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RTCC REQUIREMENTS FOR MISSION G: THE TRANSLUNAR MIDCOURSE CORRECTION PROCESSOR

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MISSION PLANNING AND ANALYSIS DIVISION

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PROJECT APOLLO

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RTCC REQUIREMENTS FOR MISSION G: THE TRANSLUNAR MIDCOURSE CORRECTION PROCESSOR

By Bernard F. Morrey, Brody O. McCaffety, and Alfred E. Morrey

SUMMARY

This note documents the formulation of the Mission G translunar midcourse correction processor for the Real-Time Computer Complex (RTCC). The processor contains several midcourse correction and alternate lunar mission strategies. The options available in the program and the logic necessary for implementation are described in detail.

INTRODUCTION

During the translunar coast phase of the Apollo Mission G, it is necessary that the RTCC have the capability to either correct dispersions in the nominal trajectory or determine an alternate flight plan which is within the existing capability of the spacecraft. This capability is provided by the midcourse correction processor. The basic computation module in the program is the "generalized iterator" which has been documented previously in reference 1.

A number of requirements have been imposed upon the midcourse correction program. These requirements include the ability to correct a dispersed state vector to some nominal end conditions, reoptimize the landing mission, and generate a circumlunar flyby alternate mission.

These requirements are obtained through three computation modes:

1. The x, y, z, and t target update. (XYZ midcourse mode).
2. The best adaptive path (BAP) reoptimization.
3. The free-return lunar flyby mode.

One or more mission options are available under each mode. The mission options, listed below, are defined by manual entry device (MED) codes which specify the mode, type return, lunar parking orbit (LPO) orientation, and whether the mission is tied to a landing site.

1. x, y, z, and t target update.

2. Free-return, fixed LPO orientation, landing site.

3. Free-return, free LPO orientation, landing site.

4. Nonfree-return, fixed LPO orientation, landing site.

5. Nonfree-return, free LPO orientation, landing site.

6. Circumlunar free-return flyby to nominal H_{pc} and ϕ_{pc}.

7. Circumlunar free-return flyby, specified H_{pc} and nominal ϕ_{pc}.

Each of these options can be flown in a docked or undocked configuration.

This document contains an operational flow chart (flow chart 1) delineating the above seven options and functional flow charts (flow chart 2) for each of the three computation modes. The text describes the logic supporting these three modes - the x, y, z, and t target update, the BAP reoptimization, and the lunar flyby mode. Flow charts 3, 4, and 5 give the detailed logic for each of these modes. Reference 2 presents the detailed logic for the LOI processor.

Tables I through III present the input and output for the processor and defines the data table parameters. Equations defining display parameters not presently computed by the midcourse processor are described in the appendix.

NOTATION

Abbreviations

BAP	best adaptive path
CON	consumables due to EECOM based on timeline
CSM	command and service modules
EECOM	electrical, environmental, and communications systems
FSD	Flight Software Division
g_o	gravitational acceleration
g.e.t.	ground elapsed time
GF	guidance flag
G.m.t.	Greenwich Mean Time
I_{sp}	specific impulse
LM	lunar module
LOI	lunar orbit insertion
LPO	lunar parking orbit
M	mass
MCC	midcourse correction
MED	manual entry device
MPT	mission planning table
n. mi.	nautical miles
RCS	reaction control system (to be used in end of mission fuel reserve)
RTCC	Real-Time Computer Complex
SC	spacecraft

TEI	transearth injection
TLMC	first guess logic for ΔV, $\Delta\gamma$, $\Delta\psi$ of the midcourse maneuver

Symbols

H	height from surface
I	inclination
PC	CSM plane change
r	radial distance between vehicle and moon
Rtny Rng	reentry range
T	time
$\Delta\overline{V}$	characteristic velocity
V	magnitude of velocity
ψ	azimuth
γ	flight-path angle
ϕ	latitude
λ	longitude
Δt	difference between the nominal translunar flight time and the predicted.
ΔV	scalar velocity

Subscripts

act	actual
cir	circularization burn
cont	contingency
d	desired
el	earth landing
dy	dry

f	final
fr	free return
fr-rtny	reentry of free return
i	initial
ip	earth impact point
lo	lunar orbit
loi	lunar orbit insertion
lopc	lunar orbit plane change
lc	landing computed at earth
lls	lunar landing site
ls	lunar surface
max	maximum
mcc	midcourse correction
min	minimum
msn	mission, defined to be from the MCC to reentry
nd	node
pc	pericynthion
pr	powered return
rem	remaining
rtny	reentry
t	time
te	transearth (used with transearth flight time)
tei	transearth injection
cal	calibration

INPUT - OUTPUT

Inputs for all midcourse modes fall into two categories: those from the data table, and those which are manually entered during the mission by a MED. The data table contains variables which are needed to execute the different options. These variables may be target parameters used in the x, y, z, and t mode or first guesses for certain independent variables. The table also contains parameters which change according to the nominal mission design and launch day (e.g., lunar landing site). If a BAP midcourse is transferred to the MPT, the data table is updated by the appropriate parameters. (Input updated in this way as well as those variables computed prior to TLI are referred to as "nominal" in this text.) Each time an option is to be computed, the appropriate independent and dependent variables are called from the data table. The data table and the MED quantities are defined in tables I and II, respectively.

Outputs from the MCC program are of three types: those displayed, those sent to the MPT, and those which update the data table. Displayed parameters, defined in reference 4 and shown in table III, are subject to revision. Output for the data table is shown in table I. BAP's are the only options that update the data table.

Only the first maneuver in a sequence is sent to the MPT. When a midcourse option is computed, only the midcourse maneuver is transferred to the MPT. The information sent to the MPT for the MCC includes the following orbital elements before and after the impulsive burn:

1. X
2. Y
3. Z
4. $\dot{X}$
5. $\dot{Y}$
6. $\dot{Z}$
7. Time of maneuver (GMT)

End of Mission Fuel Reserves

The mass computation used in the trajectory computer is not designed to be accurate enough for real-time end-of-mission fuel reserves, but is designed to allow the iterator to optimize the mission. The mass computation described here will be called after all of the desired ΔV's have been computed. The $\Delta\overline{V}_{mcc}$ is an impulsive computation and is calculated after the integrated translunar trajectory. The $\Delta\overline{V}_{loi}$ is computed based on the integrated translunar trajectory. (See page 12.) The $\Delta\overline{V}_{lopc}$ and $\Delta\overline{V}_{tei}$ are impulsive calculations from conic trajectories. The $\Delta\overline{V}_{cir}$ is a constant for the MCC processor.

Only two types of expendables will be considered by this method of computation. These two expendables, EECOM consumables and RCS propellant, will be deducted based on a timeline. This timeline will be determined by IBM and FSD. The mass of the crew and their equipment that will be transferred to the LM will not be considered in computation of the ΔV_{lopc}. A study showed that for a 200-fps ΔV at the LOPC there was a difference in mass of only 13 lbs between computing with and without the crew and equipment. For a more accurate mass computation, a ΔV bias will be used for the MC, LOI and TEI maneuvers. This bias is the difference between an impulsive burn and integrated burn arc. The computation will be as follows:

$T_{lopc} = T_{nd}\,(\text{G.m.t.})$ + T to first pass + T from first pass to the lunar orbit plane change

$T_{cir} = T_{nd}\,(\text{G.m.t.})$ + T from LOI to circularization

$$M_{mcc} = (M_i - CON_t - RCS_t)/\exp\left[(\Delta\overline{V}_{mcc})/g_o * I_{sp}\right]$$
$$M_{loi} = (M_{mcc} - CON_t - RCS_t)/\exp\left[(\Delta\overline{V}_{loi} + \Delta V_{loi_{cal}})/g_o * I_{sp}\right]$$
$$M_{cir} = (M_{loi} - CON_t - RCS_t)/\exp\left[\Delta\overline{V}_{cir}/g_o * I_{sp}\right]$$
$$M_{lopc} = (M_{cir} - CON_t - RCS_t - M_{LM})/\exp\left[\Delta\overline{V}_{lopc}/g_o * I_{sp}\right]$$
$$M_f = (M_{lopc} - CON_t - RCS_t)/\exp\left[(\Delta\overline{V}_{tei} + \Delta V_{tei_{cal}})/g_o * I_{sp}\right]$$
$$|\Delta V_r| = g_o * I_{sp} * \ln\left[M_f/M_{dy}\right]$$

TLMC - FIRST GUESS LOGIC FOR MIDCOURSE CORRECTION

This logic is called using the nominal time of pericynthion and converges to the midcourse correction position; that is, a trajectory is generated from a specified condition at the moon to the position vector where the correction maneuver will occur. The ΔV, $\Delta\gamma$, and $\Delta\psi$ of the maneuver are then computed by taking the difference between the V, γ, and ψ of the current trajectory and the V, γ, and ψ of the trajectory generated by the first guess logic.

This is a general description of TLMC and its variables. The particular array will be specified in each option.

The variables needed for this operation are as follows:

1. Independent variables and their empirical first guess equations

$$\left.\begin{aligned} \lambda &= 3.1 - 0.025\ \Delta t \\ V &= \sqrt{.184 + .553/r} - .0022\Delta t \\ \psi &= 270^\circ \end{aligned}\right\} \quad \text{(step sizes will be } 2^{-19}\text{)}$$

2. Dependent variables

$$\left.\begin{aligned} &X \\ &Y \\ &Z \end{aligned}\right\} \quad \text{position vector at MCC}$$

3. Other parameters

$$\left.\begin{aligned} &T \\ &H \\ &\phi \\ &\gamma \end{aligned}\right\}$$

These are the parameters required, in addition to the independent variables, to provide the initial state vector to TLMC.

First guessing ψ to be 270° starts a retrograde approach at the moon. This convergence method is referred to as a backward iteration. The first guess logic will be used in this manner for all options.

XYZ MIDCOURSE MODE

The XYZ midcourse mode will be employed to correct a mildly dispersed state vector during translunar coast. The target objectives for this maneuver are generated either in the pre-mission count-down or in earth parking orbit. These nodal targets are computed using option 2.

This mode does not guarantee a free return.

The target objectives for the midcourse maneuver are:

1. The position vector defining the node between the approach hyperbola plane and the desired LPO plane, where x, y, and z refer to the earth-moon plane longitude, latitude, and radius magnitude of the nodal point, respectively.

2. The nominal time of arrival (t) at this node.

The computational sequence for this mode is begun with a check to determine the distance between the spacecraft and the moon. If the distance is 20 e.r. or less, computations are made in moon reference, but if the distance is greater than 20 e.r., computations are made in earth reference with a sphere ratio of 0.275.

The computation procedure for this mode is as follows.

1. Converge TLMC to the desired end conditions in order to provide good first guesses. The following array will be used[a].

Independent variables	First guess	Weight	Step size
V	Empirical first guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ	270°	512	2^{-19}
H_{pc}	Nominal[b] (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ	Empirical first guess	512	2^{-19}
T_{pc}[c]	Nominal (not triggered)	--	--

[a]For a detailed explanation of the program input in terms of independent and dependent variables, see reference 3.

[b]When an independent variable is given a first guess and is not triggered, this value does not change during the computation.

[c]When either option 4 or option 5 is computed, the difference in time at pericynthion between the resulting integrated trajectory and the integrated nominal time at pericynthion is saved and used, if the maneuver is sent to the MPI, in computing later x, y, z and t options. This ΔV is used in the empirical equations for longitude and velocity to obtain first guesses for these parameters in TLMC.

