table 7.3 are established in that section.

7.4 OUT-OF-ORBIT END CONDITIONS

The vehicle will arrive at the time for the S-IVB second burn with perturbations in both position and velocity. To return to the nominal orbit would require a dog-leg maneuver, in general. Substantial payload gains can be obtained by revising the trajectory to be optimum for the actual, that is, the perturbed, conditions. To determine a true optimum trajectory requires more extensive computation than can be accommodated in the flight computer, but a serviceable approximation can be made. This approximation is used in the flight program to compute the end conditions for the S-IVB second burn. The computation must be made shortly before the initiation of the burn, when the perturbations are known. Table 7.4 shows the equations used, and Figure 2.11 shows the logic leading to the calculations and to reignition. The details of the calculation are described below.

The nominal cutoff conditions for the second burn are used to determine the geocentric ellipse which would be the flight path using the simple two-body theory. From this ellipse is generated a family of "nearby" ellipses which meet the mission constraints and are nearly optimum in the sense of the calculus of variations. Injection is then made on that member of the family meeting the actual (perturbed) flight conditions.

The computation described here is peculiar to the 501 mission; the computation for a lunar mission will differ in some significant ways. The equations for out-of-orbit given here are provisional. Since changes are expected, they will not be described in detail here. They are taken from the Mission Defining Document, change number 7. Figure 7.5 shows the geometry of the injection ellipse corresponding to the equations of Table 7.4. These equations are computed only once, just before ignition; they correspond to block 2 of Figure 7.1. The perturbed ellipse has the same eccentricity and semi-latus rectum as the nominal, but lies in a different plane.

TABLE 7.3

End Conditions as a Function of Range Angle

$$\Delta\phi = \phi_T + \alpha$$

$$\theta_T = \tan^{-1} \left[\frac{e \sin \Delta\phi}{1 + e \cos \Delta\phi} \right]$$

$$\eta_T = p / (1 + e \cos \Delta\phi)$$

$$V_T = K_5 (1 + e^2 + 2e \cos \Delta\phi)^{1/2}$$

$$\dot{\eta}_T = V_T \sin \theta_T$$

$$\dot{\xi}_T = V_T \cos \theta_T$$

TABLE 7.4

$$t_D = K_L (T_L - T_{LO}) + J$$

$$K = 1 - T_{CD}^2 t_D^2 / 2$$

$$T_X = (T_{XN} + T_{CDX} t_D) K$$

$$T_Y = (T_{YN} + T_{CDY} t_D) K$$

$$T_Z = (T_{ZN} + T_{CDZ} t_D) K$$

$$e = (e_N + K_O t_D)$$

$$C_3 = (C_{3N} + K_C t_D)$$

$$\cos \sigma = \sigma_N + \sigma_{ND} t_D$$

$$a_{TS} = a_{TSN} + K_{a1} \Delta T_4 + K_{a2} (\Delta T_4)^2$$

$$[A] = \begin{bmatrix} \sin A_Z & 0 & \cos A_Z \\ -\sin \phi_L \cos A_Z & \cos \phi_L & \sin \phi_L \sin A_Z \\ -\cos \phi_L \cos A_Z & -\sin \phi_L & \cos \phi_L \sin A_Z \end{bmatrix}$$

$$\theta_E = \theta_{EO} + \omega_E (T_L - T_{LO})$$

$$E_{PH} = [A]^{-1} \begin{bmatrix} -\sin \theta_E & \cos \theta_E & 0 \\ \cos \theta_E & \sin \theta_E & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

$$\bar{T}_P = [E_{PH}] \bar{T}$$

$$\bar{N} = \bar{R}X\bar{V} / |\bar{R}X\bar{V}|$$

$$\bar{R}_1 = \bar{R} / |\bar{R}|$$

$$\bar{P}_1 = \bar{N}X\bar{R}_1$$

$$\bar{S} = \bar{R}_1 \cos \beta + \bar{P}_1 \sin \beta$$

TABLE 7.4 (Continued)

$$\cos \psi^1 = \bar{S} \cdot \bar{T}_P$$

$$\sin \psi^1 = (1 - \cos^2 \psi^1)^{1/2}$$

$$\bar{S}_1 = (1/\sin \psi^1) (\bar{S} \cos \psi^1 - \bar{T}_P)$$

$$\bar{C}_1 = \bar{S}_1 \times \bar{S} = \bar{N}$$

$$\bar{\Omega}_X = A_{11}\bar{i} + A_{12}\bar{j} + A_{13}\bar{k}$$

$$\bar{\Omega}_Y = A_{21}\bar{i} + A_{22}\bar{j} + A_{23}\bar{k}$$

$$\bar{\Omega}_Z = A_{31}\bar{i} + A_{32}\bar{j} + A_{33}\bar{k}$$

$$i = \cos^{-1} (\bar{\Omega}_Z \cdot \bar{C}_1)$$

$$X_1 = \bar{\Omega}_X \cdot \bar{C}_1 \times \bar{\Omega}_Z$$

$$X_2 = \bar{\Omega}_Y \cdot \bar{C}_1 \times \bar{\Omega}_Z$$

$$\theta_N = \tan^{-1}(X_1/X_2)$$

$$[B] = \begin{bmatrix} \cos i \cos \theta_N & -\cos i \sin \theta_N & \sin i \\ \sin \theta_N & \cos \theta_N & 0 \\ -\sin i \cos \theta_N & \sin i \sin \theta_N & \cos i \end{bmatrix}$$

TABLE 7.4 (Continued)

$$[G] = [B] \quad [A]$$

$$R_n = R$$

$$P_n = \left[\mu / C_3 \right] \left[e_n^2 - 1 \right]$$

$$R_M = P_n / (1 - e_n \cos \sigma)$$

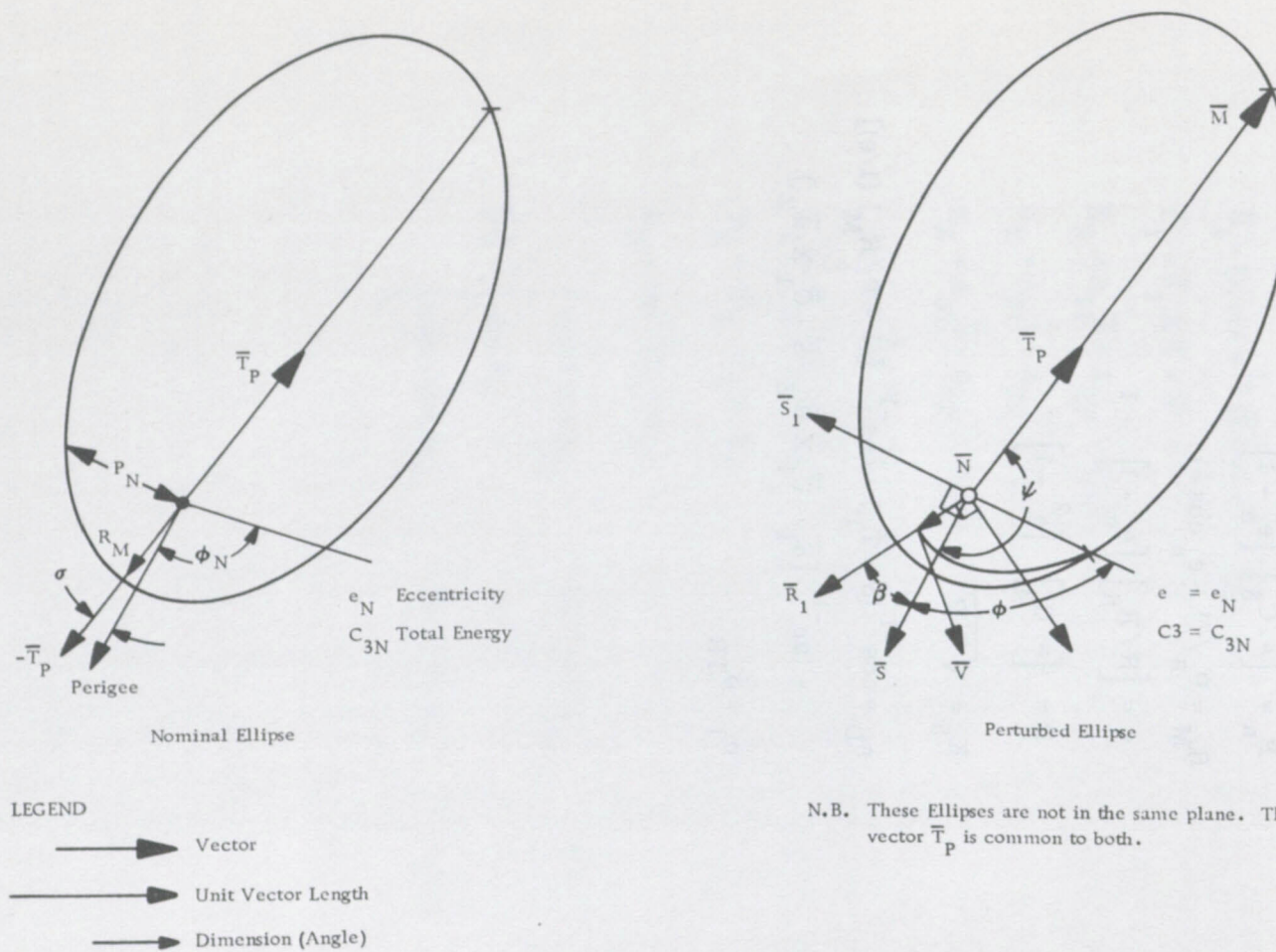
$$e = \left[R / R_n \right] \left[e_n - 1 \right] + 1$$

$$P = \left[\mu / C_3 \right] \left[e^2 - 1 \right]$$

$$K_5 = \sqrt{\mu / P}$$

$$\begin{aligned} \alpha_D = & \cos^{-1} (\bar{S} \cdot \bar{T}_P) - \cos^{-1} [(1 - P/R_M) (1/e)] \\ & + \tan^{-1} [\bar{S}_1 \cdot \bar{C}_1 \times \bar{\Omega}_Z / \bar{S} \cdot \bar{C}_1 \times \bar{\Omega}_Z] \end{aligned}$$

$$\phi_T = \phi_{TR}$$



N.B. These Ellipses are not in the same plane. The vector \vec{T}_P is common to both.

Figure 7.5 Waiting Orbit Injection Ellipse

8. ORBITAL GUIDANCE

8.1 WAITING ORBIT

The attitude of the CSM/SLA/S-IVB, after S-IVB second burn, is oriented to the optimum attitude for cold soaking the CM reentry heat shield to simulate terminal trans-earth conditions. To achieve the cold soak requirement, the spacecraft -Z side is oriented toward the solar vector, the X - Z plane is inclined to the solar vector $\pm 10^\circ$, and the X - Y plane is inclined at an angle of $130^\circ \pm 5^\circ$ from the solar vector as measured counter clockwise from +X toward -X (see Figure 8.1). The above inertial orientation is required for approximately 4 hours.

The equations necessary for the vehicle to attain this orientation are described below:

$$x_x(T) = \text{desired value}$$

$$SCY = Z_1 / (0.76604 \cdot R_1)$$

$$x_y(T) = \tan^{-1} (SCY / \sqrt{1 - SCY^2})$$

$$S_1 = X_1 - 0.839Y_1$$

$$S_2 = R_1 \cdot (0.76604 \cos(x_y(T)) + 0.539)$$

$$S_3 = \sqrt{S_2^2 - S_1^2}$$

$$x_z(T) = \tan^{-1}(S_3/S_1)$$

Where X_1 , Y_1 , and Z_1 , fix the position of the sun in the platform system and R_1 is the magnitude of the vector (X_1, Y_1, Z_1) .

In addition to the thermal requirements which are satisfied by the equations above, two constraints are placed on the S-IVB attitude. These are (1) that the angle between the longitudinal axis of the vehicle and the radius vector to the center of the earth, β , be greater than 15° during part of the orbit and greater than 45° near apogee, and (2) that the magnitude of the yaw gimbal angle not exceed 30° .

These constraints cannot be incorporated directly in the equations. However, since $x_x(T)$ is selected arbitrarily, a search can locate the proper range. In this case, β will be a function of $x_y(T)$ and may not always satisfy the requirements.

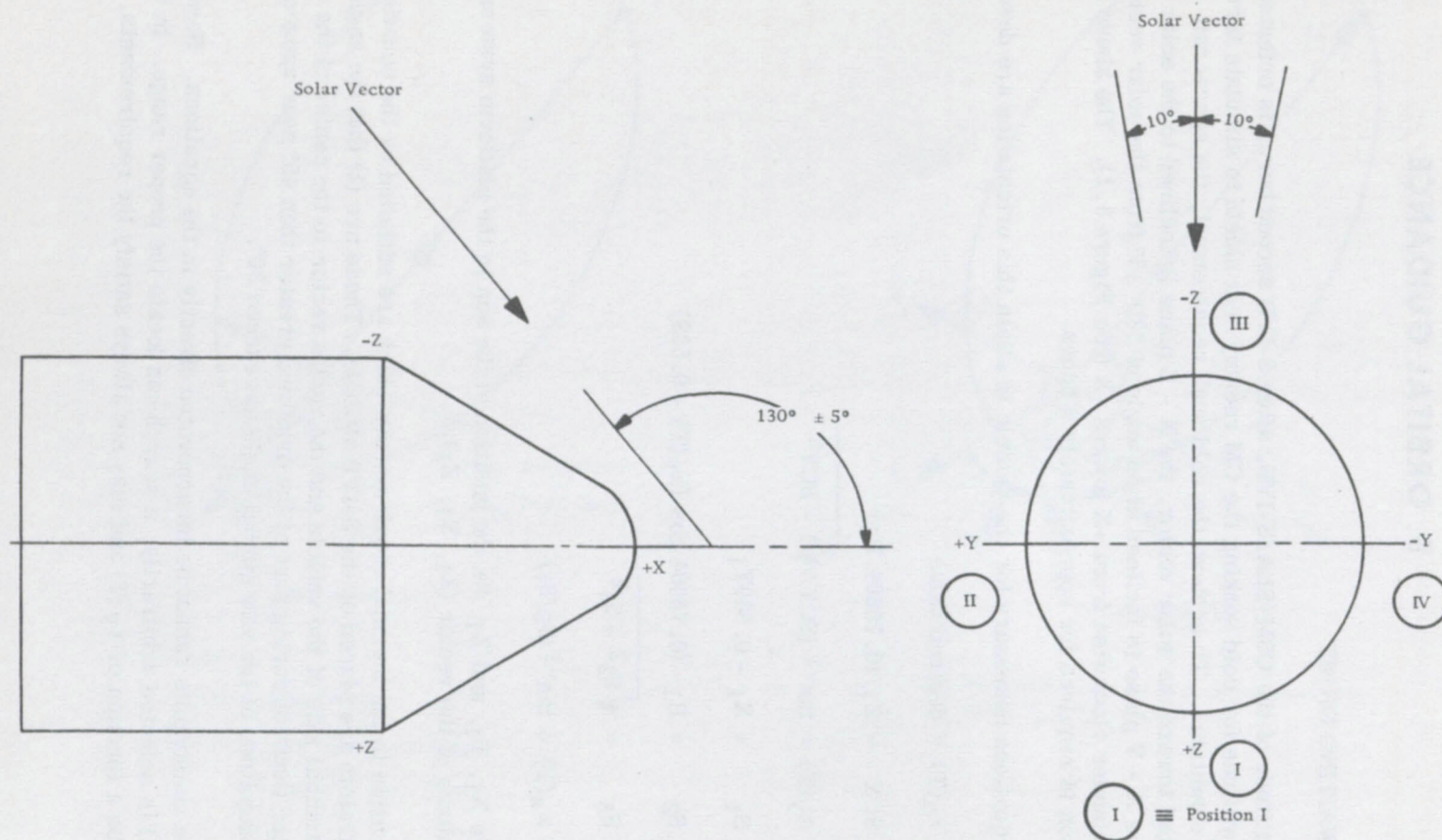


Figure 8.1 Attitude Required for CM Cold Soak During Earth Intersecting Coast Phase

Since the proper attitude depends upon the day and time of launch, many different conditions will occur, making a general solution of the problem not feasible. Therefore, in order to examine the requirements, a simulation was run which fixed the sun's position as it will appear at a particular time on January 1, 1967. The sun's coordinates in the platform system are:

$$X_1 = 1.4575343 \times 10^{11} \text{ m}$$

$$Y_1 = -0.55251378 \times 10^{10} \text{ m}$$

$$Z_1 = 1.8516172 \times 10^{10} \text{ m.}$$

The vehicle was assumed to be at the position:

$$X_S = 6090858.7 \text{ m}$$

$$Y_S = 3231483.3 \text{ m}$$

$$Z_S = -23505.4 \text{ m}$$

at the end of the S-IVB second burn.

An attempt was made, using these initial conditions, to find a combination of gimbal commands that would satisfy the requirements. Simulation runs indicated that the best solution for this particular problem existed with $\chi_X(T) = 30^\circ$. However, it should be noted that at positions close to apogee, β became slightly less than 45° , so that the requirements could not be satisfied.

In the performance of this study, several values for $\chi_X(T)$ were tried, as well as rolling the vehicle $\pm 10^\circ$ from the calculated value (10° is the maximum tolerance allowed).

There are probably other times of launch which will cause the problem to exhibit solutions that are further away from the required constraints.

On the basis of the above, it is recommended that the CSM be separated from the S-IVB soon after S-IVB second burn. If, however, the requirements on β and/or the yaw gimbal limits can be relaxed, then acceptable solutions of the problem may exist.

9. MINOR LOOP

The function of the minor loop is to process platform gimbal angle information to compute yaw, pitch, and roll corrections needed to drive the gimbals to the desired positions, and to output these commands to the LVDA. The LVDC enters the minor loop routine every 0.04 second during boost and every 0.1 second during orbit on receipt of a minor loop interrupt. The boost minor loop processing has been defined and explained in detail in IBM Memorandum HE-64-207-51 and is described here in a simplified manner.

Resolvers are used in the Saturn V vehicle to measure platform gimbal angles. The error characteristics of the resolvers designed for the IB vehicle have been studied by NASA and IBM. Since certain of their findings impact the flight program, a brief summary of these results is presented here. The principle references for this discussion are "Hardware Descriptions and Error Analysis of the Attitude Control System for the Saturn IB/V Vehicle", IBM No. 64-208-0008H (dated December 24, 1964), and "Error Analysis of the ST-124-M/LVDA Resolver System", IBM No. 65-208-0007H (dated April 1, 1965).

The 1:1 and 32:1 resolver systems have numerous error sources which have been detected in the resolvers and the digital-to-analog conversion of resolver readings. Among these errors certain ones are predictable. These are the error, E , of the form

$$E = A + B \sin(2n\theta + \alpha)$$

where A , B , and α are appropriate constants, n is 1 or 32 (depending on the resolver system being used), and θ is the gimbal angle being measured. In addition to this error in the gimbal angle measurements, there is the turn-on, turn-off, error encountered when converting analog signals to digital form. The latter error is caused by the logic needed to stop the COD counters which involves one more and/invert element than the start logic. The relation between the actual gimbal angle, θ , and the measured gimbal angle, θ_m , is

$$\theta_m = \theta + A + B \sin(2n\theta + \alpha) + E_{00} + E_v$$

where

$$E_{00} = \text{turn-on turn-off error}$$

and

$$E_v = \text{other variable error.}$$

The studies referenced above have indicated that the error E_v is as large as the error $B \sin (2n\theta + \alpha)$, but that the constant bias, A , is the largest error source of error. Furthermore, the error E_v behaves in such a way that the resolver error curves bear little resemblance to a sinusoid. These facts, together with limitations on computer speed and memory, make it desirable for the flight program to consider only the constant bias error, A , in correcting gimbal angle readings. The numerical value of the bias error must be determined for each resolver system by laboratory tests and cannot be specified here.

In orbit, the usual minor loop is not satisfactory. It requires more than 50% of the computation time (approximately 21 out of every 40 ms) to do attitude control calculations. During orbit, operation of the CIU to obtain numerous quantities will require that less time be spent in uninterruptible portions of the flight program. Control studies indicate that these minor loop computations need not be done more rapidly than 1 per second. Ladder drift and other problems preclude the 1 per second rate, but do permit the 10 per second rate if certain precautions are taken. Drift causes two difficulties in the system. First, the attitude error (ladder) command will be in error by the drifted amount, and second, if ladder B is not to be selected automatically, command changes must not exceed 8 increments from the drifted previous ladder commands. While no definite values are available to provide upper limits to the amount of ladder drift to be expected in 100 ms, current data indicates this number should be less than two ladder increments.

A conservative estimate of a 4 increment drift is used as the upper limit, which corresponds to a 0.24° drift per minor loop in the attitude error command. The drift problem will change the magnitude of the deadband of the auxiliary propulsion system (APS), but it is estimated that these changes will not seriously affect the APS operation. However, only 4 increments remain (of the maximum allowable 8) to be used for command changes. This $.24^\circ$ per minor loop limit on change (above the assumed $.24^\circ$ drift) corresponds to a 2.4° per second ladder change rate which is more than sufficient to implement the attitude error equations. The commanded change is itself limited to $.6^\circ$ per second or less during coast. This reduced sampling rate permits reduction of the time spent in the minor loop from over 50% to about 20% during orbit. However, still further reductions are possible. The 1 per second rate suggested by control studies permits elimination of gimbal sampling in nine out of ten minor loops. This change requires some additional tests but reduces the time in the minor loop still further from 20% to an estimated 10% during orbit. The minor loop during orbit can now be considered in two parts: the attitude update mode (1 per second) during which the gimbal angles are sampled, and the attitude hold mode, in which ladder commands are recomputed based on the previous gimbal sample (9 per second). It should be emphasized that both the ladder rate limit values and the sampling rate itself may be changed when better drift data is available.

In explaining the minor loop, the nominal path is considered first. Then each of the branches explaining operations in case of various failures is discussed. Since the logic needed to compute an attitude command is identical for the yaw, pitch, and roll commands, the calculations will only be discussed for one case. This logic is then processed three times by the LVDC during each minor loop.

The minor loop processing is depicted in Blocks 500-560 of Figure 9.1. A minor loop interrupt transfers control to the minor loop routine. The interrupt automatically PIO's the X fine (or backup) gimbal. The value of the X fine (or backup) gimbal is available to the computer 25 instructions following the interrupt. The first block in the flow shows the setting of the minor loop counter. In boost this counter will be set to cause an interrupt every 40 ms; in coast the interval between minor loops will be 100 ms. Block 501 exhibits a test on minor loop switch (MLSW) to determine if this pass is an attitude update or attitude hold minor loop. In boost, all minor loops will be attitude update passes. In coast, only one pass per second will update gimbal angles, and this pass will be selected following the minor loop support calculations in the orbital processor. Next, new values for x_x , x_y , and x_z are computed by adding D_x to the past x value. During boost these values are used each 1/25 second to smooth the transition from the old to the new x . During coast, this update is done once each second. The computer then reads a new gimbal angle from either a 2:1 or a 64:1 resolver. The 64:1 resolver is normally used, but excessive failures cause the 2:1 to replace the 64:1 (excessive failure is defined as three or more failures in one major loop cycle during boost, or three failures in five seconds in coast). The resolver reading comes into the computer in duplex form; that is, two counter readings of the same resolver are read in. These readings are tested for agreement by the LVDC, and a disagreement bit is set if the two disagree. In the nominal case the disagreement bit is not set, and only one of the readings is saved.

The gimbal reading is tested to see if it is zero. An unexpected zero reading is interpreted as an error and appropriate action is taken. A nonzero reading or an explainable zero reading transfers control to the reasonableness test. The new gimbal reading is compared with the previous reading to determine if the new angle is reasonable. If not, appropriate action is taken. If the angle is reasonable, the total angle, θ , is computed.

Once again the minor loop switch is tested. If it is set to the hold mode, the pass just made to compute θ was a special gimbal angle sample designed to obtain the angle θ for use in orbit navigation. Thus, this pass is not a normal minor loop and was not initiated by a minor loop interrupt. Entry was obtained from the orbital processor through "Minor Loop B". In this case the three values of θ will be obtained without any ladder processing. If the update mode applies, the normal processing continues.

The next block (511) computes attitude commands. It should be noted that no limit tests are required to assure that the angular quantities and errors are in the proper range. This will be achieved by appropriate scaling in the flight program.

The attitude commands are computed using the equations

$$\text{Pitch} = A_1 \Delta Z + A_2 \Delta X$$

$$\text{Yaw} = -A_4 \Delta Z + A_5 \Delta X$$

$$\text{Roll} = \text{SF}(\Delta Y + A_3 \Delta Z)$$

where A_1, \dots, A_5 are sine-cosine coefficients defined in Section 10, and SF is a factor used for scaling and for setting the attitude control gain (A_1, A_2, A_4 , and A_5 contain SF). The gain to be used in these equations is defined in Table 9.1. These commands are limited in magnitude throughout the AS-501 flight.

TABLE 9.1

Minor Loop Parameters For AS-501

Flight Mode	Attitude Control Gain	Attitude Rate Limits			Limits on Magnitude of Attitude Commands		
		Yaw	Pitch	Roll	Yaw	Pitch	Roll
S-IC Burn	1	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	15°	15°	15°
SII Burn	1	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	15°	15°	15°
S-IVB 1st Burn	1	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	15°	15°	3.5°
Coast	1	$\pm 2.4^\circ/\text{sec}$	$\pm 2.4^\circ/\text{sec}$	$\pm 2.4^\circ/\text{sec}$	2.5°	2.5°	3.5°
SIVB 2nd Burn	1	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	$\pm 12^\circ/\text{sec}$	15°	15°	15°
Coast	1	$\pm 2.4^\circ/\text{sec}$	$\pm 2.4^\circ/\text{sec}$	$\pm 2.4^\circ/\text{sec}$	2.5°	2.5°	2.5°

The yaw attitude command is sent out on the LVDA ladder network. The command goes out either on Channel A or Channel B, since the ladder configuration is duplex. Immediately after the yaw command is loaded on the ladders, an instruction is given to reset the ladders to Channel A provided three failures in Channel A have not been detected in

any computation cycle. If A has failed three times, Channel B is automatically switched in and no change is necessary or desirable. This is achieved in Blocks 516-518. Processing of the first command is now complete and pitch and roll will then be processed.

The attitude control portion of the minor loop has been described except for disagreement bit (DB) processing and reasonableness test failures. If the disagreement bit is set, exit is made from Block 504 to DB processing (Block 547). If permanent failures, which cause the DB to be set each minor loop, have previously been found, the DB is ignored. The flow is then reentered as indicated by the nature of the error previously found. If no such permanent failure exists, then the DB processing subroutine searches for an explanation of the DB. The disagreement in Counter A and Counter B arises from one of four sources.

1. Either Counter A or Counter B (or both) is faulty.
2. The DB circuitry has failed.
3. A multiplexer circuit is bad.
4. One counter reading is very small (near zero) and the other counter reading large (near $2016 = 0$) or vice versa, but the two are actually within acceptable limits of one another if the readings are correctly interpreted.

Error sources 1, 2, and 4 are handled by the DB processing. Error source 3 can only be detected by the reasonableness test. Error source 4 is looked for first. Next, the DB circuitry is tested. Finally, the counters are tested by permitting them to run for a known time at a known rate and comparing their counts with a stored constant. If neither counter is bad, no reason has been found for the DB. Its presence is thus due to an intermittent error of type 1 or to an error of type 3. In any event, no action is taken and exit is made to the normal minor loop flow. If either Counter A or Counter B is faulty, a count is updated and checked. Two failures of one counter in one major loop cause the other counter reading to be permanently selected. The DB processing is subsequently by-passed. If both counters fail, the DB processing is also by-passed in the future, and attitude commands from the previous minor loop are used for steering since no correct gimbal angles can be obtained. The DB processing logic is found in Blocks 547-560.

Blocks 542-545 are processed when a reasonableness test has failed. A count of reasonableness test failures is incremented and, based on this, a decision is made on whether or not the backup resolver should be switched in to replace the 64:1 resolver. The 64:1 resolver is judged to have failed if the reasonableness test has failed three or more times in one major loop. When the backup is used to replace the 64:1 resolver, the program is modified to effect the change. Steering commands from the previous minor loop are used for outputs when the reasonableness test has failed.

The logic in blocks 524 and 539 provides for the sampling of accelerometers in the minor loop once per computation cycle; that in blocks 540 and 541 prepares for S-IVB cutoff. The latter logic is needed to insure that S-IVB cutoff occurs exactly when it should. After this is completed, control is transferred either to the interrupt processing routine (See Section 13) which, in turn, transfers to the major loop, or to some other appropriate exit point established by Blocks 520, 521, 523, or 528.

The LVDC enters the attitude update minor loop once every 40 ms in boost and once every 100 ms during coast. Its duration is dependent on which of the available paths is taken. The nominal path is taken when only fine gimbals are read, with no disagreement bits set and no crossovers, and with no reasonable tests failed. The average time to process the minor loop, excluding transit times to and from the major loop, is approximately 20 ms. The actual minor loop duration, including transit time to and from the major loop, is close to 21 ms.

If the disagreement bit subroutine must be entered, the duration of the minor loop is lengthened. The time for the DB subroutine (including time to exit from and return to normal flow) will be between 0.410 ms and 4.166 ms. The former time will be required if it has been previously observed that further processing of the DB subroutine is of no value, the latter if the counters must be checked. The latter, i.e., the duration of 4.166 ms, could be expected to happen at most twice, with 0.410 ms subsequently becoming the actual duration of the DB subroutine.

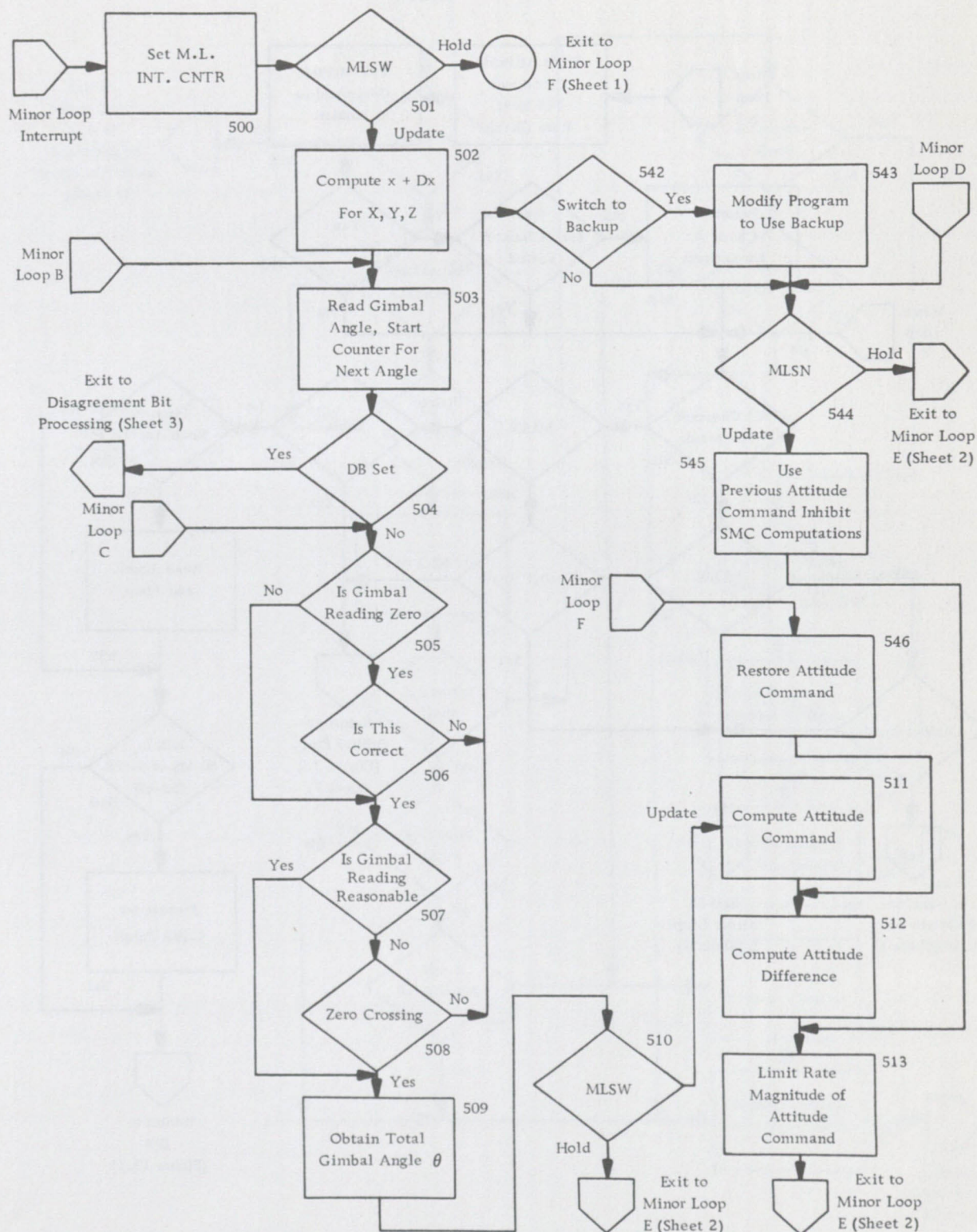


Figure 9.1 Minor Loop (Sheet 1 of 3)

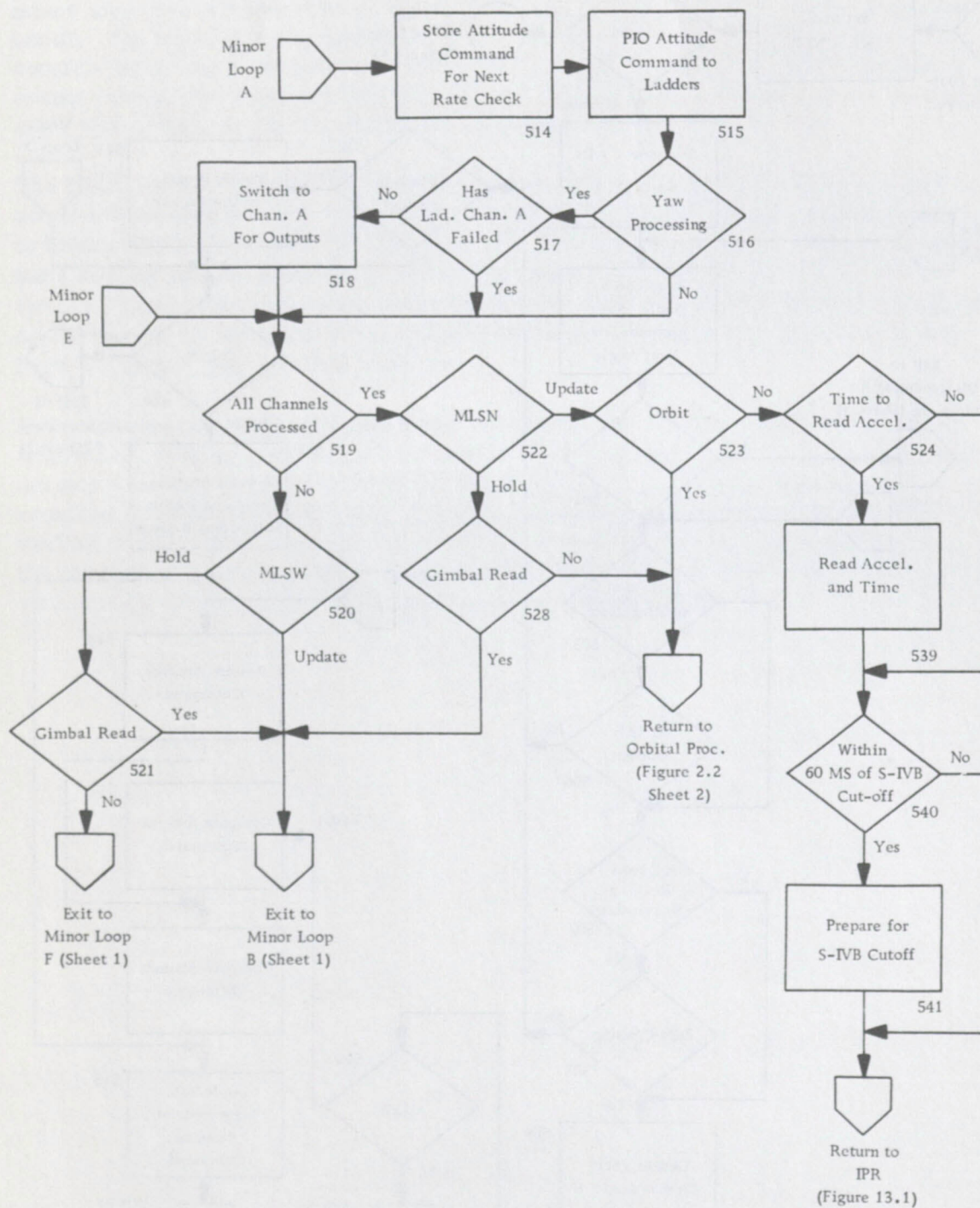


Figure 9.1 Minor Loop (Sheet 2 of 3)

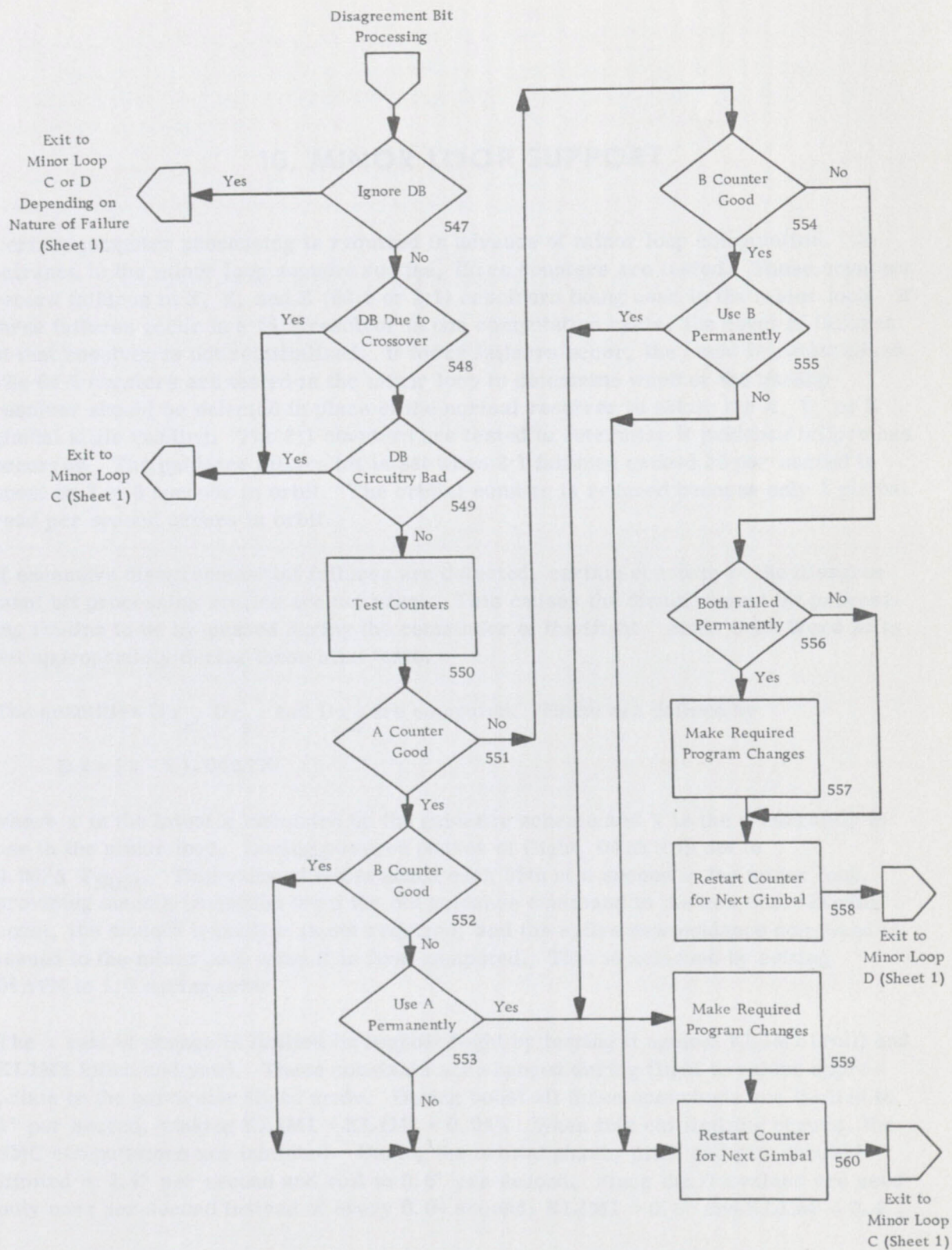


Figure 9.1 Minor Loop (Sheet 3 of 3)

10. MINOR LOOP SUPPORT

Certain computer processing is required in advance of minor loop computation. On entrance to the minor loop support routine, three counters are tested. These counters record failures in X, Y, and Z (64:1 or 2:1) resolvers being used in the minor loop. If three failures occur in a 64:1 resolver in one computation cycle, the count of failures of that resolver is not reinitialized. If fewer failures occur, the count is reinitialized. The 64:1 counters are tested in the minor loop to determine whether the backup resolver should be selected in place of the normal resolver to obtain the X, Y, or Z gimbal angle reading. The 2:1 counters are tested to determine if guidance failure has occurred. The guidance failure bit is set when 2:1 failures exceed 15 per second in boost or 3 in 5 seconds in orbit. The orbital number is reduced because only 1 gimbal read per second occurs in orbit.

If excessive disagreement bit failures are detected, certain counters in the disagreement bit processing routine are not reset. This causes the disagreement bit processing routine to be by-passed during the remainder of the flight. Mode Code Word 24 is set appropriately during these MLS tests.

The quantities Dx_x , Dx_y , and Dx_z are computed. These are defined by

$$Dx = (x - \bar{x}) \cdot 0.04 \Delta TN$$

where x is the latest x computed by the guidance scheme and \bar{x} is the x currently in use in the minor loop. During powered phases of flight, $0.04 \Delta TN$ is set to $0.04/\Delta T_{NOM}$. This value of Dx is added each 25th of a second in the minor loop, providing smooth transition from the old guidance command to the new one. During coast, the smooth transition is not required, and the entire new guidance command is issued to the minor loop when it is first computed. This is achieved by setting $0.04 \Delta TN$ to 1.0 during orbit.

The x rate of change is limited throughout flight by testing it against KL1M1 (roll) and KL1M2 (pitch and yaw). These constants are changed during flight to values appropriate to the particular flight mode. During boost all three commands are limited to 1° per second, making $KL1M1 = KL1M2 = 0.04^\circ$. When this chi limiting occurs, the SMC computations are inhibited. During the orbital phase, pitch and yaw should be limited to 0.4° per second and roll to 0.6° per second. Since the Dx values are used only once per second instead of every 0.04 second, $KL1M1 = 0.6^\circ$ and $KL1M2 = 0.4^\circ$.

