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TITLE SATURN V LAUNCH VEHICLE GUIDANCE EQUATIONS, SA-504

MODEL NO. SATURN V

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SATURN V
LAUNCH VEHICLE
GUIDANCE EQUATIONS,
SA-504

15 JULY 1967

REVISIONS

REV. SYM	DESCRIPTION	DATE	APPROVED

ABSTRACT AND LIST OF KEY WORDS

The basic guidance equations for the Saturn V/SA-504 launch vehicle are presented in this document. The equations provide vehicle steering and attitude commands for all flight phases from liftoff through separation of the Apollo/LM configuration from the launch vehicle. The basic logic and presettings required for the SA-504 flight program are defined.

The boost guidance scheme has three modes. A time-programmed tilt steering mode, pre-IGM, is used from liftoff to Launch Escape Tower (LET) jettison. A reduced-loads chi-freeze program modifies the tilt program for an engine shutdown. An iterative guidance mode (IGM) is used for the powered-flight phases from approximately LET jettison to translunar-orbit injection. The IGM uses five guidance stages (three into parking orbit, two out of orbit) to handle mixture-ratio shifts and vehicle staging. If there is an engine shutdown, guidance parameters are modified as a function of shutdown time. Appropriate command schemes are used for vehicle orientation during the parking-orbit and translunar-coast phases.

Logic is provided for reignition on the first or second opportunity. The equations and logic presented provide capability for into-orbit and out-of-orbit targeting and for selection of alternate targeting during flight.

Saturn V Guidance
Pre-IGM
Iterative Guidance Mode

CONTENTS

ILLUSTRATIONS

TABLES

TABLES (Continued)

REFERENCES

1. MSFC Memo R-AERO-DGA-1-67, "Preliminary Launch Vehicle Equations for the Saturn V SA-504 Mission," dated January 24, 1967 (Boeing Document D5-15429-4, "Saturn V Launch Vehicle Guidance and Navigation Equations, SA-504," dated October 12, 1966.)

2. MSFC R-AERO-DAG-68-66, "Launch Vehicle Reference Trajectory, Saturn V, AS-504 Missions," dated August 2, 1966 (Boeing Document D5-15481, AS-504 Preliminary Launch Vehicle Reference Trajectory," dated July 13, 1966.)

3. Boeing Document D5-15481-1, "Saturn V AS-504 Launch Vehicle Reference Trajectory," dated May 15, 1967.

4. OMSF Memo SE 008-001-1, "Project Apollo Coordinate System Standards," dated June 1, 1965.

5. Boeing Document D5-15707-4, "Saturn V Launch Vehicle Navigation Equations, SA-504," dated July 15, 1967.

6. OMSF Memo M-D-E 8020.008B, "Natural Environment and Physical Standards for the Apollo Program," dated April 1, 1965.

7. MSFC Flight Program Change Report 338, no title, dated February 9, 1967.

8. MSFC Memo R-P&VE-PTF-66-M-96, "Variations in S-IVB/V Continuous Vent Thrust," dated December 12, 1966.

9. MSFC Memo R-P&VE-66-M-94, "Orbital Venting of the Saturn V/S-IVB Stage," dated November 17, 1966.

10. Boeing Coordination Sheet OFA-H-135, "Rotated Terminal Coordinates," dated July 1, 1967.

11. MSFC No. III-4-423-12, "LVDC Equation Defining Document for the AS-504 Flight Program," dated March 3, 1967.

PREFACE

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SOURCE DATA PAGE

The following listed government-furnished documentation is used in the preparation of this document release:

Exhibit FF Line Item Number	GFD Title	Date of Issue	Revision Date
I-V-S-IVB 5	MSFC Memo-R-AERO-FM-16-67, "Saturn Retro and Ullage Rockets."	1-11-67	
	North American Aviation Memo, R-150125, "Model Specification 100-pound Thrust Liquid Propellant Rocket Engine, Rocketdyne Model SE7-1."	7-1-66	
AERO 2	MSC Memo 66-FM-70, "AS-504 Preliminary Spacecraft Reference Trajectory."	7-1-66	
AERO 5	NASA Joint Trajectory Document 67-FMP-3, "AS-504 and Subsequent Mission Joint Reference Constraints."	3-15-67	
AERO 12.c	NASA Memo TMX-53139, "A Reference Atmosphere for Patrick AFB, Florida, Annual (1963 Revision)."	9-23-64	
AERO 12.d,12.e	OMSF Memo M-D-E 8020.008B, "Natural Environment and Physical Standards for the Apollo Programs."	4-1-65	
AERO 12.e	MSFC Memo R-AERO-FMT-93-66, "Computation of the Geocentric Radius to C.G. and Geometry of Launch Complex 39A."	12-1-66	
ASTR 3	MSFC Memo R-ASTR-F-67-83, "Stabilization Networks for S-IC Stage Burn, Pitch and Yaw."	3-22-67	
P&VE 23	MSFC Memo R-AERO-DAP-4-67, "Mass Characteristics for AS-504 Reference Trajectory and Performance Analysis Document."	1-13-67	

SOURCE DATA PAGE (Continued)

Exhibit FF Line Item Number	GFD Title	Date of Issue	Revision Date
P&VE 26	MSFC Memo R-P&VE-PT-65-274-F, "Venting Impulse During Orbital Coast for S-IVB Saturn 203 and Saturn V Stages."	7-14-65	
	MSFC Memo R-P&VE-PTF-66-M-96, "Variations in S-IVB/V Continuous Vent Thrust."	12-15-66	
	MSFC Memo R-P&VE-PP-66-M-94, "Orbital Venting of the Saturn V/S-IVB Stage."	11-17-66	
	MSFC Memo R-P&VE-PP-66-M-96, "S-IVB O_2/H_2 Burner Propulsive Disturbance."	11-1-66	
P&VE 46	MSFC Memo R-P&VE-PPE-66-M-47, "S-IVB, J-2 Fuel Lead Time at Orbital Restart."	1-2-66	
P&VE 67	MSFC Drawing 10M30524 Revision B, "Saturn V/SA-504 Flight Sequence."	7-13-66	

SECTION 1

SUMMARY

1.0 INTRODUCTION

The launch vehicle guidance equations for the Apollo/Saturn V 504 mission are provided in this document. Presettings for the Launch Vehicle Digital Computer (LVDC) flight program are included. This represents the final release of the SA-504 guidance equations, updating the October 12, 1966, initial release (Reference 1). This release reflects changes from the preliminary reference trajectory (Reference 2) to the reference trajectory (Reference 3) and basic changes made in formulating the guidance equations.

1.1 GENERAL

The basic equations, logic, and typical presettings required from liftoff to launch vehicle/spacecraft separation are provided for the AS-504 mission. The input discretes necessary to implement the scheme and the outputs required for the propulsion and flight control systems are identified. The equations are presented in the standard Apollo coordinate system shown in Figure 1-1. (See Reference 4.)

Guidance modes associated with the mission and the related discretes and timebases are presented. Abort and alternate mission capability is discussed.

To fulfill the requirements of the AS-504 mission, the guidance package consists of the following three phases:

a. Atmospheric boost guidance.

b. Vacuum boost guidance.

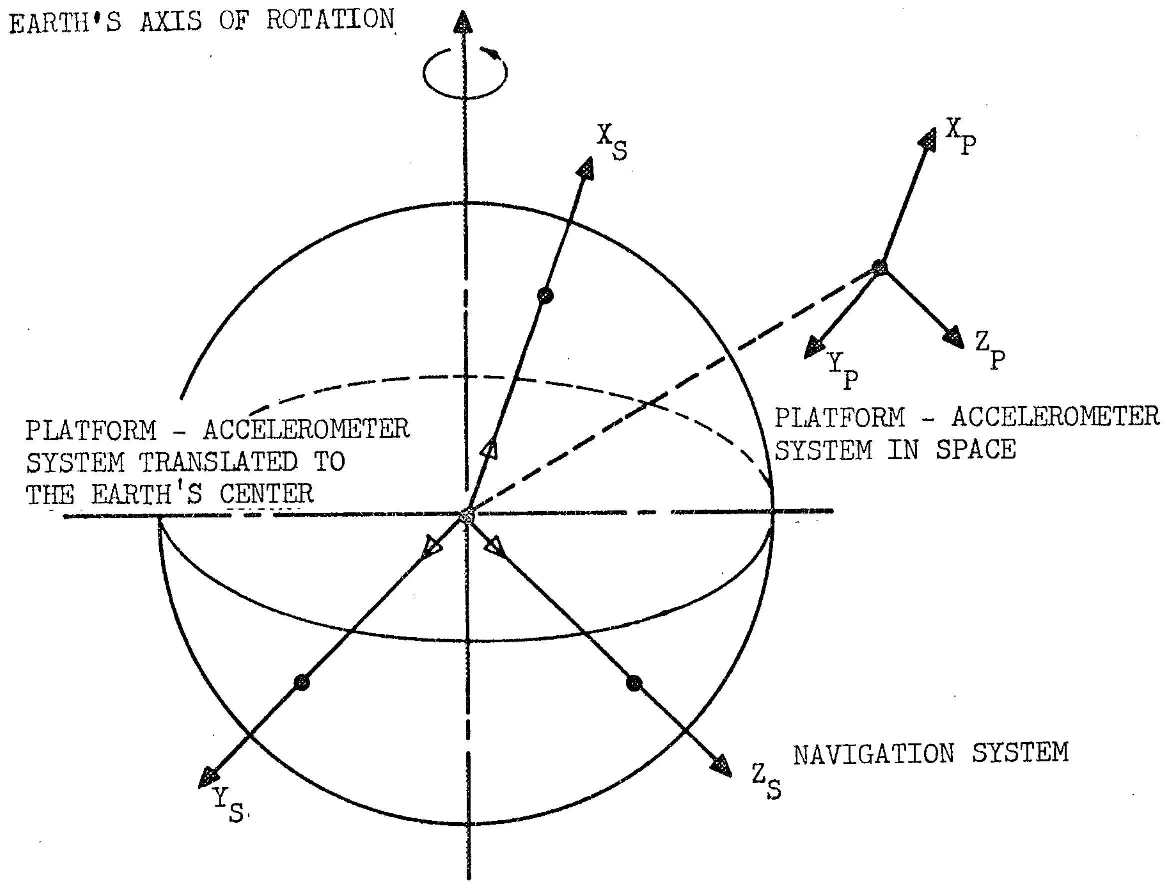
c. Orbital coast guidance.

A detailed description of the equations and logic associated with each of the guidance phases is presented.

Atmospheric guidance is initiated at launch and used through S-IC burn and a portion of S-II flight. This guidance phase employs steering polynomials to generate pitch commands as a function of time.

Vacuum boost guidance employs Iterative Guidance Mode (IGM) for the remainder of powered flight. IGM equations are divided into five stages to accommodate boost to parking orbit and boost to translunar injection.

Orbital guidance is employed during parking orbit and translunar-orbit coast. The orbital guidance logic and equations allow for the vehicle attitudes required to facilitate groundtrack telemetry, account for



TYPE: Nonrotating, earth-centered

ORIGIN: The center of the earth

ORIENTATION AND LABELING:

This system is translatable from the Launch Vehicle Platform-Accelerometer system at guidance reference release for the launch vehicle. The positive X_P - axis is opposite and parallel to the local gravity vector. The Z_P - axis is positive along the launch azimuth; the Y_P - axis completes the orthogonal right-handed set.

The X_S axis is parallel to the X_P axis of the Launch Vehicle Platform-Accelerometer system.

The Y_S axis is parallel to the Y_P axis of the Launch Vehicle Platform-Accelerometer system.

The Z_S axis completes a standard right-handed system.

FIGURE 1-1 COORDINATE SYSTEM

1.1 (Continued)

hydrogen venting, make landmark sightings, and other required orbital operations. The presettings currently required for the LVDC flight program are also contained in this document. Definitions of all terms and symbols employed in the document are presented.

1.2 GUIDANCE SCHEME DIFFERENCES

The navigation equations and logic are published in a separate document (Reference 5) to comply with the current Data Requirement Description. The SA-504 final guidance equations update the SA-504 initial guidance equations. (See Reference 1.) Differences in the initial and final release are presented in Table 1-I and include the following:

a. A fourth-degree segmented polynomial in scaled launch time is used to calculate launch azimuth. Alternate calculation of inclination and descending node is provided (Page 4-11).

b. A fourth-degree segmented polynomial replaces the third-degree polynomial to allow a better fit of a wind-biased pre-IGM tilt program (Page 4-14).

c. The S-IC yaw maneuver for tower clearance is included (Page 4-14).

d. The intermediate IGM parameter, L_Y, is not used to calculate $\tilde{X}_y$ (Page 4-24).

e. The TRY and TRP factors are eliminated because they are unnecessary (Page 4-25).

f. Increased detail is included for the modification required for direct staging(Page 4-27).

g. The time of S-IVB first ignition is calculated to determine the difference between the actual and nominal S-IVB first-burn times (Page 4-29).

h. High-speed cutoff logic is updated, and equations for the cutoff velocity and T_{GO} are presented (Pages 4-29 and 4-30).

i. High-speed cutoff exit settings are included in the T_{GO} calculation logic to initialize out-of-orbit flight parameters and to provide for high-speed-logic termination (Page 4-30).

j. Steering misalignment correction (SMC) is used during IGM phases of powered flight to reduce the effects of thrust misalignment (Page 4-32).

1.2 (Continued)

k. Out-of-orbit targeting uses tables rather than the functional form (Page 4-35).

l. The ephemeris matrix is updated to conform to Project Apollo Coordinate System Standards (Page 4-35). (See Reference 4.)

m. A test on the slope of $\bar{S}\cdot\bar{T}_P$ is used to simplify selection of the T_{ST} quadrant test (Page 4-35).

n. Orbital guidance attitude equations are updated to comply with presently defined orbital attitude timelines (Page 4-38).

o. T_{1c} and T_T' are included as presettings to provide complete information to IGM on the initial pass (Page 5-4).

TABLE 1-I GUIDANCE SCHEME DIFFERENCES

ITEM	INITIAL RELEASE	FINAL RELEASE
a.	$A_Z = \sum_{n=0}^{8} h_n T_L^n$	$t_D = T_L - T_{LO}$
		$A_Z = \begin{cases} \sum_{n=0}^{4} h_{1n}[(t_D - t_{D1})/t_{SD1}]^n & t_{DO} \le t_D < t_{DS1} \\ \sum_{n=0}^{4} h_{2n}[(t_D - t_{D2})/t_{SD2}]^n & t_{DS1} \le t_D < t_{DS2} \\ \sum_{n=0}^{4} h_{3n}[(t_D - t_{D3})/t_{SD3}]^n & t_{DS2} \le t_D \le t_{DS3} \end{cases}$
	$i = \sum_{n=0}^{6} f_n A_Z^n$	$i = \begin{cases} \sum_{n=0}^{6} f_n[(A_Z - A_{ZO})/A_{ZS}]^n & i(op) = 0 \\ \sum_{n=0}^{6} f_n' [(t_D - t_{DO})/t_S]^n & i(op) = 1 \end{cases}$
	$\theta_N = \sum_{n=0}^{6} g_n A_Z^n$	$\theta_N = \begin{cases} \sum_{n=0}^{6} g_n[(A_Z - A_{ZO})/A_{ZS}]^n & \theta_N(op) = 0 \\ \sum_{n=0}^{6} g_n'[(t_D - t_{DO})/t_S]^n & \theta_N(op) = 1 \end{cases}$
	(none)	$C_3 = TABLE_{15}(t_D)$
		$\dot{e} = TABLE_{15}(t_D)$
		$f = TABLE_{15}(t_D)$
		$\alpha_D = TABLE_{25}(t_D)$

TABLE 1-I GUIDANCE SCHEME DIFFERENCES (Continued)

ITEM	INITIAL RELEASE	FINAL RELEASE
b.	$t_{ct} = t_c - \Delta t_f + 2\Delta t$	$t_{cf} = t_c - \Delta t_f$
	$\chi_Y = \begin{cases} \sum_{n=0}^{3} F_{1n} t_{ct}^n & t_c < t_{S1} \\ \sum_{n=0}^{3} F_{2n} t_{ct}^n & t_{S1} \le t_c < t_{S2} \\ \sum_{n=0}^{3} F_{3n} t_{ct}^n & t_{S2} \le t_c < t_{S3} \\ \sum_{n=0}^{3} F_{4n} t_{ct}^n & t_{S3} < t_c \end{cases}$	$\chi_Y = \begin{cases} \sum_{n=0}^{4} f_{1n} t_{cf}^n & t_{cf} < t_{S1} \\ \sum_{n=0}^{4} F_{2n} t_{cf}^n & t_{S1} \le t_{cf} < t_{S2} \\ \sum_{n=0}^{4} F_{3n} t_{cf}^n & t_{S2} \le t_{cf} < t_{S3} \\ \sum_{n=0}^{4} F_{4n} t_{cf}^n & t_{S3} \le t_{cf} \end{cases}$
c.	$\chi_Z = 0°$	$\chi_Z = 0°$ $\quad 1.0 > t_c$
		$\chi_Z = 1.25°$ $\quad 1.0 \le t_c < 8.75$
		$\chi_Z = 0°$ $\quad 8.75 \le t_c$
d.	$\tilde{\chi}_y = \sin^{-1} (\Delta\dot{\eta}/L_Y)$	$\tilde{\chi}_y = \tan^{-1} [\Delta\dot{\eta}/(\Delta\dot{\xi}^2+\Delta\dot{\zeta}^2)^{\frac{1}{2}}]$
e.	$K_1 = K_1' [1-(K_1')^2/TRY]$	$K_1 = K_1'$
	$K_3 = K_3' [1-(K_3')^2/TRP$	$K_3 = K_3'$
f.	$T_3' = T_3' + C_f(V_{SII}-V)$	$T_3' = T_3' + C_f(V_{S2T}-V) + \Delta T_{COST}$
	ROV = KROV	$T_1 = 0$ SET S-IVB IGNITION = YES
	T_c = KTC	$T_2 = 0$ SET GATE 4 = YES
	TRP = KTRP	$T_c = 0$
	TRY = KTRY	$T_{1c} = 0$
		$T_T = T_3'$
		ROV = ROV*

TABLE 1-I GUIDANCE SCHEME DIFFERENCES (Continued)

ITEM	INITIAL RELEASE	FINAL RELEASE
g.	(none)	$t_{3i} = TB4 + T_c$
h.	(none)	$V = \frac{1}{2}(V + V_i^2/V)$ $V_0 = V_1$ $V_1 = V_2$ $\Delta t_1' = \Delta t_2'$ $\Delta t_2' = \Delta t$ $a_2 = \frac{(V_2 - V_1)\Delta t_1 - (V_1 - V_0)\Delta t_2'}{\Delta t_2' \; \Delta t_1' \; (\Delta t_2' + \Delta t_1')}$ $a_1 = \frac{V_2 - V_1}{\Delta t_2'} + a_2 \; \Delta t_2'$ $T_{GO} = \frac{(V_T - \Delta V_B) - V_2}{a_1 + a_2 \; T_{GO}}$ $T_{CO} = TAS + T_{GO}$
i.	(none)	GATE 5 = NO $T_T' = 1000.0$ sec HSL = NO
j.	(none)	$SMCY = SMCG \left[\frac{\ddot{Z}_I X_{S1} - \ddot{X}_I X_{S3}}{\ddot{X}_I X_{S1} + \ddot{Z}_I X_{S3}} \right] \Delta t + SMCY$ $SMCZ = SMCG \left[\frac{X_{S2} - \ddot{Y}_I (m/F)_S}{(1 - (X_{S2})^2)^{\frac{1}{2}}} \right] \Delta t + SMCZ$ $\chi_Y = \chi_{Yi} + SMCY$ $\chi_Z = \chi_{Zi} + SMCZ$

TABLE 1-I GUIDANCE SCHEME DIFFERENCES (Continued)

ITEM	INITIAL RELEASE	FINAL RELEASE
k.	$t_D = K_L\,(T_L - T_{LO})$	$t_D = T_L - T_{LO}$ Subscript J = 1 = First Opportunity Subscript J = 2 = Second Opportunity
	$T_N = \sum_{i=0}^{2} d_i\, t_D^i + J\,K_{TN}$	$RAS_J = TABLE_{15}\,(t_D)$
	$K = (1 + \dot{T}^2(t_D+J)^2 + T_N^2)^{-\frac{1}{2}}$	$DEC_J = TABLE_{15}\,(t_D)$
	$T_X = (T_X^* + \dot{T}_X(t_D+J) + T_N\omega_X)K$	$T_{XJ} = \cos RAS_J \cos DEC_J$
	$T_Y = (T_Y^* + \dot{T}_Y(t_D+J) + T_N\omega_Y)K$	$T_{YJ} = \sin RAS_J \cos DEC_J$
	$T_Z = (T_Z^* + \dot{T}_Z(t_D+J) + T_N\omega_Z)K$	$T_{ZJ} = \sin DEC_J$
	$C_3 = \sum_{i=0}^{4} C_{3i}\, t_D^i + JK_{C3}$	$C_{3J} = TABLE_{15}\,(t_D)$
	$\cos\sigma = \sum_{i=0}^{4} \sigma_i\, t_D^i + JK_b$	$\cos\sigma_J = TABLE_{15}\,(t_D)$
	$e_n = \sum_{i=0}^{4} e_{ni}\, t_D^i + JK_{Ne}$	$e_{NJ} = TABLE_{15}\,(t_D)$
	$\alpha_D = \cos^{-1}(\bar{S}\cdot\bar{T}_p) - \cos^{-1}[(1-p/T_M)(1/e)] + \tan^{-1}[(\bar{S}_1\cdot\bar{C}_1 \times \bar{\Omega}_Y)/(\bar{S}\cdot\bar{C}_1 \times \bar{\Omega}_Y)]$	$\alpha_D = \begin{cases} \cos^{-1}(\bar{S}\cdot\bar{T}_p) - \cos^{-1}[(1-p/T_M)(1/e)] + \tan^{-1}[(\bar{S}_1\cdot\bar{C}_1 \times \bar{\Omega}_Y)/(\bar{S}\cdot\bar{C}_1 \times \bar{\Omega}_Y)] & \alpha_D(op) = 1 \\ TABLE_{25}\,(t_D) & \alpha_D(op) = 0 \end{cases}$
	$f = \phi_{TR} + \alpha_D$	$f = TABLE_{15}\,(t_D)$

TABLE 1-I GUIDANCE SCHEME DIFFERENCES (Continued)

ITEM	INITIAL RELEASE	FINAL RELEASE
l.	$[EPH]=[A]^{-1}\begin{bmatrix}\sin\theta_E & 0 & \cos\theta_E \\ 0 & -1 & 0 \\ \cos\theta_E & 0 & -\sin\theta_E\end{bmatrix}$	$[EPH]=[A]^{-1}\begin{bmatrix}\cos\theta_E & \sin\theta_E & 0 \\ 0 & 0 & -1 \\ -\sin\theta_E & \cos\theta_E & 0\end{bmatrix}$
m.	(none)	$\bar{\dot{R}}' = \bar{V}/\lvert\bar{R}\rvert$ $\bar{\dot{P}} = \bar{N} \times \bar{\dot{R}}'$ $\bar{\dot{S}} = \bar{\dot{R}}'\cos\beta + \bar{\dot{P}}\sin\beta$
n.	$[E]^{-1} = [\chi_{Y4}+\chi_Y'][\chi_Z'][\chi_X'][G]$ $\chi_Z = \tan^{-1}[E_{12}/(E_{11}+E_{13})^{\frac{1}{2}}]$ $\chi_Y = \tan^{-1}[-E_{13}/E_{11}]$ $\chi_X = \tan^{-1}[-E_{32}/E_{22}]$	$\sin\chi_{Yi}' = (X_{4i}\cos\alpha_1 + Z_{4i}\sin\alpha_1)/(-R)$ $\cos\chi_{Yi}' = (Z_{4i}\cos\alpha_1 - X_{4i}\sin\alpha_1)/(-R)$ $\sin\chi_{Zi}' = \sin\alpha_2$ $\cos\chi_{Zi}' = \cos\alpha_2$ $\begin{bmatrix}X_{S1} \\ X_{S2} \\ X_{S3}\end{bmatrix} = [G]^{-1}\begin{bmatrix}\cos\chi_{Yi}'\cos\chi_{Zi}' \\ \sin\chi_{Zi}' \\ -\sin\chi_{Yi}'\cos\chi_{Zi}'\end{bmatrix}$ $\chi_{Xi} = \chi_{Xi}'$ $\chi_{Yi} = \tan^{-1}(-X_{S3}/X_{S1})$ $\chi_{Zi} = \sin^{-1}X_{S2}$
o.	(none)	presettings: $T_{1c} = 342.4$ sec $T_T' = 462.965$ sec

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SECTION 2

MISSION DEFINITION

2.0 MISSION OBJECTIVES

The SA-504 flight is the first Lunar Landing Mission. The primary mission objectives are to demonstrate the capability to perform a lunar landing and return to earth, and to perform selenological inspection, survey, and sampling. The secondary objectives are as follows:

a. Demonstrate operational launch vehicle capability by injecting a fully loaded Apollo spacecraft onto a specified circumlunar conic.

b. Demonstrate the adequacy of all spacecraft systems and operational procedures for translunar and transearth flight.

c. Demonstrate the adequacy of deep-space navigation techniques and adequacy of guidance accuracy during translunar and transearth midcourse corrections.

d. Demonstrate acceptable SPS performance and spacecraft guidance during the lunar orbit insertion boost and the transearth injection boost.

e. Demonstrate acceptable Lunar Module (LM) systems performance during the descent-to-hover boost.

f. Demonstrate acceptable LM systems performance during the ascent and rendezvous mode.

2.1 MISSION CONSTRAINTS

The following trajectory and launch vehicle constraints are imposed upon the SA-504 Launch Vehicle targeting equations.

2.1.1 Trajectory Profile Constraints

a. Launch shall occur along an azimuth of not less than 72 degrees and not greater than 108 degrees east of north.

b. Translunar injection shall occur from the Pacific window at either the first or second opportunity after completing one revolution in parking orbit.

c. At free-return perigee, the direction of vehicle motion is co-rotational with the earth.

2.1.1 (Continued)

d. Launch vehicle targeting is based upon the data of Reference 3. It provides the desired pericynthian (periselenum) selenographic latitudes and altitudes for a desired free-return perigee altitude of 25 ± 12 NMI (based upon the Apollo reference equatorial radius as defined in Reference 6).