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

2. Using answers from step 1 as first guesses, an integrated TLMC is converged according to the following input.

Independent variables	First guess	Weight	Step size
V_{pc}	Step 1	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ_{pc}	Step 1	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ_{pc}	Step 1	512	2^{-19}
T_{pc}	Nominal (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

3. Converge an integrated x, y, z, and t trajectory as specified in the following array:

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 2	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 2	512	2^{-19}
ΔV_{mcc}	Step 2	512	2^{-23}
Δt_{nd}	Nominal (not triggered)		

Dependent variables	Value	Weight	Class designator
H_{nd}	Nominal ±0.5 n. mi.	--	1
ϕ_{nd}[a]	Nominal ±0.01°	--	1
λ_{nd}[a]	Nominal ±0.01°	--	1
I_{pc}	90° - 182°	64	0

[a]These are input in earth-moon plane coordinates.

4. The $\Delta\overline{V}_{loi}$ is now calculated. This entails obtaining the burn out mid-course state vector from step 2 and integrating to the γ_{nd} from step 3. This is done in the supervisor by making a call to the integrator.

To determine the three components of the $\Delta\overline{V}_{loi}$, the following will be used:

a. γ_{nd} from step 3

b. $|\Delta V_{loi}|$ will be the difference between the V of the approach hyperbola from step 4 and the V of the resultant lunar orbit at the point of transfer.

c. $\Delta\psi_{nd}$ will be obtained from the dot product of the angular momentum vectors of the lunar orbit and approach hyperbola computed at the time of landing. (See appendix.)

This completes the computation sequence for the XYZ midcourse mode. The supporting logic is presented in flow chart 3.

BAP MIDCOURSE MODE

Excessive performance penalties associated with an XYZ correction may require reoptimizing the landing mission. This mode optimizes the mission for maximum spacecraft fuel reserves by computing the remaining CSM maneuvers (e.g., MCC, LOI, PC, and TEI) as a set.

Two constraints can be applied to the reoptimization of the landing mission. The first constrains targeting of the midcourse correction so that the resultant trajectory is free return. The second constrains the approach azimuth to the lunar landing site so that the orientation of the LPO remains fixed. The alternative to these constraints is to relax the free-return requirement and let the approach azimuth vary within defined bounds enabling the LPO to seek an optimum orientation. If the above constraints or alternatives are applied to the program, the landing missions proliferate into four types (options 2-5).

During the reoptimization process, the x, y, z, and t targeting parameters are computed for the new flight plan. The transfer of a BAP option to the MPT automatically updates the appropriate x, y, z, and t parameters in the data table (see table 1).

The calculation procedures for options 2-5 are considered in detail below. At this point it should be mentioned that the midcourse program uses the same reentry model for all BAP options. In these cases reentry is simulated by requiring the trajectory to satisfy a constant flight path angle at a constant height at reentry. The desired λ_{ip} is a preflight constant and is obtained through a constant reentry range and delta time from reentry to landing. The accuracy in the λ_{ip} need not be iterated to greater than .2°. No cross range is necessary. Free return transearth trajectories terminate on a constant flight path angle at a constant height at reentry. The transearth flight time terminates on this constant flight-path angle.

The calculation procedures for the landing missions (options 2, 3, 4, and 5) follow. Flow chart 4 presents the detailed flow for this mode.

Free-Return Options

Option 2.- The free-return, fixed lunar orbit orientation is calculated as follows.

1. Converge TLMC using the following array:

Independent variables	First guess	Weight	Step size
V	Empirical first guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ	270°	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ	Empirical first guess	512	2^{-19}
T_{pc}	Nominal (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

2. Converge a conic, free-return trajectory passing through the nominal H_{pc} and ϕ_{pc} in order to get a better first guess for the midcourse maneuver before entering the full mission step. This step is initiated by values obtained from step 1.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 1	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 1	512	2^{-21}
ΔV_{mcc}	Step 1	512	2^{-21}

Dependent variable	Value	Weight	Class designator
H_{pc}	Nominal ± 0.5 n. mi.	--	1
ϕ_{pc}	Nominal $\pm 0.01°$	--	1
I_{pc}	90° - 182°	64	0
$H_{fr\ rtny}$	Nominal ±1.735 n. mi.	--	1
I_{fr}	(a)	8	0

3. Converge a conic full mission using the midcourse maneuver from step 2 as a first guess while relaxing the constraints on H_{pc} and ϕ_{pc}.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{tei}$	Nominal	8	2^{-21}
ΔV_{tei}	Nominal	1	2^{-21}
T_{lo}	Nominal	10^{-6}	2^{-21}
ΔT_{lls}	Nominal	10^{-3}	2^{-18}
$\Delta\psi_{loi}$	Nominal	1	2^{-19}
γ_{loi}	Nominal	1	2^{-19}
$\Delta\psi_{mcc}$	Step 2	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 2	512	2^{-21}
ΔV_{mcc}	Step 2	512	2^{-21}

[a] The minimum value is 0°, and the maximum is obtained from the data table.

Dependent variables	Values	Weight	Class designator
H_{pc}	40 - 100 n. mi.	1	0
I_{pc}	90° - 182°	64	0
H_{lo} [a]	Nominal ±0.5 n. mi.	--	1
$H_{fr\ rtny}$	Nominal ±1.735 n. mi.	--	1
I_{fr}	(a)	8	0
ϕ_{lls}	Nominal ± 0.01°	--	1
λ_{lls}	Nominal ± 0.01°	--	1
I_{pr}	0° - 40°	8	0
H_{rtny}	Nominal ±1.735 n. mi.	--	1
T_{te} [b]	Nominal ± 8 hr	0.125	0
$\Delta\lambda_{el}$	0° ± 0.2°	--	1
ψ_{lls}	Nominal ± 0.01°	--	1

4. Once the dependent variable constraints are satisfied, the mission is reoptimized. This is done by including the mass after TEI as a class 3 dependent variable with limits of 3000 lb greater than the selected value from step 3. If this results in as much as 2500 lbs gain in M_{tei}, an additional 2500 lbs is added to the limits of the variable to be optimized and the optimization continues (see flow chart 4, p. 56). The dependent variable T_{te} will be turned off during optimization.

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[a]This is the height above the lunar landing site. This is applicable to all full mission options.

[b]The T_{te} will be biased by the difference between the nominal translunar flight time and the translunar flight time computed from step 2.

At this time the mission has been reoptimized, and there is now a new target H_{pc} and ϕ_{pc}. Because up to this point all phases of the reoptimization were in the conic mode, it is necessary to generate an integrated free-return to obtain the corresponding ΔV_{mcc}. This precision ΔV_{mcc}, the recalculated $\Delta \overline{V}_{loi}$, the conic lunar orbit plane change and the conic $\Delta \overline{V}_{tei}$ are used to obtain the end of mission fuel reserves.

5. To obtain better first guesses for the integrated free-return trajectory, an integrated TLMC trajectory is generated using the following array:

Independent variables	First guess	Weight	Step size
V_{pc}	Step 4 guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ_{pc}	Step 4	512	2^{-19}
H_{pc}	Step 4 (not triggered)	--	--
ϕ_{pc}	Step 4 (not triggered)	--	--
λ_{pc}	Step 4 guess	512	2^{-19}
T_{pc}	Step 4 (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

6. An integrated free-return trajectory is generated to pass through the updated H_{pc} and ϕ_{pc} from step 4. The first guess for the independent variables will be from step 5.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 5	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 5	512	2^{-21}
ΔV_{mcc}	Step 5	512	2^{-21}

Dependent variable	Value	Weight	Class designator
H_{pc}	Step 4 ±0.5 n. mi.	--	1
ϕ_{pc}	Step 4 ±0.01°	--	1
I_{pc}	90° - 182°	64	0
$H_{fr\ rtny}$	Nominal ± 1.735 n. mi	--	1
I_{fr}	(a)	8	0

7. The $\overline{\Delta V}_{loi}$ is now determined. This is done by making a call to the integrator and propagating from MCC to the γ_{loi} from step 4. After the γ_{loi} is obtained, LIBRAT is called to get the EMP system and to calculate H_{nd}, ϕ_{nd}, λ_{nd}, and t_{nd}. The components of the $\overline{\Delta V}_{loi}$ are; γ_{loi} from step 4, the difference between the V of the approach hyperbola at LOI and the V of the resultant lunar orbit, and $\Delta\psi_{loi}$ which will be from the dot product of the angular momentum vectors of the approach hyperbola and the lunar orbit taken at the time of landing.

[a]The minimum value is 0°, and the maximum is obtained from the data table.

Option 3.- The free-return, free-orbit orientation, offers two methods within itself. The first is to enter a specific azimuth over the lunar landing (not necessarily the nominal) by manually entering through the MED AZmin = AZmax for the desired value. Both the select and optimized modes are solved with azimuth as a class 1 variable. The second method is to MED the desired azimuth range. In the select mode the azimuth is set as a class 1, but in the optimized mode the azimuth is set as a class 2 variable. Flow chart 4 shows the check that will be made to determine whether the azimuth MED will be a specific value or whether it will relax the azimuth range.

The free-return, free lunar orbit orientation, is calculated as follows:

1. Converge TLMC using the following array.

Independent variables	First guess	Weight	Step size
V	Empirical first guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ	270°	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ	Empirical first guess	512	2^{19}
T_{pc}	Nominal (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

2. Converge a conic, free-return trajectory passing through the nominal H_{pc} and ϕ_{pc}, using first guesses from the first guess logic.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 1	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 1	512	2^{-21}
ΔV_{mcc}	Step 1	512	2^{-21}

Dependent variable	Value	Weight	Class designator
H_{pc}	Nominal ±0.5 n. mi.	--	1
ϕ_{pc}	Nominal ±0.01°	--	1
I_{pc}	90° - 182°	64	0
$H_{fr\ rtny}$	Nominal ±1.735 n. mi.	--	1
I_{fr}	(a)	8	0

3. Converge a conic full mission using the midcourse maneuver from step 2 as a first guess while relaxing the constraints on H_{pc} and ϕ_{pc}.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{tei}$	Nominal	8	2^{-21}
ΔV_{tei}	Nominal	1	2^{-21}
T_{lo}	Nominal	10^{-6}	2^{-21}
ΔT_{lls}	Nominal	10^{-3}	2^{-18}
$\Delta\psi_{loi}$	Nominal	1	2^{-19}
γ_{loi}	Nominal	1	2^{-19}
$\Delta\psi_{mcc}$	Step 2	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 2	512	2^{-21}
ΔV_{mcc}	Step 2	512	2^{-21}

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[a]The minimum value is 0°, and the maximum is obtained from the data table.

Dependent variables	Values	Weight	Class designator
H_{pc}	40 - 100 n. mi.	1	0
I_{pc}	90° - 182°	64	0
H_{lo}	Nominal ± 0.5 n. mi.	--	1
$H_{fr\ rtny}$	Nominal ± 1.735 n. mi.	--	1
I_{fr}	(a)	8	0
ϕ_{lls}	Nominal ± 0.01°	--	1
λ_{lls}	Nominal ± 0.01°	--	1
I_{pr}	0° - 40°	8	0
H_{rtny}	Nominal ± 1.735 n. mi.	--	1
T_{te} [b]	Nominal ± 8 hr	0.125	0
$\Delta\lambda_{el}$	0° ± 0.2°	--	1
ψ_{lls} [c]	MED 1) AZmin = AZmax 2) Az range	--	1

[a] The minimum value is 0°, and the maximum is obtained from the data table.

