5.3 POWERED FLIGHT NAVIGATION AND GUIDANCE

5.3.1 GENERAL COMMENTS

The objective of the powered flight guidance routines is to maintain an estimate of the CSM state vector during the thrusting maneuvers, and to control the thrust direction such that the desired velocity cut-off conditions are achieved. The powered flight navigation program used to maintain estimate of the vehicle state vector during all thrusting conditions is referred to as the Average-G Routine and is presented in Section 5.3.2.

For the Lunar Landing Mission the basic powered flight guidance concept used in the CMC is a velocity-to-be-gained concept with cross product steering (Section 5.3.3.4) which is used in each of the following two procedures:

1. Lambert Aim Point Maneuver Guidance (Section 5.3.3.3.2).

2. External ΔV Maneuver Guidance (Section 5.3.3.3.1).

These two procedures, based on the cross product steering concept, differ only in the unique generation of the desired velocity vector, $\underline{v}_R$ and are used to control all CMC guided powered maneuvers for the Lunar Landing Mission.

5.3.2 POWERED FLIGHT NAVIGATION - AVERAGE-G ROUTINE

The purpose of the Powered Flight Navigation Subroutine is to compute the vehicle state vector during periods of powered flight steering. During such periods the effects of gravity and thrusting are taken into account. In order to achieve a short computation time the integration of the effects of gravity is achieved by simple averaging of the gravity acceleration vector. The effect of thrust acceleration is measured by the IMU Pulsed Integrating Pendulous Accelerometers (PIPA) in the form of velocity increments ($\Delta \underline{v}$) over the computation time interval (Δt). The computations are, therefore, in terms of discrete increments of velocity rather than instantaneous accelerations. The repetitive computation cycle time Δt is set at 2 seconds to maintain accuracy and to be compatible with the basic powered flight cycle.

The Average-G Routine, in contrast to the Coasting Integration Routine, is used when a short computing time is required such as during powered flight. The Average-G Routine computations are illustrated in Figs. 3.2-1 and 3.2-2. The following defines the parameters used in these figures:

$\underline{r}(t)$	Vehicle position vector at time t.
$\underline{v}(t)$	Vehicle velocity vector at time t.
P_C	Planet designator $\begin{cases} 0 & \text{Earth} \\ 1 & \text{Moon} \end{cases}$
Δt	Computation cycle of 2 seconds.

$\Delta\underline{v}(\Delta t)$ — The velocity vector change sensed by the IMU PIPA's over the time interval Δt. This velocity vector increment is initially sensed in IMU or Stable Member Coordinates and then transformed to the Basic Reference Coordinate System.

$\underline{g}_p(t)$ — Previous gravity acceleration vector. This is a required initialization parameter and is supplied by the calling program.

$\underline{u}_r$ — Unit vector in the direction of $\underline{r}$.

$\underline{u}_z$ — Unit vector in the direction of the polar axis of the earth.

μ_E — Earth gravitational constant.

μ_M — Moon gravitational constant.

r_E — Equatorial radius of the earth.

J_{2E} — Second-harmonic coefficient of the earth's potential function.

$\underline{g}_b(t)$ — Component of the earth gravity acceleration vector representing earth oblateness effects.

With reference to Fig. 3.2-2 it can be seen that a single oblateness term is included in the earth gravity subroutine computation, but none for the lunar case.

The PIPA measured velocity $\Delta\underline{v}$ is compensated for instrument errors as described in Section 5.6.13 prior to being transformed into the Basic Reference Coordinate System and processed in the Average-G Subroutine of Fig. 3.2-1.

AVG: Proc Assign; ({SV})
DCL 1 SV
2 etc.

ENTER

↓

$\underline{r}(t),\ \underline{v}(t),\ \Delta t,\ \Delta\underline{v}\,(\Delta t),\ \underline{g}_p(t),\ P_C$

↓

UPDATE:
$\bar{R} = \bar{R} + \ldots$
close;

$$\underline{r}(t+\Delta t) = \underline{r}(t) + \Delta t\left[\underline{v}(t) + \underline{g}_p(t)\,\frac{\Delta t}{2} + \frac{\Delta\underline{v}\,(\Delta t)}{2}\right]$$

↓

call Grav.

Call Gravity Subroutine, (Fig. 3. 2-2), $\underline{r}(t+\Delta t)$, P_C
Resume $\underline{g}\,(t+\Delta t)$, $\underline{g}_b\,(t+\Delta t)$

↓

Update
$\bar{v} = \bar{v}$
$\bar{g} = g$
Close

$$\underline{v}\,(t+\Delta t) = \underline{v}(t) + \frac{\Delta t}{2}\left[\underline{g}\,(t+\Delta t) + \underline{g}_p(t)\right] + \Delta\underline{v}\,(\Delta t)$$

$$\underline{g}_p(t+\Delta t) = \underline{g}\,(t+\Delta t)$$

$$t = t + \Delta t$$

↓

RETURN

$\underline{r}(t),\ \underline{v}(t),\ \underline{g}_p(t),\ \underline{g}_b(t)$

Figure 3. 2-1 Average-G Subroutine

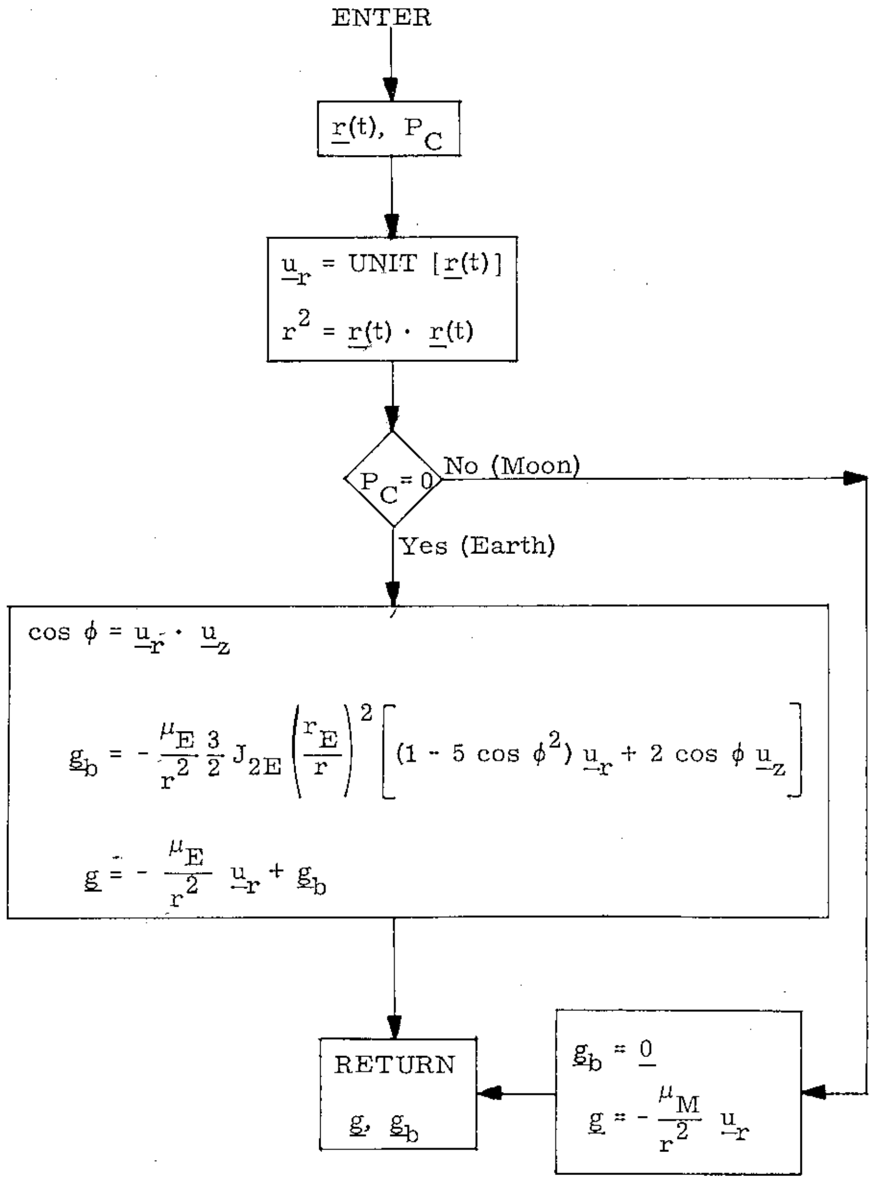


Figure 3.2-2 . Gravity Subroutine

5.3.3 POWERED FLIGHT GUIDANCE USING CROSS PRODUCT STEERING

5.3.3.1 Introduction

The cross product steering concept is used to control the following maneuvers:

(a) Cislunar Midcourse Corrections, P-31 or P-30

(b) Lunar Orbit Insertion (LOI) P-31 and P-30

(c) Lunar Orbit Plane Change Maneuvers (LOPC), P-31

(d) Rendezvous Intercept (P-34) and Midcourse Correction Maneuvers (P-35), Stable Orbit Rendezvous Maneuvers (P-38 and P-39)

(e) Return-to-Earth Maneuvers, P-37

(f) External ΔV and Orbital Phasing Maneuvers (RTCC or LGC Targeted Maneuver) P-30

(g) Transearth Injection (TEI) P-31

The External ΔV Guidance mode (Section 5.3.3.3.1) is used for maneuvers in which the required cut-off velocity, $\underline{v}_R$, is specified by a source external to the CMC by use of program P-30. All other maneuvers are controlled by the Lambert Aim Point Maneuver Guidance Mode (Section 5.3.3.3.2) in which the $\underline{v}_R$ is periodically computed by the Lambert subroutine during the maneuver to establish the desired intercept trajectory. Both External ΔV and Lambert Aim Point Guidance modes use the cross product steering concept to control the thrust direction along the velocity-to-be-gained vector, and terminate thrust when the desired velocity increment has been achieved.

Three subroutines are used repetitively in sequence (Section 5.3.3.2) during cross product controlled maneuvers to accomplish this function. These are:

1. The Powered Flight Navigation Average-G Routine which computes the state vector accounting for the effects of thrust acceleration and gravity.

2. The Cross-Product Steering Subroutine which has 3 functions:

   a) incremental updating of the velocity-to-be-gained vector.

   b) generation of steering commands to the vehicle autopilot.

   c) computation of time-to-go before engine shut-off and the issuance of engine-off commands.

3. The Velocity-to-be-Gained Subroutine which repetitively solves the Lambert intercept problem when in the Lambert Aim Point guidance mode.

The Average-G Routine is described in Section 5.3.2. The other subroutines listed above are described in Sections 5.3.3.4 to 5.3.3.6. The Pre-Thrust Subroutines of Section 5.3.3.3 initialize the powered maneuver programs for either the External ΔV or Lambert Aim Point guidance modes, and for the selected engine for the maneuver.

The CMC powered flight programs described by the computation subroutines presented in Section 5.3.3 are

P-40	Service Propulsion System (SPS) Thrust Prog.
P-41	Reaction Control System (RCS) Thrust Prog.

Active steering and engine-off commands are provided by program P-40. Maneuvers using RCS translation control (P-41) are manually controlled and terminated by the astronaut while the CMC displays the required velocity-to-be-gained in control coordinates (Section 5.3.3.3.3).

The functions of the External ΔV Pre-Thrust Program, P-30 are described in the pre-thrust subroutine description of Section 5.3.3.3.1.

The Lambert Aim Point Maneuver Guidance Program, P-31 is a RTCC targeted pre-thrust program in which all required target parameters are uplinked via the CMC Update Program P-27. Program P-31 uses the same routines as CMC targeted intercept maneuvers as shown in Section 5.3.3.3.2.

5.3.3.2 Powered Flight Guidance Computation Sequencing

The time sequencing of SPS powered flight subroutines for External ΔV steering is illustrated in Figs. 3.3-1 thru 3.3-3, and for Lambert Aim Point steering in Figs. 3.3-4 thru 3.3-6. These figures represent the sequence of operations for P-40 SPS maneuvers lasting longer than 6 seconds. RCS controlled maneuvers (P-41) require manual steering control, and the general timing sequence is different from that described for SPS maneuvers. The general cross product steering concept is used to compute and display the required velocity-to-be-gained vector, but no engine-off computations are made for RCS maneuvers. The following description of sequence operations is restricted to SPS Maneuvers.

Figures 3.3-1 and 3.3-4 show the sequencing during the ignition count down which starts 30 seconds before the nominal ignition time. Figures 3.3-2 and 3.3-5 show the normal sequencing for an engine-on time greater than 6 seconds as predicted by the pre-thrust subroutines. Figures 3.3-3 and 3.3-6 illustrate the sequencing during engine thrust termination.

The basic computation cycle time of the steering is 2 seconds and, as shown on the above figures, is initiated by the reading of the PIPA $\Delta \underline{v}$ registers. The various subroutines utilized during the 2 second cycle are sequenced in time as shown.

During Lambert Aim Point steering, however, the velocity-to-be-gained ($\underline{v}_G$) updating is anticipated to occur nominally every four seconds. However during SPS maneuvers the CMC computation occasionally prevents completion of the Lambert solution in 2 to 4 seconds. The program is capable of processing an N cycle update where N can be greater than 2. The time sequencing diagrams show only the nominal two and four second $\underline{v}_G$ update cases. This allows sequenced parallel computing functions, such as the demands of the autopilots and telemetry, to take place without interference with the basic two second cycle time. Should the $\underline{v}_G$ computation be completed in time for use during a given 2 second cycle, it will be utilized.

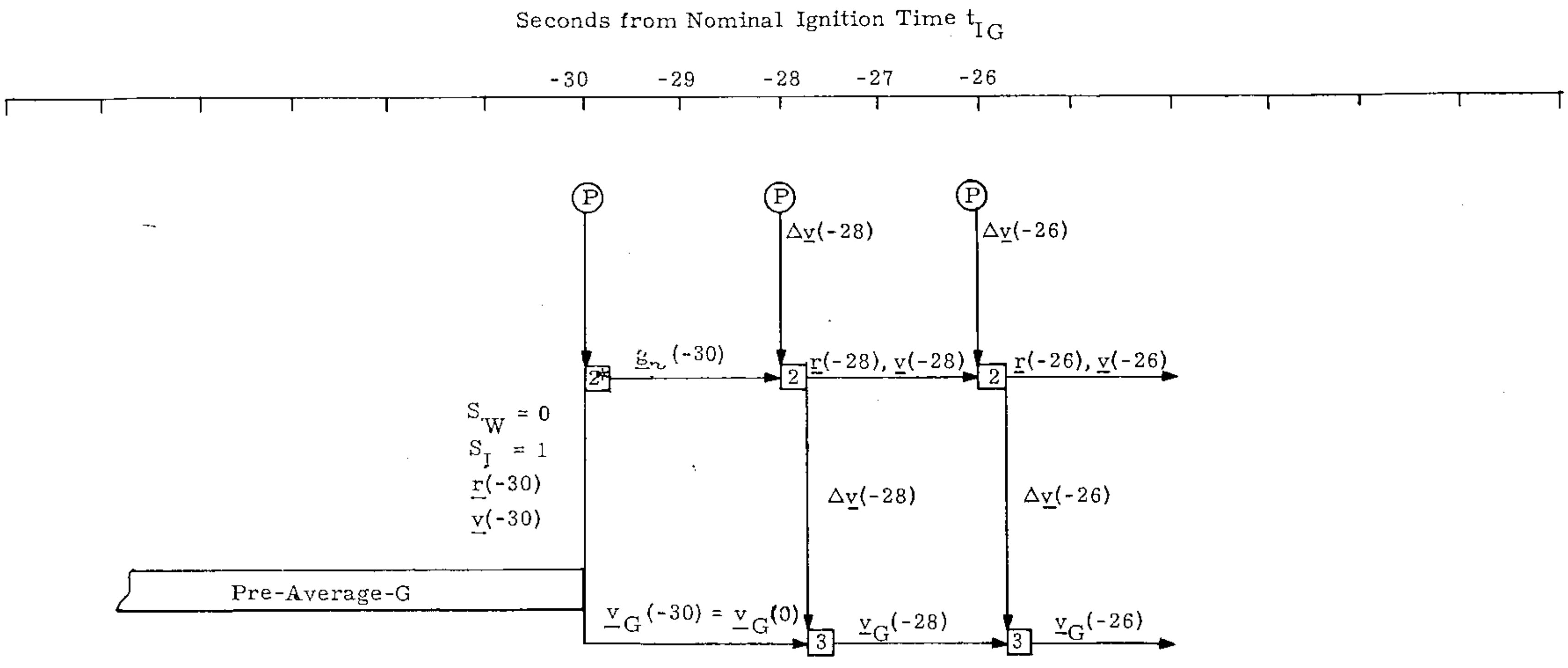
If the calculations conducted prior to the thrusting period (pre-thrust) indicate that the maneuver objective can be reached with a 6 second thrust period or less, provision is included (switches S_I and S_w) to preclude the generating of steering commands during the thrusting period with the engine-off signal being generated prior to ignition.