2.1.2 Launch Vehicle Constraints

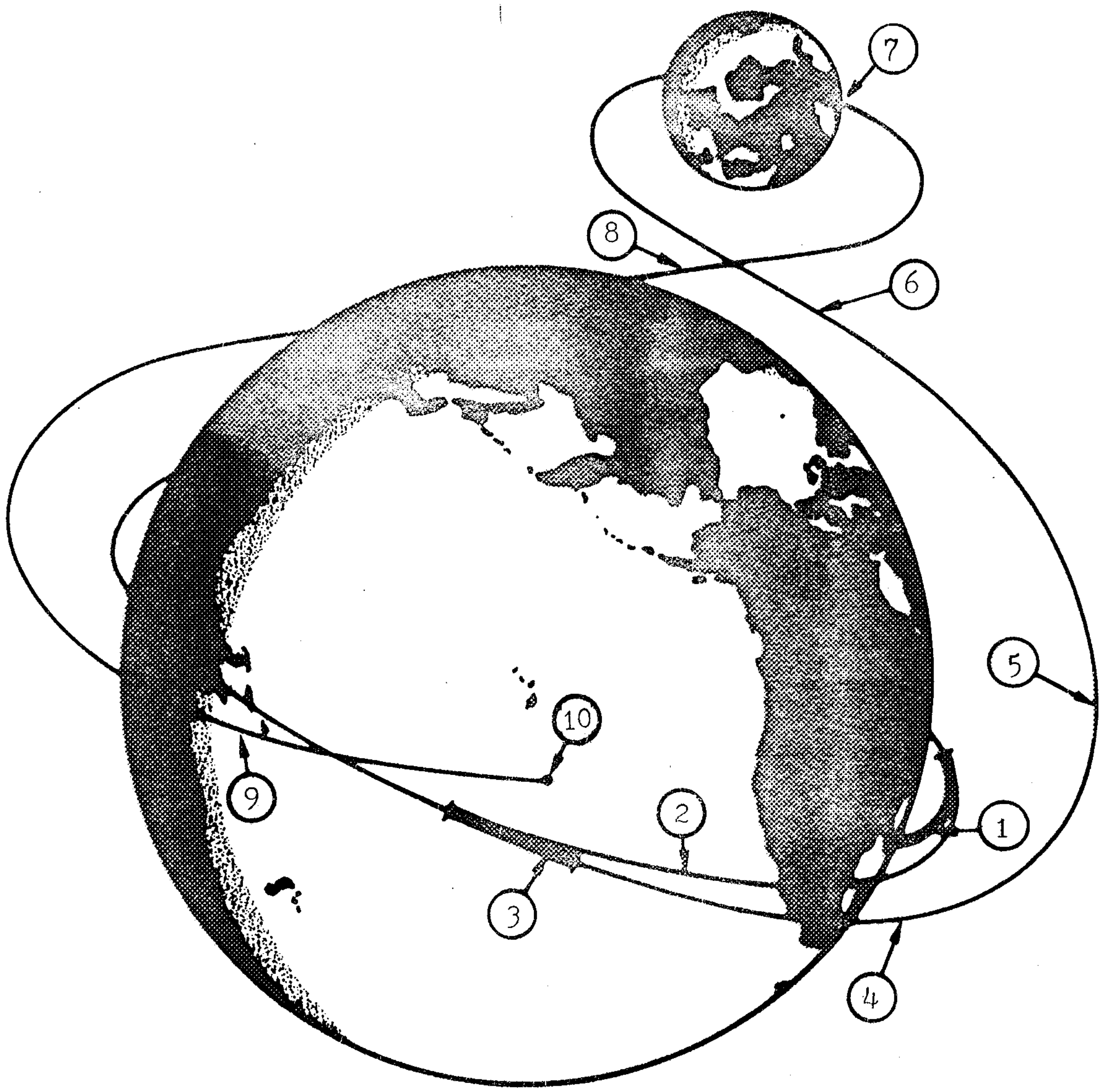
The launch vehicle constraints are:

a. The guidance-command angle rate shall not exceed one degree per second in pitch and yaw (First-stage tilt program and upper-stage guidance program).

b. The maximum command attitude in the yaw plane shall not exceed 45 degrees.

2.2 MISSION EVENTS

Simulated trajectory data are provided in Reference 3 for each of the twelve launch dates. Trajectories are simulated for five launch azimuths (72, 81, 90, 99, and 108 degrees) during each day, including trajectories for two translunar injection opportunities with each launch azimuth. An example of the sequence of events is shown in Table 2-I, listing times and events for a 72-degree launch azimuth simulation for a typical day. A mission profile showing the launch vehicle trajectory phases during a lunar landing mission is depicted in Figure 2-1.



1. BOOST TO EARTH ORBIT - S-IC, S-II, AND S-IVB OPERATION.
2. COAST IN EARTH ORBIT.
3. S-IVB TRANSLUNAR INJECTION BOOST.
4. INITIATE TRANSPOSITION AND DOCKING MANEUVER.
5. COMPLETE TRANSPOSITION AND DOCKING MANEUVER - LV/SC SEPARATION.
6. TRANSLUNAR COAST.
7. LUNAR PASSAGE.
8. FREE-RETURN TRANSEARTH COAST.
9. EARTH ATMOSPHERE REENTRY.
10. SPLASHDOWN.

FIGURE 2-1 SA-504 LAUNCH VEHICLE REFERENCE TRAJECTORY PROFILE

TABLE 2-I TYPICAL SEQUENCE OF EVENTS

EVENT	TIME FROM LAUNCH (SECONDS) FIRST OPPORTUNITY	SECOND OPPORTUNITY
GUIDANCE REFERENCE RELEASE	-17.000	-17.000
LIFTOFF	0.000	0.000
BEGIN TILT MANEUVER	12.000	12.000
S-IC INBOARD ENGINE THRUST TERMINATION	147.329	147.329
TILT ARREST	153.000	153.000
S-IC OUTBOARD ENGINE THRUST TERMINATION AND S-IC/S-II SEPARATION	159.329	159.329
S-II STAGE AT 90-PERCENT THRUST	163.759	163.759
JETTISON LAUNCH ESCAPE TOWER	194.559	194.559
INITIATE ITERATIVE GUIDANCE MODE	200.000	200.000
S-II MIXTURE-RATIO SHIFT	437.627	437.627
S-II THRUST TERMINATION AND S-II/S-IVB SEPARATION	537.424	537.424
S-IVB STAGE AT 90-PERCENT THRUST	543.142	543.142
S-IVB STAGE FIRST THRUST TERMINATION - PARKING ORBIT INSERTION - BEGIN POST-INSERTION APS ULLAGE	658.378	658.378
OPEN CONTINUOUS LH_2 VENT	717.378	717.378
CUTOFF ULLAGE ENGINES	742.378	742.378
BEGIN MANEUVER TO LANDMARK-SIGHTING ATTITUDE	3358.378	3358.378
VEHICLE IN LANDMARK-SIGHTING ATTITUDE	3598.378	3598.378
BEGIN MANEUVER TO NORMAL ORBITAL ATTITUDE	5818.378	5818.378
VEHICLE IN NORMAL ORBITAL ATTITUDE	6058.378	6058.378

TABLE 2-I TYPICAL SEQUENCE OF EVENTS (Continued)

EVENT	TIME FROM LAUNCH (SECONDS) FIRST OPPORTUNITY	SECOND OPPORTUNITY
PREIGNITION SEQUENCE INITIATION	9144.000	14456.000
CLOSE CONTINUOUS LH_2 VENT IGNITE O_2/H_2 BURNER	9229.000	14541.000
BEGIN APS ULLAGE	9490.000	14802.000
CUT OFF O_2/H_2 BURNER	9491.000	14803.000
INITIATE ENGINE START SEQUENCE	9594.000	14906.000
S-IVB STAGE AT 90-PERCENT THRUST-CUT OFF ULLAGE ENGINES	9604.000	14916.000
INITIATE ITERATIVE GUIDANCE MODE	9610.000	14922.000
S-IVB MIXTURE-RATIO SHIFT	9646.728	14988.565
S-IVB STAGE SECOND THRUST TERMINATION - TRANSLUNAR INJECTION	9937.232	15231.592
PERISELENUM	279046.060	284796.890
FREE-RETURN VACUUM PERIGEE	538726.900	544181.640

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SECTION 3

GUIDANCE MODES

3.0 GENERAL

A functional diagram of the Saturn V guidance, navigation, and control system is shown in Figure 3-1. The stabilized inertial platform provides gimbal-angle information and integrated acceleration components in plumbline coordinates for the guidance equations. The platform gimbal system resolves the vehicle attitude relative to the inertial axes. The integrating accelerometers measure the time integral of propulsive and atmospheric effects. Gravitational accelerations are computed from the inertial-position information. During coast phases, the accelerometer outputs are replaced by a stored program.

The guidance scheme provides vehicle attitude error signals to the flight control computer for vehicle steering during powered flight and for attitude orientation in the coast phases. The computations are performed in the LVDC. Information flow between the inertial platform, LVDC, and flight control computer is processed in the Launch Vehicle Data Adapter (LVDA).

3.1 NOMINAL FLIGHT MODES

Relationships between the vehicle flight sequence and the guidance modes are shown in Figure 3-2. Descriptions of the modes are given by flight phase; discretes and timebases are defined in Paragraph 3.2. Provisions for abort and alternate mission capability are included in Paragraph 3.3.

The iterative guidance mode consists of three distinct guidance stages for the boost-to-orbit phase. The last two stages are reused for the out-of-orbit burn and are denoted by the fourth and fifth guidance stages when used in this capacity. The boundaries of the guidance stages are:

- Stage 1 - LET Jettison + 5.4 seconds to the programmed S-II MRS
- Stage 2 - Initiation of programmed S-II MRS to S-II burnout
- Stage 3 - S-IVB ignition to parking-orbit insertion
- Stage 4 - S-IVB reignition to assumed MRS
- Stage 5 - S-IVB assumed MRS to translunar injection

3.1.1 Boost to Parking Orbit

Pre-IGM and IGM are employed for the SA-504 boost-to-parking-orbit phase. During pre-IGM, altitude information is used to initiate the roll and pitch maneuvers after tower clearance. An initial yaw maneuver, based upon the data of Reference 7, ensures tower clearance if there are specific vehicle anomalies and unusually high ground-wind gusts. An open-loop time-programmed pitch profile is employed from liftoff to initiation of IGM. The steering function is adjusted to ensure minimum angle of attack in the region of maximum dynamic pressure.

Steering commands are provided by IGM from termination of pre-IGM to parking-orbit insertion. A coast period is defined between the second and third IGM stages to allow for S-II/S-IVB staging. The steering angles are frozen when the S-II cutoff signal is received. The steering angles remain frozen until S-IVB stage ignition (90-percent thrust). S-IVB first cutoff is commanded by IGM. Cutoff velocity is biased to account for J-2 engine thrust decay at shutdown and the expected post-cutoff vents.

3.1.2 Parking Orbit

Orbital guidance uses inertial navigation outputs to calculate attitude commands. The vehicle is normally oriented with the longitudinal axis perpendicular to local vertical and in the orbital plane with the nose of the vehicle in the direction of flight. A 180-degree roll and a 20-degree nosedown attitude maneuver is performed during the first revolution in parking orbit to facilitate navigation sightings. This attitude is maintained for approximately 45 minutes. The S-IVB continuous-venting history for parking-orbit coast, based upon the data of Reference 8, is shown in Figure 3-3.

Out-of-orbit targeting is calculated in parking orbit. The guidance system uses navigation information to predict S-IVB stage reignition for injection onto the desired lunar conic. Restart preparation and reignition logic is applied throughout parking orbit. Reignition is commanded on the first or second opportunity.

3.1.3 Boost to Translunar Injection

The fourth and fifth IGM stages assume a mixture-ratio shift during the S-IVB second burn of the nominal AS-504 mission. The two-stage IGM is capable of performing in the presence of the expected off-nominal mixture ratios resulting from the two-opportunity propellant loading philosophy and the three-sigma propulsion perturbations. S-IVB engine cutoff is commanded by the high-speed cutoff logic. Cutoff conditions are biased to account for the expected velocity contribution due to thrust decay and post-injection blowdown.

3.1.4 Translunar Coast

At the completion of S-IVB second burn, the propellant tanks are blown down, reducing tank pressures sufficiently to prevent automatic venting for one hour. The blowdown history from Reference 9 is the best available prediction of these forces. Following blowdown, the vehicle attitude is space-fixed for the transposition and docking phase. Navigation and coast guidance are continued through launch vehicle/spacecraft separation. Transposition, docking, and separation should be completed within one hour after injection. The launch vehicle continues to coast on the translunar trajectory. Telemetry continues until the IU power supply is depleted.

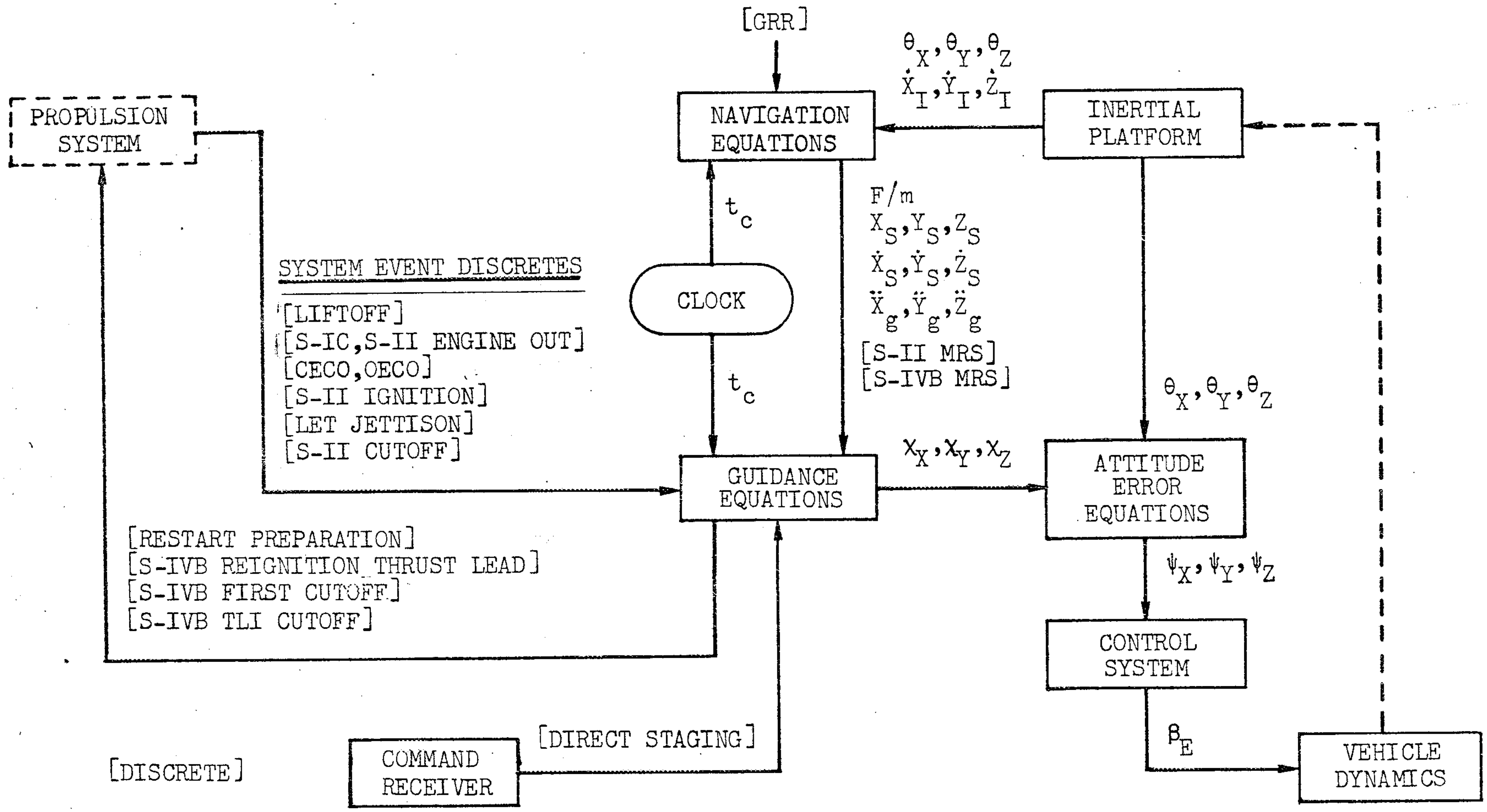

FIGURE 3-1 GUIDANCE AND NAVIGATION INFORMATION FLOW

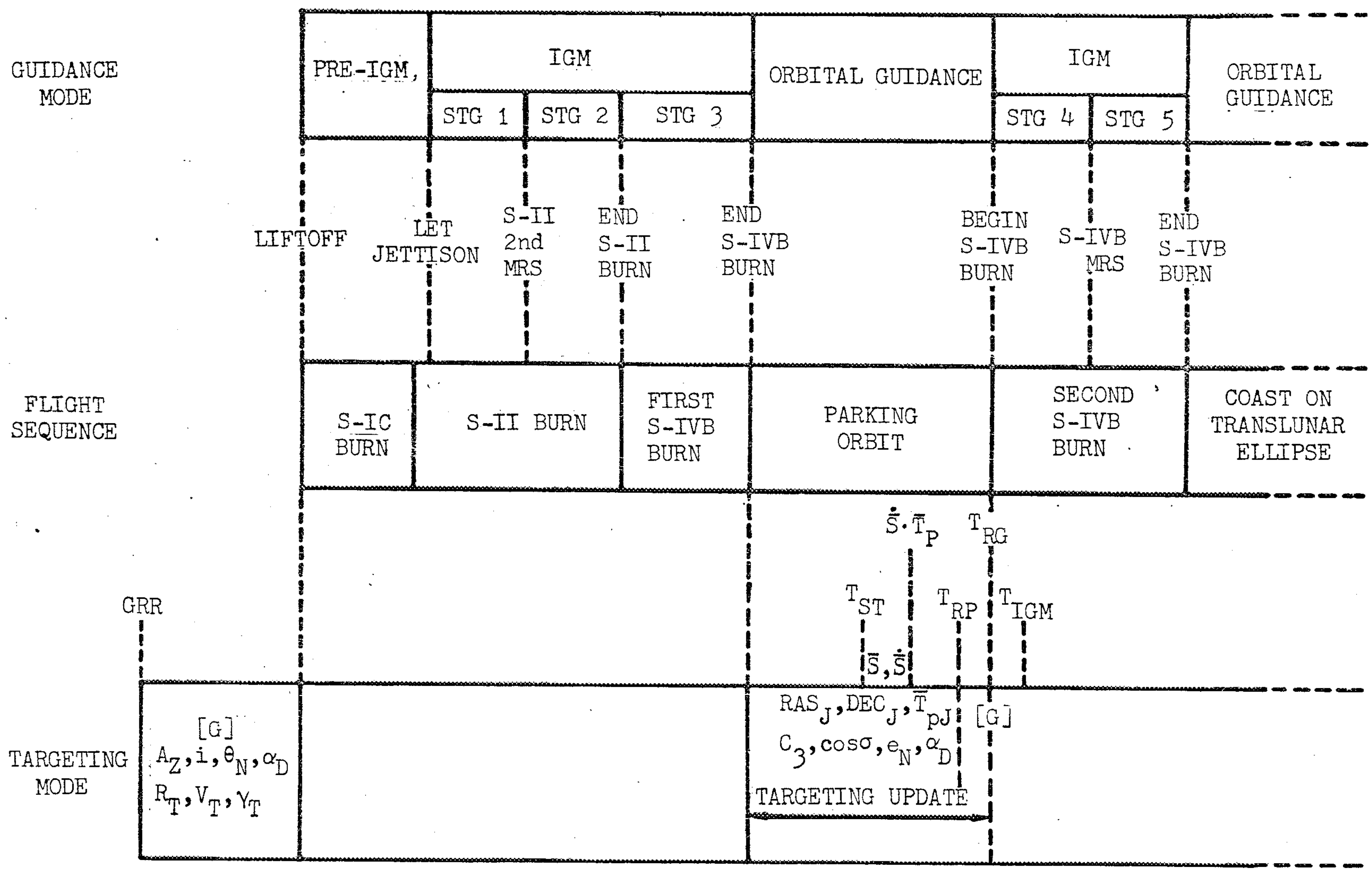

FIGURE 3-2 GUIDANCE AND TARGETING MODES

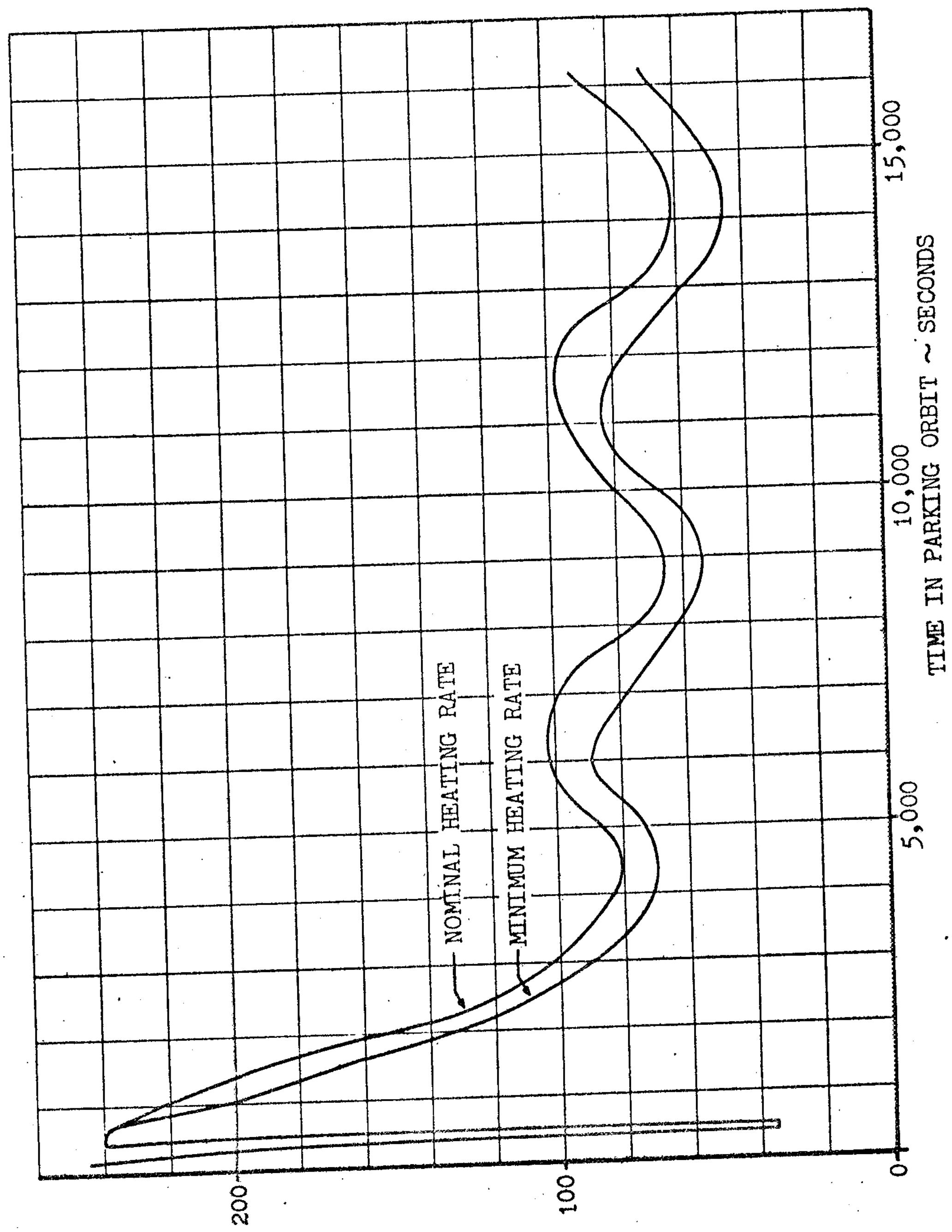

FIGURE 3-3 S-IVB LH_2 CONTINUOUS-VENTING HISTORY

3.2 DISCRETES AND TIMEBASES

Seven timebases are used in the guidance scheme to account for uncertainties in environmental, vehicle, and propulsion-system parameters. The timebases are initiated by the system-event discretes input to the LVDC as illustrated in the system information diagram of Figure 3-1. Alternate timebases are used to account for S-II/S-IVB direct staging, O_2-H_2 burner malfunctions, and a translunar injection inhibit. Table 3-I gives the listing of the timebases with each initiating discrete.

3.3 ABORT AND ALTERNATE MISSION CAPABILITY

Provisions are made in the guidance schemes for abort and alternate mission capability if there is a system malfunction. Single engine-out provisions are defined in Paragraph 3.3.1. Direct-staging provisions are defined in Paragraph 3.3.2.

3.3.1 Single Engine-Out Capability

The launch vehicle is capable of achieving parking-orbit insertion with a single engine out during S-IC or S-II stage burns. The following features are incorporated into the guidance schemes to implement this capability:

a. For failures during S-IC burn, a modified tilt program based upon time of failure is used in conjunction with a revised tilt-arrest time. A chi-freeze schedule for this provision is given in Figure 3-4.

b. For failures between S-II ignition and IGM initiation, modifications are made in the IGM precomputations to account for variations in S-II burn time and thrust.

c. For failure between IGM initiation and S-II burnout, direct compensation for single engine-out effects on S-II burn time and thrust is made in the IGM scheme.

3.3.2 Direct Staging

If the S-II stage fails during flight, two direct-staging modes are possible:

a. For direct staging to the S-IVB for S-II stage failure occurring between S-II ignition and 35 seconds prior to nominal S-II burnout, modifications are made to the guidance equations,and new presettings are selected. This mode is initiated only by ground command.

b. Direct staging to the S-IVB for failures occurring during the last 35 seconds prior to nominal S-II burnout is initiated by the LVDC as standard S-II/S-IVB staging. The modified guidance equations and presettings are used only when the ground-command capability is used during this flight period.

TABLE 3-I AS-504 MISSION TIMEBASES

TIMEBASES	SOURCE
TB1 Liftoff	Liftoff interrupt to LVDC upon actuation of relay to umbilical disconnect
TB2 S-IC CECO	Interrupt to LVDC upon actuation of CECO low-level sensors
TB3 S-IC OECO	Interrupt to LVDC upon actuation of OECO propellant-depletion sensors
TB4 S-II ECO	Interrupt to LVDC upon actuation of S-II propellant-depletion sensors
TB4a S-II D.S.	Command receiver interrupt for S-II/S-IVB direct staging
TB5 S-IVB ECO	Satisfaction of terminal velocity criterion at parking orbit insertion
TB6 S-IVB R.P.	Meeting of restart preparation criterion - the LVDC issues signal to begin restart preparations
TB6a O_2-H_2 Burner Malfunction	Initiated by LVDC upon receipt of an "Oxygen-Hydrogen Burner Malfunction" signal between the time TB6 + 91.7 seconds and TB6 + 235 seconds
TB6b O_2-H_2 Burner Malfunction	Initiated by LVDC upon receipt of an "Oxygen-Hydrogen Burner Malfunction" signal between the time TB6 + 235 seconds and TB6 + 346.6 seconds
TB6c Translunar Inhibit	Entered during TB6 upon receipt of the "Translunar Injection Inhibit" signal from the spacecraft
TB7 S-IVB ECO	Satisfaction of the out-of-orbit terminal-velocity criterion at lunar-orbit injection

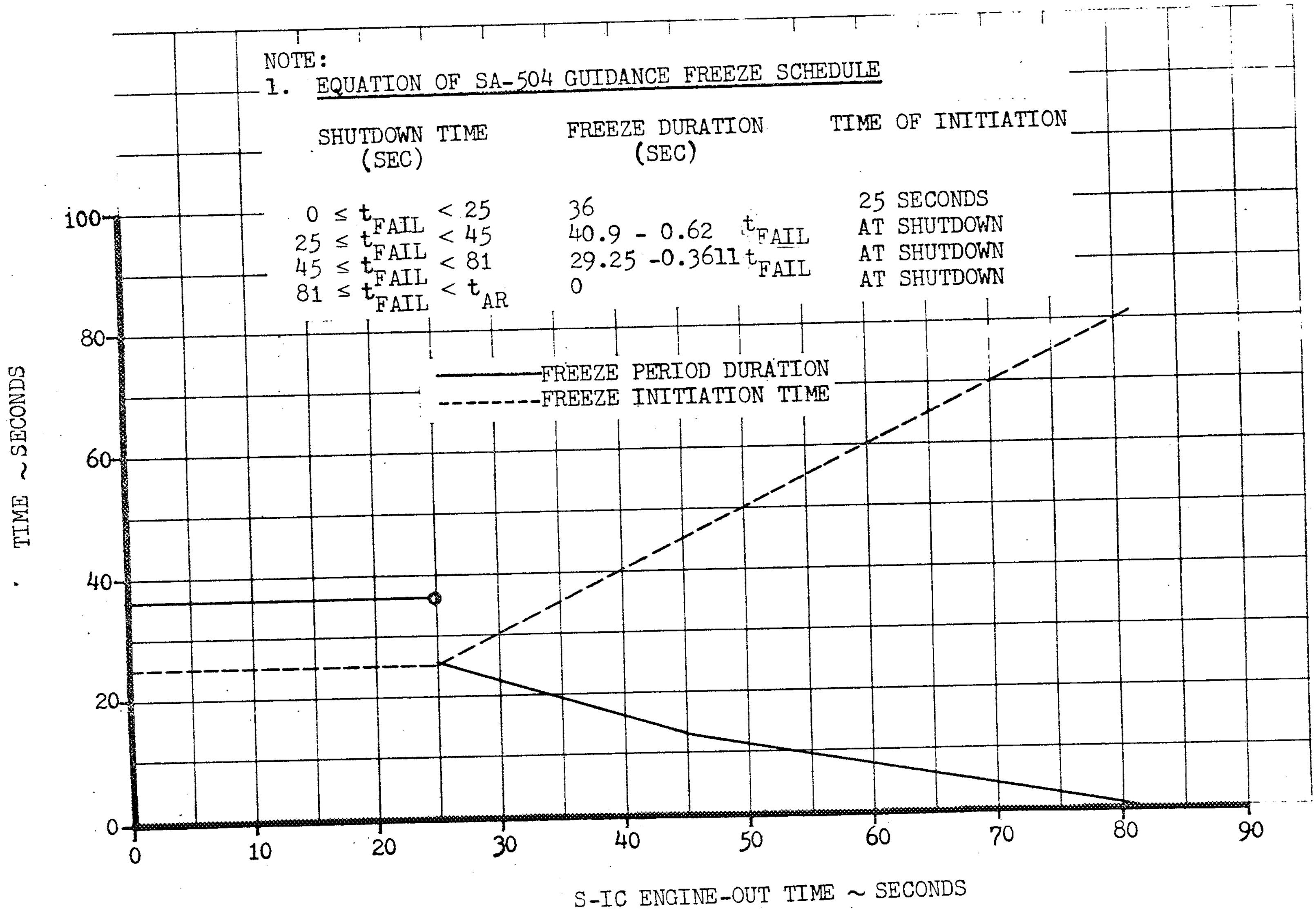

FIGURE 3-4 SA-504 REDUCED-LOADS CHI-FREEZE SCHEDULE

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SECTION 4

EQUATIONS AND LOGIC

4.0 GENERAL

This section lists the equations, mode logic, engine-out logic, presettings, and nomenclature required to implement the SA-504 guidance program. The total information package is divided into several elements. In each case,a functional or logic diagram is used to organize the material. Pertinent details needed to understand and implement the scheme are found on the diagrams only. The general guidance flow is presented in Figure 4-1.