[b] The T_{te} will be biased by the difference between the nominal translunar flight time and the translunar flight time computed from step 2.

[c] MED values for ψ_{lls} must lie between 250° and 290°. A check will be made to determine if the values are within this range.

4. Once the dependent variable constraints are satisfied, the mission is reoptimized. This is done by including the mass after TEI as a class 3 dependent variable with limits of 3000 lb greater than the selected value from step 3. If this results in as much as 2500 lb gain in M_{tei}, an additional 2500 lb is added to the limits of the variable to be optimized and the optimization continues (see flow chart 4, p. 56). If the MED on azimuth specifies a range then ψ_{lls} is set as a class two variable for optimization, the weight on this variable will be 1. The variable T_{te} will be turned off during optimization.

5. Before converging a precision free-return trajectory, better first guesses are obtained by integrating a TLMC trajectory to the optimized pericynthion.

Independent variables	First guess	Weight	Step size
V_{pc}	Step 4	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ_{pc}	Step 4	512	2^{-19}
H_{pc}	Step 4 (not triggered)	--	--
ϕ_{pc}	Step 4 (not triggered)	--	--
λ_{pc}	Step 4	512	2^{-19}
T_{pc}	Step 4 (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

6. An integrated free-return trajectory is generated to pass through the updated H_{pc} and ϕ_{pc} from step 4. The first guess for the independent variables will be from step 5.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 5	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 5	512	2^{-21}
ΔV_{mcc}	Step 5	512	2^{-21}

Dependent variable	Value	Weight	Class designator
H_{pc}	Step 4 ±0.5 n. mi	--	1
ϕ_{pc}	Step 4 ±0.01°	--	1
I_{pc}	90° - 182°	64	0
$H_{fr\ rtny}$	Nominal ± 1.735 n. mi	--	1
I_{fr}	(a)	8	0

7. The $\overline{\Delta V}_{loi}$ is now calculated. This is done by making a call to the integrator and propagating from MCC to the γ_{loi} from step 4. After the trajectory is integrated to the γ_{loi}, LIBRAT is called to get the EMP system and to calculate H_{nd}, ϕ_{nd}, λ_{nd}, and t_{nd}. Calculate the $\Delta\psi_{loi}$ from the dot product of the angular momentum vectors of the approach hyperbola and the lunar orbit taken at the time of landing. The other components of $\overline{\Delta V}_{loi}$ are: γ_{loi} from step 4, and the ΔV_{loi} from the difference between the velocity of the approach hyperbola at the node and the velocity of the resultant lunar orbit at the node.

Nonfree-Return Options

The nonfree-return BAP options have a somewhat similar procedure in computation to that of the free-return options. The following are the major differences in the two methods.

1. The use of a polynomial (ref. 6) to update the time of the node. This adjustment to the time to the node is shown in flow chart 4. The polynomial cannot be used if the MCC occurs later than 20 hours after TLI. The time from this polynomial is referred to as the $\delta(\Delta t)$.

2. The dropping of the $H_{fr-rtny}$ and I_{fr} from the dependent variable array.

3. There are two other time adjustments that must be taken into consideration when using the nonfree-return trajectory:

   a. Translunar time in which the DPS retains the ability to return the spacecraft safely if the SPS fails to ignite for LOI. This transit time (ΔT_{dps}) must not be exceeded.

   b. The transit time must be such that the sun elevation at the lunar landing site is within the desired range. This transit time is referred to as G.m.t. of the maximum sun elevation.

The use of these translunar flight times in controlling the time to the node is shown in flow chart 4.

4. The weight on ΔV, $\Delta\gamma$, $\Delta\psi$ of the midcourse maneuver will be 8 for the full mission select step.

Option 4. Following is the sequence for computing a nonfree-return, fixed lunar orbit. The Δt_{nd} to be used will be selected as shown in flow chart 4. The time required for the first guess logic for nonfree-return options is also determined by this logic in flow chart 4. This time for TLMC is the most constraining of the three times - time from $\delta(\Delta T)$ polynomial, maximum time for DPS abort, and maximum time for sun elevation constraint.

1. Converge TLMC as follows:

Independent variables	First guess	Weight	Step size
V	Empirical first guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ	270°	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ	Empirical first guess	512	2^{-19}
T_{pc}	Flow chart 4 (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

2. Converge a conic nonfree-return select full mission. The variables for this step are shown below.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{tei}$	Nominal	8	2^{-21}
ΔV_{tei}	Nominal	1	2^{-21}
T_{lo}	Nominal	10^{-6}	2^{-21}
ΔT_{lls}	Nominal	10^{-3}	2^{-18}
$\Delta\psi_{loi}$	Nominal	1	2^{-19}
γ_{loi}	Nominal	1	2^{-19}
$\Delta\psi_{mcc}$	Step 1	8	2^{-19}
$\Delta\gamma_{mcc}$	Step 1	8	2^{-21}
ΔV_{mcc}	Step 1	8	2^{-21}

Dependent variables	Value	Weight	Class designator
H_{pc}	40 - 100 n. mi.	1	0
I_{pc}	90° - 182°	64	0
H_{lo}	Nominal ± 0.5 n. mi.	--	1
ϕ_{lls}	Nominal ± 0.01°	--	1
λ_{lls}	Nominal ± 0.01°	--	1
ΔT_{nd}	min = (value from logic of flow chart 4) - 2 hr max = (value from logic of flow chart 4) + 2 hr	0.125	0
T_{te}	Nominal ± 8 hr	0.125	0
I_{pr}	0 - 40	0.125	0
$\Delta\lambda_{el}$	0° ± 0.2°	--	1
H_{rtny}	Nominal ± 1.735 n. mi.	--	1
ψ_{lls}	Nominal ± 0.01°	--	1

For nonfree-return full missions the ΔT_{nd} may vary. To bound this class two variable properly, a check is made as shown in flow chart 4. This logic assures that both the upper and lower bound for ΔT_{nd} is determined by the most constraining of the times derived from the DPS abort constraint and the sun elevation constraint.

The nominal transearth flight time will be adjusted by the same Δt applied to the translunar flight time by the logic of flow chart 4.

The flight controller will have the option via a MED to change the earth landing time by one day.

3. Optimization is effected by maximizing the mass after TEI; the limits on this variable should be 3000 lb above the selected value. If this results in as much as 2500 lb gain in M_{te}, an additional 2500 lb is added to the limits of the variable to be optimized and the optimization continues (see flow chart 4, p. 56).

The limiting values on Δt_{nd} will be the values that come from flow chart 4. During optimization T_{te} will be turned off.

4. Converge an integrated TLMC.

Independent variables	First guess	Weight	Step size
V_{nd}	Step 3	512	2^{-19}
γ_{nd}	Step 3 (not triggered)	--	--
ψ_{nd}	Step 3	512	2^{-19}
H_{nd}	Step 3 (not triggered)	--	--
ϕ_{nd}	Step 3 (not triggered)	--	--
λ_{nd}	Step 3	512	2^{-19}
T_{nd}	Step 3 (not triggered)	--	--

Dependent variables	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

5. To get the displayed impulsive $\overline{\Delta V}_{mcc}$, a precision trajectory is converged to the optimized LOI conditions, as shown below.

Independent variables	First guess	Weight	step size
$\Delta\psi_{mcc}$	Step 4	512	2^{-21}
$\Delta\gamma_{mcc}$	Step 4	512	2^{-21}
ΔV_{mcc}	Step 4	512	2^{-23}
ΔT_{nd}	Step 4 (not triggered)		

Dependent variables	Value	Weight	Class designator
H_{nd}	Step 4 ± 0.5 n. mi.	--	1
ϕ_{nd}	Step 4 $\pm 0.01°$	--	1
λ_{nd}	Step 4 $\pm 0.01°$	--	1
I_{pc}	90° - 180°	64	0

6. The $\overline{\Delta V}_{loi}$ is now calculated. This involves making one call to the integrator and propagate to the γ_{loi} from step 5.

The components of the $\Delta\overline{V}_{loi}$ are as follows: γ_{loi} is that from step 5; ΔV_{loi} is the difference between the velocity of the approach hyperbola at the node and the velocity of the resultant lunar orbit at the point of transfer; $\Delta\psi_{loi}$ is from the dot product of the angular momentum vectors of the approach hyperbola and the lunar orbit taken at the time of landing.

Option 5.- The computation procedure for the nonfree-return, free lunar orbit orientation is similar to the nonfree-return option 4 with the exception of ψ_{lls}. The freeing of the orbit orientation is handled in the same way as is done for the free-return free orbit case, option 3. First guesses of zero are used for $\Delta\psi_{tei}$, γ_{loi}, $\Delta\psi_{loi}$.

1. Converge TLMC as follows:

Independent variables	First guess	Weight	Step size
V	Empirical first guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ	270°	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ	Empirical first guess	512	2^{-19}
T_{pc}	Flow chart 4 (not triggered)	--	--

The time required for the first guess logic for nonfree-return options is also determined by this logic in flow chart 4. This time for TLMC is the most constraining of the three times - time from $\delta(\Delta T)$ polynomial, maximum time for DPS abort, and maximum time for sun elevation constraint.

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

2. Converge a conic full mission using the midcourse maneuver from step 1 as a first guess while relaxing the constraints on H_{pc} and ϕ_{pc}.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{tei}$	0	8	2^{-21}
ΔV_{tei}	Nominal	1	2^{-21}
T_{lo}	Nominal	10^{-6}	2^{-21}
ΔT_{lls}	Nominal	10^{-3}	2^{-18}
$\Delta\psi_{loi}$	0	1	2^{-19}
γ_{loi}	0	1	2^{-19}
$\Delta\psi_{mcc}$	Step 1	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 1	512	2^{-21}
ΔV_{mcc}	Step 1	512	2^{-21}

Dependent variables	Value	Weight	Class designator
H_{pc}	40 - 100 n. mi.	1	0
I_{pc}	90° - 182°	64	0
H_{lo}	Nominal ± 0.5 n. mi.	--	1
ϕ_{lls}	Nominal ± 0.01°	--	1
λ_{lls}	Nominal ± 0.01°	--	1
ΔT_{nd}	min = (value from logic of flow chart 4) - 2 hr max = (value from logic of flow chart 4) + 2 hr	0.125	0
T_{te}	Nominal ± 8 hr	0.125	0
I_{pr}	0 - 40	0.125	0
$\Delta\lambda_{el}$	0° ± 0.2°	--	1
H_{rtny}	Nominal ± 1.735 n. mi.	--	1
ψ_{lls}	MED 1) AZmin = AZmax 2) AZ range	--	1

For nonfree-return full missions the ΔT_{nd} may vary. To bound this class two variable properly, a check is made as shown in flow chart 4. This logic assures that both the upper and lower bound for ΔT_{nd} is determined by the most constraining of the times derived from the DPS abort constraint and the sun elevation constraint.

The nominal transearth flight time will be adjusted by the same Δt applied to the translunar flight time by the logic of flow chart 4.

The flight controller will have the option via a MED to change the earth landing time by one day.