In addition to timing information, the sequence diagrams of Figs. 3. 3-1 to 3. 3-6 also show the basic information utilized by each subroutine and its source.

The guidance computer program which controls the various subroutines to create a powered flight sequence is called the Servicer Routine. The sequence diagrams of Figs. 3. 3-1 to 3. 3-6 define what the Servicer Routine does, but do not show the logic details of how these functions are accomplished.

The subroutines listed in Figs. 3. 3-1 to 3. 3-6 are described in Section 5. 3. 2 and the following Sections 5. 3. 3. 3 to 5. 3. 3. 6. These sections should be referenced in tracing the powered flight computation sequencing.

Ullage will be turned off at the fixed time of 2 seconds from engine-on command. Steering will be enabled (S_W set to 1) at the fixed time of 2 seconds from engine-on command.



*Initial Average-G cycle computes gravity terms only.

NOTE: SPS ullage will be turned on by the Astronaut at a time depending on the vehicle weight and propellant loading. It will be turned off at the fixed time of 2 secs from the engine on command

(P) Read and Zero PIPA Registers
[2] Average G Subroutine
[3] Cross Product Steering Subroutine

Fig. 3.3-1 Ignition Countdown - External ΔV Subroutine Sequencing for SPS Maneuvers

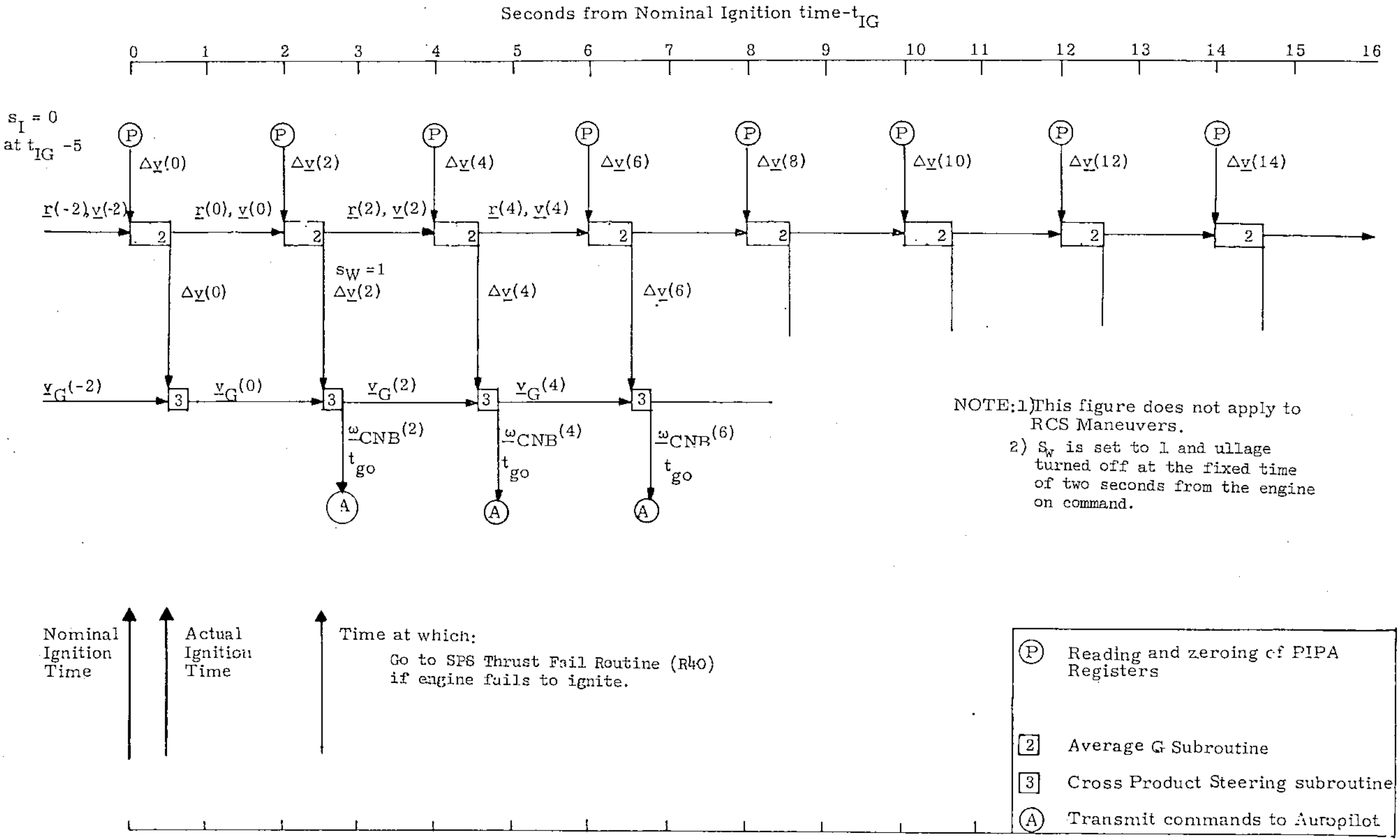


Fig. 3.3-2 Normal External ΔV Subroutine Sequencing (Maneuver time greater than 6 sec) for SPS Maneuvers

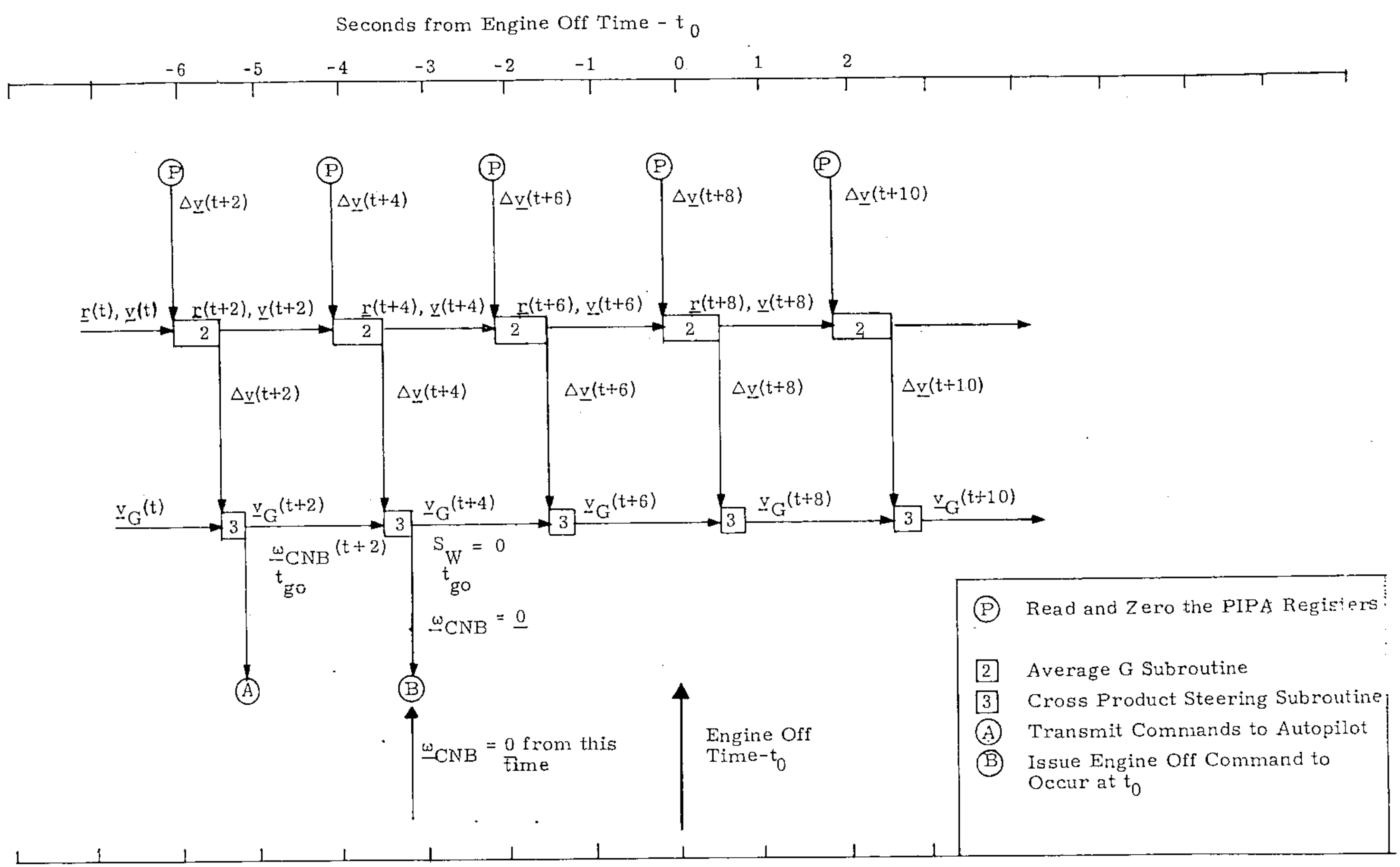


Fig. 3.3-3 Engine Off External ΔV Subroutine Sequencing for SPS Maneuvers

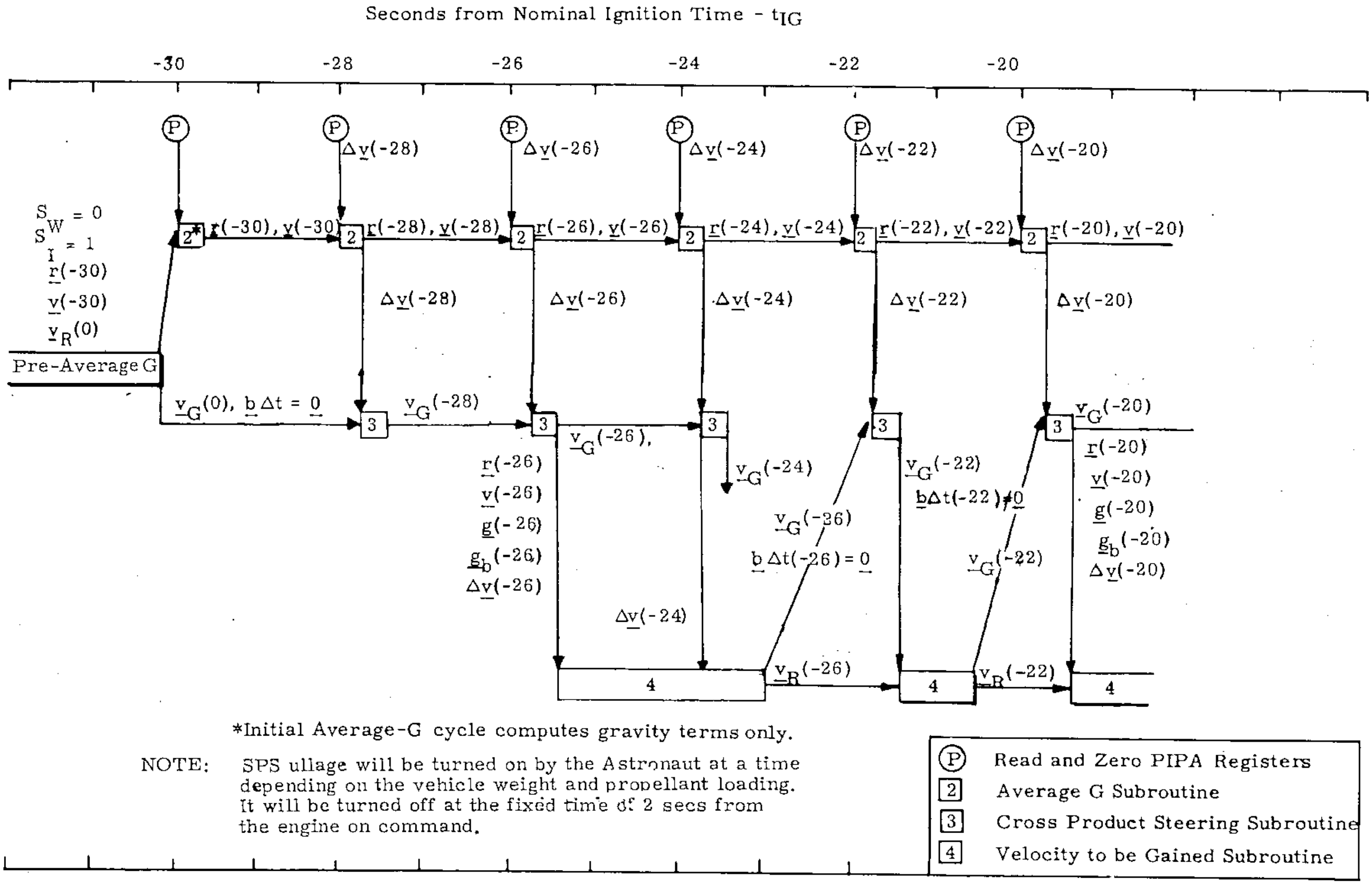


Fig. 3.3-4 Ignition Countdown - Lambert Aim Point Subroutine Sequencing for SPS Maneuvers