4.1 GUIDANCE

Guidance employs the LVDC to provide correct vehicle steering angles. These angles are computed in various modes as the flight progresses. The flight program determines the proper mode for computing these steering angles.

The equations for targeting, pre-IGM, IGM, coast guidance, and attitude commands are given in this section. A change of guidance mode is initiated by discretes received by the guidance computer.

4.1.1 Ground-Launch Targeting

Ground-launch targeting is formulated to minimize onboard complexity and to maximize the versatility in the selection of targeting parameters. Guidance reference release (GRR) marks the beginning of the first guidance cycle. Actual flight azimuth, desired parking-orbit inclination and descending nodal angle, direct-ascent parameters, and the into-orbit G matrix are calculated between GRR and liftoff. The general ground-launch targeting logic flow is presented in Figure 4-2.

The targeting logic provides for two sets of inclination and nodal angle calculations to provide flexibility in targeting. Inclination is calculated as a function of flight azimuth or as a function of time from the opening of the launch window depending upon the behavior of the parameter to be fitted. The logic to facilitate the calculations is presented in Figure 4-3.

When ground-launch targeting is entered from GRR, t_D is calculated. Flight azimuth is calculated from a three-segment polynomial in t_D. A three-segment polynomial is implemented to provide the required 0.02-degree accuracy in determining flight azimuth for 99 percent of the launch window time on the most difficult day to curve-fit.

A test gate determines the method for calculating inclination. The i(op) = 1 setting allows calculation of inclination in terms of flight azimuth. Otherwise, inclination is calculated in terms of t_D.

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4.1.1 (Continued)

A similar test gate is entered for the nodal-angle calculation. Again, a setting of $\theta_N(op) = 1$ provides for the calculation of the nodal angle in terms of azimuth.

The coefficients used in the calculation of inclination and nodal angle are stored in one location in the LVDC regardless of whether the independent variable is A_Z or t_D. To facilitate this, the independent variables, A_Z and t_D, are scaled or normalized. The targeting functions are presented in Table 4-I. The form of the normalization is selected to produce the same order of magnitude on all polynomial terms for either an Atlantic or a Pacific opportunity. When the data for a Pacific opportunity have been fit and an Atlantic opportunity is required, t_{D1} is preset at the closing time rather than the opening time of the segment. t_{S1} is preset as the negative of the duration of the segment.

4.1.2 Pre-IGM Guidance

The pre-IGM guidance logic is shown in Figure 4-4. This logic block is entered at liftoff and once each major cycle until IGM initiation. The logic establishes pitch, yaw, and roll commands; provides engine-out capability; and initializes the IGM equations. A roll attitude of A_Z- 90 degrees and a pitch attitude of zero degrees is maintained until tower clearance is assured. The time-tilt steering program and roll command to the desired flight azimuth are initiated when an altitude of 137 meters is reached or a time backup (t_1) test is satisfied. The equations used for pre-IGM guidance are presented in Table 4-II.

Zero yaw attitude is commanded through pre-IGM flight, with the exception of a period during vertical rise where a nonzero command is issued to ensure tower clearance. Pitch-attitude commands are generated by the pre-IGM steering function unless a freeze is initiated. For an S-IC engine-out, pitch steering is modified to compensate for the reduced thrust and increased burn time through use of the freeze schedule shown in Figure 3-4. The pitch-polynomial evaluation time is biased by the freeze time Δt_f so that it is reentered at the prefreeze time. The bias is continued until tilt arrest occurs. With an engine failure prior to t_2, logic delays the freeze until pitch attitude is sufficient to assure that the vehicle flies eastward of the launch area. During this period, a single S-IC engine failure causes a pass through the pre-IGM engine-out equations.

4.1.3 IGM Stage Logic

The IGM stage logic shown in Figure 4-5 is entered prior to the IGM steering equations. The stage logic functions as a vehicle monitor to provide correct time parameters to the stage integrals in the IGM steering equations. The nominal guidance-stage burn times (T_1, T_2, and T_3) are the upper limits on the stage integrals. The nominal coast

4.1.3 (Continued)

time between S-II cutoff and S-IVB ignition is T_c. A steering-angle freeze is initiated at S-II cutoff and maintained until the S-IVB stage ignition test is satisfied. The ratios of the characteristic velocities to F/m for each of the guidance stages are defined as τ_1, τ_2, and τ_3. A nominal value or an adjusted nominal value of tau is used until each of the stages is entered. The τ's are parameters developed to simplify the IGM stage integrals. The guidance-time parameters are altered if a vehicle perturbation is detected.

The following vehicle performance deviations, as well as the expected three-sigma perturbations, are accounted for during the into-orbit and out-of-orbit IGM phases:

a. S-II engine-out.
b. Early second MRS (S-II stage burn).
c. Late second MRS (S-II stage burn).
d. S-II stage early cutoff.
e. S-II stage late cutoff.
f. S-IVB stage early ignition.
g. Thrust anomalies at S-IVB first and second ignition.
h. Early S-IVB MRS.
i. Late S-IVB MRS.

The mass flowrates are assumed to change by a factor of four-fifths for an S-II engine-out. Consequently, the guidance times (T_1, T_2, and τ_2) associated with the S-II stage are updated by a factor of five-fourths. (See Figure 4-6.) This updating compensates for the longer burn period required at reduced thrust. The S-II engine-out equations are included in pre-IGM to provide S-II engine-out corrections at the earliest possible time. S-IVB vehicle perturbations are handled similarly. The S-IVB MRS forcing logic, which accounts for a late S-IVB MRS, is presented in Figure 4-7.

An artificial tau mode is employed for C_o' seconds at S-IVB ignition and reignition. This tau mode provides relatively continuous steering commands in the presence of thrust oscillations or anomalies. The adjustment of τ_2 and τ_3 for the S-II and S-IVB stage MRS prevents large IGM steering-angle discontinuities that are possible with the F/m fluctuations occurring during these transition periods. The equations are presented in Table 4-III.

4.1.4 Chi-Tilde Logic

The Chi-Tilde logic (Figure 4-8) is entered from the IGM stage logic. The calculations and equations used in Chi-Tilde logic are presented in Table 4-IV. The stage integral calculations provide an estimate of vehicle performance capability. These calculations are based upon the current predictions of S-II and S-IVB burn times.

4.1.4 (Continued)

Range-angle-to-go computations are made to estimate the location of the terminal radius vector, providing a reference to establish the terminal coordinate system. The unrotated terminal conditions are selected for the into-orbit burn,and the rotated terminal conditions are selected for the out-of-orbit burn, based upon the data of Reference 10. In the latter case,the terminal coordinates are rotated to a system with the ξ_T axis perpendicular to the velocity vector.

The K matrix transforms the vehicle position, velocity, and gravitational acceleration vectors to the terminal coordinate system. A correction to the estimated S-IVB burn time, T_3, is made by comparing the current velocity deficiency with the current estimate of the velocity to be gained prior to insertion. Two passes are made through the terminal range-angle calculation in each major cycle. This provides for more accurate end-conditions in the presence of three-sigma propulsion system variations. Also, it reduces the sensitivity of IGM to propellant utilization system fluctuation. The steering angles, $\tilde{\chi}_y$ and $\tilde{\chi}_p$, required to achieve the velocity end-conditions are evaluated after the K matrix is computed.

4.1.5 K_i Calculations

The K_i calculations provide biases to the Chi-Tilde pitch and yaw steering angles. These biases allow the terminal radius constraint to be satisfied without disturbing the terminal velocity constraint. The K_i terms are calculated until the total time-to-go, T_T', becomes less than a preset time, t_2. The K_i terms are then set equal to zero for both the into-orbit and out-of-orbit burns. The pitch and yaw steering angles are then equal to $\tilde{\chi}_p$ and $\tilde{\chi}_y$, respectively. The K_i calculations are presented in Figure 4-9.

4.1.6 S-II/S-IVB Direct Staging

S-II/S-IVB direct staging follows an S-II stage ignition failure or a premature S-II propulsion system shutdown. The guidance equations and logic are not designed to detect these malfunctions; therefore, ground-monitor detection and ground-command LVDC interrupt are required to initiate an alternate flow sequence and a guidance update. Nominal S-II guidance is used until the direct-stage interrupt is received. Direct-staging guidance update is shown in Figure 4-10.

If the S-II stage fails to ignite, the commanded attitudes are arrested. Accelerometer outputs are used in the navigation system to compute accelerations, velocities, and positions. Upon receipt of the command-receiver interrupt, guidance update occurs and alternate timebase 4 is initiated. Active IGM occurs at a specified time, TS4BS, after initiation of alternate timebase 4.

4.1.6 (Continued)

Following a premature S-II propulsion system shutdown, a single-engine shutdown is indicated rather than a complete stage shutdown. Any event such as LET or interstage jettison occurs at its nominal time prior to a command-receiver interrupt. The sequence is identical to direct staging following an S-II stage ignition failure after a command-receiver interrupt.

A timeguard against starting timebase 4 prematurely is removed approximately 35 seconds prior to nominal S-II cutoff. Any total S-II shutdown subsequent to this time starts timebase 4 and the vehicle stages to the S-IVB nominally.

4.1.7 High-Speed Cutoff Logic

The high-speed cutoff logic is entered when the IGM total time-to-go, T_T', is less than ϵ_4. The high-speed loop determines the actual cutoff time, processes the accelerometer inputs from the stabilized platform, performs navigation calculations, examines the S-IVB engine-out hardwire input, and determines the cutoff criteria to be used. Logic for determining the actual cutoff time, T_{GO}, is presented in Figure 4-11. The equations required for the cutoff velocity and T_{GO} calculations are presented in Table 4-V.

A chi-freeze is initiated and logic parameters are initialized on the first pass through the high-speed logic. The variation from the nominal S-IVB burn time is computed each pass for the into-orbit phase. The predicted time-to-cutoff, T_{GO}, is determined from the desired parking-orbit-insertion velocity and from a bias, ΔV_B, that compensates for J-2 engine thrust decay at shutdown. Gravity losses are also considered. The predicted time-to-cutoff for translunar orbit injection is determined from the predicted terminal velocity and from a new thrust decay bias that includes the expected LOX blowdown impulse. The predicted terminal velocity is a function of the desired orbital energy and the predicted terminal radius. Subsequent passes through the high-speed logic update the value of T_{GO} for either parking-orbit or translunar-orbit cutoff until S-IVB commanded cutoff. The high-speed-logic exit setting is entered to initialize out-of-orbit flight parameters. The high-speed logic is then terminated.

4.1.8 Guidance Time Update

The guidance-time-update computation is shown in Figure 4-12. The computation provides the necessary logic to decrement the guidance-time parameters. The time remaining in the first stage of guidance is decremented by Δt, the IGM evaluation interval prior to the second S-II mixture-ratio shift. The MRS transition time, t_{B1}, is decremented for the tau calculation. The time of coast, T_c, is decremented between S-II cutoff and S-IVB ignition. The time remaining in the third stage of guidance is decremented after S-IVB stage ignition. The time-to-go in

4.1.8 (Continued)

stage four is decremented until stage five is entered during the out-of-orbit burn. Stage five time-to-go is then decremented.

4.1.9 Steering Misalignment Correction

Steering misalignment correction (SMC) is used during IGM phases of powered flight. The SMC equations provide a bias for the IGM commanded steering angles to reduce the effects of thrust misalignments. The use of SMC terms is controlled by a test based upon time TSMC. Three time parameters, TSMC1, TSMC2, TSMC3, measured from timebases 3, 4 or 4 alternate, and 6 respectively, are used to implement SMC. The SMC equations based upon the data of Reference 11 are presented in Figure 4-13.

4.1.10 Restart Preparation and Opportunity Logic

Restart preparation and opportunity logic is presented in Figure 4-14. The equations are presented in Table 4-VI. The logic is entered at parking-orbit insertion. Out-of-orbit targeting parameters are calculated. Gate settings determine the flow of logic. Opportunity selection is controlled by an inhibit switch that is nominally set to NO to enable first opportunity and is manually controlled onboard. Restart preparation is initiated upon satisfaction of an α_{TS} test. Restart guidance is then entered and maintained for a specified length of time. At a preset elapsed time, T_{RG}, the IGM precalculations for S-IVB second burn are made, and the out-of-orbit G matrix is computed.

Provisions are incorporated to allow target updating. Either a seven-parameter or ten-parameter update may be implemented. Update is initiated by a TU=YES signal from ground command. A TU10 test is then made to determine the type of update desired. If TU10=YES, a ten-parameter update is implemented and T_X, T_Y, T_Z, α_{TS}, β, θ_N, C_3, f, cos σ, and T_{ST} are updated. Reignition time is then determined. These constants replace the values calculated during prelaunch for the first or second opportunity.

A TU10=NO signal indicates a seven-parameter target update. Seven parameters, T_{RP}, C_3, i, θ_N, e_N, α_D, and f, are then updated in the LVDC. This update yields the orientation of the target plane and the time to begin restart preparation, T_{RP}. The $\bar{S} \cdot \bar{T}_p$ tests are bypassed, and TB6 is initiated at restart preparation.

Out-of-orbit IGM precalculation logic is presented in Figure 4-15. IGM out-of-orbit precalculation logic is entered at S-IVB reignition or immediately following a seven-parameter target update. Nominal elliptical parameters are calculated unless a seven-parameter target update occurs. The semilatus rectum, p, is the only elliptical parameter calculated for a seven-parameter target update.

4.1.10 (Continued)

The out-of-orbit G matrix is calculated, and specific IGM parameters are updated to complete the out-of-orbit IGM precalculations. An entrance gate provides for a single pass through the precalculations except for a seven-parameter target update inhibit.

4.1.11 Orbital-Guidance Logic

The orbital-guidance logic is shown in Figure 4-16. During the first 45 minutes of parking-orbit coast, the vehicle is oriented with the + X body axis along the local horizontal and the + Z body axis pointing toward the earth along the local vertical, with the + X body axis in the general direction of motion. This is commonly called "tail-chase-nose." From 45 minutes after insertion to the end of the first orbit, the vehicle is rolled 180 degrees and pitched 20 degrees below local horizontal. After the first orbit, the pitch attitude is returned to zero before rolling back to avoid the excess propellant consumption associated with a combined maneuver. These maneuvers are programmed with update and inhibit capability. Unless a ground command alters the operation, the inhibits are turned off initially so that the maneuvers occur at the planned times. The orbital-guidance equations are presented in Table 4-VII.

The orbital-guidance logic also provides attitude steering in the early phases of translunar-orbit coast. The attitude commands allow for launch vehicle-spacecraft separation and Instrument Unit-to-ground communications.

4.1.12 Steering Angle Limit Test

The steering angles commanded by the pre-IGM and IGM guidance modes and the attitude-orientation angles provided by the coast-guidance mode are subjected to the limit test shown in Figure 4-17. This ensures that the vehicle does not exceed the maximum allowable turning rate. The commanded roll, pitch, and yaw attitudes are compared to the present commands. The turning rates resulting from the IGM steering angle commands are rate-limited. In addition, the yaw command is prohibited from exceeding the allowable platform yaw limits.

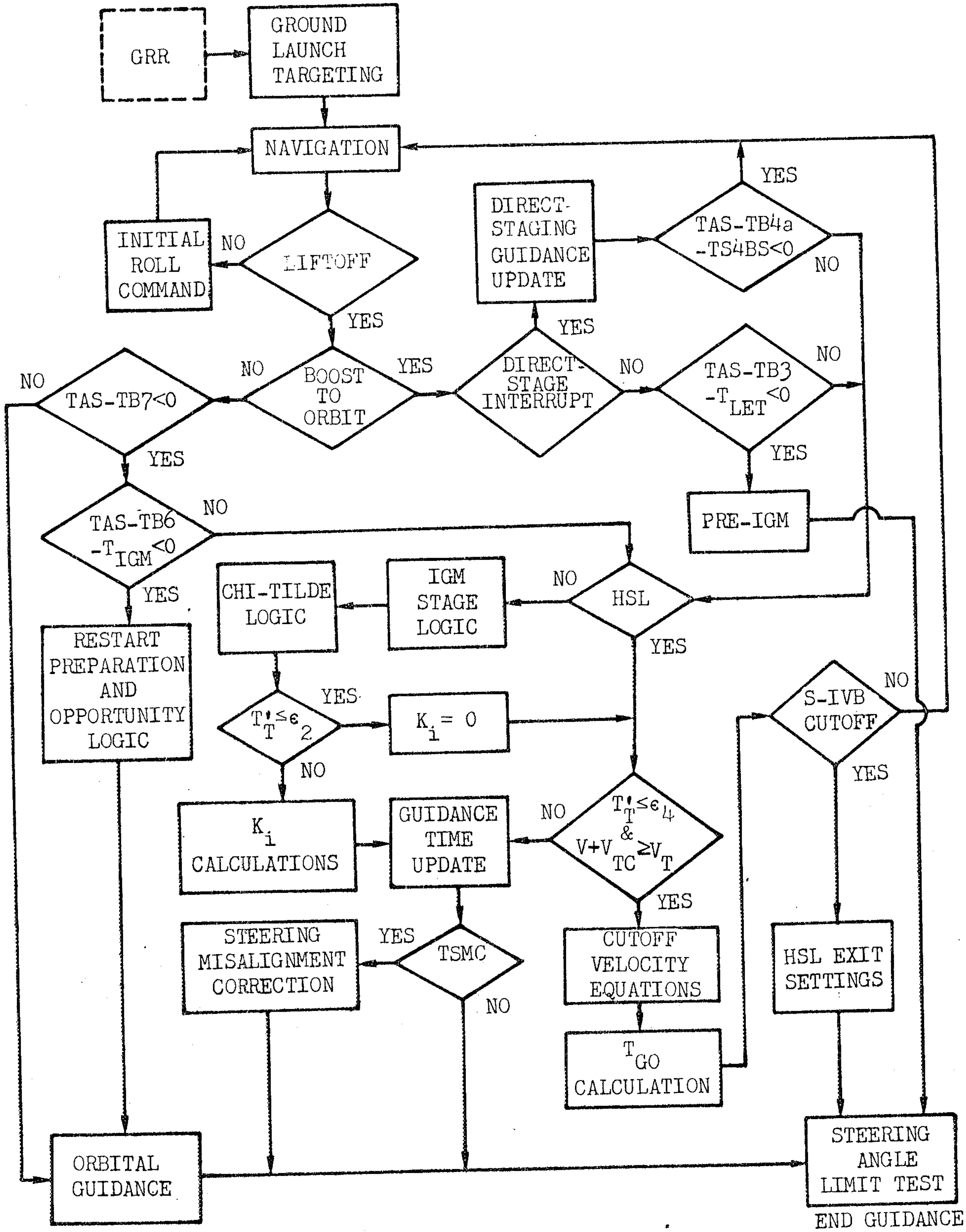

FIGURE 4-1 GENERAL GUIDANCE LOGIC FLOW

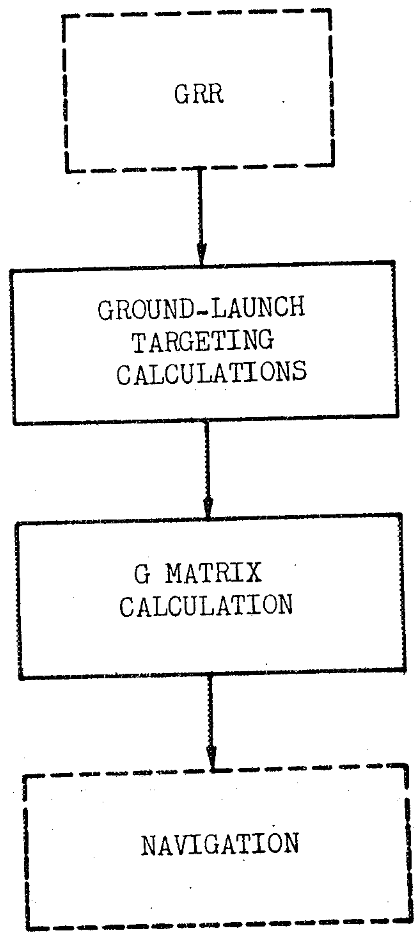

FIGURE 4-2 GROUND-LAUNCH TARGETING

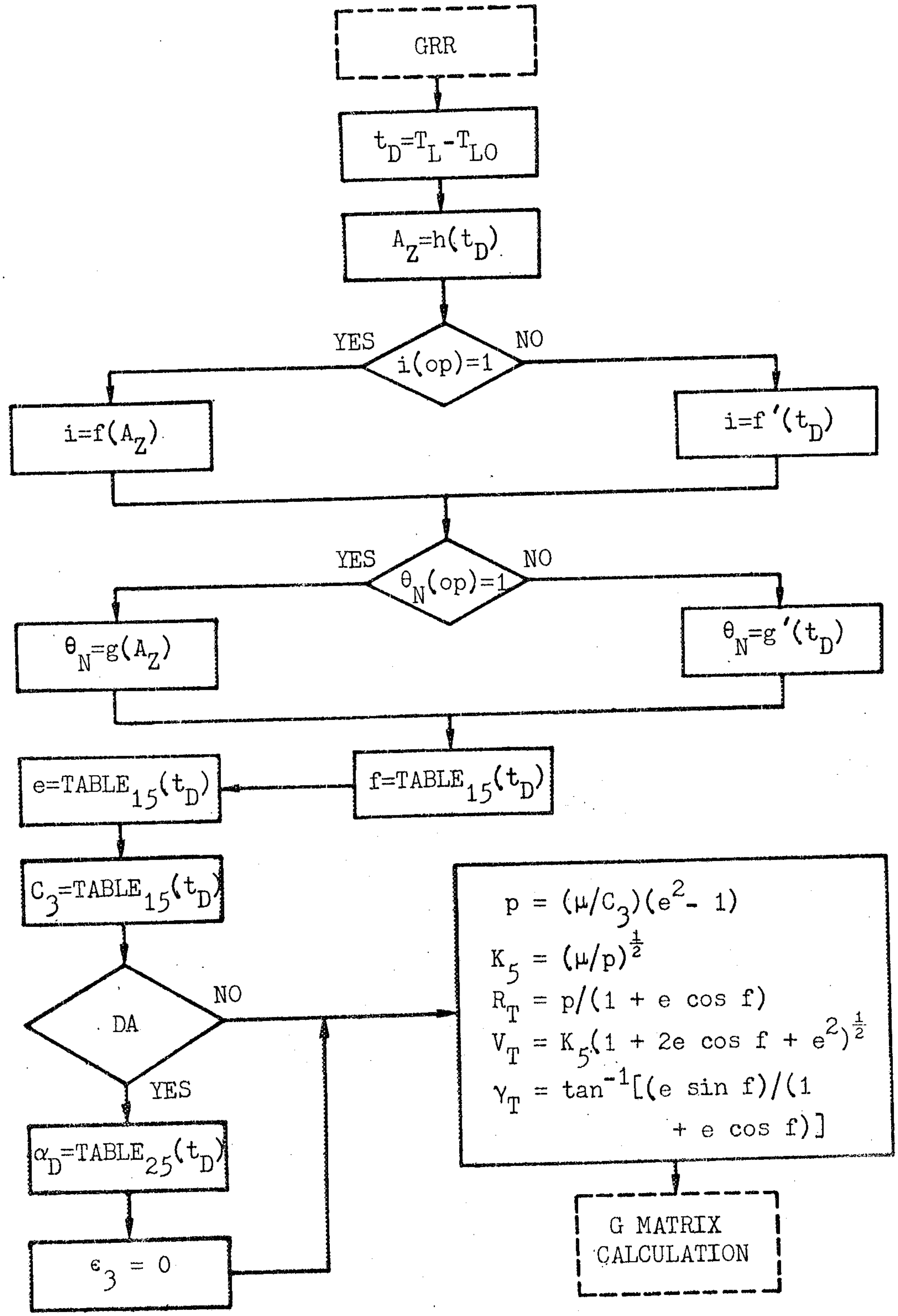

FIGURE 4-3 GROUND-LAUNCH TARGETING CALCULATIONS

TABLE 4-I GROUND-LAUNCH TARGETING EQUATIONS

GROUND-LAUNCH TARGETING CALCULATIONS

$$t_D = T_L - T_{LO}$$

$$A_Z = \begin{cases} \sum_{n=0}^{4} h_{1n}[(t_D - t_{D1})/t_{SD1}]^n & t_{DS0} \le t_D < t_{DS1} \\ \sum_{n=0}^{4} h_{2n}[(t_D - t_{D2})/t_{SD2}]^n & t_{DS1} \le t_D < t_{DS2} \\ \sum_{n=0}^{4} h_{3n}[(t_D - t_{D3})/t_{SD3}]^n & t_{DS2} \le t_D \le t_{DS3} \end{cases}$$

$$i = \begin{cases} \sum_{n=0}^{6} f_n [(A_Z - A_{ZO})/A_{ZS}]^n & i(op) = 1 \\ \sum_{n=0}^{6} f'_n [(t_D - t_{DO})/t_S]^n & i(op) = 0 \end{cases}$$

$$\theta_N = \begin{cases} \sum_{n=0}^{6} g_n [(A_Z - A_{ZO})/A_{ZS}]^n & \theta_N(op) = 1 \\ \sum_{n=0}^{6} g'_n [(t_D - t_{DO})/t_S]^n & \theta_N(op) = 0 \end{cases}$$

$$C_3 = \text{TABLE}_{15} (t_D)$$

$$e = \text{TABLE}_{15} (t_D)$$

$$f = \text{TABLE}_{15} (t_D)$$

$$\alpha_D = \text{TABLE}_{25} (t_D)$$

TABLE 4-I GROUND-LAUNCH TARGETING EQUATIONS (Continued)