3. Optimization is effected by maximizing the mass after TEI; the limits on this variable should be 3000 lb above the selected value. If this results in as much as 2500 lb gain in M_{tei}, an additional 2500 lb is added to the limits of the variable to be optimized and the optimization continues (see flow chart 4, p. 56).

The limiting values on Δt_{nd} will be the values that come from flow chart 4. During optimization T_{te} will be turned off. If the MED on azimuth specifies a range then ψ_{lls} is set as a class two variable for optimization, the weight on this variable will be 1.

4. Converge an integrated TLMC as follows.

Independent variables	First guess	Weight	Step size
V_{nd}	Step 3	512	2^{-19}
γ_{nd}	Step 3 (not triggered)	--	--
ψ_{nd}	Step 3	512	2^{-19}
H_{nd}	Step 3 (not triggered)	--	--
ϕ_{nd}	Step 3 (not triggered)	--	--
λ_{nd}	Step 3	512	2^{-19}
T_{nd}	Step 3 (not triggered)	--	--

Dependent variables	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

5. To get the displayed impulsive $\overline{\Delta V}_{mcc}$, a precision trajectory is converged to the optimized LOI conditions, as shown on the following page.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 4	512	2^{-21}
$\Delta\gamma_{mcc}$	Step 4	512	2^{-21}
ΔV_{mcc}	Step 4	512	2^{-23}
ΔT_{nd}	Step 4 (not triggered)	--	--

Dependent variables	Value	Weight	Class designator
H_{nd}	Step 3 ±0.5 n. mi.	--	1
ϕ_{nd}	Step 3 ±0.01°	--	1
λ_{nd}	Step 3 ±0.01°	--	1
I_{pc}	90° - 180°	64	0

5. The $\overline{\Delta V}_{loi}$ is now calculated. This involves integrating the translunar coast to the γ_{loi} from step 4, by making one call to the integrator.

To obtain the $\overline{\Delta V}_{loi}$, its components will be the following: ΔV_{loi} will be the difference between the velocity of the approach hyperbola at the node and the velocity of the resultant lunar orbit at the transfer point; $\Delta\psi$ will be calculated from the dot product of the angular momentum vectors of approach hyperbola and the lunar orbit taken at time of landing; the γ will be the value from step 5.

LUNAR FLYBY MODE

The third computation mode generates the circumlunar flyby alternate mission. The logic supporting this mode is simply a circumlunar, free-return trajectory to the nominal height and latitude of pericynthion. The transearth portion of the trajectory satisfies a constant flight path angle, height of reentry, reentry range, and delta time from reentry to landing. No direct control is available over the λ_{ip}.

If the earth-return longitude is not acceptable, the flight controller will have the ability, through a MED, to vary the H_{pc} which, in turn, will control the return longitude. The ϕ_{pc} remain the nominal value as the height is changed by a MED.

Option 6.- The circumlunar flyby free-return trajectory is a return to nominal, as shown in flow chart 5. The computational sequence for this mode is begun with a check to determine the distance between the SC and the moon. If the distance is 20 e.r. or less, computations are made in moon reference, but if the distance is greater than 20 e.r., computations are made in earth reference with a sphere ratio of 0.275. There will be a maximum of 20 iterations for each step.

1. Converge the TLMC first guess logic as follows:

Independent variables	First guess	Weight	Step size
V	Empirical first guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ	270°	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ	Empirical first guess	512	2^{-19}
T_{pc}	Nominal (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position $\pm .0657$ n. mi.	--	1
Y	Midcourse position $\pm .0657$ n. mi.	--	1
Z	Midcourse position $\pm .0657$ n. mi.	--	1

2. Once the first guess values are obtained from the conic TLMC an integrated TLMC trajectory is converged using the following array.

Independent variables	First guess	Weight	Step size
V_{pc}	Step 1	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ_{pc}	Step 1	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ_{pc}	Step 1	512	2^{-19}
T_{pc}	Nominal (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

3. Use the converged values from step 2 as first guesses for the integrated free-return trajectory.

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 2	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 2	512	2^{-21}
ΔV_{mcc}	Step 2	512	2^{-21}

Dependent variables	Value	Weight	Class designator
H_{pc}	Nominal ±0.01	--	1
ϕ_{pc}	Nominal ±0.01	--	1
I_{pc}	90° - 182°	64	0
$H_{fr\ rtny}$	Nominal ± 1.735 n. mi	--	1
I_{fr}	(a)	8	0

[a]Minimum value is 0° and the maximum value is obtained from the data table.

Option 7.- The circumlunar flyby with the ability to specify the H_{pc} will use the same procedure as option 6. The flight controller will have control over earth-return longitude by a MED value to the height of pericynthion. Flow chart 5 shows the relation between option 6 and option 7.

1. Converge TLMC using the following array:

Independent variables	First guess	Weight	Step size
V	Empirical first guess	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ	270°	512	2^{-19}
H_{pc}	MED value (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ	Empirical first guess	512	2^{-19}
T_{pc}	Nominal (not triggered	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

2. Converge an integrated TLMC trajectory as follows:

Independent variables	First guess	Weight	Step size
V_{pc}	Step 1	512	2^{-19}
γ_{pc}	0 (not triggered)	--	--
ψ_{pc}	Step 1	512	2^{-19}
H_{pc}	Nominal (not triggered)	--	--
ϕ_{pc}	Nominal (not triggered)	--	--
λ_{pc}	Step 1	512	2^{-19}
T_{pc}	Nominal (not triggered)	--	--

Dependent variable	Value	Weight	Class designator
X	Midcourse position ±.0657 n. mi.	--	1
Y	Midcourse position ±.0657 n. mi.	--	1
Z	Midcourse position ±.0657 n. mi.	--	1

3. Converge an integrated free-return trajectory to the specified H_{pc}

Independent variables	First guess	Weight	Step size
$\Delta\psi_{mcc}$	Step 2	512	2^{-19}
$\Delta\gamma_{mcc}$	Step 2	512	2^{-21}
ΔV_{mcc}	Step 2	512	2^{-21}

Dependent variable	Value	Weight	Class designator
H_{pc}	MED ± 0.5 n. mi.	--	1
ϕ_{pc}	Nominal ±0.01°	--	1
I_{pc}	90° - 182°	64	0
$H_{fr\ rtny}$	Nominal ± 1.735 n. mi.	--	1
I_{fr}	(a)	8	0

[a]Minimum value is 0° and the maximum value is obtained from the data table.

TABLE I.- INPUT/OUTPUT DATA TABLE[a] WITH SPECIFIC STEP FROM WHICH EACH VARIABLE WILL BE TAKEN TO UPDATE THE DATA TABLE

Input/output variables	Mission options										
	1	2		3		4		5		6	7
			Step		Step		Step		Step		
GMT_{pc}	Y	X,Y	6	X,Y	6	X,Y	5[b]	X,Y	5[b]	Y	Y
GMT_{nd}	Y	X	7[c]	X	7[c]	X	5	X	5		
H_{nd}	Y	X	7[c]	X	7[c]	X	3	X	3		
ϕ_{nd}	Y	X	7[c]	X	7[c]	X	3	X	3		
λ_{nd}	Y	X	7[c]	X	7[c]	X	3	X	3		
H_{pc}	Y	X,Y	4	X,Y	4	X,Y	3	X,Y	3	Y	
ϕ_{pc}	Y	X,Y	4	X,Y	4	X,Y	3	X,Y	3	Y	Y
γ_{loi}		X,Y	4	X,Y	4	X,Y	3	X	3		
$\Delta\psi_{loi}$		X,Y	4	X,Y	4	X,Y	3	X	3		
Δt_{lls}	Y	X,Y	4	X,Y	4	X,Y	3	X,Y	3		
T_{lo}		X,Y	4	X,Y	4	X,Y	3	X,Y	3		
ψ_{lls}	Y	Y	4	X,Y	4	Y	3	X,Y	3		
$\Delta\psi_{tei}$		X,Y	4	X,Y	4	X,Y	3	X	3		
ΔV_{tei}		X,Y	4	X,Y	4	X,Y	3	X,Y	3		
T_{te}		X,Y	4	X,Y	4	X,Y	3	X,Y	3		
ϕ_{lls}	P	P		P		P		P			
λ_{lls}	P	P		P		P		P			
R_{lls}	P	P		P		P		P			

[a]X - updated if option is sent to MPT.
Y - value drawn from data table
P - preflight constant

[b]Call EBETA and XBETA to compute time from node to pericynthion, H_{pc} and ϕ_{pc}.

[c]Call DGAMMA and XBETA to compute time from pericynthion to the node, H_{nd}, ϕ_{nd} and λ_{nd}.

TABLE II.- MED QUANTITIES

MED	Mission options						
	1	2	3	4	5	6	7
T_{mcc}	X	X	X	X	X	X	X
Configuration	X	X	X	X	X	X	X
AZ_{min}[a]			X		X		
AZ_{max}[a]			X		X		
γ_{rtny}[b]						X	X
Rtny Rng[b]						X	X
Adjustment to transearth flight time[c]				X	X		
H_{pc}							X
Min DPS time				X	X		
Max DPS time				X	X		
Min SEA time				X	X		
Max SEA time				X	X		
Max I_{fr}		X	X			X	X

[a]Formulation in the appendix.

[b]These MED parameters are needed to cover the open-loop reentry when there is a G&N failure.

[c]The adjustment to T_{te} will be to change the earth landing by one day.

TABLE III.- DISPLAY OUTPUT[a]

Output	Mission options						
	1	2	3	4	5	6	7
Mode	ω	ω	ω	ω	ω	ω	ω
Return	NA	ω	ω	ω	ω	ω	ω
AZ_{min}	NA	η	η	η	η	NA	NA
AZ_{max}	NA	η	η	η	η	NA	NA
Config.	ω	ω	ω	ω	ω	ω	ω
$g.e.t._{mcc}$[b]	η	η	η	η	η	η	η
$\Delta\overline{V}_{mcc}$	η	η	η	η	η	η	η
YAW_{mcc}[b]	η	η	η	η	η	η	η
h_{pc}	η	η	η	η	η	η	η
$g.e.t._{loi}$[b]	η	η	η	η	η	NA	NA
$\Delta\overline{V}_{loi}$	η	η	η	η	η	NA	NA
AZ_{act}	η	η	η	η	η	NA	NA
H_{bo}	η	η	η	η	η	NA	NA
$\Delta\phi$	NA	η	η	η	η	NA	NA
$H_A LPO$	NA	η	η	η	η	NA	NA
$H_P LPO$	NA	η	η	η	η	NA	NA
$\Delta\overline{V}_{lopc}$	NA	η	η	η	η	NA	NA
$g.e.t._{tei}$	NA	η	η	η	η	NA	NA
$\Delta\overline{V}_{tei}$[c]	NA	η	η	η	η	NA	NA
ΔV_{rem}	NA	η	η	η	η	NA	NA
$g.e.t._{lc}$	NA	η	η	η	η	η	η
ϕ_{ip}[d]	NA	η	η	η	η	η	η
λ_{ip}[d]	NA	η	η	η	η	η	η

[a]η = number; ω = word; NA = not applicable.

[b]Formulation in the appendix. YAW_{mcc} will be formulated by Flight Support Division and delivered to IBM.

[c]$\Delta\overline{V}_{tei}$ will be corrected by +85 fps.

[d]Coordinates of earth landing will be Geodetic.