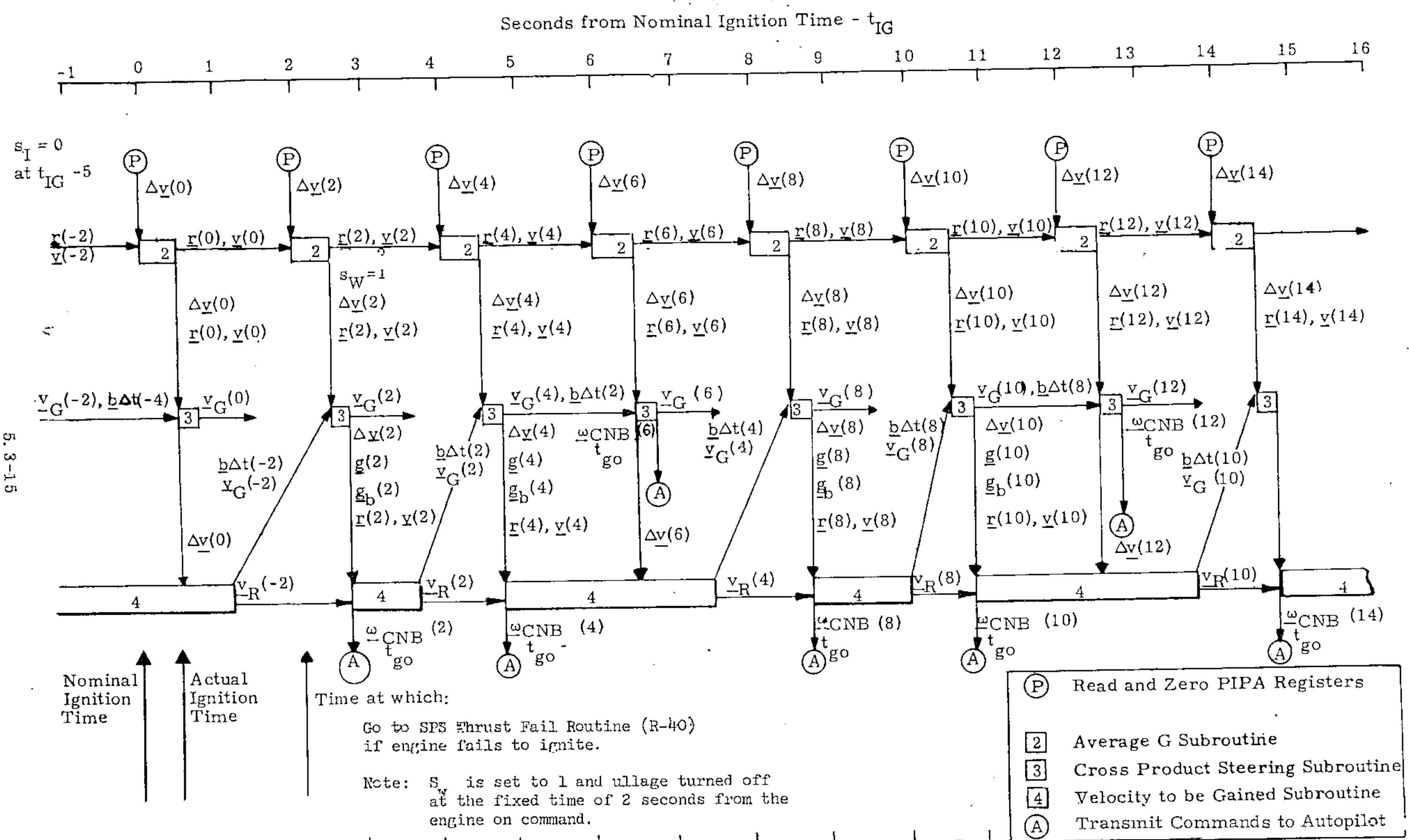


Fig. 3.3-5 Normal Lambert Aim Point Subroutine Sequencing (Maneuver time greater than 6 sec) for SPS Maneuvers

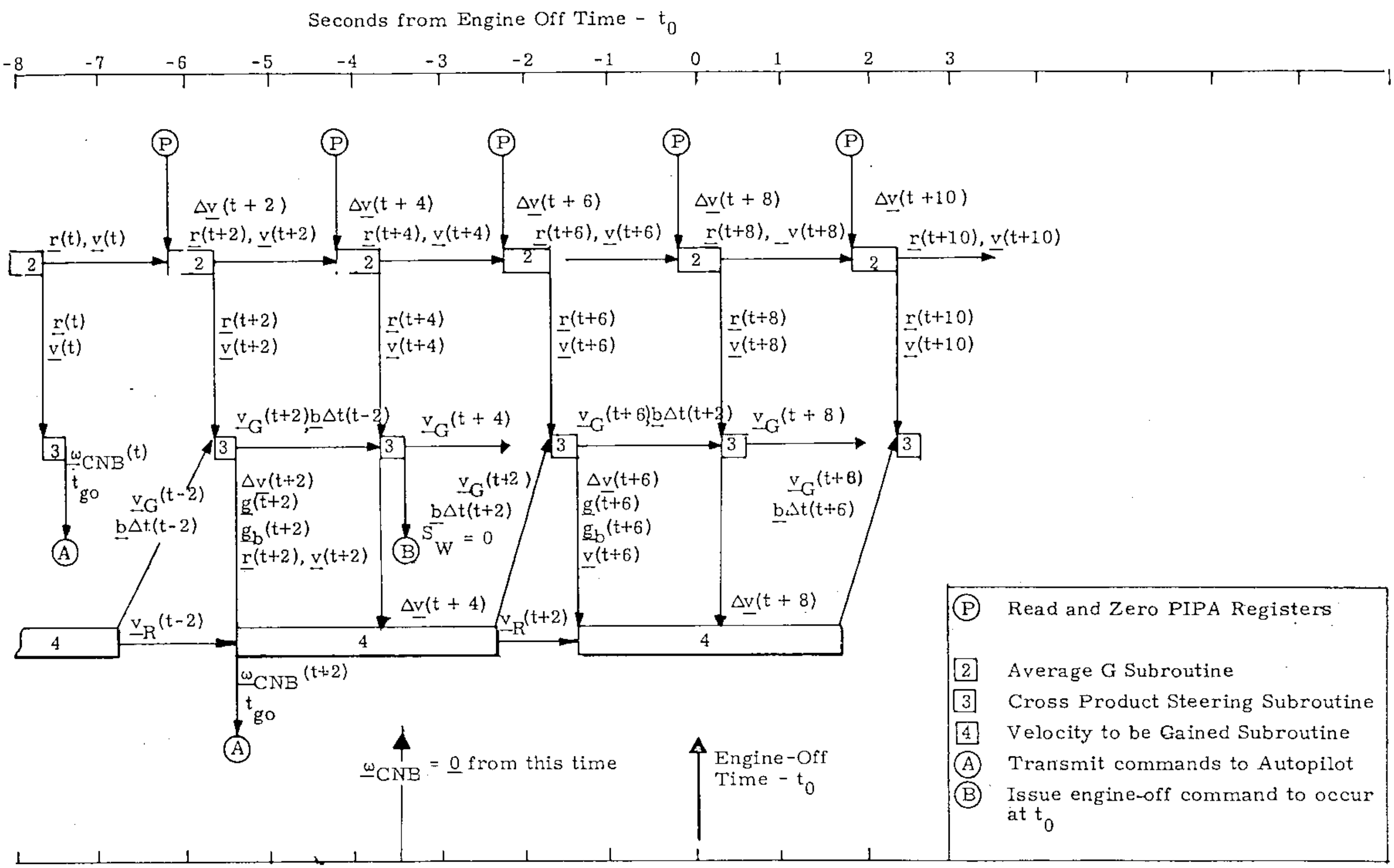


Fig. 3.3-6 Engine-off Lambert Aim Point Subroutine Sequencing for SPS Maneuvers

5.3.3.3 Pre-Thrust Computations

The objective of the computations required prior to thrusting maneuvers is to determine the following:

(1) The desired thrust direction at ignition.

(2) At time t_{IG} - 5 the duration of the powered maneuver is estimated to determine if there will be enough time to allow active steering for the SPS.

(3) Whether an IMU realignment is required to avoid gimbal lock.

(4) Various parameters and variables required by subsequent powered flight routines.

The two major guidance modes using cross product steering are the External ΔV guidance mode and the Lambert Aim Point Maneuver guidance mode. The pre-thrust computations required for the External ΔV mode are presented in Section 5.3.3.3.1. Those required for the Lambert Aim Point Maneuver mode are described in Section 5.3.3.3.2. The initial IMU alignment computations and maneuver time logic is summarized in Section 5.3.3.3.3.

The following description of pre-thrust computations applies to both SPS (P-40) and RCS (P-41) maneuvers.

5.3.3.3.1 External ΔV Maneuver Pre-Thrust Computations

External ΔV maneuver guidance is normally used to control orbital phasing maneuvers or an externally targeted maneuver in which a constant thrust attitude is desired. The guidance program accepts input data via the DSKY (P-30) or the telemetry uplink (P-27) in the form of 3 components of an impulsive $\Delta \underline{V}_{LV}$ expressed in a local vertical coordinate system of the active vehicle at the ignition time t_{IG}. An approximate compensation for the finite maneuver time is made within the program by rotating the $\Delta \underline{V}_{LV}$ vector, and the guidance program issues commands to the spacecraft control system so as to apply the compensated velocity increment along an inertially fixed direction. The active vehicle state vector is normally either available or can be extrapolated to the ignition time in the CMC.

The pre-thrust computations required for the External ΔV guidance mode are shown in Fig. 3. 3-7. The following parameter definitions refer to this figure.

$\Delta \underline{V}_{LV}$ Specified velocity change in the local vertical coordinate system of the active vehicle at the time of ignition. This is an input parameter.

$$\Delta \underline{V}_{LV} = \begin{pmatrix} \Delta V_X \\ \Delta V_Y \\ \Delta V_Z \end{pmatrix}$$

$\Delta \underline{V}$ Specified velocity change in Basic Reference Coordinates

t_{IG} Ignition time, an input parameter.

$\Delta \underline{V}_P$ The inplane velocity components of $\Delta \underline{V}_{LV}$ in the Basic Reference Coordinate System.

θ_T The approximate central angle traveled during the maneuver.

MGA Angle equivalent to the IMU middle gimbal angle when the vehicle X axis is aligned along $\Delta \underline{v}$. This angle is used to cneck for gimbal lock tolerance.

ENTER

$\underline{r}(t)$, $\underline{v}(t)$, $\Delta \underline{V}_{LV}$, t_{IG}, S_E, P_C, m

Extrapolate state vector to t_{IG} using Coasting Integration Routine (Sec. 5. 2. 2) obtaining $\underline{r}(t_{IG})$, $\underline{v}(t_{IG})$

Middle Gimbal Angle (MGA) Computation

$$MGA = \sin^{-1} [\underline{Y}_{REF} \cdot \text{UNIT}(\Delta \underline{V})]$$

($\underline{Y}_{REF}$ is second row of [REFSMMAT])

MGA < 0 — Yes → $MGA = MGA + 360^{\circ}$

No

$$\underline{X} = \text{UNIT}\ \{ [\underline{r}(t_{IG}) \times \underline{v}(t_{IG})] \times \underline{r}(t_{IG}) \}$$

$$\underline{Y} = \text{UNIT}\ [\underline{v}(t_{IG}) \times \underline{r}(t_{IG})]$$

$$\underline{Z} = -\text{UNIT}\ [\underline{r}(t_{IG})]$$

P-30

P-40
P-41

Select F based on S_E

$$\Delta \underline{V}_P = \Delta V_X \underline{X} + \Delta V_Z \underline{Z}$$

$$\theta_T = \frac{|\underline{r}(t_{IG}) \times \underline{v}(t_{IG})|\ \Delta V_{LV}\ m}{r^2(t_{IG})\ F}$$

$$\Delta \underline{V}_C = \Delta V_P \left\{ \text{UNIT}(\Delta \underline{V}_P) \cos\left(\frac{\theta_T}{2}\right) + \text{UNIT}(\Delta \underline{V}_P \times \underline{Y}) \sin\left(\frac{\theta_T}{2}\right) \right\}$$

$$\underline{v}_G(t_{IG}) = \Delta \underline{V}_C + \Delta V_Y \underline{Y}$$

$$\underline{u}_{TD} = \text{UNIT}\ [\underline{v}_G(t_{IG})], \quad \underline{b}\Delta t = \underline{0}, \quad c = 0$$

Extrapolate State to t_{IG} - 30

* See Section 5.3.3.3.4 for ignition delay procedure

Go to Initial Attitude and t_{go} Routines (Fig. 3. 3-10 and Fig. 3. 3-11)

Figure 3. 3-7 External ΔV Prethrust Routine

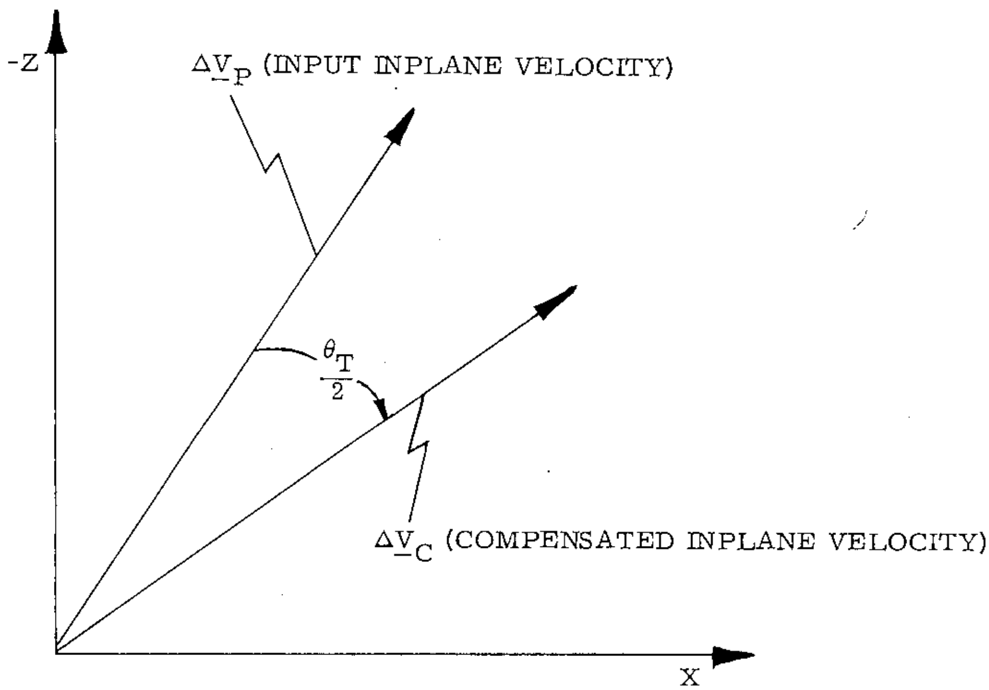


Figure 3.3-8 Inplane External ΔV Maneuver Angle Compensation

m — Vehicle mass.

S_E — Engine Select Switch $\begin{cases} 1 & \text{P-40 (SPS)} \\ 0 & \text{P-41 (RCS)} \end{cases}$

F — Prestored nominal thrust based on the engine selection switch S_E

F_{SPS} for the SPS (P-40)

F_{RCS} for the RCS (P-41)

The values of the various engine thrust levels are listed in Section 5.9. In the case of P-41, RCS, the astronaut can select either a 2 or 4 jet translation maneuver.

$\Delta\underline{V}_C$ — The compensated inplane velocity-to-be-gained vector.

$\underline{v}_G(t_{IG})$ — Total velocity-to-be-gained at t_{IG}.

$\underline{u}_{TD}$ — Unit vector in the desired initial thrust direction.

c — Cross Product Steering Constant

This steering constant (Section 5.3.3.4) is set equal to zero for External ΔV maneuvers.

The inplane External ΔV maneuver angle compensation involving $\Delta\underline{V}_P$ and $\Delta\underline{V}_C$ is illustrated in Fig. 3.3-8.

5.3.3.3.2 Lambert Aim Point Maneuver Pre-Thrust Computations

The objective of the Lambert Aim Point Maneuver Guidance program is to control the cut-off velocity vector such that the resulting trajectory intercepts a specified target position vector at a given time. The target position vector for the TEI, LOI and LOPC maneuvers are determined by the RTCC and no CMC targeting routines exist for these maneuvers. Return to earth aborts initiated within the lunar sphere of influence must also be RTCC targeted.

The table below summarizes the maneuvers performed by Lambert Aim Point Maneuver Guidance.

Maneuvers Controlled by Lambert Aim Point Maneuver Guidance

Maneuver	Program	*Targeting Parameters From
TEI	P-31	RTCC
LOI (First Maneuver)	P-31	RTCC
LOPC	P-31	RTCC
Rendezvous Intercept	P-34	RTCC, CMC or LGC
Rendezvous Midcourse Maneuver	P-35	RTCC, CMC or LGC
Stable Orbit Rendezvous Maneuvers	P-38, P-39	RTCC, CMC or LGC
Some Cislunar Midcourse Corrections	P-31	RTCC (Within Lunar Sphere) RTCC or CMC (Outside Lunar Sphere)
Return-to-Earth Maneuvers	P-37	RTCC (Within Lunar Sphere) RTCC or CMC (Outside Lunar Sphere)

*Targeting Parameters
1) Ignition time t_{IG}
2) Time of flight to conic target aim vector (t_F)
3) Conic target aim vector $\underline{r}$ (t_2) where $t_2 = t_F + t_{IG}$
4) c cross product steering constant

The Lambert Aim Point Maneuver guidance mode basically uses the Lambert Subroutine of Section 5. 5. 6 called through the Initial Velocity Subroutine of Section 5. 5. 11 during the pre-thrust phase to determine the required initial thrust direction, $\underline{u}_{TD}$. The pre-thrust computations required for the Lambert Aim Point guidance mode are shown in Fig. 3. 3-9. The primary operation shown in this figure is the computation of the required intercept velocity vector $\underline{v}_R$ at the ignition time, t_{IG}. The following parameter definitions refer to Fig. 3. 3-9.