INTO-ORBIT G MATRIX CALCULATION

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

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

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

INITIAL ROLL COMMAND

$$\chi_X = A_Z - 90^{\circ}$$

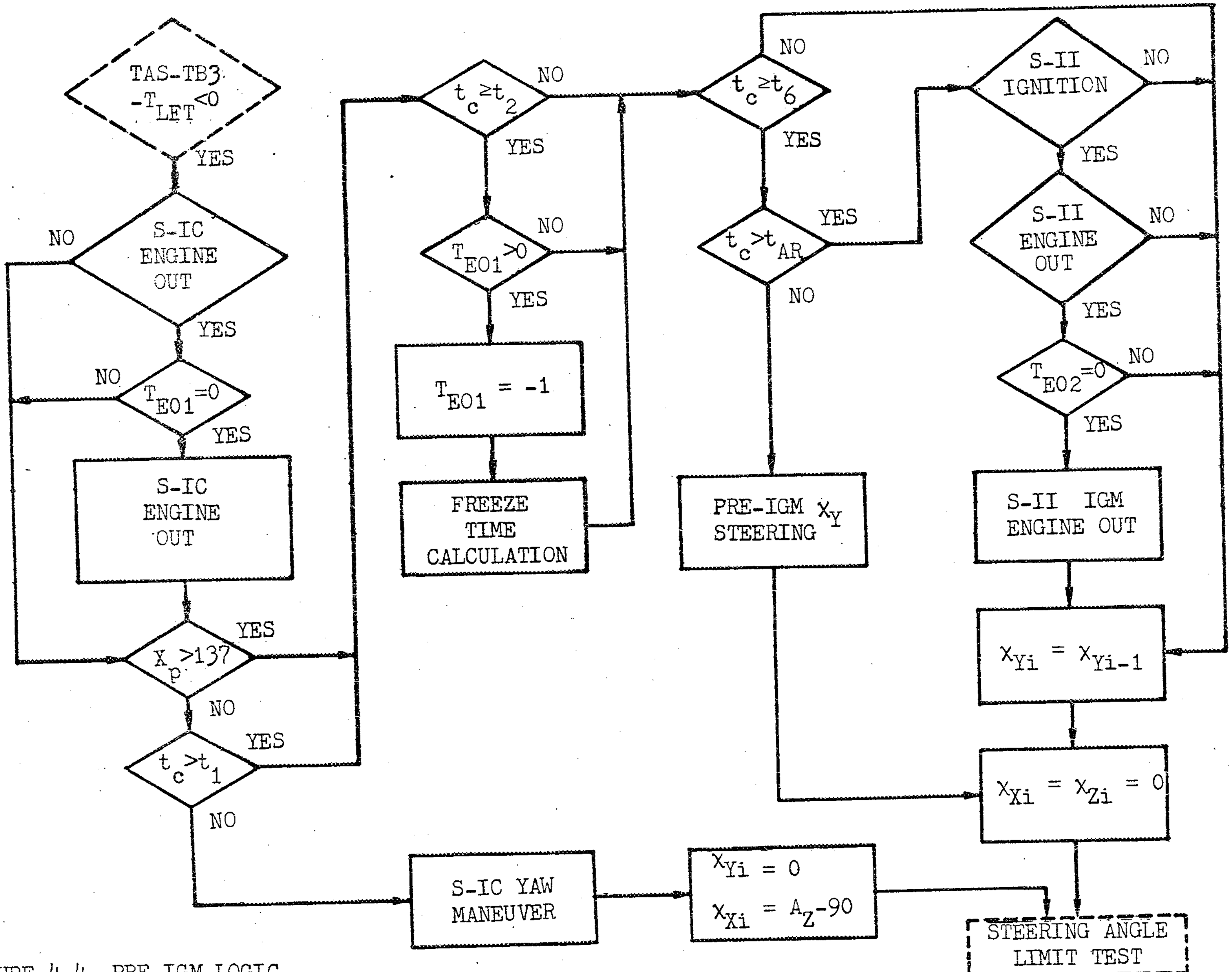

FIGURE 4-4 PRE-IGM LOGIC

TABLE 4-II PRE-IGM EQUATIONS

S-IC ENGINE OUT

$T_{EO1} = 1$

$t_{FAIL} = t_c$

PRE-IGM χ_Y STEERING

$\chi_Y = \sum_{n=0}^{4} F_{1n}(t_c - \Delta t_f)^n \qquad t_c - \Delta t_f < t_{S1}$

$\chi_Y = \sum_{n=0}^{4} F_{2n}(t_c - \Delta t_f)^n \qquad t_{S1} \le t_c - \Delta t_f < t_{S2}$

$\chi_Y = \sum_{n=0}^{4} F_{3n}(t_c - \Delta t_f)^n \qquad t_{S2} \le t_c - \Delta t_f < t_{S3}$

$\chi_Y = \sum_{n=0}^{4} F_{4n}(t_c - \Delta t_f)^n \qquad t_{S3} \le t_c - \Delta t_f$

S-II IGM ENGINE OUT

$T_{EO2} = 1$

$T_0 = t_{21} + \Delta t_{LET} - t_c$

$T_1 = T_0/4 + 5\,T_1/4$

$T_2 = 5\,T_2/4$

$\tau_3 = 5\,\tau_2/4$

S-IC YAW MANEUVER

$\chi_Z = 0^\circ \qquad 1.0 > t_c$

$\chi_Z = 1.25^\circ \qquad 1.0 \le t_c < 8.75$

$\chi_Z = 0^\circ \qquad 8.75 \le t_c$

TABLE 4-II PRE-IGM EQUATIONS (Continued)

FREEZE TIME CALCULATION

$\Delta t_f = t_3$	$t_{FAIL} \leq t_2$
$\Delta t_f = B_{11}\ t_{FAIL} + B_{12}$	$t_2 < t_c \leq t_4$
$\Delta t_f = B_{21}\ t_{FAIL} + B_{22}$	$t_4 < t_c \leq t_5$
$\Delta t_f = 0$	$t_5 < t_c$

$$t_6 = t_c + \Delta t_f$$

$$t_{AR} = t_{AR} + (1/4)\ (t_{AR} - t_{FAIL})$$

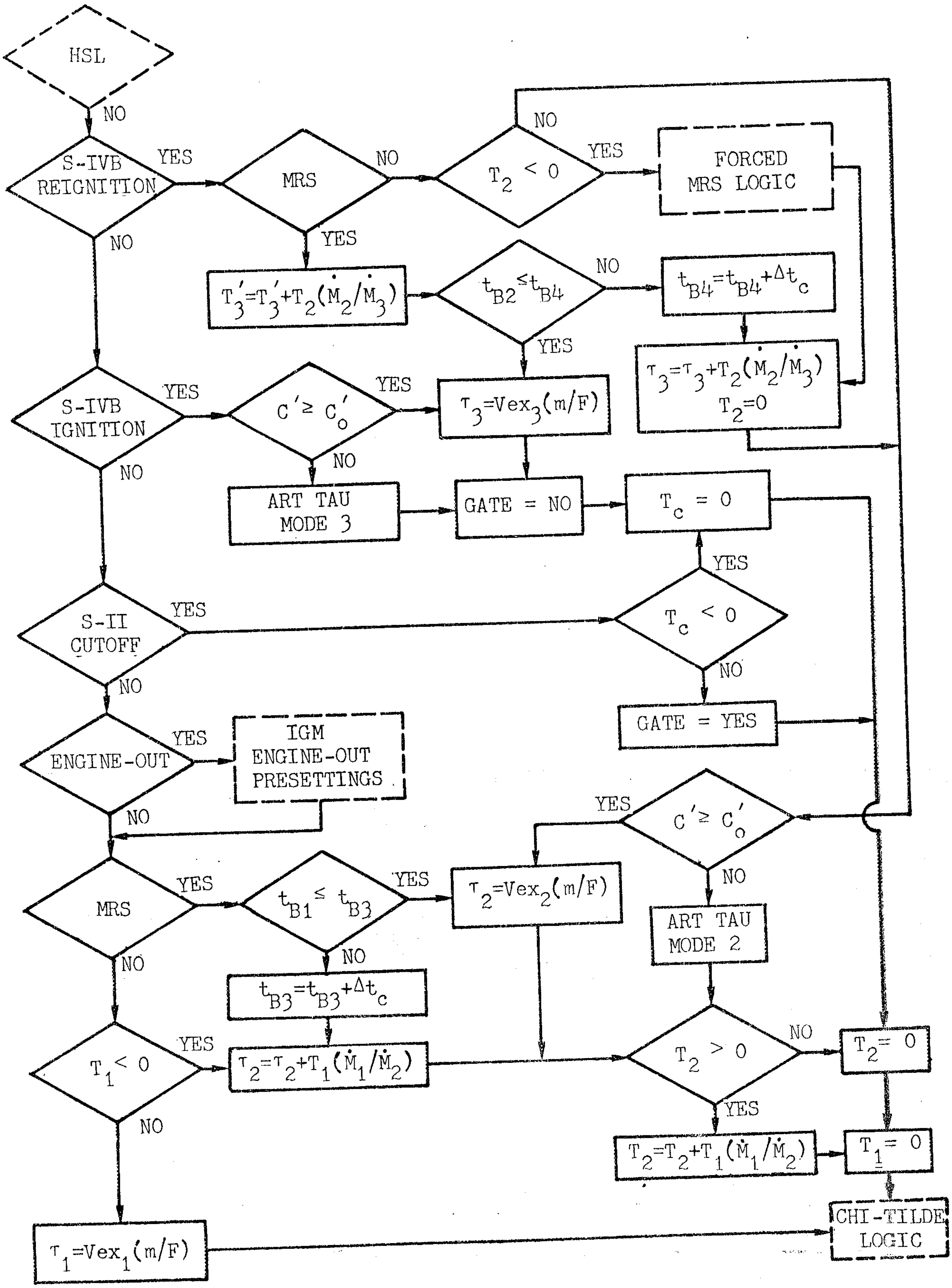

FIGURE 4-5 IGM STAGE LOGIC

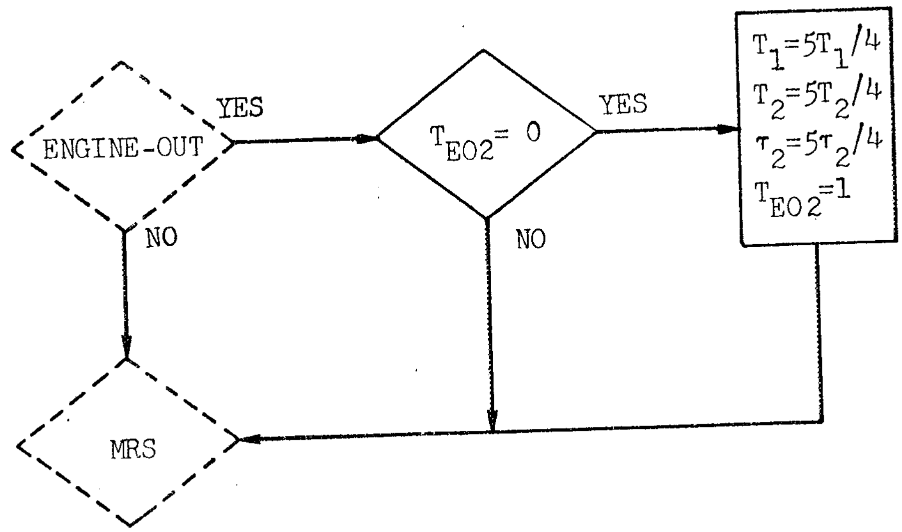

FIGURE 4-6 IGM ENGINE-OUT PRESETTINGS

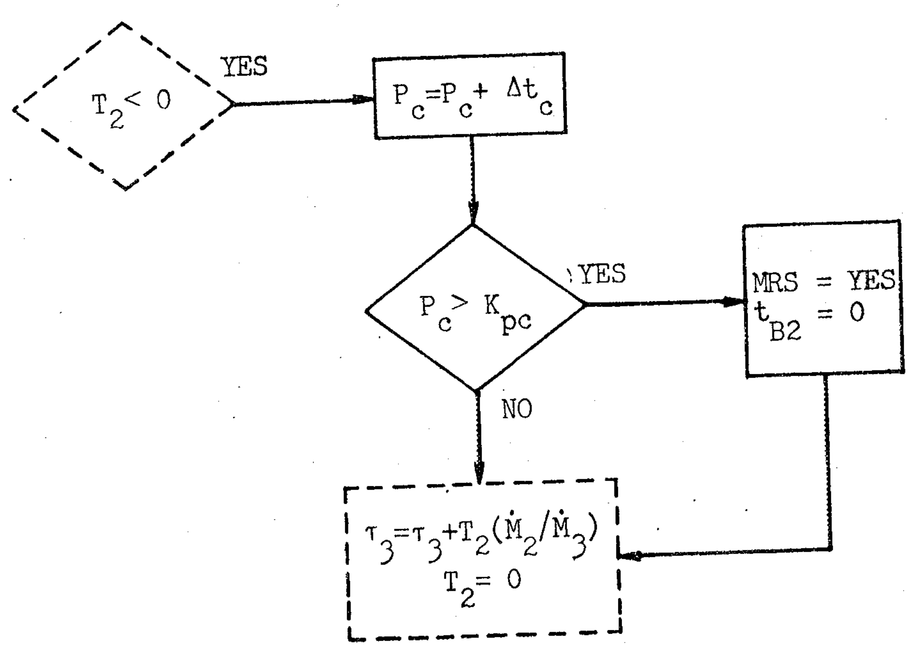

FIGURE 4-7 FORCED MRS LOGIC

TABLE 4-III ARTIFICIAL TAU MODE EQUATIONS

ART TAU MODE 2

$$\tau_2 = \tau_{2N} + [Vex_2 \, (m/F) - \Delta t_c/2 - \tau_{2N}] \, (C'/C'_o)^4$$

$$\tau_{2N} = \tau_{2N} - \Delta t_c$$

$$C' = C' + \Delta t_c$$

ART TAU MODE 3

$$\tau_3 = \tau_{3N} + [Vex_3 \, (m/F) - \Delta t_c/2 - \tau_{3N}] \, (C'/C'_o)^4$$

$$\tau_{3N} = \tau_{3N} - \Delta t_c$$

$$C' = C' + \Delta t_c$$

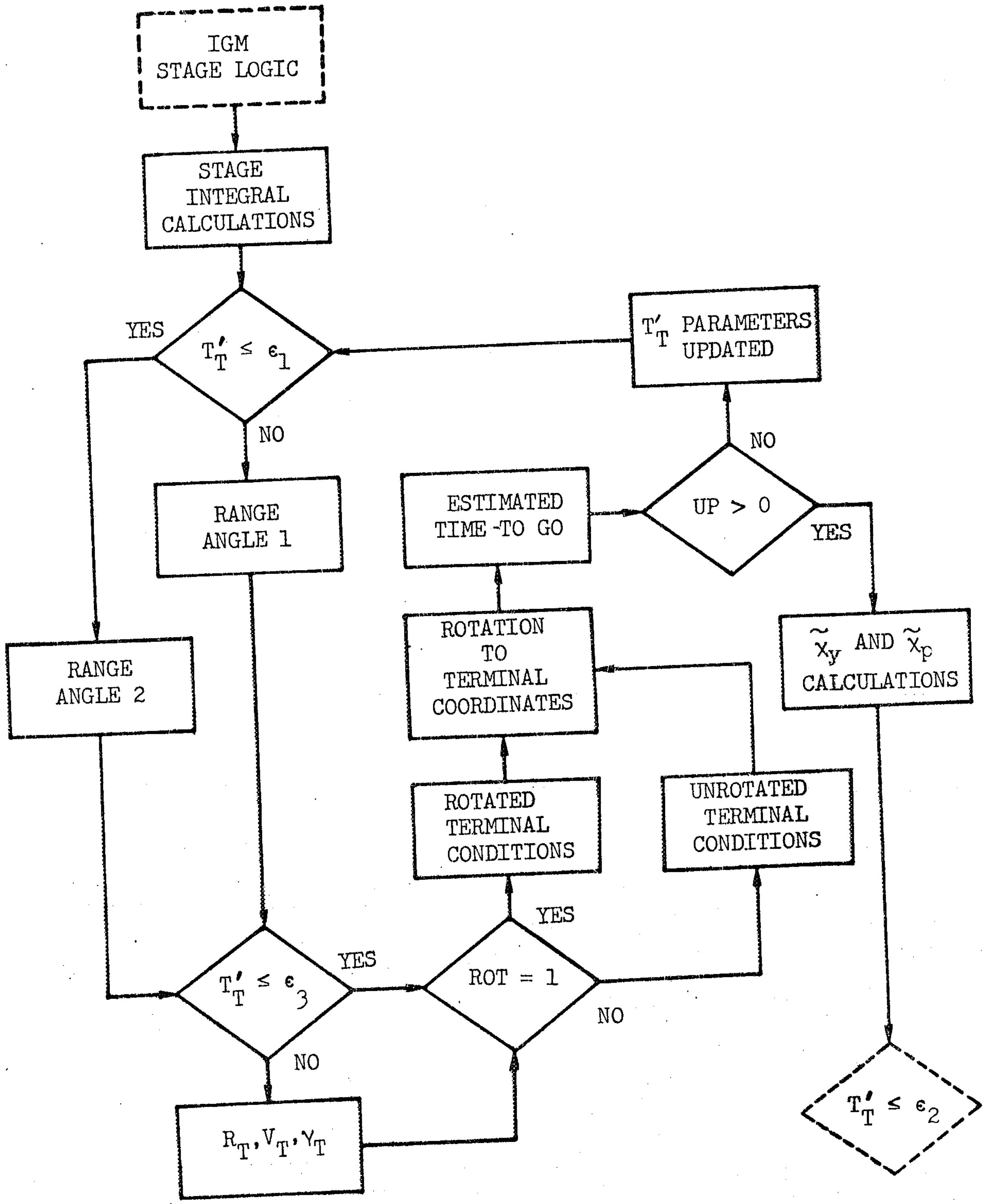

FIGURE 4-8 CHI-TILDE LOGIC

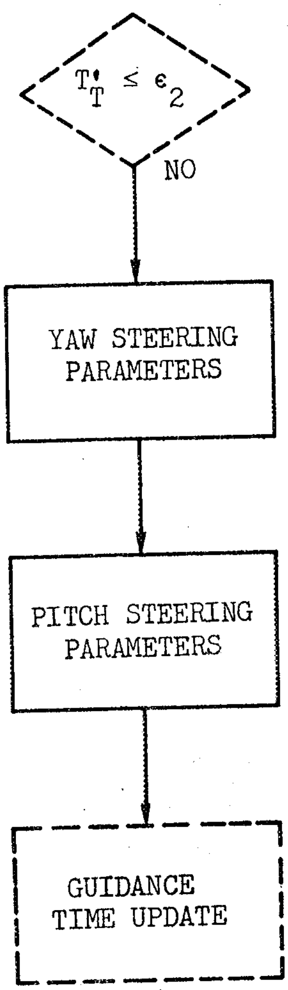

FIGURE 4-9 K_i CALCULATIONS

TABLE 4-IV IGM STEERING EQUATIONS

STAGE INTEGRAL CALCULATIONS

$[\bar{X}_4] = [G][\bar{X}_S]$

$L_1 = Vex_1 \; Ln(\tau_1/(\tau_1 - T_1))$

$J_1 = L_1\tau_1 - Vex_1 T_1$

$S_1 = L_1 T_1 - J_1$

$Q_1 = S_1\tau_1 - Vex_1 T_1^2/2$

$P_1 = J_1\tau_1 - Vex_1 T_1^2/2$

$U_1 = Q_1\tau_1 - Vex_1 T_1^3/6$

$L_2 = Vex_2 \; Ln(\tau_2/(\tau_2 - T_2))$

$J_2 = L_2\tau_2 - Vex_2 T_2$

$S_2 = L_2 T_2 - J_2$

$Q_2 = S_2\tau_2 - Vex_2 T_2^2/2$

$P_2 = J_2\tau_2 - Vex_2 T_2^2/2$

$U_2 = Q_2\tau_2 - Vex_2 T_2^3/6$

$L_{12} = L_1 + L_2$

$J_{12} = J_1 + J_2 + L_2 T_1$

$S_{12} = S_1 - J_2 + L_{12}(T_2 + T_c)$

$Q_{12} = Q_1 + Q_2 + S_2 T_1 + J_1 T_2$

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

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

$L_3' = Vex_3 \; Ln(\tau_3/(\tau_3 - T_3'))$

$J_3' = L_3'\tau_3 - Vex_3 T_3'$

$L_Y' = L_{12} + L_3'$

RANGE ANGLE 1

$$\delta_2 = VT_T' - J_3' + L_Y'T_3' - [ROV/Vex_3][(\tau_1 - T_1)L_1 + (\tau_2 - T_2)L_2 + (\tau_3 - T_3')L_3'][L_Y' + V - V_T]$$

$$\phi_T = \tan^{-1}(Z_4/X_4) + (1/R_T)(S_{12} + \delta_2)\cos\gamma_T$$

RANGE ANGLE 2

$V = (\dot{X}_S^2 + \dot{Y}_S^2 + \dot{Z}_S^2)^{\frac{1}{2}}$

$R = (X_S^2 + Y_S^2 + Z_S^2)^{\frac{1}{2}}$

$\sin\gamma = (X_S\dot{X}_S + Y_S\dot{Y}_S + Z_S\dot{Z}_S)/RV$

$\cos\gamma = (1 - \sin^2\gamma)^{\frac{1}{2}}$

$\dot{\phi}_1 = (V\cos\gamma)/R$

$\dot{\phi}_T = (V_T\cos\gamma_T)/R_T$

$\phi_T = \tan^{-1}(Z_4/X_4) + [((\dot{\phi}_1 + \dot{\phi}_T)/2)\;T_T']$

TABLE 4-IV IGM STEERING EQUATIONS (Continued)

R_T, V_T, γ_T

$$f = \phi_T + \alpha_D$$

$$R_T = p/(1 + e \cos f)$$

$$V_T = K_5 \, (1 + 2 e \cos f + e^2)^{\frac{1}{2}}$$

$$\gamma_T = \tan^{-1}[(e \sin f)/(1 + e \cos f)]$$

$$G_T = -\mu/R_T^2$$

ROTATED TERMINAL CONDITIONS

$$\xi_T = R_T \cos \gamma_T$$

$$\dot{\zeta}_T = V_T$$

$$\dot{\xi}_T = 0$$

$$\ddot{\zeta}_{GT} = G_T \sin \gamma_T$$

$$\ddot{\xi}_{GT} = G_T \cos \gamma_T$$

$$\phi_T = \phi_T - \gamma_T$$

UNROTATED TERMINAL CONDITIONS

$$\xi_T = R_T$$

$$\dot{\zeta}_T = V_T \cos \gamma_T$$

$$\dot{\xi}_T = V_T \sin \gamma_T$$

$$\ddot{\zeta}_{GT} = 0$$

$$\ddot{\xi}_{GT} = G_T$$

TABLE 4-IV IGM STEERING EQUATIONS (Continued)

ROTATION TO TERMINAL COORDINATES

$$[\phi_T] \quad \begin{bmatrix} \cos\phi_T & 0 & \sin\phi_T \\ 0 & 1 & 0 \\ -\sin\phi_T & 0 & \cos\phi_T \end{bmatrix}$$

$$[K] = [\phi_T][G]$$

$$\begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = [K] \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix}$$

$$\begin{bmatrix} \dot{\xi} \\ \dot{\eta} \\ \dot{\zeta} \end{bmatrix} = [K] \begin{bmatrix} \dot{X}_S \\ \dot{Y}_S \\ \dot{Z}_S \end{bmatrix}$$

$$\begin{bmatrix} \ddot{\xi}_G \\ \ddot{\eta}_G \\ \ddot{\zeta}_G \end{bmatrix} = \frac{1}{2} \left\{ \begin{bmatrix} \ddot{\xi}_{GT} \\ 0 \\ \ddot{\zeta}_{GT} \end{bmatrix} + [K] \begin{bmatrix} \ddot{X}_g \\ \ddot{Y}_g \\ \ddot{Z}_g \end{bmatrix} \right\}$$

ESTIMATED TIME-TO-GO

$$\Delta\dot{\xi}' = \dot{\xi}_T - \dot{\xi} - \ddot{\xi}_G T_T'$$

$$\Delta\dot{\eta}' = -\dot{\eta} - \ddot{\eta}_G T_T'$$

$$\Delta\dot{\zeta}' = \dot{\zeta}_T - \dot{\zeta} - \ddot{\zeta}_G T_T'$$

$$\Delta L_3 = [(\{(\Delta\dot{\xi}')^2 + (\Delta\dot{\eta}')^2 + (\Delta\dot{\zeta}')^2\}/L_Y') - L_Y']/2$$

$$\Delta T_3 = \Delta L_3(\tau_3 - T_3')/Vex_3$$

$$T_3 = T_3' + \Delta T_3$$

$$T_T = T_T' + \Delta T_3$$

TABLE 4-IV IGM STEERING EQUATIONS (Continued)

T' PARAMETERS UPDATED

$UP = 1$

$T_3' = T_3$

$T_T' = T_T$

$L_3' = L_3' + \Delta L_3$

$L_Y' = L_Y' + \Delta L_3$

$J_3' = J_3' + \Delta L_3 T_3$

$\tilde{\chi}_y$ AND $\tilde{\chi}_p$ CALCULATIONS

$L_3 = L_3' + \Delta L_3$

$J_3 = J_3' + \Delta L_3 T_3$

$S_3 = L_3 T_3 - J_3$

$Q_3 = S_3 \tau_3 - Vex_3 \, T_3^2/2$

$P_3 = J_3(\tau_3 + 2T_{1c}) - Vex_3 \, T_3^2/2$

$U_3 = Q_3(\tau_3 + 2T_{1c}) - Vex_3 \, T_3^3/6$

$\Delta\dot{\xi} = \Delta\dot{\xi}' - \ddot{\xi}_G \, \Delta T_3$

$\Delta\dot{\eta} = \Delta\dot{\eta}' - \ddot{\eta}_G \, \Delta T_3$

$\Delta\dot{\zeta} = \Delta\dot{\zeta}' - \ddot{\zeta}_G \, \Delta T_3$

$L_Y = L_{12} + L_3$

$\tilde{\chi}_y = \tan^{-1} \left[\Delta\dot{\eta}/(\Delta\dot{\xi}^2 + \Delta\dot{\zeta}^2)^{\frac{1}{2}}\right]$

$\tilde{\chi}_p = \tan^{-1}(\Delta\dot{\xi}/\Delta\dot{\zeta})$

$UP = -1$

TABLE 4-IV IGM STEERING EQUATIONS (Continued)

YAW STEERING PARAMETERS

$$J_Y = J_{12} + J_3 + L_3 T_{1c}$$

$$S_Y = S_{12} - J_3 + L_Y T_3$$

$$Q_Y = Q_{12} + Q_3 + S_3 T_{1c} + (T_c + T_3)\ J_{12}$$

$$K_Y = L_Y / J_Y$$

$$D_Y = S_Y - K_Y Q_Y$$

$$\Delta\eta = \eta + \dot{\eta}\ T_T + \ddot{\eta}_G\ T_T^2/2 + S_Y \sin \tilde{\chi}_y$$

$$K_3 = \Delta\eta / (D_Y \cos \tilde{\chi}_y)$$

$$K_4 = K_Y K_3$$

PITCH STEERING PARAMETERS

$$L_P = L_Y \cos \tilde{\chi}_y$$

$$C_2 = \cos \tilde{\chi}_y + K_3 \sin \tilde{\chi}_y$$

$$C_4 = K_4 \sin \tilde{\chi}_y$$

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

$$S_P = S_Y C_2 - C_4 Q_Y$$

$$Q_P = Q_Y C_2 - C_4 (U_{12} + U_3 + T_{1c}^2 S_3 + (T_3 + T_c) P_{12})$$

$$K_P = L_P / J_P$$

$$D_P = S_P - K_P Q_P$$

$$\Delta\xi = \xi - \xi_T + \dot{\xi} T_T + \ddot{\xi}_G T_T^2/2 + S_P \sin \tilde{\chi}_p$$

$$K_1 = \Delta\xi / (D_P \cos \tilde{\chi}_p)$$

$$K_2 = K_P\ K_1$$

TABLE 4-IV IGM STEERING EQUATIONS (Continued)

