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LEVEL C REQUIREMENTS FOR THE SHUTTLE MISSION CONTROL CENTER ORBITAL GUIDANCE SOFTWARE

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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1.0 SUMMARY

This document identifies the Level C requirements for the Shuttle Mission Control Center (SMCC) orbital guidance software. The requirements are formulated to provide a functional simulation of the onboard Powered Explicit Guidance (PEG) software as required by various processors in the SMCC [e.g., Mission Plan Table (MPT), Powered Flight Numerical Integrator (PFNI), and Deorbit Planning Processor (DPP)]. These Level C guidance software requirements are consistent with the Level B requirements of those SMCC processors which require a guidance simulation (see References 1, 2, and 3) and at a minimum reflect the current status (July 1976) of the onboard PEG software as detailed in the preliminary Level C Functional Subsystem Software Requirements (FSSR). (See Reference 4.)

This document presents the formulation of Level C requirements for the SMCC guidance software. Section 3.0 presents detailed requirements for a PEG supervisor which controls all input/output interfaces with other SMCC processors and determines which PEG mode is to be utilized. Sections 4.0 and 5.0 present the detailed description (i.e., logic flow diagrams, mathematical equations, etc.) of the two guidance modes (7 and 4, respectively) for which these Level C requirements have been formulated. Sections 6.0 and 7.0 define functions required for proper execution of the guidance software. Section 6.0 defines the requirements for a navigation function that is used in the prediction logic of PEG mode 4. This function is extracted from the current navigation FSSR (Reference 5). The function PRECISE PREDICT as defined in Section 6.0 may be used in the SMCC guidance software for prediction of the burnout state until such time that a more concise replacement function is defined. Section 7.0 contains routine LTVCON which is used in determining a burn/coast-to-target guidance solution. The LTVCON routine is defined separately since it will perform a function required within the SMCC by users other than PEG. (See Reference 3.)

2.0 INTRODUCTION

The generation of accurate mission profiles (both nominal and abort) in the SMCC necessitates a functional simulation of the onboard guidance software. As specified in the Level B documents for the MPT, PFNI and DPP (References 1, 2, and 3), the requirement exists for the simulation of PEG modes 4 and 7 within the SMCC. PEG-4 (linear terminal velocity constraint guidance) is the primary guidance algorithm used during nominal and abort ascent maneuvers involving the Orbital Maneuvering System (OMS) engines and for all deorbit burns. PEG-7 (guidance for external delta velocity maneuvers) is the guidance algorithm for all on-orbit maneuvers and serves as the back-up guidance algorithm for all PEG-4 maneuvers.

The orbital guidance requirements of this memo have been defined by McDonnell Douglas Technical Services Company under the Space Shuttle Engineering and Operations Support (SSEOS) contract. The requirement definitions were developed for the Guidance and Dynamics Branch (GDB) of the Mission Planning and Analysis Division (MPAD) in support of the GDB response to Reference 6.

3.0 GUIDANCE SUPERVISOR

This section defines the requirements for a routine (PEGSUP) which performs the supervisory function in the orbital guidance software. This routine is called by the various SMCC processors and provides all necessary input/output and data interfaces needed to provide a functional simulation of the onboard guidance software.

3.1 Detailed Description

PEGSUP is called using the inputs as detailed in Reference 2. Input requirements for PEGSUP are contained in Table I. The table contains a list of required inputs for the orbital guidance simulations (e.g. target vectors, gravitational constants, propulsion and mass characteristics). Using the indicated inputs, the function of PEGSUP may be summarized by the following sequence:

a. Test first pass flag (K_{FPASS}) and initialize guidance request flags and initialization flag (K_{INIT}) as required.

b. Test the guidance specification flag (KD_{GUID}) to determine if PEG-4 or PEG-7 is to be used. If PEG-4 guidance is desired, determine if the maneuver is a nominal, abort, or deorbit and set appropriate flag.

c. Compute the change in sensed velocity ($\Delta\overline{V}_S$) and update the guidance position and velocity vectors ($\overline{R}_{GD}$, $\overline{V}_{GD}$) and time (T_{GD}).

d. Determine if active steering computations are desired (computation of thrust direction $\overline{U}_T$).

e. Decrement time-to-go (T_{GO}) and velocity-to-go (V_{GO}) if active guidance has been terminated.

f. Update the estimated vehicle mass and acceleration (ATR).

g. Cycle the guidance computations until a converged solution is achieved.

h. Determine if active guidance computations are to be terminated.

3.2 Logic Flow

The logic flow of PEGSUP is illustrated in Figure 1. Definitions of symbols used in the logic flow diagram are included in Table II. Included in Table II is an indicator (TYPE) of the function of each variable:

TYPE	DEFINITION
I	Parameter is an input variable to this routine
C	Parameter is computed in this routine
O	Parameter is an output from this routine to the functional guidance routines
GO	Parameter is a guidance output

4.0 EXTERNAL DELTA-VELOCITY ROUTINE

This section defines the routine PEG-7 which performs the computations necessary to functionally simulate the onboard external delta-velocity guidance algorithms. This guidance mode is primarily used to perform powered flight guidance during normal on-orbit maneuvers and is designated as the backup guidance algorithm to the linear terminal velocity constraint mode (PEG-4) during ascent and deorbit maneuvers.

4.1 Detailed Description

This guidance routine is called by the guidance supervisor PEGSUP to simulate the external delta-velocity algorithm. Using the input velocity-to-be-gained vector ($\overline{V}_{GO}$), estimated vehicle acceleration (ATR) and total effective exhaust velocity (V_{EX}) of the propulsion system, PEG-7 determines the time-to-go until thrust termination (T_{GO}) and the resulting thrust direction (unit vector $\overline{U}_T$). On the first call to PEG-7, the thrust vector turning rate ($\dot{\lambda}$) is set equal to zero and is not updated in subsequent passes through PEG-7. This insures that the resulting thrust direction ($\overline{U}_T$) is equivalent to the desired thrust direction ($\overline{\lambda}$) for PEG-7 operation.

4.2 Logic Flow

The routine PEG-7 is called from the guidance supervisor PEGSUP whenever the guidance mode flag (K_{MODE}) is equal to 7. The detailed logic flow of this routine is shown in Figure 2. The symbols used in the PEG-7 flow diagram are defined in Table III.

5.0 LINEAR TERMINAL VELOCITY CONSTRAINT GUIDANCE ROUTINE

This section defines PEG-4 the routine which provides a functional simulation of the linear terminal velocity constraint guidance algorithm as currently defined in References 4 and 7. This mode performs guidance computations necessary to ensure achievement of the desired relationship between horizontal and vertical velocity components at a given target position vector. As currently planned all OMS ascent maneuvers and the deorbit maneuver will be simulated utilizing this mode as the primary guidance algorithm.

5.1 Detailed Description

This routine (in conjunction with its utility routines) determines the velocity-to-be-gained ($\overline{V}_{GO}$), time-to-go until thrust termination (T_{GO}) and the resultant thrust direction vector ($\overline{U}_T$) required to solve the linear terminal velocity constraint guidance problem. Having been called by the guidance supervisor (PEGSUP) with the proper input parameters (Table I), this routine then sequences the following utility routines to perform the guidance computations:

Utility Routine	Function Performed
INIT	Parameter initialization (Section 5.1.1)
UPVGO	Update velocity-to-go vector ($\overline{V}_{GO}$) (Section 5.1.2)
TGO	Calculate time-to-go (T_{GO}) until thrust termination (Section 5.1.3)
INTEG	Calculate thrust integrals (Section 5.1.4)

Utility Routine	Function Performed
TURNR	Calculate turning rate vector ($\bar{\dot{\lambda}}$) (Section 5.1.5)
PREDICTOR	Predict position and velocity vectors at cutoff (Section 5.1.6)
CORRECTOR	Compute $\bar{V}_{GO}$ and test for convergence of of guidance solution (Section 5.1.7)
PRECISE PREDICT	Perform a state vector prediction function (Section 6.0)
LTVCON	Compute the velocity required at an initial point in order to intercept a target position with a specified linear relationship between the terminal radial and horizontal velocity components (Section 7.0)

Upon first entry into PEG-4, INIT is called for parameter initialization. On all subsequent passes, UPVGO is called to update $\bar{V}_{GO}$ and the current guidance phase number. If $\bar{V}_{GO}$ is zero, PEG-4 is exited (no guidance computations are required). After determining T_{GO}, the desired thrust vector ($\bar{\lambda}$), and the turning rate vector ($\bar{\dot{\lambda}}$), a test is made to check for unit thrust direction ($\bar{U}_T$) calculation. If active steering is enabled (K_{STEER}=1) and PEG-4 has computed a converged solution with no significant differences between the current and previous predicted burnout times, $\bar{U}_T$ is computed. Otherwise this calculation is bypassed. Following thrust direction calculations, burnout position and velocity-to-go are determined.

The linear terminal velocity constraint logic (PEG-4) is called from PEGSUP to perform mode 4 guidance computations. The detailed logic flow of PEG-4 is shown in Figure 3. Definitions of symbols used in PEG-4 and its utility routines are found in Table IV.

5.1.1 Utility Routine INIT

This routine is called only on the first pass through the mode 4 guidance computations. INIT sets the predicted burnout state ($\overline{R}_p$, $\overline{V}_p$) equal to the current state and calls utility routine CORRECTOR to determine an initial $\overline{V}_{GO}$. INIT also initializes the current guidance phase indicator (K_{PHASE}) to one.

A detailed logic flow of INIT is shown in Figure 4. Definitions of symbols used in this routine are found in Table IV.

5.1.2 Utility Routine UPVGO

On all passes through PEG-4 subsequent to the first pass, utility routine UPVGO is called to update the velocity-to-be-gained before thrust termination ($\overline{V}_{GO}$). $\overline{V}_{GO}$ is decremented by the computed change in accumulated sensed velocity ($\Delta\overline{V}_S$) as determined in PEGSUP. UPVGO also tests to determine when the current guidance phase is terminated and increments the phase indicator (K_{PHASE}), initializes the burn time of the new phase ($T_B(K_{PHASE})$) and initializes guidance phase time-to-go ($T_{GO\Lambda}(K_{PHASE})$). A detailed logic flow of utility routine UPVGO is shown in Figure 5. Definitions of symbols used in the flow diagram are found in Table IV.

5.1.3 Utility Routine TGO

Utility routine TGO is called by PEG-4 to compute time-to-go until thrust termination (T_{GO}) and to update predicted burnout time (T_p). A test is made to determine if multi-phase logic (N>1) is to be utilized to compute T_{GO}. If single phase logic is specified, T_{GO} is computed as a function of the vehicle estimated acceleration (ATR), total exhaust velocity (V_{EX}) and magnitude of the velocity-to-go (V_{GOMAG}). If multi-phase logic is utilized, estimated burn times of all phases are computed and summed to determine the total T_{GO} for the maneuver. Following the T_{GO} computation, predicted burnout time (T_p) is computed by summing current time and T_{GO}. It should be noted that the multi-phase software requirements specified in Figure 6 are limited by: a) multi-phase implies two phases only

b) multi-phase is designed for an OMS/RCS parallel burn followed by an OMS burn.

Detailed logic flow of routine TGO is shown in Figure 6. Definitions of symbols used in the logic flow diagrams are found in Table IV.

5.1.4 Utility Routine INTEG

INTEG is a utility routine called by PEG-4 to compute a set of inputs for determining the first and second order thrust integrals. The integral calculations assume a constant force magnitude and are time integrals of force over mass. The integrals are used in the thrust vector turning rate calculations and the prediction equations of guidance. The integrals are computed for each phase and summed over the total number of guidance phases.

As currently defined in Reference 7, the deorbit and AOA OMS-2 guidance algorithms consist of single phase logic, utilizing only first order thrust integrals.

The orbital guidance requirements specified in this report are consistent with the reference. The computation of second order integrals and multi-phase logic are deleted depending on a test which is incorporated into INTEG to determine if deorbit/AOA OMS-2 guidance is desired.

After determining the thrust integrals, INTEG computes a reference time (T_λ) used in the calculation of the resultant thrust direction ($\overline{U}_T$).

Detailed logic flow of INTEG is illustrated in Figure 7. Definitions of symbols used in the logic flow diagram are given in Table IV.

5.1.5 Utility Routine TURNR

Routine TURNR is called by PEG-4 to determine thrust vectors $\overline{\lambda}$ and $\dot{\overline{\lambda}}$.. The desired thrust vector ($\overline{\lambda}$) is computed as a unit vector in the direction of $\overline{V}_{GO}$. If the simulated maneuver is a deorbit or AOA OMS-2, the turning rate vector ($\dot{\overline{\lambda}}$) is computed as a function of the primer rate ($\dot{\lambda}_{XZ}$), thrust vector ($\overline{\lambda}$) and a unit vector ($\overline{U}_Y$) which is normal to the desired orbital plane. If the maneuver is not a deorbit or AOA OMS-2, $\dot{\overline{\lambda}}$ is computed as a function of the range-to-go vector ($\overline{R}_{GO}$), $\overline{\lambda}$ and the thrust integrals. A test is made to insure that $\dot{\overline{\lambda}}$ does not result in a violation of small angle approximations used in development of the guidance equations.

Detailed logic flow of TURNR is illustrated in Figure 8. Definitions of symbols used in the logic flow diagram are found in Table IV.

5.1.6 Utility Routine PREDICTOR

Routine PREDICTOR is called by PEG-4 to predict the burnout state vector. To perform this function, the first and second integrals of thrust acceleration and gravity must be determined. The function of PREDICTOR and its interface with a navigation-defined state propagation routine are described in this section.

5.1.6.1 Determination of Thrust Integrals

The thrust time integrals ($\overline{V}_{THRUST}$, $\overline{R}_{THRUST}$) are computed as functions of the reference thrust vectors ($\overline{\lambda}$, $\dot{\overline{\lambda}}$) and the force over mass integrals of INTEG for all simulated maneuvers except deorbit and AOA OMS-2. As specified in Section 5.1.4, Reference 7 indicates that the second order integrals of force over mass are negated for these maneuvers. Hence, the thrust time integrals are determined by setting $\overline{V}_{THRUST}$ equal to $\overline{V}_{GO}$ and $\overline{R}_{THRUST}$ equal to $\overline{R}_{GO}$ for deorbit and AOA OMS-2.

5.1.6.2 Determination of Gravity Acceleration Integrals

Integrals of gravity acceleration are approximated by propagation of the state vector over a coasting arc which remains close to the powered trajectory. The initial state vector ($\overline{R}_{C1}$, $\overline{V}_{C1}$) input to the state propagation routine are computed as a function of the current guidance state vector ($\overline{R}_{GD}$, $\overline{V}_{GD}$), the thrust integrals ($\overline{V}_{THRUST}$, $\overline{R}_{THRUST}$), and T_{GO}. Current onboard guidance software specifications (Reference 4) indicate that the state propagation is to be performed by a navigation function. The logic for this navigation function has been extracted from the navigation FSSR (Reference 5) and is defined in this memo as routine PRECISE PREDICT. A description of PRECISE PREDICT is given in Section 6.0.

As part of the inputs to PRECISE PREDICT, PREDICTOR determines a maximum value for integration step size (ΔT_{AVG}). Step size ΔT_{AVG} is set equal to the middle value of ΔT_{MAX}, T_{GO}/N_{SEG} and ΔT_{MIN}. in PREDICTOR.

5.1.6.3 PREDICTOR/PRECISE PREDICT Interface

Targets for a PEG-4 maneuver are based on a burn-coast sequence (input target values are for the end coast phase). The burn arc of the PEG-4 solution includes oblateness effects ($J_2 \neq 0$) in the gravity potential model. The coast arc within PEG-4 is calculated using a spherical earth model. Thus it is necessary to bias guidance input targets in order to achieve the desired terminal state vector. The desired terminal conditions ($\overline{R}_T$, C_1, C_2) are biased ($\overline{R}_T + \Delta\overline{R}_T$, $C_1 + \Delta C_1$) to account for oblateness effects (J_2) which will be experienced during the actual coast. The target biases ($\Delta\overline{R}_T$ and ΔC_1) are inputs to the guidance software as defined in this paper.

The target biases are computed based on a given burn arc with no engine failure; nominal burn arc is assumed to be accurately predicted. However, to account for off-nominal situations (predicted burn arc does not equal given burn arc), the position at cutoff

($\bar{R}_p$, $\bar{V}_p$) must be adjusted for the oblateness effects. This necessitates two calls to PRECISE PREDICT. The first call propagates $\bar{R}_{C1}$ and $\bar{V}_{C1}$ (with J_2 effect included) over a time interval equivalent to T_{GO} minus the difference between the targeted coast time ($\Delta T_{COAST\ (REF)}$) and the actual coast time (ΔT_{COAST}). The second PRECISE PREDICT call propagates the state resulting from the first call ($\bar{R}_{INT}$, $\bar{V}_{INT}$) over an interval equivalent to $\Delta T_{COAST\ (REF)}$ minus ΔT_{COAST} (without J_2 effect). The final state vector is defined as $\bar{R}_{C2}$, $\bar{V}_{C2}$.

Having accomplished the state extrapolation, the gravity biases ($\bar{R}_{GRAV}$, $\bar{V}_{GRAV}$) are computed and are used to adjust the predicted burnout state ($\bar{R}_p$, $\bar{V}_p$).

5.1.6.4 PREDICTOR Logic Flow

Detailed logic flow of routine PREDICTOR is illustrated in Figure 9. Definitions of symbols used in the logic flow diagram are found in Table IV.

5.1.7 Utility Routine CORRECTOR

CORRECTOR is called by PEG-4 to set the desired position vector ($\bar{R}_D$), to determine the desired velocity ($\bar{V}_D$) at burnout, to correct $\bar{V}_{GO}$ for any desired fuel depletion burns and to perform the check on guidance convergence. Desired velocity ($\bar{V}_D$) is determined by routine LTVCON. LTVCON computes $\bar{V}_D$ such that the target position (at end coast) is intercepted with a desired relationship between horizontal and vertical velocity. Before the LTVCON call is executed, corrections are made to the target position ($\overline{R}_T$). If the simulated maneuver is an abort or deorbit, $\overline{R}_T$ is constrained to be in the predicted cutoff plane. If the maneuver is an AOA OMS-2 or deorbit maneuver, the magnitude of $\overline{R}_T$ is adjusted to be consistent with the desired geodetic altitude (H_{TGT}) above the Fischer ellipsoid.

After determining $\overline{V}_D$, a correction is applied to $\overline{V}_{GO}$ using a scalar damping factor (RHO_{MAG}) and miss velocity (difference between $\overline{V}_p$ and $\overline{V}_D$). If fuel depletion burns are to be performed, $\overline{V}_{GO}$ is corrected to include the out-of-plane velocity accumulated by the depletion burn. After correcting $\overline{V}_{GO}$, a convergence check is made to determine if miss velocity ($\overline{V}_{MISS}$) is within acceptable limits.

Detailed logic flow of routine CORRECTOR is illustrated by Figure 10. Definitions of symbols used in the logic flow diagram are given in Table IV.

6.0 STATE PREDICTION ROUTINE

This section defines routine PRECISE PREDICT. The routine is called by PREDICTOR to perform the state extrapolation function. The extrapolation is required to determine gravitational effects to be used in the prediction of burnout position and velocity vectors ($\overline{R}_p$, $\overline{V}_p$). PRECISE PREDICT is developed from a modification of the current "Super G" algorithm. (See Reference 5.)

6.1 Detailed Description

The function of PRECISE PREDICT is to calculate an extrapolation of a state vector. To accomplish this the following inputs are required:

a) initial state vector - ($\overline{R}_I$, $\overline{V}_I$, T_I)

b) time for computation of final state (T_F)

c) upper bound on integration step size (ΔT_{MAX})

d) indicators for gravity, drag and vent models (GMD, GMO, DM, VM)

Using the above inputs, PRECISE PREDICT determines an integration interval for use in the calculations and the initial acceleration. The routine then:

a) advances current time (T)

b) integrates current radius ($\overline{R}_F$) and velocity ($\overline{V}_F$)

c) updates acceleration

d) corrects radius by the "Super G" algorithm.

This process is repeated iteratively until time T_F. The last pass values of $\bar{R}_F$ and $\bar{V}_F$ are the state vector at the final time.

Sections 6.1.1 and 6.1.2 contain descriptions of two utility routines (ACCEL and ACCEL GRAV) which are used by PRECISE PREDICT.

Detailed logic flow of routine PRECISE PREDICT is illustrated by Figure 11. Definitions of symbols used in PRECISE PREDICT and its utility routines are contained in Table V.

6.1.1 Utility Routine ACCEL

ACCEL is a function routine. It is called from PRECISE PREDICT to compute gravitational and non-gravitational (drag, venting) accelerations. The SMCC requirements for drag and venting models (within the guidance link) are unclear at this time. (See Reference 7.) These models are controlled by input flags DM and VM and are not called if DM = 0, VM = 0. Because the requirement for these models is not clearly defined at this time, only the logic for accessing drag and venting models is included in this report.

ACCEL is the supervisor for the acceleration calculations. It computes acceleration due to a central body force, controls the calling of a higher order gravitational model (ACCEL GRAV), controls calling of drag and vent models (ACCEL DRAG and VENT), and computes the total acceleration. In addition, it issues calls for vehicle attitude (ATT) and atmospheric density (DENSITY). Vehicle attitude is required by VENT and ACCEL DRAG. An attitude control flag (ATM) is set in the prediction routine. The flag is consistent with the Reference 5 logic in that the referenced attitude determination logic requires an indicator for propagation (ATM = 0) or prediction (ATM = 1).

Logic flow for routines ACCEL and ACCEL GRAV is provided in this report. The vehicle attitude (ATT), vent (VENT), density (DENSITY) and drag (ACCEL DRAG) models are not included. The outputs required from these routines are specified in Figure 12 and Table V.

Detailed logic flow of the function ACCEL is illustrated by Figure 12. Definitions of symbols used in the logic flow diagram are listed in Table V.