TABLE III.- DISPLAY OUTPUT[a] - Concluded

Output	Mission options						
	1	2	3	4	5	6	7
H_{pc}	η	η	η	η	η	η	η
Az_{act}	NA	η	η	η	η	NA	NA
ΔV_{rem}[b]	NA	η	η	η	η	NA	NA
STA ID[c]	ω	ω	ω	ω	ω	ω	ω
G.m.t. V[d]	η	η	η	η	η	η	η
g.e.t. V[e]	η	η	η	η	η	η	η
CSM WT[f]	η	η	η	η	η	η	η
LM WT[g]	η	η	η	η	η	η	η

[a] η = number; ω = word; NA = not applicable.

[b] Formulation in the appendix.

[c] STA ID - Standard vector identification of the state vector used to compute the maneuver sequence.

[d] G.m.t. V - G.m.t. time tag of the state vector, hours:minutes:seconds.

[e] g.e.t. V - g.e.t. time tag of the state vector, hours:minutes:seconds.

[f] CSM WT - Total CSM weight, lb.

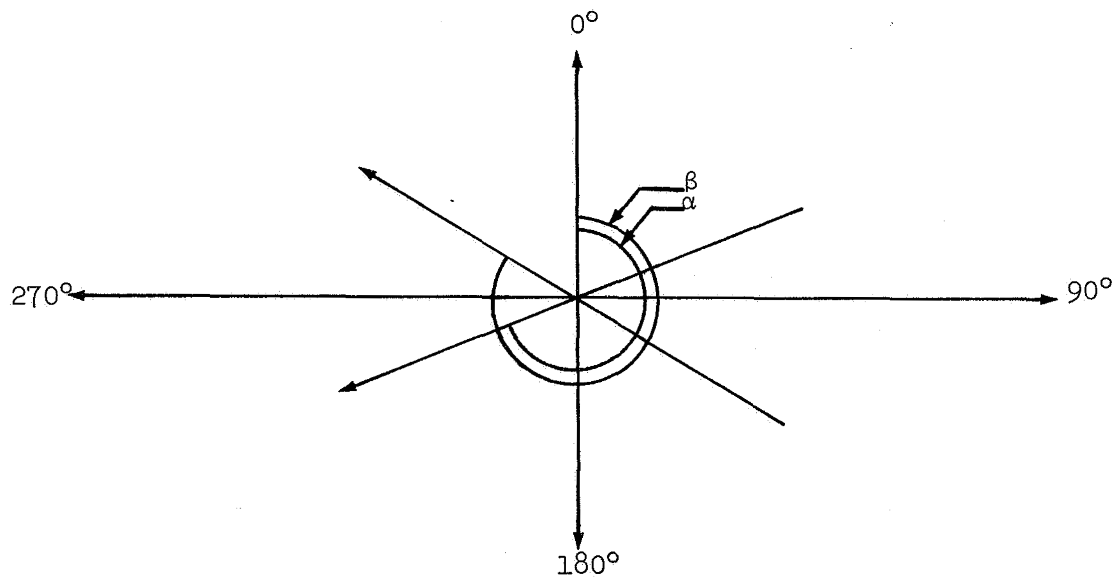
[g] LM WT - Total LM weight, lb.

APPENDIX

OPERATIONAL AND FUNCTIONAL FLOW CHARTS

$AZ_{min} - AZ_{max}$

The MED convention for entering this parameter will be changed to a positive 0° - 360° system as shown below.



For example,

$$\psi_\alpha = 240°$$

and

$$\psi_\beta = 300°$$

$T_{loi\ ign}$

g.e.t.$_{loi}$ is defined to be the time of LOI ignition.

$$T_{LOI\ ign} = T_{nd} + T_{start}$$

$$T_{start} = -\frac{W_o}{\dot{W}}\left[1 + \frac{e^{\frac{-\Delta V}{g_o I_{sp}}} - 1}{\frac{\Delta V}{g_o I_{sp}}}\right]$$

where

W_o = initial mass

$\dot{W}$ = mass flow rate

$\Delta V = \overline{\Delta V}_{loi}$ from the LOI calibration

g_o = gravitational constant

I_{sp} = specified impulse

Calculation of $\Delta\psi_{loi}$

To calculate the $\Delta\psi_{loi}$ the following procedure will be used:

1. Call RVIO with inputs of

$r = 1$

$v = 1$

ϕ = latitude LLS

θ = longitude LLS

$\gamma = 0$

$\psi = \psi_{lls}$

Output will be the unit selenographic cartesian position and velocity vectors U_1 and U_2.

2. Call LIBRAT at the time of landing with U_1 and U_2 as input vectors to get the selenocentric vectors (U_1' and U_2') corresponding to the landing site at the time of landing.

3. Compute $\Delta\psi_{loi} = \cos^{-1}\left[h_1 \cdot (U_1' \times U_2')\right]$

Where h_1 is the unit angular momentum vector at the node, as defined in the precision trajectory computer.

Delta Delta Time Polynomial

The δ (Δt) polynomial determines the optimum nonfree-return translunar flight time (from translunar injection cutoff to lunar orbit insertion). The independent variables are as follows:

a(e.r.): semi-major axis of the shutdown state

$\Delta t'$(hr): delay time from TLI cutoff to translunar midcourse maneuver, this value will be: g.e.t. of TLI_{ign} + 328 sec.

X_m(e.r.): radial distance of the moon at time of lunar orbit insertion of the nominal free-return trajectory

β_m(rad): flight-path angle (measured from local vertical) of the moon at time of LOI of the nominal free return

Δt(hr): nominal free-return flight time from TLI to LOI (value to be used during RT will be the time to pericynthion)

The range of the independent variables is as follows:

a(e.r.) , 13 to 81; $\Delta t'$(hr), 2 to 20; X_m(e.r.), 56 to 63; β_m 1.5 to 1.7; Δt(hr), 61 to 74.7. A check should be provided to determine the value of the semimajor axis. If its value is less than 14 e.r. and positive then it should be set at 14 e.r. If its value is greater than 91 e.r. or less than zero then it should be set at 91 e.r.

This is done because the polynomial is fit between 13 and 81 e.r. and the lower end is not very accurate so the value of a will not be allowed to go below 14 e.r. The upper end is accurate and extropolated very well; therefore, the upper limit will be set at 91 e.r.

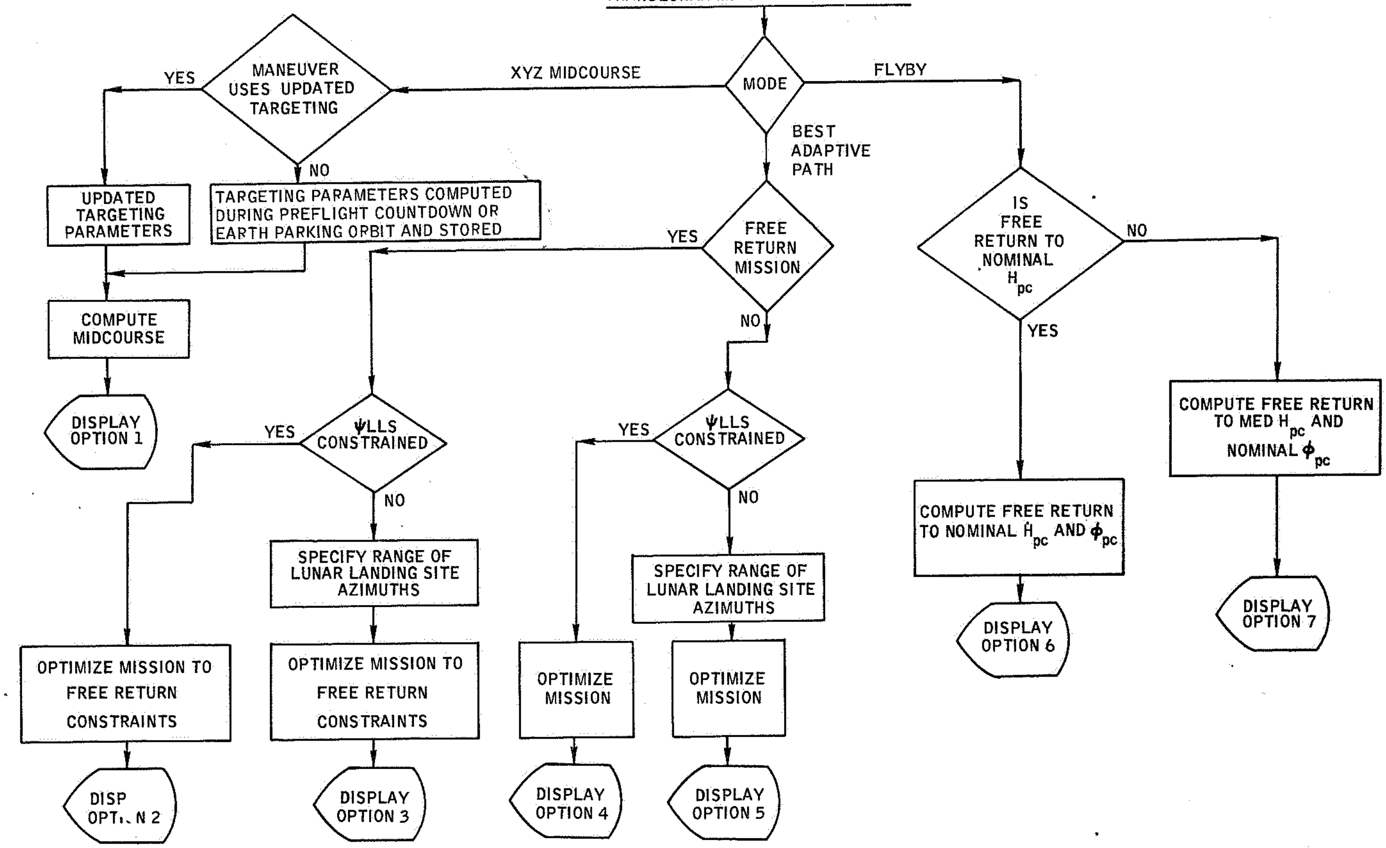
The polynomial is of the form:

$$\begin{aligned}\delta(\Delta t) = {} & b_o + b_1/a + b_2/a^2 + b_3\Delta t'/a + b_4\Delta t'^2 + b_5\Delta t' + b_6X_m + b_7X_m\,\Delta t' \\ & + b_8X_m/a + b_9X_m\Delta t'/a + b_{10}\Delta t'/a^2 + b_{11}\Delta t'^2/a + b_{12}/a^3 + b_{13}\Delta t'^3 \\ & + b_{14}X_m/a^2 + b_{15}X_m\Delta t'^2 + b_{16}\Delta t'^2X_m/a + b_{17}X_m\Delta t'/a^2 + b_{18}\Delta t'^2X_m/a^2 \\ & + b_{19}X_m\cos\beta_m + b_{20}/a^4 + b_{21}\Delta t^3 + b_{22}X_m^{\ 3} + b_{23}\Delta t'/a^4 + b_{24}\Delta t \\ & + b_{25}\Delta t^2 + b_{26}\Delta tX_m/a + b_{27}\Delta tX_m + b_{28}\Delta t/a + b_{29}\Delta t^2\,X_m^{\ 2}/a^2\end{aligned}$$