IGM STEERING ANGLES

$$\chi_y'' = \tilde{\chi}_y - K_3 + K_4\, t$$

$$\chi_p'' = \tilde{\chi}_p - K_1 + K_2\, t$$

$$\begin{bmatrix} X_{S1} \\ X_{S2} \\ X_{S3} \end{bmatrix} = [K]^{-1} \begin{bmatrix} \sin \chi_p'' \cos \chi_y'' \\ \sin \chi_y'' \\ \cos \chi_p'' \cos \chi_y'' \end{bmatrix}$$

$$\chi_{Zi} = \sin^{-1} X_{S2}$$

$$\chi_{Yi} = \tan^{-1} (-X_{S3}/X_{S1})$$

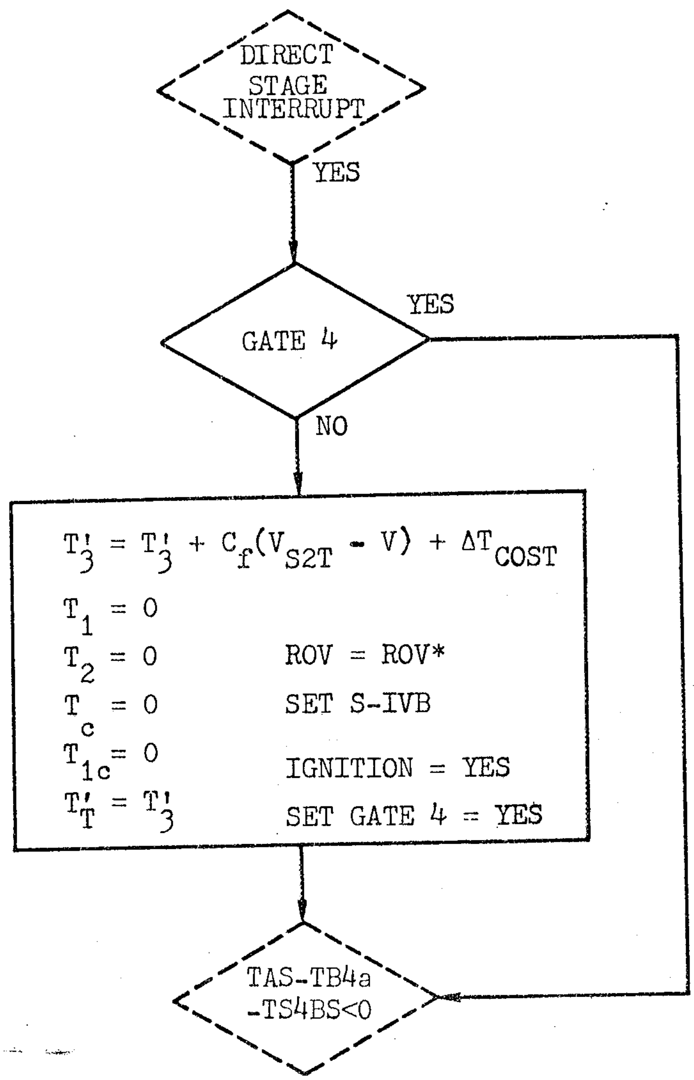

FIGURE 4-10 DIRECT-STAGING GUIDANCE UPDATE

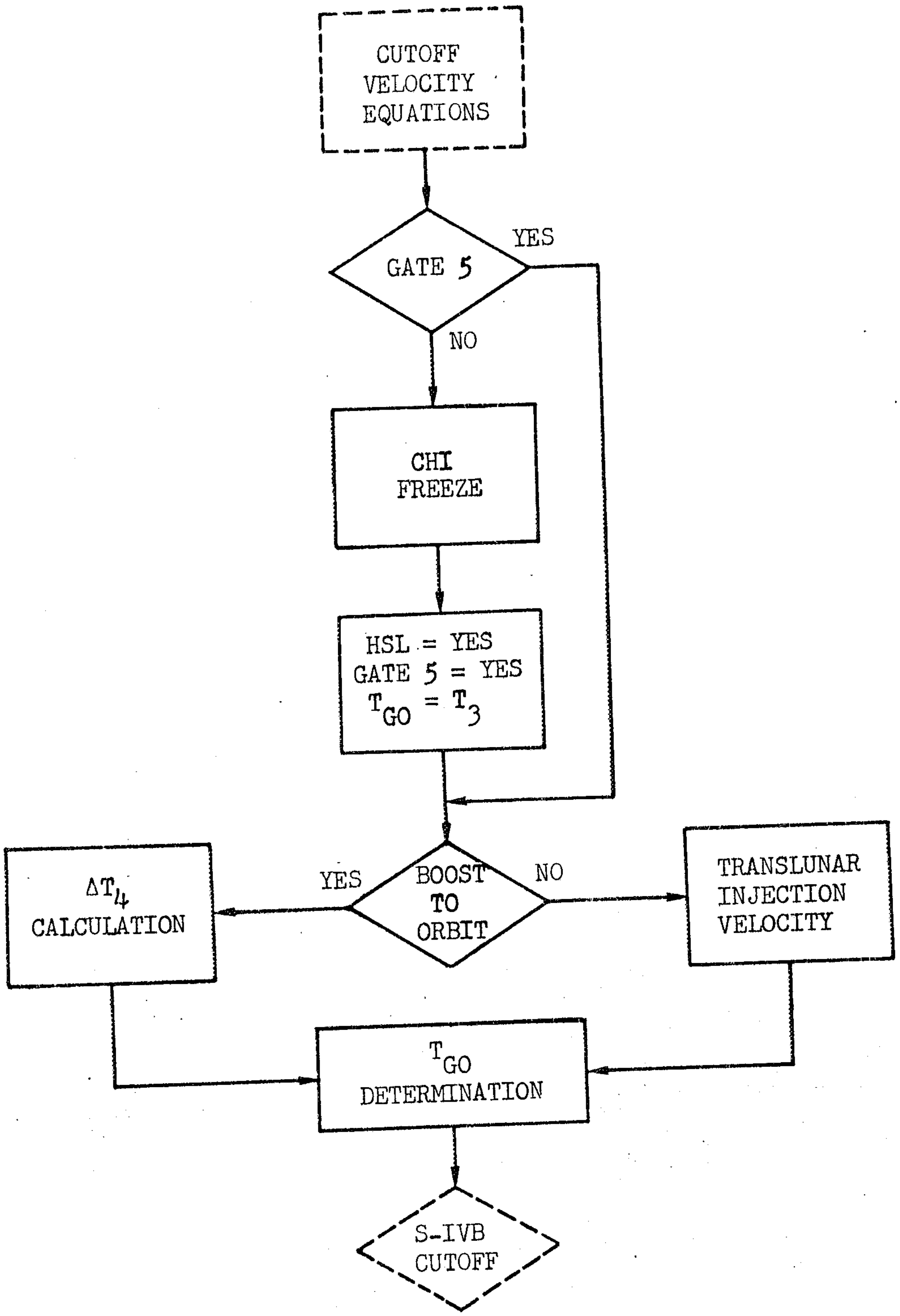

FIGURE 4-11 T_{GO} CALCULATION

TABLE 4-V HIGH-SPEED CUTOFF EQUATIONS

CUTOFF VELOCITY EQUATIONS

$$V = \frac{1}{2}\left(V + \frac{V_i^2}{V}\right)$$

$$V_0 = V_1$$

$$V_1 = V_2$$

$$V_2 = V$$

$$\Delta t_1' = \Delta t_2'$$

$$\Delta t_2' = \Delta t$$

ΔT_4 CALCULATION

$$t_{3i} = TB4 + T_c$$

$$\Delta T_4 = TAS - t_{3i} - T_{4N}$$

$$\Delta T_4' = \Delta T_4 \qquad \text{if } |\Delta T_4| \le \Delta T_{LIM}$$

$$\Delta T_4' = \Delta T_{LIM}[\Delta T_4 / |\Delta T_4|] \qquad \text{if } |\Delta T_4| > \Delta T_{LIM}$$

TRANSLUNAR INJECTION VELOCITY

$$\dot{R} = (\overline{R} \cdot \overline{V})/R$$

$$R_t = R + \dot{R}(T_3 - \Delta t)$$

$$V_T = (C_3 + 2\mu/R_t)^{\frac{1}{2}}$$

$$\Delta V_B = \Delta V_{BR}$$

CHI FREEZE

$$\chi_{Yi} = \chi_{Yi-1}$$

$$\chi_{Zi} = \chi_{Zi-1}$$

TABLE 4-V HIGH-SPEED CUTOFF EQUATIONS (Continued)

T_{GO} DETERMINATION

$$a_2 = \frac{(V_2-V_1)\Delta t_1' - (V_1-V_0)\Delta t_2'}{\Delta t_2' \, \Delta t_1'(\Delta t_2'+\Delta t_1')}$$

$$a_1 = \frac{V_2-V_1}{\Delta t_2'} + a_2 \Delta t_2'$$

$$T_{GO} = \frac{(V_T-\Delta V_B) - V_2}{a_1 + a_2 \, T_{GO}}$$

$$T_{CO} = TAS + T_{GO}$$

HSL EXIT SETTINGS

GATE 5 = NO

T_T' = 1000.0 sec

HSL = NO

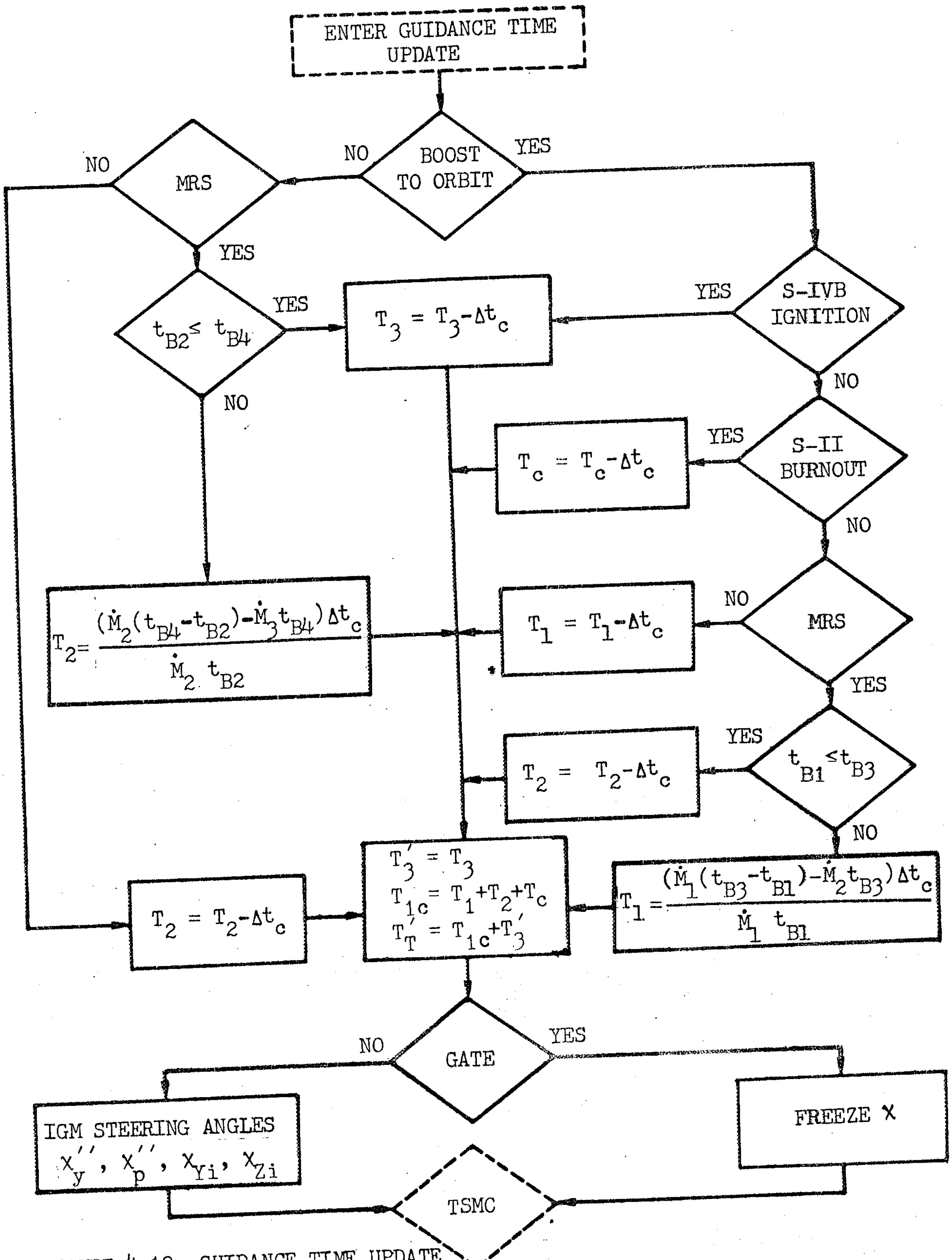

FIGURE 4-12 GUIDANCE TIME UPDATE

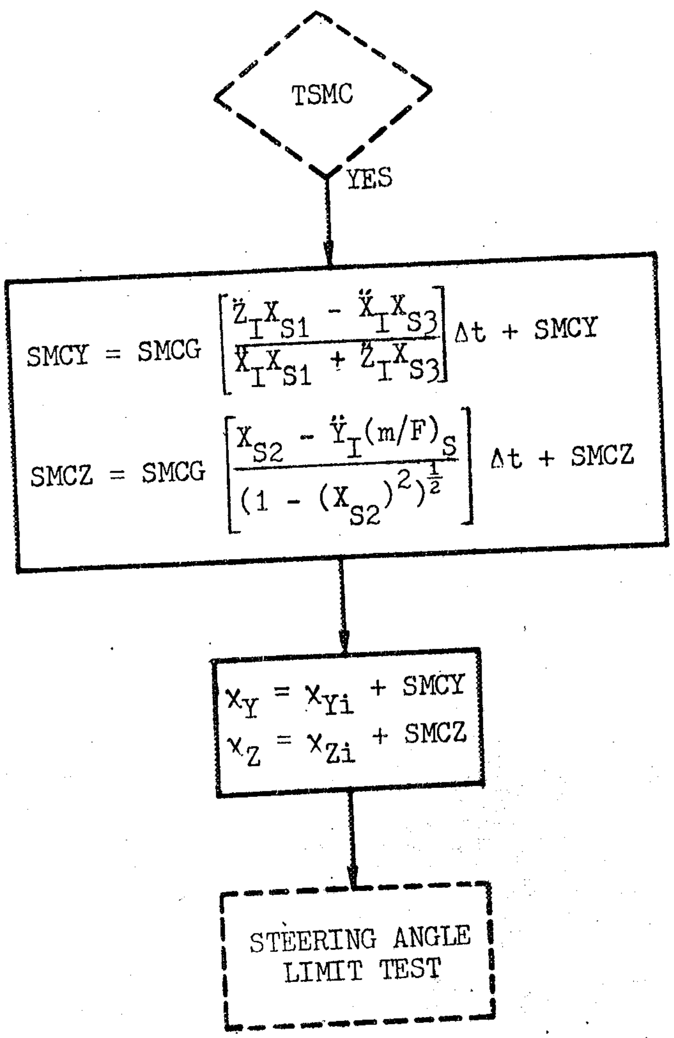

FIGURE 4-13 STEERING MISALIGNMENT CORRECTION

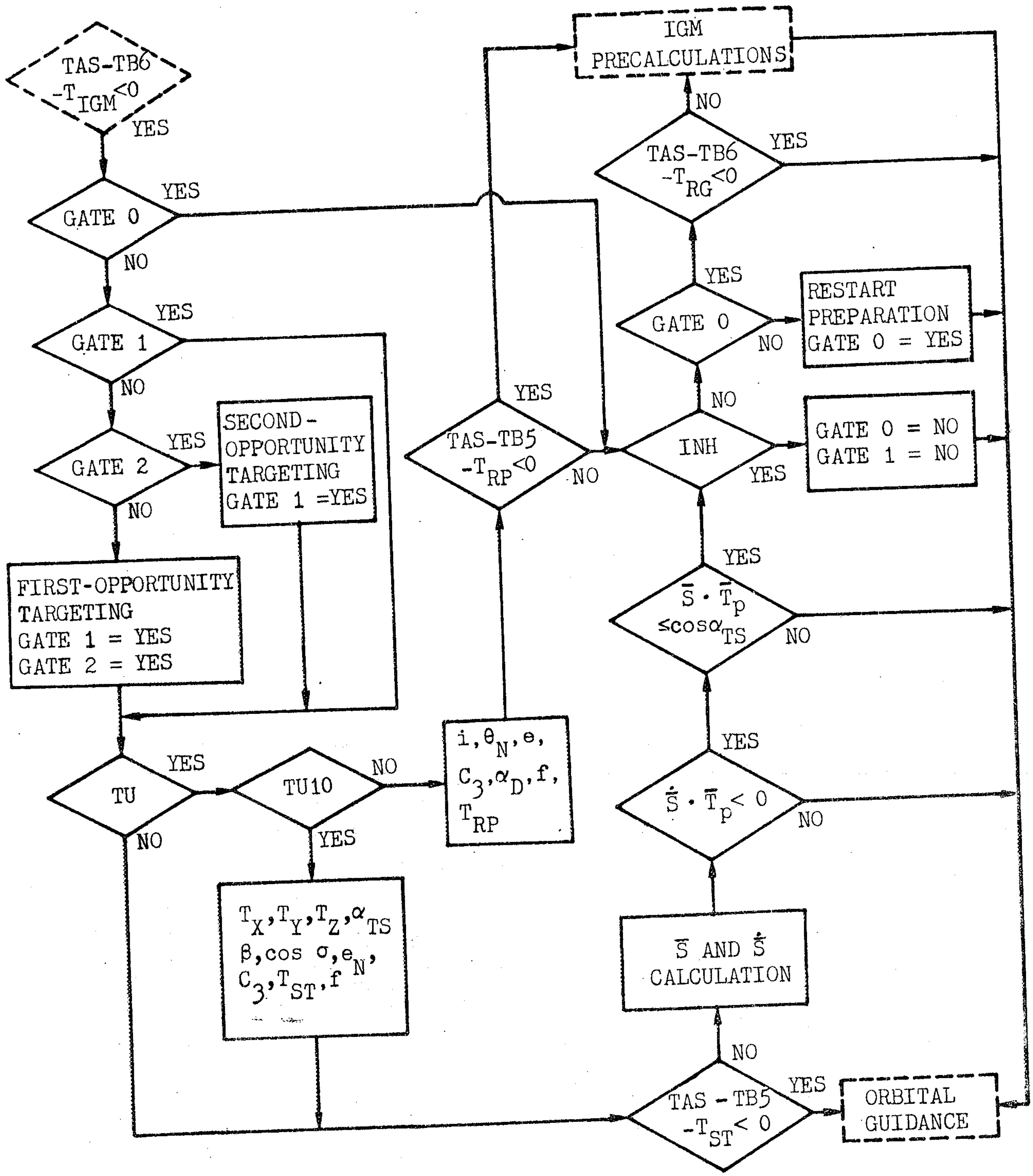

FIGURE 4-14 RESTART PREPARATION AND OPPORTUNITY LOGIC

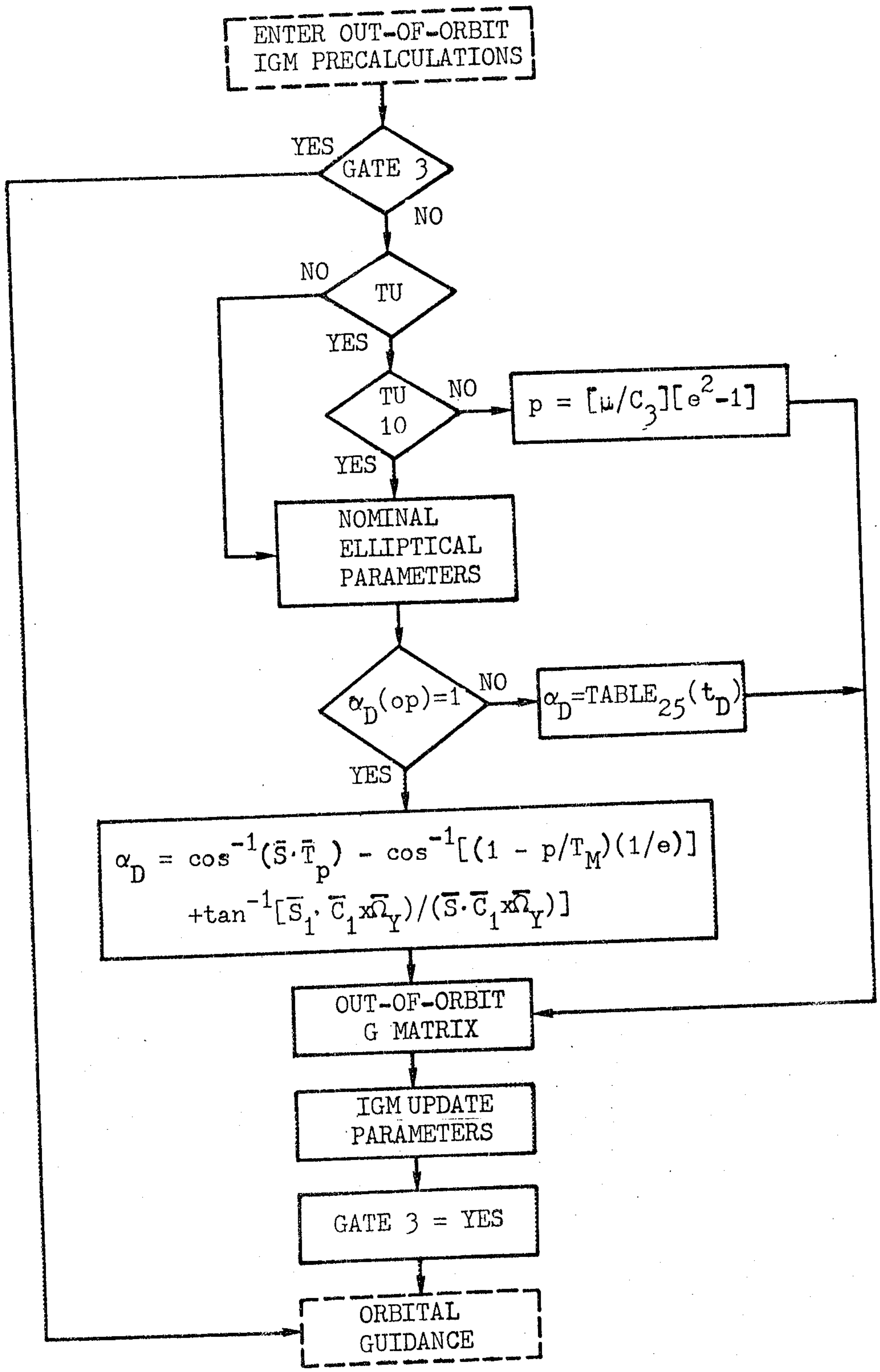

FIGURE 4-15 OUT-OF-ORBIT IGM PRECALCULATIONS

TABLE 4-VI OUT-OF-ORBIT IGM TARGETING AND PRECALCULATION EQUATIONS

OUT-OF-ORBIT TARGETING

$RAS_J = TABLE_{15}\ (t_D)$

$DEC_J = TABLE_{15}\ (t_D)$

$C_{3J} = TABLE_{15}\ (t_D)$

$\cos\sigma_J = TABLE_{15}\ (t_D)$

$e_{NJ} = TABLE_{15}\ (t_D)$

$f = TABLE_{15}\ (t_D)$

$\alpha_D = TABLE_{25}\ (t_D)$

$T_{XJ} = \cos RAS_J \cos DEC_J$

$T_{YJ} = \sin RAS_J \cos DEC_J$

$T_{ZJ} = \sin DEC_J$

Subscript J = 1 = First Opportunity

Subscript J = 2 = Second Opportunity

$\bar{S}$ AND $\dot{\bar{S}}$ CALCULATIONS

$\theta_E = \theta_{EO} + \omega_E t_D$

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

$\bar{T}_P = [EPH]\ \bar{T}$

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

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

$\bar{P} = \bar{N} \times \bar{R}'$

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

$\dot{\bar{R}}' = \bar{V}/|\bar{R}|$

$\dot{\bar{P}} = \bar{N} \times \dot{\bar{R}}'$

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

$\alpha_{TS} = \alpha^*_{TS} + K_{\alpha 1}\ \Delta T_4' + K_{\alpha 2}(\Delta T_4')^2$

TABLE 4-VI OUT-OF-ORBIT IGM TARGETING AND PRECALCULATION EQUATIONS (Continued)