6.1.2 Utility Routine ACCEL GRAV

This section contains a brief description of utility routine ACCEL GRAV. The logic flow of ACCEL GRAV is illustrated in Figure 13. The logic for the model is taken from Reference 5 and is based on Reference 8. This model determines gravitational effects resulting from the oblateness of the Earth. The model is controlled by input flag GMD (GMD $\neq$ 0: compute oblateness effects). Input flag GMO indicates the order of calculation for the model. The inputs are restricted in that GMO $\leq$ GMD with a maximum value of 8 for GMD. The limits which are imposed on the arrays of ACCEL GRAV are specified in Table V.

The logic contained in Figure 13 for determining gravitational acceleration includes both sectorial and zonal effects. The acceleration calculations are performed in earth-fixed coordinates and rotated into the mean of 1950 (M50) system for use by ACCEL. A detailed description of the logic of ACCEL GRAV is contained in Reference 8. Table V contains definitions of the symbols used in the Figure 13 logic flow.

7.0 LINEAR TERMINAL VELOCITY CONSTRAINT ROUTINE

This section describes routine LTVCON which is used to determine the velocity required at an initial point ($\overline{R}_0$) to intercept a target position ($\overline{R}_1$) such that a specified linear relationship between the terminal radial and horizontal velocity components is satisfied. This linear relationship is specified by:

$$V_{RADIAL} = C_1 + C_2 * V_{HORIZONTAL}$$

The solution involves a set of two-body differential equations of motion for a spacecraft center of mass in an inverse square central force field.

7.1 Detailed Description

Within the logic flow as specified for calculating required velocity, LTVCON is an executive routine. LTVCON controls the calculation of velocity-required through the calling of three utility routines. The routines and their function are as specified:

UTILITY ROUTINE	FUNCTION
INITIAL	Compute unit vector specifying transfer plane. Determine transfer triangle and constants for normalizing velocity and transfer time.
REQVEL	Compute velocity vectors at $\overline{R}_0$ and $\overline{R}_1$ such that terminal velocity satisfies the desired linear constraint.
TRANSTIME	Compute time required to traverse the transfer angle given a specified initial velocity ($\overline{V}_0$).

The logic flow of LTVCON is illustrated by Figure 14. Table VI contains definitions of the variables used in the entire LTVCON link including the specified utility routines.

7.1.1 Utility Routine INITIAL

Utility routine INITIAL performs an initialization operation. It computes the magnitudes and unit vectors for input position vectors $\overline{R}_0$ and $\overline{R}_1$. The routine also computes sines (Sθ) and cosines (Cθ) of the transfer angle and sets the constants (R_{CIRC} and V_{CIRC}) required to normalize transfer velocity and time.

Figure 15 contains an illustration of the logic flow of INITIAL. Definitions of the symbols used in the figure are contained in Table VI.

7.1.2 Utility Routine REQVEL

REQVEL computes the velocity vector ($\overline{V}_0$) required at an initial position ($\overline{R}_0$) in order to achieve the required velocity vector ($\overline{V}_1$) at a final position ($\overline{R}_1$). Since the terminal radial velocity component (V_{R1}) is specified as a linear function of the terminal horizontal velocity component (V_{H1}), a quadratic equation in V_{H1} exists as follows:

$$A * V_{H1}^2 + B * V_{H1} + C = 0,$$

where the coefficients A, B, and C are functions of the position magnitudes ($R_{0_{MAG}}$, $R_{1_{MAG}}$), the transfer angle, and the constraint coefficients (C_1, C_2). The radical of the equation (D) is computed as:

$$D = B^2 - 4 (A * C)$$

If D is less than zero, no solution to the problem exists and an error flag is set and a message displayed. At this point LTVCON and the calling routine should be exited. If D is greater than or equal to zero, the velocities $\overline{V}_0$ and $\overline{V}_1$ are computed such that the desired velocity constraint condition is fulfilled.

The logic flow of REQVEL is illustrated in Figure 16. Definitions of the symbols used in the figure are contained in Table VI.

7.1.3 Utility Routine TRANSTIME

Routine TRANSTIME computes the time required to traverse from $\overline{R}_0$ to $\overline{R}_1$. To determine the free-fall time required to traverse the transfer angle, an indicator (U) is computed to determine if a solution exists. If U is less than or equal to a -1, the REQVEL solution results in a hyperbolic trajectory. In this case an error flag is set, an error message displayed and LTVCON and its calling routine should be exited. If U is greater than -1, transfer time (ΔT) is computed. The computation of ΔT requires the use of a function QM. This function routine computes

$$QM = W + (1 - WW) (5 - (F) (WW))/15$$

where F is a hypergeometric function which is the transcendental portion of the normalized transfer time.

Figure 17 contains an illustration of the logic flow of TRANSTIME. Figure 18 contains the logic flow of function QM. The symbols used in the figures are defined in Table VI.

8.0 CONCLUSIONS

The logic and logic flow given in this report are developed to satisfy the Level C orbital guidance software requirements for the SMCC. The resulting functions are to provide guidance simulation capability within the SMCC. The logic and flow presented in this report are modeled after the current guidance FSSR but are not restricted to being identical. The routines used to perform guidance functions are as depicted in Figure 19.

Some of the functions defined in this report may be performed by other disciplines within the SMCC. Orbital guidance is only a "user" of these functions (e.g. the gravity model). Some of these functions are defined in this report for completeness. In some instances the capability (or requirement) for the functions (e.g. vent model and drag model) and its interface with the models of this report are defined.

As of this date it is understood that here is no requirement for simulating the drag and vent models within the orbital guidance function of the SMCC. The logic for these two routines should be removed from these requirements.

9.0 REFERENCES

1. JSC Internal Note No. 76-FM-40, "Real Time Computer Complex Requirements for Shuttle Orbital Flight Test Missions - The Mission Plan Table (MPT) and Detailed Maneuver Table (DMT)," dated 27 May 1976.
2. JSC Internal Note No. 76-FM-43, "Preliminary Shuttle Mission Control Center (SMCC) Level B Requirements for Orbital Flight Test Missions Finite Burn Simulation Support (The Confirmation/ Direct Input Processor (CDI), The Power-Flight Iterator (PFI), and the Capabilities Required in the Powered Flight Numerical Integrator (PFNI))," dated 29 June 1976.
3. JSC Internal Note No. 76-FM-47, "OFT SMCC Level B Requirements for the Deorbit Planning Processor," dated 28 June 1976.
4. JSC Internal Note No. 76-FM-Preliminary, "Preliminary Ascent Guidance FSSR Input," dated 23 July 1976.
5. JSC Internal Note No. 75-FM-80, "Navigation Input to Level C OFT Navigation Function Subsystem Software Requirements - Revision 1," dated 11 March 1976.
6. JSC Internal Note No. 76-FM-13, "MPAD SMCC Software Development Plan," dated 9 April 1976.
7. JSC Internal Note No. 76-FM-67, "On Orbit 1 Guidance and Targeting FSSR Inputs," dated 1 September 1976.
8. MDTSCO Report Number W0013, (NASA CR 147478), "Pines' Non-singular Gravitational Potential: Derivation, Description, and Implementation," dated 9 February 1976.

TABLE I - DEFINITIONS OF INPUTS TO SMCC GUIDANCE SOFTWARE

SYMBOL	UNITS	DIMENSION	USER ROUTINES*	DEFINITION
C_1	FT/SEC	1	C	Target velocity constraint coefficient in the equation $V_{RADIAL} = C_1 + C_2 * V_{HORIZ}$
C_2	NA	1	C	Target velocity constraint coefficient in the equation $V_{RADIAL} = C_1 + C_2 * V_{HORIZ}$
C_L	NA	L=1, 35	C	Constants which account for tesseral harmonics in gravity potential model
[EF TO M50(T)]	NA	3,3	C	Transformation matrix from earth-fixed to mean of 1950 (M50) coordinates
ELLIPT	NA	1	C	Earth ellipticity constant
H_{TGT}	FT	1	C	Geodetic altitude of target above Fischer ellipsoid
F_{OMS}	LB	1	A/C	Nominal OMS vacuum thrust level
F_{RCS}	LB	1	A/C	Nominal RCS vacuum thrust level
KD_{GUID}	NA	1	A	Guidance control option = 1; nominal PEG-4 maneuver = 2; PEG-7 maneuver = 3, 4, 5; manual steering modes = 6; deorbit maneuver = 7; abort maneuver (AOA or ATO) = 8; AOA OMS-2 maneuver
K_{FPASS}	NA	1	A	First pass flag = 0; subsequent passes = 1; first pass through guidance

*A = PEGSUP; B = PEG-7; C = PEG-4

TABLE I - DEFINITIONS OF INPUTS TO SMCC GUIDANCE SOFTWARI
(CONTINUED)

SYMBOL	UNITS	DIMENSION	USER ROUTINES*	DEFINITION
K_{FUELD}	NA	1	C	Fuel depletion flag = 0; no fuel wasting = -1; waste right = +1; waste left
K_{DM}	NA	1	C	Drag model flag used in PRECISE PREDICT = 0; no drag = 1; compute drag acceleration
K_{VM}	NA	1	C	Vent model flag used in PRECISE PREDICT = 0; no venting = 1; compute vent accelerations
MASS	SLUGS	1	A/C	Mass of orbiter at start of maneuver
$M_{CG_{OMS}}$	SLUGS	1	A/C	Mass of OMS propellant burned during a fuel depletion maneuver to achieve the desired orbiter mass
$\dot{M}_{OMS}$	SLUGS/SEC	1	A/C	Nominal OMS mass flow rate
$\dot{M}_{RCS}$	SLUGS/SEC	1	A/C	Nominal RCS mass flow rate
N_{MAX}	NA	1	A	Maximum number of guidance iteration cycles allowed
N_{PHASE}	NA	1	A	Number of guidance thrust phases
N_{SEG}	SEC	1	C	Number of integration time steps used for gravity prediction
$\overline{R}$	FT	3	A	Current vehicle inertial position vector (M50)
R_{EQ}	FT	1	C	Earth equatorial radius

*A = PEGSUP; B = PEG-7; C = PEG-4

TABLE I - DEFINITIONS OF INPUTS TO SMCC GUIDANCE SOFTWARE (CONTINUED)

SYMBOL	UNITS	DIMENSION	USER ROUTINES*	DEFINITION
R_{EGRAV}	FT	1	C	Radius of earth used for gravity computations
$\overline{R}_T$	FT	3	C	Target radius vector (M50)
S_L	NA	L=1, 35	C	Constants which account for sectorial harmonics in gravity potential model
S_{MISS}	NA	1	C	Decimal fraction of $\|\overline{V}_{GO}\|$ used as a convergence criterion for $\|\overline{V}_{MISS}\|$
T	SEC	1	A	Current time (GMT)
$T_{GO_{MIN}}$	SEC	1	A	Time before thrust termination at which active guidance computations are inhibited
T_{IG}	SEC	1	A	Maneuver ignition time
T_{RCSOFF}	SEC	1	C	RCS cutoff time during AOA OMS-1 parallel OMS/RCS maneuver
$\overline{U}_{EP}$	NA	3	C	Unit vector in direction of the Earth's axis of rotation
$\overline{V}$	FT/SEC	3	A	Current vehicle velocity vector (M50)
$\overline{V}_S$	FT/SEC	3	A	Current vehicle sensed velocity vector
$\overline{V}_{GO}$	FT/SEC	3	B	Required velocity-to-be-gained vector (PEG-7)
XLD_{XZ}	NA	1	C	Fractional multiplier of circular orbital rate used in computation of primer rate ($\dot{\lambda}_{XZ}$)
$ZONAL_I$	NA	I=1, 8	C	Constants which account for zonal harmonics in gravity acceleration model

*A = PEGSUP; B = PEG-7; C = PEG-4

TABLE I - DEFINITIONS OF INPUTS TO SMCC GUIDANCE SOFTWARE
(CONTINUED)

SYMBOL	UNITS	DIMENSION	USER ROUTINES*	DEFINITION
ΔC_1	FT/SEC	1	C	Offset applied to true target velocity constraint C_1 to obtain a conic constraint
$\Delta \bar{R}_T$	FT	3	C	Offset applied to true target position vector $\bar{R}_T$ to achieve a conic target
$\Delta T_{COAST(REF)}$	SEC	1	C	Reference coast time used in prediction logic
ΔT_{CUTOFF}	SEC	1	A/C	Effective thrust tail-off time
ΔT_{MAX}	SEC	1	C	Maximum integration time step for gravity prediction
ΔT_{MIN}	SEC	1	C	Minimum integration time step for gravity prediction
ε_{STEER}	SEC	1	C	Convergence criterion applied to predicted burnout time used to inhibit computation of $\bar{U}_T$
ϕ_{MAX}	RAD	1	C	Small angle approximation constraint
μ_{EARTH}	FT^3/SEC^2	1	C	Earth gravitational constant

*A = PEGSUP; B = PEG-7; C = PEG-4

TABLE II - DEFINITIONS OF SYMBOLS USED IN PEGSUP

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
ATR	FT/SEC^2	1	C/O	Current estimated thrust acceleration
F_{OMS}	LB	1	I	Nominal OMS vacuum thrust level
F_{RCS}	LB	1	I	Nominal RCS vacuum thrust level
FT	LB	1	C	Total vehicle vacuum thrust
IFLAG	NA	1	C/O	PEG error flag = 0; no error = 1; no physical solution (from LTVCON) = 2; hyperbolic trajectory (from LTVCON) = 3; $\bar{V}_{GO}$ equals zero
K_{ABORT}	NA	1	C/O	Abort guidance request flag = 0; no abort simulation = 1; abort simulation (AOA or ATO)
K_{AOMS2}	NA	1	C/O	OMS-2 burn guidance flag (used only when K_{ABORT} = 1) = 0; AOA OMS-2 guidance not desired = 1; perform AOA OMS-2 guidance
K_{CONV}	NA	1	C	Convergence flag = 0; PEG solution has not converged = 1; PEG solution has converged
K_{CUTOFF}	NA	1	C	Active guidance termination flag = 0; do not perform guidance cutoff logic = 1; perform guidance cutoff logic
K_{DEORB}	NA	1	C/O	Deorbit guidance request flag = 0; not deorbit maneuver = 1; deorbit maneuver

*C = COMPUTED; I = INPUT; O = OUTPUT TO PEG-4 OR PEG-7; GO = GUIDANCE OUTPUTS

TABLE II - DEFINITIONS OF SYMBOLS USED IN PEGSUP
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
K_{FPASS}	NA	1	I	First pass flag = 0; subsequent passes = 1; first pass through guidance
K_{INIT}	NA	1	C/O	Initial pass flag (set to 1 on initial pass)
K_{MODE}	NA	1	C	Guidance mode option = 4; use PEG-4 = 7; use PEG-7
K_{STEER}	NA	1	C/O	Active steering flag = 0; do not compute $\bar{U}_T$ = 1; compute $\bar{U}_T$
KD_{GUID}	NA	1	I	Guidance control option = 1; nominal OMS burn guidance (PEG-4) = 2; external ΔV guidance (PEG-7) = 3, 4, 5; manual steering modes = 6; deorbit maneuver (PEG-4) = 7; abort maneuever (AOA or ATO) (PEG-4) = 8; AOA OMS-2 maneuver (PEG-4)
MASS	SLUGS	1	I/C	Estimated mass of orbiter
M_{BO}	SLUGS	1	C	Desired mass of orbiter at termination of fuel depletion maneuver
$M_{CG_{OMS}}$	SLUGS	1	I	Mass of OMS propellant burned during a fuel depletion maneuver to achieve the desired orbiter mass

*C = COMPUTED; I = INPUT; O = OUTPUT TO PEG-4 OR PEG-7; GO = GUIDANCE OUTPUTS

TABLE II - DEFINITIONS OF SYMBOLS USED IN PEGSUP
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\dot{M}_{OMS}$	SLUGS/SEC	1	I	Nominal OMS mass flow rate
$\dot{M}_{RCS}$	SLUGS/SEC	1	I	Nominal RCS mass flow rate
$\dot{M}$	SLUGS/SEC	1	C	Total vehicle mass flow rate
N_{CYC}	NA	1	C	Number of calls to PEG-4 or PEG-7 per guidance cycle
N_{MAX}	NA	1	I	Maximum number of guidance iteration cycles allowed
N_{PHASE}	NA	1	I	Number of guidance cycles
$\bar{R}$	FT	3	I	Current vehicle position vector input to guidance
$\bar{R}_{GD}$	FT	3	C/O	Vehicle position vector used by guidance
T	SEC	1	I	Current time
T_{CUTOFF}	SEC	1	C	Current time of engine cutoff
T_{GD}	SEC	1	C	Current guidance time
T_{GDP}	SEC	1	C	Previous value of guidance time
T_{GO}	SEC	1	C/GO	Time-to-go to thrust cutoff
$T_{GO_{MIN}}$	SEC	1	I	Value of T_{GO} when active guidance is inhibited
T_{IG}	SEC	1	I	Maneuver ignition time

*C = COMPUTED; I = INPUT; O = OUTPUT TO PEG-4 OR PEG-7; GO = GUIDANCE OUTPUTS

TABLE II - DEFINITIONS OF SYMBOLS USED IN PEGSUP (CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\overline{U}_T$	NA	3	GO	Unit vector in the thrust direction
$\overline{V}$	FT/SEC	3	I	Current vehicle velocity vector input to guidance
V_{EX}	FT/SEC	1	C/O	Total effective exhaust velocity
$\overline{V}_{GD}$	FT/SEC	3	C/O	Vehicle velocity vector used by guidance
$\overline{V}_{GO}$	FT/SEC	3	I/C/O/GO	Velocity-to-be gained vector
$\overline{V}_S$	FT/SEC	3	I	Current sensed velocity
$\overline{V}_{SP}$	FT/SEC	3	C	Previous pass sensed velocity
ΔT_{CUTOFF}	SEC	1	I	Effective thrust tail-off time
ΔT_{GD}	SEC	1	C	Difference between current and previous values of T_{GD}
$\Delta\overline{V}_S$	FT/SEC	3	C/O	Change in accumulated sensed velocity from previous value
$\Delta V_{S_{MAG}}$	FT/SEC	1	C	Magnitude of $\Delta\overline{V}_S$ vector

*C = COMPUTED; I = INPUT; O = OUTPUT TO PEG-4 OR PEG-7; GO = GUIDANCE OUTPUTS

TABLE III - DEFINITIONS OF SYMBOLS USED IN PEG-7.

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
ATR	FT/SEC^2	1	I	Current estimated acceleration
K_{CONV}	NA	1	C	Convergence flag = 0; PEG solution has not converged = 1; PEG solution has converged K_{CONV} = 1 for PEG-7 guidance
K_{INIT}	NA	1	I	Initialization request flag = 0; no initialization required = 1; perform initialization
K_{STEER}	NA	1	I	Active steering flag = 0; do not compute $\overline{U}_T$ = 1; compute $\overline{U}_T$
T_{GO}	SEC	1	C/O	Time-to-go to thrust cutoff
T_λ	SEC	1	C	Reference time for thrust vectors $\overline{\lambda}$ and $\dot{\overline{\lambda}}$
$\overline{U}_T$	NA	3	C/O	Unit vector in the resultant thrust direction
V_{EX}	FT/SEC	1	I	Total effective exhaust velocity
$\overline{V}_{GO}$	FT/SEC	3	I/C/O	Velocity-to-be-gained vector
V_{GOMAG}	FT/SEC	1	C	Magnitude of $\overline{V}_{GO}$
$\Delta\overline{V}_S$	FT/SEC	3	I	Change in accumulated sensed velocity
$\overline{\lambda}$	NA	3	C	Unit vector in direction of desired thrust
$\dot{\overline{\lambda}}$	NA	3	C	Thrust vector turning rate
τ	SEC	1	C	Ratio of mass to mass flow rate

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
ATR	FT/SEC^2	1	I	Current estimated thrust acceleration
C_1	FT/SEC	1	I	Target velocity constraint coefficient in the equation $V_{RADIAL} = C_1 + C_2 V_{HORIZ}$
C_2	NA	1	I	Target velocity constraint coefficient in the equation $V_{RADIAL} = C_1 + C_2 V_{HORIZ}$
ELLIPT	NA	1	I	Earth ellipticity constant
F_{OMS}	LB	1	I	Nominal OMS vacuum thrust
H	FT-SEC	1	C	Time integral from zero to T_{GO} of $(FT/M)T^2$
HA( )	FT-SEC	N_{PHASE}	C	Segment of H contributed by each guidance phase
H_{TGT}	FT	1	I	Geodetic altitude of target above Fischer ellipsoid
IFLAG	NA	1	C	PEG error flag = 0; no error = 1; no physical solution = 2; hyperbolic trajectory = 3; $\overline{V}_{GO}$ equals zero
J	FT	1	C	Time integral from zero to T_{GO} of $(FT/M)T$
JA( )	FT	N_{PHASE}	C	Segment of J contributed by each guidance phase
JOL	SEC	1	C	Burn centroid time

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
K_{ABORT}	NA	1	I	Abort guidance request flag = 0; no abort simulation = 1; abort simulation (AOA or ATO)
K_{AOMS2}	NA	1	I	OMS-2 burn guidance request flag (used only when K_{ABORT} = 1) = 0; AOA OMS-2 guidance not desired = 1; perform AOA OMS-2 guidance
K_{CONV}	NA	1	C	Convergence flag = 0; PEG solution has not converged = 1; PEG solution has converged
K_{DEORB}	NA	1	I	Deorbit guidance request flag = 0; not deorbit maneuver = 1; deorbit maneuver
K_{DM}	NA	1	I	Drag model flag for precise predictor = 0; do not compute acceleration due to drag = 1; compute acceleration due to drag
K_{FUELD}	NA	1	I	Fuel depletion flag = 0; no fuel wasting = +1; waste left = -1; waste right

*C - COMPUTED; I - INPUT; O - OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4 (CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
K_{INIT}	NA	1	I	Initialization request flag = 0; no initialization required = 1; perform initialization
K_{J2}	NA	1	C	J2 compensation flag = 0; do not include J_2 effects in precise predictor = 1; include J_2 effects in precise predictor
K_{PHASE}	NA	1	C	Current guidance thrust phase indicator
K_{STEER}	NA	1	I	Flag to enable active steering = 0; do not compute $\overline{U}_T$ = 1; compute $\overline{U}_T$
K_{VM}	NA	1	I	Vent model flag for precise predictor = 0; do not compute acceleration due to venting = 1; compute acceleration due to venting
L	FT/SEC	1	C	Time integral from zero to T_{GO} of FT/M
LA( )	FT/SEC	N_{PHASE}	C	Segment of L contributed by each guidance phase
MASS	SLUGS	1	I/C	Current estimated mass of orbiter
$\dot{M}$	SLUGS/SEC	1	C	Current mass flow rate
M_{BO}	SLUGS	1	C	Desired mass of orbiter at thrust cutoff