$\underline{r}(t_2)$	Offset target intercept position vector at time t_2. This parameter is determined by the preceding targeting program and is an input to the Lambert Aim Point prethrust subroutine.
t_2	Intercept time of arrival associated with the offset target vector, $\underline{r}(t_2)$. This is an input parameter.
S_R	Target rotation switch set in P-34, P-35, P-38 or P-39 indicating that the target vector was rotated into the orbital plane due to proximity to 180° transfer conditions. $S_R \begin{cases} 1 & \text{Target vector rotated} \\ 0 & \text{No rotation} \end{cases}$
N_1	Number of target offset iterations desired in the Initial Velocity Subroutine of Section 5. 5. 11.
ϵ	Initial Velocity Subroutine parameter.
$\underline{v}_R(t_{IG})$	Required velocity vector at the ignition time t_{IG} to establish the intercept trajectory.
$\underline{g}$	Total gravity vector associated with $\underline{r}(t_{IG})$.
$\underline{b}\,\Delta t$	Incremental change of the velocity-to-be-gained vector over one sample period.
MGA	The angle equivalent to the IMU middle gimbal angle when the vehicle X axis is aligned along $\underline{v}_G$.

c	Cross Product Steering Constant The cross product steering constant, c, is set equal to one if the pre-thrust program was P-34 P-35, P-38 or P-39, and 1/2 if the pre-thrust program was P-37, (Section 5.4). If the pre-thrust program was the External ΔV Program, P-30, c is set equal to zero (Fig. 3.3-7). For RCS maneuvers (P-41) the constant c is set to zero before the Lambert Aim Point Maneuver Pre-Thrust Computation as shown in Fig. 3.3-9. In pre-thrust program P-31 (Lambert Aim Point Maneuver Guidance) the value of c is determined by RTCC and uplinked with other target parameters (Fig. 3.3-9).
ec	Pad loaded value of the cross product steering constant. RTCC uplink can modify the value of ec through the range -4 to +4 for Lambert targeting (Fig. 3.3-7).

The rotation switch S_R is set in the Lambert Aim Point targeting programs P-34, P-35, P-38 and P-39 to indicate whether the target aim point vector was within a specified cone angle, ϵ, measured from the 180° transfer angle condition. If the initial target vector was within this cone angle, it is rotated into the active vehicle orbital plane in the Initial Velocity Subroutine of Section 5.5.11 so that excessive plane change and ΔV requirements are avoided about the 180° transfer angle condition. In the intercept targeting programs P-34 and P-35 the cone angle ϵ is set at 15°, and active vehicle transfer angles between 165° to 195° are normally avoided in the targeting procedure. If a transfer angle condition falling within this $180^{\circ} \pm 15^{\circ}$ sector ($S_R = 1$) is intentionally selected either during the TPI targeting (P-34), or results from a rendezvous midcourse correction maneuver (P-35) during an intercept trajectory targeted for more than 180°, the Lambert Aim Point Maneuver Pre-Thrust Routine of Fig. 3.3-9 increases the Initial Velocity Subroutine cone angle ϵ to 45° so that the active vehicle transfer angle will not change from inside to outside the cone angle during the powered maneuver. Such a condition is undesirable since the intercept trajectory would be retargeted during the powered maneuver. Likewise, if the initial transfer central angle falls outside the 15° cone angle ϵ of programs P-34 and P-35 ($S_R = 0$), ϵ is decreased to 10° in Fig. 3.3-9 to reduce the possibility of the transfer angle changing from outside to inside the cone angle during a powered maneuver. It should be noted that all other targeting programs (P-31, and P-37) set S_R equal to zero.

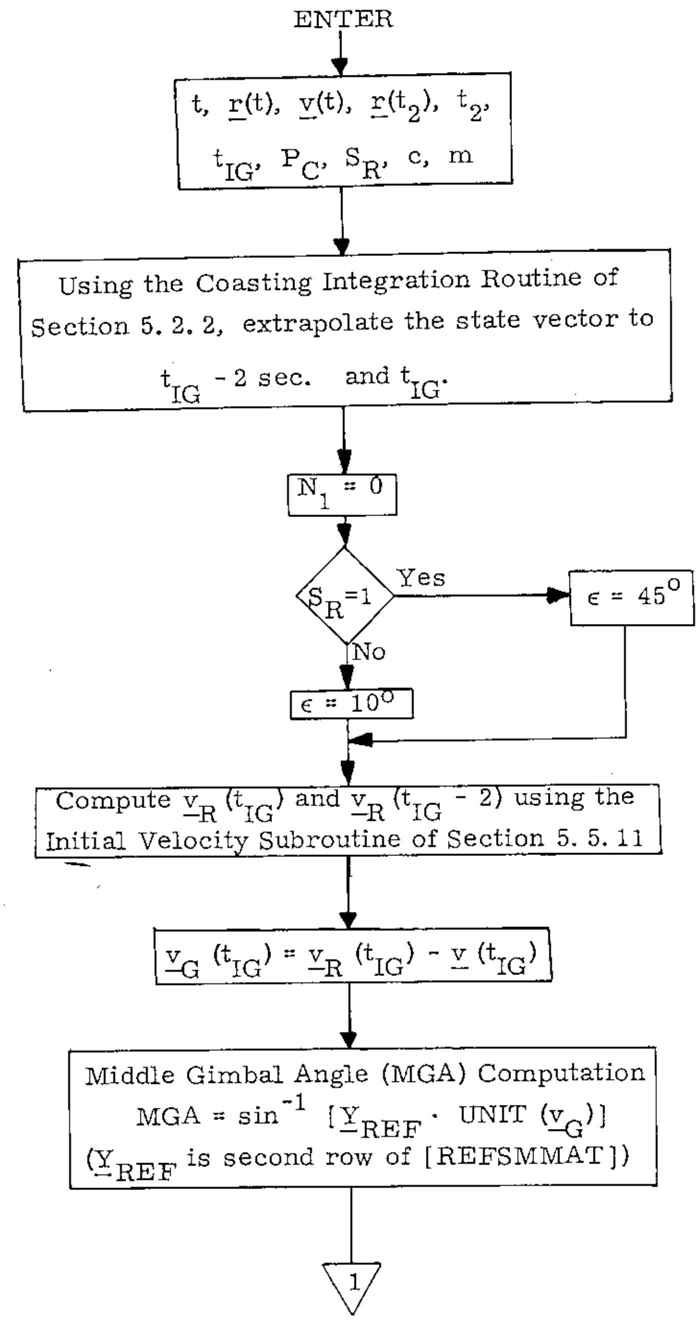
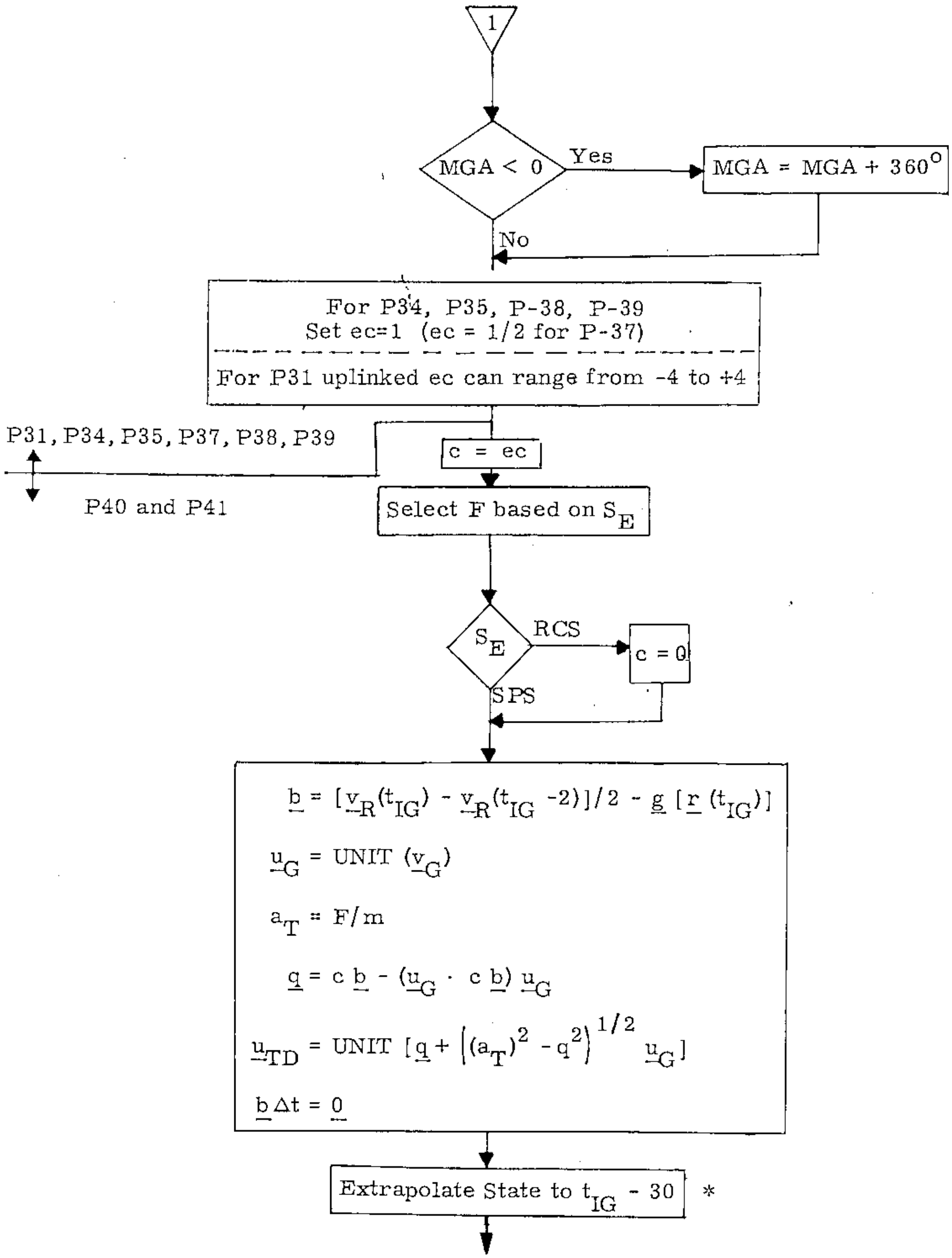


Figure 3. 3-9 Lambert Aim Point Maneuver Pre-Thrust Routine
(page 1 of 2)



Go to Initial Attitude and t_{go} Routines (Fig. 3.3-10 and Fig. 3.3-11)

*See Section 5.3.3.3.4 for ignition delay procedure.

Figure 3.3-9 Lambert Aim Point Maneuver Pre-Thrust Routine (page 2 of 2)

5.3.3.3.3 Initial IMU Alignment and Maneuver Time-to-Go Computations

Initial Attitude Routine

The following pre-thrust computations and functions are required for both the External ΔV and Lambert Aim Point guidance modes:

1. Determination of the preferred IMU alignment for the thrusting maneuver (Section 5. 1. 4. 2. 1).
2. Alignment of the vehicle thrust axis along the desired initial thrust direction, $\underline{u}_{TD}$.
3. Estimate the maneuver time, t_{go}, prior to engine ignition.

In Fig. 3. 3-10 the following parameter definitions apply:

[REFSMMAT]	Transformation matrix from the BRC System to the IMU or Stable Member Coordinate System (Section 5. 6. 3. 3)
[SMNB]	Transformation matrix from the Stable Member Coordinate System to the Navigation Base Coordinate System (Section 5. 6. 3. 2)
$\underline{u}_A$	Unit vector of the assumed thrust acceleration in Navigation Base Coordinates. For the SPS, the unit vector $\underline{u}_A$ is along the engine axis (called engine bell).
$\underline{u}_D$	Unit vector of the desired thrust direction in Stable Member Coordinates.

$p_T = p + p_0$ Total pitch trim offset angle about the spacecraft Y axis.

$y_T = y + y_0$ Total yaw trim offset angle about the spacecraft Z axis.

where:

p and y Electrical pitch and yaw trim angles respectively.

p_0 Mechanical pitch trim angle equal to -2.15° about the spacecraft Y axis.

y_0 Mechanical yaw trim angle equal to $+0.95^{\circ}$ about the spacecraft Z axis.

For an SPS burn, because of pitch and yaw trim, $\underline{u}_A$, the unit vector of the assumed thrust acceleration vector in Navigation Base Coordinates is not a unit vector along the spacecraft X axis (1, 0, 0) but is a function of the pitch and yaw trim angles given above. In Fig. 3.3-10 it is called the Engine Axis unit vector, $\underline{u}_A$. The maneuver then places the engine axis unit vector ($\underline{u}_A$) along the desired unit thrust direction $\underline{u}_D$.

Time-to-Go Prediction Routine

Very short burns require special consideration since some interval of time elapses before effective steering is achieved. Not only must the autopilot react to the pointing commands, but the engine-off signal may be required before the $\Delta\underline{V}$ from the PIPA's can be measured. To this end an estimate of the burn time, t_{go}, is made on the basis of SPS engine data, prior to engine ignition as shown in Fig. 3.3-11.