NOMINAL ELLIPTICAL PARAMETERS

$\cos \Psi' = \bar{S} \cdot \bar{T}_p$

$\sin \Psi' = (1 - \cos^2 \Psi')^{\frac{1}{2}}$

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

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

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

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

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

$p_N = [\mu/C_3]\ [e_N^2 - 1]$

$T_M = p_N/(1 - e_N \cos \sigma)$

$e = [R/R_N]\ [e_N - 1] + 1$

$p = [\mu/C_3]\ [e^2 - 1]$

OUT-OF-ORBIT G MATRIX

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

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

$R_T = p/(1 + e \cos f)$

$K_5 = (\mu/p)^{\frac{1}{2}}$

$V_T = K_5(1 + 2 e \cos f + e^2)^{\frac{1}{2}}$

$\gamma_T = \tan^{-1} [(e \sin f)/(1 + \cos f)]$

$G_T = -\mu/R_T^2$

IGM UPDATE PARAMETERS

$C' = 0.0$ sec

$\dot{M}_2 = \dot{M}_{2R}$

$\dot{M}_3 = \dot{M}_{3R}$

$P_c = 0.0$ sec

$ROT = ROTR$

$ROV = ROVR$

$T_2 = T_{2R}$

$T_{1c} = T_2$

$T_3' = T_{3R}' - K_{T3}\ \Delta T_4'$

$T_T' = T_2 + T_3'$

$t_{B4} = 0.0$ sec

$Vex_2 = Vex_{2R}$

$Vex_3 = Vex_{3R}$

$\epsilon_1 = \epsilon_{1R}$

$\epsilon_2 = \epsilon_{2R}$

$\epsilon_3 = \epsilon_{3R}$

$\epsilon_4 = \epsilon_{4R}$

$\tau_3 = \tau_{3R} - \Delta T_4'$

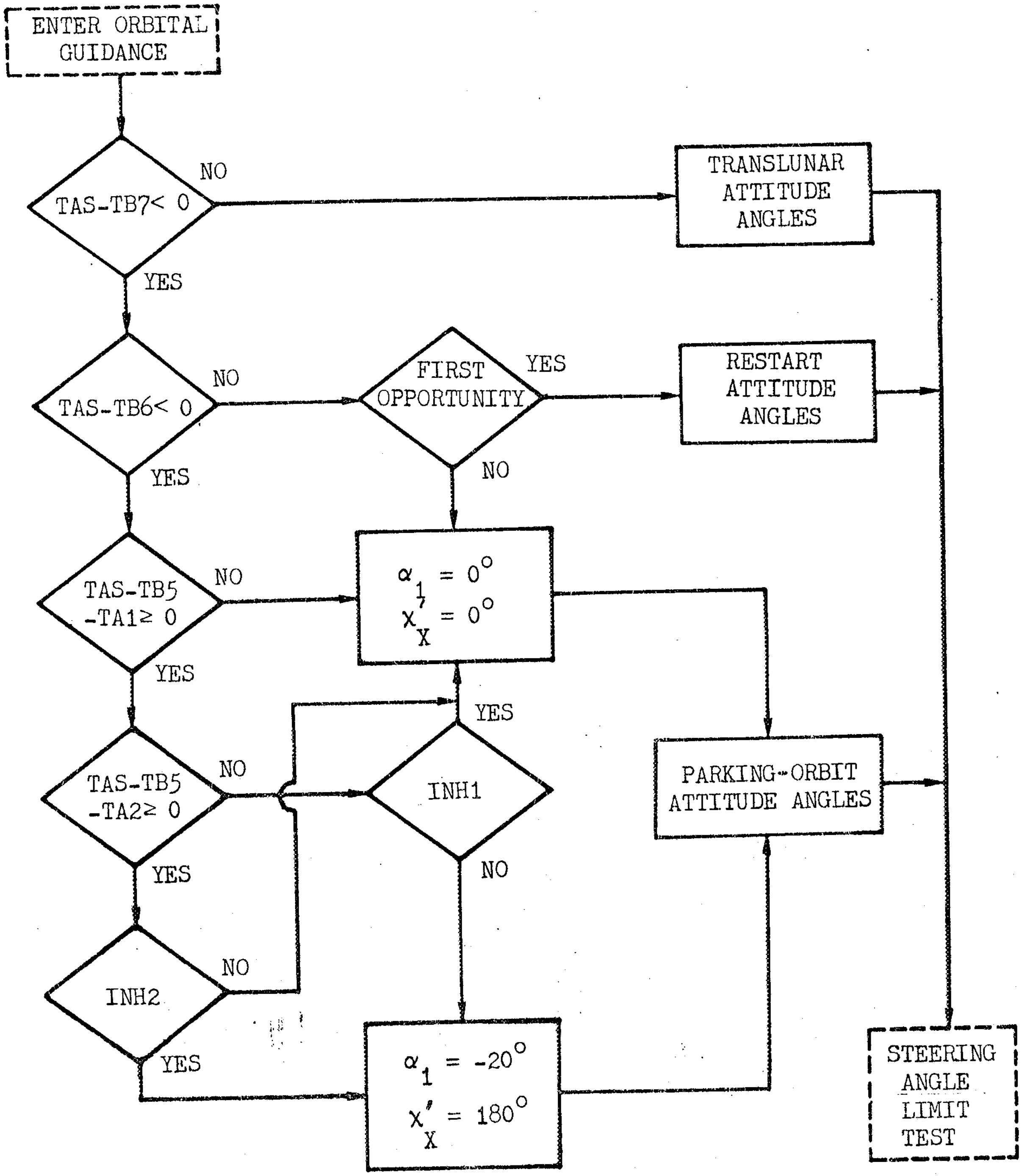

FIGURE 4-16 ORBITAL-GUIDANCE LOGIC

TABLE 4-VII ORBITAL GUIDANCE EQUATIONS

RESTART ATTITUDE ANGLES

$$\alpha_1 = K_{P1} + K_{P2}\,\Delta T_4'$$

$$\alpha_2 = K_{Y1} + K_{Y2}\,\Delta T_4'$$

PARKING-ORBIT ATTITUDE ANGLES

$$\sin \chi_{Yi}' = (X_{4i}\cos\alpha_1 + Z_{4i}\sin\alpha_1)/(-R)$$

$$\cos \chi_{Yi}' = (Z_{4i}\cos\alpha_1 - X_{4i}\sin\alpha_1)/(-R)$$

$$\sin \chi_{Zi}' = \sin\alpha_2$$

$$\cos \chi_{Zi}' = \cos\alpha_2$$

TRANSFORMATION MATRIX

$$\begin{bmatrix} X_{S1} \\ X_{S2} \\ X_{S3} \end{bmatrix} = [G]^{-1} \begin{bmatrix} \cos\chi_{Yi}' \cos\chi_{Zi}' \\ \sin\chi_{Zi}' \\ -\sin\chi_{Yi}' \cos\chi_{Zi}' \end{bmatrix}$$

$$\chi_{Xi} = \chi_{Xi}'$$

$$\chi_{Yi} = \tan^{-1}(-X_{S3}/X_{S1})$$

$$\chi_{Zi} = \sin^{-1} X_{S2}$$

TRANSLUNAR ATTITUDE ANGLES

$$\chi_{Xi} = \chi_{XC}$$

$$\chi_{Yi} = \chi_{YC}$$

$$\chi_{Zi} = \chi_{ZC}$$

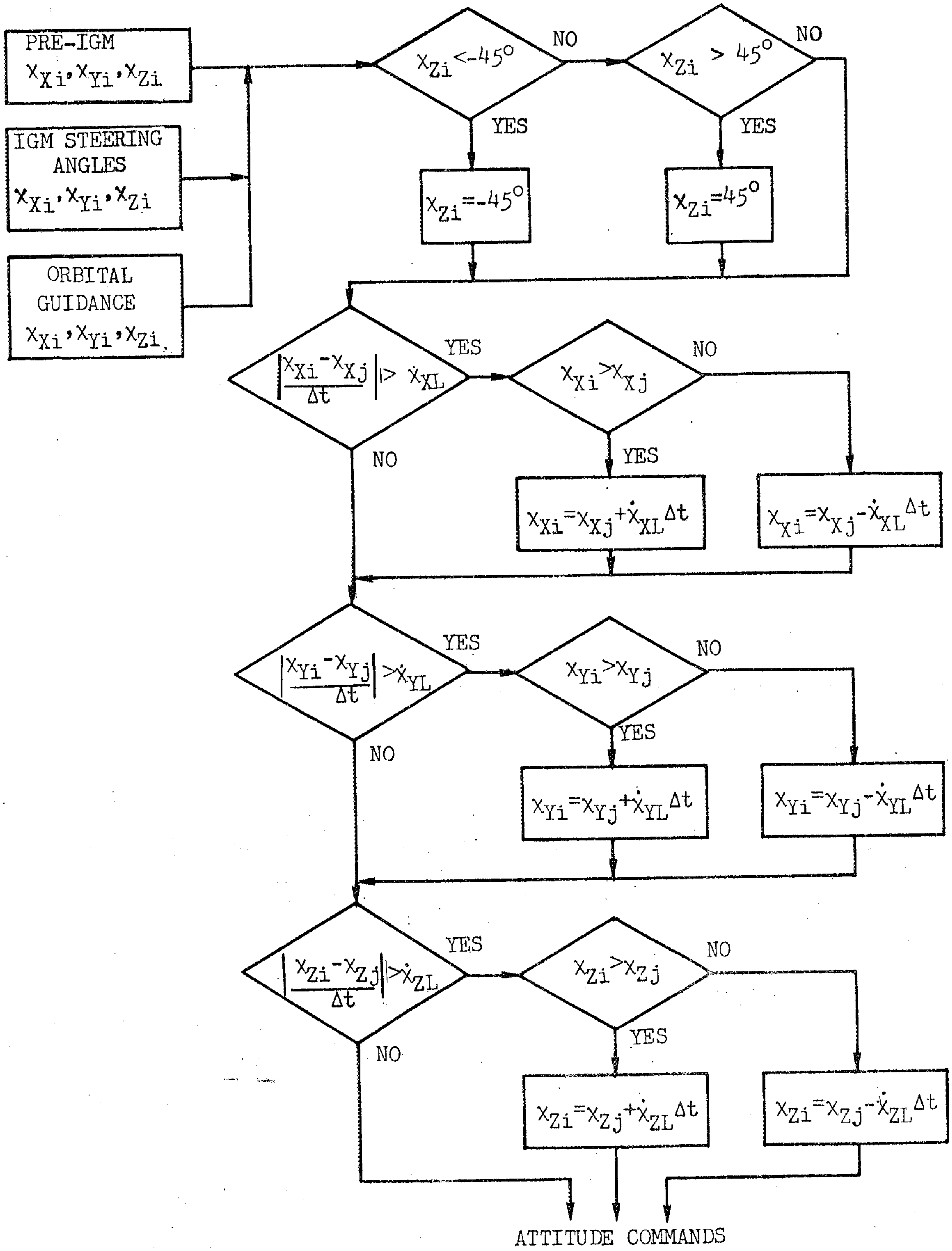

FIGURE 4-17 STEERING ANGLE LIMIT TEST

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SECTION 5

PRESETTINGS AND NOMENCLATURE

5.0 GUIDANCE PRESETTINGS

The presettings needed to implement the SA-504 guidance equations are presented in this section. The presettings presented are used to simulate the 120 trajectories of Reference 3. Presettings that have only one or two values during the simulation of these trajectories are presented in Table 5-I. All other parameters are presented in Tables 5-II through 5-XVI.

The presettings of Table 5-I are categorized according to usage. They are divided into the following categories: General, Pre-IGM, IGM Boost-to-Orbit, and IGM Out-of-Orbit.

General presettings are used in all guidance phases. In most cases, these presettings serve as logic gates to implement the various guidance modes.

Pre-IGM presettings are required to implement the logic and equations for Pre-IGM Steering. The coefficients for the χ_Y steering polynomials and freeze time calculations are presented in this section. The times used for segmenting the χ_Y steering polynomials are also in this section.

The presettings needed to implement the IGM equations and logic for the boost-to-orbit portion of flight are presented as IGM Boost-to-Orbit presettings. These include the coefficients of the inclination and nodal angle polynomials, stage performance parameters, and terminal conditions. The three-segment polynomials for azimuth provide ± 0.02-degree accuracy over the entire launch span except for launch opportunities B-3 and C-1. These curves are fit to 105.0 and 105.5 degrees, covering 99.5 and 99.7 percent of the launch-window time, respectively. Evaluation of the polynomial at 108 degrees results in errors of 0.404 and 0.299 degree, respectively.

The IGM Out-of-Orbit presettings are used to implement IGM for out-of-orbit flight. These presettings are used in stages 4 and 5 of IGM.

Presettings needed to implement the versatile ground-launch targeting or the out-of-orbit targeting are presented in Tables 5-II through 5-XVI. The presettings are presented in terms of launch windows and dates within the launch windows. The presettings for three launch windows are presented. They are: Launch Window A, Launch Window B, and Launch Window C. There are four dates within each launch window. They are: Date 1, Date 2, Date 3, and Date 4.

Alternate targeting for a variety of possible direct-ascent missions is provided in Table 5-XVII. The inclination and node polynomial coefficients, as a function of t_D, are for launch opportunity A-1. True anomaly is not required for ascent to the circular parking orbits, but values are specified to indicate scalings that are required.

TABLE 5-I GUIDANCE PRESETTINGS

GENERAL

e	= 0	TA2	= 5160.0 sec
f	= 0 deg	TB1	= 10^5
C_3	= -60.7315302 km^2/sec^2	TB2	= 10^5
DA	= NO	TB3	= 10^5
GATE	= NO	TB4	= 10^5
GATE 0	= NO	TB5	= 10^5
GATE 1	= NO	TB6	= 10^5
GATE 2	= NO	TB7	= 10^5
GATE 3	= NO	T_{LET}	= 40.671
GATE 4	= NO	TU	= NO
GATE 5	= NO	TU10	= NO
INH	= NO	UP	= 0
INH1	= NO	α_D(op)	= 1
INH2	= NO	i(op)	= 1
TA1	= 2700.0 sec	θ_N(op)	= 1

PRE-IGM GUIDANCE

B_{11}	= -0.62	F_{14}	= 0.0000113886 deg/sec^4
B_{12}	= 40.9 sec	F_{20}	= -10.9607 deg
B_{21}	= -0.3611	F_{21}	= 0.946620 deg/sec
B_{22}	= 29.25 sec	F_{22}	= -0.0294206 deg/sec^2
F_{10}	= 3.19840 deg	F_{23}	= 0.000207717 deg/sec^3
F_{11}	= -0.544236 deg/sec	F_{24}	= -0.000000439036 deg/sec^4
F_{12}	= 0.0351605 deg/sec^2	F_{30}	= 78.7826 deg
F_{13}	= -0.00116379 deg/sec^3	F_{31}	= -2.83749 deg/sec

TABLE 5-I GUIDANCE PRESETTINGS (Continued)

PRE-IGM GUIDANCE (Continued)

F_{32}	$= 0.0289710$ deg/sec^2	t_6	$= 0.0$ sec
F_{33}	$= -0.000178363$ deg/sec^3	t_{AR}	$= 153.0$ sec
F_{34}	$= 0.000000463029$ deg/sec^4	t_{S1}	$= 35.0$
F_{40}	$= 69.9191$ deg	t_{S2}	$= 80.0$
F_{41}	$= -2.007490$ deg/sec	t_{S3}	$= 115.0$ sec
F_{42}	$= 0.0105367$ deg/sec^2	T_{E01}	$= 0$
F_{43}	$= -0.0000233163$ deg/sec^3	T_{E02}	$= 0$
F_{44}	$= 0.0000000136702$ deg/sec^4	Δt	$= 1.0$ sec
t_1	$= 13.0$ sec	Δt_f	$= 0.0$ sec
t_2	$= 25.0$ sec	Δt_{LET}	$= 35.100$ sec
t_3	36.0 sec	$\dot{\chi}_{XL}$	$= 1.0$ deg/sec
t_4	$= 45.0$ sec	$\dot{\chi}_{YL}$	$= 1.0$ deg/sec
t_5	$= 81.0$ sec	$\dot{\chi}_{ZL}$	$= 1.0$ deg/sec

IGM BOOST TO ORBIT

C'	$= 0.0$ sec	f_5	$= -28.9526$
C'_o	$= 25.0$ sec	f_6	$= 9.8794$
C_f	$= 0.087996$ sec^2/m	g_0	$= 123.2094$
$\cos \phi_L$	$= 0.877916$	g_1	$= -56.5034$
f_0	$= 32.5597$	g_2	$= -21.6675$
f_1	$= -16.2615$	g_3	$= -14.5228$
f_2	$= 15.6919$	g_4	$= 47.5320$
f_3	$= -6.7370$	g_5	$= -22.5502$
f_4	$= 26.9593$	g_6	$= 1.8946$

TABLE 5-I GUIDANCE PRESETTINGS (Continued)

IGM BOOST-TO-ORBIT

MRS	= NO	t_{B3}	= 0.0 sec
$\dot{M}_1$	= 1243.77 kg/sec	Δt	= 1.7 sec
$\dot{M}_2$	= 1009.04 kg/sec	Δt_{LIM}	= 90.0 sec
$\dot{M}_3$	= 248.882 kg/sec	Vex_1	= 4,169.23 m/sec
ROT	= 0	Vex_2	= 4,204.26 m/sec
ROV	= 1.5	Vex_3	= 4,170.57 m/sec
ROV*	= 1.5	V_{S2T}	= 7,007.18 m/sec
$\sin \phi_L$	= 0.478814	V_{TC}	= 300 m/sec
SMCG	= 0.05 deg/sec	ΔV_B	= 2.0275 m/sec
TS4BS	= 13.5 sec	ϵ_1	= 0.0 sec
TSMC1	= 20.0 sec	ϵ_2	= 10.0 sec
TSMC2	= 5.0 sec	ϵ_3	= 10,000.0 sec
T_c	= 4.718 sec	ϵ_4	= 8.0 sec
T_1	= 237.796 sec	μ	= 3,986,032. x 10^8 m^3/sec^2
T_2	= 99.886 sec	τ_2	= 309.23 sec
T_{1c}	= 342.4 sec	τ_3	= 665.86 sec
T_{4N}	= 120.565 sec	τ_{3N}	= 665.86 sec
T_3'	= 120.565 sec	$\dot{\chi}_{XL}$	= 1.0 deg/sec
T_T'	= 462.965 sec	$\dot{\chi}_{YL}$	= 1.0 deg/sec
t	= 2.0 sec	$\dot{\chi}_{ZL}$	= 1.0 deg/sec
t_{B1}	= 50.0 sec		

TABLE 5-I GUIDANCE PRESETTINGS (Continued)

IGM OUT OF ORBIT

C'	=	0.0 sec	T_{SMC3}	=	466.0 sec
C'_0	=	25.0 sec	t	=	2.0 sec
K_{P1}	=	4.3 deg	t_{B2}	=	0.0
K_{P2}	=	0.0 deg/sec	t_{B4}	=	0.0 sec
K_{T3}	=	-0.274	Δt	=	1.7 sec
K_{Y1}	=	0.0 deg	Vex_{2R}	=	4,228.02 m/sec
K_{Y2}	=	0.0 deg/sec	Vex_{3R}	=	4,193.05 m/sec
K_{PC}	=	75.0 sec	V_{TC}	=	150.0 m/sec
$K_{\alpha 1}$	=	0.0 deg/sec	ΔV_{BR}	=	2.8816 m/sec
$K_{\alpha 2}$	=	0.0 deg/sec^2	ϵ_{1R}	=	500.0 sec
$\dot{M}_{2R}$	=	187.007 kg/sec	ϵ_{2R}	=	15.0 sec
$\dot{M}_{3R}$	=	218.586 kg/sec	ϵ_{3R}	=	3.59 sec
P_c	=	0.0 sec	ϵ_{4R}	=	3.59 sec
ROTR	=	1.0	τ_{2N}	=	721.0 sec
ROVR	=	0.0	τ_{3R}	=	576.0 sec
R_N	=	6,575,100 m	$\dot{\chi}_{XL}$	=	1.0 deg/sec
SMCG	=	0.1 deg/sec	$\dot{\chi}_{YL}$	=	1.0 deg/sec
T_{IGM}	=	466.0 sec	$\dot{\chi}_{ZL}$	=	1.0 deg/sec
T_{RG}	=	460.0 sec	ω_E	=	4.17753×10^{-3} deg/sec

TABLE 5-II INTO-ORBIT TARGETING FOR LAUNCH WINDOW A

	DATE 1	DATE 2	DATE 3	DATE 4
h_{10}	72.008	72.008	72.013	72.020
h_{11}	23.250	21.632	20.416	18.470
h_{12}	-5.917	-4.281	-2.531	-0.512
h_{13}	4.739	3.123	0.360	-3.532
h_{14}	-0.587	0.512	2.729	5.023
h_{20}	93.506	93.007	93.010	91.502
h_{21}	11.671	11.153	9.790	6.082
h_{22}	2.147	3.066	4.289	1.779
h_{23}	-0.515	-1.241	-2.576	-0.275
h_{24}	1.187	2.008	3.474	0.910
h_{30}	not required	not required	not required	100.003
h_{31}	not required	not required	not required	5.661
h_{32}	not required	not required	not required	1.930
h_{33}	not required	not required	not required	-0.577
h_{34}	not required	not required	not required	0.982
t_{DS1}	10,984.2	11,263.8	12,023.4	12,334.2
t_{DS2}	16,503.1	16,435.9	16,378.2	15,022.6
t_{DS3}	not required	not required	not required	16,256.2
t_{D1}	0	0	0	0
t_{D2}	10,984.2	11,263.8	12,023.4	12,334.2
t_{D3}	not required	not required	not required	15,022.6
t_{SD1}	10,984.2	11,263.8	12,023.4	12,334.2
t_{SD2}	5,518.9	5,172.1	4,354.8	2,688.4
t_{SD3}	not required	not required	not required	1,233.6

TABLE 5-III OUT-OF-ORBIT TARGETING

LAUNCH WINDOW A - DATE 1

θ_{EO} = -75.31961 T_{LO} = 56248.61

	α^*_{TS}, deg	β, deg	T_{ST}, deg
First Opportunity	15.075	49.924	7,000
Second Opportunity	14.656	49.570	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9915709	-1.3698	0.9773978	206.9182	-11.7871
1455.49	0.9915585	-1.36118	0.9774437	207.0697	-11.8459
2993.96	0.9915547	-1.35874	0.9774875	207.2378	-11.9130
4580.30	0.9915569	-1.35678	0.9775254	207.4178	-11.9869
6178.41	0.9915629	-1.35534	0.9775548	207.6052	-12.0663
7234.93	0.9915681	-1.35471	0.9775686	207.7322	-12.1216
8274.00	0.9915740	-1.35435	0.9775772	207.8599	-12.1784
9287.75	0.9915802	-1.35427	0.9775804	207.9872	-12.2363
10271.10	0.9915867	-1.35447	0.9775782	208.1133	-12.2950
11216.79	0.9915934	-1.35496	0.9775705	208.2376	-12.3541
12120.35	0.9916004	-1.35571	0.9775576	208.3594	-12.4134
13389.32	0.9916122	-1.35735	0.9775295	208.5365	-12.5018
14545.64	0.9916263	-1.35953	0.9774926	208.7057	-12.5889
15585.20	0.9916447	-1.36219	0.9774496	208.8664	-12.6737
16503.07	0.9916694	-1.36524	0.9774041	209.0183	-12.7554

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9913771	-1.36407	0.9773868	207.5467	-12.1681
1455.49	0.9913789	-1.36136	0.9774307	207.7011	-12.2216
2993.96	0.9913789	-1.35897	0.9774710	207.8688	-12.2845
4580.30	0.9913786	-1.35700	0.9775054	208.0460	-12.3550
6178.41	0.9913792	-1.35553	0.9775323	208.2294	-12.4314
7234.93	0.9913807	-1.35486	0.9775452	208.3536	-12.4848
8274.00	0.9913833	-1.35445	0.9775537	208.4785	-12.5397
9287.75	0.9913871	-1.35433	0.9775577	208.6031	-12.5957
10271.10	0.9913924	-1.35449	0.9775569	208.7269	-12.6525
11216.79	0.9913990	-1.35493	0.9775513	208.8491	-12.7098
12120.35	0.9914072	-1.35565	0.9775409	208.9693	-12.7672
13389.32	0.9914221	-1.35726	0.9775165	209.1445	-12.8532
14545.64	0.9914397	-1.35946	0.9774819	209.3124	-12.9384
15585.20	0.9914595	-1.36220	0.9774384	209.4718	-13.0223
16503.07	0.9914806	-1.36539	0.9773872	209.6218	-13.1046

TABLE 5-IV OUT-OF-ORBIT TARGETING

LAUNCH WINDOW A DATE 2

θ_{EO} = 53.77018 T_{LO} = 61170.44

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.968	49.830	8,000
Second Opportunity	14.973	50.483	13,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9919654	-1.36286	0.9774206	219.0138	-16.9498
1595.55	0.9919439	-1.35942	0.9774794	219.1748	-17.0050
3265.43	0.9919242	-1.35643	0.9775310	219.3526	-17.0676
4966.02	0.9919081	-1.35400	0.9775735	219.5409	-17.1357
6653.26	0.9918971	-1.35222	0.9776055	219.7346	-17.2075
7750.59	0.9918930	-1.35142	0.9776203	219.8646	-17.2566
8813.30	0.9918918	-1.35096	0.9776297	219.9940	-17.3063
9832.40	0.9918936	-1.35084	0.9776335	220.1217	-17.3561
10800.40	0.9918985	-1.35106	0.9776316	220.2470	-17.4058
11712.68	0.9919064	-1.35162	0.9776240	220.3694	-17.4550
12566.15	0.9919173	-1.35252	0.9776108	220.4883	-17.5036
13733.33	0.9919387	-1.35448	0.9775807	220.6595	-17.5748
14764.64	0.9919655	-1.35710	0.9775393	220.8219	-17.6436
15664.27	0.9919962	-1.36032	0.9774878	220.9760	-17.7097
16435.89	0.9920293	-1.36402	0.9774277	221.1231	-17.7731

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9917359	-1.36286	0.9774007	219.6398	-17.2862
1595.55	0.9917130	-1.35952	0.9774603	219.7973	-17.3367
3265.43	0.9916899	-1.35650	0.9775139	219.9695	-17.3952
4966.02	0.9916695	-1.35397	0.9775588	220.1517	-17.4596
6653.26	0.9916543	-1.35208	0.9775930	220.3398	-17.5280
7750.59	0.9916480	-1.35123	0.9776091	220.4667	-17.5751
8813.30	0.9916450	-1.35072	0.9776194	220.5936	-17.6228
9832.40	0.9916457	-1.35056	0.9776237	220.7198	-17.6709
10800.40	0.9916501	-1.35078	0.9776219	220.8444	-17.7190
11712.68	0.9916583	-1.35136	0.9776141	220.9668	-17.7669
12566.15	0.9916700	-1.35229	0.9776003	221.0865	-17.8144
13733.33	0.9916938	-1.35433	0.9775689	221.2597	-17.8844
14764.64	0.9917236	-1.35707	0.9775259	221.4244	-17.9528
15664.27	0.9917573	-1.36038	0.9774729	221.5800	-18.0195
16435.89	0.9917924	-1.36411	0.9774123	221.7262	-18.0847

TABLE 5-V OUT-OF-ORBIT TARGETING

LAUNCH WINDOW A - DATE 3

θ_{EO} = -31.54078 T_{LO} = 66255.02

	σ^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.861	50.483	7,000
Second Opportunity	14.495	50.178	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9924603	-1.38363	0.9770801	231.7070	-21.4602
1786.39	0.9924544	-1.38191	0.9771089	231.9082	-21.5192
3644.28	0.9924467	-1.38045	0.9771349	232.1303	-21.5858
5516.35	0.9924394	-1.37930	0.9771564	232.3621	-21.6560
7340.97	0.9924345	-1.37854	0.9771723	232.5941	-21.7264
8503.35	0.9924332	-1.37826	0.9771791	232.7450	-21.7722
9604.99	0.9924338	-1.37818	0.9771827	232.8910	-21.8162
10634.20	0.9924366	-1.37829	0.9771829	233.0304	-21.8581
11581.30	0.9924416	-1.37862	0.9771796	233.1624	-21.8975
12444.30	0.9924489	-1.37914	0.9771727	233.2862	-21.9342
13223.20	0.9924582	-1.37988	0.9771622	233.4015	-21.9683
14241.02	0.9924758	-1.38136	0.9771399	233.5590	-22.0148
15092.36	0.9924967	-1.38326	0.9771101	233.6996	-22.0565
15799.01	0.9925193	-1.38556	0.9770735	233.8270	-22.0954
16378.15	0.9925417	-1.38819	0.9770313	233.9468	-22.1337

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS,deg	DEC, deg
0.00	0.9922073	-1.38530	0.9770331	232.3499	-21.7486
1786.39	0.9921961	-1.38347	0.9770658	232.5530	-21.8043
3644.28	0.9921823	-1.38188	0.9770953	232.7713	-21.8666
5516.35	0.9921692	-1.38061	0.9771196	232.9959	-21.9321
7340.97	0.9921593	-1.37974	0.9771375	233.2195	-21.9980
8503.35	0.9921555	-1.37942	0.9771453	233.3651	-22.0411
9604.99	0.9921545	-1.37930	0.9771495	233.5060	-22.0828
10634.20	0.9921564	-1.37940	0.9771500	233.6412	-22.1227
11581.30	0.9921614	-1.37973	0.9771466	233.7699	-22.1607
12444.30	0.9921695	-1.38028	0.9771394	233.8914	-22.1964
13223.20	0.9921805	-1.38106	0.9771284	234.0054	-22.2300
14241.02	0.9922108	-1.38261	0.9771050	234.1623	-22.2762
15092.36	0.9922275	-1.38460	0.9770739	234.3033	-22.3184
15799.01	0.9922551	-1.38697	0.9770362	234.4308	-22.3578
16378.15	0.9922819	-1.38964	0.9769934	234.5487	-22.3962