Ladder rate limits previously implemented in the minor loop support section have been removed to the minor loop. No testing is required to insure proper ranges for

angles and angular differences since this will be achieved by the selected computer scaling. This method is described in IBM Memorandum Number HE-65-205-0113. A section of the memorandum follows.

"If angles are represented in units of RADIANS/PI scaled zero (PIRADS), the possibility of overflow on angular addition is eliminated. In this system angles are limited to the range

$$-180^\circ \leq \text{THETA} < +180^\circ.$$

The sum or difference of any number of angles will also be within this range automatically.

The following serves to illustrate how angles expressed in PIRADS would appear in an LVDC word:

0° - 000000000
 90° - 200000000
 180° - 400000000
 270° - 600000000
 360° - 000000000."

The sine-cosine coefficients (A_1, \dots, A_5) are needed in the attitude control equations. These are defined by the following equations:

$$A_1 = SF \cos \frac{\hat{x}_y + \theta_y}{2} \cos \frac{\hat{x}_x + \theta_x}{2}$$

$$A_2 = SF \sin \frac{\hat{x}_y + \theta_y}{2}$$

$$A_3 = \sin \frac{\hat{x}_x + \theta_x}{2}$$

$$A_4 = SF \sin \frac{\hat{x}_y + \theta_y}{2} \cos \frac{\hat{x}_x + \theta_x}{2}$$

$$A_5 = SF \cos \frac{\hat{x}_y + \theta_y}{2}$$

In this computation, the angle \hat{x} is defined as $\bar{x} + 25\Delta T_{\text{NOM}} D x$. This will differ from the x computed by the guidance loop if $D x$ has been limited. The quantity $25\Delta T_{\text{NOM}}$ is the reciprocal of $04\Delta T_{\text{N}}$ and also changes in orbit.

A test is made to determine if Channel A of the ladder output network has failed three or more times in one computation cycle. If it has, use of Channel A is abandoned in favor of use of Channel B.

11. ORBITAL FLIGHT PROGRAM

The orbital flight program is not defined at this writing. A subsequent memorandum will be issued describing it.

12. FLIGHT SEQUENCING (DISCRETE INPUTS AND OUTPUTS)

The issuance and acceptance of discretes by the LVDC requires certain logic in the flight program. A few discretes are extremely important to mission success and will be simulated by the LVDC if they are not actually received.

12.1 DISCRETE INPUTS

An indication that certain vehicle events have occurred will be given to the LVDC in one of two ways:

1. A change in the logic state of a bit associated with the particular event.
2. An interrupt in the computer program.

In the case of discrete inputs of type 1, immediate action by the computer is not essential (except in the case of liftoff, as explained later). The computer program checks discrete input bits once per computation cycle by a PIO to the digital input multiplexer. If a discrete input is detected, appropriate action is taken. Discretes of type 1 are listed in Table 12.1 for AS-501, in order of decreasing logical priority. A brief description of these discrete inputs follows:

Discrete inputs requiring immediate attention by the LVDC cause an interrupt in the flight program (Section 13).

TABLE 12.1

Discrete Input Number	LVDA Bit Position	Function	Applicable to AS-501 ?
24	Sign	Liftoff	Yes
23	1	Spare	--
22	2	S/C Initiation of S-II/S-IVB Separation "B"	Yes
21	3	S-II Outboard Engine Out	Yes
20	4	S-IVB Thrust Sequence Start	No
19	5	S-II Engines Out	Yes
18	6	S-IC Outboard Engine Cutoff	Yes
17	7	S/C Initiation of S-II/S-IVB Separation	No
16	8	Prepare for GRR	Yes
15	9	S-IC Inboard Engine Out "A"	Yes
14	10	S-IC Outboard Engine Out	Yes
13	11	S-II Inboard Engine Out	Yes
12	12	S-IC Separation	Yes
11	13	S-IC Inboard Engine Out "B"	Yes
10	14	S-II/S-IVB Separation	Yes
9	15	Control Computer Switched to S/C	No
8	16	Spare	--
7	17	Spare	--
6	18	S-IVB Inject Delay	No
5	19	S-IVB Engine Out "A"	Yes
4	20	Auto Vent 1	Yes
3	21	Auto Vent 2	Yes
2	22	Command Receiver Sync	Yes
1	23	RCA-110A Sync	Yes

DI1: RCA-110A sync is a discrete used only in the ground routines.

DI2: Command Receiver sync is also a discrete used only in the ground routines.

TABLE 12.1 (Continued)

DI3:	Auto Vent 2 is a discrete input indicating that the vent cycle for the S-IVB LH ₂ tank has stopped. This is for the S-IVB in orbit, only.
DI4:	Auto Vent 1 is a discrete input indicating that the vent cycle for the S-IVB LOX tank has stopped. This is for the S-IVB in orbit, only.
DI5:	The DI for S-IVB Engine Out will be OR'd with the S-IVB Engine Out interrupt to initiate time base 5 and time base 7.
DI10:	This DI informs the LVDC that S-II/S-IVB separation has been accomplished. This DI will be received after the start of time base 4 (i.e. after S-II Propellant Depletion interrupt has been received and processed).
DI11:	S-IC Inboard Engine Out "B".
DI12:	S-IC separation. This DI informs the LVDC that the first plane of S-IC/S-II separation has been completed. No program use of either DI11 or DI12 is made (e.g., no time bases are established on the receipt of these DI's).
DI14:	S-IC Outboard Engine Out DI will be OR'd with the corresponding interrupt to establish time base 3 only if DI is received after Arm For OEEO. If OEEO DI is received prior to this time, time for backup of OEEO will be changed. DI14 will be telemetered. \dot{X}_S must exceed 500 m/sec before time base 3 can be established.
DI15:	S-IC Inboard Engine Out DI informs the LVDC that inboard engine cutoff has occurred. It is used to change the time at which LLS will be simulated in the event that the interrupt is not received. It is also valuable in post-flight evaluation and will be telemetered.
DI16:	Guidance Reference Release Alert is used only in the ground routines. It occurs 8 seconds prior to Guidance Reference Release and warns the ground routines that GRR is coming.
DI19:	This DI will be OR'd with the S-II Propellant Depletion interrupt to establish time base 4.
DI24:	Liftoff DI establishes time base 1. The time at which liftoff occurs needs to be accurately known and a search is made for this DI once every 10 ms during the time between GRR and liftoff. After liftoff, this search is discontinued.

12.2 DISCRETE OUTPUTS

Discrete outputs are sent from the LVDC to the LVDA in one of two ways:

1. A few outputs are indicated by changing the logical state of a bit associated with the output.
2. A majority of discrete outputs are generated by the switch selector.

For AS-501, only four outputs of type 1 have been defined. The LVDC has provision for thirteen such discretes. Table 12.2 contains the most recent listing for AS-501, in decreasing logical order.

TABLE 12.2

<u>Discrete Output Number</u>	<u>LVDA Bit Position</u>	<u>Function</u>
13	Sign	Spare
12	1	Indication of GRR
11	2	Spare
10	3	Spare
9	4	Spare
8	5	Spare
7	6	Spare
6	7	Spare
5	8	Spare
4	9	Guidance Failure
3	10	Spare
2	11	RCA-110A Interrupt
1	12	Reset (LIRO)

DO's 1 and 2 are used only in the ground routines and are not relevant to the flight program. DO4 is generated when the platform fails. To determine if guidance failure has occurred, the program monitors failure counts for the X, Y, and Z resolvers. If any backup resolver fails 15 or more times in one computation cycle in boost, or 3 times in 5 seconds in orbit, the DO is generated. The logic for this test is part of the minor loop support flow.

12.3 DISCRETE BACKUPS

Certain events are particularly important because they reset the computer time base. These are: 1) liftoff, 2) S-IC low level sense, 3) S-IC outboard engine cutoff, 4) S-II engine out, and 5) S-IVB engine out. Because the issuance of switch selector outputs is a function of time relative to one of these four bases, no switch selector outputs can be generated if one of these DI's is missed. Therefore, backups must be provided in the flight program to protect against faulty inputs on these critical signals by simulation of the actual event. A discussion of these backup routines will be found in Section 14.

13. INTERRUPTS

The LVDC has an interrupt feature which permits interruption of the normal program to free the computer for priority work. When such a priority task arises, an interrupt is generated which transfers control to a special subroutine, shown in Figure 13.1, upon completion of the instruction currently being executed. This subroutine establishes the mechanism for eventual return to the main program, identifies the source of the interrupt, and then transfers to another subroutine which performs the processing called for by the interrupt. This processing is defined in Blocks 1 to 32. During interrupt processing, all interrupts except TLC are inhibited. TLC is permitted at any time during both boost and orbit with one exception: for the last 60 ms prior to S-IVB cutoff, all interrupts except Switch Selector interrupts are inhibited, to ensure that S-IVB cutoff will occur at exactly the correct time. Once S-IVB cutoff has occurred, all interrupt inhibits are released.

When the computer recognizes an interrupt and attempts to identify its source, it initially checks to see if it is a TLC. If not, it then checks to see if it is a minor loop interrupt. This is done independent of the logical priorities of the respective bits in the interrupt storage register, under program control; the minor loop interrupt bit in the interrupt storage register is actually a higher order bit than the TLC bit (See Table 13.1). If the source of the interrupt is neither TLC nor a minor loop, the computer then systematically determines the source of the interrupt by successively examining the remaining bits in the register.

When processing of the interrupt is completed, the computer returns to Blocks 36 - 40 of Figure 13.1. Here, certain interrupt inhibits are removed and the computer is returned to the main program.

The computer has provision for 12 interrupts. Table 13.1 contains a list of all interrupts currently planned for AS-501, in order of decreasing logical priority in the interrupt storage register. A subroutine is defined below for each of these interrupts. Figures 13.3 to 13.5 show these subroutines.

13.1 TIMED MINOR LOOP INTERRUPT

This interrupt occurs every 0.04 second during boost and every 0.10 second during orbit and directs the computer into the minor loop routine. This routine is described in section 9.

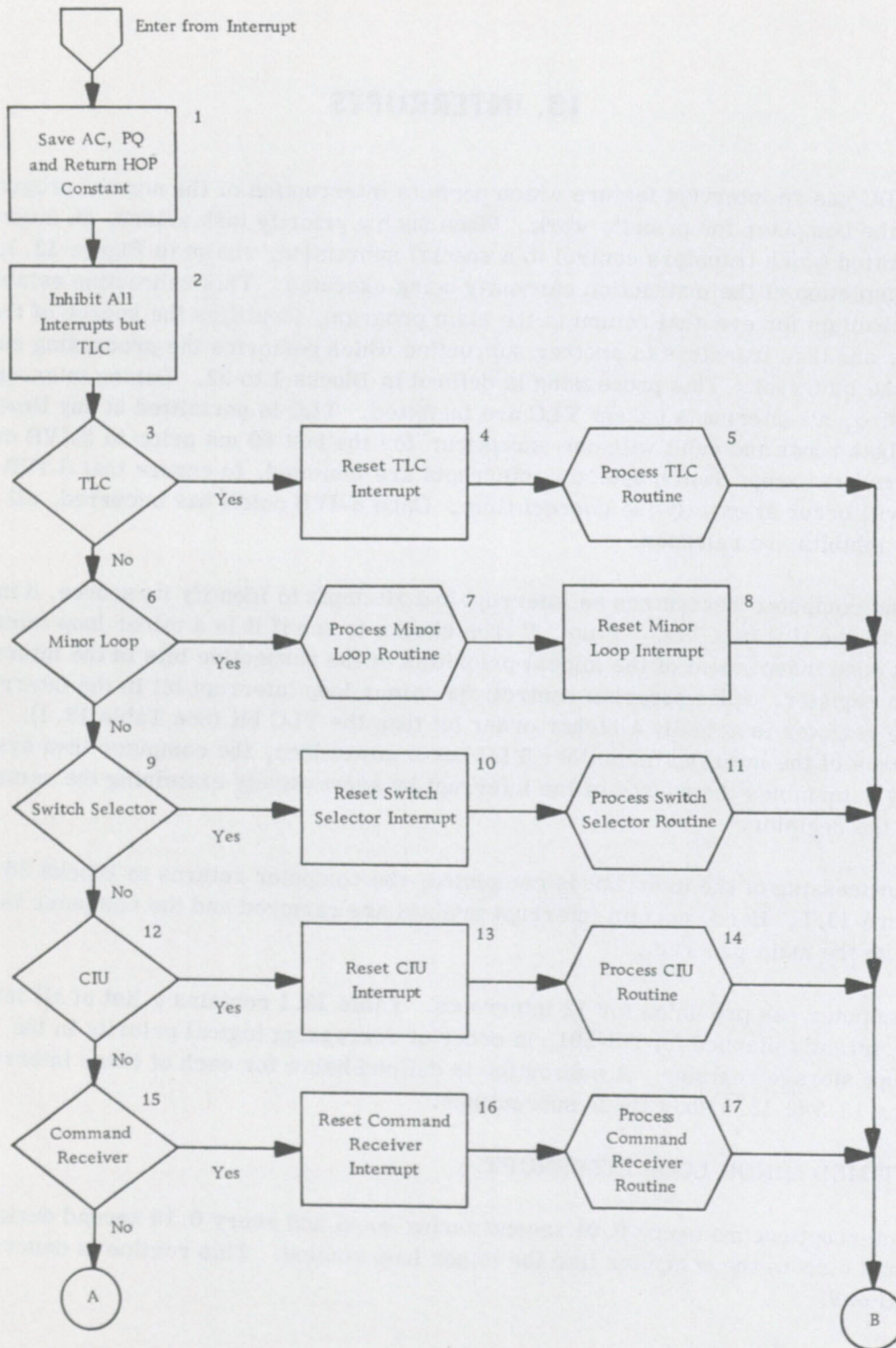


Figure 13.1 Interrupt Processing Routine (Sheet 1 of 3)
(This figure is block 14 of Figure 2.0)

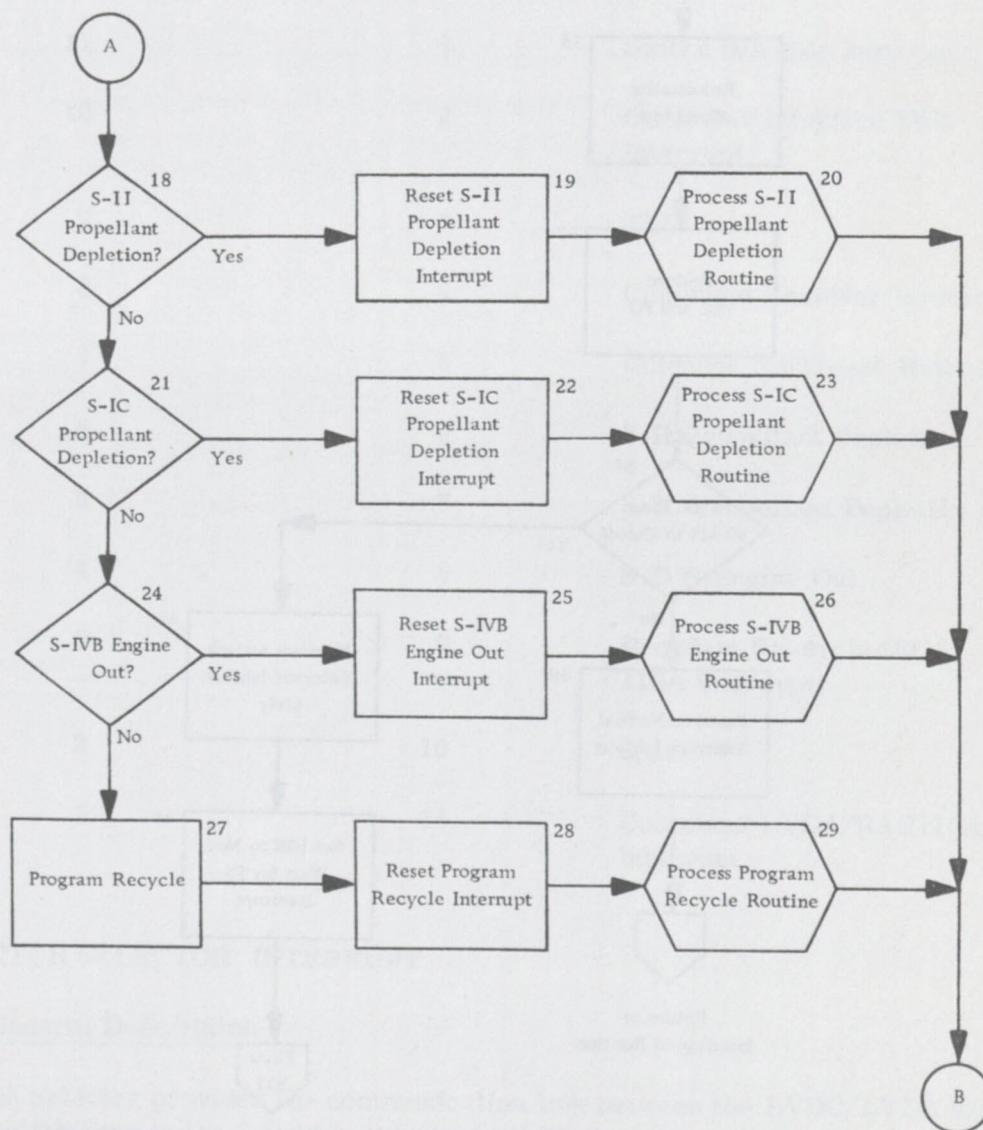


Figure 13.1 Interrupt Processing Routine (Sheet 2 of 3)

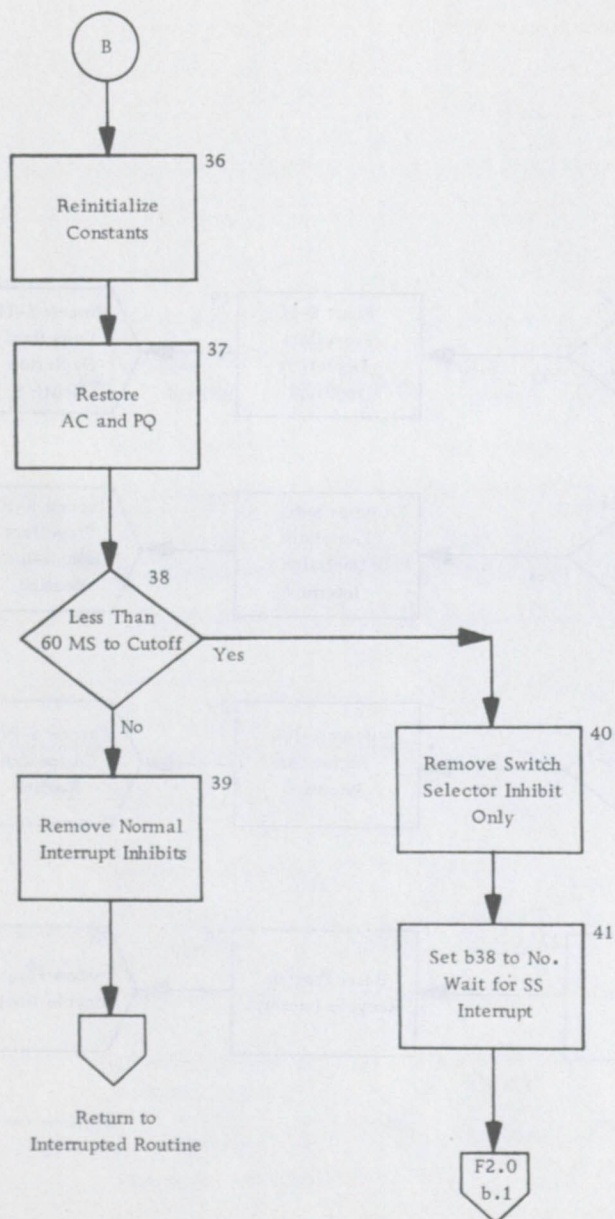


Figure 13.1 Interrupt Processing Routine (Sheet 3 of 3)

TABLE 13.1

<u>INTERRUPT STORAGE REGISTER BIT</u>	<u>LVDC DATA WORD BIT POSITION</u>	<u>FUNCTION</u>
12 (high order bit)	Sign	Timed Minor Loop Interrupt
11	1	Switch Selector Interrupt
10	2	Computer Interface Unit Interrupt
9	3	TLC
8	4	Command Receiver Interrupt
7	5	Guidance Reference Release
6	6	S-II Propellant Depletion
5	7	S-IC Propellant Depletion
4	8	S-IVB Engine Out
3	9	Program Re-cycle (RCA- 110A Interrupt)
2	10	Spare
1	11	Command LVDA/RAC110A Interrupt

13.2 SWITCH SELECTOR INTERRUPT

13.2.1 General Description

The Switch Selector provides the communication link between the LVDC/LVDA and the control distributors in the IU and in the stages. Through the switch selector, the LVDC can control sequencing in the IU and in the stages. Saturn IB vehicles have three switch selectors, one in the IU and one in each of the two stages. The LVDC logic required for a switch selector output may be divided into two sections. The first section determines if it is time to initiate a switch selector output by comparing time elapsed in

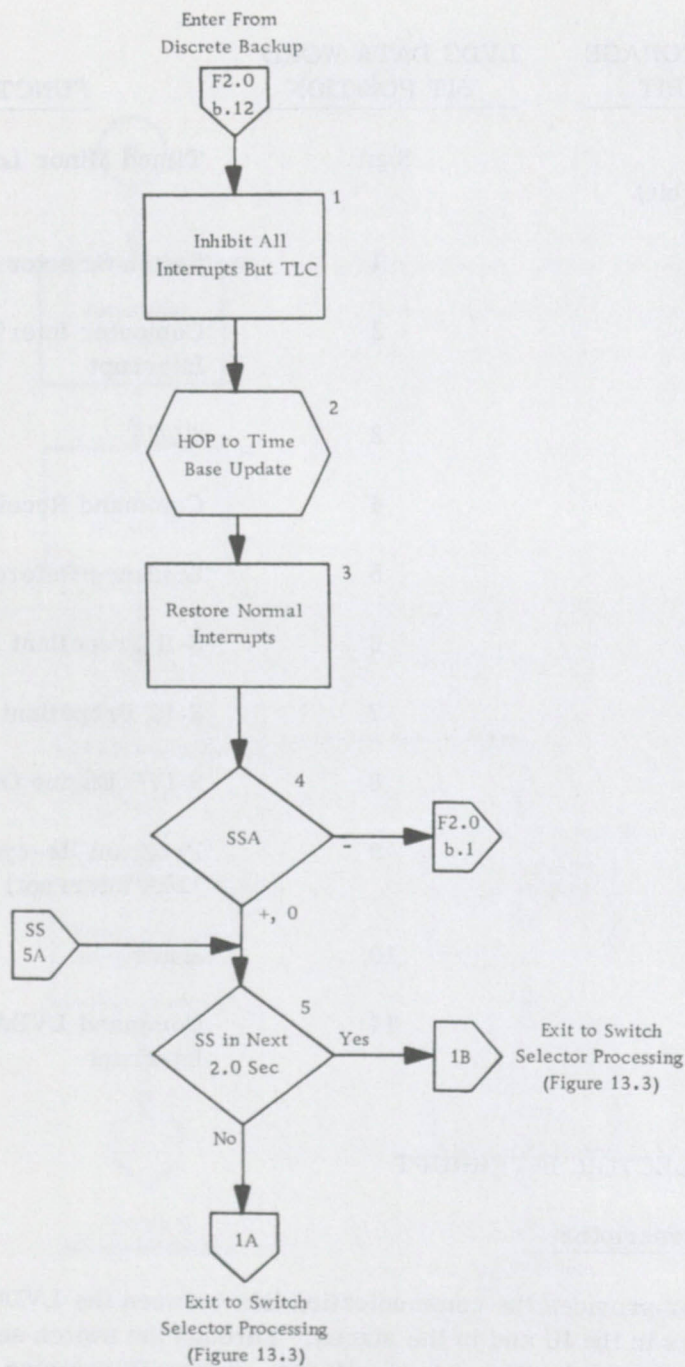


Figure 13.2 Boost Switch Selector Check
(This is block 13 of Figure 2.0)

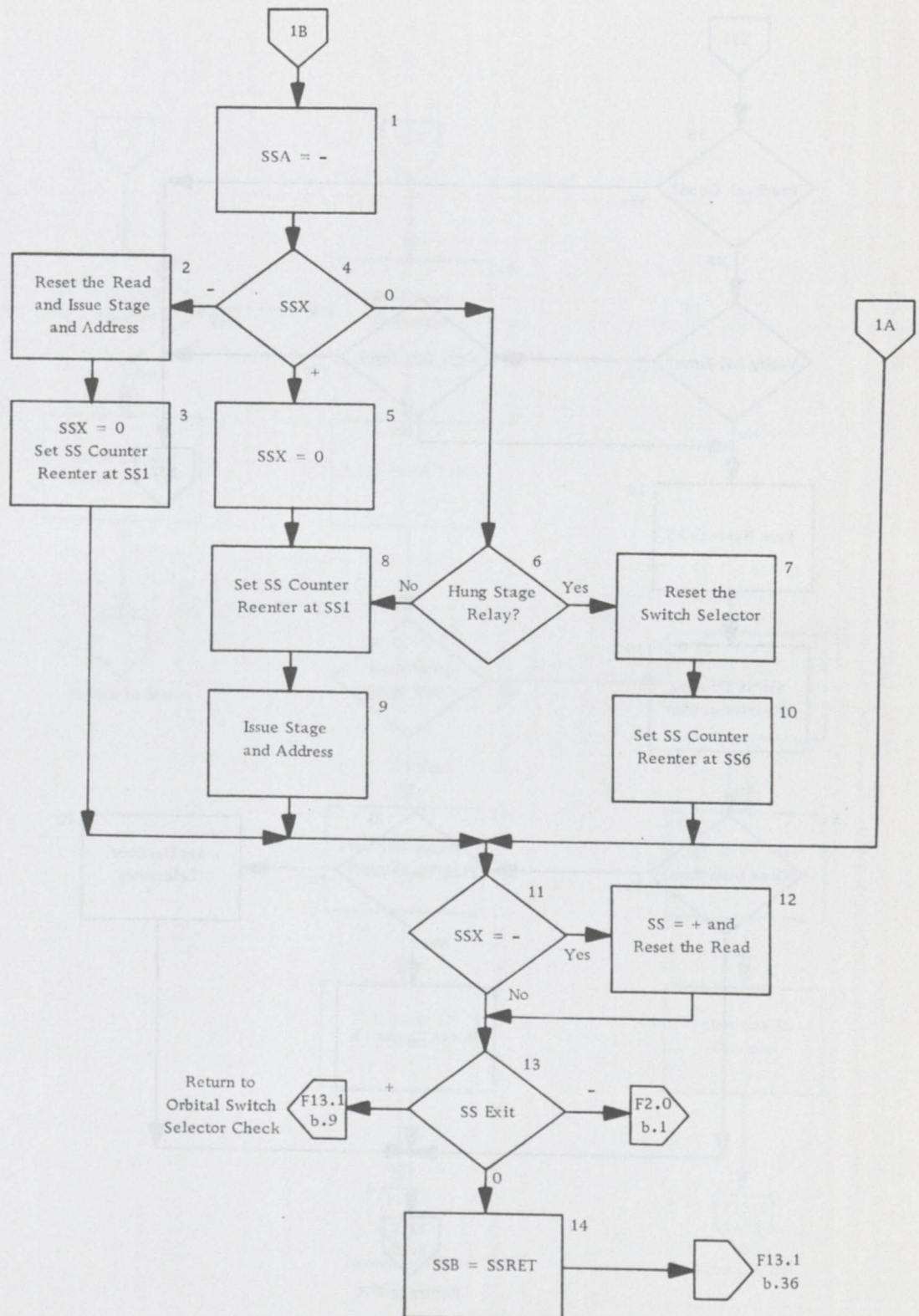


Figure 13.3 Switch Selector Interrupt Processing (Sheet 1 of 5)
(This figure is block 11 of Figure 13.1)

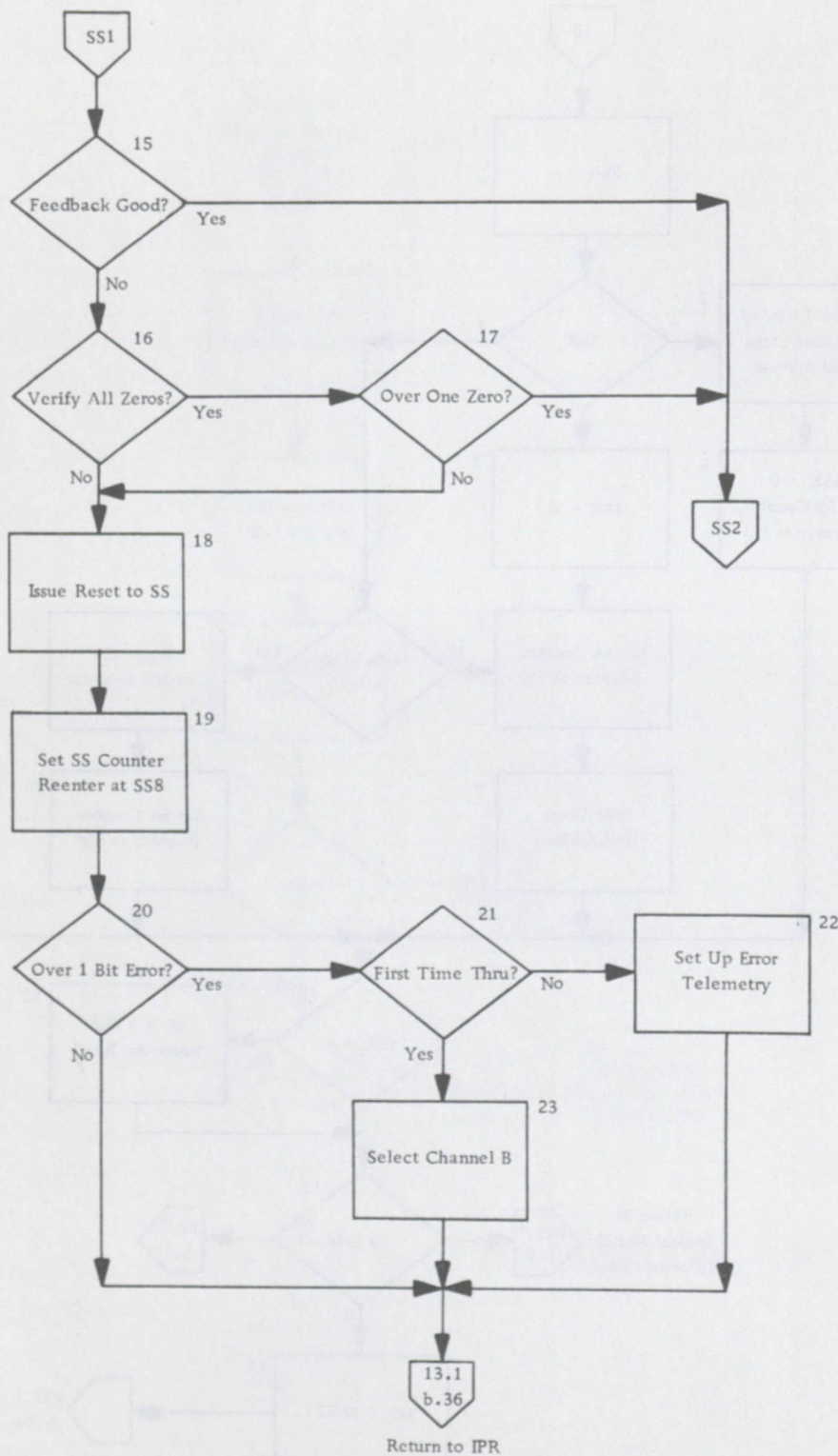


Figure 13.3 Switch Selector Interrupt Processing (Sheet 2 of 5)

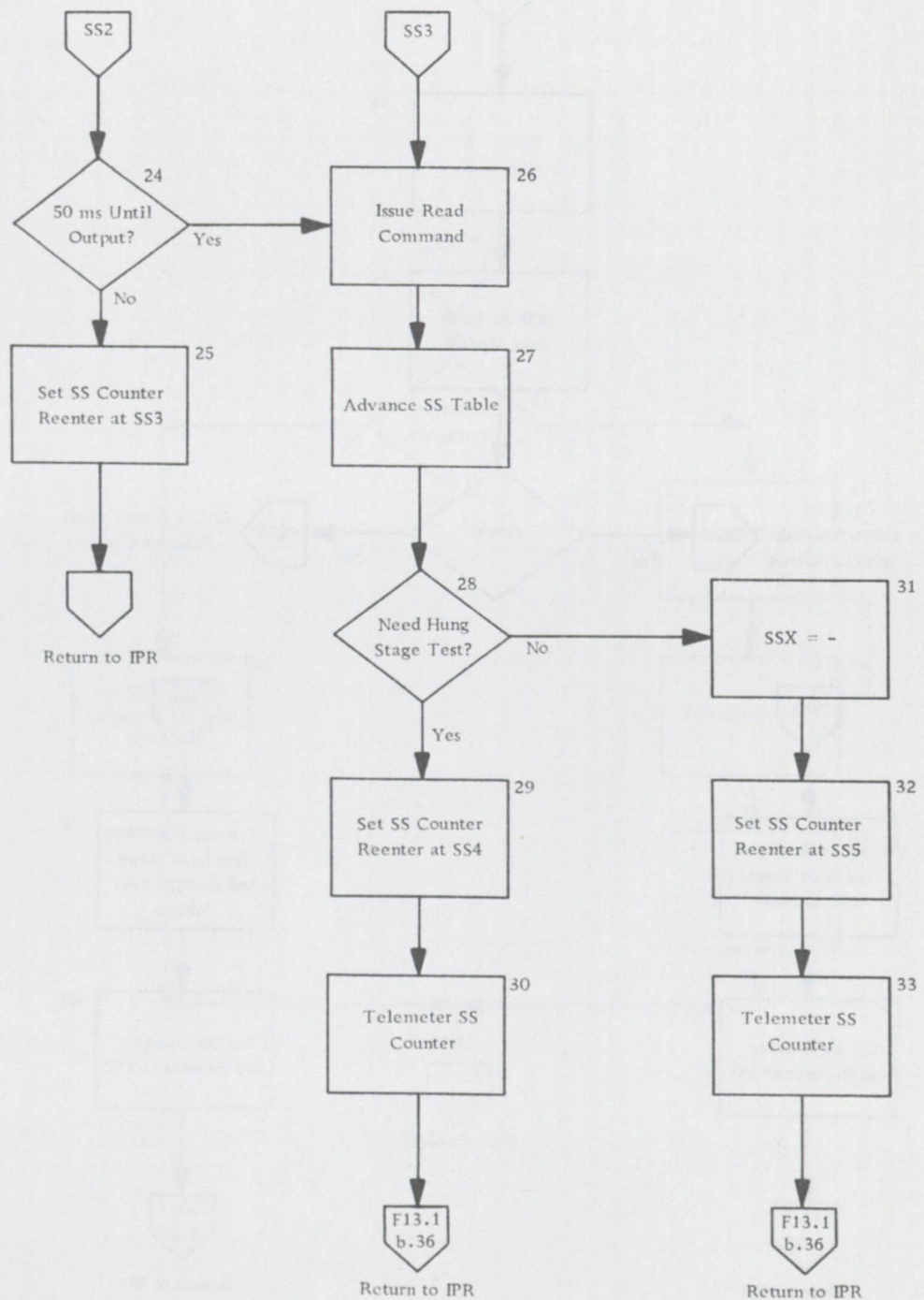


Figure 13.3 Switch Selector Interrupt Processing (Sheet 3 of 5)

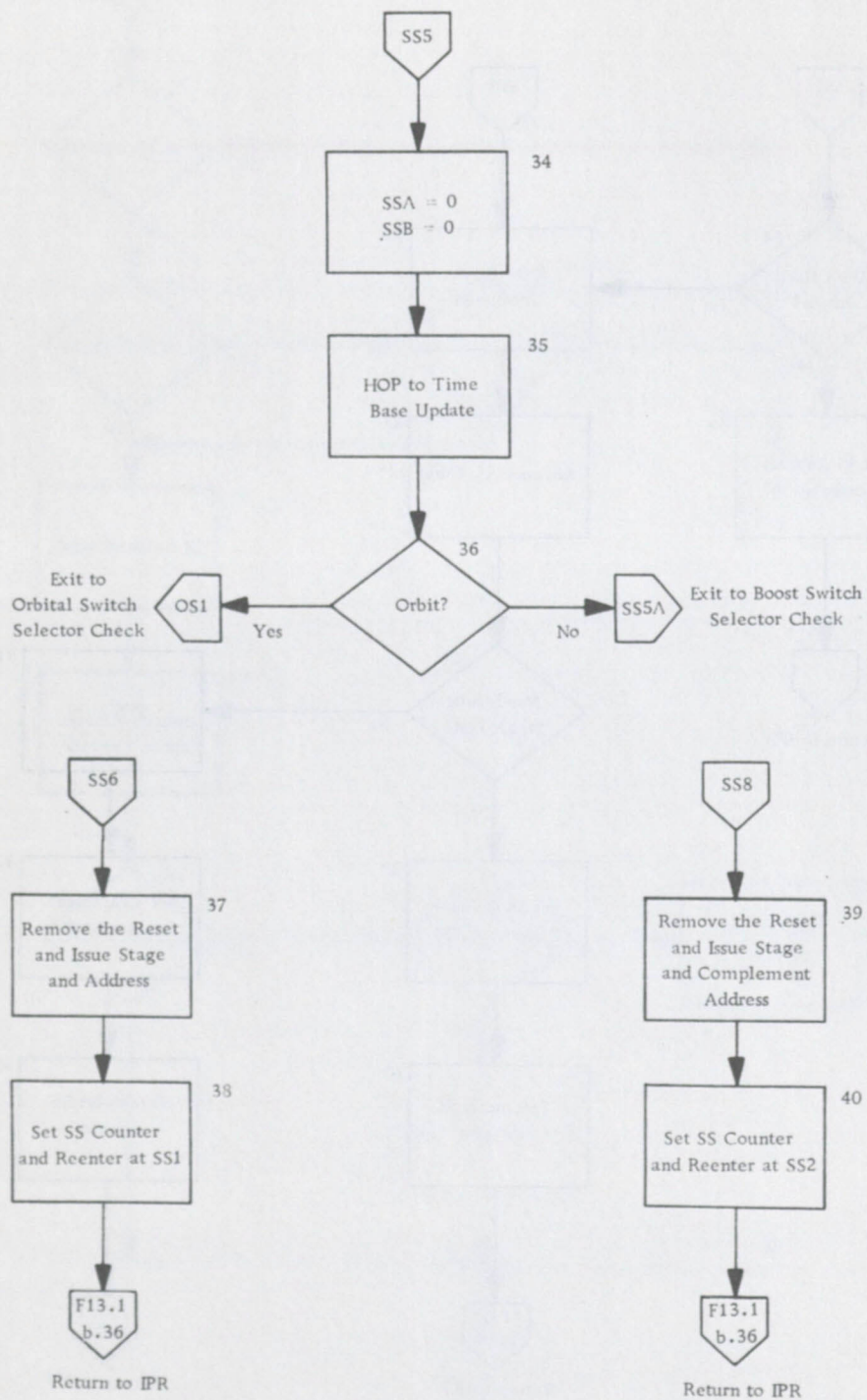


Figure 13.3 Switch Selector Interrupt Processing (Sheet 4 of 5)

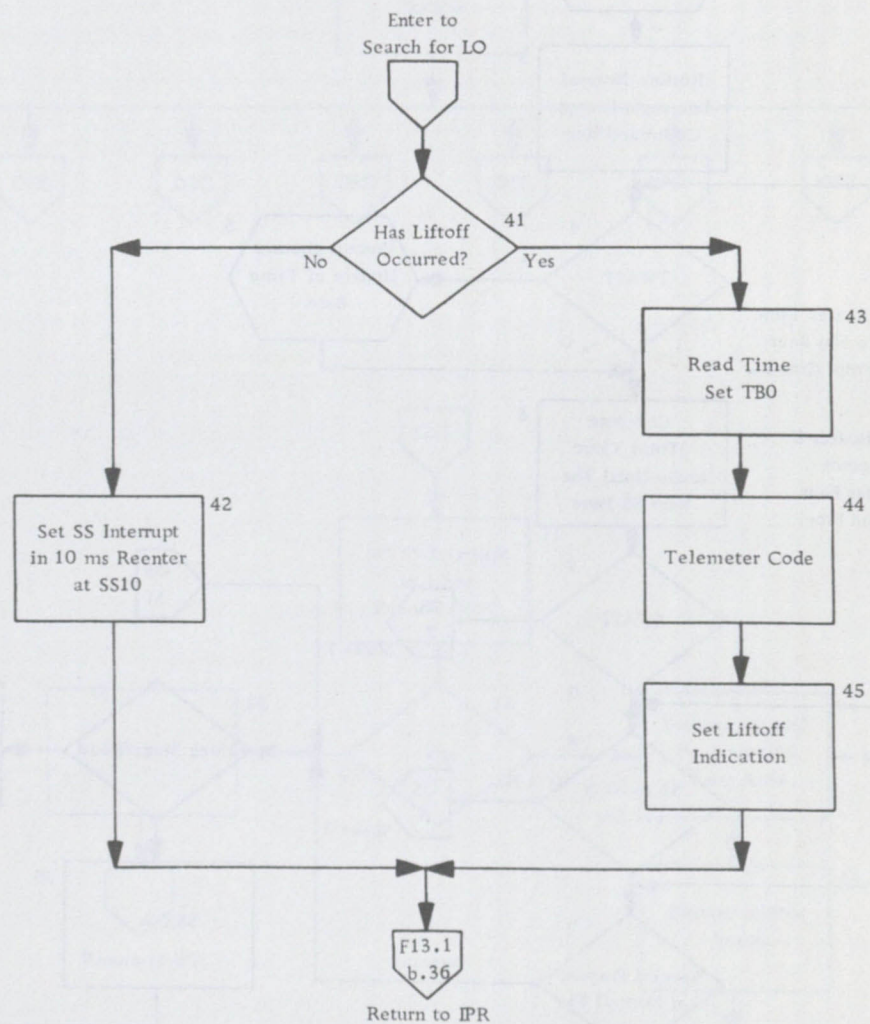


Figure 13.3 Switch Selector Interrupt Processing (Sheet 5 of 5)