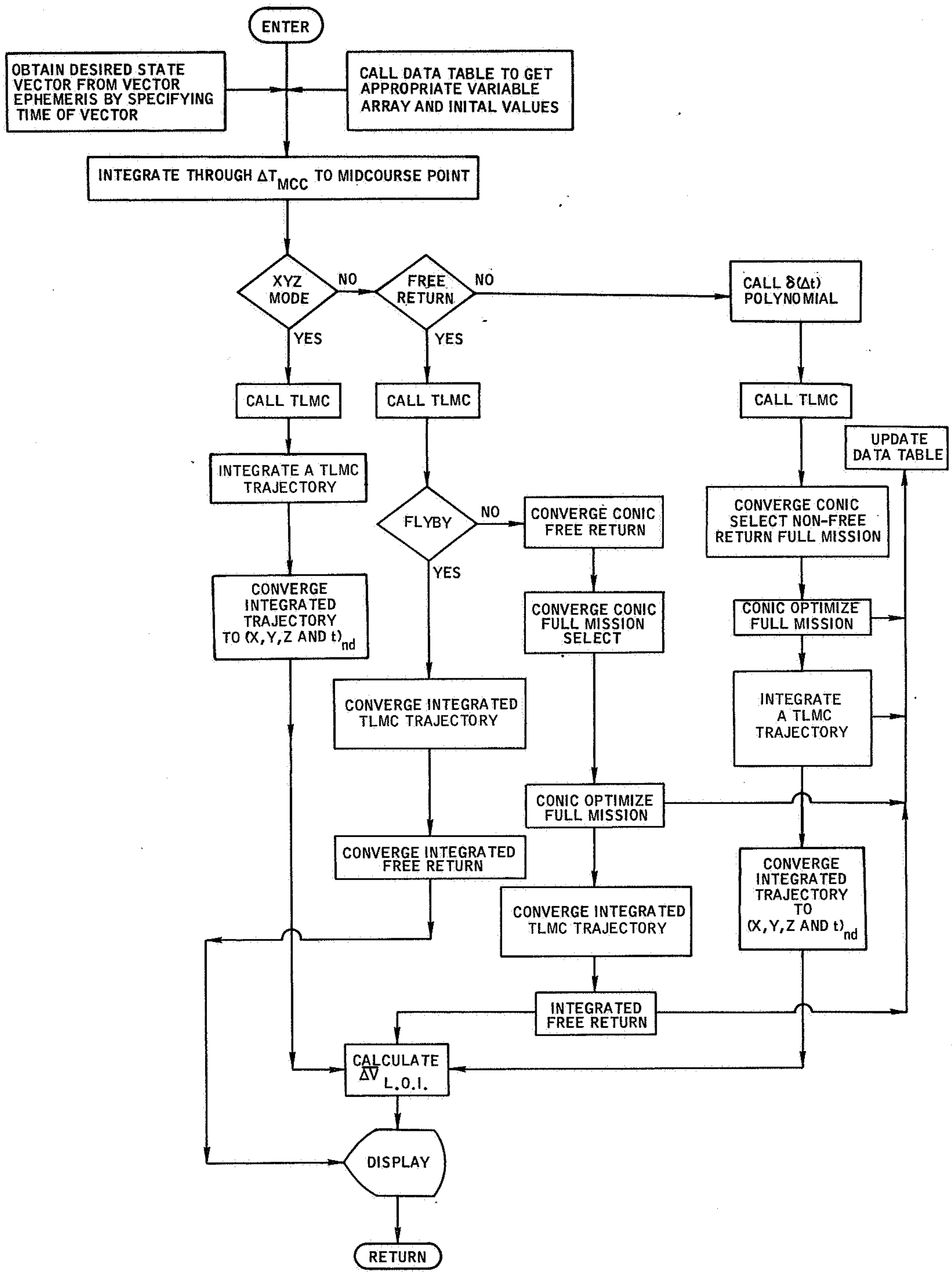
The coefficients for the $\delta(\Delta t)$ polynomial are listed below:

b_o	0.48237399×10^1	b_{13}	$0.16614352 \times 10^{-2}$
b_1	-0.33327854×10^3	b_{14}	0.10673486×10^4
b_2	0.98116717×10^4	b_{15}	$-0.12140743 \times 10^{-2}$
b_3	-0.15785115×10^3	b_{16}	$0.43980221 \times 10^{-2}$
b_4	$0.42236397 \times 10^{-1}$	b_{17}	-0.46467769×10^2
b_5	0.50951511	b_{18}	$0.44041338 \times 10^{-1}$
b_6	0.35644845	b_{19}	-0.23454849
b_7	$-0.15132136 \times 10^{-1}$	b_{20}	0.55472146×10^7
b_8	-0.77055739×10^2	b_{21}	$-0.42499530 \times 10^{-4}$
b_9	0.32689925×10^1	b_{22}	$0.22349293 \times 10^{-3}$
b_{10}	0.31964177×10^4	b_{23}	-0.55596397×10^5
b_{11}	-0.16267514×10^1	b_{24}	$0.28837746 \times 10^{-1}$
b_{12}	-0.99746361×10^6	b_{25}	$-0.91659504 \times 10^{-3}$

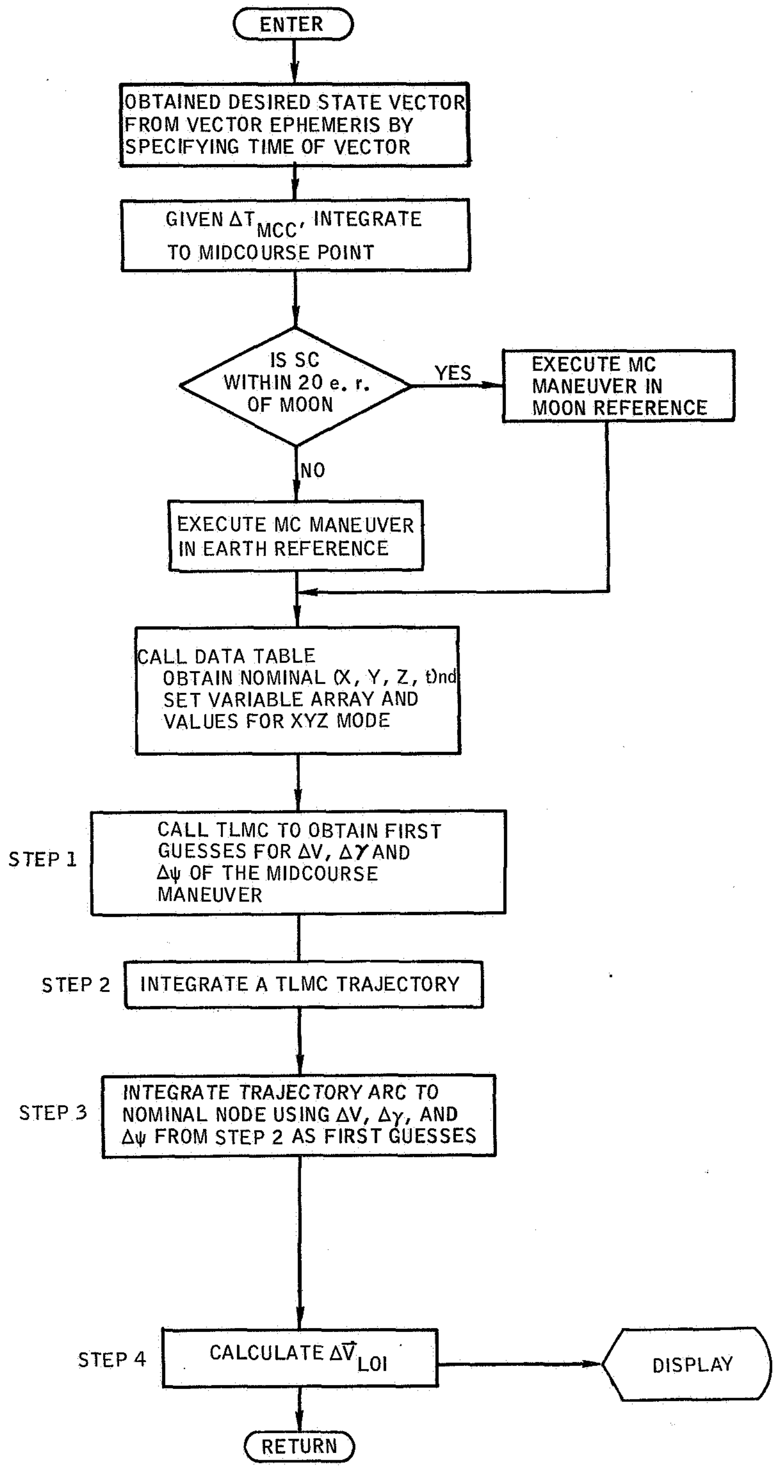
b_{26}	-0.53786773
b_{27}	$0.37944308 \times 10^{-2}$
b_{28}	0.85832895×10^{2}
b_{29}	$-0.69204019 \times 10^{-3}$



Flow chart 1.- Operational flow.



Flow chart 2.- Functional flow translunar midcourse supervisor.