TABLE 5-VI OUT-OF-ORBIT TARGETING

LAUNCH WINDOW A - DATE 4

θ_{EO} = -9.91577 T_{LO} = 71194.95

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.781	50.534	7,000
Second Opportunity	14.426	50.325	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9926313	-1.40018	0.9768045	244.7021	-24.8657
2000.20	0.9925918	-1.39760	0.9768496	244.9309	-24.9202
4080.63	0.9925364	-1.39465	0.9769014	245.1675	-24.9765
6170.35	0.9924790	-1.39188	0.9769509	245.4048	-25.0325
8182.71	0.9924305	-1.38966	0.9769913	245.6368	-25.0861
9439.06	0.9924071	-1.38865	0.9770105	245.7861	-25.1198
10598.69	0.9923928	-1.38809	0.9770222	245.9299	-25.1515
11643.26	0.9923389	-1.38800	0.9770259	246.0673	-25.1808
12548.75	0.9923946	-1.38840	0.9770212	246.1977	-25.2077
13329.29	0.9924109	-1.38929	0.9770084	246.3207	-25.2320
13992.91	0.9924366	-1.39063	0.9769878	246.4361	-25.2537
14798.30	0.9924892	-1.39338	0.9769443	246.5955	-25.2817
15416.83	0.9925520	-1.39674	0.9768902	246.7396	-25.3049
15893.09	0.9926147	-1.40035	0.9768318	246.8710	-25.3241
16256.18	0.9926637	-1.40369	0.9767776	246.9935	-25.3410

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9923201	-1.40113	0.9767808	245.3685	-25.0890
2000.20	0.9922716	-1.39847	0.9768231	245.5742	-25.1342
4080.63	0.9922053	-1.39536	0.9768756	245.7914	-25.1832
6170.35	0.9921374	-1.39238	0.9769275	246.0137	-25.2334
8182.71	0.9920802	-1.39000	0.9769707	246.2354	-25.2825
9439.06	0.9920527	-1.38891	0.9769914	246.3804	-25.3140
10598.69	0.9920358	-1.38829	0.9770043	246.5219	-25.3438
11643.26	0.9920306	-1.38819	0.9770084	246.6588	-25.3718
12548.75	0.9920375	-1.38862	0.9770036	246.7902	-25.3978
13329.29	0.9920561	-1.38957	0.9769899	246.9155	-25.4216
13992.91	0.9920856	-1.39099	0.9769679	247.0341	-25.4432
14798.30	0.9921460	-1.39389	0.9769217	247.1987	-25.4719
15416.83	0.9922178	-1.39741	0.9768649	247.3470	-25.4966
15893.09	0.9922889	-1.40110	0.9768050	247.4795	-25.5185
16256.18	0.9923434	-1.40439	0.9767521	247.5973	-25.5392

TABLE 5-VII INTO-ORBIT TARGETING FOR LAUNCH WINDOW B

	DATE 1	DATE 2	DATE 3	DATE 4
h_{10}	72.011	72.003	72.015	72.017
h_{11}	20.893	14.213	16.326	19.319
h_{12}	-3.327	-2.104	-1.264	-0.707
h_{13}	1.810	0.663	-2.807	-2.255
h_{14}	1.604	0.723	3.206	4.605
h_{20}	93.009	85.521	87.507	93.012
h_{21}	10.380	6.841	3.396	9.258
h_{22}	3.720	6.687	4.475	5.000
h_{23}	-1.869	-10.277	-7.131	-3.469
h_{24}	2.750	9.197	6.235	4.182
h_{30}	not required	98.010	94.509	not required
h_{31}	not required	5.140	4.388	not required
h_{32}	not required	5.506	5.276	not required
h_{33}	not required	-5.198	4.955	not required
h_{34}	not required	4.526	5.764	not required
t_{DS1}	11,702.3	9,993.6	12,424.8	11,864.8
t_{DS2}	16,402.6	15,103.2	14,934.6	15,630.3
t_{DS3}	not required	16,150.4	15,650.3	not required
t_{D1}	0	0	0	0
t_{D2}	11,702.3	9,993.6	12,424.8	11,864.8
t_{D3}	not required	15,103.2	14,934.6	19,630.3
t_{SD1}	11,702.3	9,993.6	12,424.8	11,864.8
t_{SD2}	4,700.3	5,109.6	2,509.8	3,765.5
t_{SD3}	not required	1,047.2	715.7	not required

TABLE 5-VIII OUT-OF-ORBIT TARGETING

LAUNCH WINDOW B - DATE 1

θ_{EO} =-40.31094 T_{LO} = 57786.38

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.905	50.326	7,000
Second Opportunity	14.518	50.010	12,000

First Opportunity

t_D, sec	cos σ	C_3,Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9922011	-1.36916	0.9773160	226.3905	-19.9115
1707.40	0.9921951	-1.36615	0.9773691	226.5741	-19.9694
3486.30	0.9921588	-1.36336	0.9774183	226.7698	-20.0329
5285.38	0.9921377	-1.36098	0.9774603	226.9729	-20.1000
7050.38	0.9921214	-1.35919	0.9774926	227.1789	-20.1687
8184.33	0.9921143	-1.35837	0.9775079	227.3160	-20.2147
9268.95	0.9921108	-1.35788	0.9775176	227.4516	-20.2604
10293.83	0.9921112	-1.35775	0.9775216	227.5850	-20.3054
11250.61	0.9921130	-1.35796	0.9775198	227.7152	-20.3495
12135.73	0.9921240	-1.35852	0.9775122	227.8415	-20.3924
12947.66	0.9921360	-1.35941	0.9774991	227.9634	-20.4341
14030.68	0.9921599	-1.36133	0.9774697	228.1366	-20.4938
14958.24	0.9921887	-1.36384	0.9774303	228.2972	-20.5501
15745.12	0.9922195	-1.36678	0.9773833	228.4443	-20.6033
16402.64	0.9922480	-1.36996	0.9773317	228.5775	-20.6534

Second Opportunity

t_D, sec	cos σ	C_3,Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9920231	-1.36916	0.9772970	227.0560	-20.2042
1707.40	0.9919924	-1.36591	0.9773549	227.2285	-20.2566
3486.30	0.9919610	-1.36296	0.9774075	227.4166	-20.3163
5285.38	0.9919331	-1.36050	0.9774518	227.6141	-20.3806
7050.38	0.9919116	-1.35866	0.9774858	227.8156	-20.4470
8184.33	0.9919020	-1.35781	0.9775019	227.9499	-20.4916
9268.95	0.9918967	-1.35731	0.9775124	228.0818	-20.5358
10293.83	0.9918961	-1.35716	0.9775170	228.2133	-20.5794
11250.61	0.9919002	-1.35735	0.9775157	228.3406	-20.6219
12135.73	0.9919090	-1.35790	0.9775084	228.4640	-20.6632
12947.66	0.9919224	-1.35880	0.9774953	228.5829	-20.7031
14030.68	0.9919499	-1.36075	0.9774655	228.7525	-20.7603
14958.24	0.9919847	-1.36334	0.9774245	228.9109	-20.8144
15745.12	0.9920239	-1.36646	0.9773744	229.0587	-20.8661
16402.64	0.9920639	-1.36996	0.9773177	229.1968	-20.9163

TABLE 5-IX OUT-OF-ORBIT TARGETING

LAUNCH WINDOW B - DATE 2

$\theta_{EO} = 3.20391$ $T_{LO} = 67729.61$

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.710	50.689	7,000
Second Opportunity	14.412	50.303	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9925677	-1.39817	0.9768442	252.7111	-26.5842
2170.24	0.9925156	-1.39595	0.9768804	252.9443	-26.6311
4447.30	0.9924329	-1.39286	0.9769334	253.1880	-26.6810
6753.89	0.9923439	-1.38968	0.9769890	253.4338	-26.7303
8960.75	0.9922675	-1.38706	0.9770363	253.6744	-26.7762
10322.80	0.9922306	-1.38584	0.9770591	253.8291	-26.8038
11546.77	0.9922081	-1.38516	0.9770729	253.9776	-26.8284
12597.86	0.9922016	-1.38506	0.9770769	254.1188	-26.8499
13461.79	0.9922117	-1.38557	0.9770706	254.2519	-26.8680
14148.37	0.9922378	-1.38667	0.9770543	254.3764	-26.8828
14684.76	0.9922784	-1.38830	0.9770288	254.4920	-26.8943
15277.49	0.9923602	-1.39154	0.9769767	254.6488	-26.9062
15673.39	0.9924547	-1.39534	0.9769150	254.7869	-26.9132
15953.60	0.9925429	-1.39908	0.9768541	254.9089	-26.9176
16150.41	0.9926006	-1.40195	0.9768079	255.0188	-26.9225

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec	e_N	RAS, deg	DEC, deg
0.00	0.9922819	-1.39913	0.9768120	253.3693	-26.7461
2170.24	0.9922150	-1.39636	0.9768580	253.5907	-26.7861
4447.30	0.9921168	-1.39297	0.9769163	253.8244	-26.8293
6753.89	0.9920138	-1,38968	0.9769742	254.0624	-26.8727
8960.75	0.9919265	-1.38704	0.9770222	254.2979	-26.9139
10322.80	0.9918844	-1.38583	0.9770450	254.4506	-26.9391
11546.77	0.9918588	-1.38515	0.9770588	254.5983	-26.9621
12597.86	0.9918513	-1.38506	0.9770628	254.7397	-26.9827
13461.79	0.9918625	-1.38557	0.9770566	254.8739	-27.0005
14148.37	0.9918918	-1.38666	0.9770404	255.0002	-27.0157
14684.76	0.9919375	-1.38828	0.9770151	255.1180	-27.0283
15277.49	0.9920297	-1.39154	0.9769629	255.2784	-27.0428
15673.39	0.9921370	-1.39542	0.9769000	255.4194	-27.0533
15953.60	0.9922385	-1.39936	0.9768356	255.5420	-27.0616
16150.41	0.9923077	-1.40267	0.9767821	255.6485	-27.0703

TABLE 5-X OUT-OF-ORBIT TARGETING

LAUNCH WINDOW B - DATE 3

θ_{E0} = 36.09563 T_{LO} = 75130.25

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.396	51.060	7,000
Second Opportunity	14.396	50.354	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9927184	-1.45844	0.9758402	280.4721	-28.1552
2310.74	0.9926811	-1.45799	0.9758509	280.7232	-28.1556
4769.50	0.9925713	-1.45672	0.9758764	281.0085	-28.1519
7309.32	0.9924377	-1.45523	0.9759059	281.3033	-28.1450
9823.82	0.9923185	-1.45398	0.9759315	281.5879	-28.1357
11385.63	0.9922607	-1.45345	0.9759433	281.7646	-28.1284
12735.34	0.9922265	-1.45323	0.9759497	281.9271	-28.1204
13758.24	0.9922190	-1.45337	0.9759498	282.0734	-28.1119
14434.04	0.9922256	-1.45386	0.9759436	282.2023	-28.1030
14855.94	0.9922848	-1.45470	0.9759313	282.3139	-28.0937
15126.71	0.9923531	-1.45584	0.9759137	282.4089	-28.0840
15383.08	0.9924842	-1.45795	0.9758800	282.5250	-28.0689
15542.42	0.9926230	-1.46020	0.9758435	282.6190	-28.0530
15650.34	0.9927294	-1.46212	0.9758125	282.7067	-28.0362
15722.96	0.9927523	-1.46308	0.9757979	282.8088	-28.0180

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9924070	-1.45994	0.9757989	281.1452	-28.1527
2310.74	0.9923563	-1.45935	0.9758122	281.3872	-28.1485
4769.50	0.9922368	-1.45808	0.9758381	281.6672	-28.1367
7309.32	0.9920968	-1.45664	0.9758670	281.9594	-28.1208
9823.82	0.9919738	-1.45547	0.9758916	282.2430	-28.1035
11385.63	0.9919146	-1.45498	0.9759029	282.4196	-28.0921
12735.34	0.9918800	-1.45479	0.9759089	282.5823	-28.0814
13758.24	0.9918728	-1.45493	0.9759089	282.7288	-28.0717
14434.04	0.9918939	-1.45543	0.9759029	282.8582	-28.0630
14855.94	0.9919417	-1.45624	0.9758910	282.9702	-28.0555
15126.71	0.9920127	-1.45735	0.9758740	283.0661	-28.0489
15383.08	0.9921495	-1.45941	0.9758414	283.1841	-28.0401
15542.42	0.9922964	-1.46164	0.9758053	283.2818	-28.0313
15650.34	0.9924136	-1.46361	0.9757734	283.3759	-28.0202
15722.96	0.9924506	-1.46476	0.9757556	283.4884	-28.0039

TABLE 5-XI OUT-OF-ORBIT TARGETING

LAUNCH WINDOW B - DATE 4

θ_{EO} = 50.22282 T_{LO} = 78039.70

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.456	50.968	7,000
Second Opportunity	14.387	50.100	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9923308	-1.49086	0.9753017	307.2121	-24.1901
1840.05	0.9922503	-1.48813	0.9753495	307.3988	-24.1492
3734.65	0.9921667	-1.48544	0.9753972	307.5964	-24.1038
5620.66	0.9920919	-1.48314	0.9754389	307.8013	-24.0552
7430.39	0.9920346	-1.48149	0.9754699	308.0100	-24.0042
8563.39	0.9920094	-1.48085	0.9754829	308.1497	-23.9694
9619.37	0.9919959	-1.48062	0.9754891	308.2889	-23.9342
10587.60	0.9919949	-1.48082	0.9754881	308.4266	-23.8989
11462.50	0.9920063	-1.48144	0.9754798	308.5621	-23.8636
12244.17	0.9920296	-1.48248	0.9754646	308.6947	-23.8287
12936.79	0.9920639	-1.48390	0.9754427	308.8237	-23.7942
13824.32	0.9921322	-1.48664	0.9753995	309.0089	-23.7437
14552.90	0.9922137	-1.48991	0.9753472	309.1825	-23.6951
15148.98	0.9922981	-1.49340	0.9752910	309.3426	-23.6489
15630.30	0.9923723	-1.49671	0.9752374	309.4878	-23.6053

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9920572	-1.49228	0.9752607	307.8940	-24.0344
1840.05	0.9919718	-1.48954	0.9753088	308.0773	-23.9893
3734.65	0.9918861	-1.48693	0.9753557	308.2737	-23.9395
5620.66	0.9918108	-1.48476	0.9753957	308.4790	-23.8866
7430.39	0.9917545	-1.48325	0.9754247	308.6890	-23.8319
8563.39	0.9917305	-1.48270	0.9754364	308.8298	-23.7951
9619.37	0.9917184	-1.48256	0.9754414	308.9701	-23.7584
10587.60	0.9917189	-1.48282	0.9754395	309.1089	-23.7220
11462.50	0.9917320	-1.48348	0.9754306	309.2454	-23.6862
12244.17	0.9917570	-1.48454	0.9754150	309.3788	-23.6511
12936.79	0.9917930	-1.48596	0.9753932	309.5083	-23.6171
13824.32	0.9918638	-1.48864	0.9753508	309.6941	-23.5680
14552.90	0.9919479	-1.49180	0.9753003	309.8679	-23.5217
15148.98	0.9920350	-1.49512	0.9752467	310.0284	-23.4781
15630.30	0.9921123	-1.49824	0.9751966	310.1742	-23.4373

TABLE 5-XII INTO-ORBIT TARGETING FOR LAUNCH WINDOW C

	DATE 1	DATE 2	DATE 3	DATE 41
h_{10}	72.016	72.017	72.006	72.006
h_{11}	16.913	16.258	18.230	21.416
h_{12}	-1.444	-0.125	-2.261	-4.754
h_{13}	-3.041	-4.212	1.390	3.868
h_{14}	3.529	4.538	1.129	-0.540
h_{20}	88.008	22.508	90.515	92.006
h_{21}	3.313	5.310	11.317	12.963
h_{22}	4.696	3.951	5.411	2.347
h_{23}	-7.503	-4.142	-4.064	-0.742
h_{24}	6.469	4.861	4.802	1.423
h_{30}	95.006	98.509	not required	not required
h_{31}	4.394	5.438	not required	not required
h_{32}	4.579	4.549	not required	not required
h_{33}	-4.198	-4.396	not required	not required
h_{34}	5.700	3.883	not required	not required
t_{DS1}	12,849.2	11,864.2	10,284.8	9,760.1
t_{DS2}	15,281.7	14,825.7	15,635.6	15,712.6
t_{DS3}	15,949.7	15,655.7	not required	not required
t_{D1}	0	0	0	0
t_{D2}	12,849.2	11,864.2	10,284.8	9,760.1
t_{D3}	2,432.5	2,961.5	5,350.8	5,952.5
t_{SD1}	12,849.2	11,864.2	10,284.8	9,760.1
t_{SD2}	2,432.5	2,961.5	5,350.8	5,952.5
t_{SD3}	668.1	830.1	not required	not required

TABLE 5-XIII OUT-OF-ORBIT TARGETING

LAUNCH WINDOW C - DATE 1

θ_{EO} = 15.91528 T_{LO} = 64166.54

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.592	50.820	7,000
Second Opportunity	14.407	50.247	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9925234	-1.39943	0.9768174	261.3438	-27.7742
2307.07	0.9924984	-1.39855	0.9768350	261.5946	-27.8075
4770.14	0.9924011	-1.39616	0.9768789	261.8749	-27.8479
7324.21	0.9922784	-1.39328	0.9769311	262.1630	-27.8893
9860.67	0.9921664	-1.39075	0.9769776	262.4416	-27.9270
11451.68	0.9921109	-1.38954	0.9770004	262.6156	-27.9483
12849.21	0.9920769	-1.38886	0.9770143	262.7768	-27.9657
13934.74	0.9920675	-1.38877	0.9770180	262.9233	-27.9788
14666.18	0.9920835	-1.38930	0.9770112	263.8540	-27.9875
15122.29	0.9921238	-1.39042	0.9769942	263.1688	-27.9918
15409.87	0.9921854	-1.39207	0.9769683	263.2682	-27.9928
15675.04	0.9923053	-1.39524	0.9769171	263.3921	-27.9870
15831.44	0.9924340	-1.39873	0.9768603	263.4937	-27.9778
15935.87	0.9925348	-1.40170	0.9768118	263.5861	-27.9694
16006.59	0.9925602	-1.40312	0.9767897	263.6865	-27.9677

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9922655	-1.40056	0.9767828	262.0384	-27.8807
2307.07	0.9922268	-1.39952	0.9768033	262.2772	-27.9119
4770.14	0.9921038	-1.39686	0.9768520	262.5415	-27.9456
7324.21	0.9919521	-1.39369	0.9769095	262.8137	-27.9786
9860.67	0.9918149	-1.39091	0.9769605	263.0793	-28.0084
11451.68	0.9917471	-1.38959	0.9769855	263.2471	-28.0254
12849.21	0.9917057	-1.38884	0.9770006	263.4046	-28.0399
13934.74	0.9916942	-1.38874	0.9770047	263.5500	-28.0515
14666.18	0.9917137	-1.38932	0.9769973	263.6822	-28.0601
15122.29	0.9917628	-1.39053	0.9769788	263.8009	-28.0659
15409.87	0.9918377	-1.39231	0.9769506	263.9062	-28.0691
15675.04	0.9919839	-1.39575	0.9768950	264.0414	-28.0696
15831.44	0.9921417	-1.39953	0.9768333	264.1547	-28.0668
15935.87	0.9922670	-1.40274	0.9767809	264.2554	-28.0631
16006.59	0.9923032	-1.40424	0.9767572	264.3562	-28.0617

TABLE 5-XIV OUT-OF-ORBIT TARGETING

LAUNCH WINDOW C - DATE 2

θ_{EO} = 41.91052 T_{LO} = 69916.55

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.465	50.873	7,000
Second Opportunity	14.402	50.093	12,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9922652	-1.42938	0.9763272	288.4879	-27.5809
2190.38	0.9921723	-1.42648	0.9763753	288.6943	-27.5687
4483.58	0.9920127	-1.42122	0.9764645	288.8911	-27.5550
6803.59	0.9918386	-1.41544	0.9765636	289.0852	-27.5391
9037.28	0.9916904	-1.41055	0.9766486	289.2817	-27.5206
10399.01	0.9916205	-1.40830	0.9766887	289.4154	-27.5068
11596.00	0.9915804	-1.40708	0.9767114	289.5517	-27.4917
12588.13	0.9915733	-1.40701	0.9767149	289.6905	-27.4755
13366.87	0.9915998	-1.40812	0.9766987	289.8312	-27.4582
13959.53	0.9916583	-1.41035	0.9766635	289.9729	-27.4399
14408.03	0.9917449	-1.41356	0.9766116	290.1141	-27.4209
14894.97	0.9919128	-1.41973	0.9765111	290.3209	-27.3914
15235.38	0.9920975	-1.42652	0.9763997	290.5145	-27.3615
15481.95	0.9922558	-1.43242	0.9763029	290.6849	-27.3325
15655.74	0.9923321	-1.43553	0.9762529	290.8197	-27.3057

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9919706	-1.43098	0.9762785	289.1749	-27.5290
2190.38	0.9918633	-1.42831	0.9763262	289.3741	-27.5123
4483.58	0.9916940	-1.42317	0.9764157	289.5648	-27.4926
6803.59	0.9915138	-1.41744	0.9765152	289.7540	-27.4704
9037.28	0.9913624	-1.41256	0.9766006	289.9468	-27.4466
10399.01	0.9912915	-1.41030	0.9766409	290.0788	-27.4301
11596.00	0.9912512	-1.40908	0.9766637	290.2139	-27.4132
12588.13	0.9912446	-1.40901	0.9766672	290.3521	-27.3961
13366.87	0.9912723	-1.41012	0.9766509	290.4927	-27.3788
13959.53	0.9913327	-1.41236	0.9766156	290.6349	-27.3616
14408.03	0.9914219	-1.41558	0.9765638	290.7770	-27.3443
14894.97	0.9915950	-1.42173	0.9764635	290.9861	-27.3187
15235.38	0.9917872	-1.42846	0.9763533	291.1829	-27.2933
15481.95	0.9919558	-1.43423	0.9762589	291.3572	-27.2684
15655.74	0.9920463	-1.43706	0.9762131	291.4964	-27.2437

TABLE 5-XV OUT-OF-ORBIT TARGETING

LAUNCH WINDOW C - DATE 3

$\theta_{EO} = 52.78235$ $T_{LO} = 72046.84$

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.405	51.034	7,000
Second Opportunity	14.386	50.312	13,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9925960	-1.50289	0.9750998	315.0633	-22.0911
1718.62	0.9925625	-1.50231	0.9751128	315.2675	-22.0314
3489.41	0.9925270	-1.50176	0.9751254	315.4798	-21.9683
5259.06	0.9924949	-1.50134	0.9751359	315.6950	-21.9032
6972.86	0.9924702	-1.50112	0.9751431	315.9088	-21.8377
8060.82	0.9924594	-1.50111	0.9751456	316.0486	-21.7943
9091.12	0.9924537	-1.50123	0.9751458	316.1851	-21.7516
10055.02	0.9924636	-1.50148	0.9751438	316.3176	-21.7097
10946.64	0.9924590	-1.50187	0.9751394	316.4453	-21.6690
11764.37	0.9924699	-1.50239	0.9751326	316.5678	-21.6295
12508.93	0.9924772	-1.50305	0.9751235	316.6845	-21.5914
13495.00	0.9925175	-1.50427	0.9751056	316.8483	-21.5372
14335.05	0.9925557	-1.50572	0.9750836	316.9983	-21.4866
15044.90	0.9925962	-1.50735	0.9750583	317.1349	-21.4396
15635.58	0.9926332	-1.50906	0.9750311	317.2590	-21.3958

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9923888	-1.50524	0.9750449	315.7522	-21.8881
1718.62	0.9923456	-1.50445	0.9750601	315.9482	-21.8274
3489.41	0.9923023	-1.50383	0.9750744	316.1542	-21.7625
5259.06	0.9922647	-1.50334	0.9750860	316.3649	-21.6955
6972.86	0.9922366	-1.50308	0.9750938	316.5757	-21.6281
8060.82	0.9922248	-1.50307	0.9750964	316.7143	-21.5837
9091.12	0.9922192	-1.50320	0.9750966	316.8502	-21.5400
10055.02	0.9922200	-1.50348	0.9750944	316.9824	-21.4975
10946.64	0.9922272	-1.50390	0.9750897	317.1103	-21.4564
11764.37	0.9922406	-1.50446	0.9750824	317.2332	-21.4169
12508.93	0.9922597	-1.50515	0.9750728	317.3505	-21.3791
13495.00	0.9922971	-1.50641	0.9750541	317.5155	-21.3257
14335.05	0.9923417	-1.50788	0.9750313	317.6665	-21.2768
15044.90	0.9923886	-1.50946	0.9750055	317.8035	-21.2318
15635.58	0.9924312	-1.51106	0.9749783	317.9270	-21.1903

TABLE 5-XVI OUT-OF-ORBIT TARGETING

LAUNCH WINDOW C - DATE 4

θ_{EO} = 57.83502 T_{LO} = 72784.35

	α^*_{TS}, deg	β, deg	T_{ST}, sec
First Opportunity	14.518	50.619	8,000
Second Opportunity	14.380	49.944	13,000

First Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9919090	-1.52703	0.9746979	339.1440	-12.6009
1402.86	0.9918622	-1.52406	0.9747500	339.2829	-12.5364
2876.26	0.9918239	-1.52180	0.9747899	339.4402	-12.4632
4386.88	0.9917948	-1.52025	0.9748180	339.6118	-12.3831
5900.87	0.9917757	-1.51940	0.9748345	339.7936	-12.2978
6898.89	0.9917686	-1.51923	0.9748391	339.9187	-12.2389
7879.03	0.9917660	-1.51935	0.9748387	340.0459	-12.1788
8834.84	0.9917679	-1.51977	0.9748334	340.1743	-12.1180
9760.14	0.9917743	-1.52048	0.9748232	340.3031	-12.0568
10651.37	0.9917849	-1.52148	0.9748083	340.4316	-11.9955
11505.08	0.9917995	-1.52276	0.9747888	340.5591	-11.9345
12709.61	0.9918284	-1.52518	0.9747510	340.7475	-11.8440
13815.60	0.9918646	-1.52819	0.9747035	340.9311	-11.7556
14818.57	0.9919067	-1.53174	0.9746466	341.1088	-11.6699
15712.59	0.9919528	-1.53580	0.9745809	341.2799	-11.5874

Second Opportunity

t_D, sec	cos σ	C_3, Km^2/sec^2	e_N	RAS, deg	DEC, deg
0.00	0.9918318	-1.52997	0.9746409	339.8707	-12.2621
1402.86	0.9917824	-1.52705	0.9746896	340.0075	-12.1972
2876.26	0.9917397	-1.52471	0.9747288	340.1613	-12.1242
4386.88	0.9917060	-1.52302	0.9747575	340.3289	-12.0446
5900.87	0.9916831	-1.52203	0.9747751	340.5072	-11.9598
6898.89	0.9916743	-1.52178	0.9747803	340.6305	-11.9010
7879.03	0.9916711	-1.52185	0.9747804	340.7564	-11.8410
8834.84	0.9916733	-1.52224	0.9747752	340.8841	-11.7800
9760.14	0.9916810	-1.52296	0.9747649	341.0128	-11.7184
10651.37	0.9916938	-1.52399	0.9747496	341.1417	-11.6566
11505.08	0.9917115	-1.52531	0.9747294	341.2700	-11.5950
12709.61	0.9917462	-1.52782	0.9746906	341.4601	-11.5037
13815.60	0.9917886	-1.53087	0.9746425	341.6451	-11.4146
14818.57	0.9918359	-1.53439	0.9745864	341.8230	-11.3289
15712.59	0.9918849	-1.53824	0.9745238	341.9917	-11.2475

TABLE 5-XVII ALTERNATE TARGETING PRESETTINGS

$\alpha_D(op) = 0$ $i(op) = 0$ $\theta_N(op) = 0$

$f_0' = 32.5622$	$g_0' = 123.1944$
$f_1' = -16.0885$	$g_1' = -54.4976$
$f_2' = 24.3113$	$g_2' = -5.0105$
$f_3' = -39.1746$	$g_3' = 9.1699$
$f_4' = 68.3411$	$g_4' = -52.4830$
$f_5' = -59.3614$	$g_5' = 62.5097$
$f_6' = 22.5380$	$g_6' = -25.4898$

Mission	C_3, Km/sec^2	e	α_D, deg	f, deg
Nominal Parking orbit 185 X 185 Km	-60.73153	0.000000	360.000	360.000
AS-501 Waiting Orbit 6,254 X 23,022 Km	-22.36078	0.470324	169.000	12.124
AS-502 Translunar 665 X 510,500 Km	-1.49680	0.975220	71.555	13.057
AS-503 High-Apogee 185 X 7,345 Km	-39.31386	0.353092	53.084	6.123
AS-503 Raised Perigee 370 X 7,345 Km	-38.95843	0.340859	170.923	16.475
AS-503 200 N. Mi. 370 X 370 Km	-59.10486	0.000000	360.000	360.000
AS-504 LLM Date A-2, $A_Z = 90^\circ$	-1.35088	0.977633	177.149	15.149
AS-504 LLM Date C-4, $A_Z = 108^\circ$	-1.53825	0.974524	175.404	13.404

5.1 NOMENCLATURE

The nomenclature presents the definitions of all terms and symbols used in this document. The nomenclature is arranged in alphabetical order. In general, $\dot{X}$ and $\ddot{X}$ are not listed if they are the first and second time derivatives of the defined parameter X. Subscripts i, j, and n are used to denote the computation cycle.