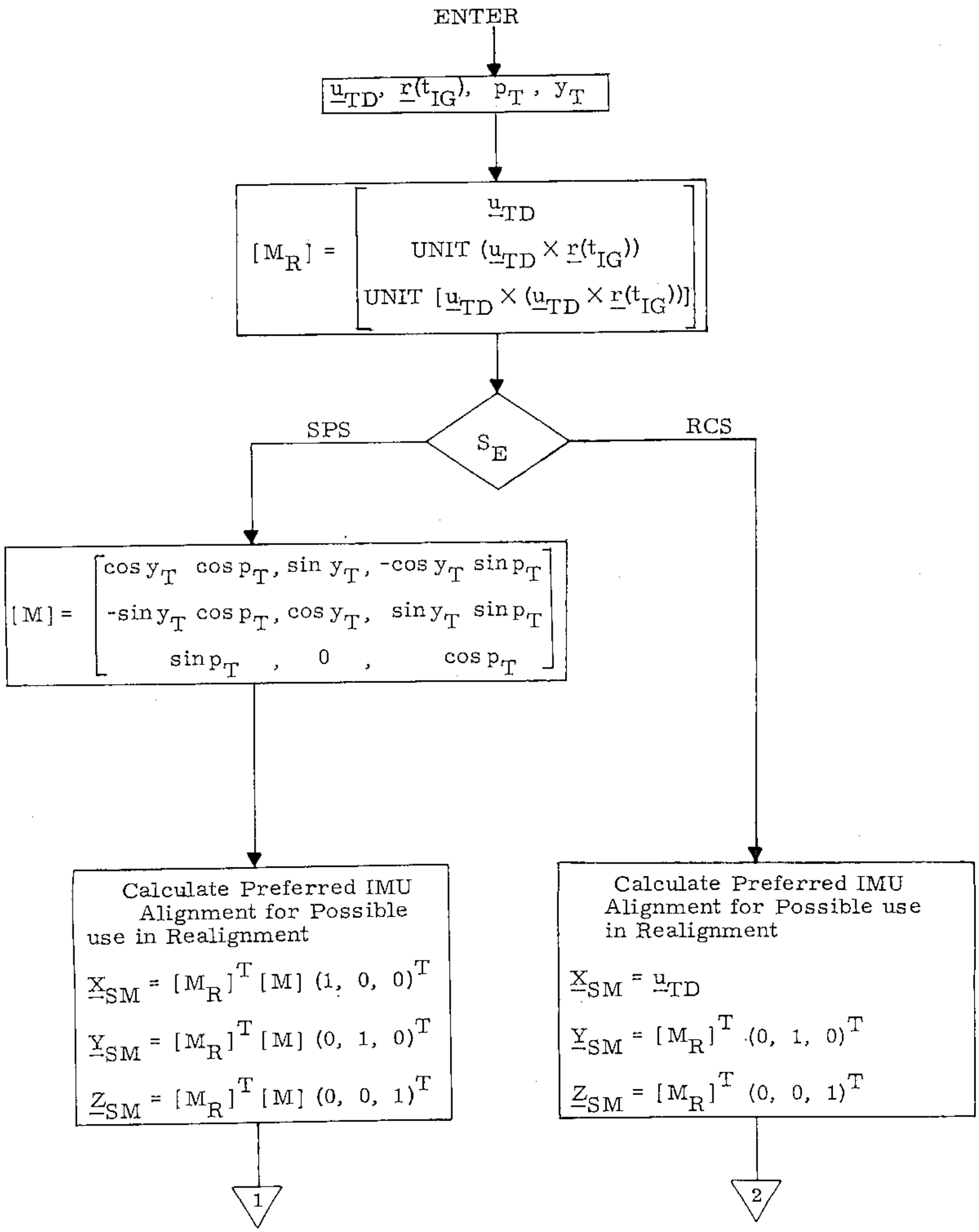


Figure 3.3-10 Initial Attitude Routine
(page 1 of 2)

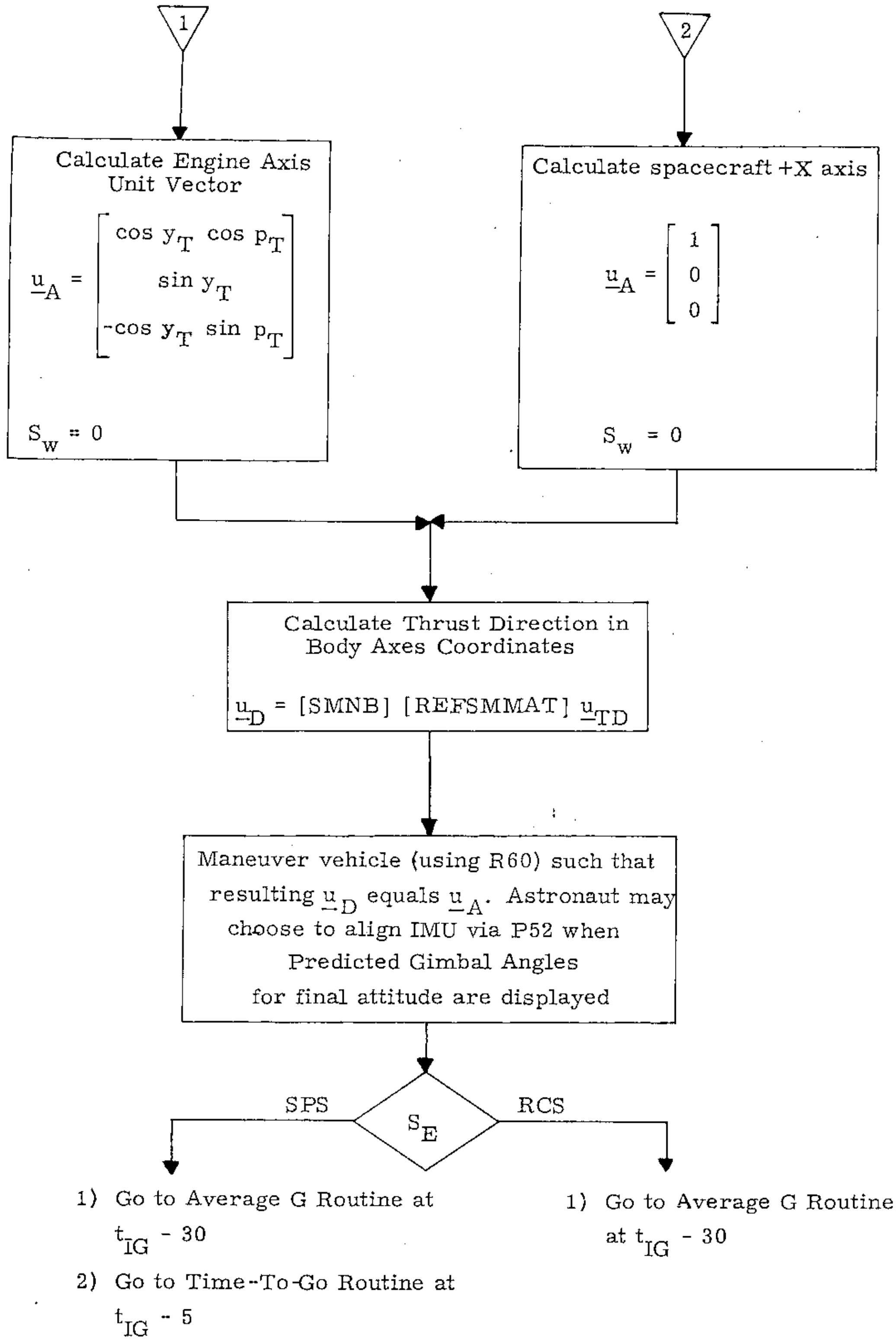


Figure 3.3-10 Initial Attitude Routine
(page 2 of 2)

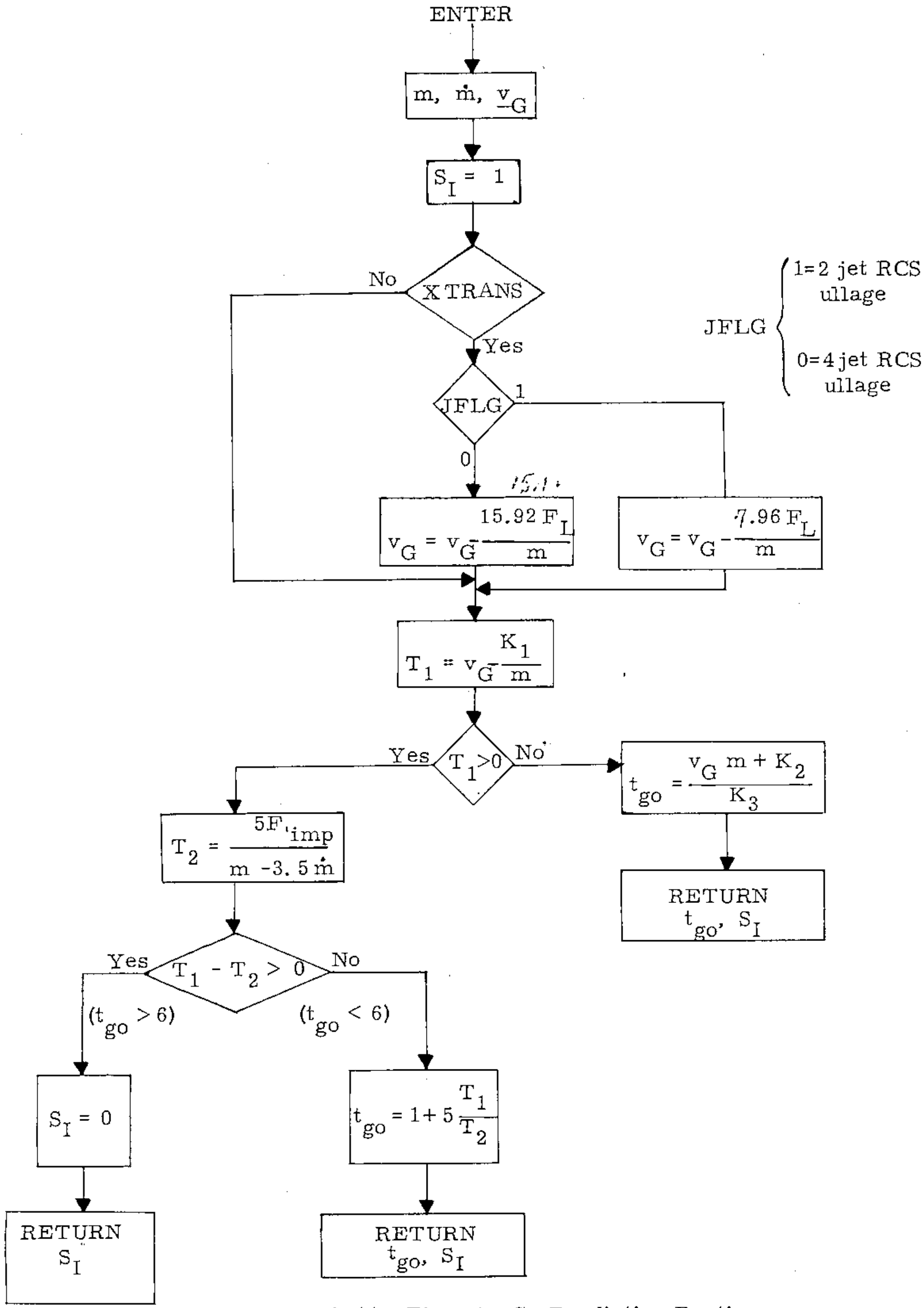


Figure 3.3-11 Time-to-Go Prediction Routine

With reference to Fig. 3.3-11:

S_I Impulse switch

$$S_I \begin{cases} 1 & \text{Indicates a maneuver less than 6 seconds and no steering is required} \\ 0 & \text{Indicates a maneuver duration of at least 6 seconds, and normal steering will occur} \end{cases}$$

F_L Ullage thrust for 2 jets

K_1 SPS impulse velocity acquired in a one second maneuver for a unit mass vehicle. This value is erasable.

K_2 SPS minimum impulse constant

K_3 SPS minimum impulse constant equal to the slope of minimum impulse curve.

F_{imp} Steady state thrust of the SPS engine. This value is used only in the short burn logic and is an erasable quantity.

The initial computation in Fig. 3.3-11 estimates the velocity-to-be-gained after ullage. There is an option of 2 jet or 4 jet RCS ullage as indicated in Fig. 3.3-11. This subroutine is performed at approximately five seconds prior to ignition, the PIPA's are read at six seconds prior to ignition and the ullage is terminated at two seconds after ignition, consequently it is for this reason about eight seconds of ullage is accounted for as shown in Fig. 3.3-11.

The hand controller signals are observed at the initiation of this routine. The ullage compensation in the time-to-go routine will be made only if +X translation (XTRANS ON) is indicated.

If the SPS were chosen (P-40), Fig. 3.3-11, a check is first made to determine if the maneuver time is less than one second. If the maneuver time is less than one second, the t_{go} estimate is made on SPS minimum impulse test data represented by the constants K_2 and K_3 (see Section 5.9). In this case, no active steering is attempted ($S_1 = 1$). If the maneuver time is greater than one second but less than 6 seconds, t_{go} is computed as shown in Fig. 3.3-11, and again no active steering is attempted. If the estimated maneuver time is greater than 6 seconds, active steering is used, and t_{go} computations are performed during the maneuver.

With reference to Fig. 3.3-10, if the RCS were chosen for the maneuver, (P-41), the t_{go} prediction calculation is not made.

If the estimated maneuver time, t_{go}, for the SPS is less than 6 seconds, the Engine-Off signal is set for the actual ignition time plus t_{go}.

5.3.3.3.4 Ignition Delay Procedures Caused by Pre-Thrust Computations

The normal pre-thrust computations (Sections 5.3.3.3.1 and 5.3.3.3.2) require an extrapolation of the CSM state vector to thirty seconds prior to nominal ignition time, i.e., $t_{IG} - 30$. If the Coasting Integration Routine of Sec. 5.2.2 does not complete the extrapolation before $t_{IG} - 40$ occurs, then an ignition delay procedure occurs as follows:

1.) The astronaut is alerted to this condition by a program alarm.

2.) The integration continues one step at a time until the CSM state vector time minus the current time minus the integration computing interval (usual 4 to 5 secs) is greater than 5 seconds. This will permit a 5 second blanking interval (Section 4 State Vector Integration (MID to AVE) Routine R-41). R-41 allows Average G initialization to occur at least 5.6 seconds after completion of last integration step.

3.) The maneuver ignition time is then redefined to be 30 seconds from the resulting CSM state vector time, and the normal pre-ignition sequence is started.

5.3.3.4 Cross Produce Steering Routine

The cross product steering concept is the basic control concept for both External ΔV and Lambert Aim Point Guidance modes. The cross product steering logic is shown in Fig. 3.3-12. The following parameter definitions not previously described apply to this figure.

$\Delta \underline{v}_{SM}$	PIPA Measured velocity vector over the computation cycle Δt in IMU coordinates
$\Delta \underline{v}$	PIPA measured velocity over the computation cycle Δt transformed to the Basic Reference Coordinate System
Δv_p	A constant which establishes the Δv which must be sensed in a 2 second computation interval. It is approximately equivalent to thrusting at 15% full SPS thrust with fully loaded vehicle for 2 seconds.
S_w	A logic switch in the cross product steering routine which when set to 1 allows steering commands and t_{go} calculations to be made. S_w is set to 1 at the fixed time of 2 seconds from engine on command. S_w is set to 0 when the computed time-to-go first becomes less than four seconds.
$\Delta t_{Tail\text{-}off}$	A constant representing the duration of a burn at maximum thrust equivalent to the tail-off impulse after the engine-off signal is issued.

$\Delta \underline{v}_G$	$\underline{b} \, \Delta t - \Delta \underline{v}$
V_e	Engine exhaust velocity = $g \, I_{SP}$
K	Guidance steering gain required for desired dynamic response of the combined powered guidance and thrust control (autopilot) loops
$\underline{\omega}_C$	Commanded attitude rate in the Basic Reference Coordinate System.
$\underline{\omega}_{CNB}$	Commanded attitude rate in Navigation Base Coordinates which is sent to the CSM attitude control system.
c	The cross product steering constant, c, is set equal to one if the pre-thrust program was P-34, P-35, P-38, or P-39, and 1/2 if the pre-thrust program was P-37, (Section 5.4). If the pre-thrust program was the External ΔV Program, P-30, c is set equal to zero (Fig. 3.3-7). For RCS maneuvers (P-41) the constant c is set to zero before the Lambert Aim Point Maneuver Pre-Thrust computation as shown in Fig. 3.3-9. In pre-thrust program P-31 (Lambert Aim Point Guidance) the value of c is determined by RTCC and uplinked with other target parameters (Fig. 3.3-9).
$\Delta \underline{m}$	$c \, \underline{b} \, \Delta t - \Delta \underline{v}$
LOFLG	This flag prevents a premature engine fail indication after a manual engine start $\text{LOFLG} \begin{cases} 1 & \text{steer} \\ 0 & \text{no steer} \end{cases}$
$\Sigma \Delta \underline{v}$	Accumulated PIPA readings used to generate an extrapolation of the Lambert soution. When a new solution becomes available $\Sigma \Delta \underline{v}$ is set to zero.

N — Number of cycles between Lambert solutions. The CMC computation during SPS maneuvers occasionally prevent completion of the Lambert solution in 2 to 4 seconds. The program is capable of processing an N cycle $\underline{v}_G$ update.

S_F — Lambert first pass flag. The Lambert first pass occurs at approximately t_{IG}-26. After the first pass it is set to zero.

$$S_F \begin{cases} 1 & \text{First Lambert pass. This results in bypass of the } \underline{b}\Delta t \text{ computation.} \\ 0 & \text{Not first Lambert pass.} \end{cases}$$

Swtich S_w is set to zero for short duration thrust periods and during the first two seconds of long duration thrust periods. In both of these cases there is no active steering and the vehicle attitude is held at the pre-thrust alignment. When S_w is set to 1, active steering is performed. The time-to-go, t_{go} computation and steering commands $\underline{\omega}_{CNB}$ are performed as shown in Fig. 3.3-12. When the computed t_{go} becomes less than 4 seconds, then the engine-off signal is set and switch S_w is reset to zero. For the remainder of the maneuver, no further computations are made except for $\underline{v}_G$ updating.