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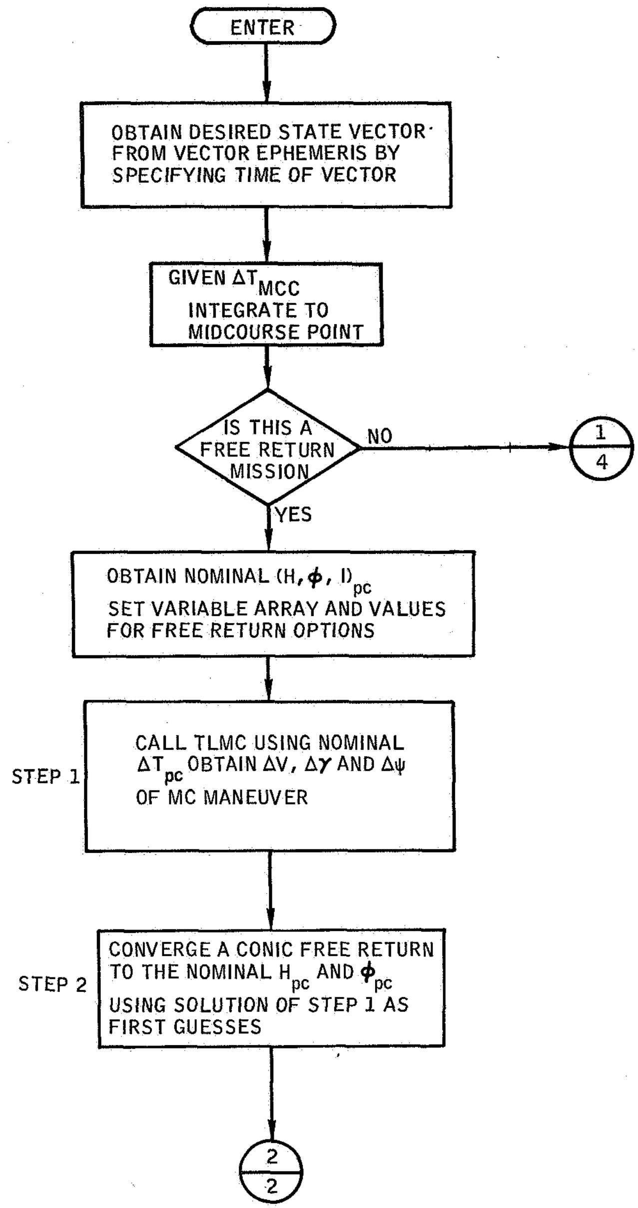
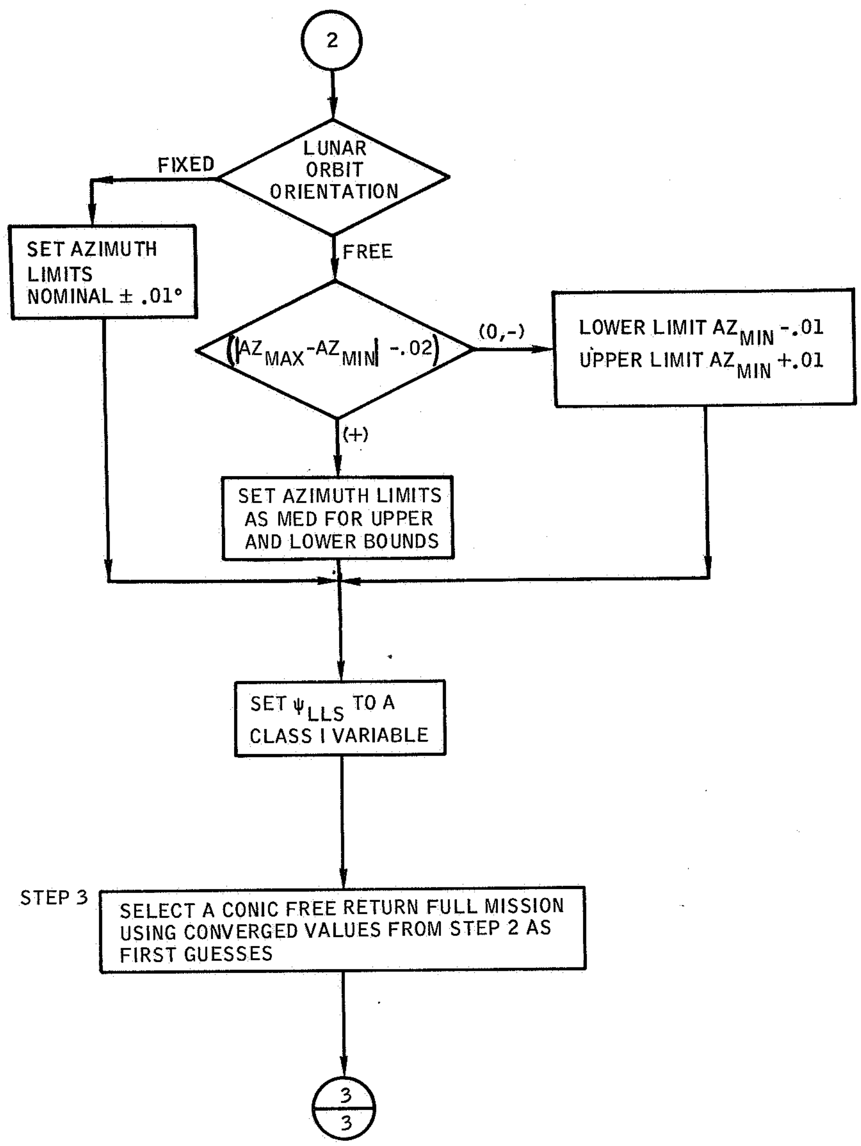
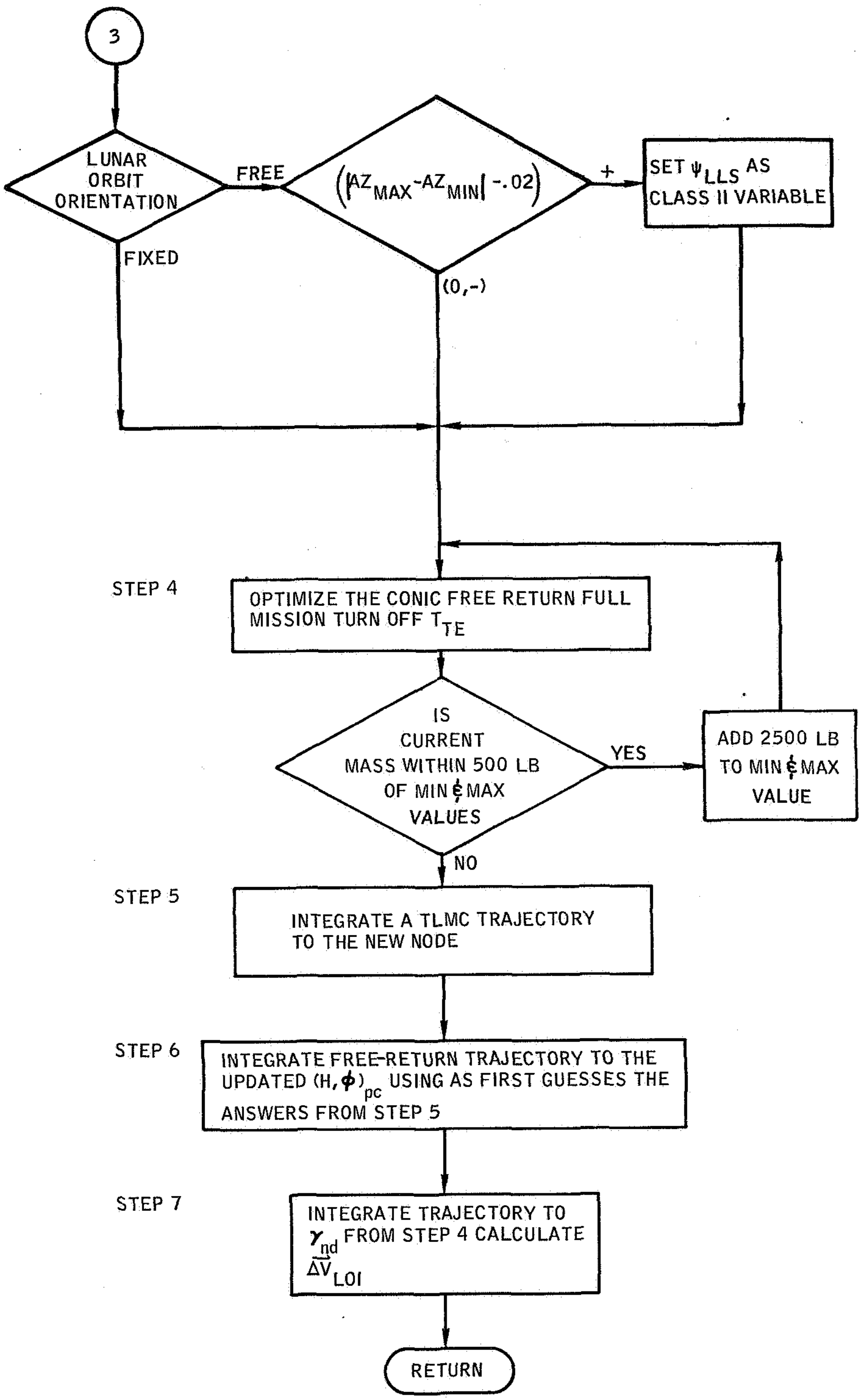
Flow chart 3.- Detailed flow of XYZ logic.



Flow chart 4.- Detailed flow of BAP.



Flow chart 4.- Detailed flow of BAP - Continued.



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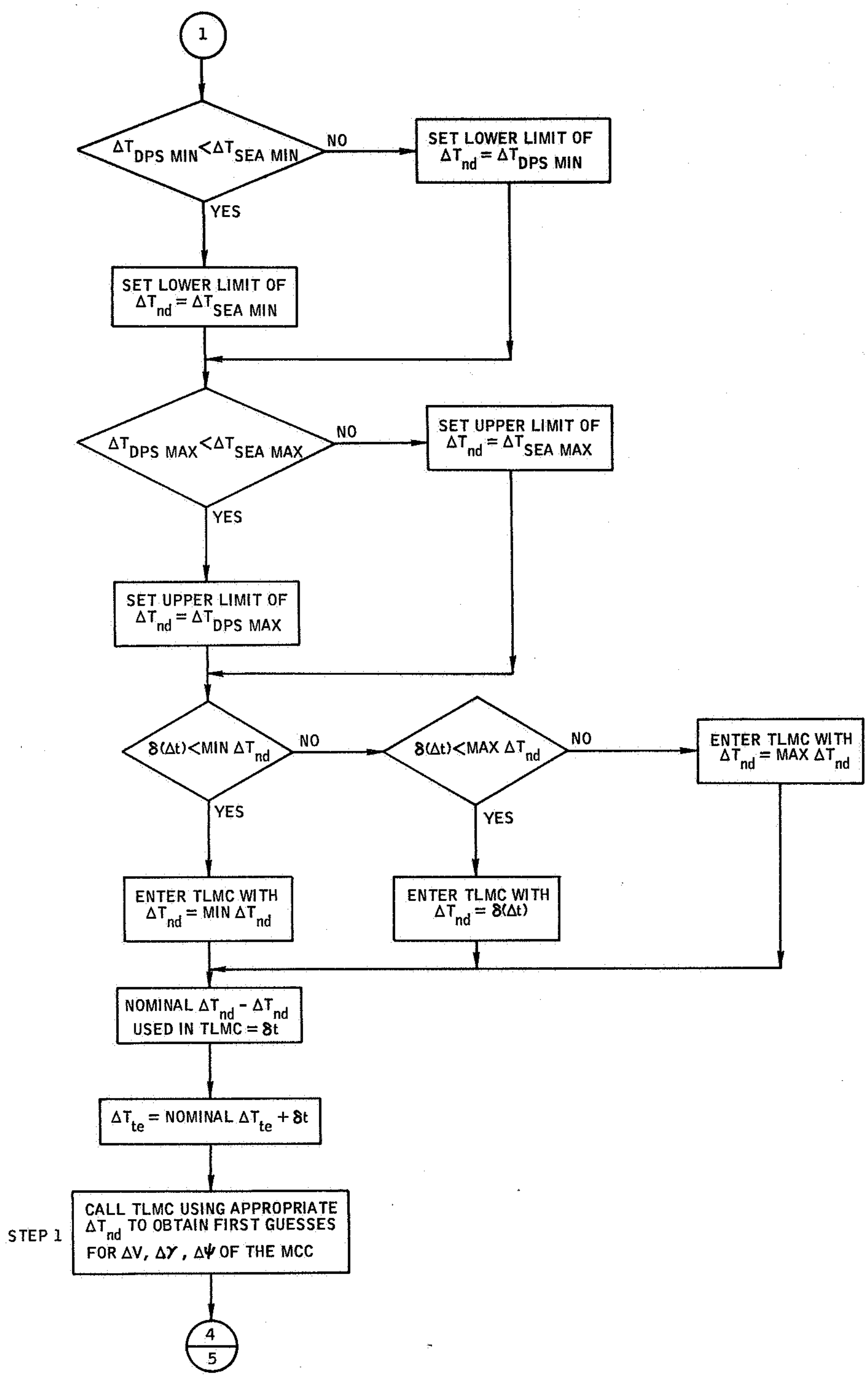
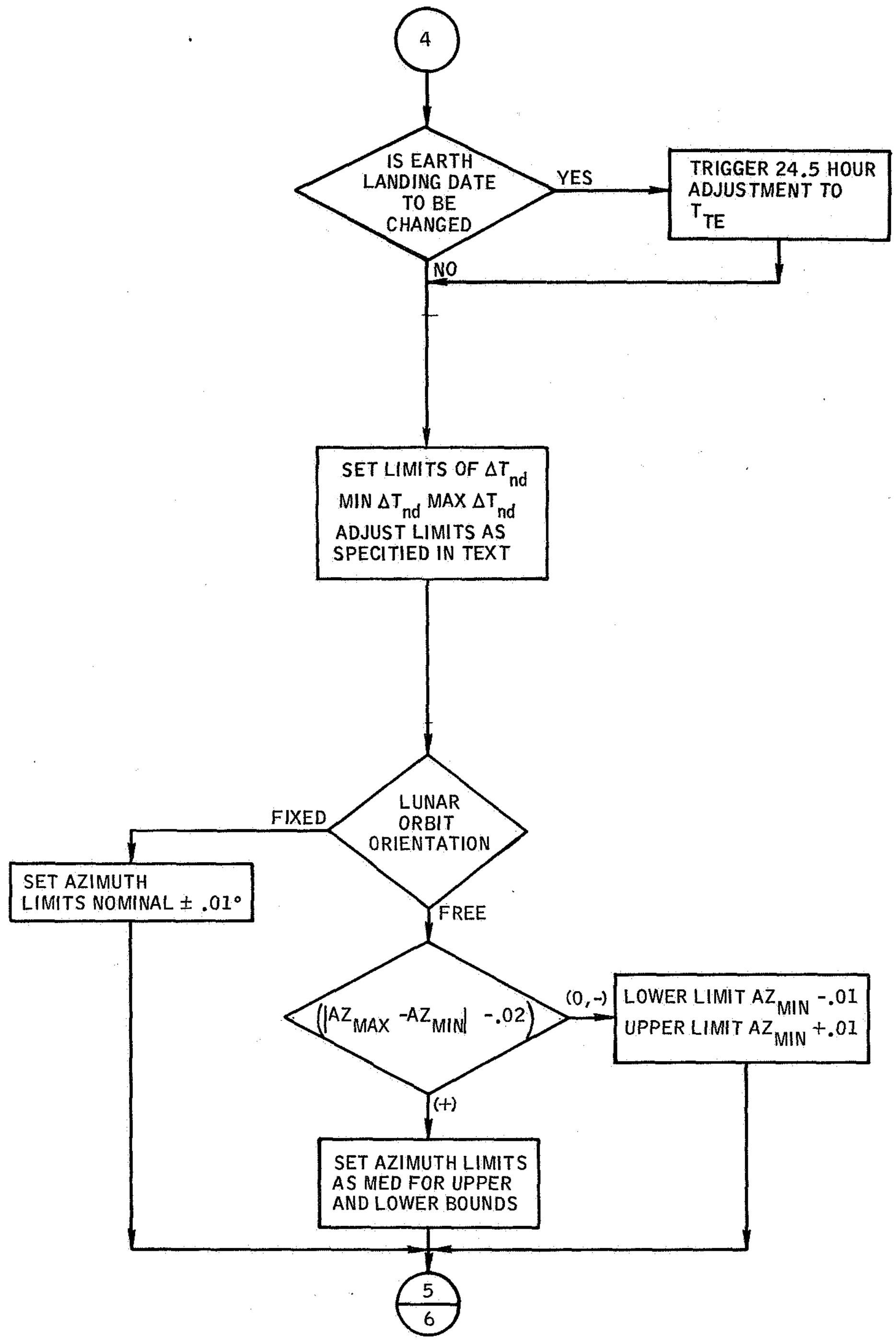
Flow chart 4.- Detailed flow of BAP - Continued.