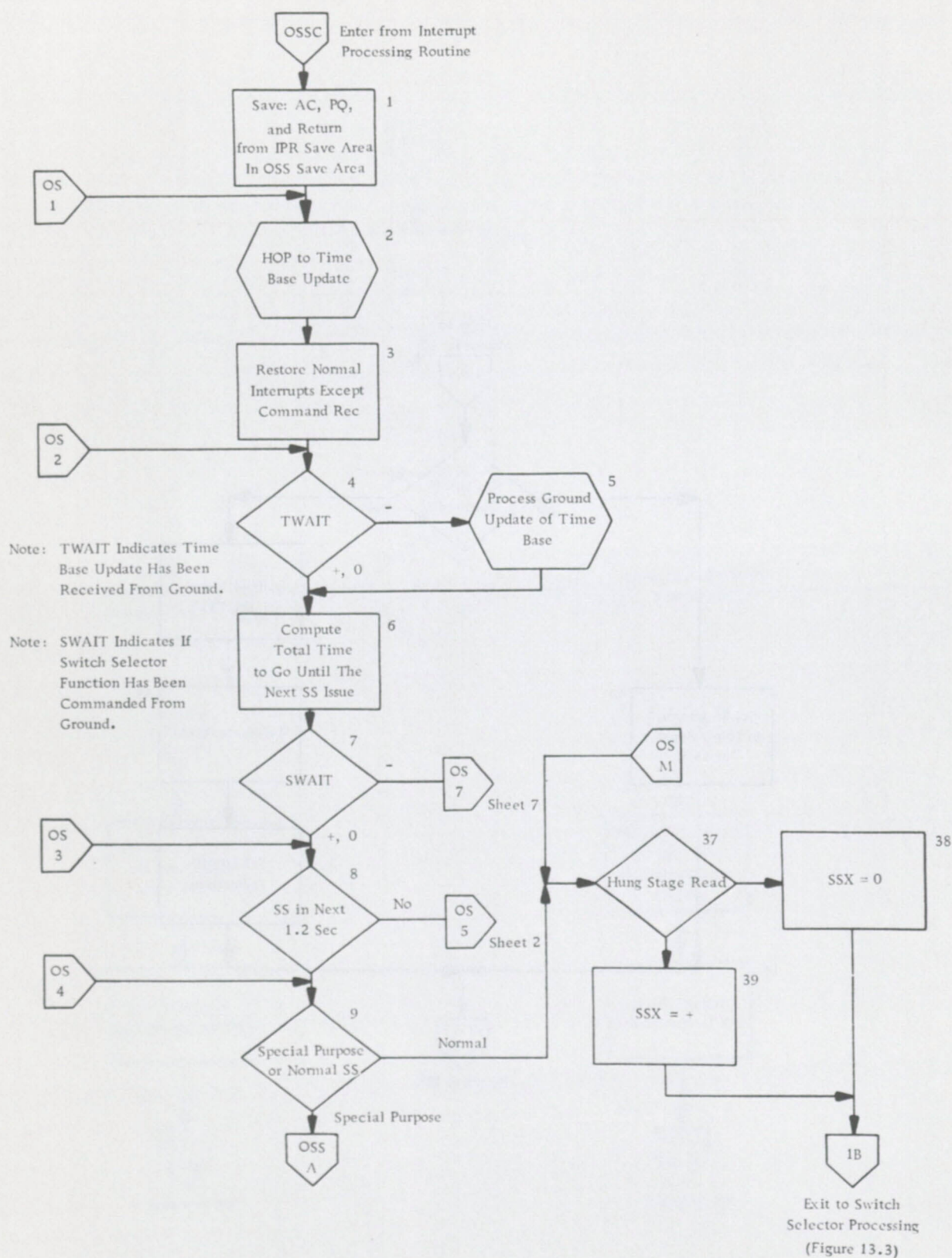


Figure 13.4 Orbital Switch Selector Check (Sheet 1 of 5)

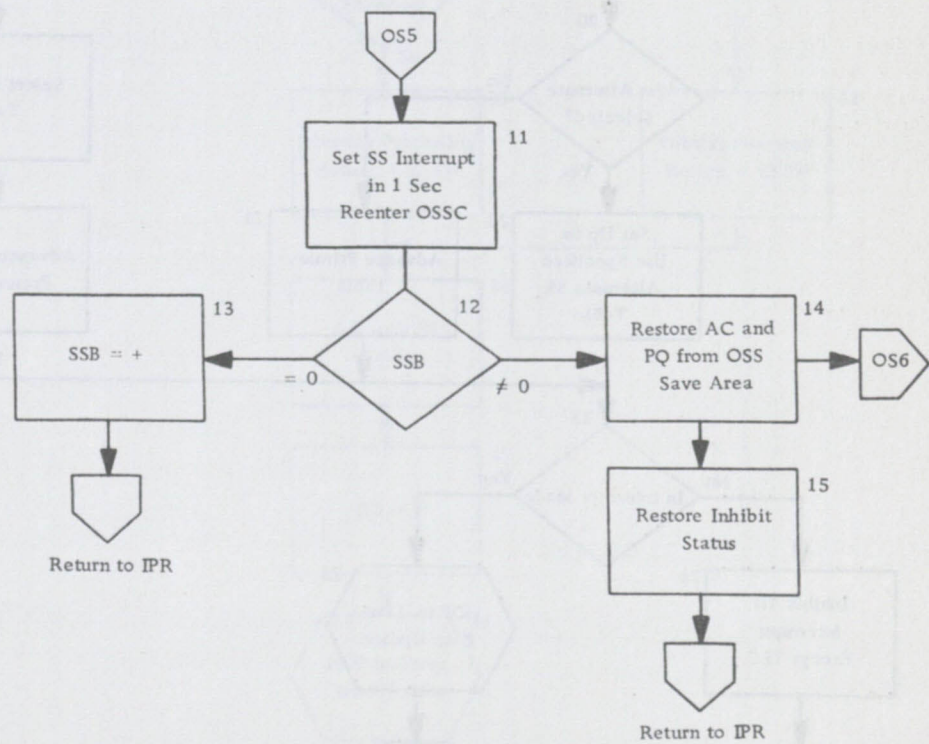
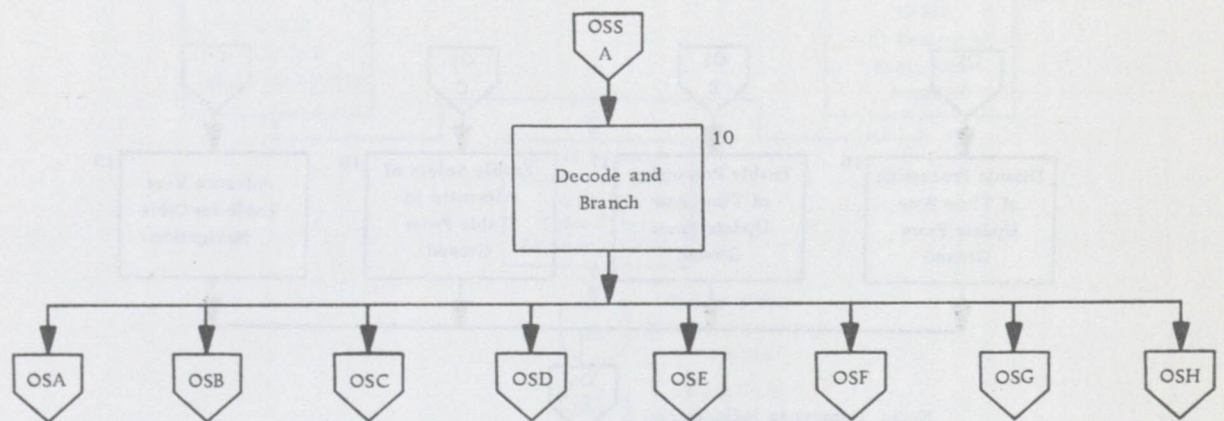


Figure 13.4 Orbital Switch Selector Check (Sheet 2 of 5)

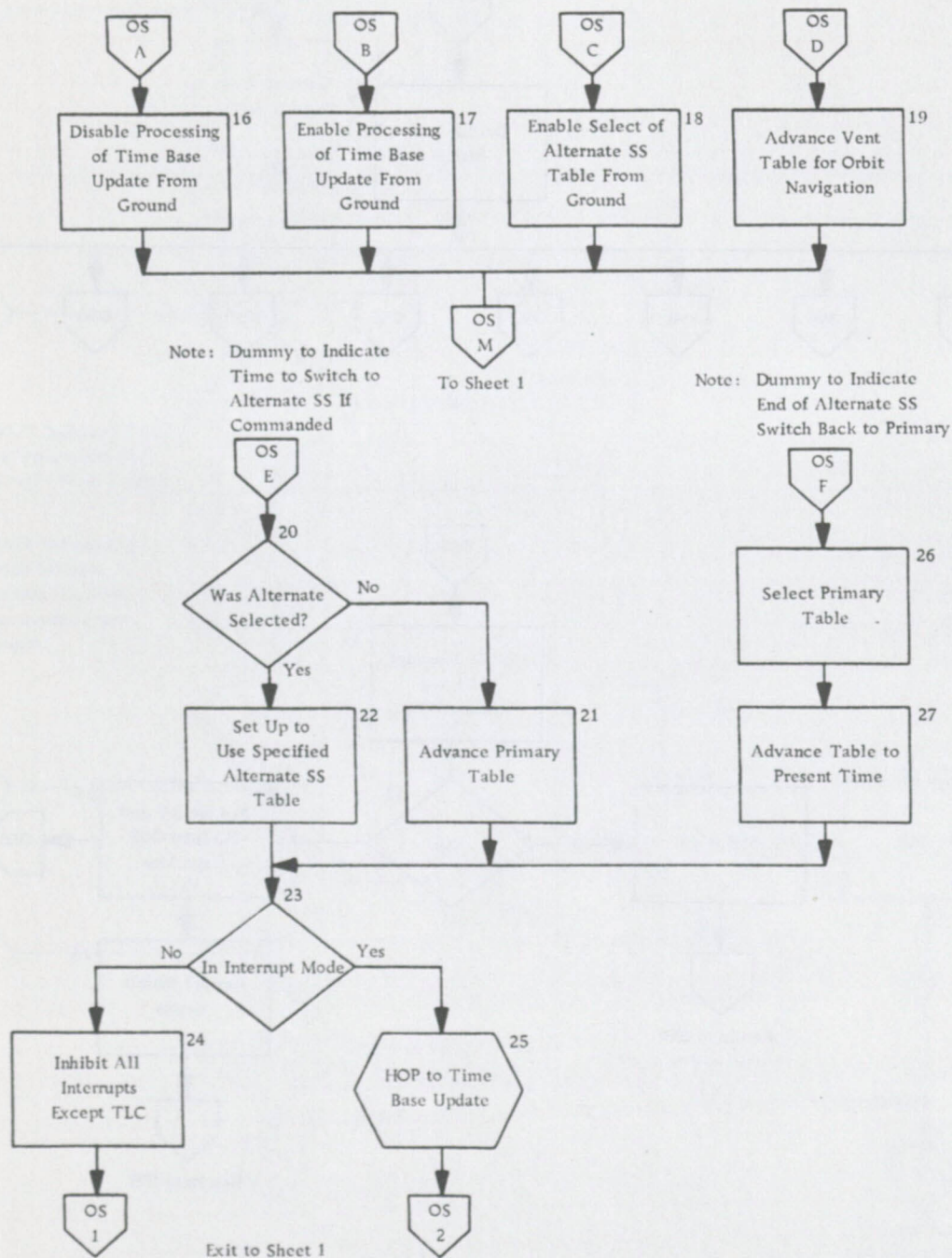


Figure 13.4 Orbital Switch Selector Check (Sheet 3 of 5)

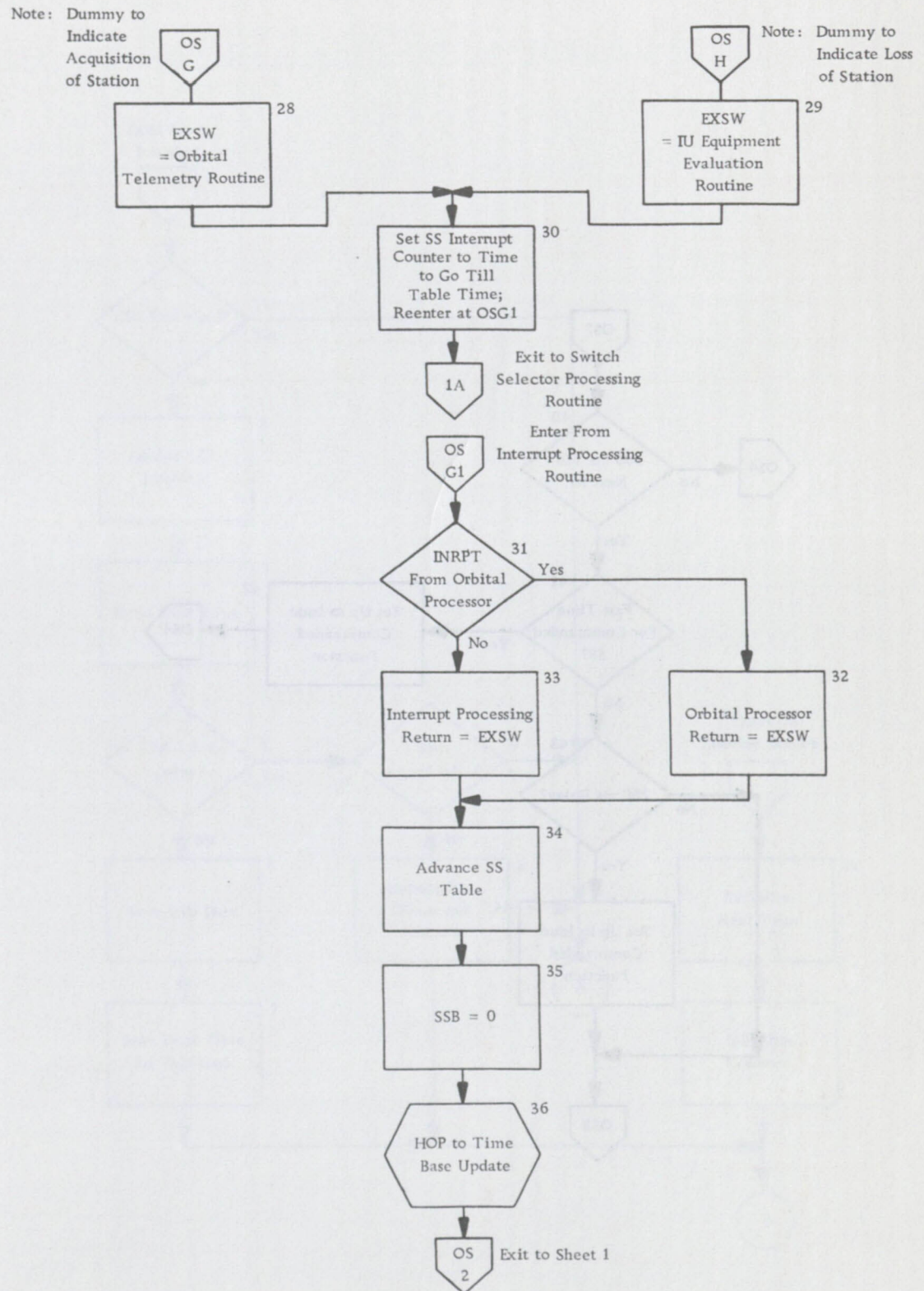


Figure 13.4 Orbital Switch Selector Check (Sheet 4 of 5)

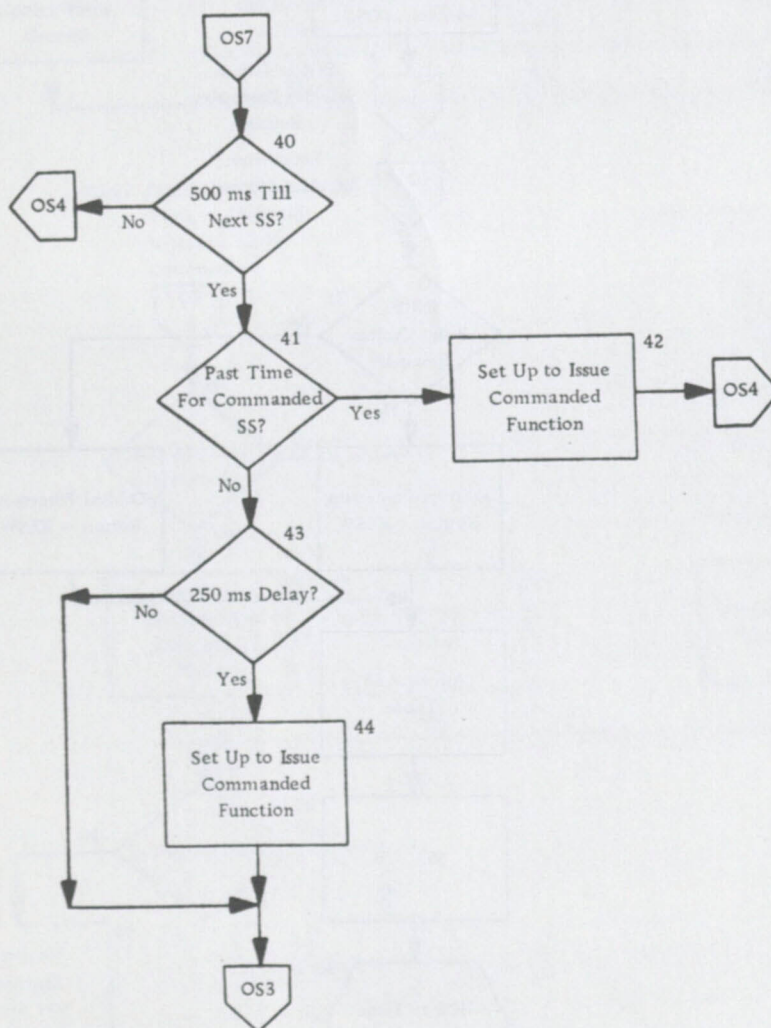


Figure 13.4 Orbital Switch Selector Check (Sheet 5 of 5)

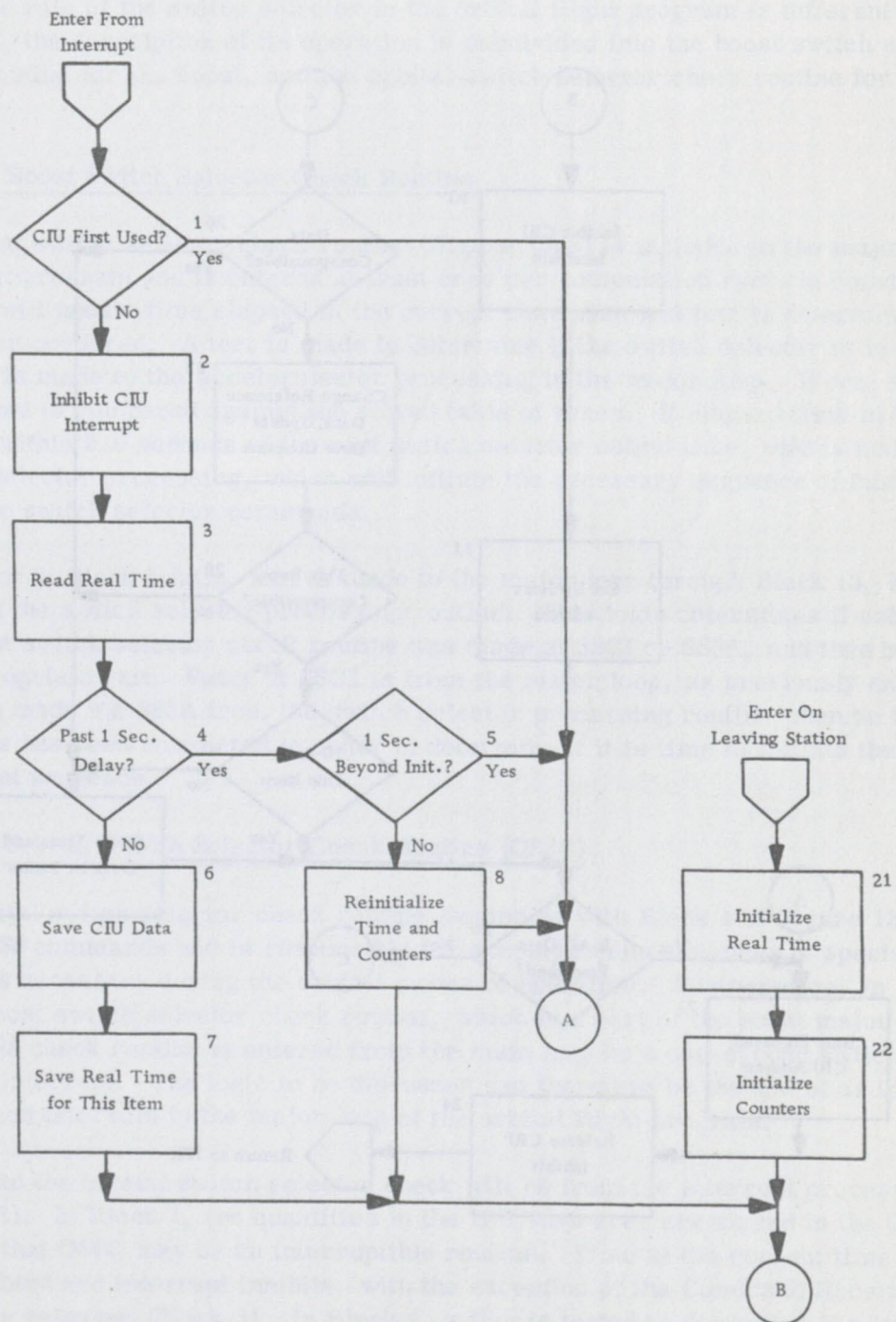


Figure 13.5 CIU Interrupt (Sheet 1 of 2)

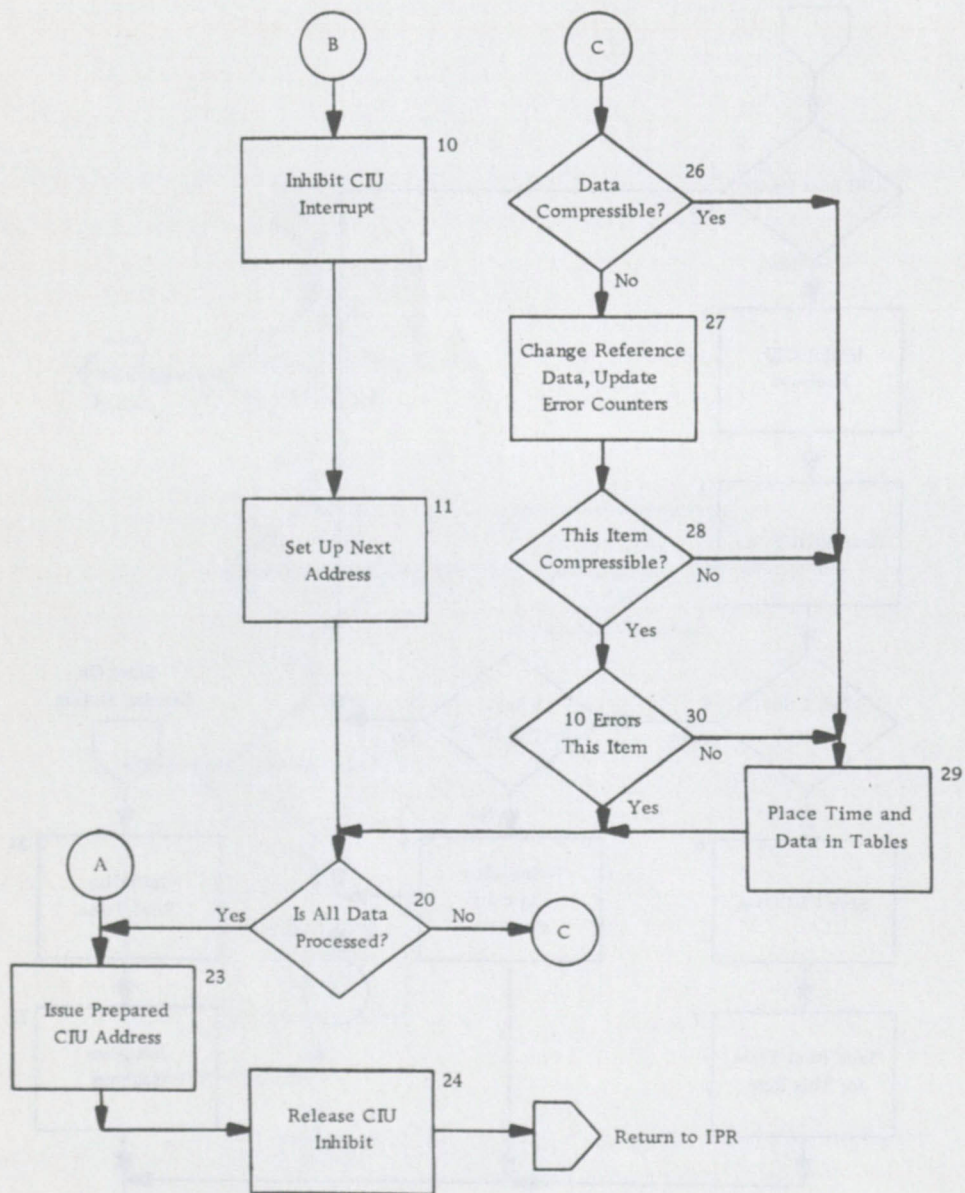


Figure 13.5 CIU Interrupt (Sheet 2 of 2)

the current time base against a prestored table of times. The second section of the logic performs the necessary functions to generate a switch selector output.

Since the role of the switch selector in the orbital flight program is different from that in boost, the description of its operation is subdivided into the boost switch selector check routine for the boost, and the orbital switch selector check routine for the orbital phase.

13.2.2 Boost Switch Selector Check Routine

The boost switch selector check routine (Figure 13.2) is included in the major loop of the boost program and is entered at least once per computation cycle in boost. This routine will update time elapsed in the current time base and test to determine if liftoff has occurred. A test is made to determine if the switch selector is in use. If it is, exit is made to the accelerometer processing in the major loop. If not, the updated time is compared against the stored table of times. If elapsed time in the time base is within 2.0 seconds of the next switch selector output time, exit is made to the switch selector processing, which will initiate the necessary sequence of functions to issue the switch selector commands.

If the test in Block 5 fails, exit is made to the major loop through Block 13, Figure 13.3, in the switch selector processing routine. This logic determines if entry to the boost switch selector check routine was made at SSCI or SS5A, and then branches to the appropriate exit. Entry at SSC1 is from the major loop, as previously explained. Entry is made via SS5A from the switch selector processing routine when an issuance sequence has been completed in order to determine if it is time to initiate the succeeding output sequence.

13.2.3 Orbital Switch Selector Check Routine (OSSC)

The orbital switch selector check routine (beginning with Block 1 of Figure 13.3) issues normal SS commands and is responsible for accomplishing a number of special purpose functions necessary during the orbital modes of operation. Furthermore, in contrast to the boost switch selector check routine, which is a part of the boost major loop, the orbital SS check routine is entered from the main loop by a one-second switch selector counter interrupt. The logic to be discussed can therefore be thought of as inserted at one second intervals in the major loop of the orbital flight program.

Entry into the orbital switch selector check will be from the interrupt processing routine (IPR). In Block 1, the quantities in the IPR save area are stored in the OSSC save area so that OSSC may be an interruptible routine. Time in the current time base is then updated and interrupt inhibits, with the exception of the Command Receiver interrupt, are released (Block 3). In Block 4, a flag is tested to determine if a time base update has been received from the ground. If so, the update is processed by a subroutine indicated in Block 5. In Block 6, an updated time in the time base is compared to

the table time (which may be biased by a fixed time if the time base has been updated from the ground), to determine total time to go till the next SS issuance time. In Block 7, a flag is tested to determine if a switch selector command has been requested by the ground.

If a switch selector has been commanded by the ground, transfer will be made to OS7 (Block 38). Time of issuance and stage and address information are made available to the switch selector routine by the command receiver routines. The command receiver routines also set the flag SWAIT to negative when information is received. Blocks 38 through 44 will process this information in such a manner as to insert the commanded function in the switch select sequence. If sufficient time (250 ms) is not available, the commanded function will be inserted at the first available point where such time is available.

Block 8 determines if current time is within 1.2 seconds of the next SS issuance time. If not, transfer is to OS5 (Block 11), where preparation is made to re-enter the routine in one second. Block 12 determines whether the routine was entered at ORBSSC via a 1-second interrupt, or through OS1, following the completion of a switch selector command issuance sequence. The appropriate exit is then chosen.

Next, if the test on Block 8 indicates that a SS output is due within the next 1.2 seconds, a test is made in Block 9 to determine whether or not a special purpose function is indicated by examination of the sign bit of the stage and address word from the sequence table. If the word is not tagged, a normal SS function is to be issued and control passes to the switch selector processing routine (Figure 13.3).

The format of a normal stage and address word is as follows:

S	1	2-6	7 - 14	15 - 25
0	0	Stage	Address	0-----0

If a special purpose function is to be indicated, the sign bit will be set to enable the test at Block 9 and the special purpose function will be coded in bits 15 through 25. In Block 10, these low order bits are decoded and the appropriate routine is entered to process the special purpose of function.

Paths OSA, OSB, OSC, and OSD are special purpose SS functions and will return to the switch selector processing routine at SS1 (Block 1 of Figure 13.2) to issue a switch selector command.

Paths OSE, F, G, and H are timing functions in the table which require no SS command output and will return to OS1 or OS2 test if another Switch Selector is due within the next 1.2 second (Figure 13.10). Exits OSA, OSB, OSC, OSE, and OSF are spares

associated with mission requirements of an earlier flight. Although no special purpose routines have been defined for these exits, they will be maintained as spares in the event that they may be required at a later date. The routine entered via exit OSD will still be used to update the pointer to a table of precomputed vent accelerations for use in the orbital navigation routine.

Paths OSA and OSB are special paths taken in the case that an alternate switch selector sequence has just been cycled, or an alternate sequence will be entered on the next SS interrupt.

Path OSC is encountered on critical sequences whose status will be monitored by the ground in order to determine whether to command an alternate sequence via the command receiver. Block 18, Figure 13.4 indicates that acceptance of an alternate sequence command is enabled at this time.

Path OSD is encountered when an event sequence is to be issued. A routine indicated by Block 19 updates the pointer to a table of precomputed vent accelerations for use in the orbital navigation routine.

Path OSE is taken when the decision must be made by the SS routine to cycle an alternate table or to continue with the primary sequence of events. The logic in Blocks 20 - 25 will disable the alternate select command from the ground and test a flag in Block 20 to determine if an alternate has been commanded. If so, the alternate specified by data from the ground is selected. If not, the primary table is advanced. The appropriate return is thus selected by Block 23.

Paths OSG and OSH of Block 10 are encountered when station acquisition is gained or lost, respectively. The logic in Blocks 28 through 30 will effect transfer to the orbital telemetry routine upon acquisition, and to the IU equipment evaluation routine upon loss of acquisition by forcing the interrupt processing routine or the orbital processor to exit to the proper executive. Both the orbital telemetry routine and the IU equipment evaluation program are interruptible on a non-return basis. The orbital processor, however, once initiated must be completed before switching can occur.

13.2.4 Switch Selector System Requirements

The primary sequencing requirement is the execution of various switch selector functions at the times listed on a sequence table prepared by NASA. The tolerance allowed in the execution of the functions is ± 50 milliseconds. The times are referenced to one of several time bases, each of which is defined to be zero when the LVDA (not the LVDC) recognizes the condition which initiates the time base. Any program or hardware interference (eg. the minor loop) which causes a delay in program recognition of the time base initiation signal causes an error in all switch selector functions. This error should be minimized and must not allow the timing of switch selector functions to exceed the ± 50 millisecond tolerance.

Some general ground rules concerning the minimum frequency of issuance of switch selector functions are described below. This frequency should be increased beyond the minimum ground rules. The maximum frequency limited by hardware is about 16 switch selector functions per second with no detected failures, and about 10 switch selector functions per second with a verify failure. Processing of switch selector functions should approach these maximums.

However, the system requirements are less severe than the hardware limits. With no failures detected, the sequencing system must have the capability of executing switch selector functions at a minimum rate of 10 functions per second. If an error is detected either in checking for a hung stage or verifying the switch selector address, the sequencing system must have the capability of executing switch selector functions at a minimum rate of 6.67 functions per second. These minimum rates include all normal flight program and hardware delays. Detected hardware failures not connected with the switch selector which cause the flight program to enter special recovery routines, such as gimbal angle reasonableness test failures and TLC interrupts, are not included in the timing requirements. When these recovery routines are in use, the switch selector rates stated above are not required.

The table of switch selector functions indicates the time in the time base when the "read" command for the function should be issued. If the final table lists functions at 150 millisecond intervals or greater, each function must be executed within the ± 50 milliseconds tolerance of the assigned execution time even with switch selector failures. This tolerance allows for inaccuracies in time base recognition, delays caused by hardware failures, and delays caused by program interference. If the final table lists functions at 100 millisecond intervals, the ± 50 millisecond tolerance applies only when there are no detectable switch selector failures. When failures occur, the functions should be executed as accurately as possible, but in the defined order. The actions described under program requirements tend to minimize the time delay caused by a switch selector failure.

The combination of timing delays, i.e., time base recognition delays, program interference, etc., tends to make switch selector functions late. Thus, in order to take advantage of the \pm nature of the tolerance attempts should be made to issue all switch selector functions 50 ms before their normal time. This will have two beneficial effects:

1. It will partially compensate for time base recognition and minor loop delays, and,
2. It will come closer to meeting the proper execution time on the 10/second functions when a verify failure has occurred.

13.2.5 Switch Selector Hardware Requirements

In order to activate one switch selector function, several switch selector operations are required. A switch selector operation is used here to mean an LVDC instruction which either loads the switch selector register in the LVDA or reads the feedback of the switch selector from the LVDA into the LVDC. Depending on the failures which are detected, different sequences of switch selector operations are required to execute a function. In some cases, the switch selector requires a minimum time delay between switch selector operations. Where minimum times are shown, they specify the time from the start of one switch selector PIO to the start of the next switch selector PIO.

13.2.6 Switch Selector Program Requirements

During the execution of a switch selector function, certain program operations are required. It is recognized that alternate program processing is possible for many of the switch selector operations. A discussion of the following procedures and available options is found in IBM-HE-65-258-078.

13.2.7 Hung Stage Test

Before the initial stage and address operation for a switch selector function, the program must assure that a "hung stage" will not cause a failure. A hung stage occurs when the stage select networks in a switch selector fail to reset after a read reset operation. The hung stage test is shown in block 6, in Figure 13.3.

A hung stage causes a possible failure only when the switch selector which failed to reset is different from the switch selector used in the next function. Therefore, it is possible to eliminate the hung stage test if the stage select to be used is the same as the previous stage select. Because of the timing required when the hung stage test is bypassed, special consideration for double stage select functions is necessary. If a single stage select function follows a double stage select function, the hung stage test is always required. But if a double stage select function follows a single stage select function which used one of the stages of the double stage select, the hung stage test may be bypassed. The bypass logic is shown in blocks 4, 5, 11, 12, and 28 to 30 of Figure 13.3.

The hung stage condition is detected by looking at the switch selector feedback (PIO 077). If this feedback does not contain zeros in the eight bit positions, a hung stage is assumed.

When a hung stage is detected, a program reset of the switch selector is executed as shown in blocks 7 & 10, 37 & 38, Figure 13.3. The next operation removes the reset and issues the stage and address. The hung stage test is performed a maximum of one time per switch selector function.

13.2.8 Verify Feedback

After the stage and address are sent to the switch selector, but before the read command, the switch selector feedback (PIO 077) is checked. If the function address was interpreted properly by the switch selector, the feedback is the ones complement of the address issued. In this case the next operation on the switch selector is the read command.

When the feedback does not equal the complement of the address issued, a program reset command is issued, except as discussed below under Zero Feedback. Before removing the reset command, the channel processing (described below) is accomplished. The next switch selector operation removes the reset and issues the stage and ones complement of the function address. The feedback is verified a maximum of once per switch selector function.

13.2.9 Zero Feedback

There is a simplex failure in the switch selector which does not affect the output but which causes the feedback to be all zeros. In order to prevent this failure from causing the sequencing program to take the long failure path, the feedback must be checked for all zeros. The all zero check must occur:

1. After the program obtains the switch selector feedback,
2. Either before or after the feedback is checked against the complement of the address used, and
3. Before the reset command is issued.

If the feedback is not all zeros, normal processing is continued. When the feedback is all zeros, an additional check is necessary.

When the address sent to the switch selector contains only one zero, a single failure which will affect the output of the switch selector can cause an all-zero feedback. Therefore, when an all-zero feedback is detected, the program must check the address originally issued to the switch selector. If this address contains only one zero, the program continues as if the feedback were not all zeros.

When the issued address contains more than one zero and the feedback is all zeros, the simplex failure is assumed. Since, in this case, the feedback verification test is not valid, the program proceeds as if the feedback equals the complement of the address.

13.2.10 Channel Switch

The address portion of the switch selector register in the LVDA can be set to use either of two channels: channel A or channel B. Channel switching is controlled by Internal Control Register Bit 12 (ICR 12).

Initially, channel A (ICR 12 = 1) is used for all switch selector operations. As shown in block 20 of Figure 13.3, following the detection of a verify feedback error, the zero feedback test, and the reset of the switch selector, a test to determine if the switch selector register should be changed to channel B is required.

In the channel switch test, the verify feedback from the switch selector is again compared to the ones complement of the function address. This comparison yields a count of the number of bit positions showing disagreement. If the disagreement count is one, no action is required. If the count is greater than one and the program has not previously switched to channel B, ICR 12 is changed from a one to a zero.

When a count greater than one is detected after the program has switched to channel B, bit 18 of mode code 24 is set and the telemetry words defined in Section 7 are assembled and sent. Even though an error has been detected, processing is continued. Since a failure in channel A is already suspected, the program continues to operate on channel B.

The reset operation is sent to the switch selector before the channel switch test. Therefore, the processing required in the test does not add to the total length of processing for a switch selector function. The test is performed a maximum of one time per function.

The logic flow for the verify failure, including the zero test and the channel switch, is found in blocks 15 through 23 in Figure 13.3.

13.2.11 DOM PIO

The special operation PIO 052 must be issued with the stage and address of the switch selector register in the LVDA. Before performing this operation, the program must make certain that a free word is available in the DOM to store the data generated. This PIO must be issued each time a different stage or address is used. This means that, in the event of a failure in the verify feedback, two DOM PIO's are issued for a single switch selector function.

The DOM PIO does not increase the processing time required for a switch selector function. The appropriate issuance times are shown following blocks 9 and 40 in Figure 13.3.

13.2.12 Switch Selector Telemetry

After the "read" command is issued to the switch selector, the sequencing program is required to telemeter the stage, address and time from the LVDC. The format and tag of this telemetry word are specified in the telemetry section. The time included in the word is the real time clock value when the read command is issued. The maximum allowable error in the clock value is +1 millisecond. If possible, the error should be constant.

Sequencing telemetry can be programmed such that it adds no time to the minimum between switch selector functions. The telemetry is indicated following block 27, in Figure 13.3.

13.3 COMPUTER INTERFACE UNIT INTERRUPT

The Computer Interface Unit (CIU) gives the LVDC access to PCM telemetry. The LVDA-CIU interface consists of 13 input lines to the CIU from the LVDA and 11 output lines from the CIU to the LVDA.

Twelve of the 13 input lines to the CIU are from the buffer register in the LVDA and are address lines. The thirteenth line is a data request line and originates at the orbital check ready latch. Of the 12 address lines, 2 are for multiplexer address, 4 are for frame address, and 5 are for channel and 1 for group address. The A & B groups correspond to the A & B multiplexer groups, respectively, and are interlaced to form one PCM frame. As indicated in Table 13.2, a logic "1" denotes a B group multiplexer, a logic "0" an A group multiplexer.

Ten of the 11 output lines to the LVDA are for parallel transfer of a 10-bit PCM word to the LVDA. The eleventh is an interrupt line. All PCM telemetry passes through the CIU. Data is requested from the CIU under program control. When the computer program directs the computer to request a telemetry word, a 12-bit parallel address is presented to the CIU. A data request bit originating in the orbiting check ready latch must appear on the thirteenth line to the CIU, accompanying the 12-bit address, for the CIU to honor the data request. The CIU locates the requested word in the PCM format and generates an interrupt signal over the eleventh output line to the LVDA. The computer recognizes the interrupt and enters the interrupt processing routine as soon as it has finished the previous instruction, as described above. When the computer requests another PCM word, even if it is the same word, a new 12-bit address must be issued, accompanied by a data request.

The orbital check ready latch is set by program control when the CIU address is issued, but is reset upon receipt of the CIU interrupt by the interrupt circuitry. However, there is no provision in the LVDA/LVDC circuitry either for inhibiting use of the buffer register for its normal telemetry between the time the CIU is addressed and the time the CIU interrupt is received by the computer, or for releasing the buffer register for its normal functions after the requested data has been received. The data

TABLE 13.2 LVDA BUFFER REGISTER-CIU ADDRESSING RELATIONSHIP

LVDA Buffer Register	CIU Address Bit	Definition
Position 26	No. 1	Logic "1" equal group B multiplexer Logic "0" equal group A multiplexer
25	No. 6	High order channel address bit
24	No. 5	Channel address bit
23	No. 4	Channel address bit
22	No. 3	Channel address bit
21	No. 2	Low order channel address bit
20	No. 10	High order frame address bit
19	No. 9	Frame address bit
18	No. 8	Frame address bit
17	No. 7	Low order frame address bit
16	No. 12	High order commutator address bit
15	No. 11	Low order commutator address bit
14		Spare
13		Spare
12		Spare

output multiplexer is automatically inhibited by the CIU address but the accumulator is not. Hence, it will be necessary to inhibit the buffer register under program control from the time the CIU is addressed until after the requested data has been received.

The CIU routine (Figure 13.5) will be required to address the CIU with the codes specified in Section 16, and at the rate defined therein. The data thus obtained, via the CIU interrupt, will be processed and compressed by this routine as described in the same section. This routine will be executed once per second whenever the vehicle is not over specified ground stations. It will not be executed when the vehicle is over these specified ground stations. The routine when executed will address and process approximately 13 quantities each second.

The CIU routine is entered and initialized from a dummy entry in the switch selector table. First entrance occurs just after loss of the first ground station and after loss

of every specified ground station thereafter. Exit from the routine is accomplished in a similar manner (dummy entry in switch selector table whenever the vehicle comes within view of a specified ground station). Once the routine has been initialized, it will keep itself going by causing a CIU interrupt to occur every 83 milliseconds. This interrupt will return control to the CIU routine, where a clock is checked to see if it is time to reenter the CIU routine. If it is not time, control is returned immediately to the orbital flight program.

The CIU routine will obtain all required PCM data in each one-second interval before processing and compression takes place. All data received during the CIU read portion of the routine is processed; items falling outside of the established limits as well as certain data which is time-compressed are placed into locations in LVDC memory which will be telemetered when the vehicle is over a specified ground station. Requirements for telemetering these quantities appear in Section 15.