The coordinate system used is the Project Apollo Coordinate System defined in Reference 4. The Launch Vehicle Platform-Accelerometer system is presented in Figure 1-1.

5.1 (Continued)

[A]		Transformation matrix from earth-centered plumbline coordinates to equatorial coordinates.
A_Z	deg	Flight azimuth measured positive clockwise from north.
A_{ZO}, A_{ZS}	deg	Flight azimuth used for scaling the azimuth polynomials.
a_{ij}		Elements of [A].
a_1, a_2	m/sec^2	Acceleration terms employed to determine T_{GO} in high-speed cutoff logic.
[B]		Transformation matrix from equatorial coordinates to the desired orbital reference system coordinates.
B_{11}, B_{21}		Coefficients for computing Δt_f.
B_{12}, B_{22}	sec	Coefficients for computing Δt_f.
C_f	sec^2/m	Constant used for S-II/S-IVB direct staging.
$\bar{C}_1$		Unit vector normal to the desired elliptical orbit plane.
C_2, C_4		IGM coupling terms for pitch steering.
C_3	m^2/sec^2	Vis-viva energy of the desired transfer ellipse.
C_{3J}	m^2/sec^2	Vis-viva energy of the desired J-th opportunity transfer ellipse.
C_{3i}	m^2/sec^{2+i}	Formerly the coefficients of the energy polynomial, i = 0, 1, 2, 3, 4.
C'	sec	Time from start of IGM third or fourth stage, used in the artificial tau mode.
C_o'	sec	Time artificial tau mode is used, measured from the beginning of IGM third or fourth stage.
DA		Direct-ascent test gate.

5.1 (Continued)

DEC_J	deg	Declination of the target vector for the J-th opportunity.
D_P, D_Y	m	Intermediate IGM parameters.
d_i	deg/sec^i	Formerly the coefficients of the T_N polynomial, i = 0, 1, 2.
[E]		Transformation matrix formerly used to transform from vehicle fixed coordinates to earth-centered plumbline coordinates.
E_{ij}		Elements of [E].
[EPH]		Transformation matrix from ephemeral coordinates to earth-centered plumbline coordinates.
e		Eccentricity of the transfer ellipse.
e_N		Eccentricity of the nominal transfer ellipse.
e_{NJ}		Eccentricity of the J-th opportunity nominal transfer ellipse.
e_{ni}	sec^{-i}	Formerly the coefficients of the eccentricity polynomial, i = 0, 1, 2, 3, 4.
F_{1j}, F_{2j}, F_{3j}, F_{4j}	deg/sec^j	Coefficient of pre-IGM pitch polynomials, j = 0, 1, 2, 3, 4.
F/m	m/sec^2	Magnitude of the sensed acceleration.
f	deg	True anomaly of the predicted cutoff radius vector used in the iterative guidance mode.
f_n, f_n'	deg	Coefficients for the inclination polynomials, n = 0, 1, 2, 3, 4, 5, 6.
[G]		Transformation matrix from earth-centered plumbline coordinates to the desired orbital reference system coordinates.
GATE		Logic gate that permits IGM steering commands to be arrested.

5.1 (Continued)

GATE 0		Logic gate that permits entrance into restart preparation.
GATE 1		Logic gate that permits entrance into out-of-orbit targeting.
GATE 2		Logic gate that permits only a single pass through first-opportunity targeting.
GATE 3		Logic gate that permits entrance into IGM out-of-orbit precalculations.
GATE 4		Logic gate that permits only a single pass through direct-staging guidance update.
GATE 5		Logic gate that permits only a single pass through high-speed cutoff logic initialization.
G_T	m/sec^2	Magnitude of the desired terminal gravitational acceleration.
g_{ij}		Elements of [G].
g_n, g_n'	deg	Coefficients for the descending node polynomials, n = 0, 1, 2, 3, 4, 5, 6.
HSL		Test gate to provide entrance into high-speed loop logic.
h_{1n}, h_{2n}, h_{3n}	deg	Coefficients of the launch azimuth polynomials, n = 0, 1, 2, 3, 4.
i	deg	Inclination of the target orbit relative to the equatorial plane.
i(op)		Logic gate used to select the method of calculating parking-orbit inclination.
J	sec	Variable in time formerly used to correct target vector for first or second opportunity out of parking orbit, approximately equal to time of one orbit.

5.1 (Continued)

J_1, J_2, J_3, J_{12}, J_3', J_Y, J_P	m	Intermediate IGM parameters.
[K]		Tranformation matrix from earth-centered plumbline coordinates to terminal coordinates.
K		Constant formerly used to unitize the target vector.
KROV		Terminal range-angle bias formerly used for direct staging.
KTC	sec	Formerly the coast time between S-II burnout and S-IVB ignition for direct staging.
KTRP, KTRY		Pitch and yaw steering biases formerly used for direct staging.
K_1', K_3'	deg	Formerly the unadjusted values of K_1 and K_3, respectively.
K_{C3}	m^2/sec^3	Constant formerly used to update C_3 for second opportunity.
K_J		Constant formerly used to update reignition time for second opportunity.
K_L		Slope of the time curve, t_D, versus time of launch, T_L, formerly used for correcting the target vector as time varies across the launch window.
K_{Ne}	sec^{-1}	Constant formerly used to update eccentricity for second opportunity.
K_{P1}, K_{P2}	deg, deg/sec	Coefficients of the restart guidance pitch steering equation.
K_{T3}		Slope of the ΔT_3 versus ΔT_4 curve.
K_{TN}	sec^{-1}	Constant formerly used to update T_N for second opportunity.
K_{Yj}, K_{Zj}	deg/sec^{j-1}	Formerly the coefficients of the restart guidance equations, j = 1, 2.
K_Y, K_P	sec^{-1}	Intermediate IGM parameters.

5.1 (Continued)

K_{Y1}, K_{Y2}	deg, deg/sec	Coefficients of the restart guidance yaw steering equation.
K_b	sec^{-1}	Constant formerly used to update cos σ for second opportunity.
K_i	deg, deg/sec	Corrections to the chi-tilde steering angles, i = 1, 2, 3, 4.
K_{pc}	sec	Constant used to force MRS in the out-of-orbit forced MRS logic.
$K_{\alpha j}$	deg/sec^j	Coefficients of the polynomial defining the angle, α_{TS}, j = 1, 2.
K_5	m/sec	Constant used in the calculation of terminal velocity in IGM out-of-orbit precalculations.
L_1, L_2, L_3, L_{12}, L_3', L_Y, ΔL_3, L_P, L_Y	m/sec	Intermediate IGM parameters.
$\dot{M}_1$	kg/sec	Mass flowrate of S-II from approximately LET jettison to second MRS.
$\dot{M}_2$	kg/sec	Mass flowrate of S-II after second MRS.
$\dot{M}_3$	kg/sec	Mass flowrate of S-IVB during first burn.
$\dot{M}_{2R}$	kg/sec	Mass flowrate of S-IVB prior to assumed MRS during second burn.
$\dot{M}_{3R}$	kg/sec	Mass flowrate of S-IVB after assumed MRS during second burn.
m	kg	Instantaneous vehicle mass.
$\bar{N}$		Unit vector normal to the parking-orbit plane.
$\bar{P}$		Unit vector in the parking-orbit plane.
P_c	sec	Time parameter used in forced MRS logic, incremented after T_2 becomes less than zero in the out-of-orbit burn.

5.1 (Continued)

P_1, P_2, P_3, P_{12}	m-sec	Intermediate IGM parameters.
p	m	Semilatus rectum of the desired terminal ellipse.
p_N	m	Nominal magnitude of semilatus rectum.
Q_1, Q_2, Q_3, Q_{12}, Q_Y, Q_P	m-sec	Intermediate IGM parameters.
R	m	Instantaneous radius magnitude.
$\overline{R}$	m	Instantaneous radius vector.
$\overline{R}'$	m	Unit radius vector in the parking orbit.
RAS_J	deg	Right ascension of the J-th opportunity target vector.
ROT		Control number used to determine whether rotated terminal conditions are used during into-orbit burn.
ROTR		Control number used to determine whether rotated terminal conditions are used during out-of-orbit burn.
ROV		Constant for biasing terminal range-angle prediction.
ROV*		Direct-staging constant used for biasing terminal range-angle prediction.
ROVR		Constant for biasing the terminal range-angle prediction during S-IVB second burn.
R_N	m	Radius at nominal S-IVB reignition.
R_T, R_t	m	Desired and predicted terminal radius, respectively.
$\overline{S}$		Unit nodal vector, lying at the intersection of the parking orbit and translunar ellipse planes.
SMCG	deg/sec	Steering misalignment correction gain.

5.1 (Continued)

SMCY, SMCZ	deg	Pitch and yaw steering misalignment correction terms.
S_1, S_2, S_3, S_{12}, S_Y, S_P	m	Intermediate IGM parameters.
$\bar{S}_1$		Unit vector normal to the nodal vector in the elliptical orbit plane.
$\bar{T}$		Unit target vector in ephemeral coordinates.
TAS	sec	Time from guidance reference release.
TA1, TA2	sec	Time parameters used in orbital guidance to implement attitude maneuvers.
TB1, TB2, TB3, TB4, TB5, TB6, TB7	sec	Timebases.
TB4a, TB6a, TB6b, TB6c	sec	Alternate timebases.
T_0	sec	Time bias used to adjust IGM parameters for an engine-out between S-II ignition and nominal LET jettison.
TRP, TRY		Constants formerly used to bias the pitch and yaw steering parameters, respectively, for the into-orbit burn.
TRPR, TRYR		Constants formerly used to bias the pitch and yaw steering parameters, respectively, during second S-IVB burn.
TSMC		Time test to begin steering misalignment correction.
TSMC 1, TSMC 2, TSMC 3	sec	Time test for steering misalignment correction relative to TB3, TB4 or TB4a, and TB6, respectively.
TS4BS	sec	Time from direct-stage interrupt to initiate IGM.

5.1 (Continued)

TU		Gate used to select updated targeting.
TU10		Gate used to select 10-parameter update targeting.
T_{CO}	sec	Predicted S-IVB engine cutoff time measured from guidance reference release.
T_{E01}, T_{E02}		Constant used for engine-out conditions.
T_{GO}	sec	Predicted time to go until S-IVB engine cutoff.
T_{IGM}	sec	Preset time from the beginning of restart preparation (TB6) to entering IGM logic.
T_L	sec	Launch time from midnight.
T_{LET}	sec	Launch escape tower jettison time.
T_{LO}	sec	Reference time of launch from midnight.
T_M	m	Magnitude of the minus target vector.
T_N	sec	Formerly the displacement of the true aim vector from the moon travel plane.
T_{RG}	sec	Preset S-IVB reignition time from beginning of restart preparation (TB6).
T_{RP}	sec	Restart preparation time.
T_{ST}	sec	Constants used in the time test for entering the $\bar{S}\cdot\bar{T}_p$ test.
T_T, T_T'	sec	Total time-to-go computed using T_3 and T_3', respectively.
T_X, T_Y, T_Z		Components of the unit target vector $\bar{T}$, in ephemeral coordinates.
T_{XJ}, T_{YJ}, T_{ZJ}		Components of the J-th opportunity unit target vector, $\bar{T}$, in ephemeral coordinates.

5.1 (Continued)

T_X^*, T_Y^*, T_Z^*		Formerly the components of the reference target vector rotated into the moon travel plane, in ephemeral coordinates.
ϵ_X, ϵ_Y, ϵ_Z, ϵ	sec^{-1}	Formerly constants used to update target vector.
T_c	sec	Coast time between S-II burnout and S-IVB ignition.
$\bar{T}_p$		Unit target vector in earth-centered plumbline coordinates.
T_0	sec	Time bias used to adjust IGM parameters for an engine-out between S-II ignition and nominal LET jettison.
T_1	sec	Time remaining in the first stage of IGM guidance.
T_{1c}	sec	Burn time of the IGM first, second, and coast guidance stages.
T_2	sec	Time remaining in the second or fourth stage of IGM guidance.
T_{2R}	sec	Nominal fourth-stage burn time.
T_3	sec	Time remaining in the third or fifth stages of IGM guidance.
T_3'	sec	Estimated third- or fifth-stage burn time.
T_{3R}'	sec	Initial prediction of fifth-stage burn time.
T_{4N}	sec	Nominal time of S-IVB first burn.
ΔT_{LIM}	sec	Limit value of ΔT_4.
ΔT_3	sec	Correction to third- or fifth-stage burn time.
ΔT_4	sec	The difference between the actual burn time and the nominal burn time of the S-IVB first burn.
$\Delta T_4'$	sec	Limited value of ΔT_4.

5.1 (Continued)

t	sec	Time from accelerometer reading to next steering command.
t_{AR}	sec	Time to arrest S-IC χ_Y.
t_{B1}	sec	Transition time for the S-II mixture ratio to shift from 5.5 to 4.7.
t_{B2}	sec	Transition time for the S-IVB mixture ratio to shift from 4.5 to 5.0.
t_{B3}	sec	Time from second S-II MRS signal.
t_{B4}	sec	Time from S-IVB MRS.
t_D	sec	Time into launch window.
t_{D0}, t_{D1}, t_{D2}, t_{D3}	sec	Times of the opening or closing of a launch window segment.
t_{DS0}, t_{DS1}, t_{DS2}, t_{DS3}	sec	Time used to segment the azimuth polynomials.
t_{FAIL}	sec	Time of engine failure in S-IC.
t_S	sec	Time used to scale inclination and nodal angle polynomials.
t_{S1}, t_{S2}, t_{S3}	sec	Time to change segments of the Pre-IGM pitch polynomial.
t_{SD1}, t_{SD2}, t_{SD3}	sec	Times used to scale the azimuth polynomials.
t_c	sec	Clock time from liftoff.
t_{cf}, t_{ct}	sec	Pre-IGM χ_Y steering polynomial parameter.
t_1	sec	Time to initiate pitch and roll if altitude test is not satisfied.
t_2	sec	Time to initiate χ_Y freeze for early engine failures in S-IC.
t_{21}	sec	S-II ignition time.
t_3	sec	Constant χ_Y freeze for S-IC engine failure prior to t_2.

5.1 (Continued)

t_{3i}	sec	Clock time at S-IVB ignition.
t_4	sec	Defines the upper bound for which the first segment of the χ_Y freeze schedule is valid.
t_5	sec	Defines the upper bound for which the second segment of the χ_Y freeze schedule is valid.
t_6	sec	Time to end χ_Y freeze following an S-IC engine failure.
Δt_{LET}	sec	Nominal time interval between S-II ignition and LET jettison.
Δt	sec	Nominal powered-flight integration or coast-guidance computation-cycle interval.
Δt_c	sec	Actual integration computation cycle interval.
Δt_f	sec	Period of frozen χ_Y in S-IC.
Δt_i, $\Delta t_i'$	sec	Parameters used in cutoff velocity table and T_{GO} determination.
$\Delta t_1'$, $\Delta t_2'$	sec	Parameters used in T_{GO} determination.
UP		Control number indicating whether a recycle has been performed during the evaluation of the IGM steering.
U_1, U_2, U_3, U_{12}	m-sec^2	Intermediate IGM parameters.
V	m/sec	Instantaneous vehicle velocity.
V_i, V_1, V_2	m/sec	Cutoff velocity equation calculation parameters.
Vex_1, Vex_2, Vex_3	m/sec	Exhaust velocities for the first, second, and third stages of IGM guidance, respectively.
Vex_{2R}, Vex_{3R}	m/sec	Exhaust velocities for fourth and fifth stages of IGM guidance, respectively.
V_{SII}	m/sec	Formerly the velocity at nominal S-II cutoff.

5.1 (Continued)

V_{S2T}	m/sec	Nominal S-II cutoff velocity.
V_T	m/sec	Desired terminal velocity.
V_{TC}	m/sec	Velocity parameter used for high-speed cutoff test.
ΔV_B	m/sec	Velocity cutoff bias for parking-orbit insertion.
ΔV_{BR}	m/sec	Velocity cutoff bias for translunar injection.
X_E, Y_E, Z_E	m	Position components in the ephemeral coordinate system.
X_I, Y_I, Z_I	m	Position components in the accelerometer coordinate system.
X_P, Y_P, Z_P	m	Position components in the pad-centered plumbline coordinate system. The positive X_P - axis is opposite and parallel to the local gravity vector. The Z_P - axis is positive along the launch azimuth; the Y_P - axis completes the orthogonal right-handed set.
X_S, Y_S, Z_S	m	Position components in the earth-centered plumbline system.
X_{S1}, X_{S2}, X_{S3}		Direction cosines of the thrust vector in the earth-centered plumbline system.
X_1, X_2		Intermediate functions of the descending nodal angle calculation.
X_{4i}, Y_{4i}, Z_{4i}	m	Position components in the orbital reference system for the i-th computation cycle.
$\dot{X}_I$, $\dot{Y}_I$, $\dot{Z}_I$	m/sec	Integrating accelerometer outputs.
$\ddot{X}_g$, $\ddot{Y}_g$, $\ddot{Z}_g$	m/sec	Gravitational acceleration components in the earth-centered plumbline system.
α_D	deg	The angle from the perigee vector to the descending nodal vector measured positive in the direction of flight.

5.1 (Continued)

α_D(op)		Boost-to-orbit test parameter for α_D initialization.
α_{TS}	deg	The desired angle between the $\bar{S}$ and $\bar{T}_p$ at reignition.
α^*_{TS}	deg	The nominal angle between the $\bar{S}$ and $\bar{T}_p$ at reignition.
α_1, α_2	deg	Orbital guidance pitch and yaw steering attitudes.
β	deg	Constant angle defining the location of the pseudonodal vector, $\bar{S}$, relative to the radius vector in the ignition plane at S-IVB restart preparation time.
β_1	deg	Constant angle defining the location of the nodal vector, $\bar{S}$, relative to the radius vector in the ignition plane at S-IVB reignition.
β_E	deg	Engine gimbal angle.
δ_2	m	Intermediate IGM parameter.
ϵ_1, ϵ_{1R}	sec	Constant time for selection of guidance option that allows an alternate computation of terminal range angle for the into-orbit and out-of-orbit burns, respectively.
ϵ_2, ϵ_{2R}	sec	Constant time for selection of guidance option that enforces only terminal velocity end-conditions for the into-orbit and out-of-orbit burns, respectively.
ϵ_3, ϵ_{3R}	sec	Constant time for selection of guidance option that freezes the terminal conditions for the into-orbit and out-of-orbit burns, respectively.
ϵ_4, ϵ_{4R}	sec	Preset time for cutoff logic entry for the into-orbit and out-of-orbit burns, respectively.

5.1 (Continued)

ξ, η, ζ	m	Position components in the terminal reference system.
ξ_T, η_T, ζ_T	m	Desired position components in the terminal reference system.
$\Delta\xi, \Delta\eta$	m	Position components to be gained along ξ and η axis, respectively.
$\Delta\dot{\xi}, \Delta\dot{\eta}, \Delta\dot{\zeta}$	m/sec	Velocity to be gained along ξ, η, ζ, axes.
$\Delta\dot{\xi}', \Delta\dot{\eta}', \Delta\dot{\zeta}'$	m/sec	Intermediate velocity deficiency used in estimating time-to-go.
$\ddot{\xi}_G, \ddot{\eta}_G, \ddot{\zeta}_G$	m/sec^2	Gravitational components in the terminal reference system.
$\ddot{\xi}_{GT}, \ddot{\eta}_{GT}, \ddot{\zeta}_{GT}$	m/sec^2	Gravitational components at the desired terminal radius.
θ_E	deg	Angle from the Vernal Equinox, ♈, for the true time of launch, T_L.
θ_{EO}	deg	Angle from the Vernal Equinox to the launch meridian measured in a counter-clockwise direction for the constant time of launch, T_{LO}.
θ_N	deg	Descending nodal angle of target orbit measured counterclockwise from the launch meridian in the equatorial plane.
θ_N(op)		Logic gate used to select method for calculating the descending nodal angle.
$\theta_X, \theta_Y, \theta_Z$	deg	Platform gimbal angles.
γ	deg	Instantaneous flight-path angle, measured positive counterclockwise from the local horizontal.
γ_T	deg	Desired terminal flight-path angle, measured positive counterclockwise from the local horizontal.
μ	m^3/sec^2	Product of universal gravitational constant and earth mass.

5.1 (Continued)

σ_j	sec^{-j}	Coefficients for the cos σ polynomial $j = 0, 1, 2, 3, 4$.
σ, σ_J	deg	Angle between perigee vector and the target vector in the nominal transfer ellipse for the J-th opportunity.
τ_1	sec	Estimated time to deplete vehicle mass before second MRS.
τ_2	sec	Estimated time to deplete vehicle mass from MRS to stage cutoff, constant during first stage of guidance.
τ_3	sec	Estimated time to deplete S-IVB mass, constant during first and second stages of guidance.
τ_{3R}	sec	Estimated time to deplete vehicle mass from assumed MRS to stage cutoff, constant during initial stage of S-IVB second burn.
τ_{2N}, τ_{3N}	sec	Artificial tau mode parameters.
$\dot{\phi}_1$	deg/sec	Angular rate of vehicle motion.
ϕ_L	deg	Geodetic latitude of the launch site.
ϕ_T	deg	Angle used to estimate the location of the terminal radius vector in the desired orbit plane, measured positive clockwise from the positive X_4 - axis.
ϕ_{TR}	deg	Estimate of ϕ_T for out-of-orbit burn.
χ_{Xi}, χ_{Yi}, χ_{Zi}, χ	deg	Vehicle attitude steering parameters at the i-th computation cycle. These Eulerian angles define the orientation of the vehicle fixed coordinate system when executed in the sequence, χ_Y, χ_Z, χ_X about the vehicle fixed axis indicated by the subscripts. Positive angles result from counterclockwise rotation viewed from the origin.

5.1 (Continued)

$\tilde{\chi}_p$, $\tilde{\chi}_y$, $\tilde{\chi}$	deg	Pitch and yaw steering angles required to null out the velocity deficiencies in the remaining estimated flight time, without regard to terminal radius, and based on the assumption that the vehicle is flown in constant gravitational field for the estimated burn time. These angles are measured in the ξ, η, ζ, coordinate system.
χ_{XC}, χ_{YC}, χ_{ZC}	deg	Constant attitude values for use in the translunar orbit.
χ_{Xj}, χ_{Yj}, χ_{Zj}	deg	Steering angles used in steering angle limit test.
χ_{Y4}	deg	Command pitch attitude in the reference orbital plane formerly used in orbital guidance.
χ_{XL}, χ_{YL}, χ_{ZL}	deg/sec	Maximum allowable roll, pitch, and yaw steering rate.
χ_{Xi}, χ_{Yi}, χ_{Zi}	deg	Attitude command angles in the orbital reference system at the i-th computation cycle.
χ_p''	deg	The IGM computed pitch angle as measured in the $\xi - \zeta$ plane positive up from the ζ axis.
χ_y''	deg	The IGM computed yaw angle measured positive towards the η axis from the projection of the body axis in the $\xi - \zeta$ plane.
ψ'	deg	Angle between the $\bar{S}$ and $\bar{T}_p$ at S-IVB reignition.
ψ_X, ψ_Y, ψ_Z, ψ	deg	Attitude error signals in vehicle coordinates.
ω_E	deg/sec	Rotational rate of the earth.
ω_X, ω_Y, ω_Z		Components of the unit vector normal to the moon travel plane, in ephemeral coordinates, formerly used in updating the target vector.

5.1 (Continued)

Ω_X, Ω_Y, Ω_Z	First, second, and third rows, respectively, of $\lfloor A \rfloor$.

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APPENDIX A - SUMMARY OF IGM EQUATIONS

The IGM steering equations and the restart preparation and reignition equations are summarized in Figure A-1. The fundamental blocks and equations are presented in the approximate order of calculation. Only the basic equations are included; such features as tau modes, stage logic and alternate mission material are found in the main body text only. A brief description of the boxes follows:

Stage Integral Calculations

The IGM equations are entered from the IGM stage logic. The stage integral calculations provide an estimate of vehicle performance capability based upon the current prediction of S-IVB burn time for either into-orbit or out-of-orbit burns.

Range Angle 1 - Range Angle 2

Range angle-to-go computations are made to estimate the location of the terminal radius vector. This provides a reference for establishing the terminal coordinate system. Range angle 1 is used into orbit and Range angle 2 is used out of orbit.

R_T, V_T, γ_T

The terminal radius, velocity, flight-path angle and gravity required for translunar injection are computed from the calculated value of true anomaly. These terminal parameters are used by IGM to determine the position and velocity deficiencies necessary for time-to-go computations.

Rotated Terminal Conditions - Unrotated Terminal Conditions

The IGM desired terminal parameters are expressed in terms of either rotated or unrotated terminal conditions. The unrotated terminal conditions are used in the into-orbit burn, and the rotated terminal conditions are used in the out-of-orbit burn.

Rotation to Terminal Coordinates

The K matrix is a function of the G matrix and the ϕ_T matrix. The K matrix is used to transform the vehicle position, velocity, and gravitational acceleration vectors to the terminal coordinate system.

Estimated Time-To-Go

A correction to the estimated S-IVB burn time, T_3', is made by comparing the current velocity deficiency with the current estimate of the velocity to be gained prior to cutoff. The estimated time-to-go is used to determine the pitch and yaw steering parameters.

APPENDIX A (Continued)

T_T' Parameters Updated

Two passes are made through the terminal conditions in each major cycle. This provides for more accurate end-conditions in the presence of three-sigma propulsion system variations. This also reduces IGM sensitivity to propellant utilization system fluctuation.

$\tilde{X}_y$ and $\tilde{X}_p$

$\tilde{X}_y$ and $\tilde{X}_p$ are the steering angles required to achieve the velocity end-conditions. They are calculated in terms of an estimate on velocity to be gained.

Yaw Steering Parameters - Pitch Steering Parameters

The steering parameter equations compute biases to the $\tilde{X}$ steering angles. The K_i parameters are employed to enforce radius and velocity constraints.

IGM Steering Angles

The IGM steering angles are computed in the guidance reference system. The angles are then transformed to the inertial plumbline coordinate system to provide vehicle attitude commands.

Restart Preparation and Opportunity Logic

The $\bar{S}$ is the nodal vector that lies at the intersection of the parking orbit and transfer ellipse planes. The target vector, $\bar{T}_p$, lies on the extension of the earth-moon line at arrival. A pseudonodal vector, also denoted by the symbol $\bar{S}$, is created to test for restart preparation initiation. Restart preparation is initiated when $\bar{S} \cdot \bar{T}_p \leq \cos \alpha_{TS}$.

Precalculations of elliptical parameters and the out-of-orbit G matrix are performed at S-IVB reignition. The elliptical parameters and G matrix are required by IGM on the first pass through the equations.

An update of IGM parameters at S-IVB reignition is also performed. This completes the calculations required to properly initialize IGM for the out-of-orbit burn to translunar injection.