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\dot{M}_{OMS}$	SLUGS/SEC	1	I	Nominal OMS mass flow rate
N	NA	1	I	Number of active guidance thrust phases used by guidance ($N = N_{PHASE}$)
N_{SEG}	NA	1	I	Number of integration time steps for gravity prediction
P	$FT\text{-}SEC^2$	1	C	Double time integral from zero to T then zero to T_{GO} of $(FT/M)T^2$
PA( )	$FT\text{-}SEC^2$	N_{PHASE}	C	Segment of P contributed by each guidance phase
Q	FT-SEC	1	C	Double time integral from zero to T then zero to T_{GO} of (FT/M)T
Q'	FT-SEC	1	C	Intermediate variable in thrust integral computations
QA( )	FT-SEC	N_{PHASE}	C	Segment of Q contributed by each guidance phase
R_{EQ}	FT	1	I	Earth equatorial radius
R_{GOX}	FT	1	C	Component of $\overline{R}_{GO}$ along $\overline{U}_X$
R_{GOY}	FT	1	C	Component of $\overline{R}_{GO}$ along $\overline{U}_Y$
R_{GOZ}	FT	1	C	Component of $\overline{R}_{GO}$ along $\overline{U}_Z$

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITION OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
R_{MAG}	FT	1	C	Magnitude of $\overline{R}_{GO}$
R_{TMAG}	FT	1	C	Magnitude of $\overline{R}_T$
$\overline{R}_{THRUST}$	FT	3	C	Second integral of thrust acceleration vector over thrusting maneuver
$\overline{R}_{BIAS}$	FT	3	C	A position bias to account for effects of a rotating thrust vector
$\overline{R}_{C1}$	FT	3	C	Initial position vector input to precise predictor
$\overline{R}_{C2}$	FT	3	C	Final position output from precise predictor
$\overline{R}_D$	FT	3	C	Desired thrust cutoff position
$\overline{R}_{GD}$	FT	3	I	Vehicle position vector used by guidance
$\overline{R}_{GO}$	FT	3	C	Position-to-be-gained including bias (range-to-go)
$\overline{R}_{GOXY}$	FT	3	C	Projection of $\overline{R}_{GO}$ on plane defined by $\overline{U}_X$ and $\overline{U}_Y$
$\overline{R}_{GRAV}$	FT	3	C	Second integral of gravitational acceleration over thrusting maneuver

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\overline{R}_{INT}$	FT	3	C	Intermediate position vector computed and used in precise predictor
$\overline{R}_P$	FT	3	C	Predicted thrust cutoff position
$\overline{R}_T$	FT	3	I	Target position in inertial coordinates
RHO_{MAG}	NA	1	C	Scalar damping factor applied to $\overline{V}_{MISS}$ to correct $\overline{V}_{GO}$
S	FT	1	C	Double time integral from zero to T then zero to T_{GO} of (FT/M)
S_{MISS}	NA	1	I	Decimal fraction of $\|\overline{V}_{GO}\|$ to be used as a convergence criterion for $\|\overline{V}_{MISS}\|$
SA( )	FT	N_{PHASE}	C	Segment of S contributed by each guidance phase
T_{GD}	SEC	1	I	Current guidance time
T_{GO}	SEC	1	C/O	Time-to-go to thrust cutoff
T_{GOA}( )	SEC	N_{PHASE}	C	Time-to-go until end of each phase
T_{GOB}	SEC	1	C	Value of T_{GOA} from previous phase
T_{GOP}	SEC	1	C	Predicted thrust cutoff time

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
T_P	SEC	1	C	Predicted time of burnout
T_{PREV}	SEC	1	C	Previous value of T_P
T_{RCSOFF}	SEC	1	I	RCS cutoff time during AOA OMS-1 parallel OMS/RCS maneuver
$T_B(\ )$	SEC	N_{PHASE}	C	Estimated burn time remaining in each phase
TT	SEC	1	C	Time remaining until target is achieved
T'	SEC	1	C	Previous value of T_{GD}
T_λ	SEC	1	C	Reference time associated with $\overline{\lambda}$ amd $\dot{\overline{\lambda}}$
$\overline{U}_{EP}$	NA	3	I	Unit vector in direction of Earth's axis of rotation
$\overline{U}_T$	NA	3	C/O	Resultant unit vector in the thrust direction
$\overline{U}_X$	NA	3	C	Unit vector along desired thrust cutoff position vector
$\overline{U}_Y$	NA	3	C	Unit vector normal to desired trajectory plane (downrange X radial)
$\overline{U}_Z$	NA	3	C	Unit vector along downrange ($\overline{U}_X$ X $\overline{U}_Y$) direction at thrust cutoff

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$U\overline{U}NIT$	NA	3	C	Unit vector normal to the desired transfer plane in the direction of the angular momentum of the transfer
V_{C1}	FT/SEC	3	C	Initial velocity input to precise predictor
V_{EX}	FT/SEC	1	I	Total effective exhaust velocity
$V_{EXA}( )$	NA	N_{PHASE}	C	Effective exhaust velocity for each thrust phase
V_{GOD}	FT/SEC	1	C	Desired $\overline{V}_{GO}$ magnitude based upon desired cutoff mass for fuel depletion
V_{GOMAG}	FT/SEC	1	C	Magnitude of $\overline{V}_{GO}$
V_{GOYS}	FT^2/SEC^2	1	C	Square of out-of-plane $\overline{V}_{GO}$ required to deplete OMS fuel
$\overline{V}_{MISS}$	FT/SEC	3	C	Difference between predicted and desired thrust cutoff velocity
$\overline{V}_{P}$	FT/SEC	3	C	Predicted thrust cutoff velocity
$\overline{V}_{C2}$	FT/SEC	3	C	Final velocity output by precise predictor
$\overline{V}_{GD}$	FT/SEC	3	I	Vehicle velocity vector used by guidance

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\overline{V}_{GO}$	FT/SEC	3	C/O	Velocity-to-be-gained vector
$\overline{V}_{GIP}$	FT/SEC	3	C	Projection of $\overline{V}_{GO}$ vector into plane normal to $\overline{U}_Y$
$\overline{V}_{GRAV}$	FT/SEC	3	C	First integral of gravitational acceleration over thrusting maneuver
$\overline{V}_{INT}$	FT/SEC	3	C	Intermediate velocity used by precise predictor
$\overline{V}_{THRUST}$	FT/SEC	3	C	First integral of thrust acceleration vector over thrusting maneuver
XLD_{XZ}	NA	1	I	Fractional multiplier of circular orbital rate used in computation of λ_{XZ}
Δ_{COAST}	SEC	1	C	Difference between assumed coast time and actual coast time
ΔC_1	FT/SEC	1	I	Offset applied to true target velocity constraint C_1 to obtain a conic constraint
$\Delta \overline{R}_T$	FT	3	I	Bias applied to true target position $\overline{R}_T$ to achieve a conic target
ΔT_{AVG}	SEC	1	C	Integration time step for gravity prediction
ΔT_{COAST}	SEC	1	C	Time of coast from cutoff to target

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE IV - DEFINITIONS OF SYMBOLS USED IN PEG-4
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\Delta T_{COAST(REF)}$	SEC	1	I	Assumed time of coast segment
ΔT_{MAX}	SEC	1	I	Maximum integration time step for gravity prediction
ΔT_{MIN}	SEC	1	I	Minimum integration time step for gravity prediction
$\Delta \overline{V}_S$	FT/SEC	3	I	Change in accumulated sensed velocity
ε_{STEER}	SEC	1	I	Convergence criterion for inhibiting steering output
$\overline{\lambda}$	NA	3	C	Unit vector in the direction of $\overline{V}_{GO}$
$\dot{\overline{\lambda}}$	RAD/SEC	3	C	Derivative of unit vector instantaneously aligned along $\overline{\lambda}$ but rotating with the desired thrust vector turning rate
$\dot{\lambda}_{MAG}$	RAD/SEC	1	C	Magnitude of $\dot{\overline{\lambda}}$
$\dot{\lambda}_{XZ}$	RAD/SEC	1	C	Component of $\dot{\overline{\lambda}}$ in the X-Z plane (primer rate)
$\dot{\lambda}_{Y}$	RAD/SEC	1	C	Component of $\dot{\overline{\lambda}}$ along $\overline{U}_Y$
μ_{EARTH}	FT^3/SEC^2	1	I	Earth gravitation constant
ϕ_{MAX}	RAD	1	I	Small angle approximation constraint
$\tau(\ )$	SEC	N_{PHASE}	C	Ratio of mass to mass flow rate for each phase

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE V - DEFINITIONS OF SYMBOLS USED IN PRECISE PREDICT

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$A_{I, J}$	NA	I=1, 9 J=1,2	C	A two column array used for temporary storage of the Legendre polynomials and the derived Legendre functions (latitude dependent terms) used in the gravity acceleration model
ATM	NA	1	C	Flag indicating vehicle attitude is to be taken from a prestored table for use in drag and vent acceleration calculations; ATM always set equal to 1
AUX	NA	1	C	Intermediate scalar variable used in gravity acceleration model
C_L	NA	L = 1, 35	I	Constants which account for the tesseral harmonics in gravity acceleration model
$\overline{D}$	FT/SEC^2	3	C	Drag acceleration vector
DM	NA	1	I	Drag = 0; do not compute drag acceleration = 1; compute drag acceleration
DMN	NA	1	C	Intermediate variable used to compute effect of tesseral harmonics in gravity acceleration model
[EF TO M50 (T)]	NA	3,3	I	Transformation matrix from earth-fixed to M50 coordinates
[FIFTY]	NA	3,3	C	Transformation matrix set equal to [EF TO M50 (T)] matrix
F_1, F_2, F_3, F_4	NA	1	C	Auxiliary variables which store the result of multiplying the Legendre polynomials by the zonal harmonic coefficients

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE V - DEFINITIONS OF SYMBOLS USED IN PRECISE PREDICT
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\overline{G}$	FT/SEC^2	3	C	Gravity acceleration vector due to the Earth's non-spherical shape
$\overline{G}_{CENTRAL}$	FT/SEC^2	3	C	Acceleration vector due to the Earth's gravitational attraction as a point mass
$\overline{G}_F$	FT/SEC^2	3	C	Gravitational acceleration vector at final state
GMD	NA	1	I	Flag indicating degree of gravity potential model desired = 0; spherical earth gravity acceleration > 0; non-spherical earth gravity acceleration $0 \leq GMD \leq 8$
GMO	NA	1	I	Flag indicating order of the gravity potential model $0 \leq GMO \leq 8$; $GMO \leq GMD$
$\overline{G}_{PREV}$	FT/SEC^2	3	C	Gravitational acceleration vector at previous state
N_{STEP}	NA	1	C	Number of integration steps to be used in PRECISE PREDICT
$\overline{R}$	FT	3	C	Current radius vector used in ACCEL function
$\overline{R}_I$	FT	3	I	Initial radius vector input to PRECISE PREDICT
R_{EGRAV}	FT	1	I	Earth radius magnitude used in gravity calculations

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE V - DEFINITIONS OF SYMBOLS USED IN PRECISE PREDICT
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\overline{R}_F$	FT	3	C/O	Final radius vector output by PRECISE PREDICT
$\overline{R}_{EF}$	FT	3	C	Current radius vector in Earth-fixed coordinates
R_{INV}	FT	1	C	Inverse of current radius magnitude in inertial coordinates
$\overline{RCS}$	FT/SEC^2	3	C	Acceleration vector due to RCS venting
RO_{ZERO}	NA	1	C	Variable used as starting value for recursive relations used in Pine's formulation of the spherical harmonics development
RO_N	FT/SEC^2	1	C	Distance related term used as a starting value for the recursive relations used in Pine's formulation of the spherical harmonics development
S_L	NA	L=1, 35	I	Array of constants which account for the sectorial harmonics in the gravity potential model
T	SEC	1	C	Current time used in ACCEL function
T_F	SEC	1	I	Final time input to PRECISE PREDICT
T_I	SEC	1	I	Initial time input to PRECISE PREDICT
$\overline{U}_R$	NA	3	C	Unit vector in direction of current radius in Earth fixed coordinates
$\overline{V}$	FT/SEC	3	C/I	Final velocity output from PRECISE PREDICT and used in ACCEL
$\overline{VENT}$	FT/SEC^2	3	C	Acceleration vector due to venting forces

TABLE V - DEFINITIONS OF SYMBOLS USED IN PRECISE PREDICT (CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\overline{V}_F$	FT/SEC	3	C/O	Final velocity output from PRECISE PREDICT
$\overline{V}_I$	FT/SEC	3	C/I	Initial velocity from PRECISE PREDICT used in ACCEL
VM	NA	1	I	Vent model flag = 0; do not compute vent acceleration = 1; compute vent acceleration
$ZONAL_N$	NA	N=1, 8	I	Array of constants which account for the zonal harmonics in the gravity potential model
Z_{IMAG_I}	NA	I=1, 9	C	Array which stores the effects of tesseral harmonics in gravity potential model
Z_{REAL_I}	NA	I=1, 9	C	Array which stores the effects of tesseral harmonics in gravity potential model
ΔT_{MAX}	SEC	1	I	Maximum integration step size
ΔT_{STEP}	SEC	1	C	Integration step size
μ_{EARTH}	FT^3/SEC^2	1	I	Earth gravitational constant

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE VI - DEFINITIONS OF SYMBOLS USED IN LTVCON

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
A	NA	1	C	Quadratic coefficient in the V_{H1} quadratic equation
B	NA	1	C	Linear coefficient in the V_{H1} quadratic equation
B_D	NA	1	C	Denominator of the coefficient function used in the continued fraction evaluation of the hypergeometric function F
B_N	NA	1	C	Numerator of the coefficient function used in the continued fraction evaluation of the hypergeometric function F
C	NA	1	C	Constant coefficient in the V_{H1} quadratic equation
C_1	FT/SEC	1	I	Target velocity constraint coefficient in the equation $V_{RADIAL} = C_1 + C_2 V_{HORIZ}$
C_2	NA	1	I	Target velocity constraint coefficient in the equation $V_{RADIAL} = C_1 + C_2 V_{HORIZ}$
CR	FT	1	C	Magnitude of the chord connecting $\overline{R}_0$ and $\overline{R}_1$
Cθ	NA	1	C	Cosine of the transfer angle
D	NA	1	C	Radical of the V_{H1} quadratic equation
E	NA	1	C	Scratch variable used in the transfer time interval computation
F	NA	1	C	Hypergeometric function which is the transcendental portion of the normalized transfer time interval computation and is evaluated by means of a continued fraction

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE VI - DEFINITIONS OF SYMBOLS USED IN LTVCON
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
F_{OLD}	NA	1	C	Value of F at the previous level of the continued fraction
IFLAG	NA	1	C/O	Error flag: 0 = no error; 1 = no physical solution; 2 = hyperbolic trajectory
LEVEL	NA	1	C	A measure of the level of the continued fraction
QM	NA	1	C	Symbol representing the function subroutine which executes the continued fraction evaluation of the hypergeometric function F
R_{CIRC}	FT	1	C	Half of the semi-perimeter of the transfer triangle, and used as the basis for the normalization of the equations
$\overline{R}_0$	FT	3	I	Initial inertial position vector
$\overline{R}_1$	FT	3	I	Target radius vector
$R_{0_{MAG}}$	FT	1	C	Magnitude of $\overline{R}_0$
$R_{1_{MAG}}$	FT	1	C	Magnitude of $\overline{R}_1$
S	FT	1	C	Semi-perimeter of the transfer triangle
Sθ	NA	1	C	Sine of the transfer angle
U	NA	1	C	Lambert routine independent variable
$\overline{U}_{IN}$	NA	3	I	Unit vector normal to the transfer plane and in the direction of the angular momentum of the transfer
$\overline{U}_N$	NA	3	C	Internal vector used to represent the unit normal defining the transfer plane

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE VI - DEFINITIONS OF SYMBOLS USED IN LTVCON (CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
$\overline{U}_{RO}$	NA	3	C	Unit vector in the direction of the inertial position vector $\overline{R}_0$
$\overline{U}_{R1}$	NA	3	C	Unit vector in the direction of the target position vector $\overline{R}_1$
V	NA	1	C	Scratch variable used in the continued fraction evaluation of the hypergeometric function F.
$\overline{V}_0$	FT/SEC	3	C/O	Required inertial velocity vector at the inertial position vector $\overline{R}_0$
$\overline{V}_1$	FT/SEC	3	C/O	Resulting inertial velocity vector at the target position vector $\overline{R}_1$
V_{CIRC}	FT/SEC	1	C	Velocity magnitude of a circular orbit of radius R_{CIRC} and used in the normalization process
V_{HO}	FT/SEC	1	C	Normalized horizontal component of the resulting velocity vector V_0
V_{H1}	FT/SEC	1	C	Normalized horizontal component of the resulting velocity vector V_1
V_{RO}	FT/SEC	1	C	Normalized radial component of the required velocity vector V_0
V_{R1}	FT/SEC	1	C	Normalized radial component of the resulting velocity vector V_1
W	NA	1	C	Scratch variable used in the normalized transfer time interval computations
WW	NA	1	C	Argument of the continued fraction evaluation of the hypergeometric function F

*C = COMPUTED; I = INPUT; O = OUTPUT

TABLE VI - DEFINITIONS OF SYMBOLS USED IN LTVCON
(CONTINUED)

FLOW CHART SYMBOL	UNITS	DIMENSION	TYPE*	DEFINITION
X	NA	1	C	Scratch variable used in the continued fraction evaluation of the hypergeometric function F
ΔT	SEC	1	C/O	Resulting transfer time interval
λ	NA	1	C	Constant parameter of the problem
μ_{EARTH}	FT^3/SEC^2	1	I	Earth gravitational constant
μ	FT^3/SEC^2	1	C	Interval variable used to represent μ_{EARTH}

*C = COMPUTED; I = INPUT; O = OUTPUT

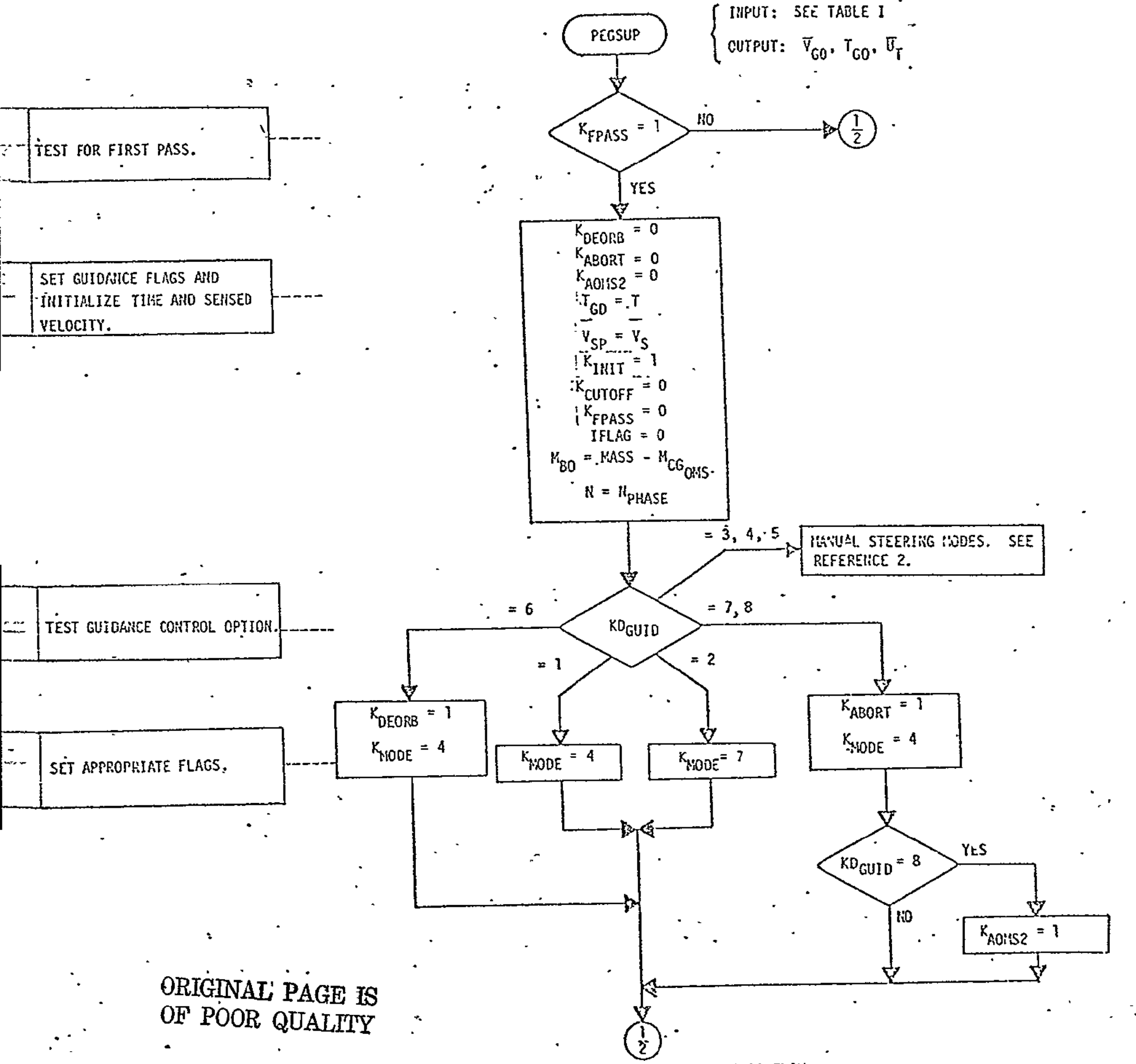

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FIGURE 1 - PEGSUP LOGIC FLOW