When leaving a ground station, the orbital telemetry routine will initialize flags and constants in the CIU routine such that the last CIU quantities sampled will become the standard values for subsequent compression in that compression period.

TABLE 13.3 LVDA DISCRETE INPUT - CIU DATA OUTPUT RELATIONSHIP

<u>LVDA Input Position</u>	<u>CIU Output Position</u>	<u>Definition</u>
TS 10	2^9	High order bit telemetry data word
TS 9	2^8	Data Bit
TS 8	2^7	Data Bit
TS 7	2^6	Data Bit
TS 6	2^5	Data Bit
TS 5	2^4	Data Bit
TS 4	2^3	Data Bit
TS 3	2^2	Data Bit
TS 2	2^1	Data Bit
TS 1	2^0	Low order bit telemetry data word

TABLE 13.4 LVDA TAG REGISTER DECODING AND DATA FORMAT

<u>Data Name</u>	<u>Tag Register Position</u>	<u>Real Time Register Position</u>	<u>Buffer Register Position</u>
	8 7 6 5 4 3 2 1	5 4 3 2 1	26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
LVDA-CIU	1 0 1 0 0 0 X X	V M ₃ M ₂ M ₁ A ₁	CIU Address (Table 1) X X X X X XXXXXXXXXXXX
LVDA-CIU Feedback	0 0 1 1 0 1 0 1	Real Time	10 9 8 7 6 5 4 3 2 1 X X X X X X X XXXXXXXXXXXX

X - Insignificant Bit or not used, can be logic 0 or logic 1

M - Mode Bit

V - Validity Bit

A - Address Bit

13.4 TLC - SIMULTANEOUS MEMORY ERROR

A TLC interrupt indicates that an error is present in both duplex memory locations containing a data or an instruction word. In the processing of this interrupt, real time should be sent to the ground together with the HOPSAVE constant. The latter indicates the instruction being executed at the time of the interrupt. Any other information likely to be of use in locating the source of the failure should also be telemetered. After this interrupt has been processed (i. e., time and HOPSAVE telemetered) the program will return to the minor loop support routine in the flight program.

13.5 COMMAND RECEIVER INTERRUPT

The command receiver will receive and demodulate phase-modulated command messages from the ground command stations and transmit them to the command decoder. The decoder decodes the command message, verifies correct vehicle and decoder address and correct digital format, and presents the data-bearing position to the LVDA.

The format of the 35-bit command word has been specified as follows:

<u>BIT NUMBER</u>	<u>BIT</u>
1-3	Vehicle Address
4-6	Decoder Address
7	LVDC Information Bit 14
8-9	LVDC Interrupt Bits
10	LVDC Mode/Data Bit
11	Decoder Address
12	LVDC Mode/Data Bit
13-14	LVDC Information Bits 13 & 12
15-18	Decoder Address
19-24	LVDC Information Bits 11-6
25	Decoder Address
26-30	LVDC Information Bits 5-1
31-35	Decoder Address

The system bit rate is 0.2 kc. Each bit will be composed of five subbits (system subbit rate is 1.0 kc). There will be three types of subbit patterns, corresponding to "0", "1" and vehicle address, respectively.

The three vehicle address bits address the IU command system. The two LVDC interrupt bits are ANDed together in the LVDA, as are the two orbital mode/data bits. For an interrupt to occur, the two interrupt bits must both be "1".

There will be two types of command words: mode words and data words. A mode command word indicates the command routine to be executed. Data command words satisfy the data requirements of the particular command routine. For mode command words, the two mode/data bits are both set to "1". Data command words are denoted by the OM/D bits both set to "0". If the ANDed OM/D bits disagree, an error message will be telemetered. Every time the LVDC enters a commanded routine (as denoted by the mode command word received), it will telemeter a status word. The general format for all status words is:

Tag - 8 bits	One unique code for all status words	
Validity - 1 bit		
Address - 1 bit		
Mode - 3 bits		
Buffer Register:		
Bits 26-15		
Bits 14-8	True	(Last 14 bits received)
Bits 7-1	Complement	(from decoder)

The LVDC will normally be executing its main orbital program prepared to receive a mode command. When interrupted by the command decoder, the LVDC will, under program control:

- a. Verify that the 2 OM/D bits are both "1" for the mode command word (the first word to be received), and "0" for all subsequent words received.
- b. Test the format of the command word and verify that bits 14-8 are complementary to bits 7-1.
- c. Decode bits 14-8 and verify that a meaningful command word has been received (i. e., one of the set of specified codes).

If these criteria are satisfied for each command word received by the LVDC, a 60-ms pulse, the Computer Reset Pulse (CRP), will be sent by the decoder to the 301 PCM telemetry assembly, where it will be sampled by PCM telemetry as a discrete at the maximum rate (240 times per second) and telemetered to ground as a PCM measurement. In addition, a status word indicating that the LVDC has entered the commanded routine will be sent twice at the maximum LVDC telemetry rate after the LVDC has

received the initial mode command word. The CRP will reset the decoder, making it possible for the next command word to be received. The next command word will not be transmitted unless the CRP is received. Each time the LVDC successfully receives a command word, it will return to the main orbital program, prepared to receive the subsequent command word. Between successive command words, the LVDC is free to perform other functions under program control.

If these criteria are not satisfied for each command word received, the LVDC will disregard the information contained in the word, telemeter an error message twice at the maximum LVDC telemetry rate, and increment an error counter. The CRP will not be issued and the decoder will not be reset, and the word will be re-transmitted. One unique combination of the LVDA's 8 tag bits will be telemetered for all error messages. The error message will be found in the data portion of the LVDC telemetry word. Each error that can be detected by the LVDC will have a unique message. Whenever possible, data that would be helpful in ground evaluation of the failure will also be included. The error counter will also be included. The following general format will be used for all error messages:

Tag	8 bits	One unique code indicating an error message is contained in the data.
Validity	1 bit	
Address	1 bit	
Mode	3 bits	
Buffer Register:		
	Bits 26 - 18	Unique code for each different error
	Bits 17 - 15	Error counter
	Bits 14 - 1	Data for evaluation of failure

Each time the LVDC fails to receive a given command word, it will increment an error counter and return to the main orbital program. The CRP will not be sent by the decoder, the decoder will not be reset, and the same word will automatically be retransmitted. If the error counter ever reaches seven for a given word, the LVDC will terminate the routine it was executing at the time, set the count to zero, and return to the main orbital program, prepared to receive a new mode command word. Each time the LVDC successfully receives a given command word, the error count will be reset to zero and the LVDC will be prepared to receive the next command word.

In any transmitted command, the initial mode command word will direct the LVDC to the desired routine. Once it has entered this routine, the only mode command word it will honor is the Terminate command, until it has received all data command words required for the routine and has executed all of the functions directed by the mode command word, or until a given word has failed to be received by the LVDC seven consecutive times. A Terminate command will direct the LVDC to immediately terminate the

command routine being executed, clear the error counter, and return to the main orbital program, to receive a new mode command word. The ground station will automatically issue a Terminate command when the error count for a given word equals seven.

If the LVDC is commanded into a routine requiring a variable number of data command words, an Execute command will be required to indicate that all data has been transmitted. For routines requiring a fixed number of data commands, the LVDC will automatically complete the routine when the last data command word has been successfully received.

Five specific command routines have been derived for AS-501:

1. Update Sequence Time Base
2. Navigation Update
3. Generalized Switch Selector
4. Sector Dump
5. Telemeter Single Memory Location

These routines are discussed in detail in the subsections below.

In Figure 13.6 is shown a functional diagram of the LVDA/LVDC and command receiver/decoder. In Figure 13.7 and 13.8, the digital formats for the mode command words and error messages are shown, respectively.

13.5.1 Update Sequence Time Base

This routine will provide the ground stations with the capability of altering the starting time of the communication sequence by altering time base 5. The format for the commands is shown in Figure 13.7.

Upon entry into this routine, the LVDC will telemeter the "Update Time Base" status code twice, and then return to the main orbital program, prepared to receive a data command or a "Terminate" mode command. When next interrupted by the command decoder, the LVDC will examine the mode/data bits. If a mode is indicated, the LVDC will accept only a "terminate" command. Any other mode will cause the LVDC to: (a) increment its error count, (b) telemeter an error message indicating that the OM/D was incorrect (mode received instead of data), and (c) return to the main orbital program.

When a valid data command is received, the LVDC will determine if the orbital program has started its communication sequence for that ground station. If the sequence has been started, the LVDC (a) will format the data for the main orbital program, (b) set a flag indicating that the main program is to increment or decrement time base 5 with

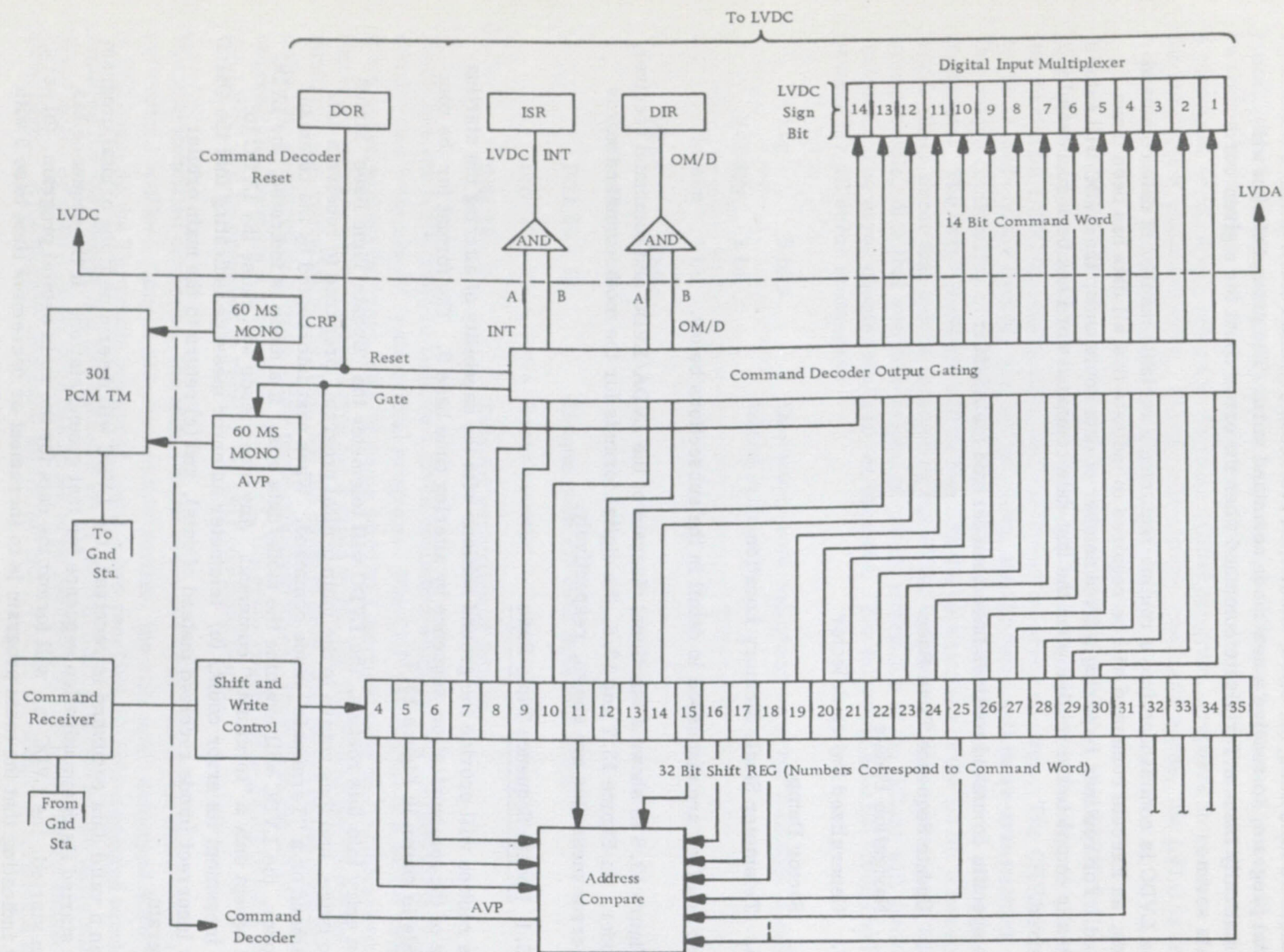


Figure 13.6 Functional Diagram of LVDC/LVDA Command Decoder

MODE COMMAND

- Name

14 Bit Command Word Transferred to LVDA/LVDC							
BIT 14	13	12	11	10	9	8	7
0	0	0	0	0	1	0	Complement of 14-8
0	0	0	0	1	0	0	
0	0	0	0	1	1	0	
0	0	0	1	0	0	0	
0	0	0	1	0	1	0	
0	0	0	1	1	0	0	
0	0	0	1	1	1	0	
0	0	1	0	0	0	0	
0	0	1	0	0	1	0	
0	0	1	0	1	0	0	
0	0	1	0	1	1	0	
0	0	1	1	0	0	0	
0	0	1	1	0	1	0	
0	0	1	1	1	0	0	
0	1	0	0	0	0	0	
0	1	0	0	0	1	0	

- Spare
- Spare
- Spare
- Spare
- Spare
- Spare
- Spare
- Update Sequence Time Base
- Navigation Update
- Generalized Switch Selector
- Sector Dump
- Telemeter Single Memory Location
- Memory Update (Not Used)
- Systems Checkout
- Terminate
- Execute

Figure 13.7 Digital Formats For Mode Command Words

ERROR MESSAGES (Preliminary)

TAG - 8 bits	Validity Mode A1	26	25	24	23	22	21	20	19	18	17	15	14	8	7	1	Error Messages
		0	0	0	1								COMMAND		WORD		1
Same for		0	0	1	0						Error		Failure Data				2
all Error		0	0	1	1						Counter		Failure Data				3
Messages,		0	1	0	0						Bit 15		Failure Data				4
to be de-		0	1	0	1						is Least		Failure Data				5
fined		0	1	1	0						Signifi-		Failure Data				6
		0	1	1	1						cant		Failure Data				7
		1	0	0	0												8
																	9
																	10
																	11
																	12
																	13
																	14

Error Messages

- | | |
|-----------------------------------|-----------------------------------|
| 1. OM/D Incorrect - Received Data | 5. Sequencing Bit Incorrect |
| 2. True - Complement Failed | 6. Sector End Less than Beginning |
| 3. Mode Invalid | 7. Spare |
| 4. OM/D Incorrect - Received Mode | 8. Spare |

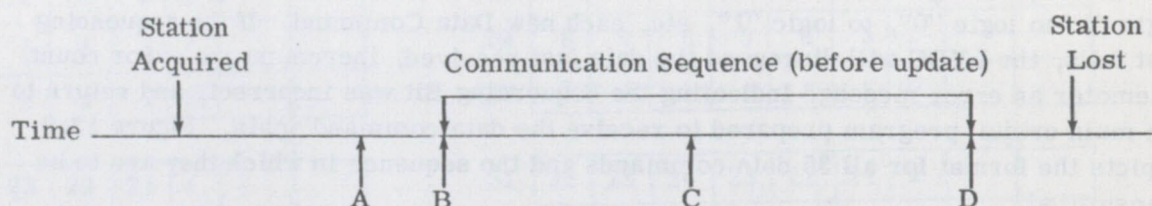
Figure 13.8 Digital Formats for Error Messages

the data just formatted as soon as it finishes the sequence for that ground station, and (c) return to the main orbital program. In the event that the increment is of such a value that a function in the sequence would be omitted if the time base were adjusted that much, the LVDC would adjust the time base no more than to the beginning of the sequence.

If more than one "Update" is received by the LVDC after the communication sequence has started, only the last "Update" will be effective. All updates received before the start of the sequence will be effective. The following diagram illustrates the various alternatives. The LVDC will return to the main orbital program after altering time base 5.

Example 1: LVDC receives Data Command at A — Adjusts Time Base by value of data, or goes to B — whichever is less.

Example 2: LVDC receives Data Command at C Orbital Program Updates at D.



The format for the data command is:

14	13	12	11	10	9	8	7 6 5 4 3 2 1
SIGN	DATA	DATA	DATA	DATA	DATA	1	COMPLEMENT OF 14-8

Low order bit (9) is equivalent to 4 seconds. Logic 1 in the sign position signifies a decrement of time base 5, logic 0 signifies an increment to time base 5. The magnitude of acceptable "Update" increments or decrements will be program limited by a preset constant.

13.5.2 Navigation Update

This routine will provide the ground station with the capability of loading six navigation parameters and an execution time into the LVDC. Instead of replacing the navigation parameters in the LVDC's navigation routine with updated data, the LVDC will store the six navigation parameters and time in pre-determined locations. This data will later be telemetered by ground command for comparison and will not be used for flight update directly.

Upon entry into this routine, the LVDC will telemeter the "Navigation Update" status code twice and return to the main orbital program, prepared to receive 35 data

commands or the Terminate mode command. The general format of a data command is:

14	13	12	11	10	9	8	7	6	5	4	3	2	1
DATA ← → DATA						SEQ. BIT	COMP ← → COMP						

Since only 6 information bits are transmitted in one data command, 5 transmissions will be required to formulate one 26-bit LVDC word. Therefore, the LVDC must form a word after every 5th transmission until all seven words are formed. The seven LVDC words will be stored in pre-determined locations. This routine will be finished after the LVDC receives the 35th valid data command and forms the seventh LVDC word. The LVDC returns to the main orbital program after completion of this routine.

As the LVDC is receiving the data commands, it must test the OM/D bit, make true-complement tests, and test for a Terminate command. In addition, the LVDC will test the Sequencing Bit (bit 8 of the command word) to verify that it sequences from logic "1" to logic "0", to logic "1", etc, each new Data Command. If the sequencing test fails, the LVDC will disregard the data just received, increment the error count, telemeter an error message indicating the Sequencing Bit was incorrect, and return to the main orbital program prepared to receive the data command again. Figure 13.9 depicts the format for all 35 data commands and the sequence in which they are to be transmitted.

13.5.3 Generalized Switch Selector

The routine will provide the capability to execute any S-IVB or IU switch selector function on command from the ground station.

Upon entry into this routine, the LVDC will telemeter the "Switch Selector" Status Code twice and return to the main orbital program prepared to receive two data commands or a Terminate mode command. The format of the two data commands will be:

14	13	12	11	10	9	8*	7	1
IU STAGE	S-IVB STAGE	X	ADDR 8	ADDR 7	ADDR 6	1	COMPLEMENT OF 14-8	
ADDR 5	ADDR 4	ADDR 3	ADDR 2	ADDR 1	X	0	COMPLEMENT OF 14-8	

* Sequencing Bit

The LVDC will make all of the normal error tests, including a sequencing test, on each data command, and will follow the normal error procedures if a test should fail. As soon as the LVDC verifies the second data command, it will attempt to execute the requested switch selector function. The switch selector functions of the main orbital

DATA COMMAND									
	14	13	12	11	10	9	8	7 1	
1	26	25	24	23	22	21	1	Comple- ment of 14-8	\dot{X}_S
2	20	19	18	17	16	15	0		
3	14	13	12	11	10	9	1		
4	8	7	6	5	4	3	0		
5	2	1	x	x	x	x	1		
6	26	25	24	23	22	21	0		\dot{Y}_S
7	20	19	18	17	16	15	1		
8	14	13	12	11	10	9	0		
9	8	7	6	5	4	3	1		
10	2	1	x	x	x	x	0		
11	26	25	24	23	22	21	1		\dot{Z}_S
12	20	19	18	17	16	15	0		
13	14	13	12	11	10	9	1		
14	8	7	6	5	4	3	0		
15	2	1	x	x	x	x	1		
16	26	25	24	23	22	21	0		X_S
17	20	19	18	17	16	15	1		
18	14	13	12	11	10	9	0		
19	8	7	6	5	4	3	1		
20	2	1	x	x	x	x	0		

DATA COMMAND									
	14	13	12	11	10	9	8	7	1
21	26	25	24	23	22	21	1	Comple- ment of 14-8	
22	20	19	18	17	16	15	0		
23	14	13	12	11	10	9	1		
24	8	7	6	5	4	3	0		
25	2	1	x	x	x	x	1		
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Figure 13.9 Digital Formats For Data Command Words For Navigation Update Command Routine

program take precedence. Therefore, the LVDC must wait until there is adequate free time before beginning the switch selector sub-routine. The main orbital program switch selector sub-routine will be used.

The Terminate command will be accepted any time before the switch selector sub-routine starts its sequence. This command will cancel the commanded switch selector function. The LVDC will return to the main orbital program when the switch selector sub-routine has been executed.

13.5.4 Sector Dump

This routine will provide the capability for commanding the LVDC to telemeter the entire contents of one LVDC memory sector, or a series of memory sectors within the same memory module. Upon entry into this routine, the LVDC will telemeter the "Sector Dump" status code twice and then return to the main orbital program to receive two data commands or a Terminate mode command. The format of the two data commands is:

14	13	12	11	10	9	8*	7	1
MODULE MSB	MODULE	MODULE LSB		FIRST SECTOR MSB	FIRST SECTOR	1	COMP. OF 14-8	
FIRST SECTOR	FIRST SECTOR LSB	LAST SECTOR MSB	LAST SECTOR	LAST SECTOR	LAST SECTOR LSB	0	COMP. OF 14-8	

*Sequencing Bit

The LVDC will make all of the normal error tests and will begin dumping the designated start sector at address 000 as soon as it verifies the second data command. Blocks of 17 LVDC words will be interleaved with other LVDC telemetry outputs until all 256 (16 blocks) LVDC locations (or some multiple of 256, if more than one sector is requested) have been telemetered one time each. Each word of the block will have a unique tag. The first word of each block will identify the information in the block by indicating in the data portion of the LVDC word the (a) module, (b) sector, and (c) block number of the sector (1-16). Since the other LVDC telemetry outputs take about 400 ms, one block of the data to be dumped will be sent about every 500 ms. Therefore, the total time to dump one sector is approximately: $[(17 \text{ words} \times 4 \text{ ms}) + 400 \text{ ms}] \times 16 \text{ blocks} = 8.0 \text{ seconds per sector}$. If only one sector is to be dumped, the starting and ending sectors will be the same. A Terminate mode command received any time before the last word of the last block is telemetered will cause the LVDC to return to the main orbital program.

13.5.5 Telemeter Single Memory Location

This routine will provide the capability to telemeter one LVDC memory location upon command from the ground station. Upon entry into this routine, the LVDC will telemeter the "Telemeter Single Location" status code twice and return to the main orbital program, prepared to receive three data commands or a Terminate mode command. The format of the data command is:

14	13	12	11	10	9	8*	7	1
MODULE MSB	MODULE	MODULE LSB	ADDR MSB	ADDR	ADDR	1	COMP. OF 14-8	
ADDR	ADDR	ADDR	ADDR	ADDR LSB	X	0	COMP. OF 14-8	
SECTOR MSB	SECTOR	SECTOR	SECTOR LSB	X	X	1	COMP. OF 14-8	

*Sequencing Bit

The LVDC will make the normal error test on each data command. After the third data command has been verified, the LVDC will telemeter the requested location 5 times in succession and return to the main orbital program. The word to be telemetered will have a unique combination of the LVDA's 8 tag bits as an identifier.

13.6 GUIDANCE REFERENCE RELEASE

This interrupt indicates that the platform has been released. It occurs 8 seconds prior to liftoff and is the point at which program control is transferred to the flight routines. Cf. Fig. 13.12.

13.7 S-II PROPELLANT DEPLETION

This interrupt indicates that propellant level has reached a certain level in the tanks and that the S-II cutoff sequence has been initiated. Time base 4 is initiated. The cutoff sequence itself is initiated and executed by the stage upon receipt of the depletion signal from the propellant level sensors. Cf. Fig. 13.12. This interrupt will be honored only after the propellant depletion arm signal is given.

13.8 S-IC PROPELLANT DEPLETION (S-IC Outboard Engine Cutoff)

This interrupt indicates that S-IC outboard engines have been cut off. Time base 3 is initiated by this cutoff. Cf. Fig. 13.12.

13.9 S-IVB ENGINE OUT

This interrupt informs the LVDC that S-IVB cutoff has occurred. It is inhibited until 10 seconds after S-IVB ignition.

There will be two S-IVB cutoffs. When the first cutoff interrupt is received, it is OR'ed with the S-IVB EO discrete input to initiate time base 5. When the first S-IVB EO DI or when the first S-IVB EO interrupt has been recognized, whichever occurs first, time is read, time base 5 is set, the S-IVB EO interrupt is inhibited, and the backup routine cancelled. If the interrupt occurs before the discrete is received, the DI will be ignored by the LVDC when it is received. The switch selector is again set to begin switch selector processing as soon as possible. Neither the interrupt nor the DI will be honored until 10 seconds after S-IVB ignition.

When the second cutoff interrupt is received, corresponding to termination of second S-IVB burn, or when the cutoff discrete is received, whichever occurs first, the same logical sequence will be implemented.

Because of the two cutoff interrupts involved in the AS-501 mission, corresponding to the two S-IVB burns, it will be necessary for the program to distinguish between the two interrupts. This will be done, as indicated in Figure 13.11, by testing time. When either the first cutoff interrupt or the first discrete is received, the LVDC will read time and test to see if TB5 has already been established. If not, TB5 will be set and the S-IVB EO interrupt inhibited until the second cutoff command is given, near the termination of second S-IVB burn. This is described in blocks 3 through 8. If TB5 has already been initiated, indicating that the S-IVB cutoff signal received is for termination of second burn, TB7 will be set and the S-IVB interrupt inhibited (blocks 3, 9 through 13, Figure 13.11).

13.10 PROGRAM RE-CYCLE (RCA-110A INTERRUPT)

This interrupt applies only to the ground routines and is not used in the flight routines. It will not be discussed here.

13.11 COMMAND LVDA/RCA-110A INTERRUPT

This interrupt is not used in AS-IU-501.

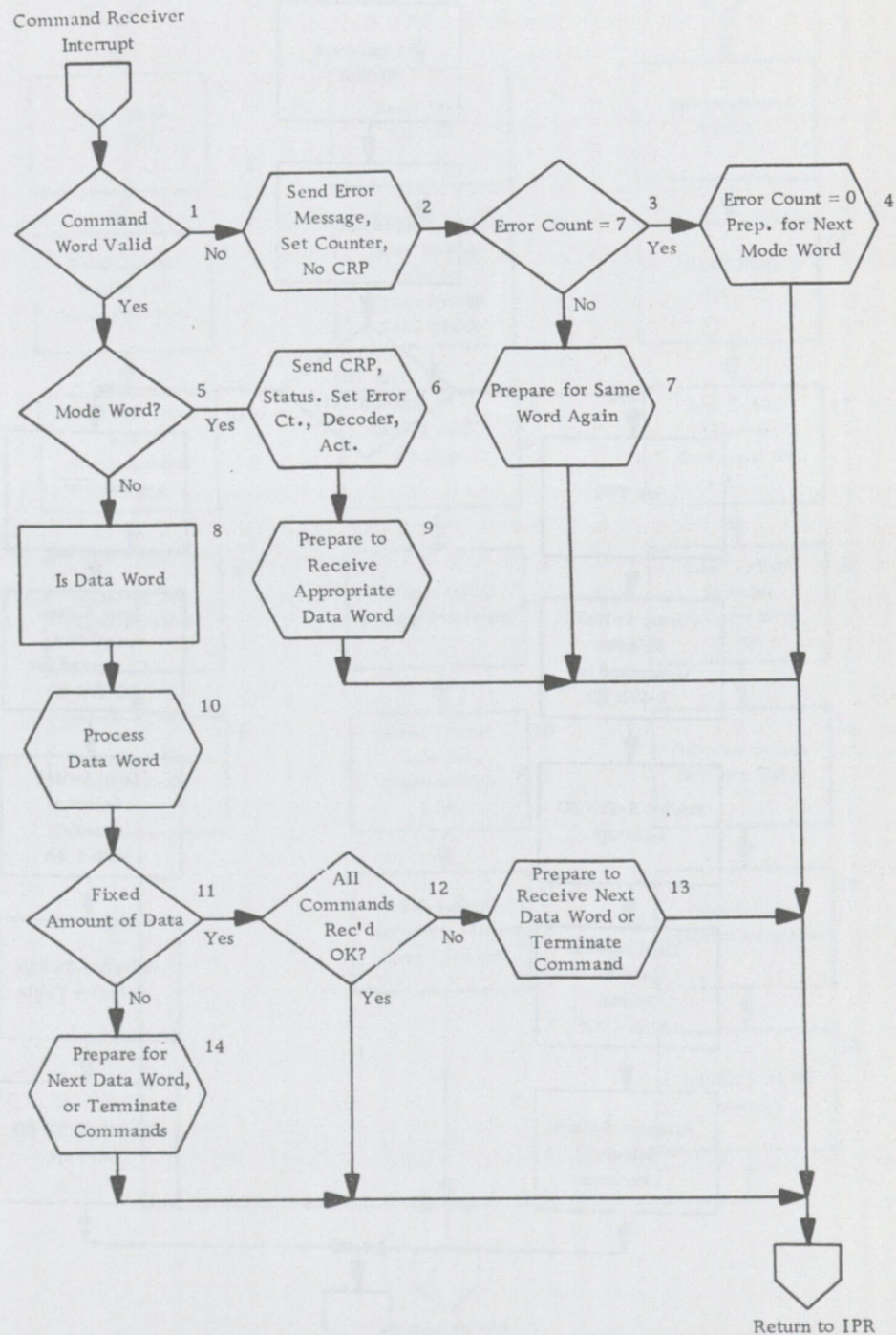


Figure 13.10 Command Receiver Interrupt

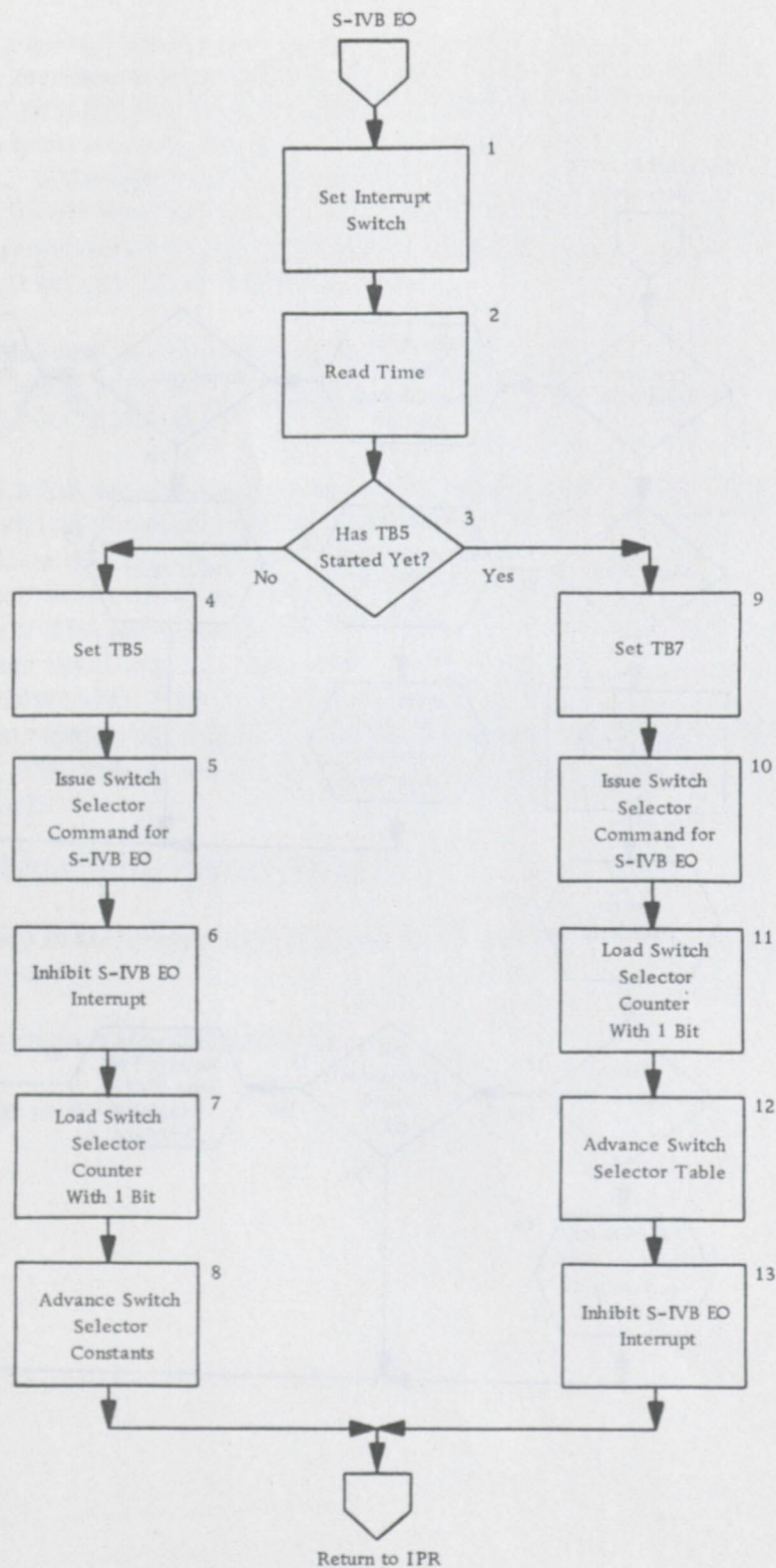


Figure 13.11 Interrupts

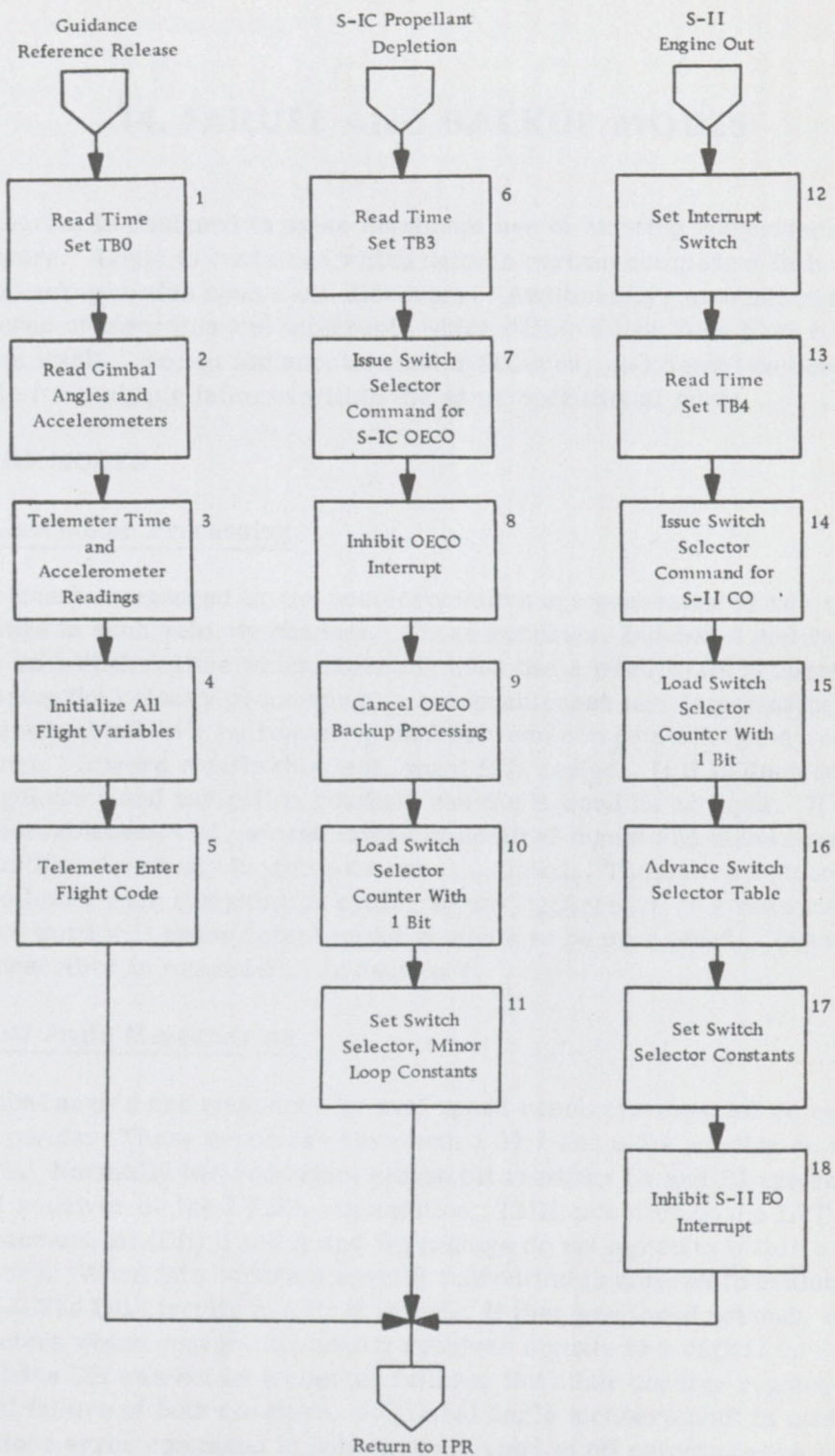


Figure 13. 12 Interrupts

14. FAILURE AND BACKUP MODES

The flight program is designed to make maximum use of existing redundancies in vehicle hardware. Logic is contained which detects certain component failures and switches into backup modes upon their discovery. Additionally, provisions are made for timed backup of discretes and interrupts which define a new time base for the flight program itself. Except for accelerometer failures, no attempt has been made to compensate for multiple failures within the same operational mode.

14.1 FAILURE MODES

14.1.1 Accelerometer Processing

Velocity increments measured by the accelerometers are generated by two independent optisyn readings in each velocity channel. These readings, labeled A and B, are processed by an LVDC routine which normally uses the A word to form current velocity. During the velocity processing, a reasonableness test is performed which compares the actual velocity increment gained between computation cycles with an expected change. If word A fails this test, word B is tested. If it is deemed reasonable, guidance and navigation routines use the B word as an input. If both A and B fail the reasonableness test, stored tables of nominal thrust and mass flow are entered and artificial velocity increments are calculated. The entire reasonableness test loop is followed each computation cycle, so any occurrence of a reasonable accelerometer word will cause actual measurements to be processed. The reasonableness test is described in more detail in Section 4.

14.1.2 Gimbal Angle Measurement

Platform gimbal angles are measured by dual speed resolvers mounted on each of the three gimbal pivots. These resolvers have both a 32:1 and a 1:1 winding on the same magnetic core. Normally two redundant eleven bit readings (A and B) are received from the 32:1 resolver by the LVDC. In addition, TMR circuitry in the LVDA generates a disagreement bit (DB) if the A and B readings do not agree to within a prescribed tolerance. When this occurs a special subroutine is entered to evaluate the error source. The DB circuits are first tested. If they are found normal, the duplexed counters which convert the analog resolver signals to a digital form are exercised. If the DB was set by a counter failure, the other counter reading is used. In the event of failure of both counters, no gimbal angle measurement is made and the last good attitude error command is subsequently used in all outputs to the LVDA. In the event the DB circuits are found to have caused the disagreement indication, the A reading is not replaced.

Once a gimbal reading has been selected, two additional LVDC tests are applied to insure a valid measurement. Each reading is first tested to see if it is zero when it should not be. In such a case the gimbal reading is called unreasonable. This test is included to detect a failure in the power source activating the resolvers. The second test on gimbal readings is a "reasonable change" test. The new reading is compared with the old reading. Too great a change (more than 0.4°) makes the new reading unreasonable. The first reading at the beginning of the flight program is automatically accepted as reasonable.

If a gimbal reading is found to be unreasonable by either of these tests, the last good attitude error command is again used as the current command. If three reasonableness tests fail in a particular (X, Y, or Z) channel during one computation cycle, the 1:1 resolver replaces the 32:1 resolver as the source of gimbal readings. This switch over results in a permanent replacement of the 32:1 resolver reading by the 1:1 resolver readings.

Operation of the minor loop after the switch over is essentially unchanged. Two gimbal readings (and, when appropriate, a disagreement bit) are issued and the reasonableness tests are executed. Test limits are expanded, however, to 4.0° for the first test, and 0.6° thereafter. Counter or reasonableness test failures which occur during this backup mode cause an immediate switch to the last valid attitude error command for all subsequent LVDC outputs.

14.1.3 Switch Selector Processing

Reliability in switch selector output is provided principally through redundancy. In addition, certain functions are performed by the LVDC to improve this aspect of operation. The first of these is a verification function. Prior to command execution, the 8 operation bits in the flight sequence command to the switch selector are fed back to the LVDA over eight parallel verify lines. A comparison is made of this feedback, which is in complement form, with the original command as stored in the LVDC. Disagreement results in the processing described under switch selector interrupt, section 13.2.

The second function also utilizes the forced reset capability of the LVDC. Prior to the initiation of a flight sequence command, the verify lines are sampled to ensure that all stage select relays have been reset. The presence of a reference voltage on any line indicates a hung stage relay and causes the forced reset command to be issued by the LVDC. Section 13 describes this operation in detail. After the reset has been executed, the normal switch selector routine is followed.

14.2 TIME BASE BACKUPS

Certain vehicle events are used to define time bases for the LVDC flight program. These time references are used for sequencing of guidance discretely and switch selector outputs, and are critical to the timing of the flight program. To insure that a missed interrupt does not cause loss of sequencing, provisions are made in the flight program to initiate time bases on receipt of backup discretely.

14.2.1 Liftoff (LO)

Liftoff nominally occurs 8 seconds after GRR and is indicated to the LVDC by a discrete input. The discrete input register is interrogated every 10 ms from GRR to liftoff so that liftoff may be accurately known.

The liftoff backup loop is entered 8.5 seconds after GRR, provided liftoff has not occurred. If the Y inertial acceleration exceeds 2 m/s^2 for 6 computation cycles, liftoff is simulated and time base one is set. At 13 seconds after GRR another test is added. If an acceleration greater than 2 m/s^2 is not sensed during any three computation cycles after this time, exit is made to the ground routines. Liftoff indication will be accepted by the LVDC any time prior to exit to the ground routines. This routine is shown in Figure 14.1.

14.2.2 S-IC Low Level Sense (LLS)

For AS-501, time base two is set at a predetermined time (TLLS). Initiation of this time base at precisely the correct time is accomplished through the use of a switch selector interrupt initiated in the low level sense discrete backup routine.

An additional safety feature is built into the routine. Before the time base can be set, a test is performed on the inertial X velocity (\dot{X}_S). If \dot{X}_S is greater than 500 m/s, the test for time base initiation is enabled. If it is not, no interrupt can be issued. This velocity test is included to insure that an on-the-pad firing of the S-II stage cannot occur if TB1 is inadvertently set.

14.2.3 S-IC Outboard Engine Cutoff (OECO)

The occurrence of outboard engine cutoff is determined by depletion sensors in the first stage fuel and LOX tanks. Normally this event will follow IECO by four seconds and time base three will be set by the S-IC Propellant Depletion Interrupt. Backup is provided by a redundant discrete signal which forces the interrupt. This routine is shown in Figure 14.1.