With reference to Fig. 3.3-12, the logic switch S_w is set to zero by the sequencing routine. The only function of the cross product steering routine is to update the velocity-to-be-gained vector $\underline{v}_G$ with $\Delta\underline{v}$ and $\underline{b}\,\Delta t$, as long as S_w is zero.

The steering command generated by this routine is $\underline{\omega}_{CNB}$ which is in Navigation Base Coordinates. The objective of the cross product steering concept is to control the thrust acceleration vector such that the following condition is satisfied:

$$\underline{v}_G \times (c\,\underline{b} - \underline{a}_T) = \underline{0}$$

In general, however, there will be a directional error and the steering command $\underline{\omega}_{CNB}$ tends to align the vehicle such that the above equation is satisfied.

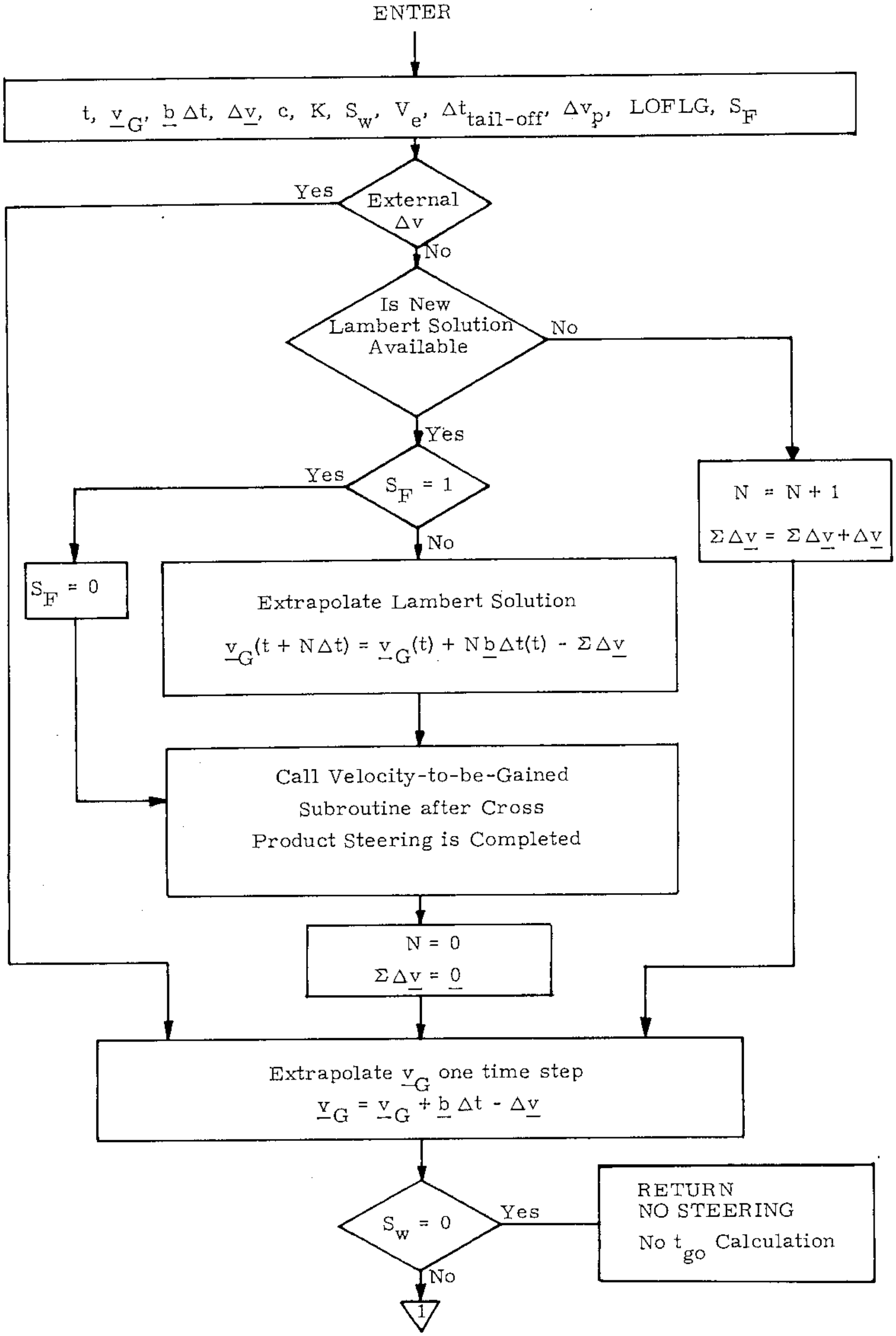


Figure 3.3-12 Cross Product Steering Subroutine (page 1 of 2)
Update $\underline{v}_G$ Section

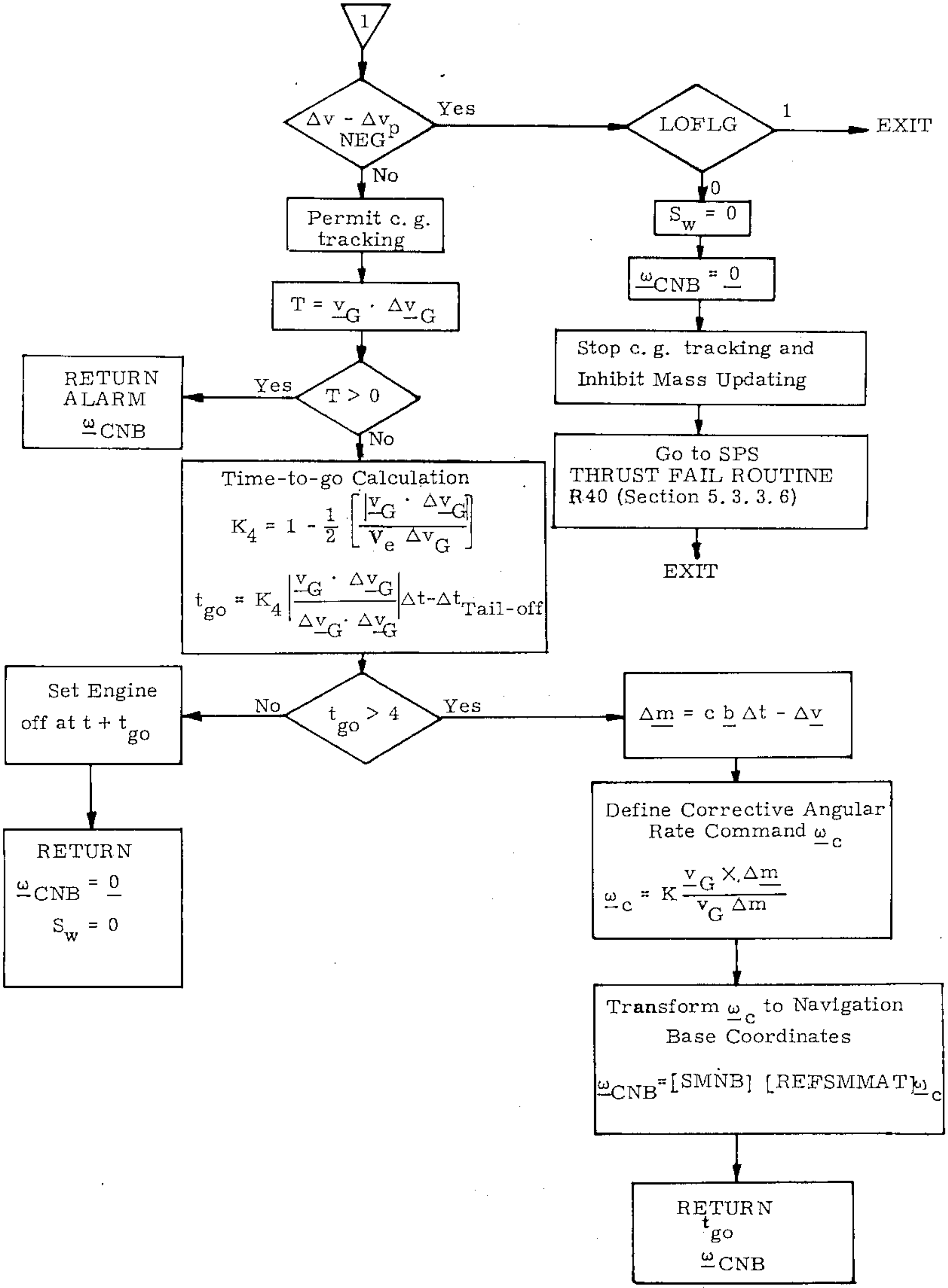


Figure 3. 3-12 Cross Product Steering Subroutine (page 2 of 2): t_{go} and Steering Command Computations

The cross-product steering routine, as shown in Fig. 3.3-12 is divided into two sections.

(a) Update $\underline{v}_G$: This portion of the cross-product steering routine provides an up to date velocity-to-be-gained, $\underline{v}_G$, for use in the t_{go} and steering command computations. In the event a new velocity-to-be-gained is not available, the old $\underline{v}_G$ is extrapolated using the old $\underline{b}\,\Delta t$ value. If a new $\underline{v}_G$ and $\underline{b}\,\Delta t$ are available, they are used.

(b) t_{go} and steering command calculations: This portion of the cross product steering routine uses the $\underline{v}_G$ generated in the update $\underline{v}_G$ section to calculate t_{go} and steering commands to be sent to the DAP. In addition the following control options are provided:

(1) If the present Δv is less than Δv_p, where Δv_p is approximately equivalent to thrusting at 15% full SPS thrust with fully loaded vehicle for 2 secs., the steering rate commands are zeroed, c. g. tracking is stopped and the SPS Thrust Fail Routine (R-40) (Section 5.3.3.5) is entered. Δv_p is an erasable quantity.

(2) An alarm is issued if $\underline{v}_G \cdot \Delta\underline{v}_G$ is positive. This is equivalent to pointing the thrust vector in the wrong direction.

5.3.3.5 Velocity-to-be-Gained Routine

The velocity-to-be-gained computations shown in Fig. 3.3-13 are those carried out during the Lambert Aim Point powered flight guidance. The velocity-to-be-gained computation for the External ΔV guidance mode is simpler than that for the Lambert Aim Point guidance mode. The External ΔV velocity-to-be-gained computation is that shown in the cross product steering routine of Fig. 3.3-12 and is equivalent to

$$\underline{v}_G = \underline{v}_G - \Delta\underline{v}$$

since $\underline{b}\Delta t = \underline{0}$ for the External ΔV mode as shown in Fig. 3.3-7.

The velocity-to-be-gained computations for the Lambert Aim Point guidance mode involve the determination of a new $\underline{v}_G$ by processing the Lambert Subroutine via the Initial Velocity Subroutine. A second objective is the computation of a new $\underline{b}\Delta t$ parameter for use by the cross product steering routine. A new required velocity, $\underline{v}_R$, is also determined for use in the next computation cycle of the velocity-to-be-gained subroutine. The CMC computations[5] during SPS maneuvers occasionally prevent completion of the Lambert Solution in 2 to 4 seconds. The program is capable of processing an N cycle $\underline{v}_G$ update (Fig. 3.3-13).

The following parameter definitions refer to Fig. 3.3-13.

$$\left.\begin{array}{l}\underline{r}(t)\\ \underline{v}(t)\\ t\end{array}\right\}$$ active vehicle state vector

$\underline{r}(t_2)$ Offset target intercept position vector at time t_2. This parameter is determined by the preceding targeting program (P-34, P-35, P-37, P-38, P-39, or P-31).

t_2	Intercept time of arrival associated with the offset target vector $\underline{r}(t_2)$. This is an input target parameter.
t_{IG}	Nominal ignition time.
$\underline{v}_R(t - \tau)$	Required velocity vector at the preceding Lambert computation cycle.
τ	Time interval between the current and previous Lambert computation cycle = $N\Delta t$.
S_R	Target rotation switch set in P-34, P-35, P-38 or P-39 indicating that the target vector was rotated into the orbital plane due to proximity to 180° transfer. $S_R \begin{cases} 1 & \text{Target vector rotated} \\ 0 & \text{No rotation} \end{cases}$
$\underline{g}$	Total gravity acceleration vector (Section 5.3.2).
$\underline{g}_b$	Component of the earth gravity acceleration vector representing earth oblateness effects (Section 5.3.2).
$\Delta\underline{v}(t)$	Measured PIPA velocity change in the Basic Reference Coordinate system.
N_1	Number of target offset iterations desired in the Initial Velocity Subroutine (Section 5.5.11).
ϵ	Initial Velocity Subroutine parameter.
$\underline{v}_R(t)$	Required velocity vector at time t.
$\underline{v}_G(t)$	Velocity-to-be-gained vector at time t.
$\underline{v}_G(t + \Delta t)$	Extrapolated $\underline{v}_G$ one computation time step.

N Number of cycles between Lambert solutions. The CMC computation during SPS maneuvers occasionally prevent completion of the Lambert solution in 2 to 4 seconds. The program is capable of processing an N cycle $\underline{v}_G$ update.

S_F Lambert first pass flag. The Lambert first pass occurs at approximately t_{IG}-26. After the first pass it is set to zero.

$$S_F \begin{cases} 1 & \text{First Lambert pass. This results in bypass of the } \underline{b}\Delta t \text{ computation.} \\ 0 & \text{Not first Lambert pass.} \end{cases}$$