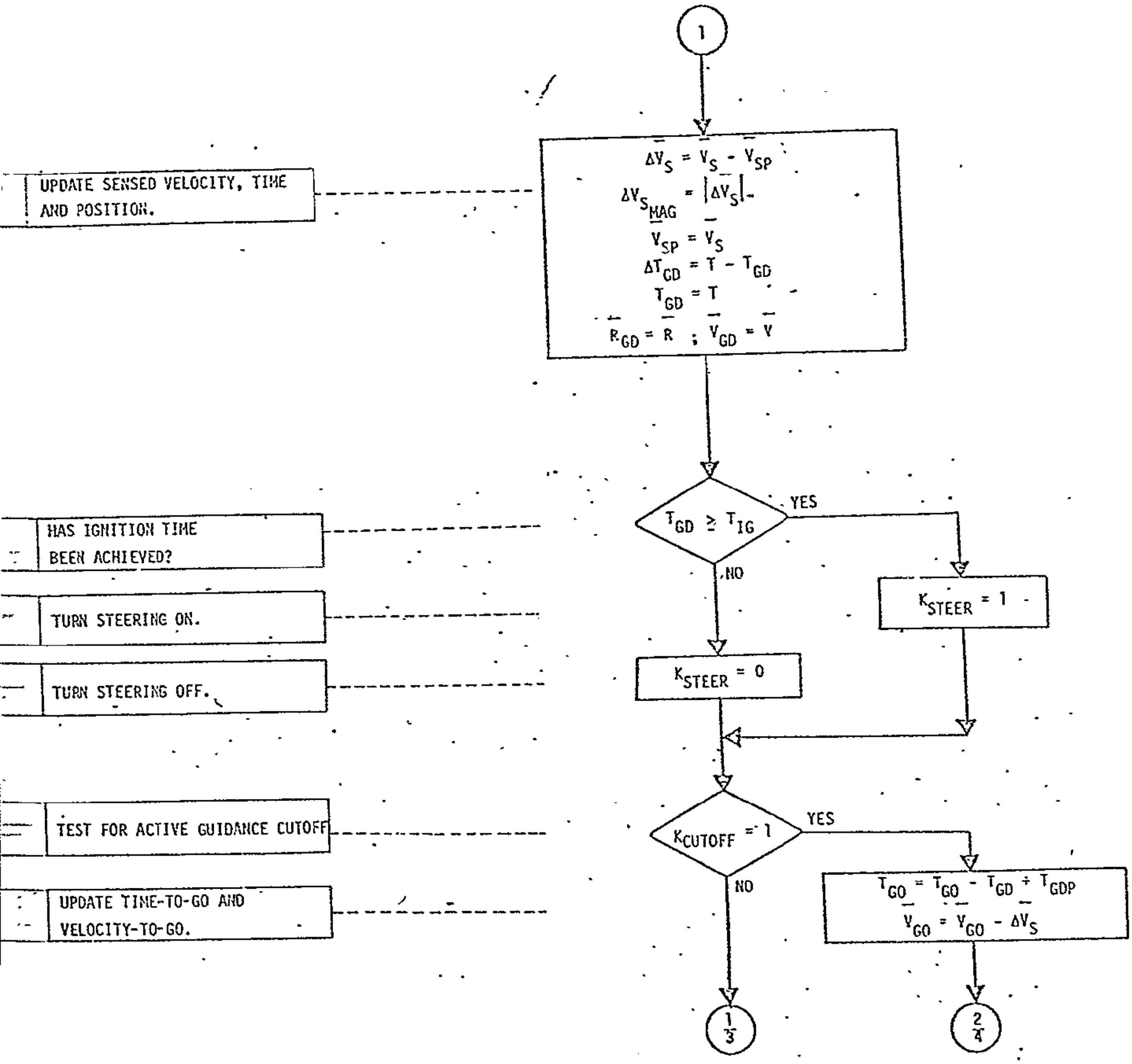

FIGURE 1 - PEGSUP LOGIC FLOW (PAGE 2)

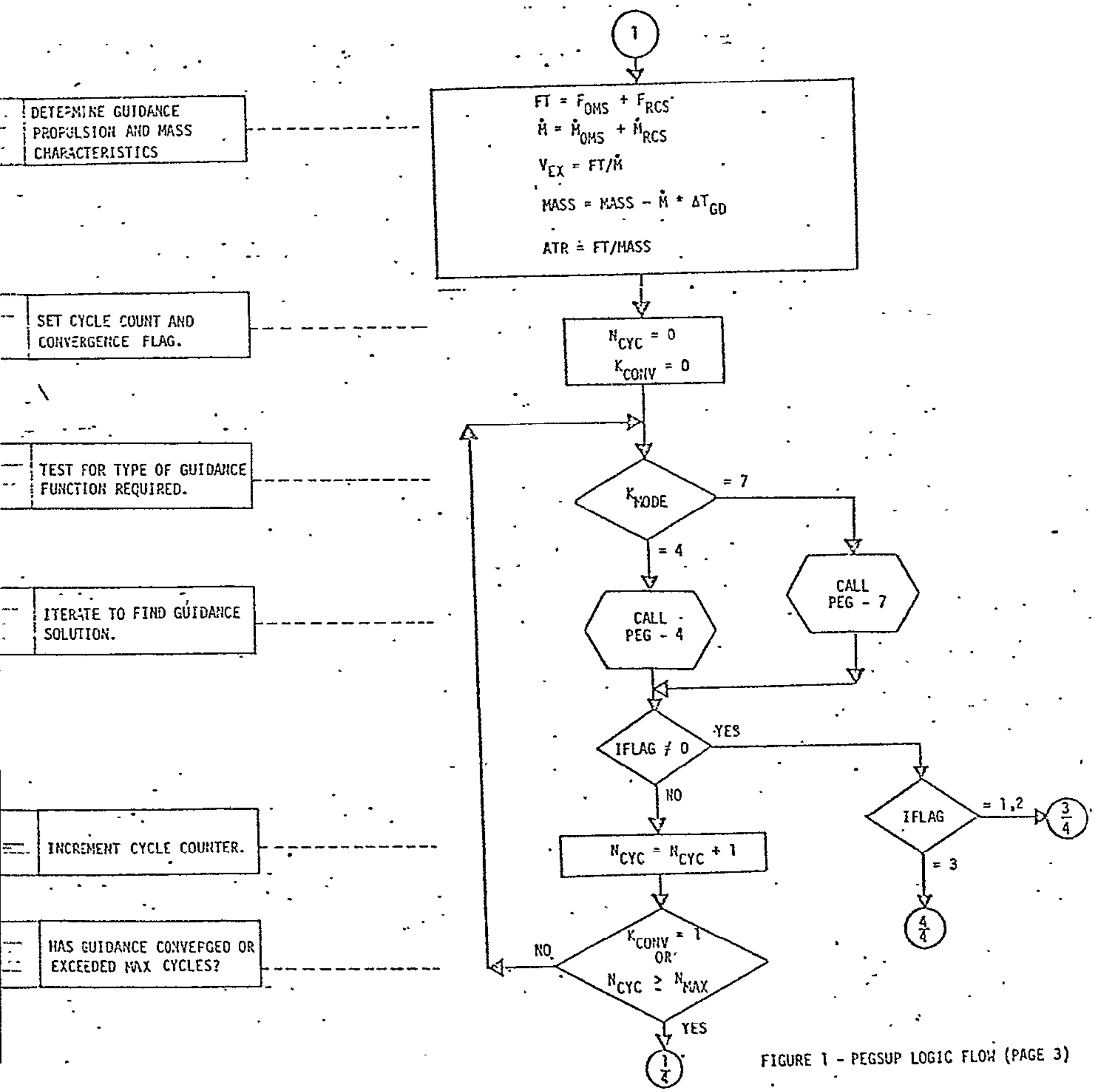

FIGURE 1 - PEGSUP LOGIC FLOW (PAGE 3)

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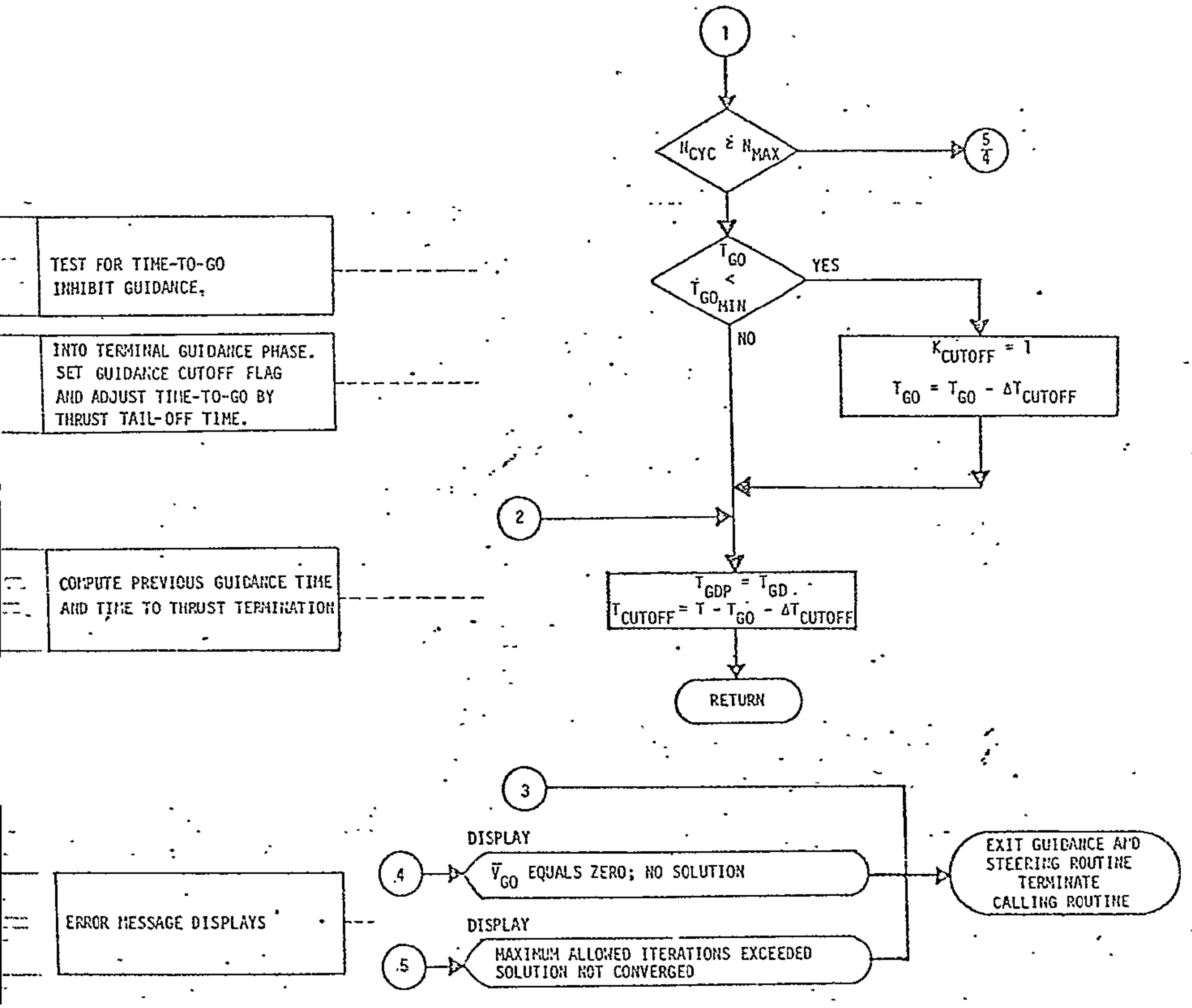

FIGURE 1 - PEGSUP LOGIC FLOW (PAGE 4)

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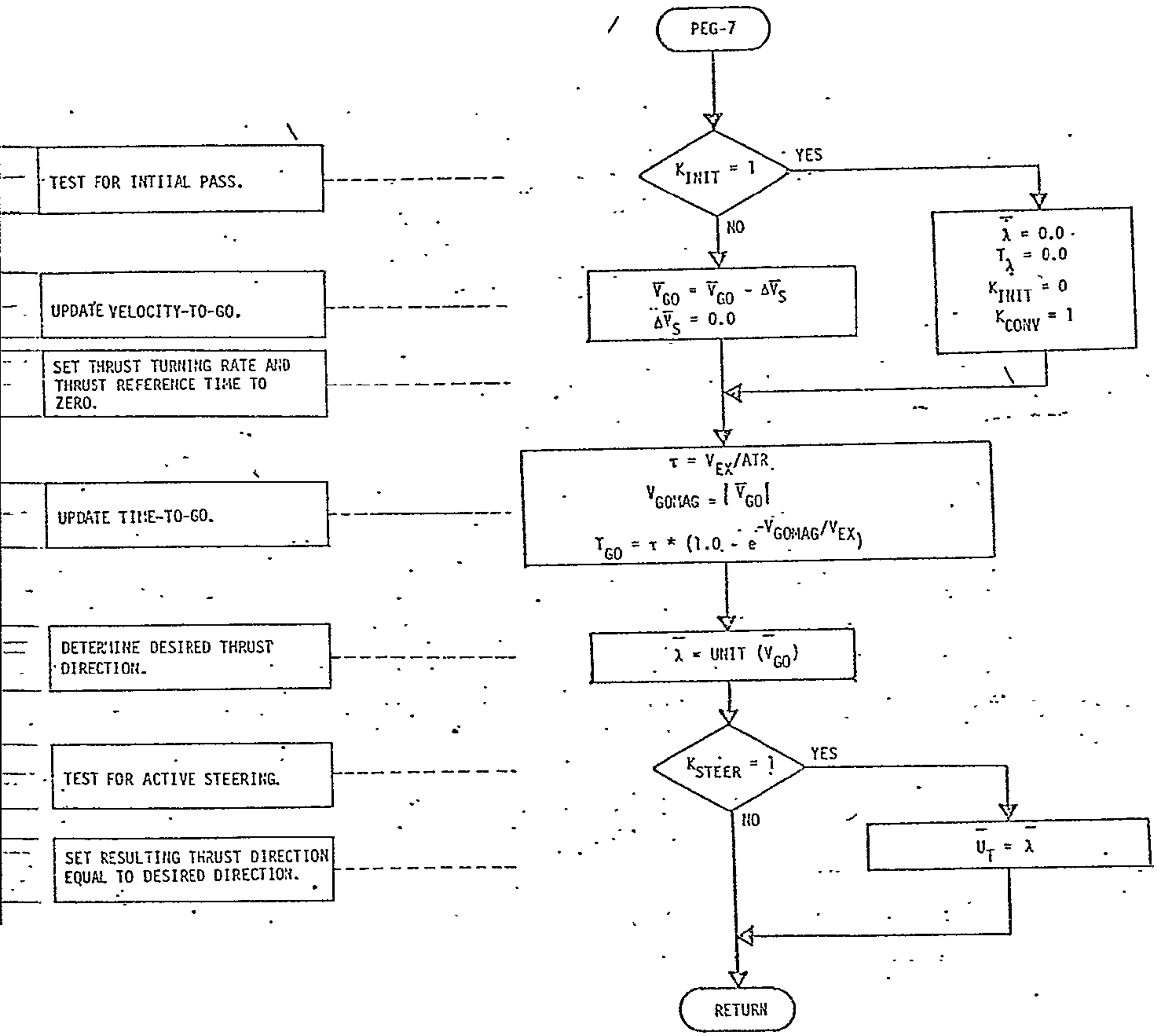

FIGURE 2 - PEG-7 LOGIC FLOW

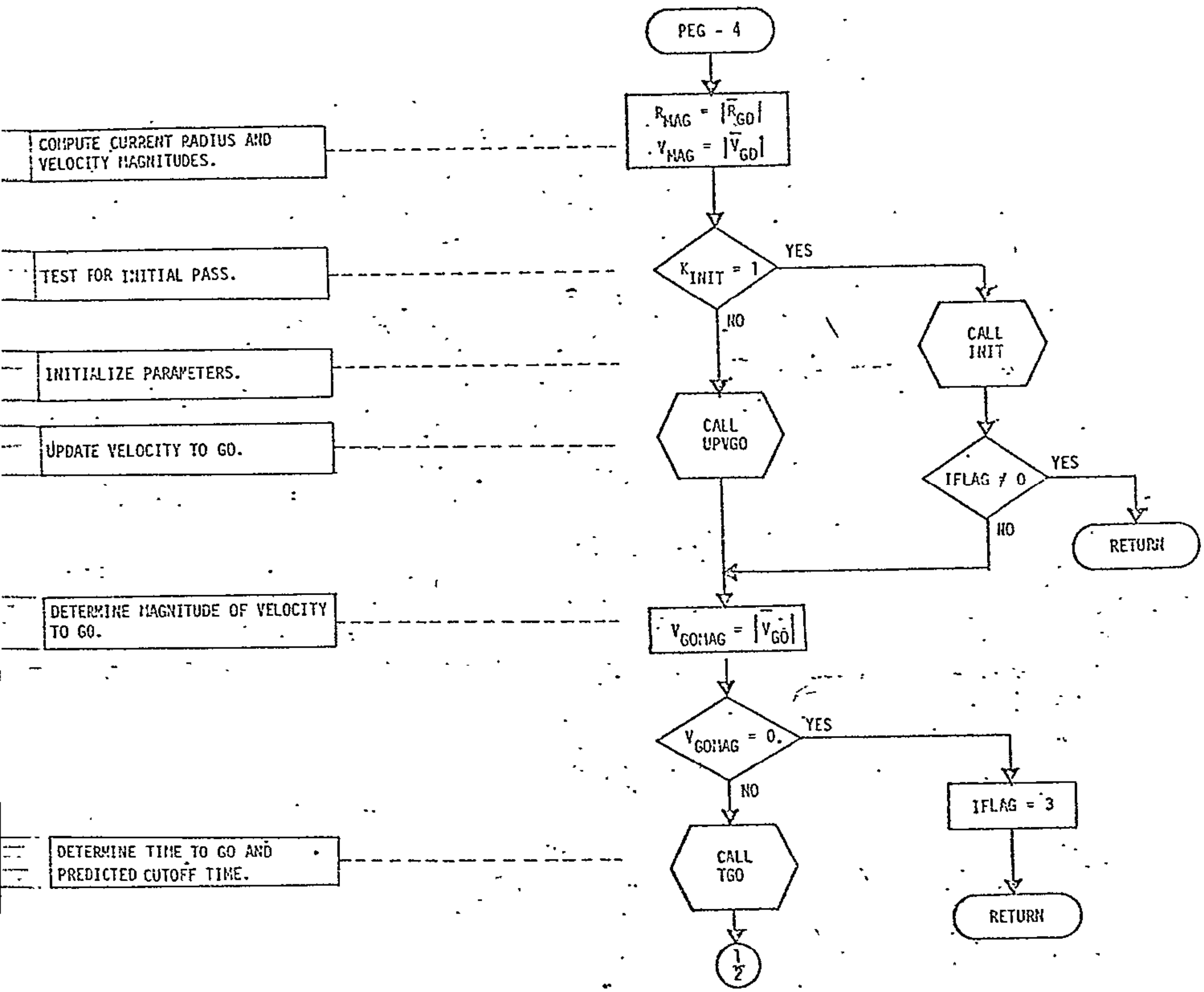

FIGURE 3 - PEG-4 LOGIC FLOW

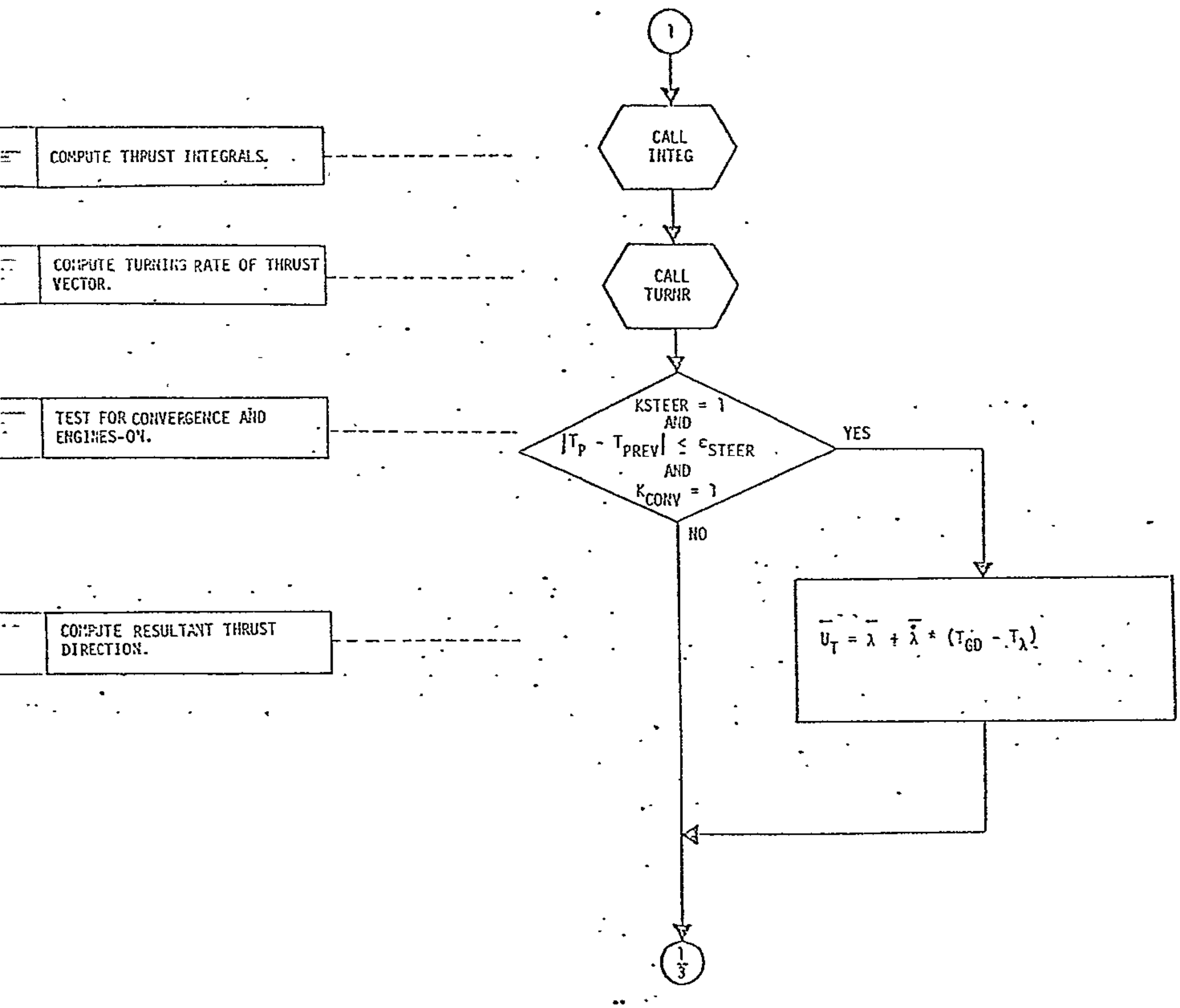

FIGURE 3 - PEG-4 LOGIC FLOW (PAGE 2)