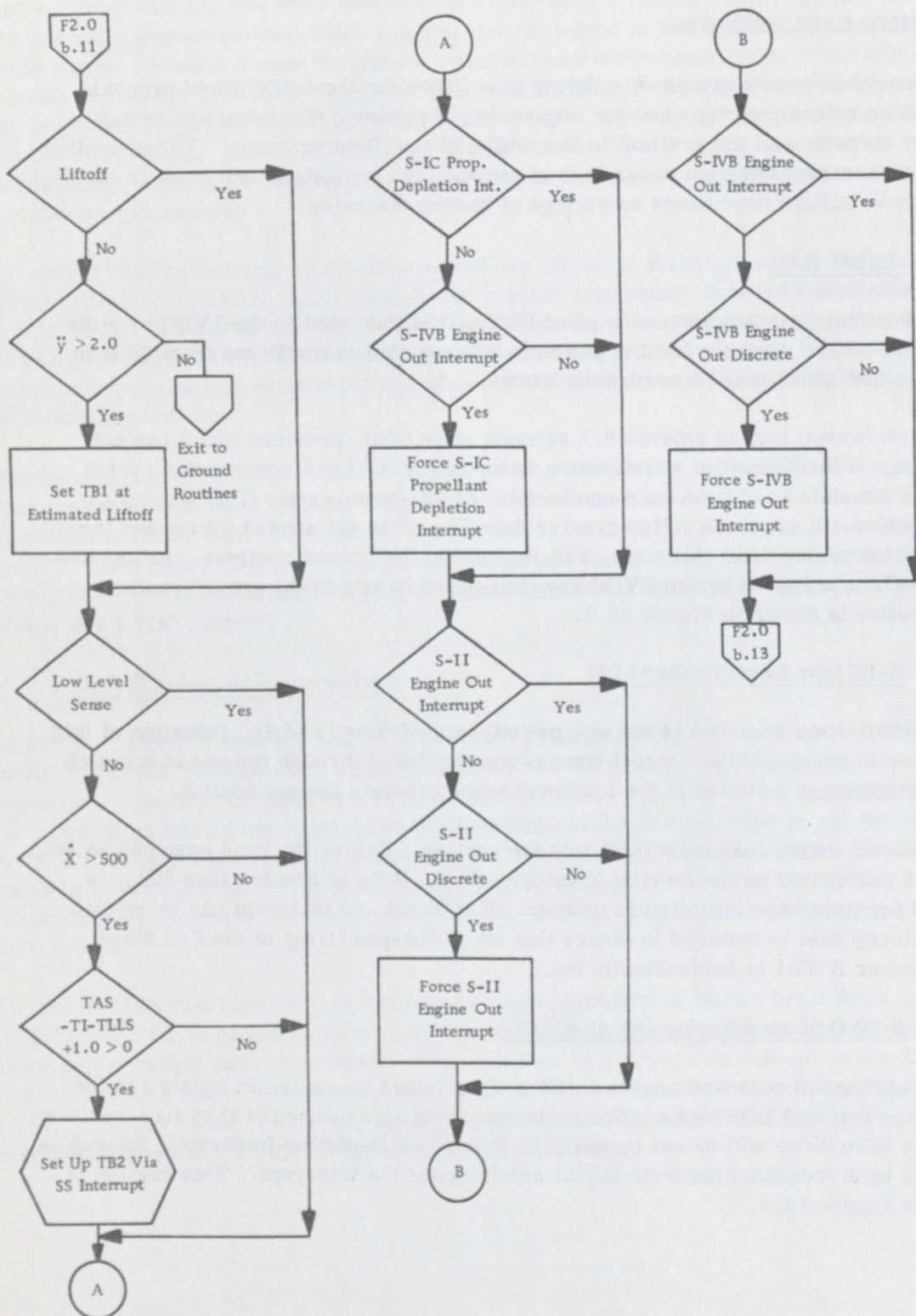


Figure 14.1 Discrete Backups
(This figure is block 12 of Figure 2.0)

14.2.4 S-II Cutoff

Cutoff of the five S-II engines is initiated by propellant level sensors located in the LOX and LH₂ tanks. Backup for the interrupt which normally sets time base four is provided by a discrete which is tested in the backup routine. This routine is shown in Figure 14.1.

14.2.5 S-IVB Cutoff (Boost Phase)

S-IVB cutoff is issued by the LVDC through the Switch Selector. When engine thrust decays, both a discrete and an interrupt are generated. If the interrupt fails to set time base five, the discrete backup routine will set it by sensing the discrete and causing the LVDC to enter the S-IVB engine out interrupt routine. Figure 14.1 illustrates this routine.

14.2.6 S-IVB Restart

No on-board backup for the initiation of time base six is included in the flight program.

14.2.7 S-IVB Cutoff (Orbital Phase)

The second cutoff of the S-IVB can be initiated by either a guidance derived signal based on velocity or by propellant depletion sensors. Either method of cutoff will reset the computer time base. Backup is provided as it was in the first cutoff; if time base seven is not set by the interrupt, a discrete is provided in the backup routine. This backup routine is shown in Figure 14.1.

15. LVDC/LVDA TELEMETRY REQUIREMENTS

The AS-501 telemetry requirements are presented in three parts. These are:

1. Identification Tags
2. Total Telemetry
3. Mission Control Center Telemetry.

Each part is considered separately in the following paragraphs. Telemetry discussed here is normal boost and orbital real time telemetry. Data compression during orbital flight is discussed in Section 18. Telemetry requirements are based on the AS-200 series scheme of spacing LVDC telemetry by reading the real time clock and delaying the next telemetry PIO if sufficient time has not elapsed. This same scheme will be used for AS-501. Telemetry tables are at the end of this section.

15.1 IDENTIFICATION TAGS

Telemetry will originate from both the LVDC and the LVDA. All LVDC telemetry will have priority over LVDA telemetry. All minor loop telemetry will be through the DOM (LVDA) except when an error path is taken. Special codes will then be telemetered from the LVDC.

LVDC telemetry can originate from either the accumulator or from computer memory. Figure 15.1 shows the telemetry format for all Saturn V flights. Address bits A1 and A3 through A9 will be used to uniquely identify up to 256 telemetry words. Address bit A2 defines the origin of the telemetry word, i. e., LVDC or LVDA.

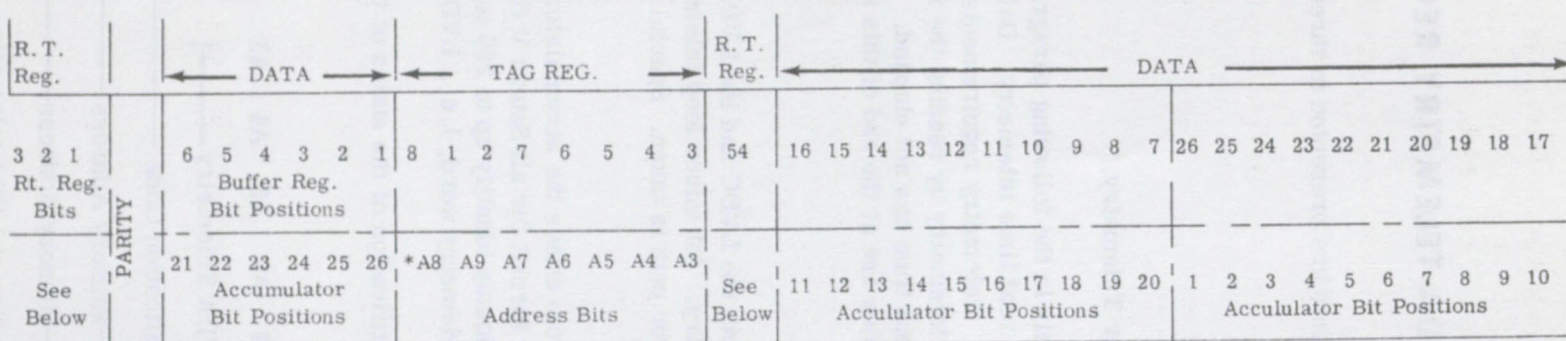
The following list shows the identification of the states of the address bits that identify the telemetry origin.

Case No.	A2	A8	A9	A7	A6	A5	A4	A3	A1	Origin
1	0	←ID for LVDA Telemetry→							*	LVDA
2	1	0	←Identification Code →							LVDC Accumulator
3	1	1	0	←Memory Address →						LVDC Main Memory
4	1	1	1	←Memory Address →						LVDC Residual Memory

*A1 is not used in identification of LVDA telemetry.

8A and 23A	9A and 24A	10A and 25A	11A and 26A
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PCM Channel Assignments



Real Time Register Bit Assignments

LVDC Telemetry

RT5 Validity
 RT4 Mode Reg. 3 (M3)
 RT3 Mode Reg. 2 (M2)
 RT2 Mode Reg. 1 (M1)
 RT1 A1

LVDA Telemetry

Real Time Bit 5 (MSB)
 Real Time Bit 4
 Real Time Bit 3
 Real Time Bit 2
 Real Time Bit 1 (LSB)

Parity is Odd

Accumulator Bit 1 is the sign bit
 Accumulator Bit 2 is the MSB
 Accumulator Bit 26 is the LSB

*Tag Register Position 8 contains $\overline{A2}$ (the inverse of A2) for all LVDC telemetry and A2 for the CIU PIO (042). These two functions never occur simultaneously.

Figure 15.1 Telemetry Format

In case 1, bit $\overline{A2}$ ($\overline{A2}$ = complement of A2) is 0 and the identification (ID) corresponds to previously published ID codes for LVDA telemetry. Case 2 yields LVDC telemetry that originates from the accumulator. The 7 remaining bits will be used for up to 128 unique ID codes. Case 3 and 4 yield LVDC telemetry originating from both the main and residual memory. In case 4, the 6 remaining bits will correspond to sector 17 (residual) memory addresses and will define an additional 64 unique ID codes. In Case 3, the 6 bits will give the memory addresses from main memory to define the final 64 unique codes for a total of 256. There are four PIO addresses which result in the same telemetry tags as the computer interface unit PIO's and cannot be used for LVDC telemetry purposes. These are:

1. 040
2. 240
3. 440
4. 640

Hence, the identification tags that correspond to these four PIO addresses cannot be used for LVDC telemetry. A complete list of the assigned ID tags will be available as the flight program becomes better defined.

The three low order bits of the mode register, M3, M2, and M1, must always be set to zero for normal LVDC real time telemetry, both boost and orbital. This is necessary to distinguish real time tags from compressed data tags.

15.2 TOTAL TELEMETRY

The telemetry will be described over eight phases of flight. These phases are defined as:

<u>Phase</u>	<u>Definition</u>
1	Guidance reference release (GRR) to liftoff (LO).
2	LO to S-II ignition.
3	S-II ignition to the S-II engine mixture ratio change (EMRC).
4	S-II EMRC to S-IVB ignition.
5	S-IVB ignition to first S-IVB cutoff.

<u>Phase</u>	<u>Definition</u>
6	S-IVB cutoff to S-IVB reignition (orbital phase). Quantities listed in this phase are telemetered in real time only when over a receiving station. The CIU is in operation the remainder of the time and telemetry cannot occur (See Section 18).
7	S-IVB reignition to S-IVB EMRC.
8	S-IVB EMRC to re-entry.

A description of each telemetry parameter is given in the list shown in Table 15.1. The number of samples per computation cycle for each phase of flight during which the quantities are telemetered is also shown. The x in the column for phase 6 indicates that the quantity is telemetered in phase 6 although the computation cycle is not a valid basis for telemetry. Present indications are that these quantities will be telemetered at most once every two seconds. A slower rate may be necessary consistent with compressed data dump and command system operation.

The parameters noted in this list will be telemetered during the computation cycle in which they are computed whenever possible. Telemetry requirements are subject to change as the mission becomes better defined.

A breakdown of the total telemetry is given below and the discussion will be presented for each topic.

- A. Navigation and Guidance
- B. Acceleration and Time
- C. Minor Loop
- D. Whole Gimbal Angles
- E. Attitude Error Signals
- F. Discretes and Interrupts
- G. Special Telemetry Codes
- H. Special Parameters
- I. Mode Code Words 24, 25 and 26
- J. Pre-Launch Telemetry
- K. Switch Selector Telemetry

A. Navigation and Guidance

Navigation quantities such as space fixed velocities, measured velocities, and the accelerometer pulse counts will be telemetered along with the IGM guidance quantities. Total space fixed velocity and the reciprocal of radius are necessary for post flight evaluation and mission control and will be computed and telemetered.

The telemetry parameters numbered as items 36 through 46 in Table 15.1 are navigation quantities that are required for all phases of flight except phase 1. During phase 6, the orbital phase, the space fixed velocity components and the gravitation accelerations are available only at 8-second intervals. The remaining navigation parameters (items 47 through 58) will be required for all phases except phase 6. Items 59 through 65 are orbital navigation parameters and will be telemetered in phase 6 only. The cutoff positions (items 66 through 68) will not be computed nor telemetered.

The guidance commands and the change in guidance commands, items 1 through 6, will be required through all flight phases. Items 7 through 35 and items 37 and 38 are IGM parameters that will be required during all IGM phases. Items 115 through 120 are required in the out of orbit IGM guidance phases.

B. Acceleration and Time

About 1.0 millisecond is required to read all three accelerometer channels. Therefore, only one value of time will be telemetered with the accelerometer readings, and this time will define the beginning of the computation cycle. The two redundant optisyns for each axis will be combined into one word by the LVDA making a total of four words for acceleration and time (items 69 through 72). These parameters are required for all phases of flight. The first set of accelerometer readings and time (used in all computations) will be telemetered twice during the computation cycle. The first telemetry will occur at the beginning of the major cycle and the second near the middle of the cycle. The accelerometers and time will be read and telemetered two additional times in the computation cycle during phase 2 for a total of 16 words per cycle. The second and third accelerometer reading will occur approximately one-third and two-thirds through the computation cycle respectively. This telemetry will require 12 unique ID codes.

C. Minor Loop

All minor loop telemetry will occur through the DOM. Information on hardware interfaces and LVDA registers will be available through this telemetry. Figure 15.2 shows a nominal flow chart of the minor loop and all telemetry quantities. With nominal minor loop timing, this scheme will yield almost all gimbal angles and ladder commands for each minor loop. Information on hardware interfaces and LVDA

Minor Loop Interrupt

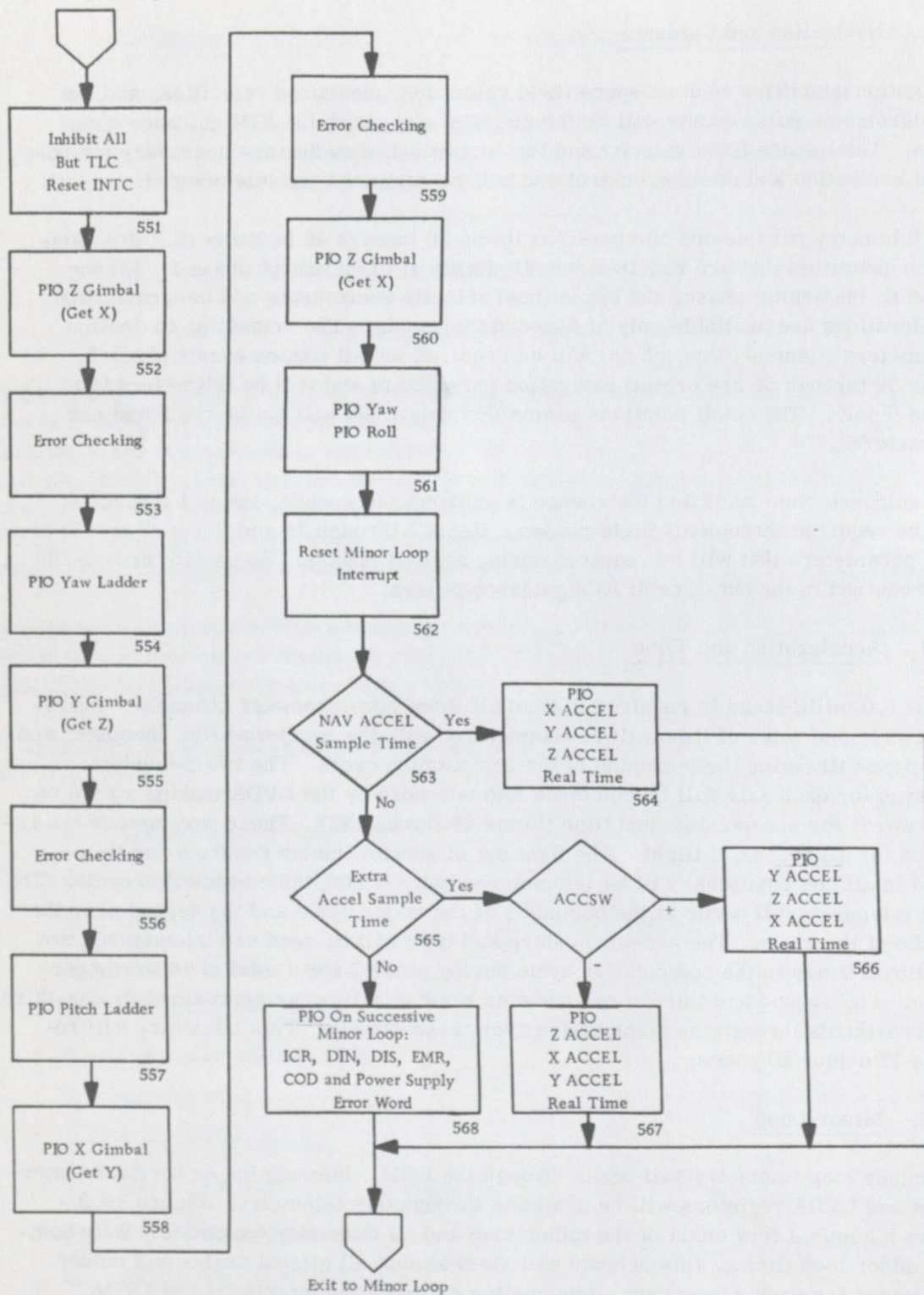


Figure 15.2 Minor Loop Telemetry Flow Chart

registers will be available approximately 3 times per second. Blocks 563 through 568 show the hardware telemetry in the minor loop. This scheme is identical to that implemented in the AS-201 Flight Program.

If the program enters a minor loop error path or backup loop, special telemetry will occur from the LVDC, instead of normal telemetry from the DOM in order to identify the error condition.

There are two types of error paths and backups in the minor loop: disagreement bits and unreasonable gimbal angles. If the program determines that the disagreement bit indicates a COD counter error, the special COD reading used to make this determination will be telemetered. If the program determines that the disagreement bit circuitry is faulty, a counter indicating the number of circuitry failures will be telemetered.

The gimbal angles can be unreasonable in three ways:

1. The angle remains at zero when it should be non-zero.
2. The angle is increasing unreasonable.
3. The angle is decreasing unreasonably.

A special code will be telemetered for each of the error paths taken.

If three angles in pitch, roll, or yaw are unreasonable in one computer cycle, the appropriate backup is selected. To verify that the backup path is taken, special codes will be telemetered after the test on the failure counters indicate the backup should be chosen.

D. Whole and Coarse Gimbal Angles

The whole gimbal angles, items 73, 74, and 75, will be telemetered once per computation cycle for all flight phases. These are not necessary in data reconstruction, since only the fine gimbal readings will be telemetered during the minor loops. The coarse or backup gimbals and time will be read and telemetered once per computation cycle to provide performance data.

E. Attitude Error Signals

The attitude error signals (P, R, and Y) are 8 bit words plus sign and can be combined into two words. The error signals, items 79 and 80, are required for all phases of flight and will be telemetered once per computation cycle.

F. Discretes and Interrupts

Discrete inputs, discrete outputs, switch selector functions, and interrupts denoted as items 81, 82, 83, and 84 will require four separate identification tags. Time from the beginning of the computation cycle at which each discrete input, discrete output, switch selector read command and interrupt occurs will be telemetered. All systems interrupts, i.e., from the vehicle to the LVDC, except the CIU interrupts, will be telemetered, beginning with Guidance Reference Release and continuing throughout the IU mission. System interrupts to be telemetered are:

1. Guidance Reference Release
2. Low Level Sense
3. S-I Outboard Engine Cutoff
4. S-II Cutoff
5. S-IVB Cutoff
6. Command Receiver Interrupt

The times of minor loop interrupts will not be telemetered. The TLC interrupt will be telemetered if it occurs. As with the minor loop telemetry, data may be destroyed by this telemetry, or it may be destroyed itself by normal telemetry since no fixed relationship between the interrupt telemetry and normal telemetry can be established. Figure 15.3 shows the telemetry formats for discrete inputs, discrete outputs, switch selector functions, and interrupts. The actual bit arrangement will correspond to the format of Figure 15.1.

These four words will be telemetered whenever the states of the respective registers change and will be telemetered an estimated maximum of 6 times in any one computation cycle.

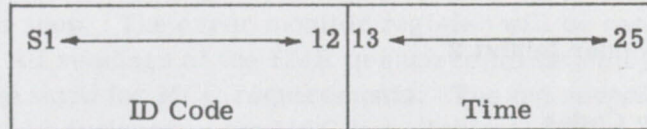
The start time of all time bases will be telemetered to aid in accurate determination of switch selector function times. This word will be telemetered every computation cycle, but will change only when a new time base begins, (or when changed by ground command).

For AS-501 the following discrete outputs from the discrete output register (DOR) are required. These include:

1. Guidance Failure
2. Indication of receipt of GRR

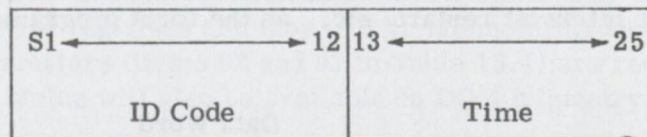
DISCRETE INPUT FORMAT

Accumulator Bit Positions



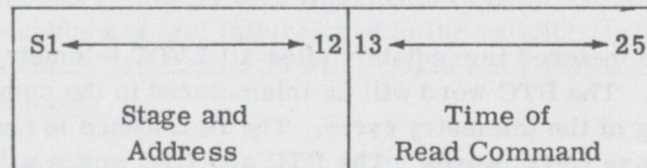
DISCRETE OUTPUT FORMAT

Accumulator Bit Positions



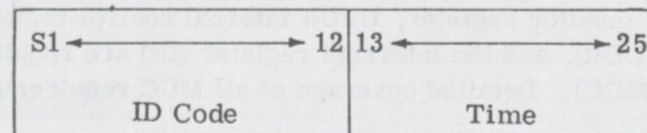
SWITCH SELECTOR FUNCTION FORMAT

Accumulator Bit Positions



INTERRUPT FORMAT

Accumulator Bit Positions



- NOTE: 1. ID Codes will be assigned by flight programmers.
2. Time will be elapsed time from beginning of computation cycle.

Figure 15.3 Discrete and Interrupt Formats

3. Indication of receipt of lift-off
4. Simultaneous Memory Failure (TLC).
5. Thrust Indication to Space Craft
6. C Band Transponder Inhibit 1.
7. C Band Transponder Inhibit 2.

G. Special Telemetry Codes

The special codes (items 92 and 93 in Table 15.1) shown below are necessary to adequately mark the end of the telemetry during any computation cycle and to mark the beginning of the telemetry for the next cycle. Additional codes and/or other parameters may be required for bit by bit restart, etc., as the flight program becomes better defined.

<u>Symbol</u>	<u>Data Word</u>
ETC (end of telemetry cycle)	7 0 7 0 7 0 7 0 6
BTC (begin telemetry cycle)	Computation Cycle counter

The ETC word will be telemetered immediately after all LVDC telemetry is completed in any computation cycle. The BTC word will be telemetered in the computation cycle just prior to the beginning of the telemetry cycle. The redundancy is necessary since interrupts can destroy these LVDC words. The BTC and ETC words will be telemetered in all flight phases.

H. Special Parameters

The contents of the error monitor register, LVDA internal control register (ICR), the discrete output register (DOR), and the interrupt register (IR) are required by the Mission Control Center (MCC). Detailed coverage of all MCC requirements is given in a later section.

The previously mentioned data for interrupts will suffice to define the state of the IR and no additional telemetry will be required.

At the time of a disagreement in any of the selected voter circuits, a bit is set in the error monitor register. At the same time, the address location of the program at the time of the disagreement, the bit time, word time, source of error, and real time are inserted into a vacant word of the data output multiplexer (DOM) delay line. This word is called the error time word (ETW). If a channel is invalid (that is, not being used), in the DOM, the ETW is placed in the invalid channel. When all four channels

are either valid or half valid, both channel 3 and channel 4 are tested. If neither is forced into channel 3, but if neither channel 2 nor channel 4 is being gated into the BR, the ETW is forced into channel 4. This information is then telemetered through the normal LVDA telemetry. When the disagreement bit is set into the error monitor register, a latch is set so that no more address error words can be set in the DOM until the error monitor register is reset by a PIO from the LVDC. Telemetry of the error monitor register is accomplished through the DOM by a PIO instruction from the LVDC in the minor loop. The error monitor register will be read into the LVDC each time it is PIO'd. All readings of the EMR in each computation cycle will be OR'd together into a single word for MCC requirements. The tag associated with this combination EMR word is assigned in the MCC list, Table 15.5.

The error monitor register telemetry will be required for all flight phases.

Since neither the ICR, nor the DOR can be read into the LVDC, the LVDC will keep up with the state of these registers and they will be telemetered once per computation cycle. These parameters (items 92 and 93 in Table 15.1) are required for all flight phases. The ICR status will also be available on DOM telemetry.

I. Mode Code Words 24, 25, and 26

Mode Code Words 24, 25, and 26 (MC 24, 25, and 26 (MC 24, MC 25, and MC 26) are status code words. MC 24 will contain information relative to accelerometer and gimbal angle reasonableness test failures and to the validity of the cross-over detector (COD) counter contents. MC 25 and 26 will contain information relative to guidance and/or flight sequencing.

1. Mode Code 24

The accelerometer readings are tested for reasonableness once per computation cycle. The first six bits of MC 24 are reserved for indicating failures in these tests. The following list explains the respective states of these three pairs of bits (1-2 for X, 3-4 for Y, and 5-6 for Z).

<u>Case</u>	<u>State of Bits</u>		<u>Explanation</u>
	<u>1, 3, or 5</u>	<u>2, 4, or 6</u>	
1	0	0	No failure in A reading. A reading was used in this cycle (B reading is not tested if A proves reasonable).
2	0	1	Failure in A reading and no failure in B. B was used in this cycle.
3	1	1	Failure in both A and B readings. Prestored F/M was used in this cycle.

Case 1 corresponds to nominal operation. Case 2 corresponds to failures in A when B readings are good. Case 3 corresponds to failures in both A and B and to the use of a prestored F/M that is resolved through the gimbal angles to obtain predicted accelerometer readings. These bits will be reset (restored to case 1 bit states) each major computation cycle.

The gimbal angles are tested for reasonableness each minor loop except when a disagreement between the duplexed counter readings prevents the test. Three counters, XRE, YRE, and ZRE, are used in the flight program to indicate the number of unreasonable gimbal angle readings. These counters are initialized to -3, and are incremented by one each time a failure occurs. If their states reach zero in any computation cycle, the backup gimbal is used for the remainder of the flight. The counters are reset to -3 if the backup is not used. If the backup gimbal is in use, they are reset to zero each cycle and are incremented by one each time a backup gimbal reading fails to prove reasonable. When either counter reaches a count that corresponds to 15 backup failures per second, the guidance failure discrete is set.

Two bits for each channel (7-8 for X, 9-10 for Y, and 11-12 for Z) will be used to indicate gimbal angle reasonableness test failures. The bit states are explained in the following list.

<u>State of Bits</u>			<u>Explanation</u>
<u>Case</u>	<u>7, 9, or 11</u>	<u>8, 10, or 12</u>	
1	0	0	Less than three failures in the fine gimbal angle reading that is presently in use during one cycle (indicates a negative state of XRE, YRE, or ZRE).
2	0	1	Three failures in the fine gimbal angle reading in one major computation cycle. The backup gimbal is in use (indicates zero state of XRE, YRE, or ZRE).
3	1	1	The backup gimbal has failed at a rate of 15 times per second over one computation cycle.

Bits 8, 10, and 12 will never be reset and bits 7, 9, and 11 will be reset to zero each computation cycle. Case 1 corresponds to the nominal case. Case two corresponds to three failures in the fine gimbal angle and marks the beginning of the use of the back-ups. Case three indicates that the backup gimbal has failed at a rate of 15 times per second over 1 computation cycle.

Whenever the contents of the duplexed COD counters disagree, the DB is set with external circuitry and processed by the flight program. DLC 1 is a counter which serves as a flag for the DB processing routine. This counter is reset to -2 each major cycle unless its state becomes zero or positive. There are three ways that the state of DLC 1 can reach zero. These are:

1. By getting two DB circuitry failures in a major cycle.
2. By getting two A counter reading failures in a major cycle.
3. By getting two B counter reading failures in a major cycle.

In case 1, the DB circuitry is assumed to have failed whenever the DB is on, but the A and B readings actually agree within 3 low order bits. Cases 2 and 3 correspond to two failures in the A and B counter readings respectively in a major computation cycle. If DLC 1 ever reaches a zero state, the DB processing is bypassed for the remainder of the flight.

DLC 1 is set positive when both A and B counter readings prove to be erroneous twice in any major cycle. If this happens, the last set of good gimbal angle readings will be used for the remainder of the flight. Bits 13 and 14 will be used to indicate the state of DLC 1. The following list explains the states.

<u>State of Bits</u>		<u>Explanation</u>
13	14	
0	0	Indicates a negative state of DLC 1.
0	1	Indicates a zero state of DLC 1.
1	1	Indicates a positive state of DLC 1.

Bits 15 and 16 will nominally be zero and will be set to one when either the A or the B reading (but not both) fail twice in a computation cycle. Bit 17 will be nominally zero and will be set to 1 when the B ladder is continually selected by the flight program. When this occurs, the error monitor register telemetry will indicate that the A ladder has failed at least three times in a computation cycle. Bit 18 will be nominally zero and will be set to 1 when the switch selector channel B is selected.

The bit description of MC 24 is shown in Table 15.2. This word will be telemetered once per computation cycle just prior to the reset of the counters that were mentioned, and it is shown as item 94 in Table 15.1.

2. Mode Code Words 25 and 26

MC 25 and 26 will yield information relative to guidance and/or flight sequencing. This information will be conveyed by setting the appropriate bit to a "1" when the defined event occurs (See Tables 15.3 and 15.4 for bit descriptions). The steering misalignment correction term bit (bit 16 of MC 26) is on when SMC is in use. Bit 19 of MC 25 will be set if the off nominal time tilt is entered at the end of both the S-II and S-IVB stages.

Bit 7 of MC 26 will be set at the second S-IVB cutoff to start TB 7 in two ways. First, when/if the S-IVB engine out interrupt (INT 4) and the corresponding discrete input (DIN 5) are sensed and second, if/when the time base backup is used. It should be noted that even though the interrupt (bit 25 of MC 25) alone will start TB 5 both the interrupt and the discrete input (bit 6 of MC 26) will be set at both cutoffs.

These two words (items 98 and 99 in Table 15.1) are telemetered once per computation cycle (as near the end of the cycle as possible).

J. Pre-Launch Telemetry

In order to establish trends and pinpoint problems occurring at liftoff, it is necessary to telemeter the gimbal angle and accelerometer readings prior to liftoff. The three fine gimbal angles, the six accelerometer readings (in 3 words), and the read times will be telemetered once per second in the interval from the prepare-to-launch signal, approximately 150 seconds before liftoff, to the guidance reference release alert (GRRA) signal at approximately 10 seconds before liftoff. In the interval between GRRA and the Guidance Reference Release (GRR) signal, approximately 2 seconds prior to ignition, the six accelerometer readings and times will be telemetered once per second. In this same interval, the fine gimbal angles will be telemetered at a rate of 25 per second. The coarse gimbal angles used in the initialize routine will also be telemetered. Tags or PIO codes and formats used for prelaunch telemetry will be the same as PIO's and formats for corresponding quantities during boost.

In the event that error or backup paths are taken during prelaunch checking, etc., telemetry is required in the error path to identify the source of error and the error path taken. If this action is already taken in connection with data transfer to the RCA-110A, this information may be adequate for evaluation purposes since it will be available on telemetry as long as the data remains in the buffer register for a time greater than 4.167 ms. If this time requirement cannot be met, special telemetry will be necessary.

The data to be telemetered will be specified in conjunction with the preflight programmers.

K. Switch Selector Telemetry

Special provisions must be made to telemeter the switch selector driver outputs via the DOM. This output must be telemetered through the DOM since it cannot be read into the LVDC for telemetry. A special PIO code will load the switch selector and discrete output driver outputs on the DOM if the DOM has an empty word. A delay of slightly greater than 8.33 ms since the last LVDC telemetry PIO or the last PIO which loads data on the DOM is necessary before issuing the special PIO to insure that an empty word exists in the DOM. This special PIO will be issued immediately after each switch selector read command.

15.3 MCC TELEMETRY

Table 15.5 is an early list of the LVDC telemetry parameters requested by MCC for Saturn V. Documentation for updating these requirements has not yet been received from MCC. The parameters that are the same as those required for Saturn IB will retain the same PIO address and telemetry tags. Any additional requirements will be assigned new tags.

15.4 SUMMARY

The parameters of Table 15.1 will all have identification codes assigned. A complete list of these tags and their corresponding PIO addresses will be available as the flight program becomes better defined.

S-IC stage telemetry will require a maximum of approximately 50 LVDC words per computation cycle. S-II stage telemetry will require approximately 100 LVDC words per computation cycle. S-IVB stage telemetry will require approximately 110 LVDC words per computation cycle. There may be additions to and/or deletions from the telemetry as presented in Table 15.1.

TABLE 15.1

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
1	x_X	Yaw guidance command in space-fixed system.	1	1	1	1	1	X	1	1
2	x_Y	Roll guidance command in space-fixed system.	1	1	1	1	1	X	1	1
3	x_Z	Pitch guidance command in space-fixed system.	1	1	1	1	1	X	1	1
4	Dx_X	Change in x_X per minor loop.	1	1	1	1	1	X	1	1
5	Dx_Y	Change in x_Y per minor loop.	1	1	1	1	1	X	1	1
6	Dx_Z	Change in x_Z per minor loop.	1	1	1	1	1	X	1	1
7	x'_X	Yaw guidance command in IGM computation system.	0	0	1	1	1	0	1	1
8	x'_Z	Pitch guidance command in IGM computation system.	0	0	1	1	1	0	1	1
9	\tilde{x}_X	Velocity correction in IGM yaw guidance angle (x_X)	0	0	1	1	1	0	1	1
10	\tilde{x}_Z	Velocity correction in IGM pitch guidance angle (x_Z)	0	0	1	1	1	0	1	1
11	K_3	Altitude correction in IGM yaw guidance angle.	0	0	1	1	1	0	1	1
12	K_1	Altitude correction in IGM pitch guidance angle.	0	0	1	1	1	0	1	1

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
13	K_4	Ideal IGM yaw rate.	0	0	1	1	1	0	1	1
14	K_2	Ideal IGM pitch rate.	0	0	1	1	1	0	1	1
15	SMCX	Yaw steering misalignment correction term.	0	0	1	1	1	0	1	1
16	SMCZ	Pitch steering misalignment correction term.	0	0	1	1	1	0	1	1
17	ϕ_T	Total range angle	0	0	1	1	1	0	1	1
18	$\Delta \zeta_V$	Total ζ_V distance to be gained.	0	0	1	1	1	0	1	1
19	$\Delta \eta_V$	Total η_V distance to be gained.	0	0	1	1	1	0	1	1
20	$\Delta \dot{\xi}_V$	$\dot{\xi}_V$ velocity to be gained.	0	0	1	1	1	0	1	1
21	$\Delta \dot{\eta}_V$	$\dot{\eta}_V$ velocity to be gained.	0	0	1	1	1	0	1	1
22	$\Delta \dot{\zeta}_V$	$\dot{\zeta}_V$ velocity to be gained.	0	0	1	1	1	0	1	1
23	T_{1i}	First plus fourth IGM phase time-to-go.	0	0	1	0	0	0	1	0
24	T_{2i}	Second IGM phase time-to-go	0	0	0	1	0	0	0	0

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
25	T_{3i}	Third plus fifth IGM phase time-to-go.	0	0	0	0	1	0	0	1
26	ΔT_{2i}	Third and fifth IGM phase time-to-go.	0	0	0	0	1	0	0	1
27	τ_1	First and fourth IGM phase total burn time.	0	0	1	0	0	0	1	0
28	τ_2	Second IGM phase total burn time.	0	0	0	1	0	0	0	0
29	τ_3	Third and fifth IGM phase total burn time.	0	0	0	0	1	0	0	1
30	$\dot{\xi}_V$	X component of velocity in IGM computation system.	0	0	1	1	1	0	1	1
31	$\dot{\eta}_V$	Y component of velocity in IGM computation system.	0	0	1	1	1	0	1	1
32	$\dot{\xi}_V$	Z component of velocity in IGM computation system.	0	0	1	1	1	0	1	1
33	ξ_V	X component of position in IGM computation system.	0	0	1	1	1	0	1	1
34	η_V	Y component of position in IGM computation system.	0	0	1	1	1	0	1	1

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
35	ζ_V	Z component of position in IGM computation system.	0	0	1	1	1	0	1	1
36	F/M	Total measured acceleration.	0	1	1	1	1	X	1	1
37	$(M/F)_i$	Reciprocal of F/M.	0	0	1	1	1	0	1	1
38	$(M/F)_S$	Smoothed value of $(M/F)_i$.	0	0	1	1	1	0	1	1
39	\dot{X}_S	X component of space-fixed velocity.	0	1	1	1	1	X	1	1
40	\dot{Y}_S	Y component of space-fixed velocity.	0	1	1	1	1	X	1	1
41	\dot{Z}_S	Z component of space-fixed velocity.	0	1	1	1	1	X	1	1
42	X_S	X component of space-fixed position.	0	1	1	1	1	X	1	1
43	Y_S	Y component of space-fixed position.	0	1	1	1	1	X	1	1
44	Z_S	Z component of space-fixed position.	0	1	1	1	1	X	1	1
45	R^{-1}	Reciprocal of total space-fixed radius.	0	1	1	1	1	X	1	1

NOTE:

X - telemetered during phase 3 when over a site.

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
46	V	Total space-fixed velocity.	0	1	1	1	1	X	1	1
47	g_X	X component of gravitational acceleration.	0	1	1	1	1	X	1	1
48	g_Y	Y component of gravitational acceleration.	0	1	1	1	1	X	1	1
49	g_Z	Z component of gravitational acceleration.	0	1	1	1	1	X	1	1
50	IGX	X component of gravitational velocity.	0	1	1	1	1	0	1	1
51	IGY	Y component of gravitational velocity.	0	1	1	1	1	0	1	1
52	IGZ	Z component of gravitational velocity.	0	1	1	1	1	0	1	1
53	\ddot{X}_M	X component of measured acceleration.	0	1	1	1	1	0	1	1
54	\ddot{Y}_M	Y component of measured acceleration.	0	1	1	1	1	0	1	1
55	\ddot{Z}_M	Z component of measured acceleration.	0	1	1	1	1	0	1	1
56	\dot{X}_M	X component of measured velocity.	0	1	1	1	1	0	1	1

NOTE:

X - telemetered during phase 3 when over a site.

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
57	\dot{Y}_M	Y component of measured velocity.	0	1	1	1	1	0	1	1
58	\dot{Z}_M	Z component of measured velocity.	0	1	1	1	1	0	1	1
59	ALT	Vehicle altitude.	0	0	0	0	0	X	0	0
60	\ddot{X}_V	Acceleration components due to venting.	0	0	0	0	0	X	0	0
61	\ddot{Y}_V	Acceleration components due to venting.	0	0	0	0	0	X	0	0
62	\ddot{Z}_V	Acceleration components due to venting.	0	0	0	0	0	X	0	0
63	\ddot{X}_D	Acceleration components due to drag.	0	0	0	0	0	X	0	0
64	\ddot{Y}_D	Acceleration components due to drag.	0	0	0	0	0	X	0	0
65	\ddot{Z}_D	Acceleration components due to drag.	0	0	0	0	0	X	0	0
66	X_{SCO}	X component of space-fixed position at cutoff.								
67	Y_{SCO}	Y component of space-fixed position at cutoff.								
68	Z_{SCO}	Z component of space-fixed position at cutoff.								

NOTE:

X - telemetered during phase 3 when over a site.

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
69	ACCX	X accelerometer optisyn readings (A_X and B_X).	*	2	4	4	4	X	4	4
70	ACCY	Y accelerometer optisyn readings (A_Y and B_Y).	*	2	4	4	4	X	4	4
71	ACCZ	Z accelerometer optisyn readings (A_Z and B_Z).	*	2	4	4	4	X	4	4
72	t_{as}	Real time of accelerometer samples.	*	2	4	4	4	X	4	4
73	θ_X	Whole yaw gimbal angle.	0	1	1	1	1	X	1	1
74	θ_Y	Whole roll gimbal angle.	0	1	1	1	1	X	1	1
75	θ_Z	Whole pitch gimbal angle.	0	1	1	1	1	X	1	1
76	θ_{Xf}	Fine yaw gimbal angle.	*	1	1	1	1	X	1	1
77	θ_{Yf}	Fine roll gimbal angle. From LVDC	*	1	1	1	1	X	1	1
78	θ_{Zf}	Fine pitch gimbal angle.	*	1	1	1	1	X	1	1

NOTES:

X - telemetered during phase 3 when over a site.

* - prelaunch telemetry, see text for explanation.

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
79	ψ_P, ψ_R	Pitch and roll attitude error signals.	0	1	1	1	1	X	1	1
80	ψ_Y	Yaw attitude error signal.	0	1	1	1	1	X	1	1
81	DI	Discrete input indication.	When these are set, an estimated maximum of 6 times							
82	DO	Discrete output indication.								
83	SWSEL	Switch Selector function indication.								
84	INT	System Interrupt indication.								
85	T_1	Time of beginning of Time Base 1	Telemetered when the respective time base is initiated.							
86	T_2	Time of beginning of Time Base 2								
87	T_3	Time of beginning of Time Base 3								
88	T_4	Time of beginning of Time Base 4								
89	T_5	Time of beginning of Time Base 5								
90	T_6	Time of beginning of Time Base 6								
91	T_7	Time of beginning of Time Base 7								

NOTES:

X - telemetered during phase 3 when over a site.

* prelaunch telemetry, see text for explanation.