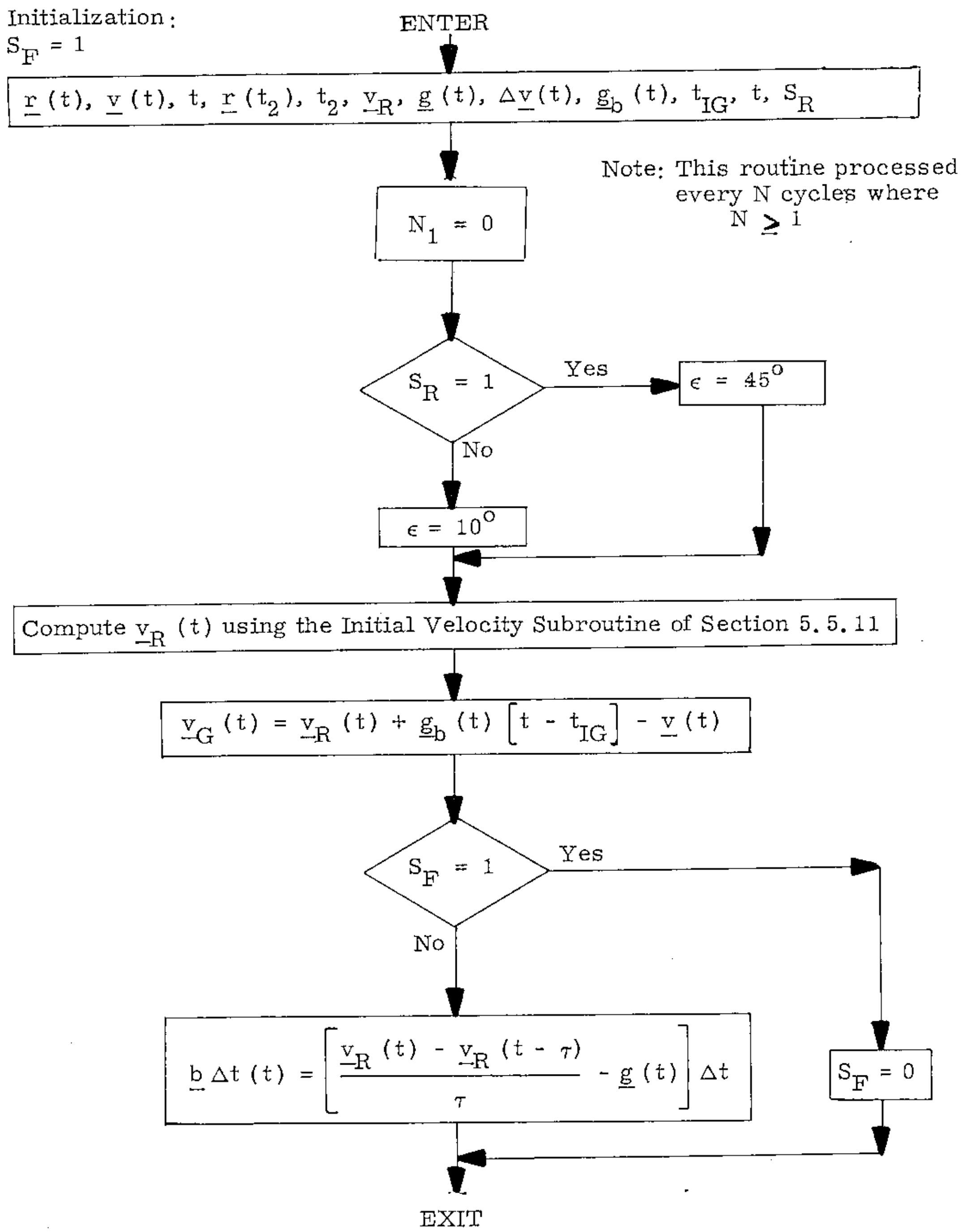


Figure 3.3-13 Velocity-to-be-Gained Subroutine for Lambert Aim Point Guidance

It should be noted that in Fig. 3.3-13 the velocity-to-be-gained, $\underline{v}_G$, derived from the Lambert solution using an offset target vector is modified by the term $\underline{g}_b(t)\ [t - t_{IG}]$. This term is an approximation to the velocity change contributed by the earth oblateness effect. The compensation used in this subroutine is computed as the current oblateness acceleration, $\underline{g}_b(t)$, multiplied by the time since nominal ignition $(t - t_{IG})$ where t_{IG} is the nominal ignition time. This correction is zero for lunar orbits. The objective of this correction is to reduce cut-off errors due to finite maneuver time effects, and to minimize commanded thrust attitude variations during the maneuver. These two effects occur during long maneuvers because in accounting for earth oblateness effects in the initial targeting programs (P-34 and P-35), it is assumed that an impulsive maneuver will be applied at ignition time. Since a finite maneuver time is required, the pre-computed target aim point becomes less accurate as the maneuver progresses. The $\underline{g}_b[(t - t_{IG}]$ correction is an approximate substitute for a retargeting procedure which cannot be performed during a powered maneuver.

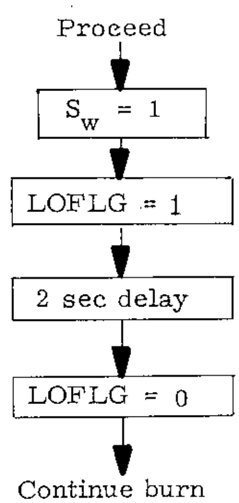
5.3.3.6 SPS Thrust Fail Routine (R-40)

The purpose of the SPS Engine Fail Routine (R-40) is to present the Astronaut with 3 options when a low SPS thrust is detected in the Cross Product Steering Subroutine (Section 5.3.3.4). The three options are:

(1) Command engine off and terminate P-40.

(2) Command engine off and return to the P-40 point where the impulse burn test is made.

(3) Proceed with the burn but with the thrust failure detection inhibited for 2 secs to prevent premature thrust fail indication as shown below:



See Section 4 for complete details of the R-40 routine

5.3.4 THRUST MONITOR PROGRAM

The Thrust Monitor Program, P-47, is used during manual or non-GNCS controlled maneuvers to monitor and display the velocity change applied to the vehicle. The program first suspends state vector updating by the VHF Range-link (resets the update and track flags), and advances the vehicle state vector to the current time by the Coasting Integration Routine of Section 5.2.2. This operation is continued until the state vector is advanced several seconds ahead of the current time as described in Section 5.3.3.3.4. The Average-G Routine of Section 5.3.2 is then initiated to allow thrusting to be started as soon as possible. The Average-G Routine is left on until the program is terminated after completion of the maneuver. The primary output of P-47 is the measured maneuver $\Delta\underline{V}$ in vehicle coordinates as described in Section 4.

The two major maneuvers during which the Thrust Monitor Program is normally used are the Translunar Injection (TLI) maneuver controlled by the Saturn guidance system, and the manually controlled terminal rendezvous maneuvers required for a CSM retrieval of the LM. During the TLI maneuver a callable display of inertial velocity, altitude above the launch pad radius and altitude rate is available to the astronaut. The altitude display parameter in this program is only valid outside the lunar sphere of influence.

During active CSM terminal rendezvous maneuvers, the Rendezvous Display Routine R-31 is normally called to display relative range, range rate, and the vehicle X axis to the horizontal plane angle θ. The operation of R-31 with the Average-G Routine of P-47 is described in Section 5.6.7.1.

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5.3.5 EARTH ORBIT INSERTION MONITOR PROGRAM - P-11

5.3.5.1 Introduction

The purpose of this section is to describe the operation and implementation of Program P-11, Earth Orbit Insertion Monitor.

This program is initiated by Program P-02, Gyro Compassing, when the liftoff discrete is detected or by the astronaut backup Verb 75 and it performs the following functions (in the order of occurrence)

(1) Zeroes the CMC clock at liftoff and updates the reference ephemeris time (see Time Definition, Section 5.1.5.5). (Time Subroutine)

(2) Computes the CMC state vector (in Basic Reference Coordinates) at liftoff and starts the Average-G computation (see Section 5.3.2) using this state vector. (State Subroutine)

(3) Computes the matrix REFSMMAT which relates the IMU Stable Member orientation to the Basic Reference Coordinate System. (State Subroutine)

(4) Computes periodically the error between the nominal desired Saturn Launch Vehicle attitude (as determined by a time dependent polynomial) and the actual Saturn Launch Vehicle attitude (as determined by the CM IMU), and transmits the error to the CDU for display by the FDAI.*
(Attitude Error Subroutine)

---

*Flight Director Attitude Indicator.

(5) Periodically computes Saturn Launch Vehicle inertial velocity magnitude, rate of change of the vehicle altitude above the launch pad radius, and the vehicle altitude above launch pad radius and displays this information via the DSKY. (Display Subroutine)

Program P-11, when activated by Program P-02 assumes

(1) The following information has been pad loaded

A_{ZP} – Azimuth of the launch vehicle on the pad measured from north to the +Z spacecraft axis positive in a right hand sense about the inward pad local vertical. See figure 3.5-1.

A_Z – launch azimuth measured from north to the X IMU Stable member axis positive in the same sense as A_{ZP}. See figure 3.5-1.

K_r – constant denoting the absolute value of the rate at which the Saturn will roll from the pad azimuth to the launch azimuth.

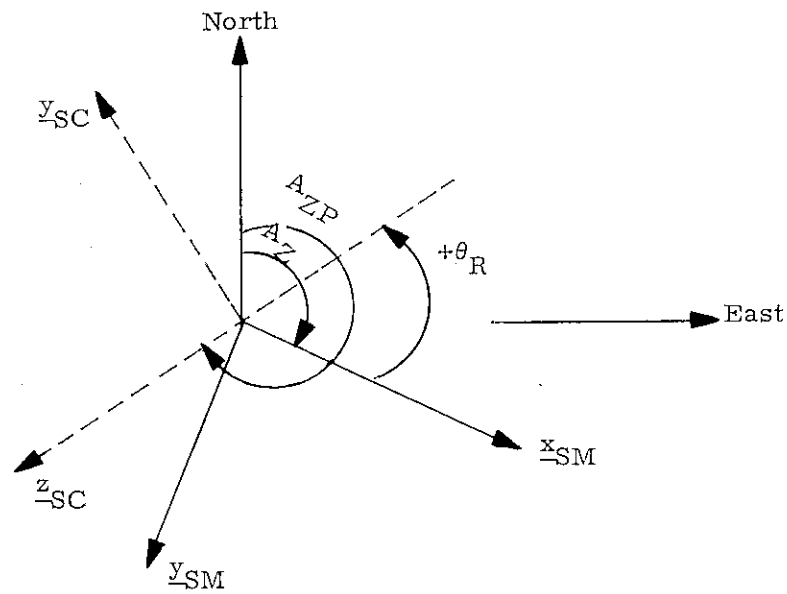
t_{E1} – the time from liftoff at which the initial Saturn roll will commence.

t_{E2} – the increment in time after t_{E1} to when the display of Saturn attitude error on the FDAI will be held constant.

$a_0, a_1, \ldots a_6$ – coefficients of a 6th order polynominal in time t, $(t_{E1} < t < (t_{E1} + t_{E2}))$ describing the nominal Saturn pitch profile.

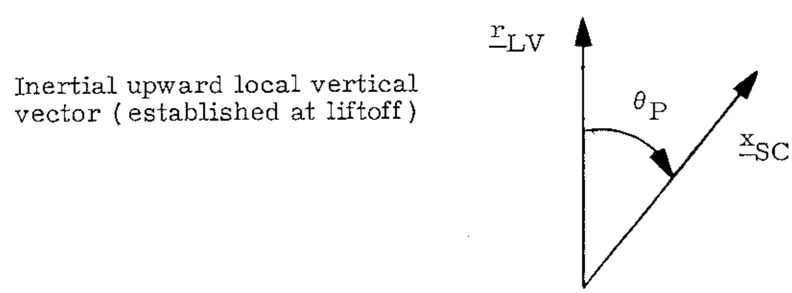
(2) The clock and reference ephemeris time were synchronized previously.

Azimuth and Roll Angle Definitions



- Plane of the paper is the pad local horizontal
- Up is out of the paper
- Spacecraft and IMU axis shown prior to launch
- After lift-off the Saturn rolls to align the $-\underline{z}_{SC}$ with $\underline{x}_{SM}$

Pitch Angle Definition



- Plane of the paper is the instantaneous pitch plane
- $\underline{y}_{SC}$ is into the paper and northerly

Figure 3.5-1 Angle Definitions

5.3.5.2 Nomenclature for P-11

t	Computer clock reading at any time t
t_0	See Section 5.1.5.5.
h	Vehicle altitude above a sphere whose radius is that of the launch pad
$\dot{h}$	Rate of change of altitude measured in the direction of the vehicle radius vector
v	Inertial velocity magnitude of the vehicle
Lat_P	Launchpad geodetic latitude
Lon_P	Launchpad geodetic longitude
Alt_I	IMU altitude above the launch pad
$\underline{U}_z$	A vector in the Basic Reference Coordinate System in the direction of the earth's rotation
ω_E	The angular velocity of the earth
[REFSMMAT]	A matrix whose rows are the location of the IMU Stable Member axes in the Basic Reference Coordinate System
$CD\underline{U}$	The current value of the IMU Gimbal Angles
θ_P	The Saturn Vehicle nominal pitch angle measured from the Launch pad local vertical at liftoff to the Saturn X axis (see figure 3.5-1).
θ_R	The Saturn nominal roll angle measured from the X IMU Stable Member axis to the negative Z spacecraft axis. (see Fig. 3.5-1).
$\underline{E}_a$	A vector representing the roll, pitch, and yaw errors about CM body axes (in a right hand sense).
$DG\underline{A}$	A vector representing the Saturn nominal desired IMU gimbal angles (x, y, z).
$\left(\frac{b}{a}\right)^2$	Square of the ratio of the earth semi minor axis to the semi major axis.

K_z	A constant computed in the State Subroutine which is utilized by the Attitude Error Display Subroutine.
t_{KS}	The elapsed time from lift-off to when the attitude error display is disabled. (Note this constant is in fixed memory).

Note that pad loaded variables are identified in Section 5.3.5.1.

5.3.5.3 Time Sequencing of P-11 Subroutines

Program P-11 is composed of four subroutines: Time Subroutine, State Subroutine, Attitude Error Subroutine, and Display Subroutine.

The Time Subroutine is selected by P-11 within 0.5 second of the lift-off discrete receipt. The State Subroutine is initiated immediately after the Time Subroutine and is through within 1 second after receipt of the lift-off discrete.

The cycling of the Attitude Error Subroutine is then started. This subroutine refreshes the attitude error FDAI display (based on the stored pitch and roll functions) approximately every 0.5 second until $t = (t_{E1} + t_{E2})$. Thereafter, until P-11 is exited, the desired gimbal angles are maintained constant at $\underline{DGA}(t_{E1} + t_{E2})$.

At the same time the attitude error display is started, the cycling of the Display Subroutine is started. This subroutine displays v, h, and $\dot{h}$ via the DSKY. It is cycled every 2 seconds following the Average-G computations and is out of synchronization with the Attitude Error Subroutine.

5.3.5.4 Time Subroutine

The procedure for clock zeroing and presetting of reference time, t_0, is shown in Fig. 3.5-2. Refer to Time Definitions, Section 5.1.5.5, for a description of how the reference ephemeris time was originally synchronized with the AGC clock prior to lift-off.

This activity does not occur precisely at lift-off, but within 0.5 second maximum of the receipt of the lift-off discrete. In any event, the clock zeroing and the constant t_0 are not changed for the remainder of the mission unless P-27 intercedes.

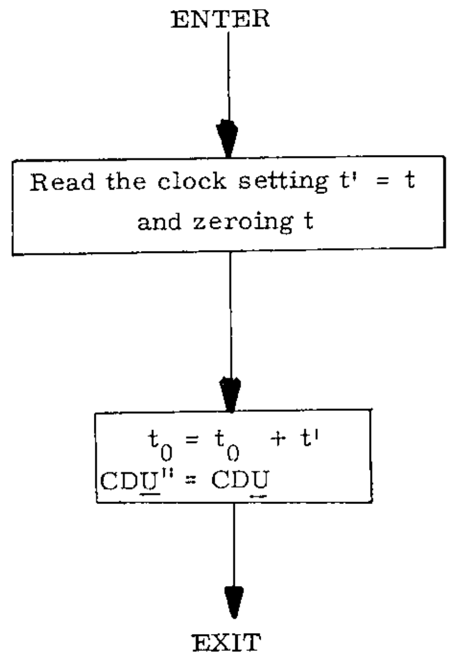


Figure 3.5-2 Time Subroutine

5.3.5.5 State Subroutine

The state vector of the vehicle at lift-off in Basic Reference Coordinates is that imparted by the earth. The first part of Fig. 3.5-3 shows this computation.

REFSMMAT, the matrix which relates the IMU stable member orientation at lift-off to the Basic Reference Coordinates, is determined as shown on page 2 of Fig. 3.5-3. This computation assumes that the stable member X and Y axes are normal to the pad local vertical and the X axis is aligned along the launch aximuth A_Z pointing down range and the Z axis toward the center of the earth. This computation determines the local vertical utilizing the characteristics of the earth's reference ellipsoid.

These computations take place within 0.75 second of the receipt of the lift-off discrete by Program P-11.

Attitude Error Subroutine

This subroutine computes and transmits to the FDAI the difference between a stored nominal Saturn Launch Vehicle attitude profile and the actual attitude profile as measured by the CM inertial measurement unit. Figures 3.5-4 and 3.5-5 present the details of these computations.

This subroutine is cycled approximately every 0.5 seconds and is terminated when mission time t reaches a preset value t_{KS}.

5.3.5.6 Display Subroutine

The computations of the display quantities v, h, $\dot{h}$ are shown on Fig. 3.5-6. Callable display parameters available during P-11 operation are described in Section 5.6.10, Orbital Parameter Display Computations.