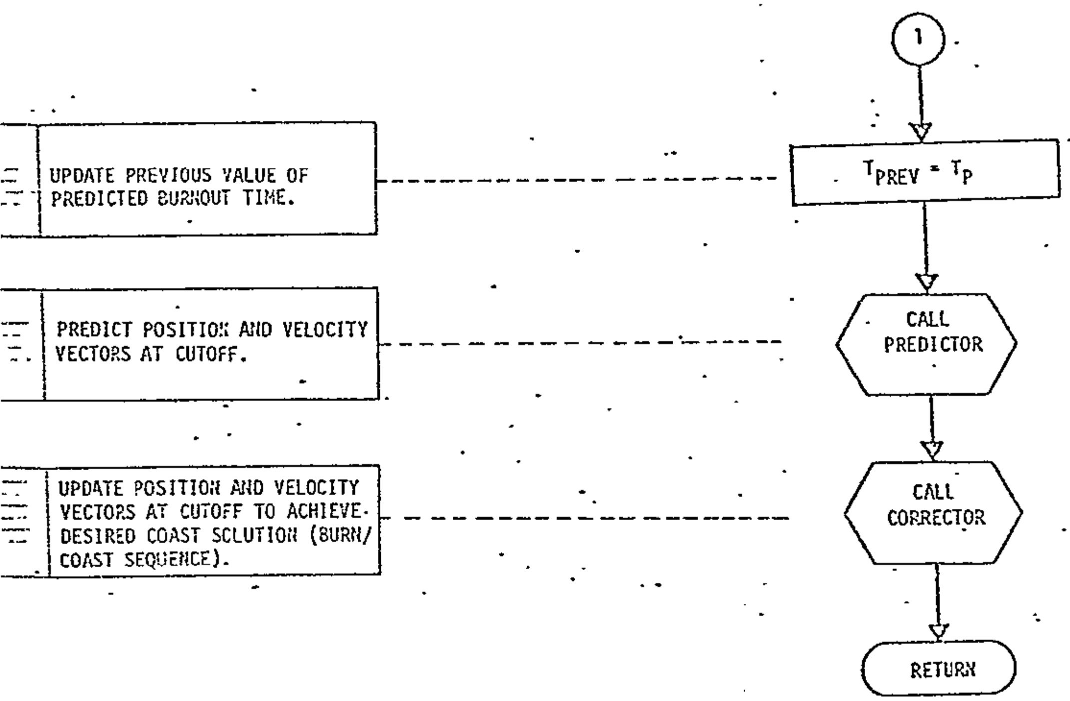

FIGURE 3 - PEG-4 LOGIC FLOW (PAGE 3)

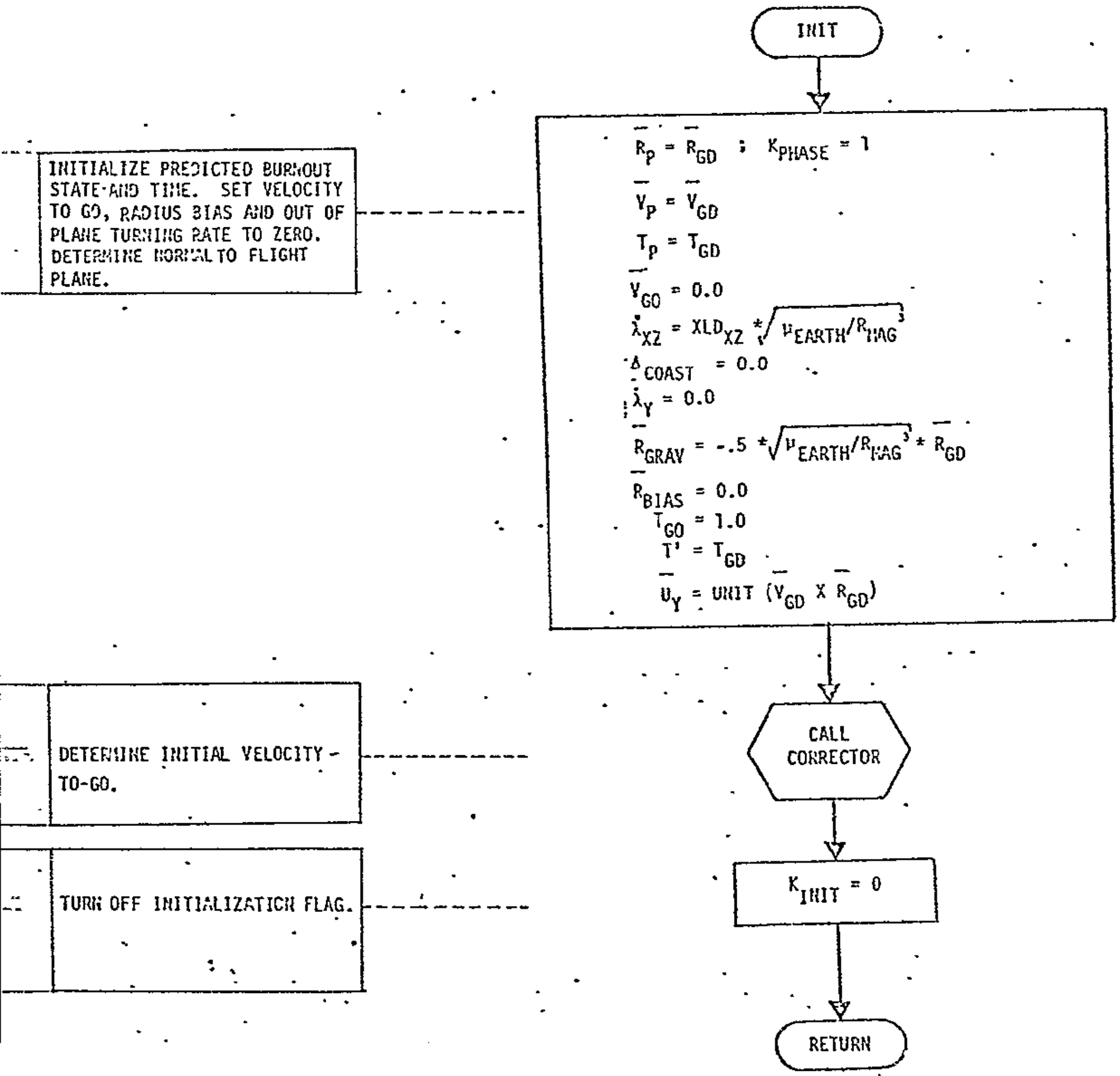

FIGURE 4 - INIT LOGIC FLOW

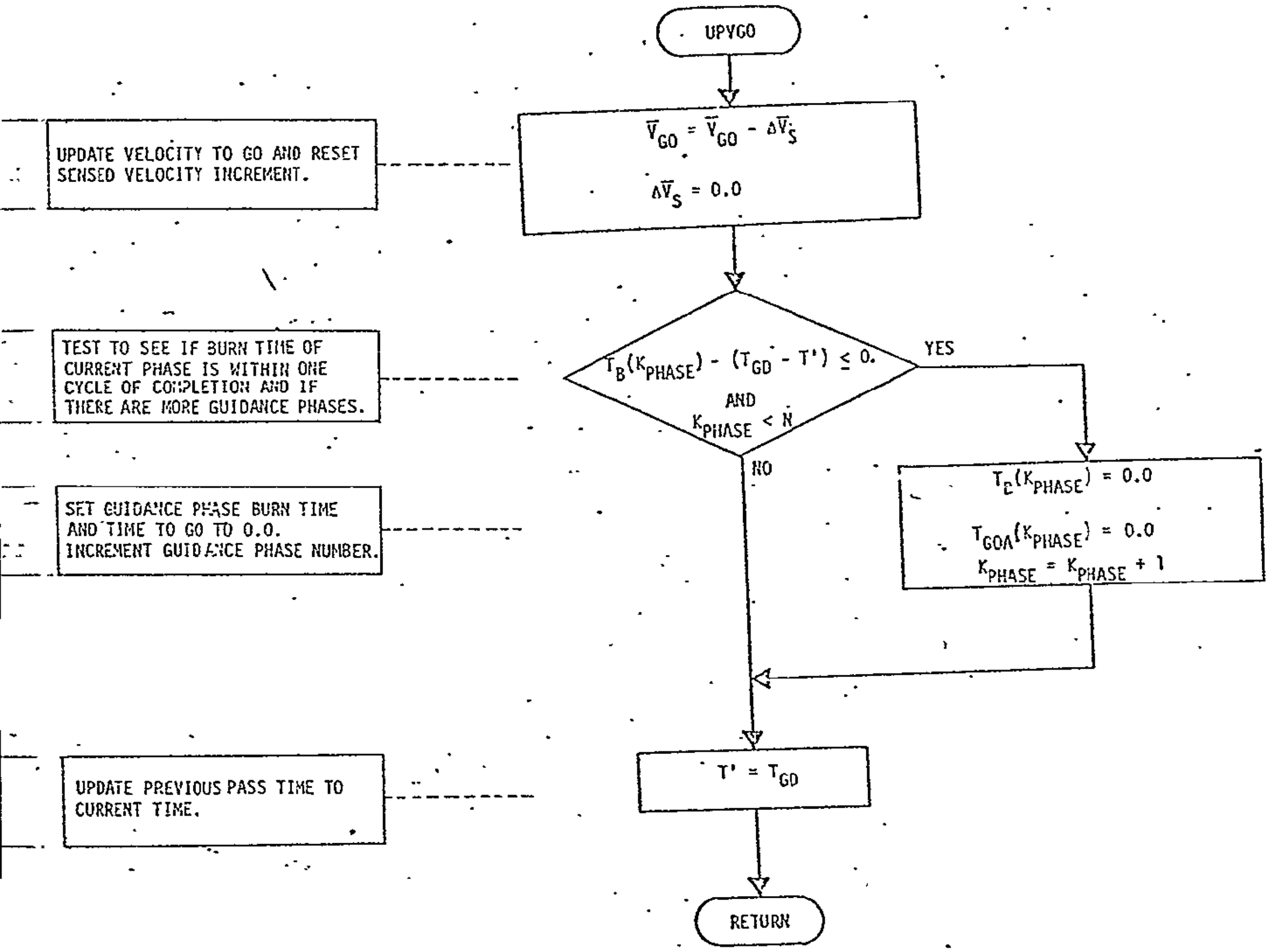

FIGURE 5 - UPVGO LOGIC FLOW

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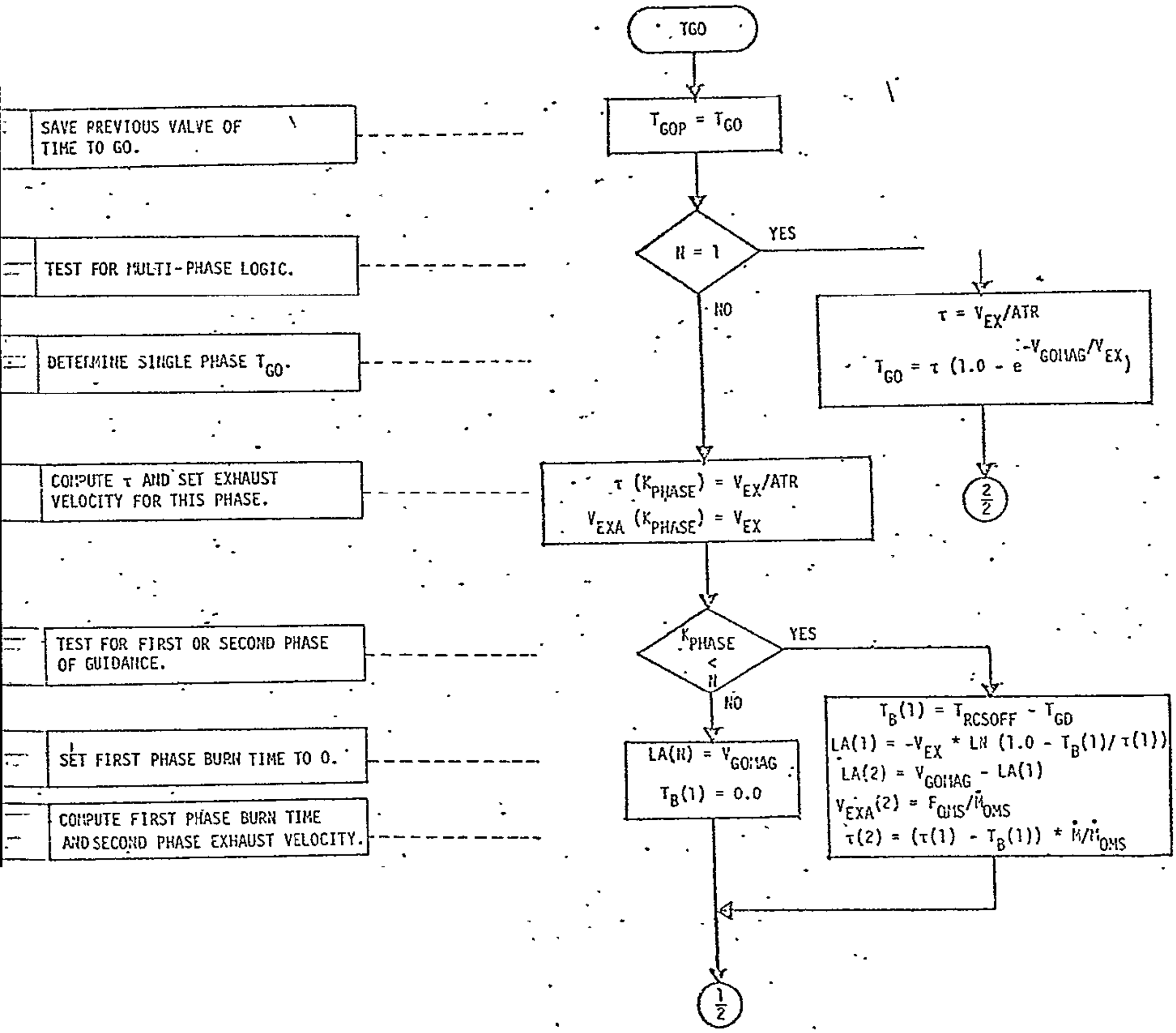

FIGURE 6 - TGO LOGIC FLOW

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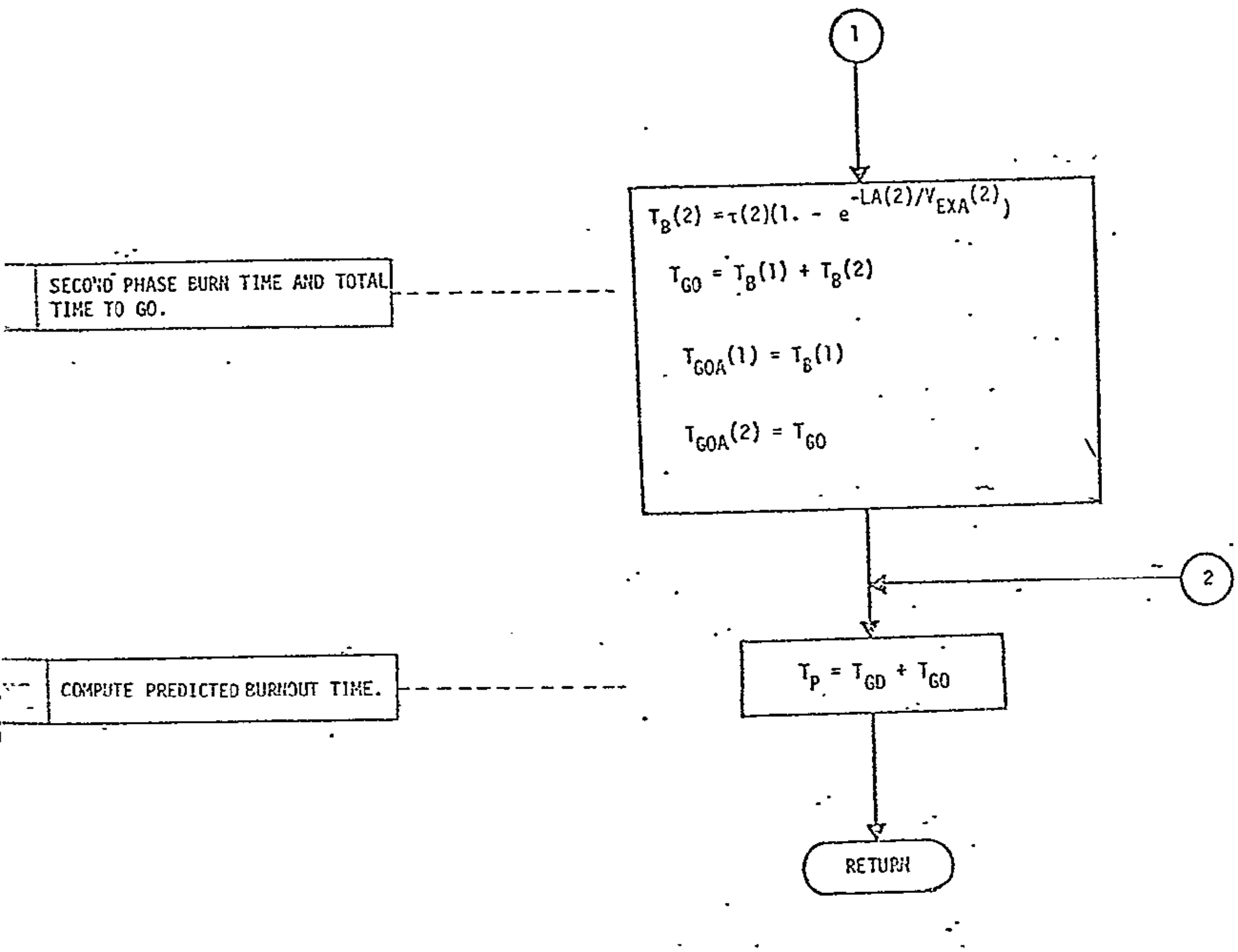

FIGURE 6 - TGO LOGIC FLOW (PAGE 2)