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
92	ETC	End of telemetry cycle.	0	1	1	1	1	X	1	1
93	BTC	Beginning of telemetry cycle.	0	1	1	1	1	X	1	1
94	EMR	Error monitor register contents.	0	1	1	1	1	X	1	1
95	ICR	LVDA internal control register contents.	0	1	1	1	1	X	1	1
96	DOR	Discrete output register contents.	0	1	1	1	1	X	1	1
97	MC24	Mode Code Word 24.	0	1	1	1	1	X	1	1
98	MC25	Mode Code Word 25.	0	1	1	1	1	X	1	1
99	MC26	Mode Code Word 26.	0	1	1	1	1	X	1	1
100	$\alpha_x, \alpha_y, \alpha_z$	Half precision position in boost.	0	1	1	1	1	0	1	1
101	$\beta_x, \beta_y, \beta_z$	Half precision position in orbit.	0	1	1	1	1	X	1	1
102	SQ_1	$(\Delta \dot{\xi}^2 + \Delta \dot{\eta}^2)^{1/2}$	0	1	1	1	1	0	1	1

NOTE:

X - telemetered during phase 3 when over a site.

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
103	SQ_2	$(\Delta \dot{\xi}^2 + \Delta \eta^2 + \Delta \dot{\zeta}^2)^{1/2}$	0	1	1	1	1	0	1	1
104	SQ_3	$(Z'_s)^{1/2}$	0	1	1	1	1	0	1	1
105	θ_{XC}	Backup yaw gimbal angle.	*	1	1	1	1	X	1	1
106	θ_{YC}	Backup roll gimbal angle.	*	1	1	1	1	X	1	1
107	θ_{ZC}	Backup pitch gimbal angle.	*	1	1	1	1	X	1	1
108	ACCT	Clock Reading When Accelerometers were read.	*	1	1	1	1	X	1	1
109	TLCHPC	Hop Save of TLC INTERRUPT	At Occurrence							
110	TBBJ	Indication that Time Base was initiated by backup.	As Required							
111	MLx_x	Minor Loop x_x .	0	1	1	1	1	X	1	1
112	MLx_y	Minor Loop x_y .	0	1	1	1	1	X	1	1
113	MLx_z	Minor Loop x_z .	0	1	1	1	1	X	1	1

NOTES:

X - telemetered during phase 3 when over a site.

* - prelaunch telemetry, see text for explanation.

TABLE 15.1 (Continued)

AS-501 TELEMETRY LIST

Item Number	Symbol	Description	Samples/Computation Cycle for Phases							
			1	2	3	4	5	6	7	8
114	TCO	Time remaining in S-IVB Coast (After S-II Cutoff)								
115	θ_T	Terminal path angle								
116	V_T	Terminal velocity								
117	η_{VT}	Terminal $\eta_{V\cdot}$								
118	$\dot{\eta}_{VT}$	Terminal $\dot{\eta}_{V\cdot}$								
119	$\dot{\xi}_{VT}$	Terminal $\dot{\xi}_{V\cdot}$								
120	$\ddot{\eta}_{VgT}$	Terminal $\ddot{\eta}_{Vg\cdot}$								

Telemetered during S-IVB Coast
(After S-II cutoff) once per cycle

These parameters are required
once per cycle during phase 7
and 8.

TABLE 15.2

BIT DESCRIPTION OF MODE CODE WORD 24

<u>Bit Number</u>	<u>Quantity</u>	<u>Purpose</u>
1 & 2	ARTFX	Indicates accelerometer reasonableness failures.
3 & 4	ARTFY	
5 & 6	ARTFZ	
7 & 8	GARTFX	Indicates Gimbal Angle reasonableness test failures.
9 & 10	GARTFY	
11 & 12	GARTFZ	
13 & 14	DLC1	Indicates Gimbal Angle disagreement bit processing.
15	AFAL	
16	BFAL	
17	LADAF1	Indicates flight program continual selection of ladder B.
18	SELB	Indicates switch selector channel B has been selected.
19 - 26	Spares	

TABLE 15.3

BIT DESCRIPTION OF MODE CODE WORD 24

<u>Bit Number</u>	<u>Event</u>	<u>Comments</u>
1	Guidance reference release (INT 7).	Begin time base zero (TB0).
2	Liftoff (DIN24) or time base backup	Begin time base one (TB1).
3	Start pitch and roll guidance	Initiate S-IC guidance
4	Stop roll	Roll maneuver complete
5	Low level sense (INT2) or time base backup	Begin time base two (TB2)
6	Stop pitch	S-IC time tilt arrest
7	S-IC inboard engine cutoff	--
8	S-IC outboard engine cutoff (INT5) or time base backup	Begin time base three (TB3).
9	S-IC inboard engine out (DIN15)	--
10	S-IC outboard engine out (DIN14)	--
11	S-IC separation (DIN12)	--
12	Spare	--
13	Begin first phase IGM guidance	S-II first burn
14	S-II engine mixture ratio change (EMRC)	Second phase IGM
15	S-II cutoff (INT6) or time base backup	Begin time base four (TB4).
16	S-II engine out (DIN13)	--

TABLE 15.3 (Continued)

BIT DESCRIPTION OF MODE CODE WORD 25

<u>Bit Number</u>	<u>Event</u>	<u>Comments</u>
17	S-II skirt separation (DIN11)	--
18	S-II/S-IVB separation (DIN10)	--
19	Begin non-nominal time tilt	Used in S-II and S-IVB
20-21	Spares	--
22	First S-IVB ignition	Third phase IGM
23	First S-IVB terminal guidance	--
24	First S-IVB cutoff command	--
25	S-IVB cutoff interrupt (INT4) or time base backup	Begin time base five (TB5) at first cutoff
26	Start S-IVB reignition sequence or time base backup	Begin time base six (TB6)

TABLE 15.4

BIT DESCRIPTION OF MODE CODE WORD 26

<u>Bit Number</u>	<u>Event</u>	<u>Comments</u>
1	S-IVB reignition	--
2	Begin fourth phase IBM	S-IVB first burn after reignition
3	S-IVB engine mixture ratio change	Begin fifth phase IGM
4	Begin fifth phase terminal guidance	--
5	Second S-IVB cutoff command	--
6	S-IVB engine out (DIN5)	--
7	Begin time base 7 (TB7)	Requires INT4 and DIN5
8	Thrust indication to space craft (S/C) (D06)	--
9	Control computer switched to S/C (DIN9)	--
10	S/C initiation of S-II/S-IVB separation (DIN17)	--
11	Start S-IVB thrust sequence (DIN20)	--
12-15	Spares	--
16	Steering misalignment correction	This bit may be intermittent
17	Command receiver interrupt (INT8)	--
18	TLC-simultaneous memory failure (INT9)	--
19	Guidance failure (D04)	--
20	C band transponder inhibit 1 (D010)	--
21	C band transponder inhibit 2 (D011)	--
22	Command receiver sync (DIN2)	--
23	Auto vent 1 (DIN3)	--
24	Auto vent 2 (DIN4)	--
25-26	Spares	--

TABLE 15.5

ORIGINAL MCC REQUESTS FOR SATURN V TELEMETRY

<u>Item Number</u>	<u>PARAMETER</u>
1	Pitch Steering Command
2	Yaw Steering Command
3	Roll Steering Command
4	\dot{X}_S Space Fixed Velocity
5	\dot{Z}_S Space Fixed Velocity
6	\dot{Y}_S Space Fixed Velocity
7	X_S Space Fixed Displacement
8	Y_S Space Fixed Displacement
9	Z_S Space Fixed Displacement
10	Onboard Computer Time
11	Time to S-IVB first cutoff
12	Time to S-IVB second ignition
13	Time to S-IVB second cutoff
14	Discrete Output Register (Guidance Failure)
15	Error Monitor Register
16	Radius Vector
17	Data Adapter Error Monitor Register
18	Fine Gimbal Angle Roll
19	Fine Gimbal Angle Pitch
20	Fine Gimbal Angle Yaw
21	Coarse Gimbal Angle Roll
22	Coarse Gimbal Angle Pitch
23	Coarse Gimbal Angle Yaw
24	Validity Error (Reasonableness Test Failure)
25	Velocity Vector Magnitude
26	COD and Power Supply Error Word
27	X Accelerometer Output
28	Y Accelerometer Output
29	Z Accelerometer Output
30	LVDA Internal Control
31	Switch Selector Register
32	Interrupt Register

16. DATA COMPRESSION

16.0 INTRODUCTION

The orbital phase of AS-501 will contain significant time intervals during which the vehicle will be out of electromagnetic view of a ground station. Therefore, it will not be possible to telemeter data continuously. During these intervals, data must be processed and stored in the LVDC for transmission by normal LVDC telemetry when the vehicle comes within electromagnetic view of the next ground station. The processing of this data is referred to as data compression. Data compression will be divided into two categories: (1) Time compression, in which desired quantities are stored at prescribed intervals as they are read or computed, and (2) Amplitude compression, in which a regularly sampled quantity is stored only when its amplitude deviates by more than a prescribed amount from a standard.

Amplitude compression will be accomplished by comparing the sampled value to a standard value stored in memory. If the sampled value differs from the standard by more than a specified amount, it will be stored and will become the new standard value. The time at which a sampled value exceeds the tolerance will be stored along with that value of the sample which disagreed with the standard. In this manner, a quantized time history of the measurement will be available. In the event that all samples read in a compression period agree with the standard, within the prescribed tolerance, only the standard will be contained in the table to be transmitted when the vehicle is over a ground station. The first sampled value will be read into memory at the beginning of a compression period and will become the initial standard for that period.

Four types of data will be compressed during the AS-501 orbital phase: (1) LVDC inputs, (2) LVDC internal data, (3) LVDC outputs, and (4) vehicle PCM data read into the LVDC through the computer interface unit (CIU). Command system inputs to the LVDC/LVDA will occur only when over a ground station. Therefore, data compression is not necessary for command system operation.

LVDC inputs consist of inertial platform data, discrete inputs, and interrupts. There are no active discrete inputs during the AS-501 orbital phase, and the only active system interrupts are the command receiver interrupt, which occur only when the vehicle is over a ground station, and the CIU interrupt treated as described below. However, provisions will be made for other discretely and interrupts so that they may be easily compressed on later vehicles.

Compressed LVDC internal data consists of the status of the various LVDA registers which are necessary for postflight failure analysis.

The LVDA compressed outputs consist of discrete outputs and switch selector functions. The majority of switch selector functions will occur when the vehicle is over a ground station. However, some switch selector operations will occur when the vehicle is between ground stations and data on these operations must be compressed.

The vehicle PCM data read into the LVDC through the CIU constitutes the bulk of the data compression scheme. These data will be sampled with time compression applied to some quantities and amplitude compression applied to others. Compression of vehicle PCM data provides the only means of evaluating vehicle performance during blackout periods when the vehicle is between ground stations.

The remainder of this section will be devoted to the requirements for compressing data, and the requirements for telemetering the data when the vehicle passes over a ground station.

16.1 CIU OPERATION

CIU operation is explained in the AS-203 LVDC Equation Defining Document, IBM Number 65-207-0008H.

Data Compression Requirements

The orbital phase will consist of alternate time periods of data compression and telemetering of compressed data. Data will be compressed only when the vehicle is between specified active ground stations and will be dumped over specified active ground stations. The compression and dump periods will be initiated by the Switch Selector on a prestored time schedule that will coincide with the arrival and departure times of the selected ground stations. This table will be revised by change form when the complete list of active stations and predicted arrival and departure times are available. Provision will be made in the flight program for inclusion of additional stations and changes in arrival and departure times. The time base can be adjusted on ground command for off-nominal orbit conditions.

The following requirements will apply for compressing data:

1. Data compression will be programmed for a minimum of nine hours. If more time is required, a new time base for compressed data will be initiated.
2. Data compression storage requirements will be based on a maximum time of 2,000 seconds between ground stations.

3. Except as noted below, each piece of time compressed data will have time of sample and an identification code stored with it. Time will be accurate to 0.5 seconds.
4. Each piece of amplitude compressed data will have time of sample, the CIU address as identification, and a counter indicating the total number of failures, stored with it.
5. The identification bits of all compressed data will occupy the same location; for example, the first 10 bits of the second word of each data word pair might be chosen as identification bits, regardless of whether the data are LVDC/LVDA data or vehicle PCM data. The identification of each piece of data will always occupy the same position in the word pair regardless of the type of data stored. For instance, if the identification bits are the first 10 bits of the second word of a word pair for Group D data, the identification must be in the first 10 bits of the second word for Groups A, B, and C data also.
6. The first 10 bits of the CIU address will be used to identify vehicle PCM data. Bits 15 and 16 of the CIU address will not be necessary for identification since they are always zero.
7. A frame address of 12, which places logical ones in bits 19 and 20 of the LVDA buffer register, will be used to identify LVDC/LVDA data. The remaining two bits of the frame address, the five bits of the channel address, and the group address bits will be used for up to 256 unique identification codes for LVDC/LVDA data.
8. No data compression will occur when compressed data dump is in progress over an active ground station.
9. The first word read for each compressed data quantity at the start of each data compression period will be stored and used as the standard during that period. Each data compression period will start shortly before the vehicle leaves the ground station so that the standard values will be available on normal PCM telemetry as a check on CIU operation.
10. The counter which indicates the number of times a data quantity fails to lie within tolerance will not be reset but will count the total number of failures for that quantity. The counter must have a capacity of at least 1200 counts.
11. Words stored in the compressed data table will not be written over during any single compression period. If the allotted number of locations for a variable are filled, the remainder of the out of tolerance samples will not be stored. However, the latest out of tolerance sample will be used as the standard. The failure counter will continue to be incremented.

12. At the beginning of each compression period, the compressed data table will be started at the first location in the table. This may require modification if a revolving table is necessary due to extremely short dump periods over ground stations.

Data to be compressed are divided into four groups:

1. Group A - Time compressed data from the LVDC/LVDA,
2. Group B - Amplitude compressed data from the LVDC/LVDA,
3. Group C - Time compressed vehicle PCM data read in through the CIU, and
4. Group D - Amplitude compressed vehicle PCM data read in through the CIU.

A summary of requirements for AS-501 is given in Table 16.1.

TABLE 16.1

	<u>TIME COMPRESSED</u>	<u>AMPLITUDE COMPRESSED</u>
	<u>Group A</u>	<u>Group B</u>
LVDC/LVDA Data	1 parameter every sec. 6 parameters every 100 sec. 4 parameters at occurrence 240 memory locations	1 parameter every 30 sec. 134 memory locations
	<u>Group C</u>	<u>Group D</u>
Vehicle PMC Data (CIU)	3 parameters during and after each switch selector operation. 120 memory locations	29 parameters 580 memory locations

Group A

Group A compressed data consists of gimbal angles, discrete inputs and outputs, switch selector functions, and interrupts. All discrete inputs and outputs, switch selector function stage and address, and interrupts (except CIU and DCS), along with the time of occurrence, will be stored. The identification in the second word will indicate whether the data are discrete input, discrete output, switch selector function, or interrupt. The "data" will identify the particular function that has occurred. The time of the read command will be the time associated with the switch selector functions as in boost telemetry. Mode Code 24 will be examined once per computation cycle and stored if any bit has changed.

The fine and backup gimbal angles will be read and stored every 100 seconds. The time of reading the first gimbal angle will be stored with the six gimbal angles.

Group A data requires 240 locations.

Group B

Group B data consists of the Error Monitor Register in the LVDA. The Error Monitor Register will be read every 30 seconds and stored if a bit is present in any location. In addition to storing the EMR contents each time any bit is present, these EMR words will be OR'd together into a single word for real time Mission Control telemetry. This single word will be telemetered separately from compressed data. Details will be covered in the compressed data dump section.

Total memory requirements for Group B data are 200 locations.

Group C

Group C data consists of switch selector data on IU PCM telemetry. Table 16.2 lists the measurement numbers, name, and telemeter channel assignment of Group C data.

The switch selector words will be read during each switch selector operation when the vehicle is not over a ground station. Channels A-13-00 and A-19-00 will be read after the final stage and address, either direct or complement, whichever is used to select the output line, are loaded into the switch selector register. Channel A-13-00 will be read first, with a minimum delay of 10 ms between the stage select and CIU read commands. Channel A-19-00 will be read second with a minimum delay of 10 ms after channel A-13-00 is read. Channel A-06-00 will be read after the switch selector read command is issued. A minimum delay of 10 ms will occur between the switch selector read command and the CIU read command.

Group C data will require 120 memory locations.

Group D

Group D data will be amplitude compressed. A maximum of ten samples of each Group D quantity will be stored for dumping. In the event that a quantity exceeds the prescribed deviation more than ten times, only the first ten will be stored, the remainder will be discarded. The standard against which the comparison is made must be changed each time the limit is exceeded. The counter indicating the total number of failures of a quantity will continue to be updated, even though the data are not being stored. Table 16.3 lists the group D data along with the measurement number and telemeter channel assignment.

The deviation from the standard for each measurement in Table 16.3 is 100 counts. This deviation may change for individual measurements. Provisions must be made in the program for a separate deviation for each measurement since the prescribed deviation may change independently for any or all measurements.

The Group D measurements listed in Table 16.4 must be sampled with a deviation of zero. In other words, these words will be stored when any bit changes in the word. Memory requirements for Group D data are 580 locations.

TABLE 16.2

Group C Data *

Meas. No.	Measurement Name	Telemeter Channel
K3-603	Sw. Sel. Zero Indicate	A0-13-00
K5-603	Sw. Sel. Stage Select	
K6-603	Sw. Sel. Read Command	
K7-603	Sw. Sel. Reset	
K4-603	Sw. Sel. Output	A0-06-00
K8-603	Sw. Sel. Reg. Verification	A0-19-00

*This data is sampled 120 times per second.

TABLE 16.3

Group D Data

Meas. No.	Measurement Name	Telemeter Channel Assignment
C11-601	Temp Sublimator Inlet m/w	A0-04-02
VXC15-601	Temp m/w Control	A0-04-07
C18-602	Temp Cold Plate Inlet Cool 9	A0-01-02
C21-603	Temp ST-124 m/w Exit	A0-02-02
XC31-603	Temp ST-124 Air Bear. In	A0-01-06
VC34-603	Temp ST-124 Int. Gimbal	A0-01-07
VC53-603	Temp Guid Comp (Logic Page)	A0-04-06
VC55-603	Temp Data Adap. 2A10A5	A0-04-08
VC56-603	Temp Data Adap. 2A10A11	A0-01-01
C69-602	Temp Cont Comp	A0-18-10
XD10-603	Pres. GN ₂ Reg In. (A.B)	A0-14-07
XD11-603	Pres. ST-124 Air Bear. In	A0-14-08
VD12-603	Pres. Int. Amb. ST-124	A0-14-09
D17-601	Pres. Cool Manifold In	A0-14-05
VXD24-601	Pres. Coolant Pump In m/w	A0-14-06
D25-601	Pres. GN ₂ Reg. In. (TC Sys)	A0-04-01
VG3-601	Position m/w Cont Valve	A0-14-04
VH40-603	X Gyro Pickup ST-124	A0-03-00
VH41-603	Y Gyro Pickup ST-124	A0-22-00

TABLE 16.3 (Continued)

Group D Data

Meas. No.	Measurement Name	Telemeter Channel Assignment
VH42-603	Z Gyro Pickup ST-124	A0-27-00
VXM1-602	Meas. Voltage	A0-14-02
XM16-601	6D10 Battery Current	A0-18-05
XM17-601	6D20 Battery Current	A0-18-06
XM18-601	6D30 Battery Current	A0-18-07
XM20-601	6D40 Battery Current	A0-18-09

TABLE 16.4

Group D Data with Zero Deviation

Measurement Number	Measurement Name	Telemeter Channel Assignment
--	Discretes	A0-17-06
--	Discretes	A0-17-07
--	Discretes	A0-17-08

16.2 TELEMETERING OF COMPRESSED DATA

Telemetry of compressed data over a ground station must be coordinated with real time telemetry requirements. Minor loops, switch selector operations, and command system operations will be processed on an interrupt basis and will affect both compressed data telemetry and real time telemetry, i. e., gaps will occur in the telemetered data when interrupts are being processed. No compressed data will be lost due to interrupts unless the interrupts preempt a significant portion of the time over a ground station; this is an unlikely situation, however. Real time telemetry is estimated to be about 25 words per second. This requires approximately 125 ms for

telemetry (5 ms per word). Minor loop operation will require approximately 125 ms per second and 25 ms will be required for LVDC self-test. This leaves approximately 725 ms/sec for telemetering compressed data. Therefore, the maximum allowed number of compressed data locations (1045) can be telemetered in approximately 7 seconds, if no interrupts other than minor loops occur.

The following ground rules will apply for compressed data telemetry.

1. The three low order bits of the mode register will be used to distinguish compressed data words from real time and command system words. The following bit assignments will be made:

M3 = 0

M2 = 1

M1 = 1

where M1 is the low order position of the mode register. The mode register will be set with this configuration each time a compressed data word is telemetered. (These mode bits will be all zeros for real time telemetry.)

2. Only the number of compressed data words actually stored during a compression period will be telemetered when over a ground station. Empty locations in the compressed data block will not be telemetered.
3. If the compressed data table is completely exhausted over a ground station, the data table will be telemetered again and will continue to be telemetered until the next data compression period begins.
4. If separate tables are kept for Groups A, B, C, and D data, a different telemetry PIO will be used for each table to aid in identification of the groups.
5. Individual words in the real time and compressed data telemetry scheme will be spaced in a manner that utilizes the telemetry system and time over a ground station to the best advantage. A scheme similar to that used in spacing real time telemetry during boost is recommended, i.e., read real time clock to space telemetry words.
6. Compressed data will be telemetered in the same order that it is stored in each table.

16.3 COMPOSITE EMR WORD

The composite EMR word made up during the data compression period by OR'ing all EMR samples together will be telemetered as real time data when the vehicle is over the next ground station. This word will be assigned the same tag as the normal EMR word during real time telemetry, i.e., a PIO of 435. This word will be telemetered

twice as soon as the vehicle is in view of the ground station and real time telemetry begins. The normal real time telemetry of the EMR contents over the ground station will not take place until this special word has been telemetered twice. At least two seconds will elapse between the first and second transmission of this special word.

16.4 REAL TIME TELEMETRY WHEN OVER GROUND STATION

Real time telemetry requirements during AS-203 orbital phase are listed in Section 15. Approximately 50 words of data are required every two seconds. The Orbital Telemetry Program operates on a one second execution cycle. All real time data are telemetered first. The remainder of the execution cycle, about 725 milliseconds, will be devoted to telemetering CIU quantities. The orbital telemetry program can be interrupted by minor loops, navigation, guidance and the digital command system. The orbital telemetry program will be entered whenever the switch selector table indicates that the vehicle is within range of a ground station. Exit will also be based upon entries in switch selector table.

Telemetry of gimbal angles, accelerometer readings, and LVDA register status will occur in the same manner as in boost, for the single minor loop in each one second interval that is identical to the boost minor loop.

It is possible that, due to short times over some of the active stations, real time telemetry may be necessary without compressed data telemetry. Therefore, provision will be made in the Orbital Telemetry Routine to intersperse real time telemetry data with normal CIU data compression.

16.5 LVDC SELF-TEST DATA

Data compression will be necessary on computer self-test operation. Only a few memory locations will be required for this information.

Each time the LVDC successfully completes a self-test cycle, a counter will be incremented. This counter will not be reset but will count the total successful self-test operations. The counter will be treated as data for compression purposes and will be stored for transmission when the vehicle is over a ground station.

The LVDC self-test consists of the verification of the LVDC control and arithmetic logic through the comparison of test solutions with known results. The test verifies the following:

1. Transfer Operations - the transfer register and address register, and syllable, and address selection.
2. Arithmetic Operations - MPY, MPH, DIV, ADD, SUB, CLA, RSU, XOR, SHF, STO, and their associated logic.
3. X and Y memory addressing in each module.

An error in this test sets bit 11 or 21 of the IU Status Word. No simplex portion of the present LVDC self-test will be executed in orbit.

The detail error message associated with this test will contain the location of the failing instruction. One error will not abort the test. After each error the test routine continues to the end of the test. The LVDC self-test will be executed once per second during orbital flight.

All self-test data, including the count of successful completions will be treated as compressed data for format purposes. The same requirements hold as for compressed data. Two words will be stored for each piece of self-test data with the identification in the same position for compressed data.

17. FLIGHT TEST ROUTINE

The Flight Test Routine will test the flight program and exercise the program IU hardware interfaces under nearly flight-like conditions. The program can be exercised in a variety of test modes, from operating completely independent of any external inputs to the LVDC/LVDA, giving bit by bit repeatable results, to an option which requires involvement of all the computer inputs used in flight. The modes of operation are discussed in the following paragraphs. Where "repeatable" is used, it corresponds to Pseudo Flight operations, the remaining tests correspond to Simulated Flight operations.

17.1 PLATFORM

In the flight test modes the signals to the LVDC from the inertial platform will differ from those received during flight. To compensate for these differences, the program will compute accelerometer and gimbal angle readings. The following computations will replace the accelerometer PIO's in Option 1, and supplement them in Option 2.

$$\frac{F}{M} = F/(m_0 - mt)$$

$$\Delta \dot{X}_i = \left[\ddot{X} - \frac{F}{M} \cos x_x \sin x_z \right] \Delta t_i$$

$$\Delta \dot{Y}_i = \left[\ddot{Y} + \frac{F}{M} \cos x_x \cos x_z \right] \Delta t_i$$

$$\Delta \dot{Z}_i = \left[\ddot{Z} + \frac{F}{M} \sin x_x \right] \Delta t_i$$

$$\Delta t_i = \text{CC length}$$

$$\begin{aligned} x_x &= \\ x_z &= \end{aligned} \left. \vphantom{\begin{aligned} x_x &= \\ x_z &= \end{aligned}} \right\} \text{Guidance commands in yaw and pitch}$$

$$X_i = X_{i-1} + \Delta \dot{X}_i$$

$$\begin{aligned} \ddot{X} \\ \ddot{Y} \\ \ddot{Z} \end{aligned} = \text{computed acceleration values to cancel expected platform input.}$$

$$\dot{Y}_i = \dot{Y}_{i-1} + \Delta \dot{Y}_i$$

$$\dot{Z}_i = \dot{Z}_{i-1} + \Delta \dot{Z}_i$$

$$Dx_j = 0 \text{ or } -K_3 L_j, j = X, Y, Z$$

$$K_3 = \text{polarity constant } (K_3 = +1 \text{ or } -1)$$

$$x_{mLj} = \Delta \theta_{Ej} + x_{mLj}$$

$$x_{mLj} = \text{the minor loop chi}$$

$$L_j = \text{ladder profile}$$

$$\Delta \theta_{Ej} = \text{computed gimbal values to cancel expected inputs } \Delta \theta_{Ej}, \ddot{X}, \ddot{Y}, \text{ and } \ddot{Z} \text{ defined by the options outlined below}$$

Option 1: No Platform Inputs Accepted

For this option, $\Delta \theta_{Ej} = 0$, $\ddot{X}, \ddot{Y}, \ddot{Z} = 0$. All gimbal PIO's are changed to clear and add x 's, and accelerometer readings are bypassed. Thus, the ladder profile will appear on the output unmodified. Guidance and navigation quantities will be repeatable in this mode, but only if the flight sequencing (defined below) is repeatable. Presence of the platform in the test will not influence this test at all.

Option 2: Platform Connected and Power Up

In this option, the platform will hold a fixed orientation in inertial space. Both accelerometer and gimbal PIO's will obtain quantities from the platform. As time progresses both the gimbal angles and the accelerometer readings will change since the test site is not fixed in inertial space. These changing quantities can be precomputed if both the latitude of the test site (λ) and the alignment azimuth (A_Z) are known. The precomputed values of acceleration, $\ddot{X}, \ddot{Y}, \ddot{Z}$ are shown below. These values will be used in the previously defined computations of $\Delta \dot{X}_i, \Delta \dot{Y}_i$, and $\Delta \dot{Z}_i$ and added to the accelerometer readings to negate the values actually read and to provide an acceptable acceleration profile to the flight program. Likewise the expected gimbal angles are defined in the following equations. They will be used in the minor loop support section as shown (x_{MLj}) to balance the actual gimbal values read from the platform.

$$\ddot{X} = -g_0 \cos \lambda [\cos A_Z \sin \lambda (1 - \cos \omega t) + \sin A_Z \sin \omega t]$$

$$\ddot{Y} = -g_0 (\sin^2 \lambda + \cos^2 \lambda \cos \omega t)$$

$$\ddot{Z} = -g_0 \cos \lambda [-\sin A_Z \sin \lambda (1 - \cos \omega t) + \cos A_Z \sin \omega t]$$

$$\ddot{\theta}_{XE} = \omega \cos \theta \cos (\lambda + \theta_{YE})$$

$$\dot{\theta}_{YE} = \omega \sin \phi + \omega \cos \phi \frac{\sin \theta_{XE} \sin (\lambda + \theta_{YE})}{\cos \theta_{XE}}$$

$$\dot{\theta}_{ZE} = -\omega \cos \phi \frac{\sin (\lambda + \theta_{YE})}{\cos \theta_{XE}}$$

$$\Delta \theta_{je} = \frac{\Delta T}{2} (\dot{\theta}_{jEi} + \dot{\theta}_{jEi-1})$$

$$\theta_{jE} = \theta_{jE} + \Delta \theta_{jE}, \quad j = X, Y, Z$$

ω = earth rate of rotation.

These equations will not match exactly the platform outputs, primarily because of non-standard platform performance. Thus, the runs will not be repeatable, and the ladder outputs will not follow the profiles exactly. However, the range of variation, both in accelerometer and gimbal angle readings, is predictable and these measurements are a good indication of platform/computer performance.

Option 3: Flight

This option is a highly specialized use of the test routines. Its purpose is to permit operation of the actual flight program from the beginning of time base 4 without having to operate in boost. It can be used only with a specialized simulator which provides realistic platform and switch selector inputs to the LVDC. When this option is selected, no other test indicators (i.e., switch selector processing, etc., discussed below) apply since the flight program itself is used. Accelerometer and gimbal PIO's will not be modified or supplemented as in the other two options. No acceleration profiles or expected platform values will be substituted by the program.

Which of the three platform options is to be used must be indicated in an input status word which selects the option, assigns polarity ($K_3 = +1$ or -1) to the ladder profile, and specifies the launch latitude (either Huntsville or Cape Kennedy). In addition to these inputs, the platform alignment azimuth, A_Z , is a required input if Option 2 is selected. This word must contain the angle in pirad units. The angle in pirads equals the angle in radians/ π , quantity scaled binary zero. (Reference HE-65-205-0113). Although the test will execute no matter what the platform azimuth, guidance and navigation quantities will differ from expected values when the platform is not aligned to the flight azimuth. If this test is run for more than 4 hours, the platform yaw gimbal angle may reach the gimbal limit (45°). The saturation time depends upon initial platform and IU alignment. The test should be terminated before saturation occurs.

17.2 SWITCH SELECTOR

The test routine provides options for the program to operate with all or selected stage switch selectors avoided, and with all or selected read commands deleted. These options will be controlled by a switch selector status input to the LVDC. No matter which option is selected, the test routine will not issue D02. Normal switch selector telemetry will be issued regardless of the option selected.

Option 1: All or Selected Stage Switch Selectors Avoided

The test program must be notified by input which stage switch selectors are not to be used. For those stages the processing will proceed as follows:

- (a) Stage selects will never be issued; address codes only will be used.
- (b) The program must generate internally the address complements.
- (c) Read commands will never be issued. However, the LVDC will telemeter switch selector data as in flight.

For all other stages the processing will be normal. To obtain a repeatable test, all switch selectors must be bypassed. This bypass must be included to insure a verify when switch selector stage power is off.

Option 2: Selected Read Commands Avoided

This option keeps the LVDC from issuing specific read commands in any stage switch selector. Use of this feature required modification of both the switch selector status indicator and the switch selector table in the LVDC.

Which of the switch selector options is to be used must be specified in inputs to the test routine. If not all read commands are to be issued, the switch selector functions which do require read commands must be identified by setting the second bit in the switch selector table entry of that function to 1. The RCA-110A must restore the LVDC switch selector table at the conclusion if this option is selected. If certain stage switch selectors are to be avoided, the appropriate bits must be set to zero in the Test Status Indicator.

17.3 DISCRETE INPUTS

The time-base-setting inputs to the LVDC are guidance reference release (GRR), liftoff (LO), low level sense (LLS), S-IB fuel depletion (OECO), S-II Propellant Depletion Interrupt, and S-IVB engine out (4BCO) is used twice. The establishment

of the sixth time base is not yet fixed. It may be set externally to the computer by the command receiver, or it may be internally generated. All tests require a GRR to force entrance from the Prepare to Launch Routine.

Option 1: Repeatable Computer Test

If repeatable flight sequencing is desired, GRR must be given, but no subsequent time base initiating inputs should be given to the LVDC. All necessary sequencing will be generated internally. Failure to observe this rule will not cause program failure but will preclude sequencing repeatability. The repeatable test will begin by using the minor loop interrupt to insure timing synchronization for this test.

Option 2: External Generation of Flight Sequencing Discretes

When GRR is recognized, the LVDC will examine the non-flight indicator, recognize the Simulated Flight Mode, restore the non-flight indicator to flight status, and issue status code 37. Liftoff must be given externally. Time base 6 may have to be started externally, depending upon the final decision about the method of initiation of the time base. All of the remaining flight sequencing discretes may be given externally or the flight program backups may be used.

17.4 BOOST AND ORBIT ROUTINES

Upon recognition of GRR, the test program will examine the test status indicator to determine if the boost portion of the program is to be bypassed. If so, a second test will be performed to determine if initialization at time base 5 (orbit), or initialization at time base 6 (begin restart procedures) is required. Control is immediately transferred to the initialize block at the beginning of the selected time base. Initialization is completed and the program is executed from the beginning of the selected time base. If a mode of operation is selected which crosses one or both of the reinitialization points, processing continues without reinitialization.

Regardless of whether boost was executed or bypassed, orbit has two principal operating modes: real or accelerated time. With accelerated time, the accumulation of real time in the computer will be modified so that one second of elapsed time will appear as ten seconds (approximately) to the computer. The program will accelerate time only when it is not in range of a ground station. The actual times to begin and end the time acceleration will be controlled by dummy switch selector entries which also mark station acquisition and loss and will be identified by special telemetry codes. If selected, the accelerated time mode will apply both to time base 5 and time base 7. Time base 6 (countdown and engine restart) will never be executed in accelerated time.

17.5 CONTROL

The minor loop will be performed at its normal rate (25/sec in powered flight, 10/sec in orbit) except when the accelerated time option is in use. The ladder outputs will follow the profiles except as described in 17.1 above.

17.6 DCS AND CIU INTERRUPTS

No special provision will be made to dummy process these interrupts. Therefore, for repeatable runs they must not be used. The program response to the DCS and CIU interrupts will be unchanged from the flight program.

17.7 TEST TERMINATION

If boost only is selected, all flight program tests will be terminated at the beginning of time base 5. Exit will be to Mode Sort. For the repeatable case, the LVDC will restore all instructions which were changed in order to run the program and perform sum checks prior to exit. In either case, sector dumps can be commanded at this time on an RCA-110A option.

Once in orbit, the repeatable flight test will be terminated by the program one hour after time base 7 begins. In addition, this test can be terminated by RCA-110A command, in which case the LVDC will restore the changed flight instructions before exit. All other tests will continue until terminated by external control. There are no other programmed exits. In all non-repeatable cases, exit will be to a special load and verify routine located such that it will not be written over by the orbital flight routines.

17.8 PROGRAM VERIFICATION

The repeatable test (Pseudo Flight), described in the various options above, can be forced by a bit in the Test Status Indicator Word. This test mode is verified by a simple sum check upon completion of the test. Prior to the sum check all instructions changed in order to run the program will be restored by the LVDC. The LVDC will do the required summations and telemeter results for ground sum check verification. For the other tests a sum check is not possible because of uncertainties introduced by the inputs to the program. In these cases post flight evaluation of telemetry data will be required to provide final verification.

18. ALGORITHMS

Throughout the math flow diagrams there are symbols for elementary functions which are to be computed by use of algorithms. The algorithms required to compute these functions are described in this section. Basically five functions are computed: sine, cosine, arctangent, log and square root. The algorithms for the calculation of each of these quantities are shown in the accompanying figures. Logic is included where necessary to make the algorithms flexible enough to accept inputs in the ranges expected for this flight. Figures are at the end of this section.

The angular measurement to be used in the flight program is radians divided by pi, or PIRADS. In this system, for example,

$$45^\circ = (\frac{\pi}{4})/\pi = 1/4,$$

$$180^\circ = \pi/\pi = 1.0.$$

All angles will be in the range -1 to 1 (or -180° to 180°). The scaling will be such that no angle can ever exceed this range.

Figures 18.1 and 18.2 both present sine-cosine routines. The sine-cosine algorithm of Figure 18.2 is a "coarse" routine and is used in the accelerometer reasonableness test described in the accelerometer processing section. The other sine-cosine algorithm is a more accurate routine and is used in the remainder of places where these particular functions are needed. Only the routine of Figure 18.1 will be discussed since that of Figure 18.2 is similar. The input angle X will be in PIRADS and will be between -1 and 1. The sine and cosine logic are intermixed, and the outputs of this routine are sin X and cos X. Basically, the logic finds the quadrant in which X lies and computes two associated quantities, \bar{X} and \tilde{X} . These quantities are chosen so that both lie between -1/2 and +1/2 and so that

$$\sin X = \sin \tilde{X},$$

$$\cos X = \sin \bar{X}.$$

The numbers \bar{X} and \tilde{X} are then substituted into the polynomial P7 to obtain $\sin \bar{X}$ and $\sin \tilde{X}$. P7 accepts as arguments only numbers between -1/2 and +1/2.

Figure 18.3 shows a square root and two inverse square root algorithms. All are iterative schemes and require a first guess at the final answer as an input. Two methods are presented for calculating $1/X$ given X^2 . Method (2) is to be used for computing $1/X$ if X does not vary greatly during one second. This routine is thus well-suited to computing $1/R$ and the reciprocal square root required in SMCX. The routine of method (1) is to be used in computing inverse square roots in other cases.

Figure 18.4 shows the arctangent algorithm. This routine requires as inputs both the numerator and the denominator of the arctangent argument. These quantities are needed to determine the quadrant in which the output should lie. The algorithm as presented yields as outputs angles (in PIRADS) which lie between -1 and $+1$. Thus, in crossing the negative X -axis, the value of the arctangent function goes from $1 - \epsilon$ to $-1 + \epsilon$ or vice versa.

The flow diagram of Figure 18.4 first computes

$$V = \frac{|Z| - |Y|}{|Z| + |Y|}$$

where the input X is defined as $X = \frac{Y}{Z}$. The principal arctangent of V is then found using the polynomial given. Since $-1 \leq V \leq 1$, the principal arctangent (in PIRADS) satisfies the inequality

$$-1/4 \leq \text{Arctan}(V) \leq 1/4.$$

The identity

$$\text{Arctan} \left| \frac{Y}{Z} \right| = 1/4 - \text{Arctan}(V)$$

is used implicitly in the flow diagrams to determine the arctangent of Y/Z which satisfies $-1 \leq \text{Arctan}(Y/Z) \leq 1$.

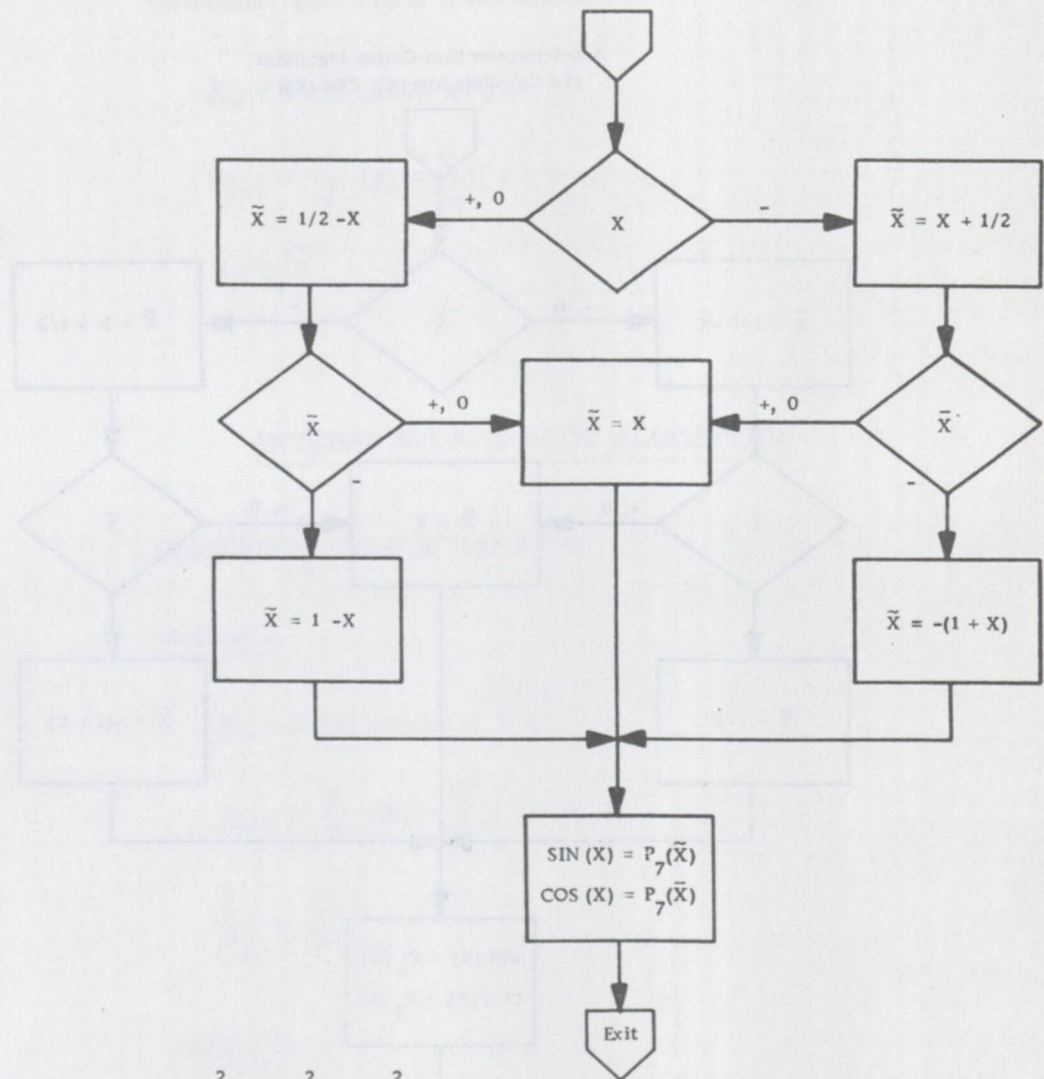
In Figure 18.5 the natural logarithm algorithm is presented. The natural logarithm algorithm will accept numbers between $1/2$ and 16 as inputs. The logarithm is used only to compute the IGM quantities L_1 and L_3 . A polynomial is used to compute $\ln(A)$ where $0 \leq A \leq 1$. To calculate the natural log of any number between $1/2$ and 16 from this polynomial the basic relation

$$\ln(2^n X) = n \ln 2 + \ln X$$

is used.