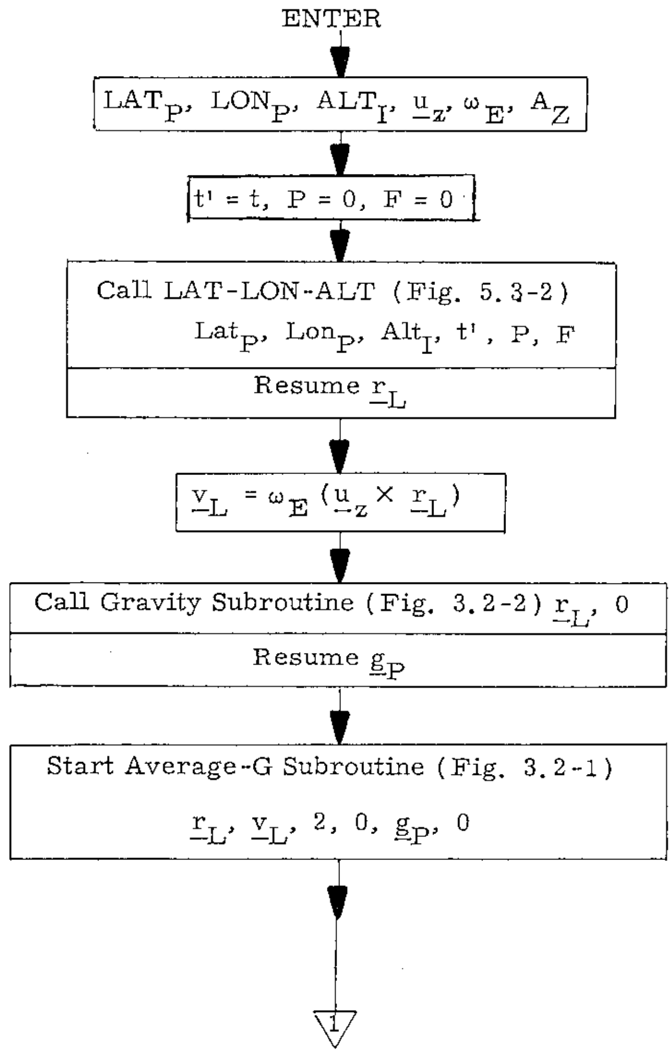


Figure 3.5-3 State Subroutine
(page 1 of 2)

1

Call Lat-Long-Alt (Fig. 5.3-2)

Lat_P, Lon_P, Alt_I, t', P, F

Force $\gamma = 1$ in Fig. 5.3-2

Resume $\underline{r}_P$

$$\underline{REFSMMAT}_6 = \text{UNIT}(-\underline{r}_P)$$

$$\underline{E} = \text{UNIT}(\underline{REFSMMAT}_6 \times \underline{u}_z)$$

$$\underline{S} = \text{UNIT}(\underline{E} \times \underline{REFSMMAT}_6)$$

$$\underline{REFSMMAT}_0 = \sin(A_Z)\,\underline{E} + \cos(A_Z)\,\underline{S}$$

$$\underline{REFSMMAT}_3 = \text{UNIT}\left[\underline{REFSMMAT}_6 \times \underline{REFSMMAT}_0\right]$$

$$\left[REFSMMAT\right] = \begin{bmatrix} (\underline{REFSMMAT}_0)^T \\ (\underline{REFSMMAT}_3)^T \\ (\underline{REFSMMAT}_6)^T \end{bmatrix}$$

$$K_Z = A_Z - 180^\circ - A_{ZP}$$

EXIT

Figure 3.5-3 State Subroutine
(page 2 of 2)

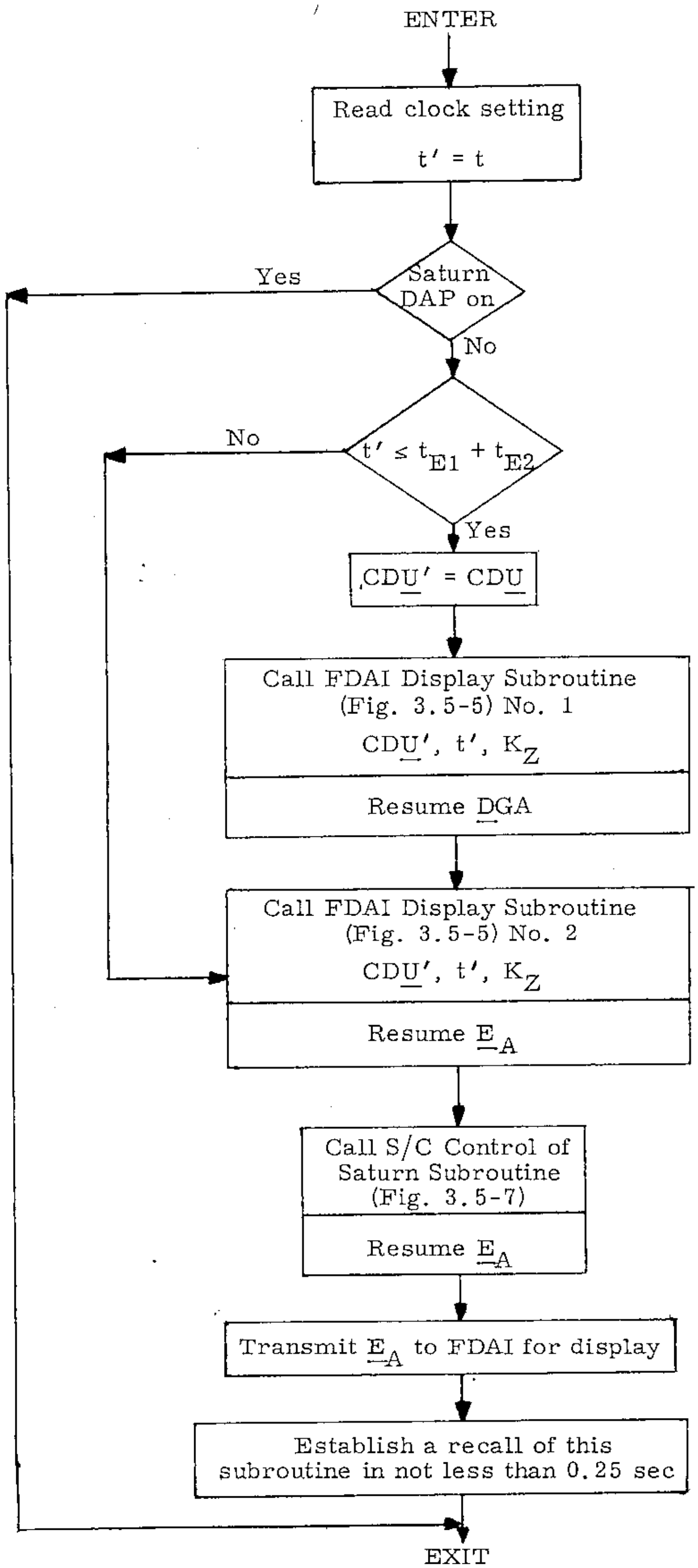


Figure 3.5-4 Attitude Error Subroutine

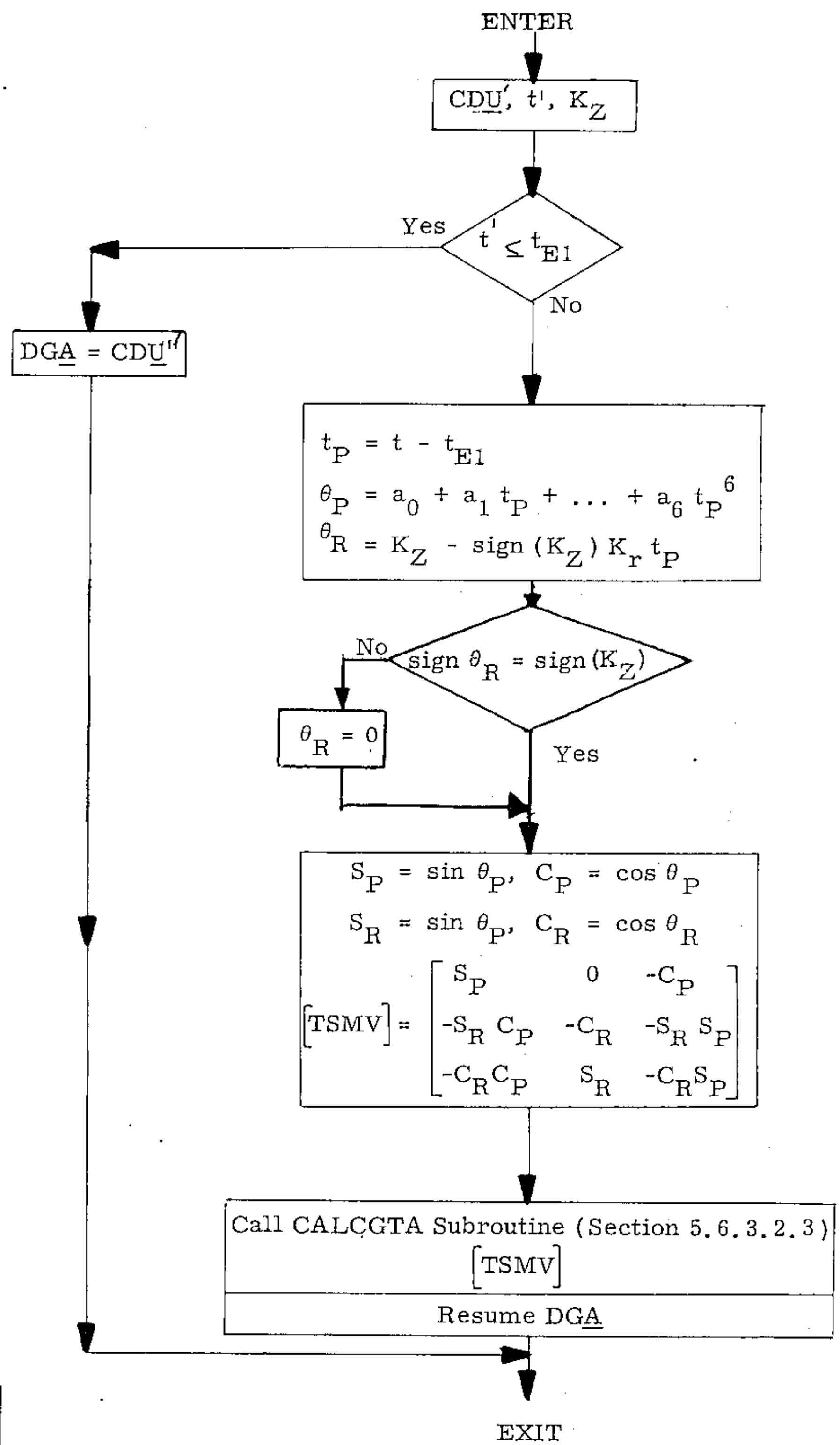


Figure 3.5-5 FDAI Display Subroutine No. 1
(page 1 of 2)

ENTER

$$\Delta \underline{CDU} = \underline{CDU}' - DG\underline{A}$$

$$S_X = \sin(CDU'_X),\ C_X = \cos(CDU'_X)$$

$$S_Z = \sin(CDU'_Z),\ C_Z = \cos(CDU'_Z)$$

$$\left[TGSC\right] = \begin{bmatrix} 1 & S_Z & 0 \\ 0 & C_X C_Z & S_X \\ 0 & -S_X C_Z & C_X \end{bmatrix}$$

$$\underline{E}_A = \left[TGSC\right] \Delta \underline{CDU}$$

Return $\underline{E}_A$

Figure 3.5-5 FDAI Display Subroutine No. 2
(page 2 of 2)

☑ Revised COLOSSUS
☐ Added GSOP # R-577 PCR # 251 Rev. 5 Date 9-18-68

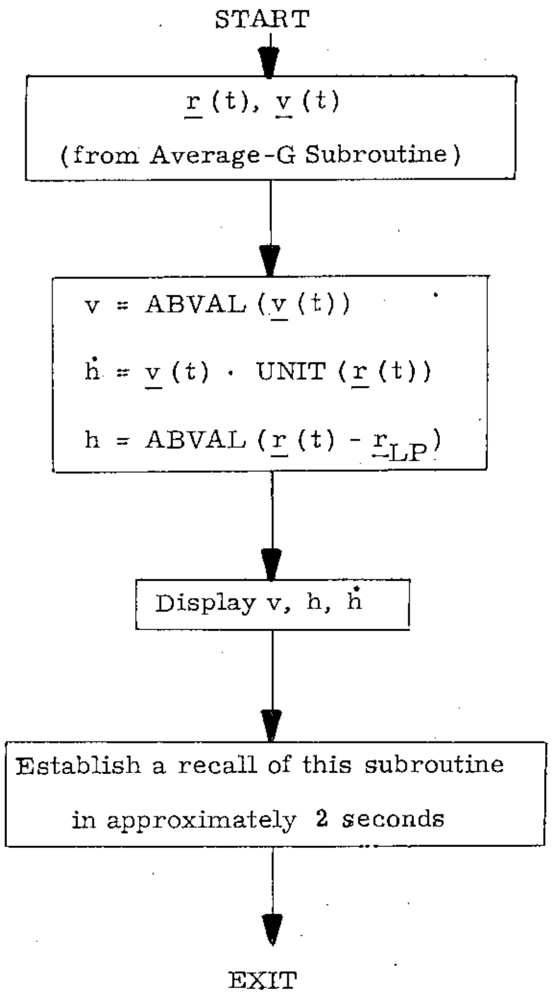


Figure 3.5-6 Display Subroutine

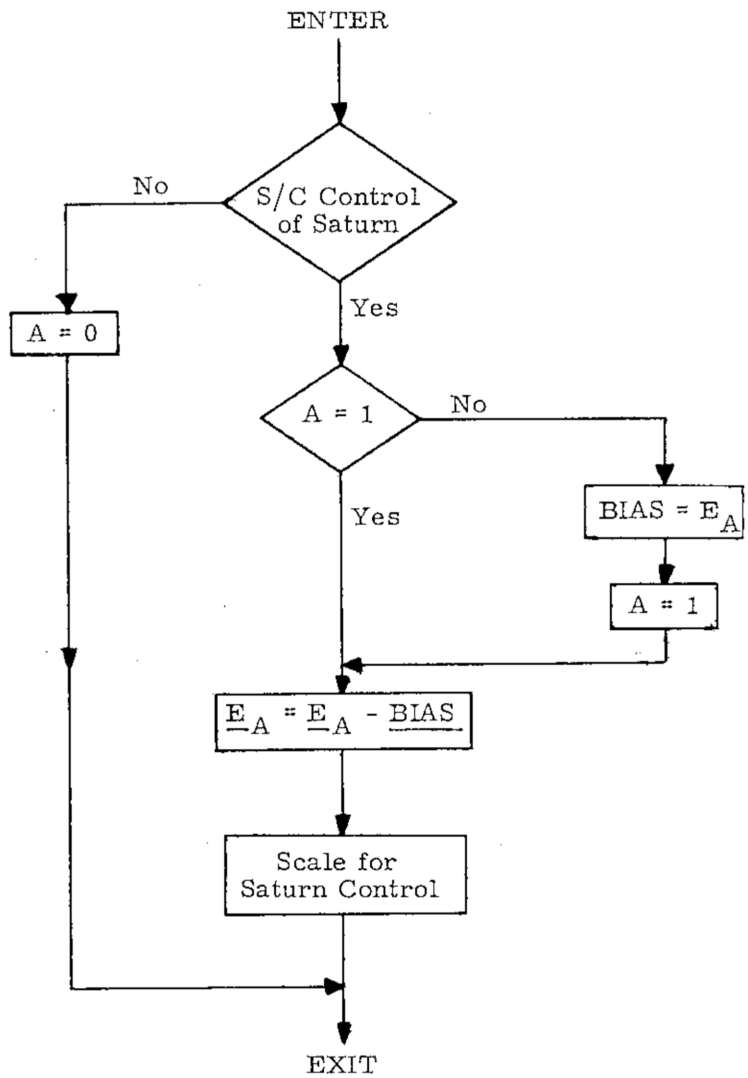


Figure 3.5-7 S/C Control of Saturn Subroutine