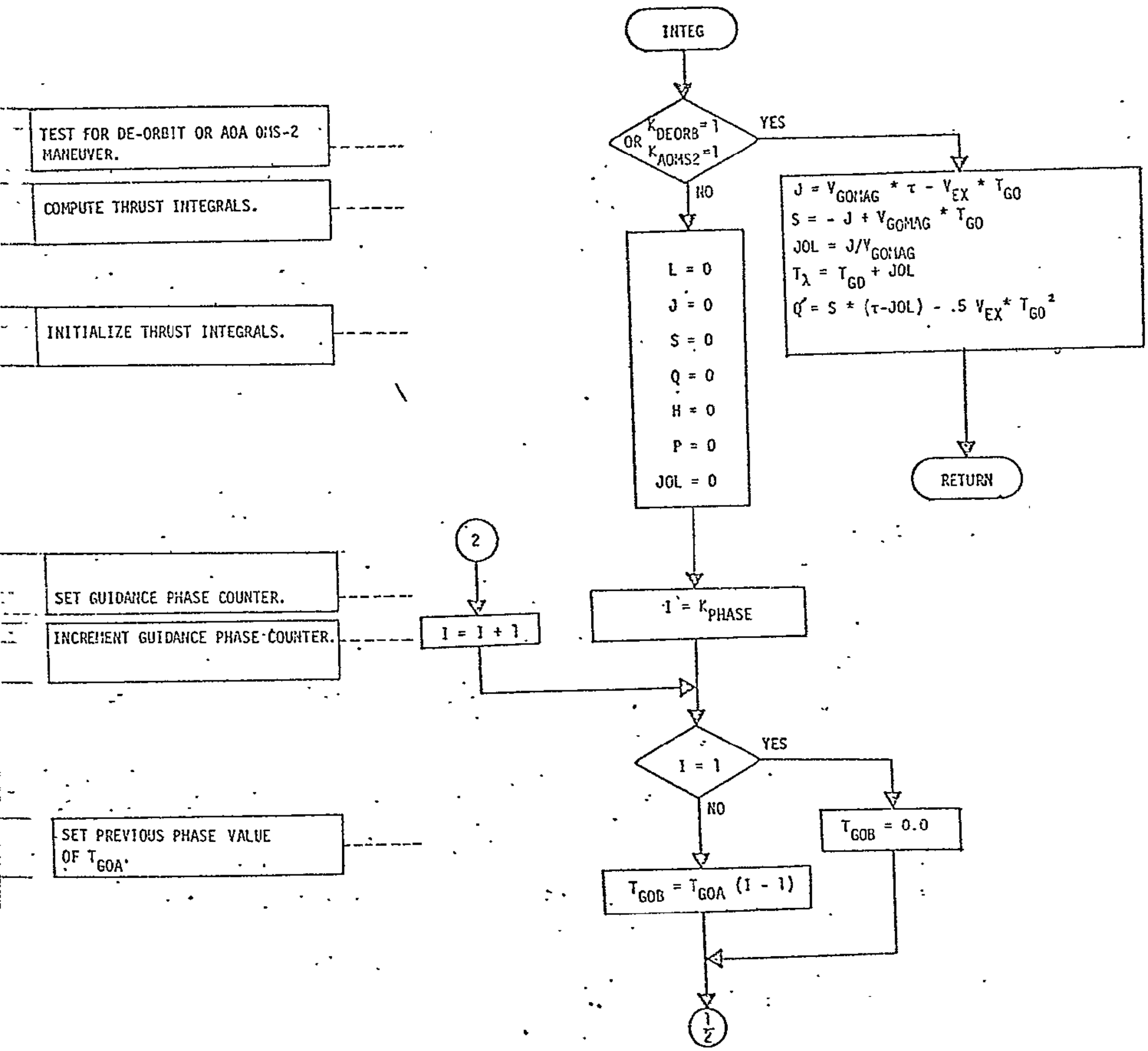

FIGURE 7 - INTEG LOGIC FLOW

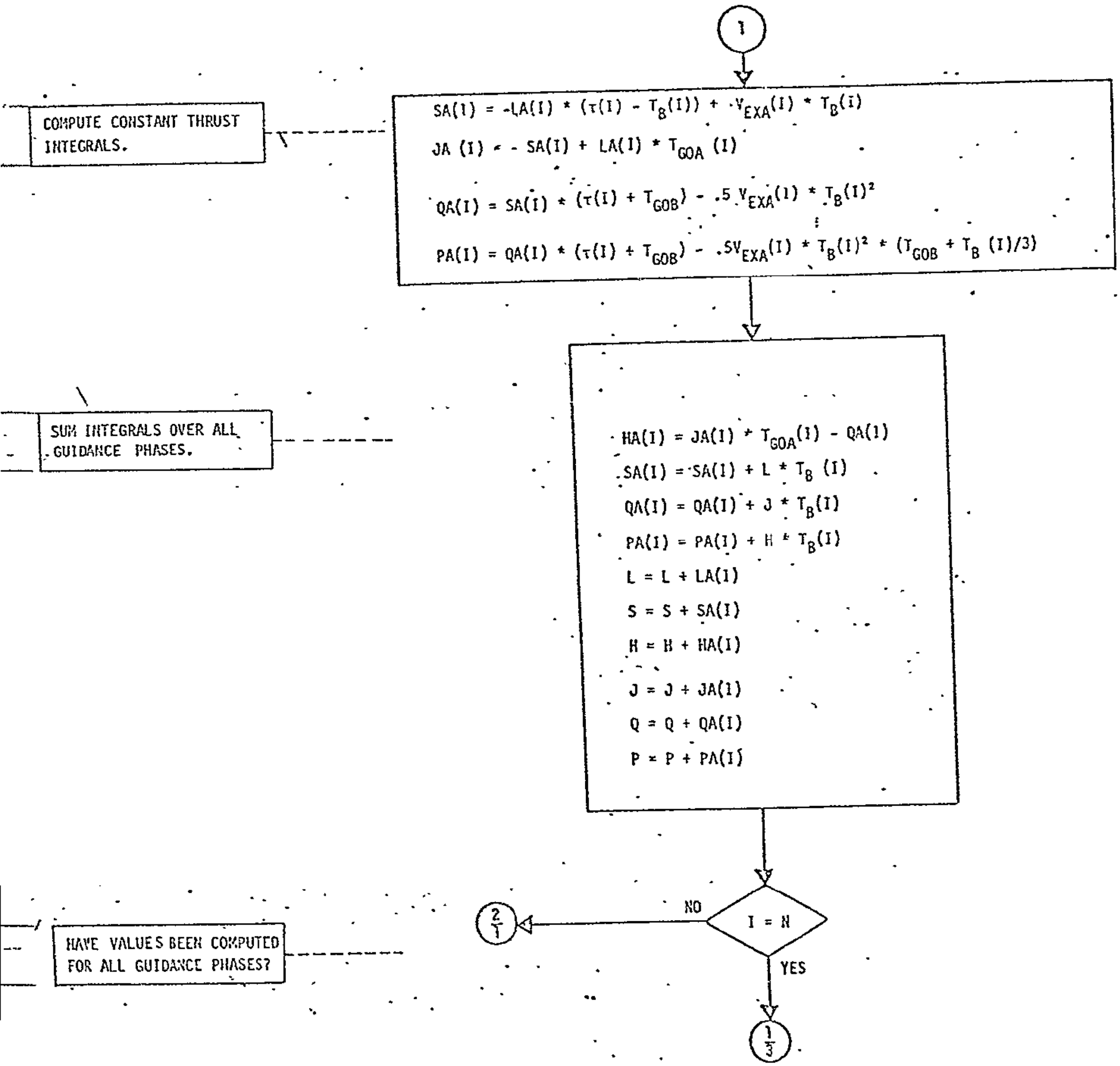

FIGURE 7 - INTEG LOGIC FLOW (PAGE 2)

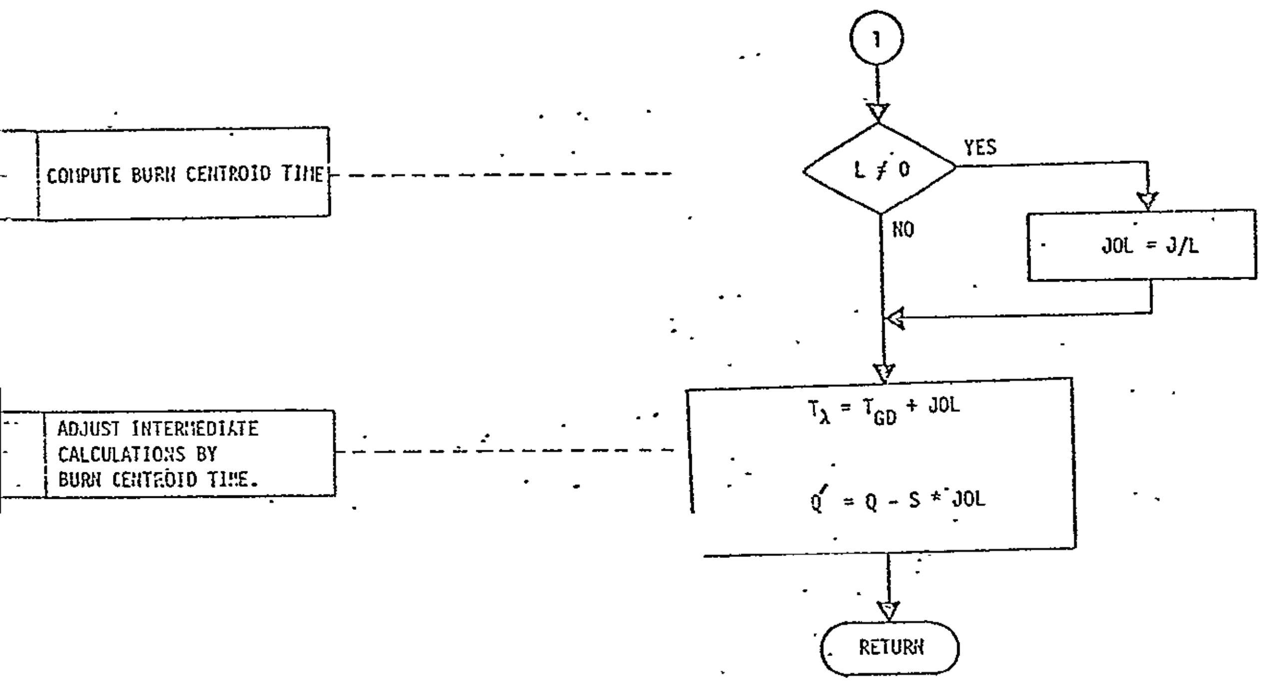

FIGURE 7 - INTEG.LOGIC FLOW (PAGE 3)

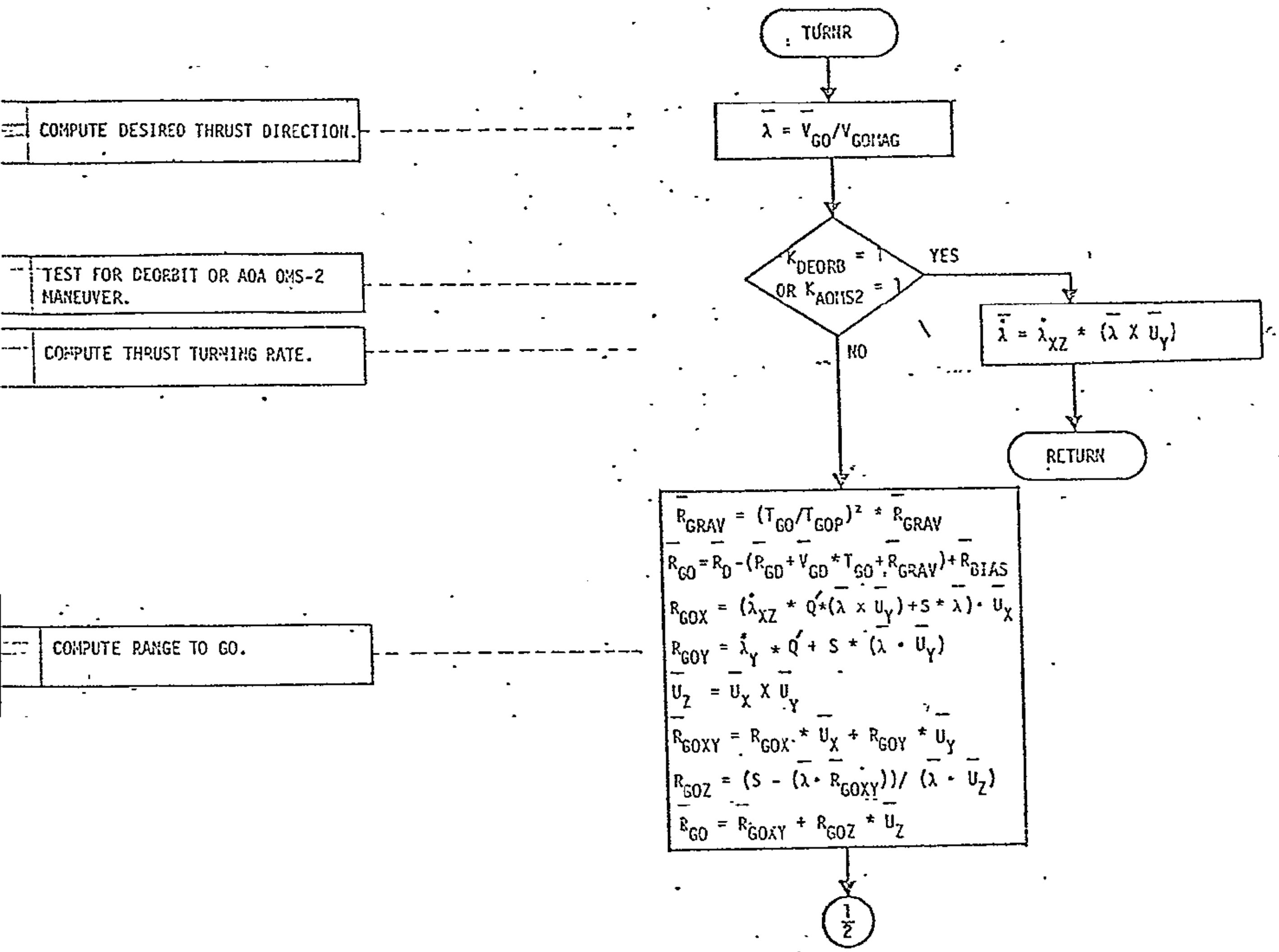

FIGURE 8 - TURNR LOGIC FLOW

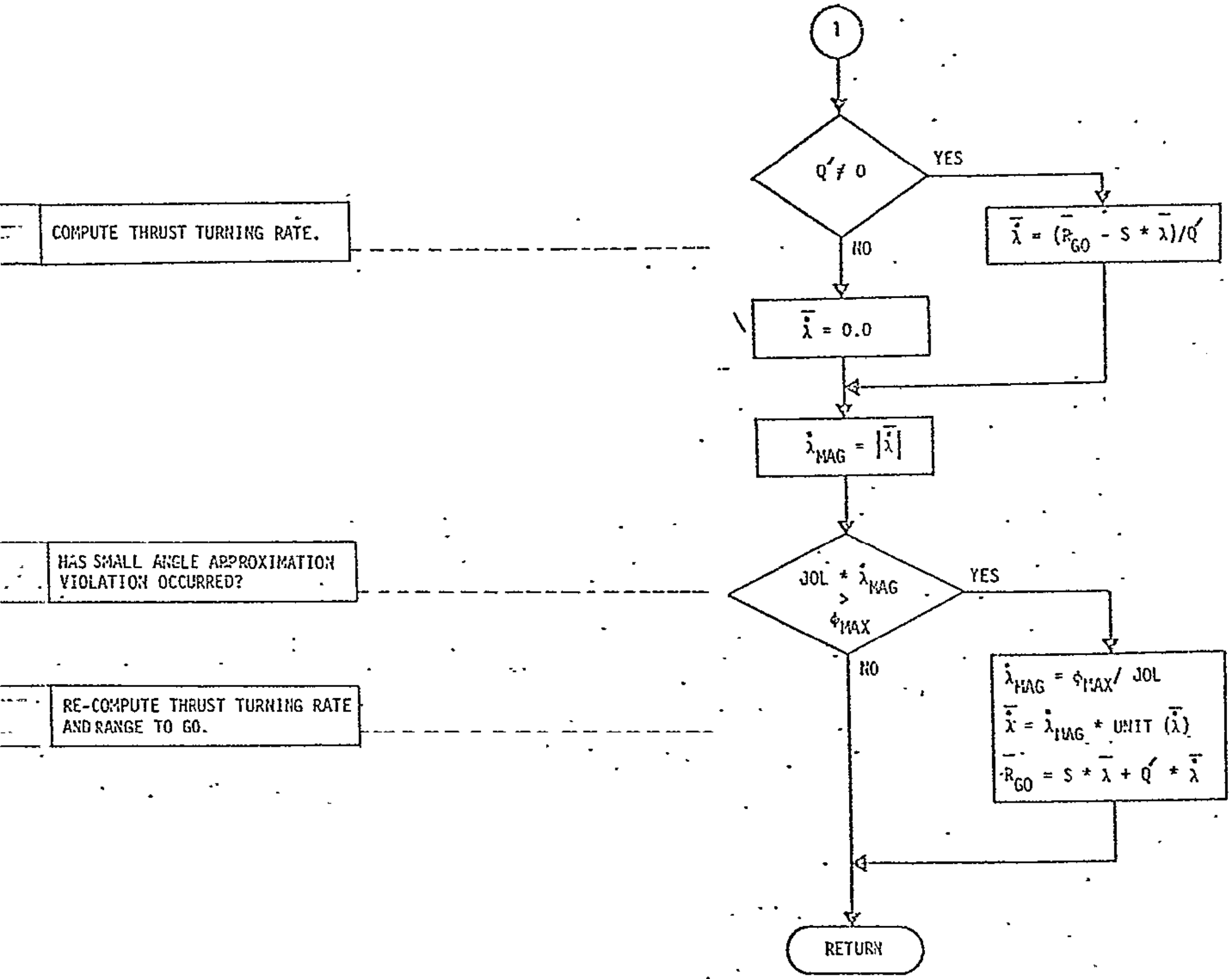

FIGURE 8 - TURNR LOGIC FLOW (PAGE 2)

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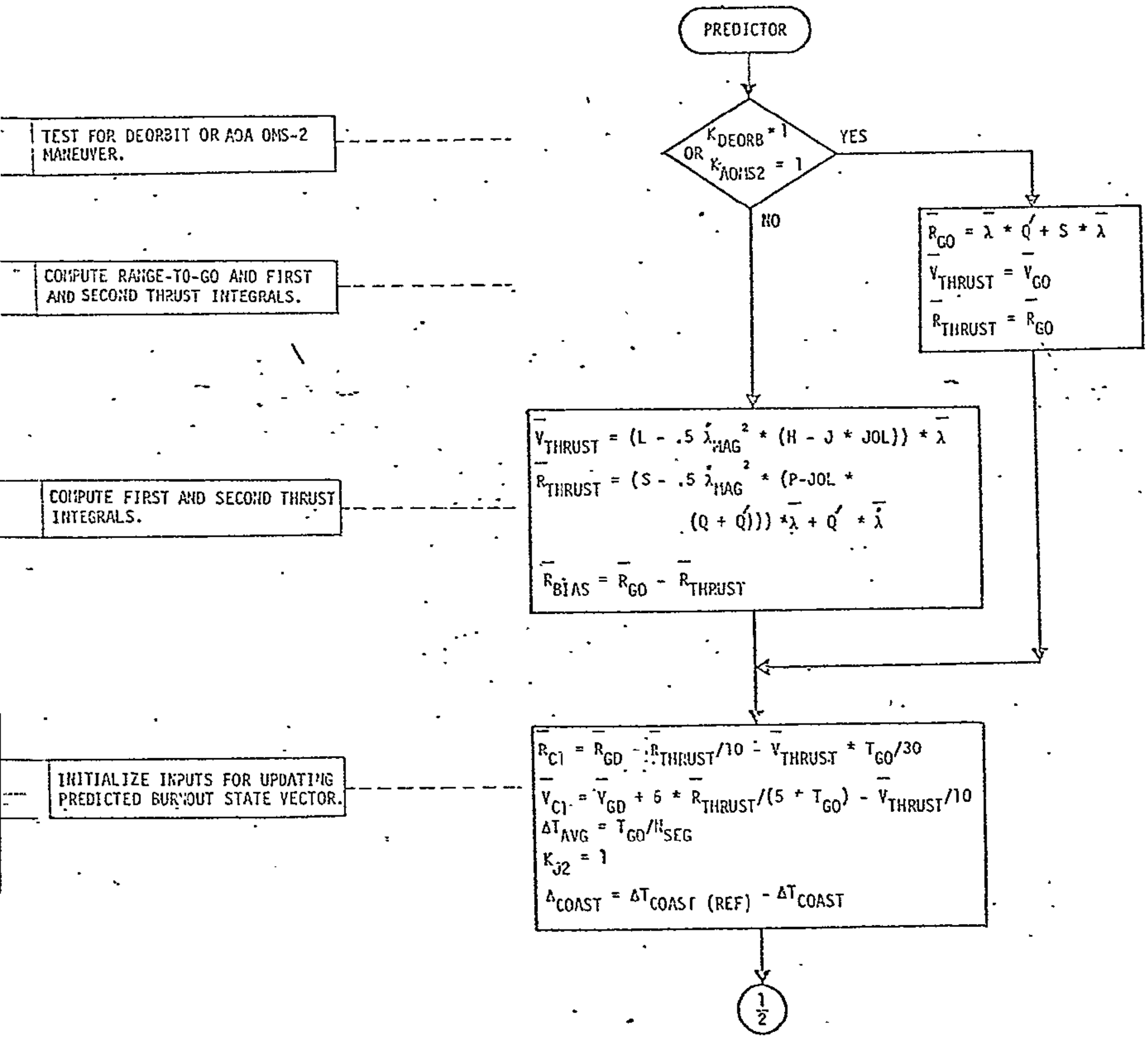

FIGURE 9 - PREDICTOR LOGIC FLOW

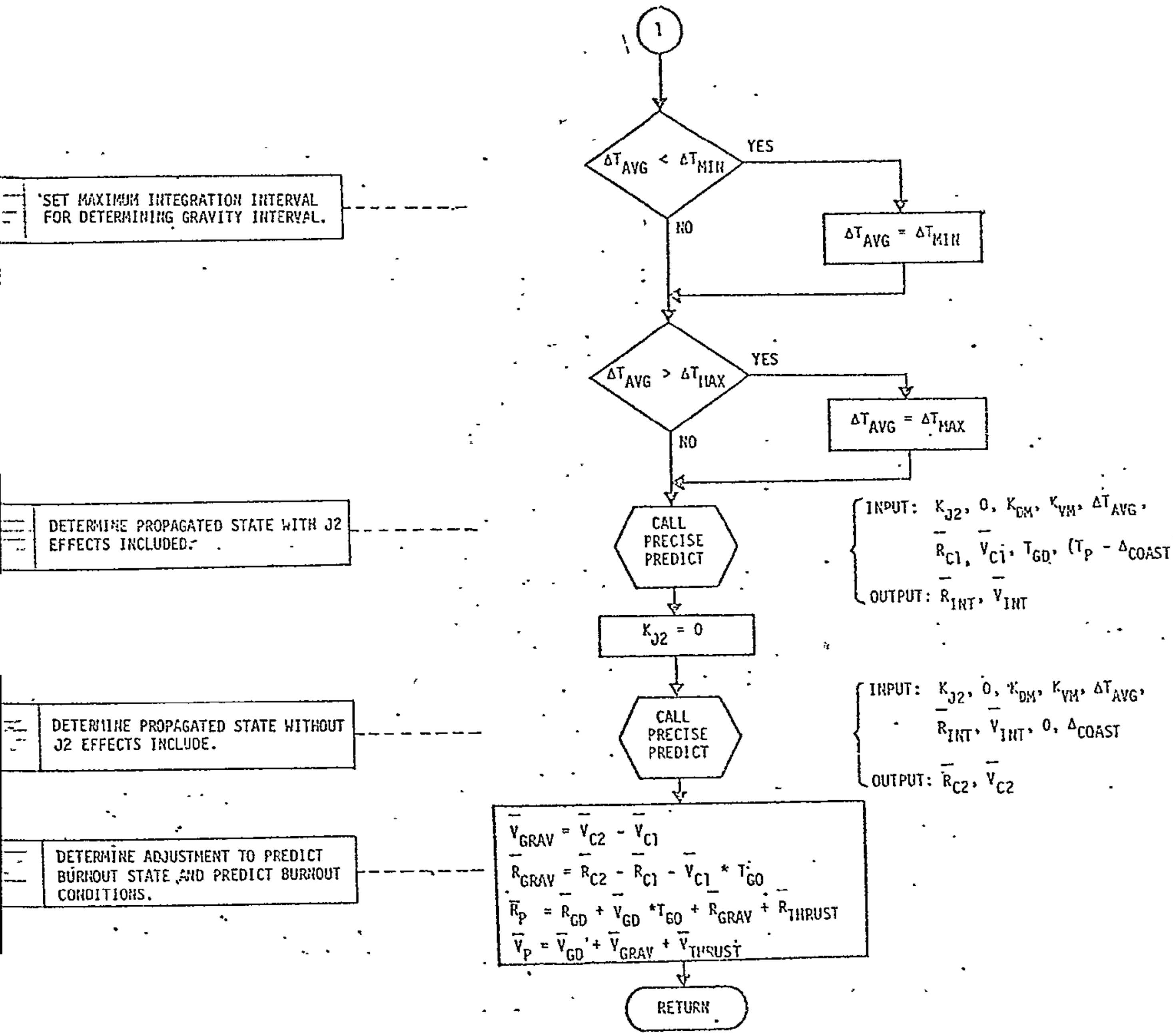

FIGURE 9 - PREDICTOR LOGIC FLOW (PAGE 2)