Flow chart 4.- Detailed flow of BAP - Continued.



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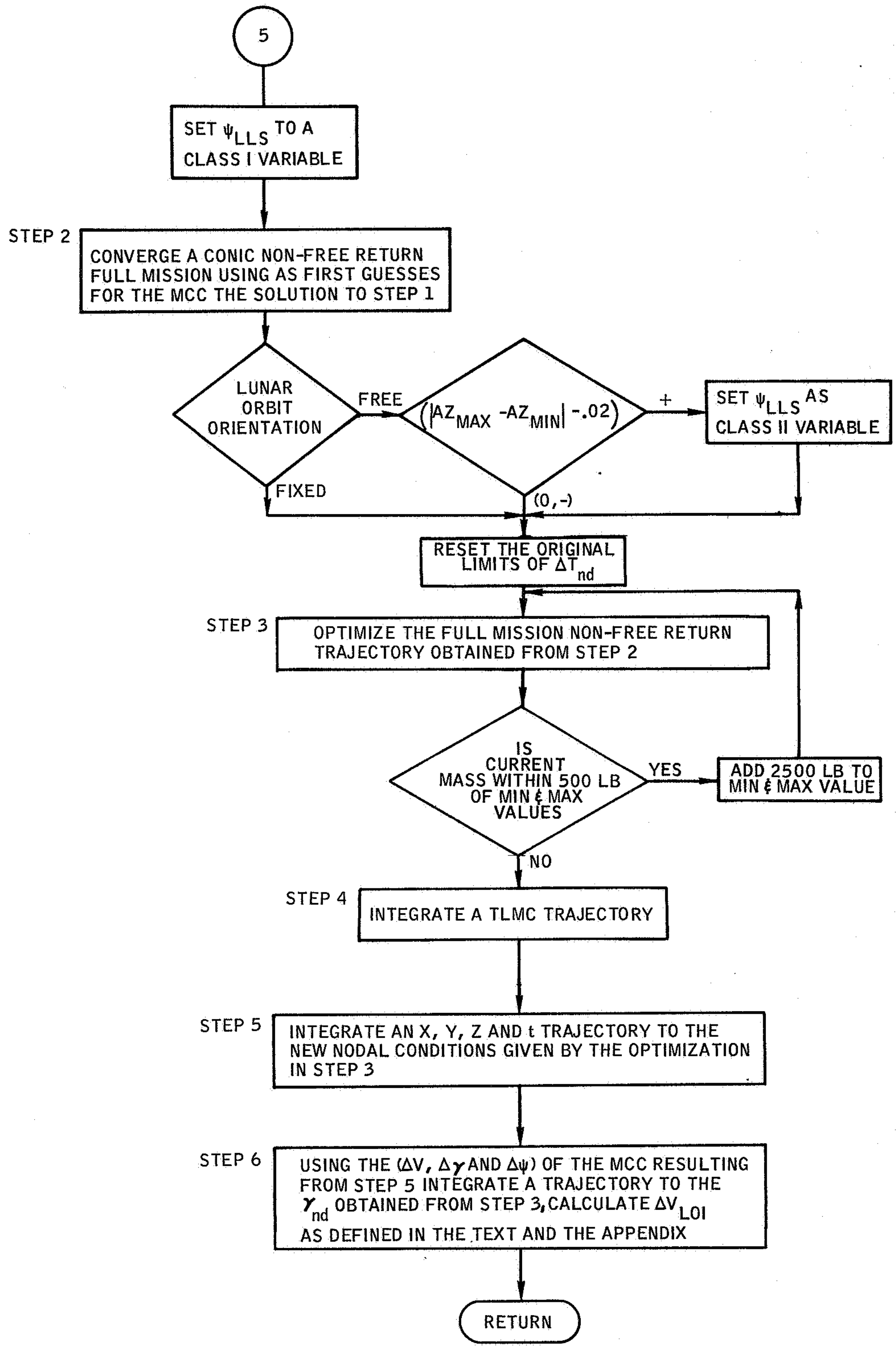
Flow chart 4.- Detailed flow of BAP - Continued.



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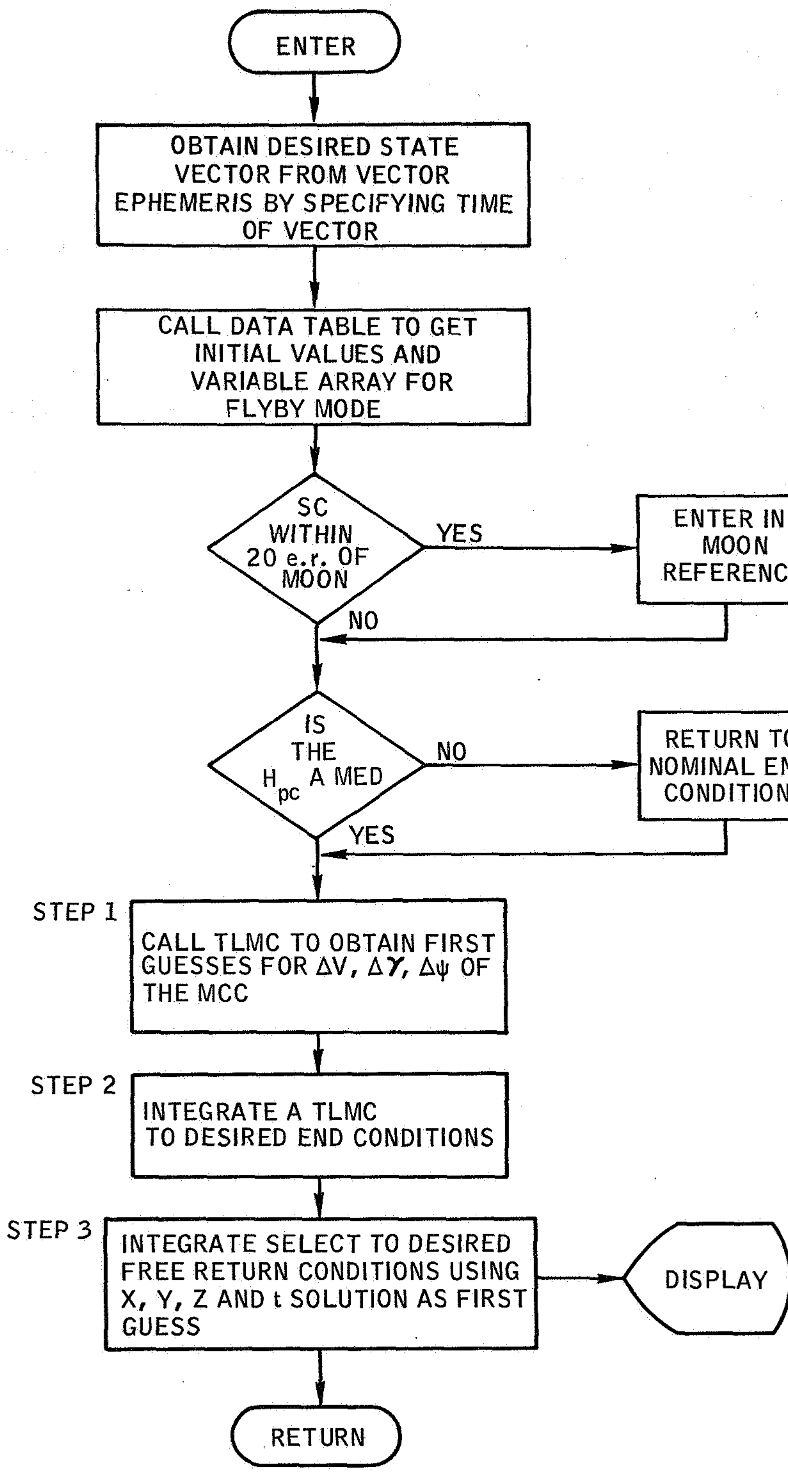
Flow chart 4.- Detailed flow of BAP - Concluded.



Flow chart 5.- Detailed flow of flyby mode.

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