The polynomials listed in the figures for the computation of sines, cosines, arctangents and natural logarithms are Chebyshev approximations given in "Approximations for Digital Computers" by Cecil Hastings, Jr. (Princeton University Press, 1955). The square root algorithms were obtained using Newton's method.

Sine-Cosine Algorithm
(To Calculate SIN(X), COS(X))



$$P_7(X) = X(C_1 + X^2(C_3 + X^2(C_5 + X^2 C_7)))$$

$$C_1 = 3.1415897$$

$$C_3 = -5.1673678$$

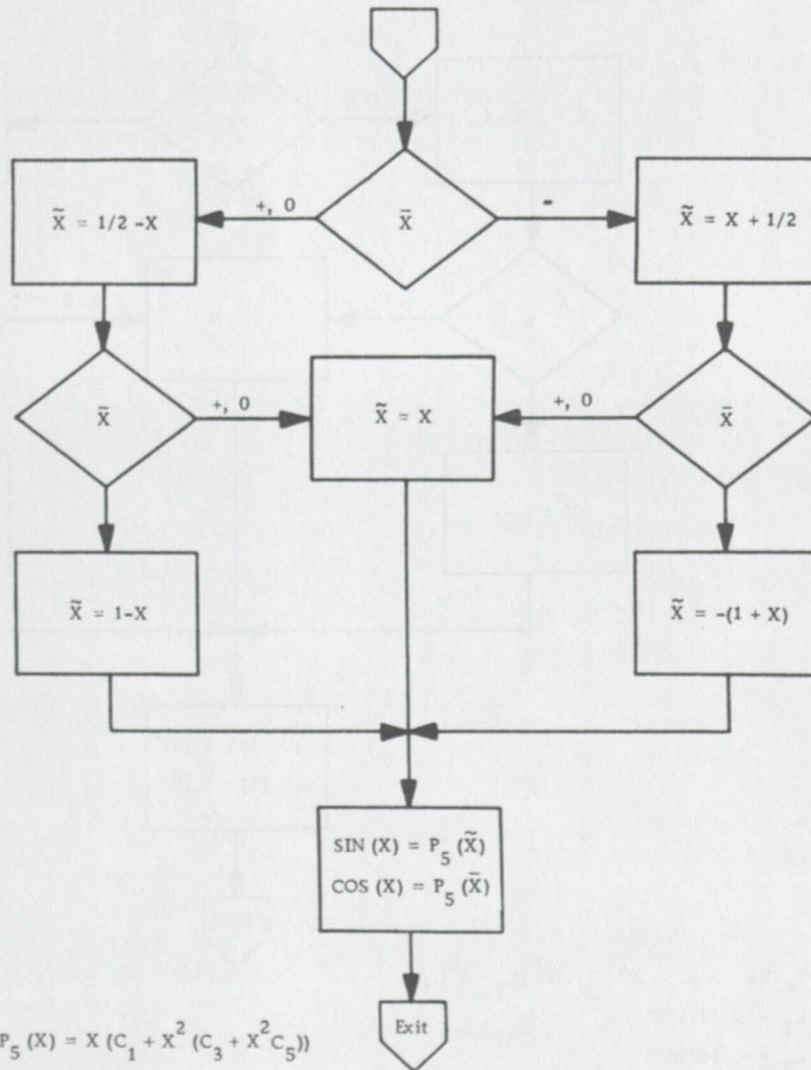
$$C_5 = 2.5436052$$

$$C_7 = -0.55839694$$

$$|\text{SIN}(X) - \text{Approximation}| \leq \left| \frac{\text{SIN}(X) - \text{Approximation}}{\text{SIN}(X)} \right| \leq 10^{-6}$$

Figure 18.1 Sine-Cosine Algorithm

Accelerometer Sine Cosine Algorithm
(To Calculate SIN (X), COS (X))



$$P_5(X) = X(C_1 + X^2(C_3 + X^2C_5))$$

$$C_1 = 3.1415897$$

$$C_3 = -5.1673678$$

$$C_5 = 2.5436052$$

$$| \sin(X) - P_5(X) | < 2 \times 10^{-4}, |X| \leq 1/2$$

Figure 18.2 Accelerometer Sine-Cosine Algorithm

SQUARE ROOT ALGORITHM

Calculate \sqrt{X} from X for $X > 0$:

X_0 = First guess at \sqrt{X}

$$X_{i+1} = \frac{1}{2} \left(X_i + \frac{X}{X_i} \right), \quad i = 0, 1, \dots$$

$$X_i \rightarrow \sqrt{X}$$

INVERSE SQUARE ROOT ALGORITHM

Calculate $\frac{1}{X}$ from X^2 for $X > 0$:

Method 1.

X_0 = First guess at $\sqrt{X^2}$

$$X_{i+1} = \frac{1}{2} \left(X_i + \frac{X^2}{X_i} \right), \quad i = 0, 1, \dots$$

$$\frac{1}{X_i} \rightarrow \frac{1}{X}$$

Method 2.

X_0 = First guess at $\frac{1}{\sqrt{X^2}}$

$$X_{i+1} = \frac{1}{2} X_i (3 - X_i^2 X^2)$$

$$X_i \rightarrow \frac{1}{X}$$

Figure 18.3 Square Root and Inverse Square Root Algorithm

Arctangent Algorithm
(To Calculate ARCTAN (X), $X = Y/Z$)

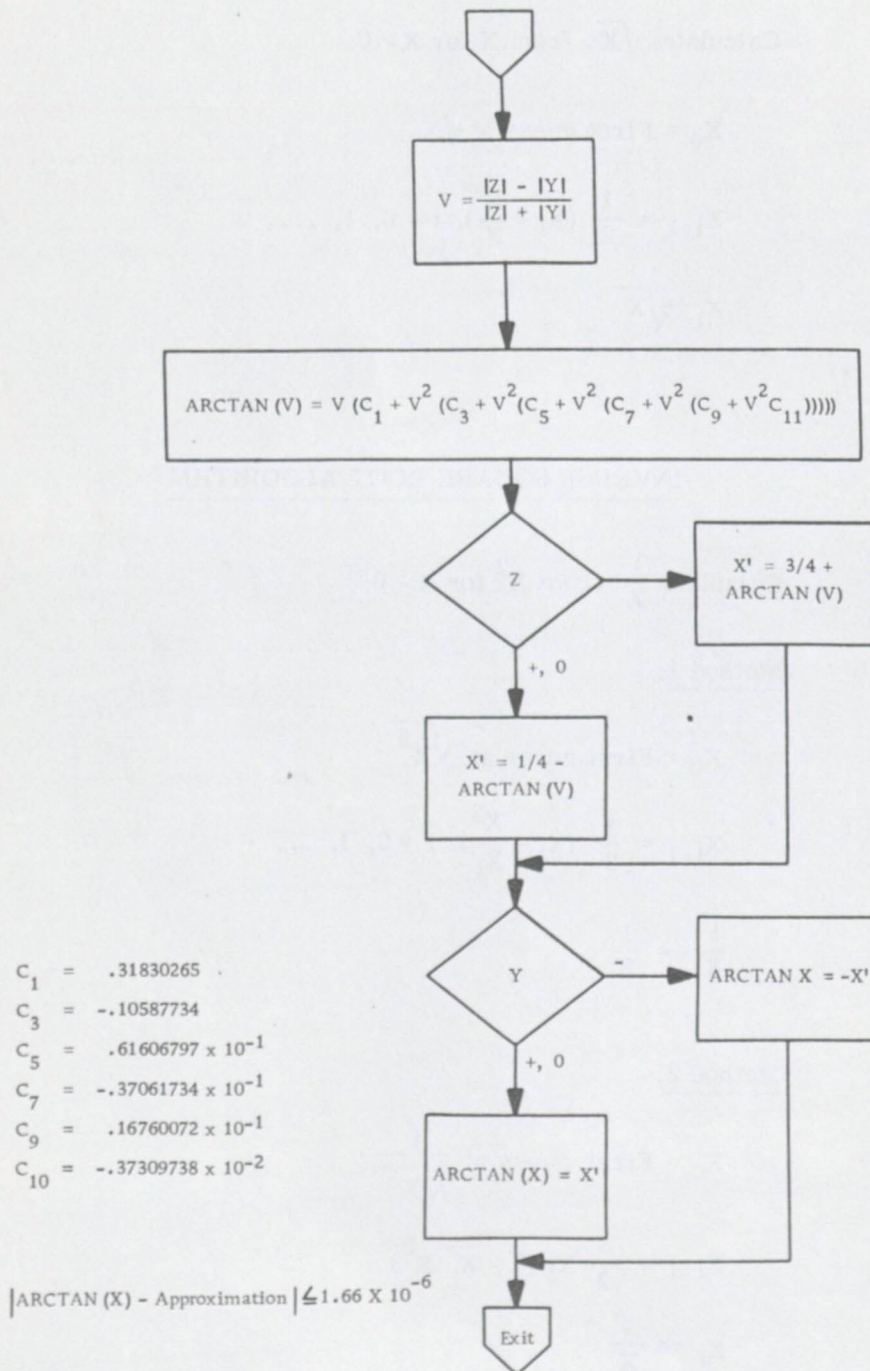
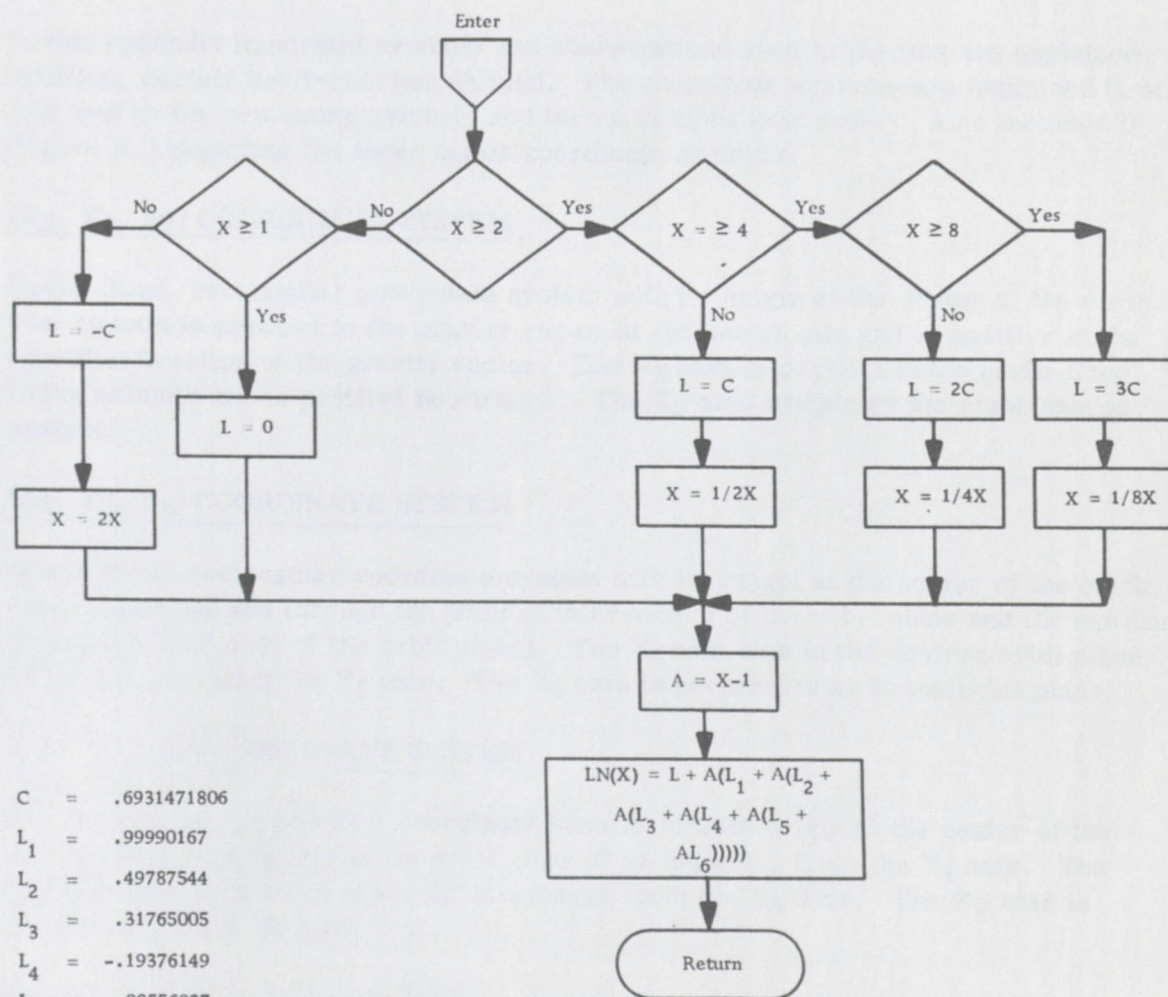


Figure 18.4 Arctangent Algorithm

Calculate LN (X), $1/2 \leq X \leq 16$



$C = .6931471806$
 $L_1 = .99990167$
 $L_2 = .49787544$
 $L_3 = .31765005$
 $L_4 = -.19376149$
 $L_5 = .08556927$
 $L_6 = -.01833831$

$|\text{LN}(X) - \text{Approximation}| < 1.5 \times 10^{-6}$

Figure 18.5 Natural Logarithm Algorithm

APPENDIX A

SYMBOLS AND ABBREVIATIONS

In this appendix important symbols and abbreviations used in the text are explained. In addition, certain key terms are defined. The coordinate systems are explained first, followed by the remaining symbols and terms in alphabetic order. Also included is Figure A.1 depicting the three major coordinate systems.

(X_S, Y_S, Z_S) COORDINATE SYSTEM

Space-fixed, rectangular coordinate system with its origin at the center of the earth. The Y_S axis is parallel to the gravity vector at the launch site and is positive in the opposite direction of the gravity vector. The X_S axis is parallel to the earth-fixed firing azimuth and is positive downrange. The Z_S axis completes the right-handed system.

(X₄, Y₄, Z₄) COORDINATE SYSTEM

Space-fixed, rectangular coordinate system with its origin at the center of the earth. The Y₄ axis passes through the point of intersection of the orbit plane and the equator (the descending node of the orbit plane). The X₄ axis lies in the desired orbit plane, 90° downrange from the Y₄ axis. The Z₄ axis is perpendicular to the orbit plane.

(X_V, Y_V, Z_V) COORDINATE SYSTEM

A space-fixed, rectangular coordinate system with its origin at the center of the earth. The Y_V axis lies in the orbit plane at an angle ψ_T from the Y₄ axis. The X_V axis lies in the orbit plane 90° downrange from the Y_V axis. The Z_V axis is collinear with the Z₄ axis.

(U, V, W) COORDINATE SYSTEM

A space-fixed, rectangular coordinate system with its origin at the center of the earth. The W axis is oriented along the earth's spin axis pointing south. V is perpendicular to W and oriented so that the VW plane contains the launch site at launch time. U is chosen so that it completes a right hand orthogonal system.

AC	Accumulator
AP Matrix	The transformation matrix between the X_S, Y_S, Z_S coordinate system and the X_4, Y_4, Z_4 system.
BR	Buffer Register
BTC	Begin telemetry cycle
CHI X (x_X) CHI Y (x_Y) CHI Z (x_Z)	Commanded platform yaw, roll, and pitch gimbal angles. These angles are the computed outputs of all the various LVDC guidance routines.
CHI X PRIME (x'_X) CHI Z PRIME (x'_Z)	Commanded yaw and pitch angles for an imagined platform in the X_4, Y_4, Z_4 system. These angles are computed during IGM and coast guidance only.
CIU	Computer Interface Unit
CM	Command Module
CO	Cutoff
COD	Cross over detector
DB	Disagreement bit
DELTA T NOM (ΔT_{NOM})	The nominal computation cycle length. This quantity varies with the different combinations of flight and navigation modes.
DELTA XG (ΔX_G)	Change in X_S caused by gravitation.
DELTA XT (ΔX_T)	Change in X_S caused by platform measured accelerations.
DIM	Digital input multiplexer
DI or DIN	Discrete input
DOM	Digital output multiplexer
DOR	Discrete output register
EC	Expected change
EMR	Engine mixture ratio

EMRC	Engine mixture ratio change
ETC	End telemetry cycle
ETW	Error time word
F	Thrust
FISCHER ELLIPSOID	An ellipsoid of revolution used to approximate the shape of the Earth.
FLIGHT PLANE	The $X_4 - Y_4$ plane is referred to as the flight (orbit) plane. At S-IVB cutoff the vehicle velocity and radius should lie in this plane.
F over M (F/M)	Magnitude of platform measured acceleration. This term is computed by numerical differentiation of platform velocities throughout boost, except for the periods immediately following liftoff and during staging. During these portions of flight (F/M) is likely to be unusually noisy, and its value is set by estimate. Following S-IVB cutoff, F/M is set to zero.
G Matrix	Transforms () _S into () ₄ Cf. Table 7.1.
GRRA	Guidance reference release alert
GUIDANCE REFERENCE RELEASE (GRR)	An interrupt occurring 8 seconds prior to launch commit. At GRR the platform is released (i.e., "goes inertial"), and the LVDC enters the flight routines. GRR starts time base 0.
GX (g'_X)	Computed gravitational acceleration in the X_S direction.
ICR	Internal control register
IECO	Inboard engine cutoff
IGM	Iterative guidance mode
IGX (I_{gX})	Computed gravitational velocity in the X_S direction.
I/O	Input/output
IPR	Interrupt processing routine
IR	Interrupt register

LIFTOFF (LO)	Discrete signal given to the LVDC to mark liftoff and begin time base 1.
LOW LEVEL SENSE (LLS)	An interrupt caused by fuel level sensors. This signal starts time base 2.
M	Mass
MCC	Mission Control Center
ORBIT PLANE	(See FLIGHT PLANE)
OUTBOARD ENGINE CUTOFF (OECO)	An interrupt which starts time base 3.
PIO	Process input-output
PIT	Pitch attitude error command.
PQ	Product-quotient register
R	Distance from center of $X_S Y_S Z_S$ coordinate system to the vehicle
ROL	Roll attitude error command.
RTC	Reasonableness test constant
SF	Scaling factor
SMC	Steering misalignment correction
SMCX	X component of SMC
S-IVB CUTOFF (4BCO)	An interrupt which starts time base 4.
TAS (t_{as})	Time of accelerometer sample, measured from zero at GRR.

TIME BASE 0 (T_0)	
TIME BASE 1 (T_1)	
.	
.	
.	
TIME BASE 7 (T_7)	
THETA X (θ_x)	
THETA Y (θ_y)	
THETA Z (θ_z)	Platform gimbal angles in yaw, roll and pitch.
TLC	Simultaneous memory error
TLD	Thrust level decay
TMD	Triple modular redundancy
THETA X COARSE (θ_{XC})	$\theta_X - \theta_{Xf}$
THETA Y COARSE (θ_{YC})	$\theta_Y - \theta_{Yf}$
THETA Z COARSE (θ_{ZC})	$\theta_Z - \theta_{Zf}$
THETA X FINE (θ_{XF})	The portion of θ_X , θ_Y , or θ_Z measured by the 64:1 or 2:1 resolver in the minor loop.
THETA Y FINE (θ_{YF})	
THETA Z FINE (θ_{ZF})	
X DOT M (\dot{X}_M)	Platform velocity in the X_S direction.
X DOT S (\dot{X}_S)	Inertial velocity in the X_S direction.
YAW	Yaw attitude error command.

$X_s Y_s Z_s$ System \equiv Platform System

$X_4 Y_4 Z_4$ System \equiv Target Plane Coordinate System

$X_v Y_v Z_v$ System \equiv Injection Coordinate System

ϕ_L \equiv Latitude of Launch Site

ψ_T \equiv Total Range Angle

i \equiv Inclination of Orbit

D.N. \equiv Descending Node

A.N. \equiv Ascending Node

Note: Z coordinates of all systems have been omitted for clarity. Not necessarily to scale for this mission.

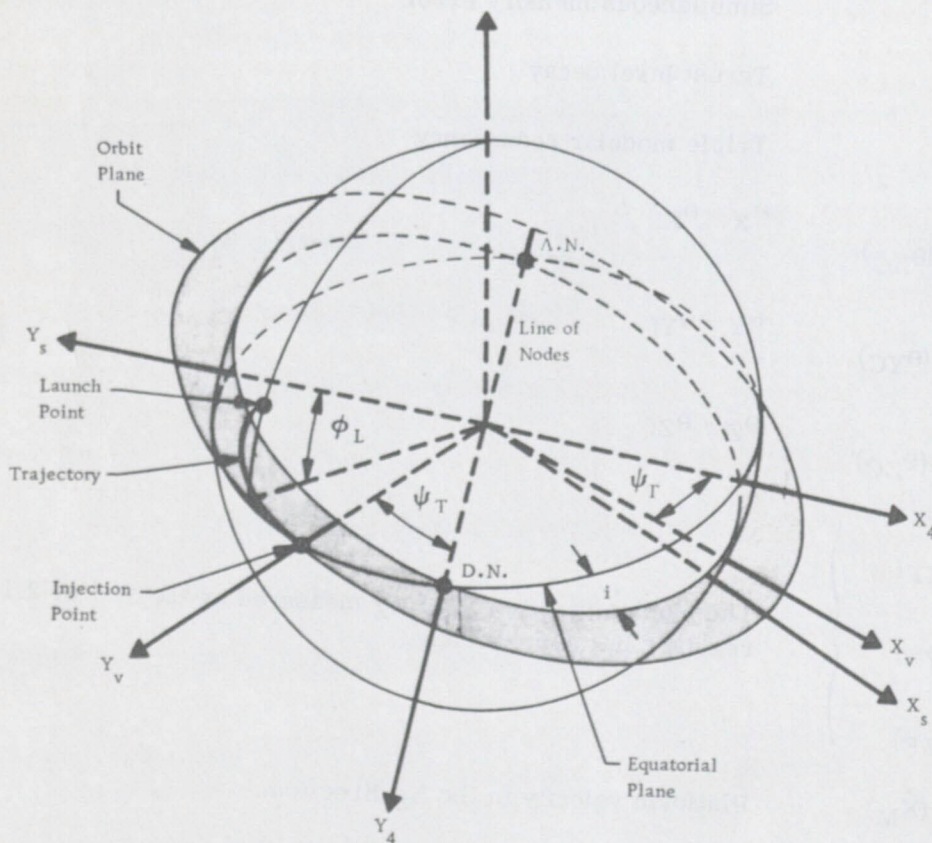


Figure A. 1 IGM Coordinate System Geometry

APPENDIX B

SIMULATION STUDIES

B.1 BOOST AND OUT OF ORBIT 6D SIMULATION STUDIES

B.1.1 Introduction

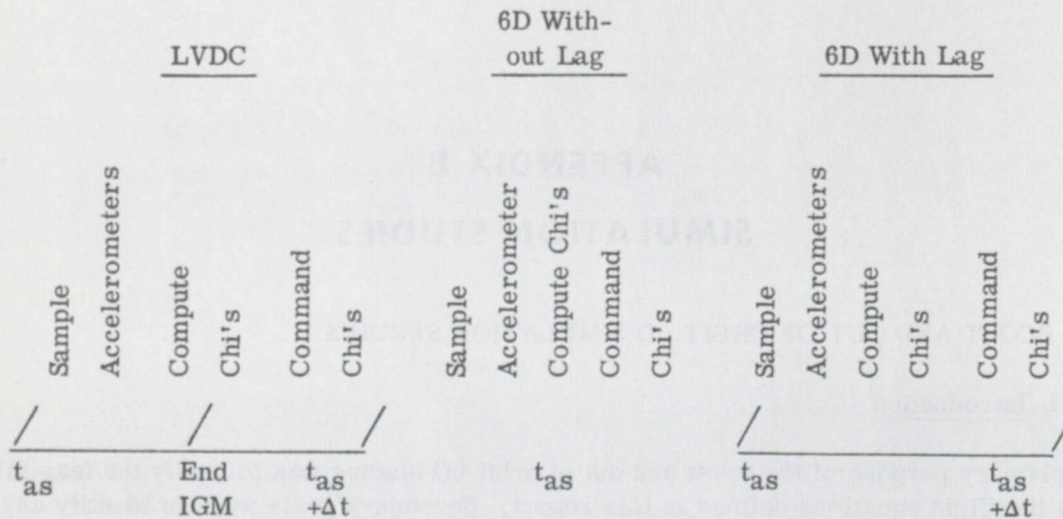
The primary purpose of the boost and out of orbit 6D studies was to verify the feasibility of the flight equations defined in this report. Secondary goals were to identify any potential problem areas not discovered by other means and to investigate possible new methods of improving the flight program. Numerous difficulties were encountered during the course of the investigations. The final specification of the boost flight equations was found to be adequate over a range of perturbations. The out of orbit equations, however, were not finally verified. Thus, only preliminary results for out of orbit were obtained.

B.1.2 Simulator Description

The simulator used for the boost, out-of-orbit, and sensitivity studies was the standard 6D digital program modified to reflect accurately the AS-501 mission profile. Vehicle parameters utilized were based primarily on information provided by R-ASTR-NG-107-65, "LVDC Mission Defining Document for the AS-501 Mission" and references therein. Additionally, more recent data on the AS-501 mission was obtained from R-P&VE-PPE-65-M-381(633), "Predicted Thrust and Propellant Weight History for S-IVB/V SA-501 Flight" and R-P&VE-PPE-65-M-373(633), "S-II Stage Flight Performance Dispersion Study", (CONFIDENTIAL). S-II and S-IVB thrust and mass flow rate for the simulation were variable functions of time in keeping with current predictions of engine performance. Moreover, in all stages the effects due to thrust decay were simulated.

Guidance, navigation, and control were provided by the equations defined in this document. Minor loop support was included in the simulated flight program, as were all onboard algorithms and M/F smoothing. Quantization of accelerometer inputs and minor loop outputs was also included.

In order to simulate time lags actually present in flight, a one computation cycle delay between computation and command of the desired steering angles (CHI's) was introduced into the 6D. The following diagram illustrates the lags in the LVDC and in the 6D simulator.



The computation cycle length used in the 6D simulation studies was a function of the flight mode. Thus, Δt was given by

$$\Delta t = \begin{cases} 1.0 & \text{during S-IC burn,} \\ 1.6 & \text{during S-II and S-IVB burn except during periods of } \tilde{\chi} \text{ steering} \\ 1.4 & \text{during } \tilde{\chi} \text{ steering in S-IVB burn.} \end{cases}$$

Such a Δt reflects variations in the LVDC computation cycle expected in actual flight.

B.1.3 Results of Boost Guidance Studies

Boost simulation studies covered the period from liftoff to first S-IVB cutoff. A major portion of the study effort was devoted to designing and verifying a workable guidance logic for the S-II and S-IVB burn period. Figures B.1.1 and B.1.2 compare boost chi pitch profiles obtained from the original IGM logic and from the final recommended IGM logic. The large oscillations in the original chi pitch curve pointed out problem areas. A discussion of these and their solution follows.

B.1.3.1 Guidance Problems at S-II PMR Shift and S-II Burnout - S-IVB Ignition

The PMR shift in the S-II burn causes some of the undesirable oscillations in chi pitch. Due to the shift, the S-II thrust decreases by approximately 19% only 42 seconds from nominal S-II burnout. Moreover, the thrust is decidedly non-constant from PMR shift to burnout. A partial solution to this problem was provided by an artificial tau mode of short duration beginning at the sensing of PMR shift. PMR shift is sensed in the flight program by a test on acceleration.

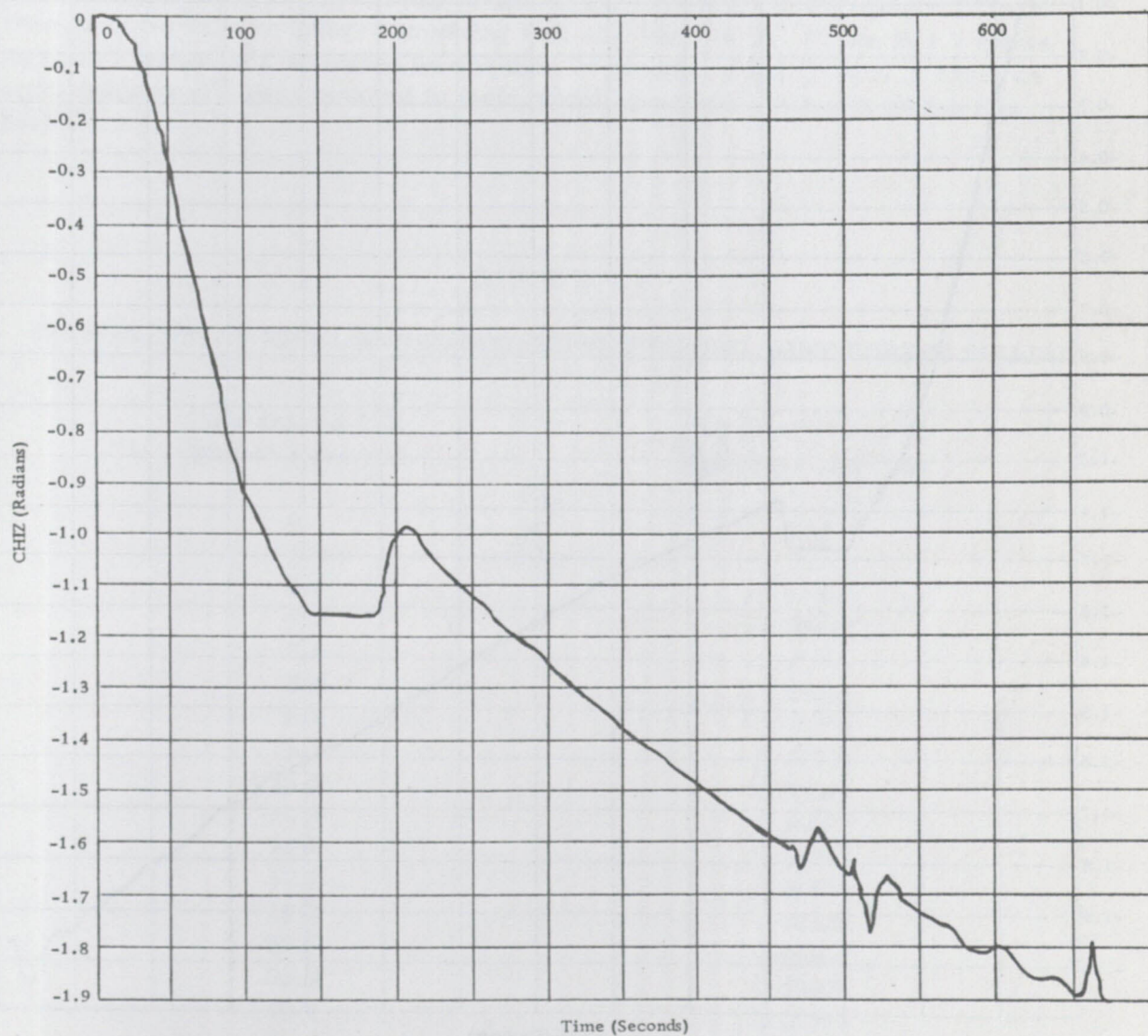


Figure B.1.1 Chi Pitch Command from Original IGM

$$1.9r = 108.87^\circ$$

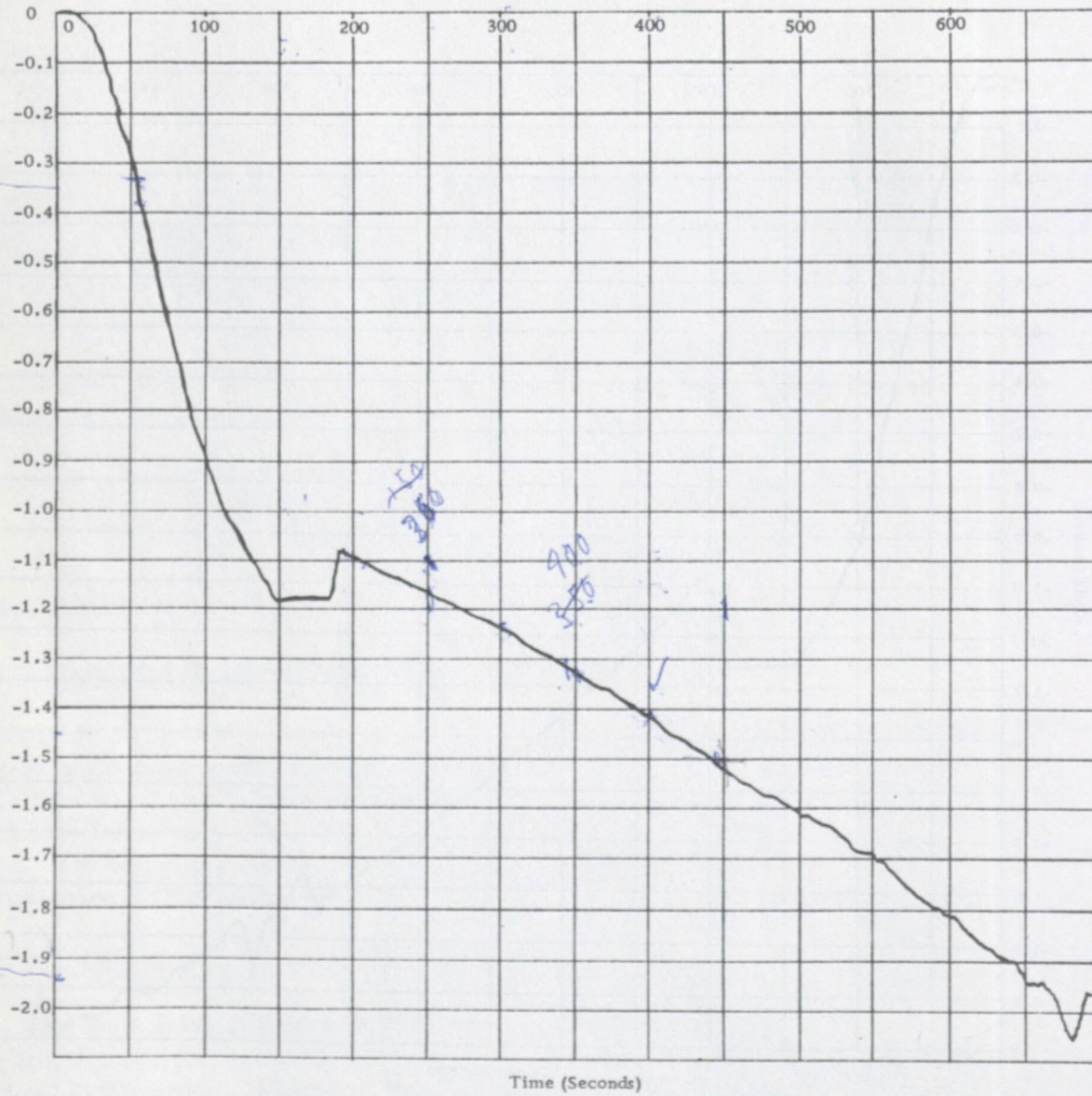


Figure B.1.2 Chi Pitch Command from Recommended IGM

A frozen vehicle attitude command around S-II burnout is required to permit the vehicle to attain the desired attitude before burnout and obviate the possibility of attitude error buildup prior to and during S-IVB ignition. To accomplish this both the chi pitch and chi yaw rates were zeroed shortly before S-II burnout and remained zero until after S-IVB ignition.

Since IGM relies on smoothed M/F for the computation of tau, further guidance problems were caused by thrust buildup in the S-IVB. Smoothed M/F required 20 to 30 seconds of S-IVB burn before comparing well with ideal M/F. (Table B.1.1 shows ideal M/F minus M/F smoothed for the first 34 seconds of S-IVB burn.) Again an artificial tau mode was employed to yield smooth guidance commands during this period.

TABLE B.1.1

COMPARISON OF IDEAL AND SMOOTHED M/F DURING S-IVB THRUST BUILDUP

Time from S-IVB Ignition (seconds)	Ideal M/F - M/F Smoothed (sec ² /m)
0	2.63543
1.6	1.17364
3.2	-0.01209
4.8	-0.09608
6.4	-0.06985
8.0	-0.04656
9.6	-0.02914
11.2	-0.01591
12.8	-0.00614
14.4	-0.00029
16.0	0.00343
17.6	0.00505
19.2	0.00526
20.8	0.00517
22.4	0.00402
24.0	0.00341
25.6	0.00224
27.2	0.00170
28.8	0.00064
30.4	0.00040
32.0	0.00008
33.6	0.00006

B.1.3.2 S-II Engine Out Provisions

If an S-II engine out occurs, IGM must still meet end conditions at S-IVB burnout. Thus certain IGM parameters are updated when an engine out discrete is received. Simulation studies show that the recommended technique does guide the vehicle to the desired end conditions. When the engine out is first sensed, however, an excessively large ΔT_3 may occur. This problem will be further studied to develop better engine-out guidance.

B.1.3.3 Terminal Steering

Injection accuracy at S-IVB at S-IVB burnout was enhanced by using velocity to be gained (\tilde{x}) steering during the last ϵ seconds of S-IVB burn. The length of the \tilde{x} steering mode (i.e., the value of ϵ) was selected during the simulation studies. The choice of $\epsilon = 10$ seconds was motivated by results shown in Table B.1.2 ($\Delta \gamma_T$ is the terminal path angle error, ΔR is terminal radius error).

TABLE B.1.2

EVALUATION OF TERMINAL STEERING

<u>Simulation Conditions</u>	<u>$\Delta \gamma_T$</u>	<u>ΔR</u>
Nominal Vehicle, $\epsilon = 10.0$	-0.0056	-70.0
Nominal Vehicle, $\epsilon = 15.0$	-0.0061	-66.0
Nominal Vehicle, $\epsilon = 20.0$	-0.0118	-77.0

B.1.3.4 Perturbation Runs

A summary of the perturbations simulated and end conditions achieved is contained in Table B.1.3. These results show that the recommended boost flight equations achieved accurate end conditions despite severe perturbations. Figures B.1.2 through B.1.5 show critical IGM and vehicle parameters for a nominal vehicle. Figure B.1.6 shows an expected range for values of chi pitch. All perturbed runs should yield a chi pitch that lies within the indicated band about the nominal chi pitch.

In Table B.1.3 note that out of plane errors are considerably larger than for Saturn IB missions. This degradation is attributable to a difference in \tilde{x} steering between Saturn IB and Saturn V. Saturn V employs velocity to be gained steering in both pitch and yaw, whereas Saturn IB uses it only in pitch.

Accuracies achieved in the boost simulation runs meet requirements and demonstrate the adequacy of the equation specifications.