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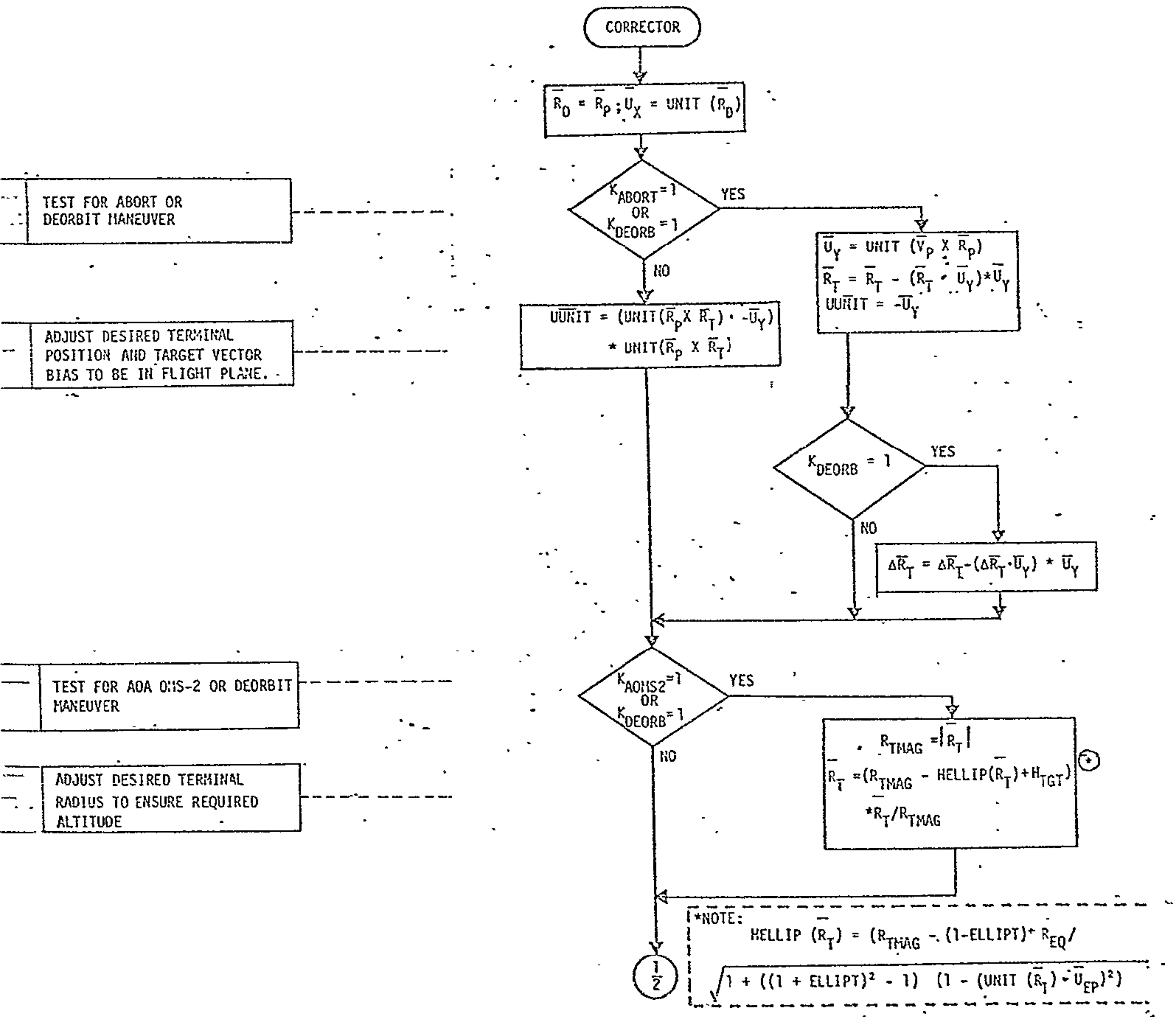

FIGURE 10 - CORRECTOR LOGIC FLOW

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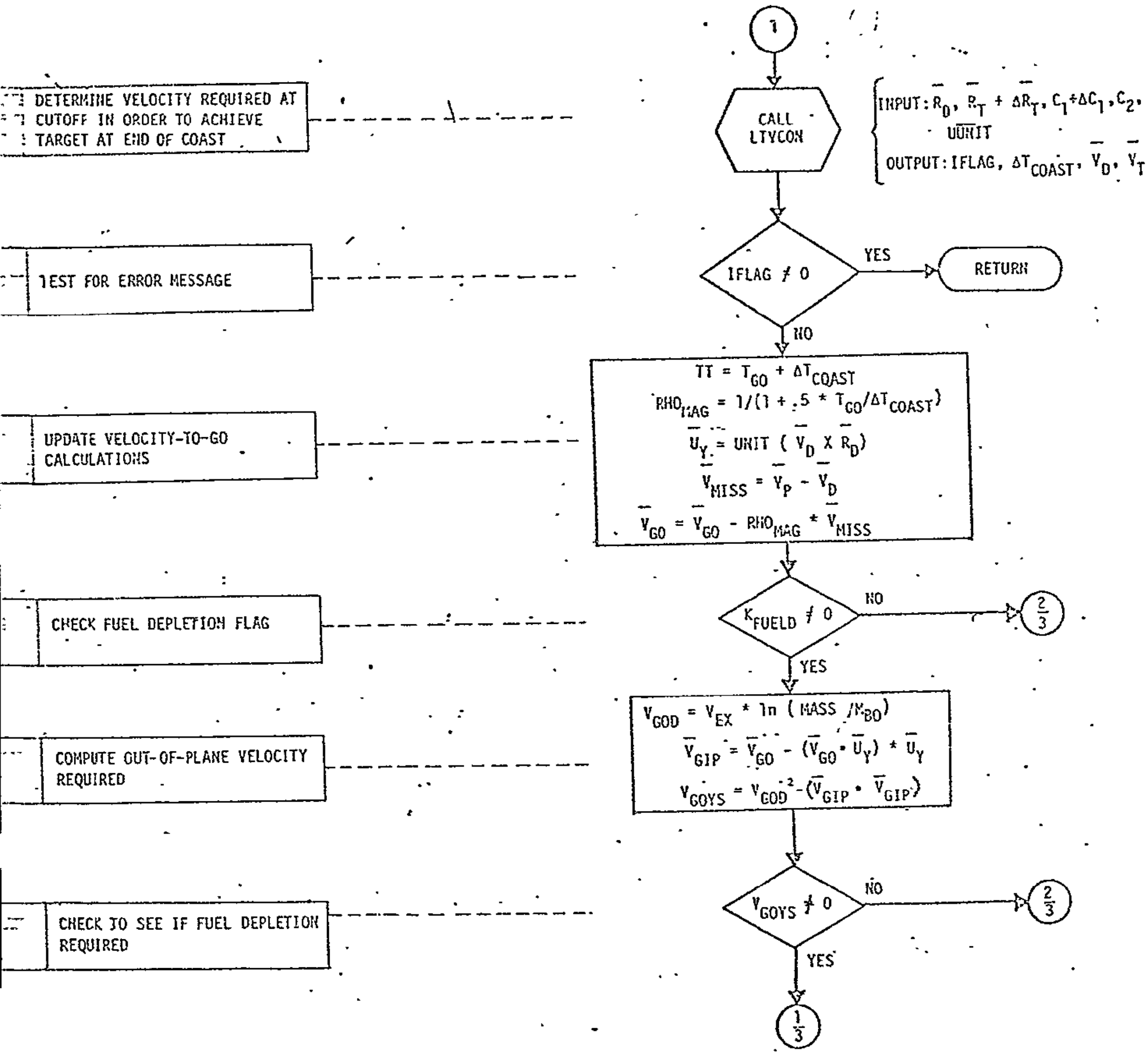

FIGURE 10 - CORRECTOR LOGIC FLOW (PAGE 2)

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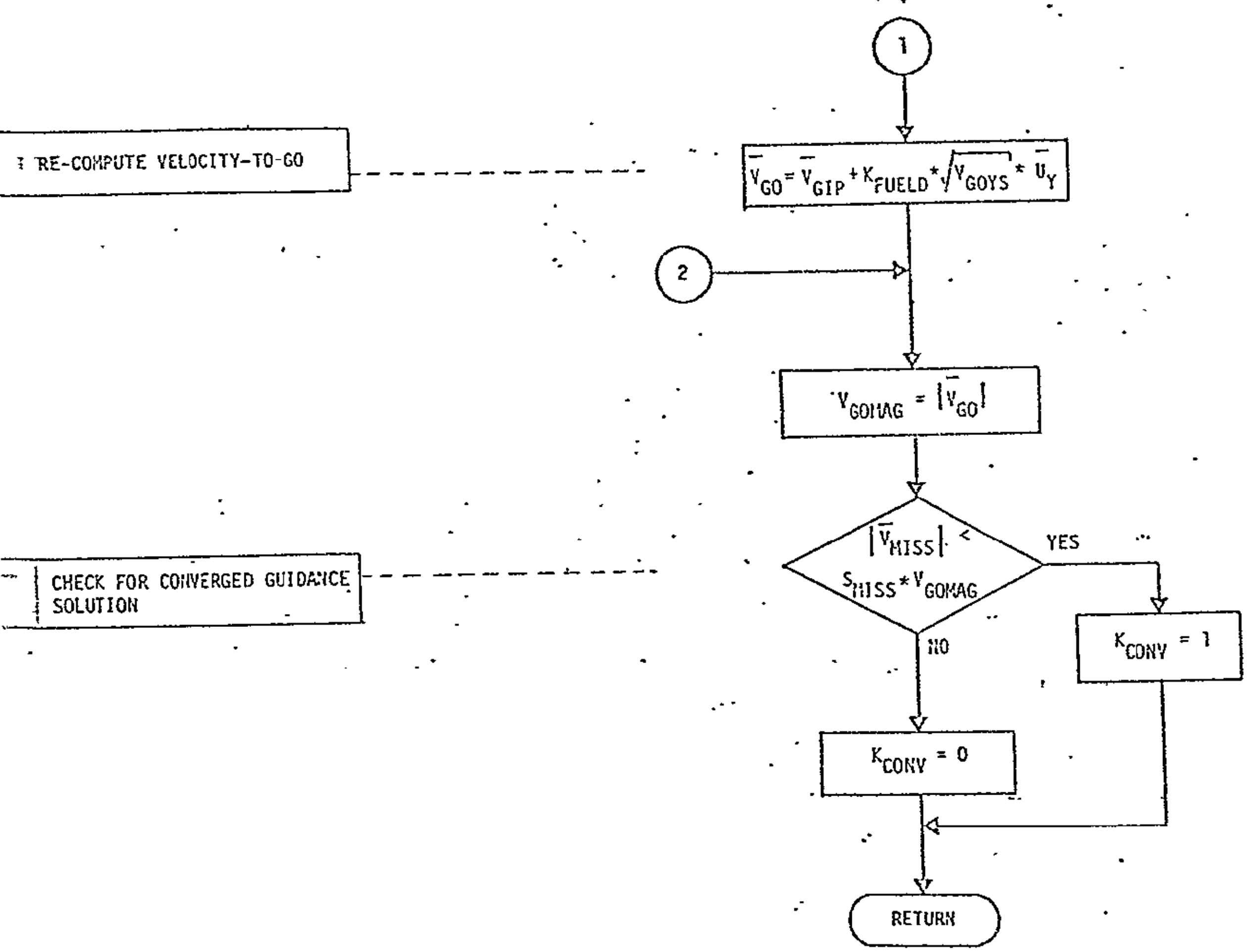
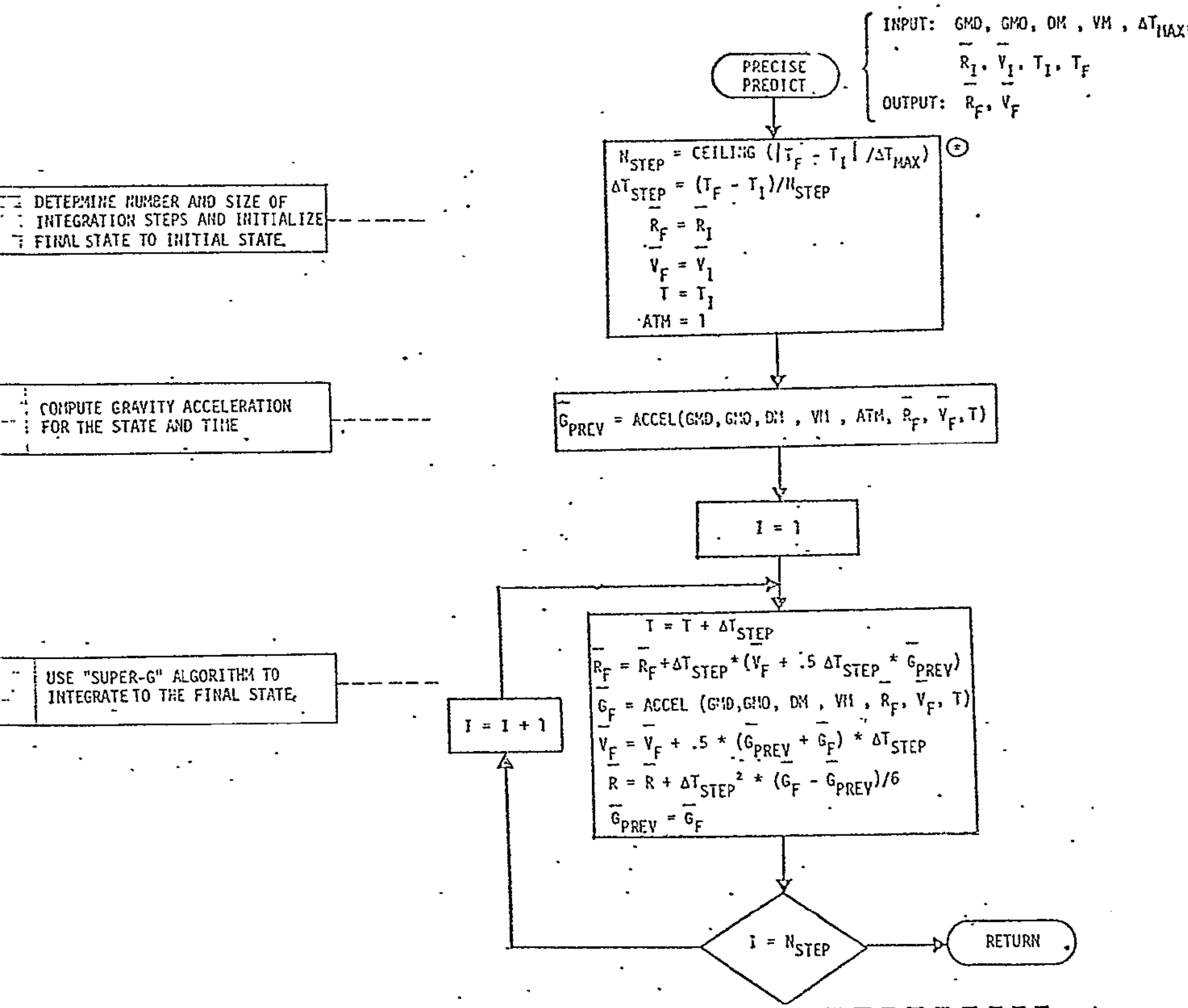


FIGURE 10 - CORRECTOR LOGIC FLOW (Page 3)



* CEILING (A/B) IS A FUNCTION WHICH TAKES THE MAXIMUM INTEGER VALVE OF (A/B) AND INCREMENTS THAT VALVE BY ONE.

FIGURE 11 - PRECISE PREDICT LOGIC FLOW

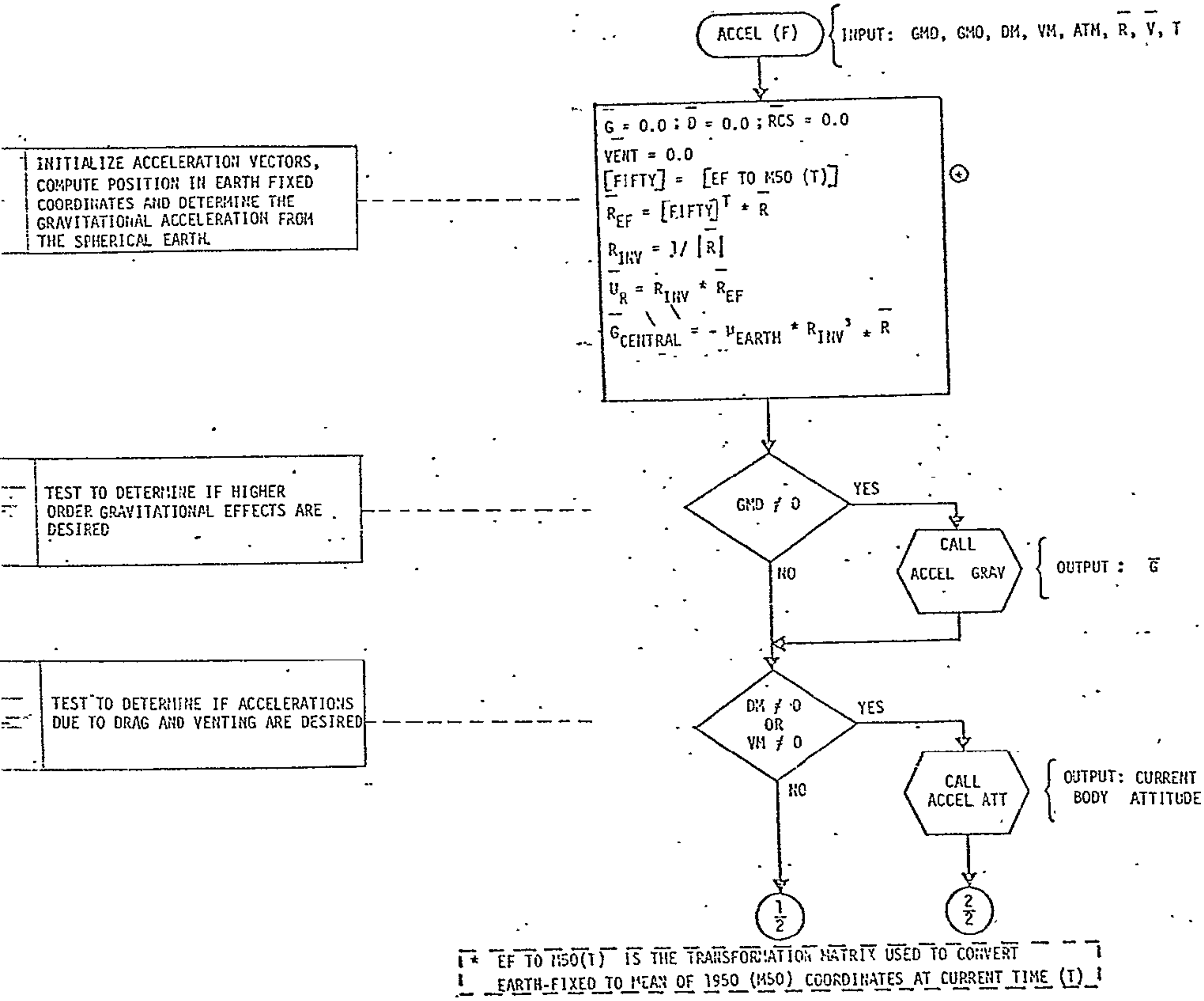


FIGURE 12 - ACCEL LOGIC FLOW

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IF VENT ACCELERATION DESIRED CALL VENT-MODEL

IF DRAG ACCELERATION DESIRED CALL DENSITY AND DRAG MODELS

SUM THE ACCELERATION VECTORS OF SPHERICAL EARTH, NON-SPHERICAL EARTH, DRAG AND VENT FORCES

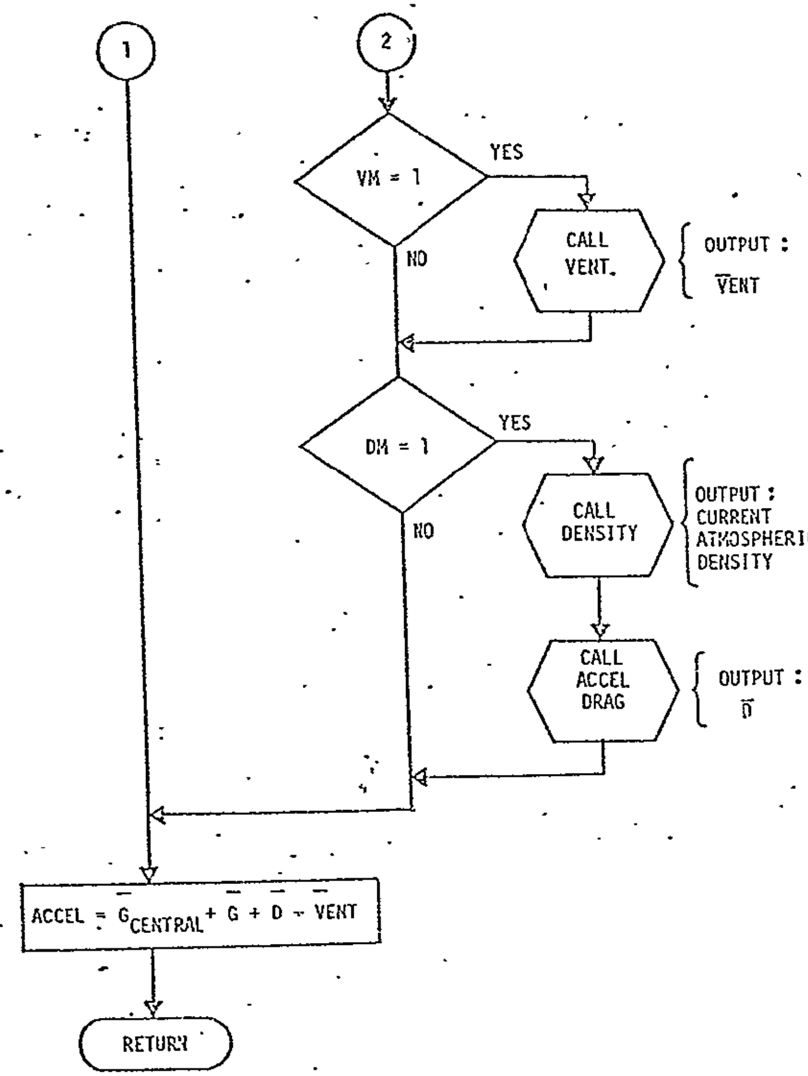

FIGURE 12 - ACCEL LOGIC FLOW (PAGE 2)