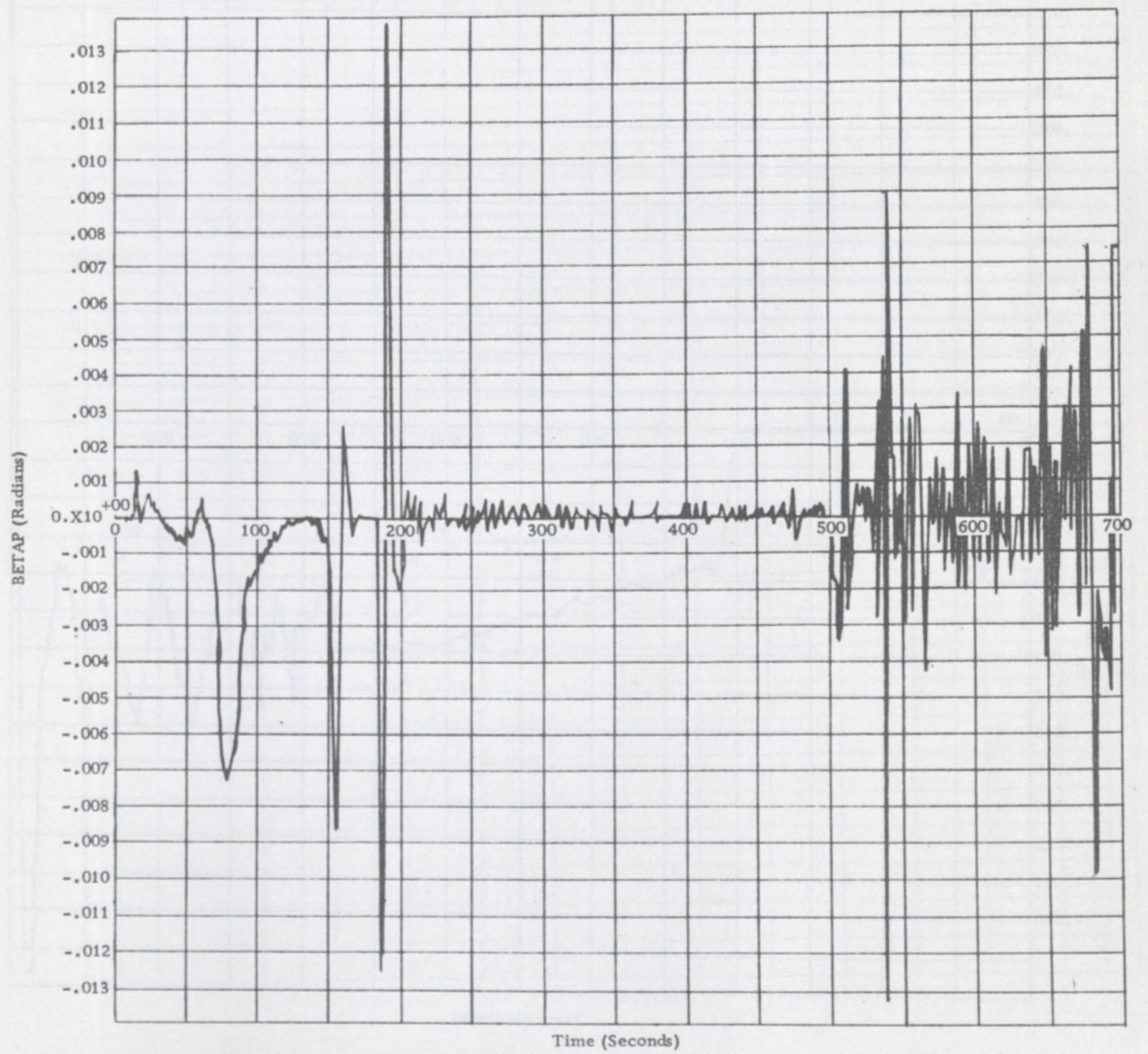


Figure B.1.3 Nominal Pitch Engine Swivel Angle

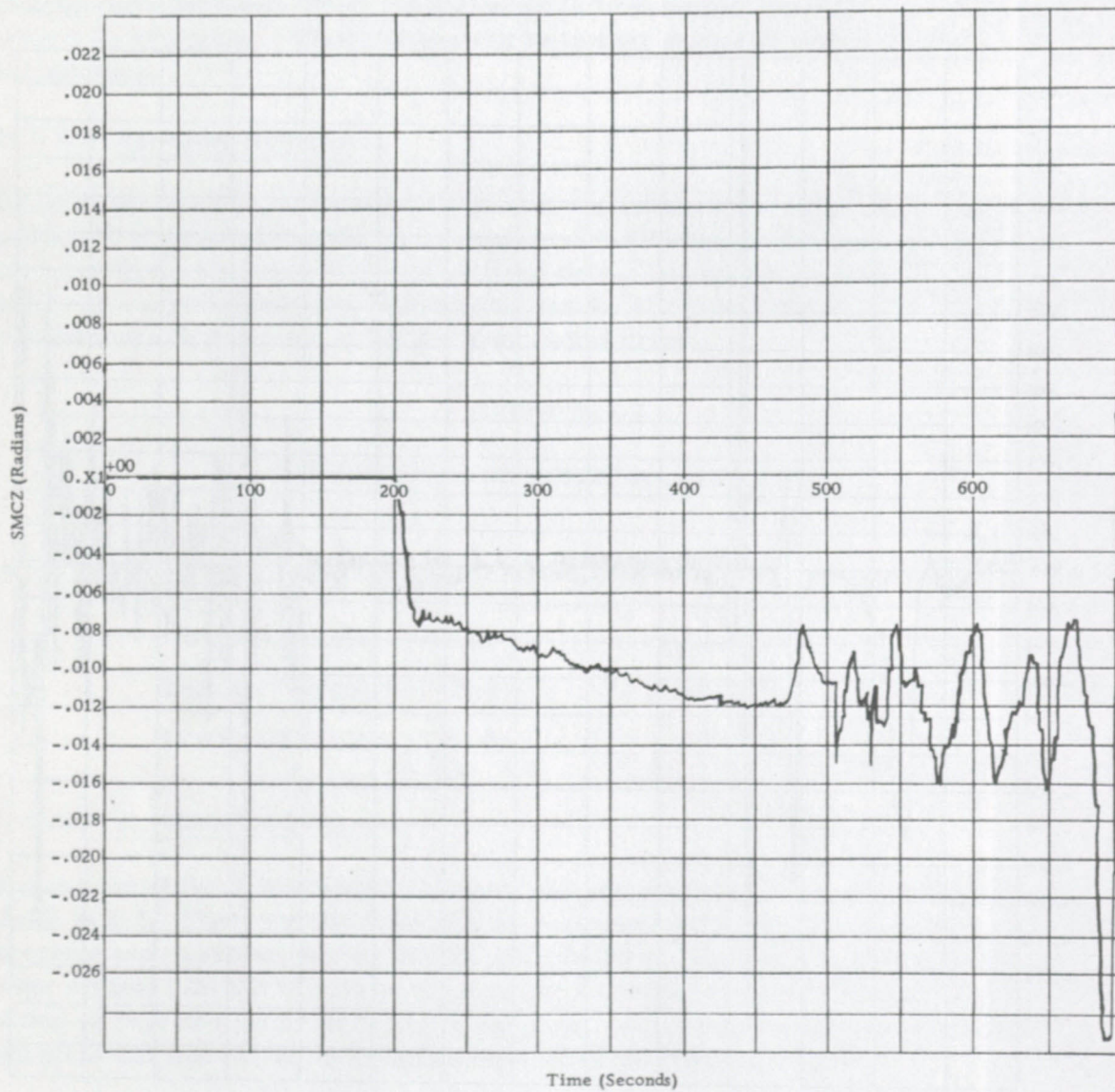


Figure B.1.4 Nominal Steering Misalignment Correction in Pitch

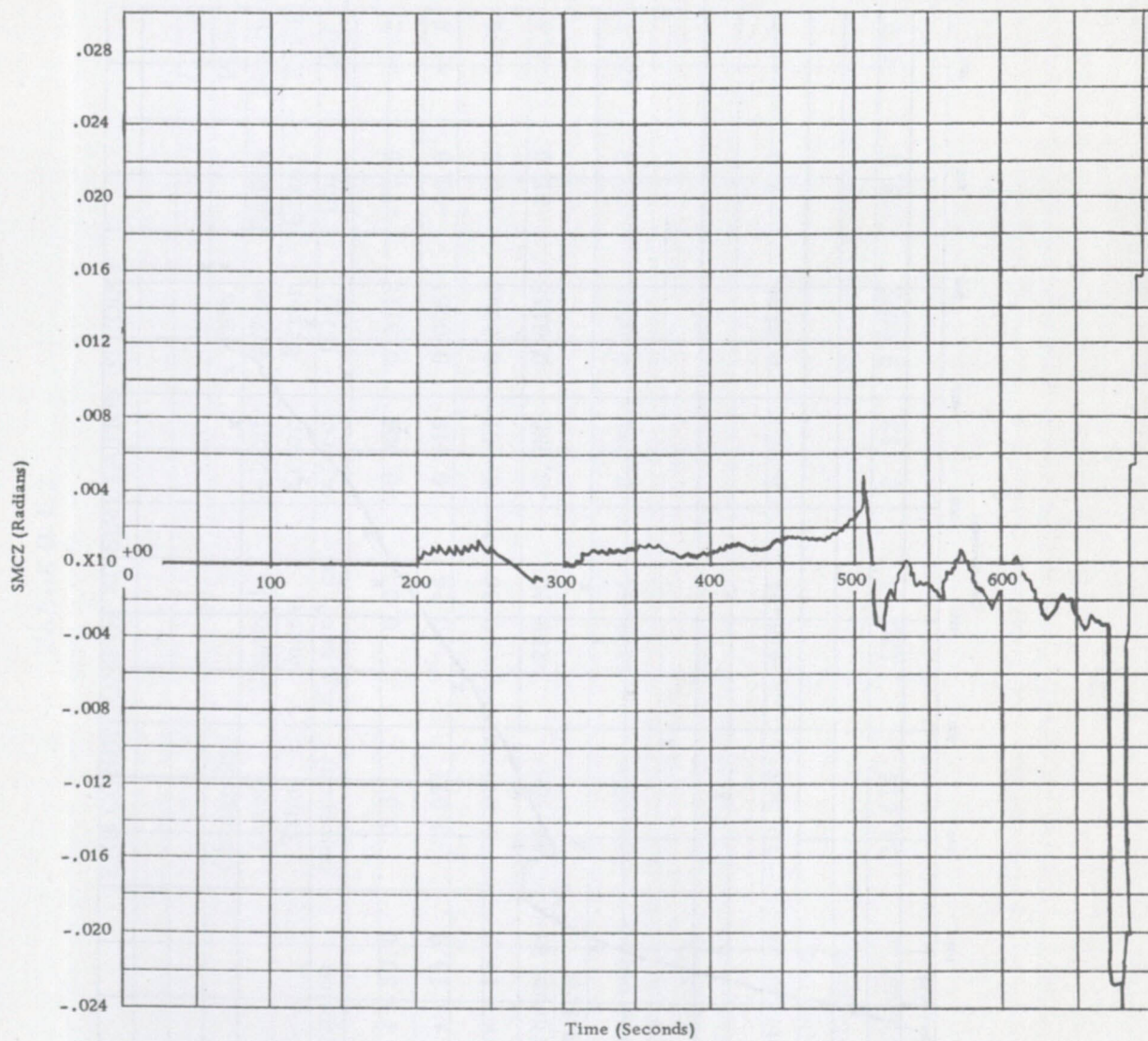


Figure B.1.5 Nominal Steering Misalignment Correction in Yaw

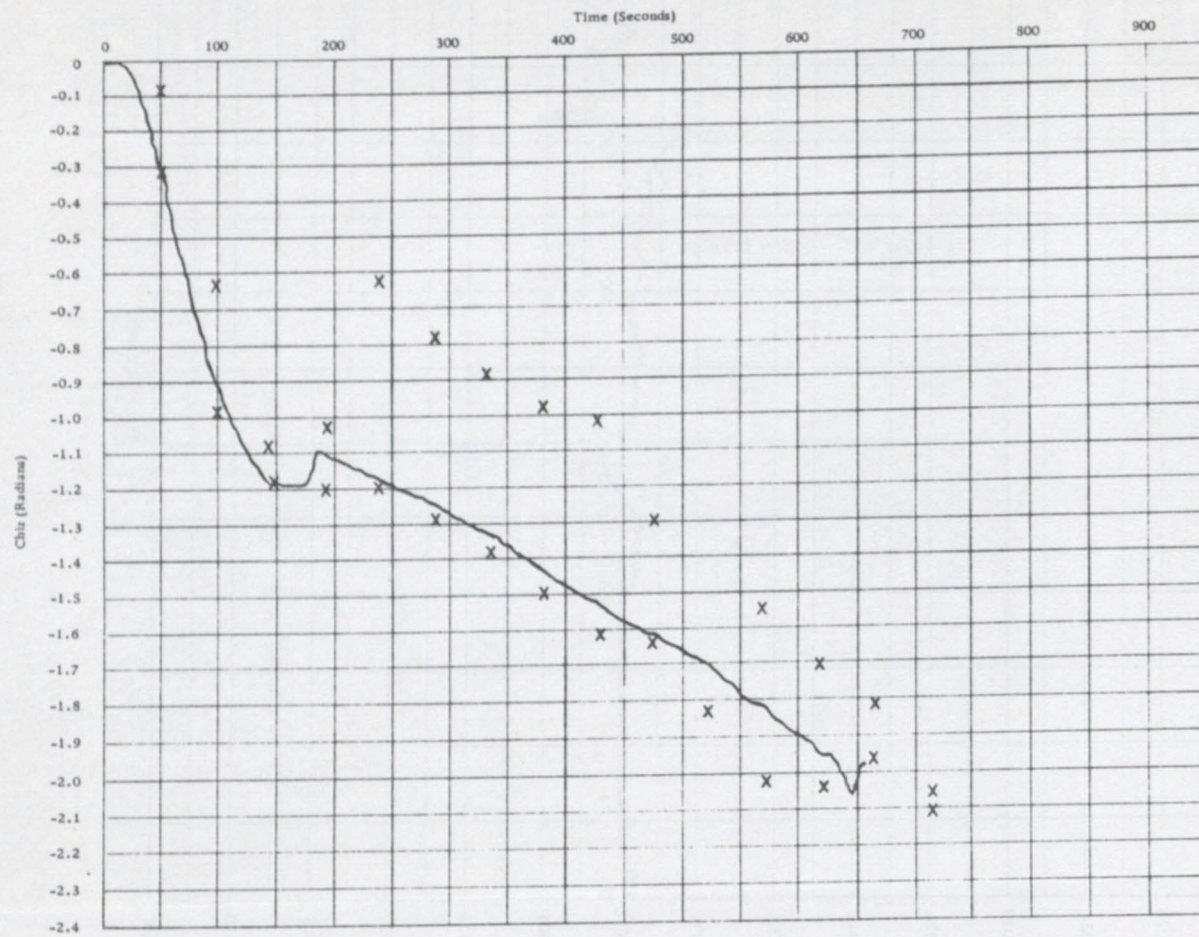


Figure B.1.6 Chi Pitch Envelope

TABLE B.1.3

END CONDITIONS OF 6D SIMULATION STUDIES

Run Number	Description	Change In Cutoff Time (seconds)	Change In Mass (Kg. sec ² /m)	Velocity Error (m/sec)	Path Angle Error (deg)	Radius Error (m)	Out of Plane Position Error (m)	Out of Plane Velocity Error (m/sec)
1	Nominal $\epsilon = 20.0$	0.0	0.0	-0.004	0.0118	-77.0	-1.2	-1.10
2	Nominal $\epsilon = 15.0$	-0.011	0.24	-0.019	0.0061	-66.0	45.9	0.73
3	Nominal $\epsilon = 10.0$	0.017	-0.38	0.351	0.0056	-70.0	57.5	2.31
4	5% Low Thrust in S-II and S-IVB	46.136	-299.22	-0.035	0.0138	31.0	-4.4	-1.26
5	S-IC Engine out at Liftoff + 25 sec., 20 sec. late PMR Shift	134.050	-2401.64	-0.191	0.0043	75.0	-20.7	-1.34
6	S-II Engine Out at Liftoff + 190 sec., Early PMR Shift	70.583	-433.31	0.023	0.0156	2.0	-4.5	-0.75
7	5% High Thrust in S-II and S-IVB	-34.414	130.84	0.113	0.0092	-123.0	0.9	-1.26

B.1.4 Boost Sensitivity Studies

The 6D simulator was used to study the sensitivity of the IGM chi pitch to changes in F/M , X_S , Y_S , Z_S , \dot{X}_S , \dot{Y}_S , and \dot{Z}_S . The sensitivities (numerical partial derivatives) were computed on each pass through the IGM equations. Figure B.1.7 shows the sensitivity of chi pitch to F/M ($\Delta x_z / \Delta (F/M)$) from IGM release to first S-IVB burnout. Table B.1.4 catalogues sensitivities of x_z to the other parameters at 50 second intervals. From these numbers plots of all the sensitivity curves can be obtained.

The results reveal that chi pitch is as sensitive to changes in the state variables in AS-501 as it was in the AS-201 and AS-202 missions. This points out the need for M/F smoothing and provides a strong argument for use of artificial tau during large thrust oscillations.

B.1.5 Out-Of-Orbit Studies

The initial conditions for the out of orbit studies were generated by the orbital simulation described in Appendix B.3 from nominal parking orbit injection data. These initial conditions were then used, along with the S-IVB second burn characteristics, to simulate the AS-501 injection into waiting orbit.

It was not possible to achieve the waiting orbit using the data described above. Excessive pitch steering corrections (K_1) resulted in failure of the guidance sine-cosine algorithm. The cause of this error was traced to incorrect input conditions (out-of-orbit target conditions). Reinitialization of the simulation using a new value for the longitude of the descending node allowed a successful simulation to within a few seconds of cutoff. Excessive vertical velocity to be gained during this terminal portion, however, precluded accurate cutoff conditions. Studies are continuing to isolate and correct the cause of this steering inaccuracy.

This section will be updated to include results of hyper-surface equation examinations as soon as significant results are achieved.

B.2 MINIMUM FUEL TRAJECTORY STUDIES FOR BOOST (MFT)

The boost minimum fuel trajectory program contains a three-degree-of-freedom model of the S-II and S-IVB stages of the Saturn V vehicle. The program yields the optimum boost trajectory (from IGM release to S-IVB burnout) for a given initial and a desired final state with specified mass and thrust time functions. The program accepts a continuously varying thrust profile such as the one projected for the AS-501 mission.

As a preliminary step, the thrust curve used in the AS-501 6D simulator was approximated by a piecewise constant thrust function. Step changes in the thrust level thus occurred at the S-II PMR shift, S-II burnout, and S-IVB ignition. With the initial state variables from a nominal 6D run, the MFT deck was flown to the desired end conditions.

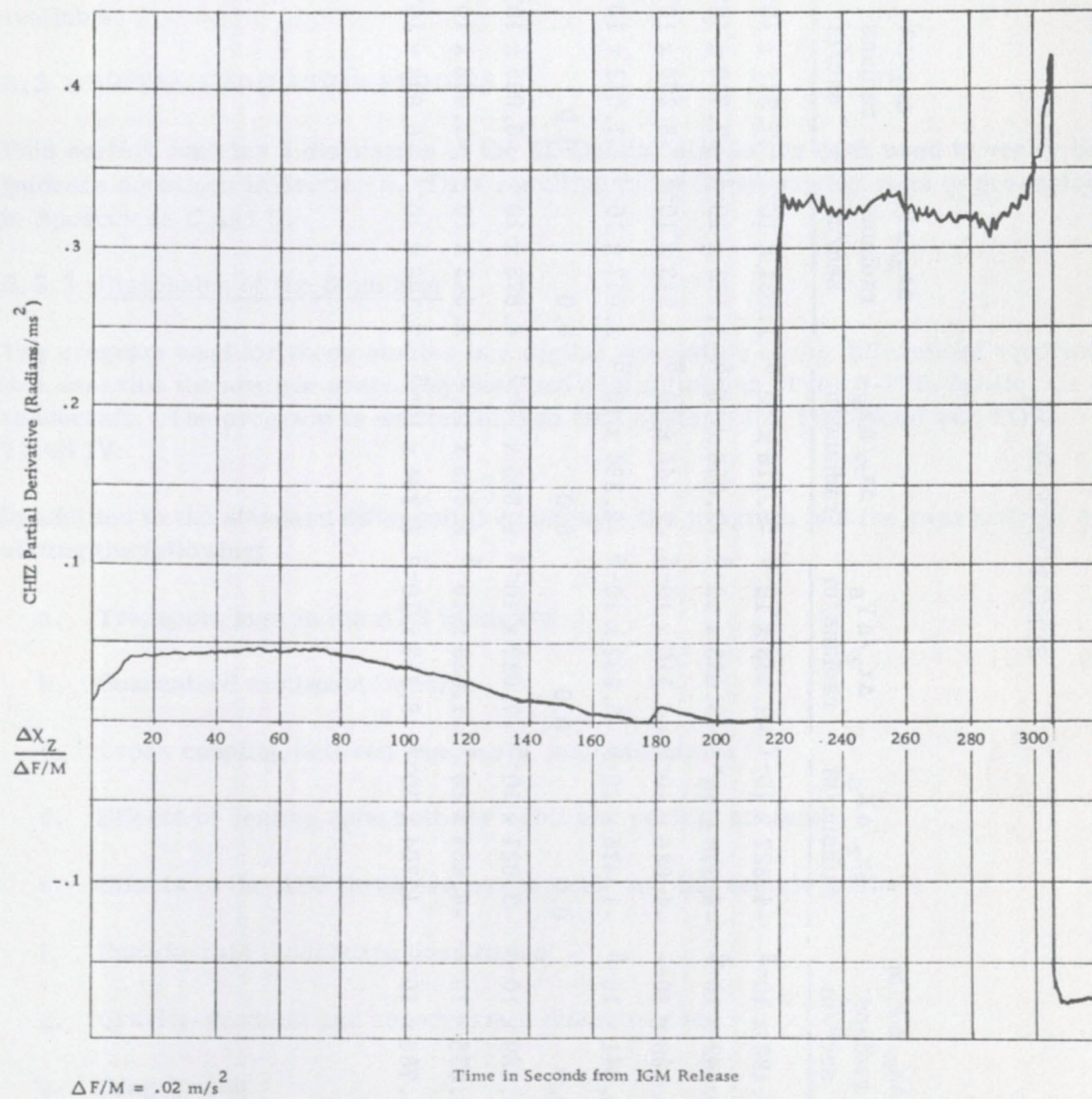


Figure B.1.7 Partial Derivative of Chi Pitch with Respect to F/M

TABLE B.1.4
SENSITIVITY OF x_z

TIME (Seconds from IGM Release)	$\Delta x_z / \Delta F / M$ radians· sec ² /m	$\Delta x_z / \Delta X_s$ radians/m	$\Delta x_z / \Delta Y_s$ radians/m	$\Delta x_z / \Delta Z_s$ radians/m	$\Delta x_z / \Delta \dot{X}_s$ radians· sec/m	$\Delta x_z / \Delta \dot{Y}_s$ radians· sec/m	$\Delta x_z / \Delta \dot{Z}_s$ radians· sec/m
1	1.122×10^{-2}	-4.327×10^{-7}	-2.353×10^{-6}	-2.116×10^{-8}	1.631×10^{-5}	-7.313×10^{-4}	-1.153×10^{-5}
51	4.442×10^{-2}	-6.378×10^{-7}	-3.083×10^{-6}	-2.056×10^{-8}	1.172×10^{-4}	-7.720×10^{-4}	-1.207×10^{-5}
101	3.405×10^{-2}	-1.026×10^{-6}	-4.110×10^{-6}	-2.146×10^{-8}	1.943×10^{-4}	-8.296×10^{-4}	-1.112×10^{-5}
151	8.041×10^{-3}	-1.875×10^{-6}	-5.983×10^{-6}	-2.384×10^{-8}	2.067×10^{-4}	-1.012×10^{-3}	-9.298×10^{-6}
201	0.0	0.0	0.0	0.0	0.0	0.0	0.0
251	3.289×10^{-1}	-3.021×10^{-5}	-7.027×10^{-5}	9.805×10^{-5}	4.878×10^{-4}	-6.095×10^{-3}	-1.220×10^{-4}
301	3.536×10^{-1}	-4.864×10^{-4}	-1.033×10^{-3}	2.746×10^{-5}	2.542×10^{-3}	-2.436×10^{-2}	-6.937×10^{-4}
319 (First S-IVB Burn Cutoff)	-1.736×10^{-1}	-1.704×10^{-4}	8.258×10^{-5}	1.284×10^{-6}	-2.198×10^{-1}	-6.893×10^{-2}	-1.704×10^{-2}

The comparison between 6D and MFT burn times was very poor - the MFT deck met the end conditions in 4.57 seconds less than IGM. Almost all of this error is attributable to differences in the thrust model. On the other hand no clear picture of the non-optimality of IGM is obtainable from this result.

Further work is now in progress to converge the MFT deck using exactly the same thrust model in the MFT as was used in the 6D. Results will be documented when available.

B.3 ORBITAL SIMULATION STUDIES

This section contains a discussion of the 6D Orbital simulation deck used to verify the guidance equations in Section 8. Data resulting from the simulator runs is presented in Appendices C and D.

B.3.1 Discussion of the Simulator

The program used for these studies is a digital simulation of the differential equations that describe the attitude control system and orbital motion of the S-IVB/Apollo spacecraft. The program is written in both IBM System/360 FORTRAN and FORTRAN IV.

In addition to the standard differential equations, the program has the capability of simulating the following:

- a. Transport lags in the APS hardware
- b. Guaranteed minimum impulse
- c. Cross coupling between yaw, roll, and pitch axis
- d. Effects of venting upon both the orbit and vehicle attitude
- e. Effects of the APS thrusters on the orbit and the vehicle attitude
- f. Pseudo-rate modulation dead bands
- g. Gravity-gradient and aerodynamic disturbances
- h. Drag forces
- i. Variable atmospheric density
- j. Variable coefficient of drag and vehicle center of pressure based on angle of attack

k. Limits on steering angles and rate of change of commanded gimbal angles

l. Flight program minor loop

In addition, the simulation uses actual flight program routines for trigonometric functions which appear explicitly in the LVDC guidance equations.

The navigation subroutine for the simulation is a duplicate of the routine that will be programmed for the LVDC. Details of this routine are found in Section 5.

APPENDIX C

APS STUDIES

The amount of fuel expected to be consumed by the attitude control system is determined by simulation. The simulator is that described in Appendix B.3.

The fuel consumed by the vehicle for the parking orbit was 57.4 lbs. in Module I and 48.5 lbs. in Module III. During the waiting orbit the fuel consumed was 8.4 lbs. in Module I and 8.7 lbs. in Module III.

APPENDIX D

TIME OVER TRACKING STATIONS

The times of effective visibility from tracking stations were found from the simulator described in Appendix B. 3.

The results from this simulation are shown in Table D. 1 and Figure D. 1. Figure D. 1 is an orbital projection of the AS-501 flight during the parking orbit period. This figure also shows the locations of various telemetry stations and their approximate coverage areas for this period of flight. Table D. 1 lists times when the vehicle is in range of the telemetry stations shown in Figure D. 1. All studies of this nature reflect the fact that the earth is rotating under the vehicle. Also, the atmosphere is assumed to be rotating with the same angular velocity as the earth.

Visibility in the waiting orbit is described in "AS-501 Launch Vehicle Ground Support Planning Document" (NASA) and in "Tracking and Telemetry Analysis for AS-501" (Boeing). Both of these documents are in preparation.

TABLE D.1
ACQUISITION AND LOSS TIMES FOR THE TELEMETRY STATIONS USED
DURING THE AS-501 MISSION (PARKING ORBIT ONLY)

<u>Station Number</u>	<u>Telemetry Station</u>	<u>Time Acquired (sec. after 4BCO)</u>	<u>Time Lost (sec. after 4BCO)</u>	<u>View Time (min.)</u>
2	Bermuda	0	22	0.37
4	Canary	393	682	4.82
8	Guaymas	4680	4972	4.87
7	Texas	4861	5139	4.63
1	KSC	5099	5362	4.38
11	G. Bahamas	5149	5372	3.72
2	Bermuda	5294	5589	4.92
5	Carnarvon	7054	7154	1.67
6	Hawaii	9616	9840	3.73
8	Guaymas	10266	10530	4.40
7	Texas	10458	10705	4.12
1	KSC	10671	After S-IVB second ignition	
11	G. Bahamas	10716	After S-IVB second ignition	

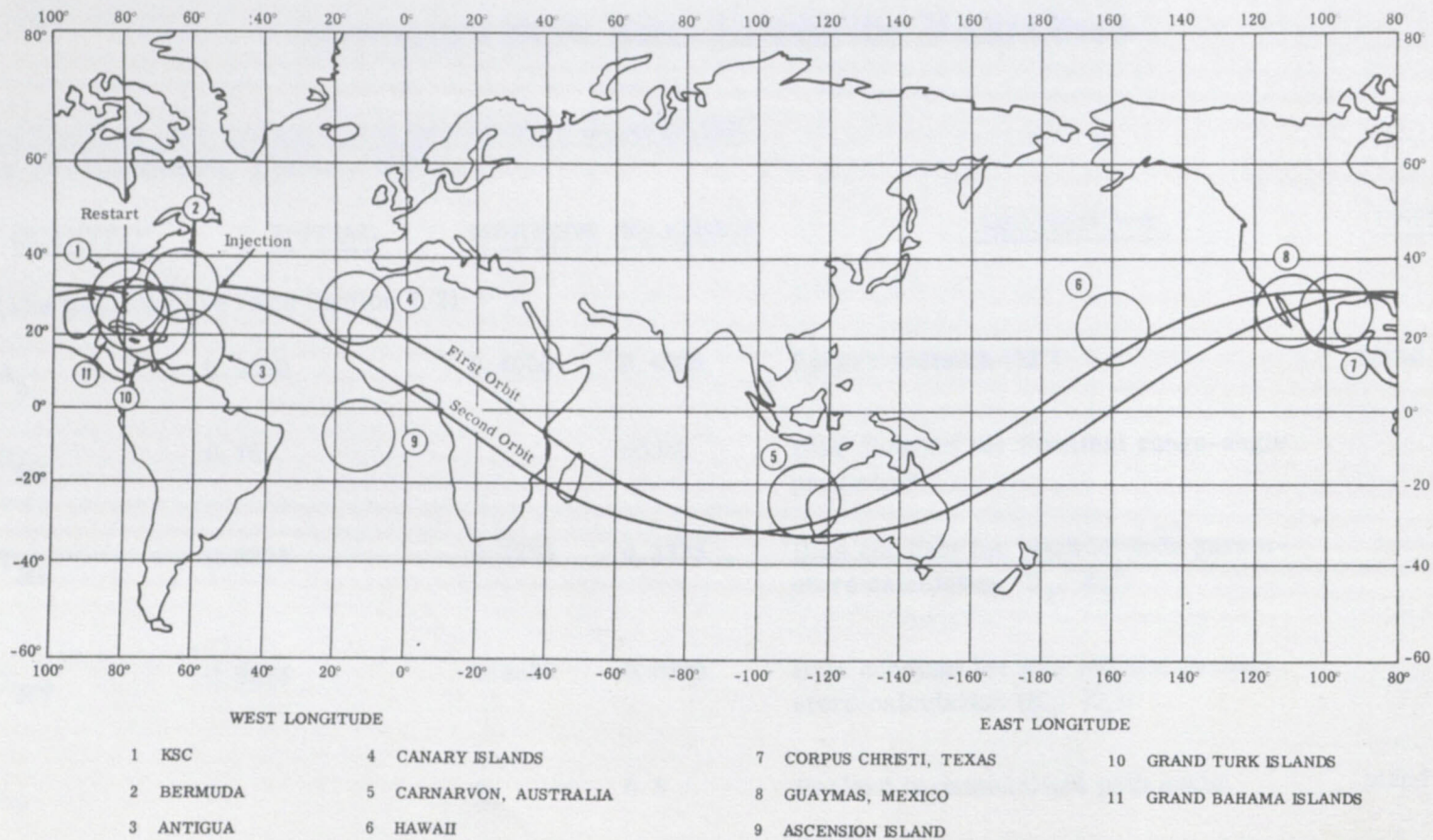


Figure D.1 AS-501 Orbital Projection (Parking Orbit)

APPENDIX E

INITIALIZATION AND RANGE OF VARIABLES

(NOTATION AND VALUES FOR IMPORTANT QUANTITIES)

m denotes meters, 1 pirad = 180°

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
(The following are from Section 7.2)					
A_z	0.4000	0.4000	0.4000	Launch Azimuth (72°)	pirad
R_{OV}	0.75		const	Bias constant for terminal range-angle prediction.	
T_{RP}	0.3333	0.3333	0.3333	Bias constant for pitch attitude parameters calculation (K_1 , K_2).	
T_{RY}	0.3333	0.3333	0.3333	Bias constant for yaw attitude parameters calculation (K_3 , K_4).	
θ_T	0	0	0.5	Desired terminal flight path angle.	pirad

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
(The following are from Section 7.3)					
α	Comp	0	1	angle, descending node to \bar{S} vector	pirads
ϕ_T	Comp	0	1	range angle, to burnout point	pirads
$\Delta \phi$	Comp	0	1	true anomaly of burnout point	pirads
θ_r	Comp	0	1	path angle at burnout	pirads
η_r	Comp	0	3.2×10^7	radius at burnout	m
V_T	Comp	0	9800	velocity magnitude at burnout	m/sec
e	Comp	0	1	eccentricity of injection ellipse	numeric
p	Comp	0	10^8	semi-latus rectum of injection ellipse	m
K_5	Comp	0	10^5	velocity constant of injection ellipse	m/sec

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
(The following are from Section 7.4)					
A _Z	0.40	.2	.7	Launch aximuth, measured positive clockwise from north (72°).	pirad
C ₃	calc	10 ⁷	10 ⁸	Energy of the transfer ellipse	m ² /sec ²
C _{3N}	-27180311	10 ⁷	10 ⁸	Energy and eccentricity of the nominal transfer ellipse.	m ² /sec ²
e	calc	0	1	Eccentricity of the desired transfer ellipse.	numeric
e _N	0.57250880	0	1	Eccentricity of the nominal transfer ellipse.	numeric
i		0	1	Inclination of orbit	pirad
J	0	0	10 ⁷	Correction for opportunity out of parking orbit	sec
K ₅	6401.4898	0	10 ⁵	Velocity constant of transfer ellipse	m/sec ²
K _C	0	0	0	Slopes of energy versus time curves	m ² /sec ³
K _e	0	0	0	Slopes of eccentricity versus time curves	1/sec
Ko' ₁	-0.005633827			Coefficients of polynominal defining the angle α _{TS}	deg/sec

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
Ko'2	0.00020939407			Coefficients of polynomial defining the angle α TS	deg/sec ²
P	calc	0	10 ⁹	Semi-latus rectum of the transfer ellipse	m
P _N	9726994	0	10 ⁹	Semi-latus rectum of the nominal transfer ellipse	m
R		0	3.2 x 10 ⁷	Radius vector	m
R _N		0	3.2 x 10 ⁷	Magnitude of the radius vector at nominal S-IVB reignition.	m
R _T		10 ⁶	3.2 x 10 ⁷	Desired terminal radius	m
\bar{S}		0	3.2 x 10 ⁷	Nodal vector, lies at the intersection of the parking orbit and transfer ellipse planes.	m
T _L		0	10 ⁵	Launch time from midnight.	sec
T _{LO}		0	10 ⁵	A constant reference time of launch from midnight.	sec
T _X , T _Y , T _Z		0	1	Components of the unit target vector, \bar{T} , in ephemeris coordinates	
T _{PX} , T _{PY} , T _{PZ}		0	1	Components of the unit target vector, \bar{T} , in platform coordinates	
T _{XN} , T _{YN} , T _{ZN}		0	1	Components of the reference unit target vector, \bar{T}_0 , in ephemeris coordinates	

<u>QUANTITY</u>	<u>NOMINAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
$T_{CDX}, T_{CDY}, T_{CDZ}, T_{CD}$	0	0	0	Constants used to update target vector.	
t_c	0	0	10^5	Clock time from liftoff.	sec
t_D	0	0	10^5	Function of launch time and time of departure from parking orbit, approximately S-IVB reignition time.	sec
ΔT_4	0	0	5	S-IVB burn time, actual-nominal	sec
\bar{V}	0	0	10^5	Vehicle velocity vector	m/sec
V_T	0	0	10^5	Desired terminal velocity	m/sec
μ	3.986032×10^{14}	-	-	Product of universal gravitational constant and mass of the earth (constant)	m^3/sec^2
		0	10^7	Position components in the terminal reference system.	m
β	0.19220422			Constant angle defining the location of the pseudo nodal (\bar{S}) vector with respect to the radius vector in the ignition plane at S-IVB restart preparation time (34.59676°)	pirad
β_1	0.06762811			Constant angle defining the location of the nodal (\bar{S}) vector with respect to the radius vector in the ignition plane at S-IVB reignition (12.173060°)	pirad

QUANTITY	INITIAL	MINIMUM	MAXIMUM	DESCRIPTION	UNIT
θ_E		0	1	Angle from the Vernal Equinox for the true time for launch, T_L .	pirad
θ_{EO}		0	1	Angle from the Vernal Equinox to the launch meridian measured in a counterclockwise direction for the constant time to launch, T_{LO}	pirad
θ_N		0	1	Descending node of target orbit as measured counterclockwise from the launch meridian in the equatorial plane	pirad
θ_T		0	1	Desired terminal flight path angle, measured positive counterclockwise from the local horizontal.	
σ	-0.1405333			Angle between perigee vector and the minus aim vector in the nominal transfer ellipse (-25.2960°)	pirad
ϕ_L	0.15915262			Geodetic latitude of the launch site (28.6474722°)	pirad
ϕ_T		0	1	Angle used to estimate the location of the terminal radius vector in the desired orbit plane, measured clockwise from the positive Y_4 - axis	pirad
ϕ_{TR}		0	1		pirad

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
ω_E	$0.23211525 \times 10^{-4}$			Rotational rate of the earth ($0.72921158 \times 10^{-4}$ rad/sec)	pirad/sec
α	0.60666667	0	1	The angle between the descending node and perigee, nominal is 109.2°	pirad
α_{TS}		0	1	The angle between the \bar{S} and \bar{T} vectors at reignition	pirad
α_{TSN}	ϵ ϵ ϵ	0	1	The nominal angle between the \bar{S} and \bar{T} vectors at reignition	pirad

(The following are IGM quantities. Rescaling takes place after second S-IVB burn. The symbol E is to be read "times 10 to the exponent".)

ENGOUT	plus			Switch	(switch)
TLD	minus			Switch, Thrust Level Detector	(switch)
AC1	0	60	}		m/s^2
AC2	0	60			m/s^2
AC3	0	60		Table for EMR shift test counter	m/s^2
AC4	0	60			m/s^2
AC5	0	60			m/s^2
FLAG	-2	2		Counter	--

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
ISWCH	minus			Switch for guidance time update.	(switch)
T_{1i}	278.4		1000	Burn time - first S-II burn and S-IVB restart	sec
T_{2i}	38.48		1000	Burn time - second S-II burn	sec
T'_3	186.1		1000	Burn time - S-IVB burn (boost) and second burn (restart)	sec
T_{Ci}	2		1000	Coast time	sec
τ_1			1000	Time (M/M) for burns 1 and 4 (early S-II and early S-IV reignition)	sec
τ_2	244.0		1000	Time (M/M) for burn 2 (late S-II)	sec
τ_3	750.8261		1000	Time (M/M) for burns 3 and 5 (S-IV boost and late S-IV reignition)	sec
AT1T			10	Artificial tau parameters	sec
AT1	8		constant	Artificial tau parameters	sec
T_{smc}	minus			Time for SMC computations.	(switch)
S4AT	plus			Switch	(switch)
τ_{3N}	738.086		1000	Nominal 3 at S-IVB ignition.	sec
COUNT	0		32	Counter	sec

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
CO4I	$0.5 \cdot 10^{-4}$		constant	Reciprocal of C_O^4 .	
\dot{M}_2	24.71396		constant	Mass flow rate for first S-II burn (per engine)	kg. s ² /m
\dot{M}_3	20.32037		constant	Mass flow rate for 2nd S-II burn (per engine)	kg. s ² /m
G ₁	-0.48021793	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₂	-0.87702060	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₃	-0.015018582	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₄	0.87701863	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₅	-0.48037148	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₆	-0.90323091.E-2	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₇	-0.015135944	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₈	-0.88341832.E-2	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
G ₉	0.99984634	0	1	Element of rotation matrix, () _S to () ₄ .	numeric
V _{ex1}	4129.5803		5000	Exhaust velocity for burns 1 and 4	m/s
V _{ex2}	4172.4354		5000	Exhaust velocity for burn 2	

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
V_{ex3}	4177.6329		5000	Exhaust velocity for burns 3 and 5	
R/V_{ex3}	0.359055004.E-3		.67E-3	IGM intermediate quantity	
$\frac{1}{\pi} \left(\frac{\cos \theta_T}{Y_{VT}} \right)$	0.484979637E-7				
\ddot{X}_{AVgT}	0.4467493E-3			Terminal gravity acceleration component.	m/s^2
\ddot{Y}_{AVgT}	-9.2549473			Terminal gravity acceleration component.	m/s^2
\ddot{Z}_{AVgT}	-0.128556E-1			Terminal velocity acceleration component.	m/s^2
\dot{X}_{VT}	7793.036			Terminal velocity component.	m/s
\dot{Y}_{VT}	0			Terminal velocity component.	m/s
\dot{Z}_{VT}	0			Terminal velocity component.	m/s
Y_{VT}	6563366.0			Terminal position component ($X_{VT} \equiv Z_{VT} \equiv 0$)	m
S_{mcx}	0	0	1	Steering misalignment correction	pirads
S_{mcz}	0	0	1	Steering misalignment correction	pirads

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
V_T	7793.036		9800	Terminal velocity	m/s
x_x	--		1	Desired thrust attitude in S system	pirads
x_z	--		1	Desired thrust attitude in S system	pirads
X_s	--		8E6	Position in S system	m
Y_s	--		8E6	Position in S system	
Z_s	--		8E6	Position in S system	
\dot{X}_s	--		16,000	Velocity in S system	m/s
\dot{Y}_s	--		16,000	Velocity in S system	
\dot{Z}_s	--		16,000	Velocity in S system	m/s
(F/M)	--		60	Total acceleration	m/s ²
(M/F) _s	--		0.4	Smoothed acceleration reciprocal	s ² /m
g_x	--		10	Gravitational acceleration in S system.	m/s ²
g_y	--		10		
g_z	--		10		

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
\ddot{X}_I	--		60	Thrust acceleration in S system	m/s^2
\ddot{Y}_I	--		60		
\ddot{Z}_I	--		60		
V	--		16,000	Inertial velocity	
I_{gx}	--		16,000	Gravitational velocity	m/s
I_{gy}	--		16,000		
I_{gz}	--		16,000		
X_4			8E6	Position in () ₄ system	m
Y_4			8E6		
Z_4			8E6		
\dot{X}_4			16,000	Velocity in () ₄ system	m/s
\dot{Y}_4			16,000		
\dot{Z}_4			16,000		
L_1			8,000	Intermediate IGM Quantity	
J_1			720,000	Intermediate IGM Quantity	
S_1			500,000	Intermediate IGM Quantity	

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
Q_1			0. 6E8	Intermediate IGM Quantity	
P_1			0. 16E9	Intermediate IGM Quantity	
U_1			0. 84E10	Intermediate IGM Quantity	
L_2			8, 000	Intermediate IGM Quantity	
J_2			720, 000	Intermediate IGM Quantity	
S_2			500, 000	Intermediate IGM Quantity	
Q_2			0. 6E8	Intermediate IGM Quantity	
P_2			0. 16E9	Intermediate IGM Quantity	
U_2			0. 84E10	Intermediate IGM Quantity	
L_{12}			10, 000	Intermediate IGM Quantity	
J_{12}			1E6	Intermediate IGM Quantity	
S_{12}			1E6	Intermediate IGM Quantity	
P_{12}			2E8	Intermediate IGM Quantity	
Q_{12}			8E7	Intermediate IGM Quantity	
U_{12}			0. 13E11	Intermediate IGM Quantity	

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
T_{1C}			1, 000	Intermediate IGM Quantity	
T_I			1, 000	Intermediate IGM Quantity	
L'_3			5, 000	Intermediate IGM Quantity	
J'_3			500, 000	Intermediate IGM Quantity	
L'_y			6, 000	Intermediate IGM Quantity	
D_2			3E6	Intermediate IGM Quantity	
ψ		0	1	Range Angle	pirads
X_V			8E6	Position in injection system	m
Y_V			8E6		
Z_V			8E6		
\dot{X}_V			16, 000	Velocity in injection system	m/s
\dot{Y}_V			16, 000		
\dot{Z}_V			16, 000		

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
X_{vg}^*			2		
Y_{vg}^*			10		
Z_{vg}^*			1		
$\Delta \dot{X}_{vs}$			5,000	Intermediate IGM quantities	
$\Delta \dot{Y}_{vs}$			5,000		
$\Delta \dot{Z}_{vs}$			5,000		
ΔL_3			10,000		
$\Delta T'_3$			500	Correction to T'_3	secs
T_{3i}			1,000	Burn time for 1st S-IVB burn and 2nd S-IVB burn after reignition	secs
T'			1,000	Intermediate IGM quantities	
L_3			5,000		
L_y			8,000		
J_3			720,000		
S_3			500,000		
Q_3			0.6E8		
P_3			0.16E9		
U_3			0.84E10		
$\Delta \dot{X}_V$			5,000		
$\Delta \dot{Y}_V$			5,000		
$\Delta \dot{Z}_V$			5,000		

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
\tilde{x}_x			1	Intermediate IGM quantities	
\tilde{x}_z			1		
J_y			1.3E6		
S_y			1.7E6		
Q_y			0.3E9		
K_y			0.1		
Δyaw			600,000		
ΔZ_V			300,000		
K'_3			2		
K_3			2		
K_4			0.2		
L'			8,000		
C_3			1.9		
C_4			0.2		
J'			1.4E6		
S'			1.6E6		
Q'			0.3E9		
K'			0.2		
D'			390,000		
ΔY_V			400,000		
K'_1			2		
K_1			2		
K_2			0.2		

<u>QUANTITY</u>	<u>INITIAL</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>DESCRIPTION</u>	<u>UNIT</u>
$^x X_4$		0	1	Desired thrust attitude in target plane	pirads
$^x Z_4$		0	1	Desired thrust attitude in target plane	pirads
X'_s		0	1	Components of unit thrust vector in () _s system.	1
Y'_s		0	1		
Z'_s		0	1		



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