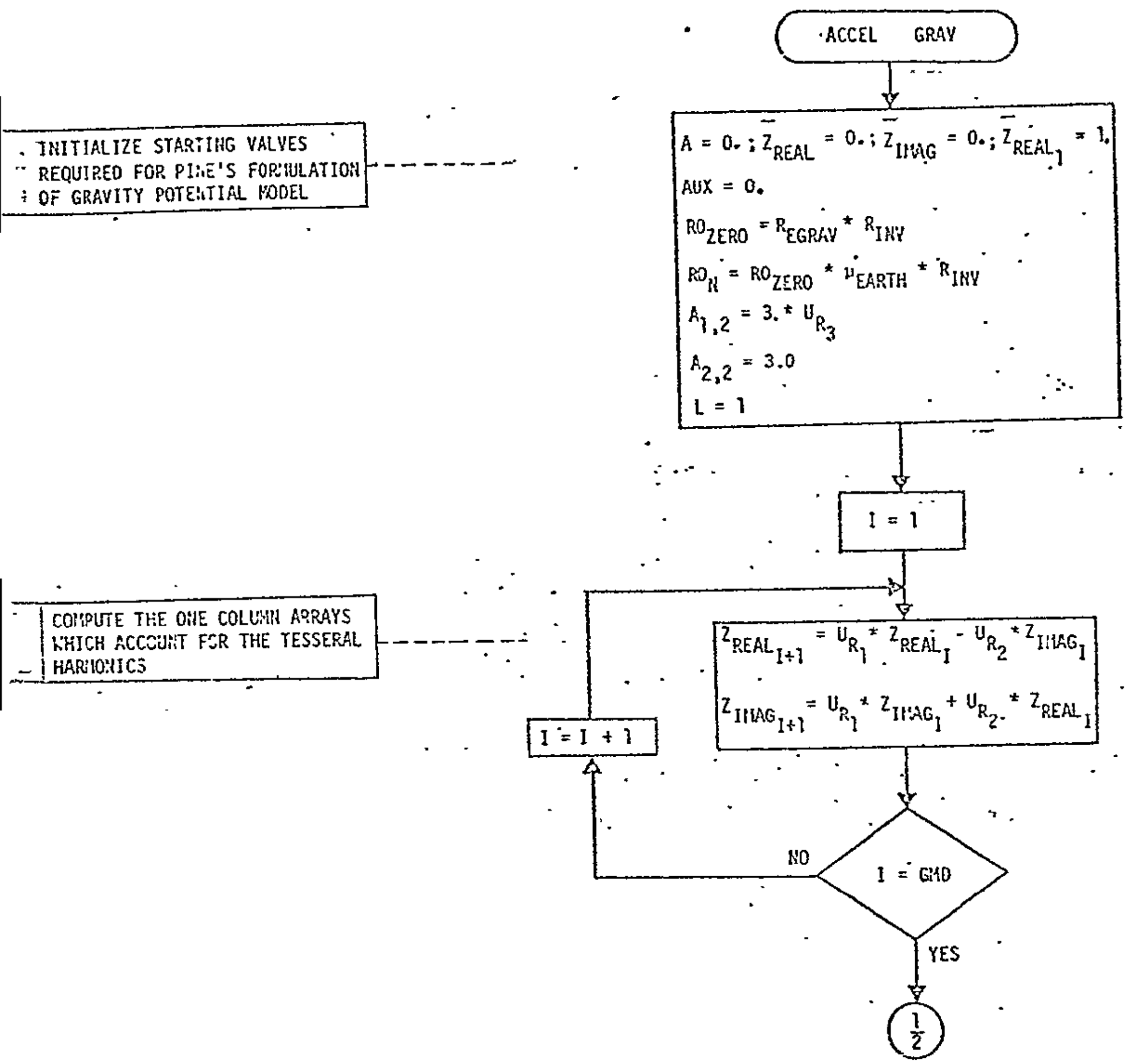

FIGURE 13 - ACCEL GRAV LOGIC FLOW

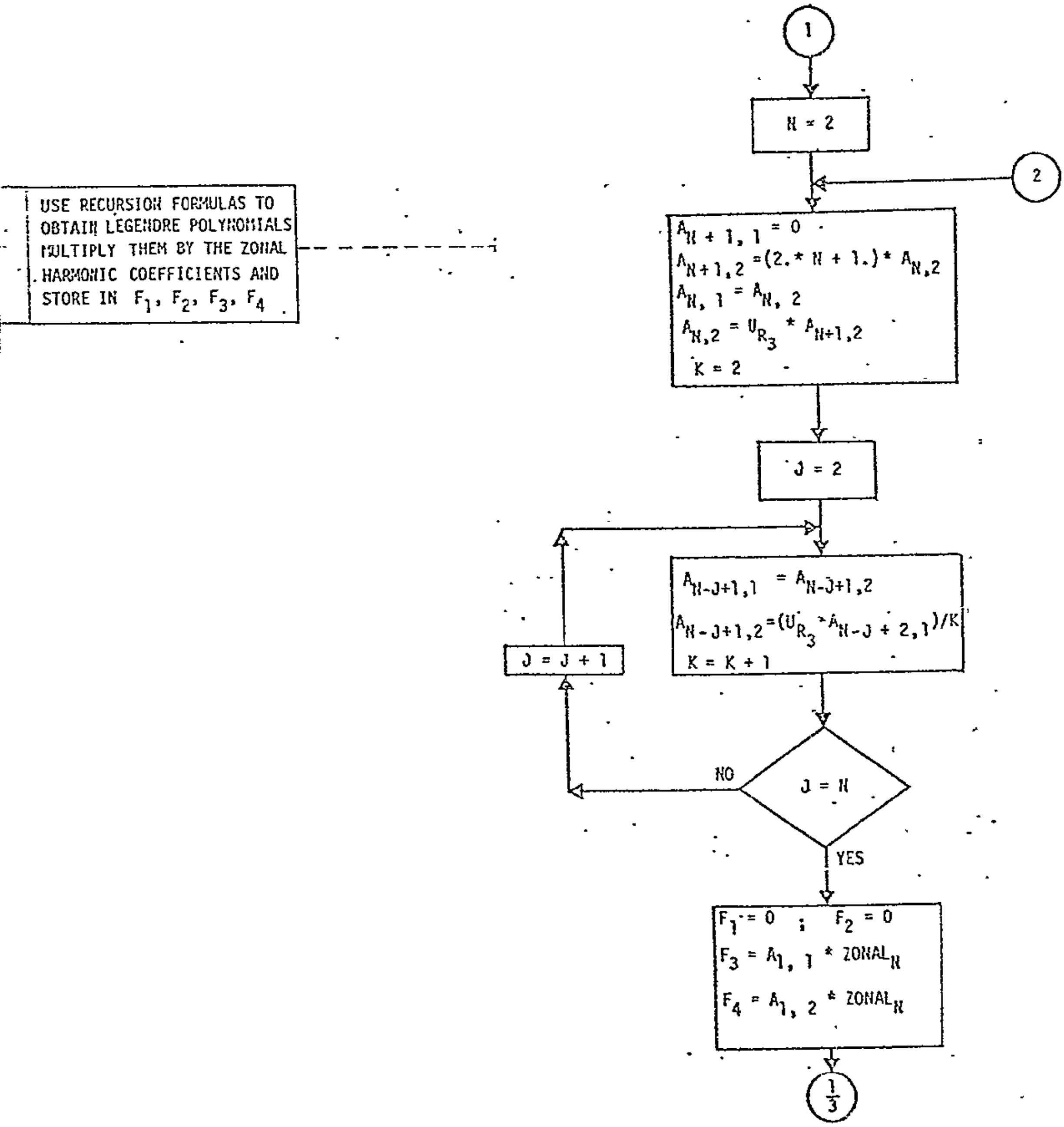

FIGURE 13 - ACCEL GRAV LOGIC FLOW (PAGE 2)

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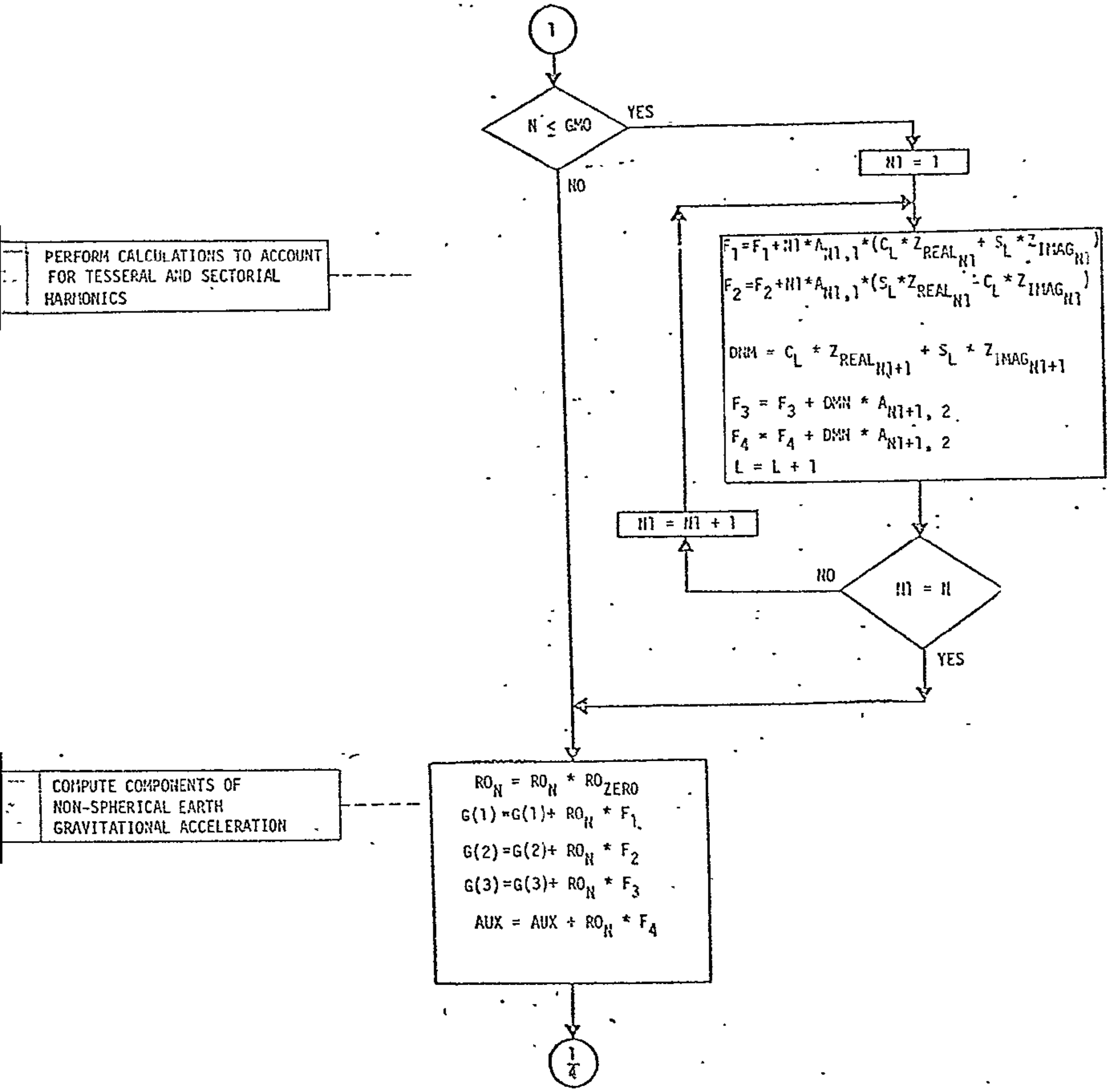

FIGURE 13 - ACCEL GRAV LOGIC FLOW (PAGE 3)

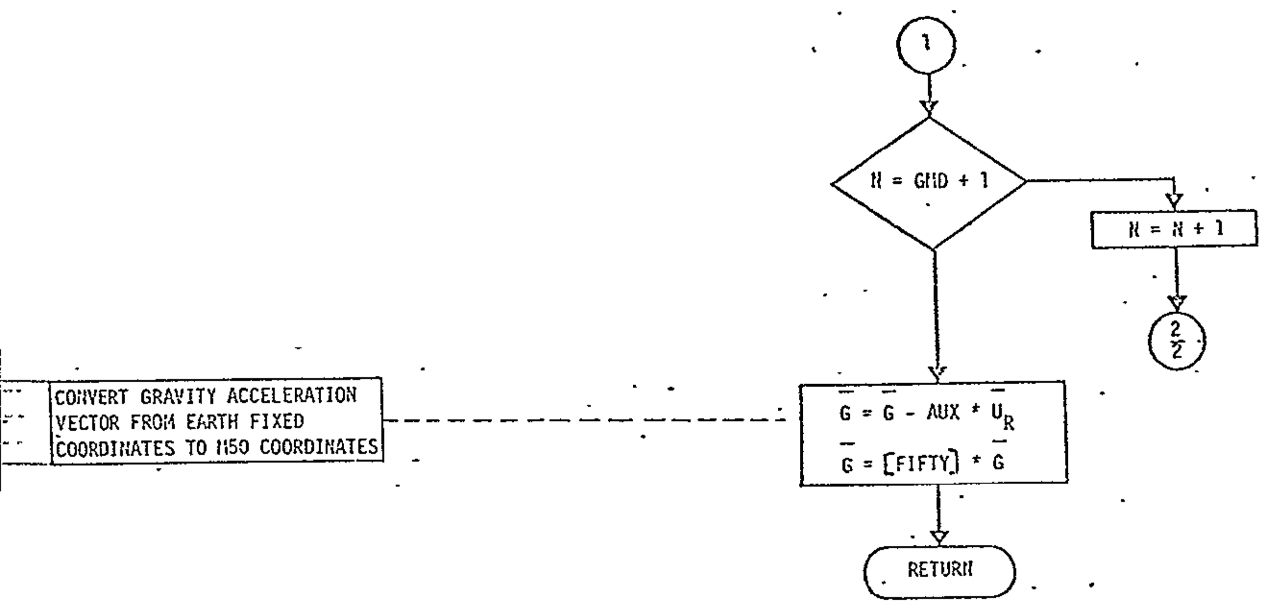

FIGURE 13 - ACCEL GRAV LOGIC FLOW (PAGE 4)

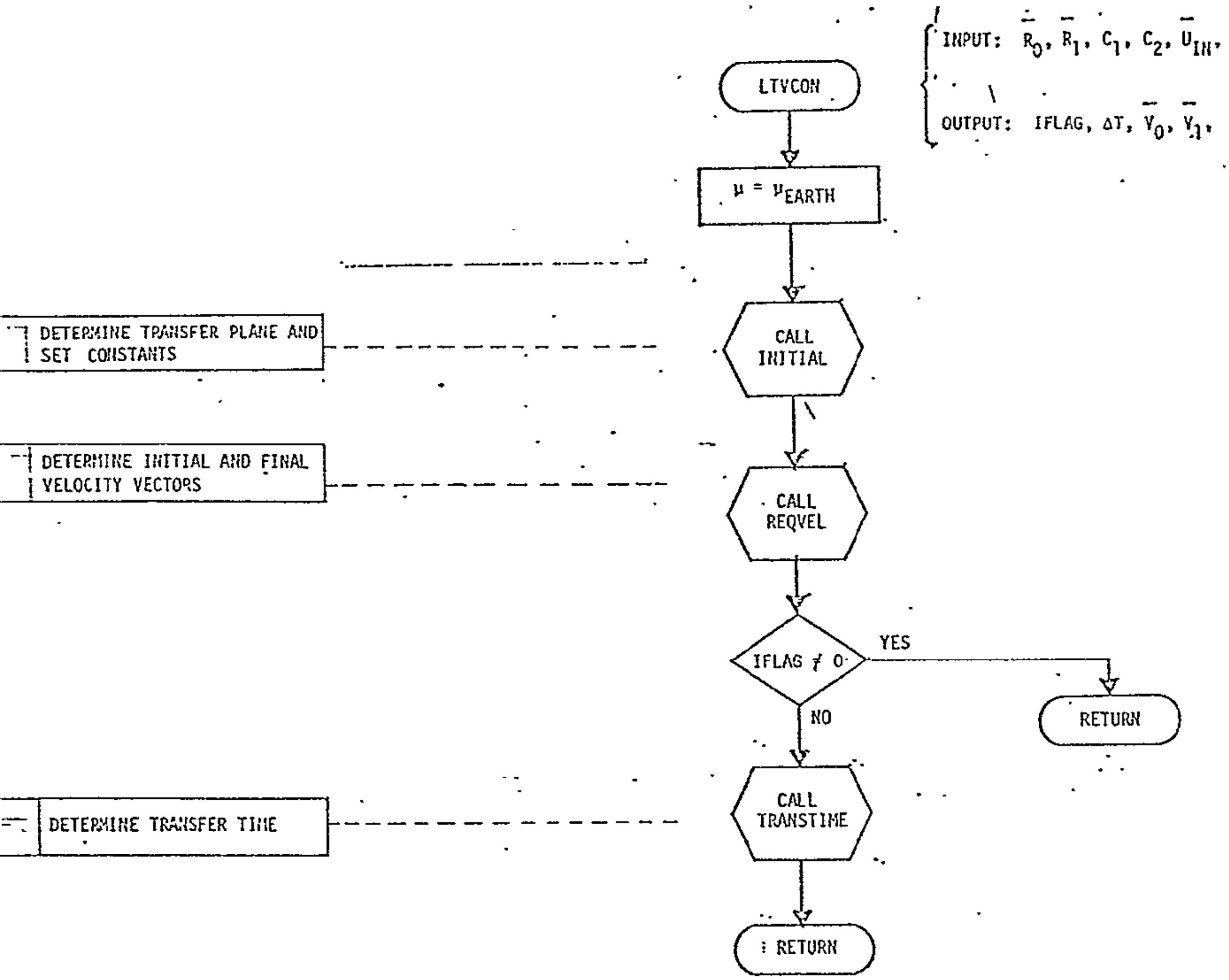

FIGURE 14 - LTVCON LOGIC FLOW

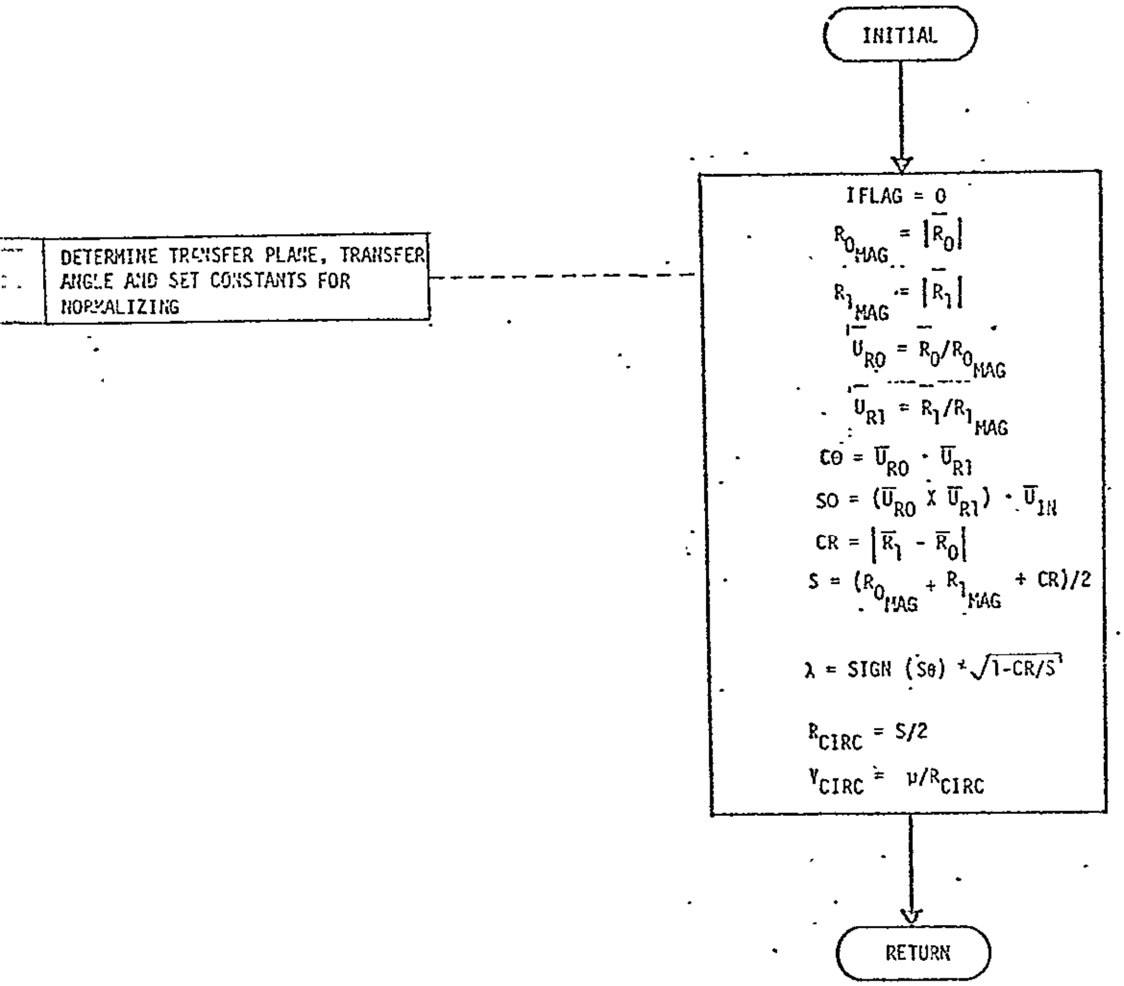

FIGURE 15 - INITIAL LOGIC FLOW

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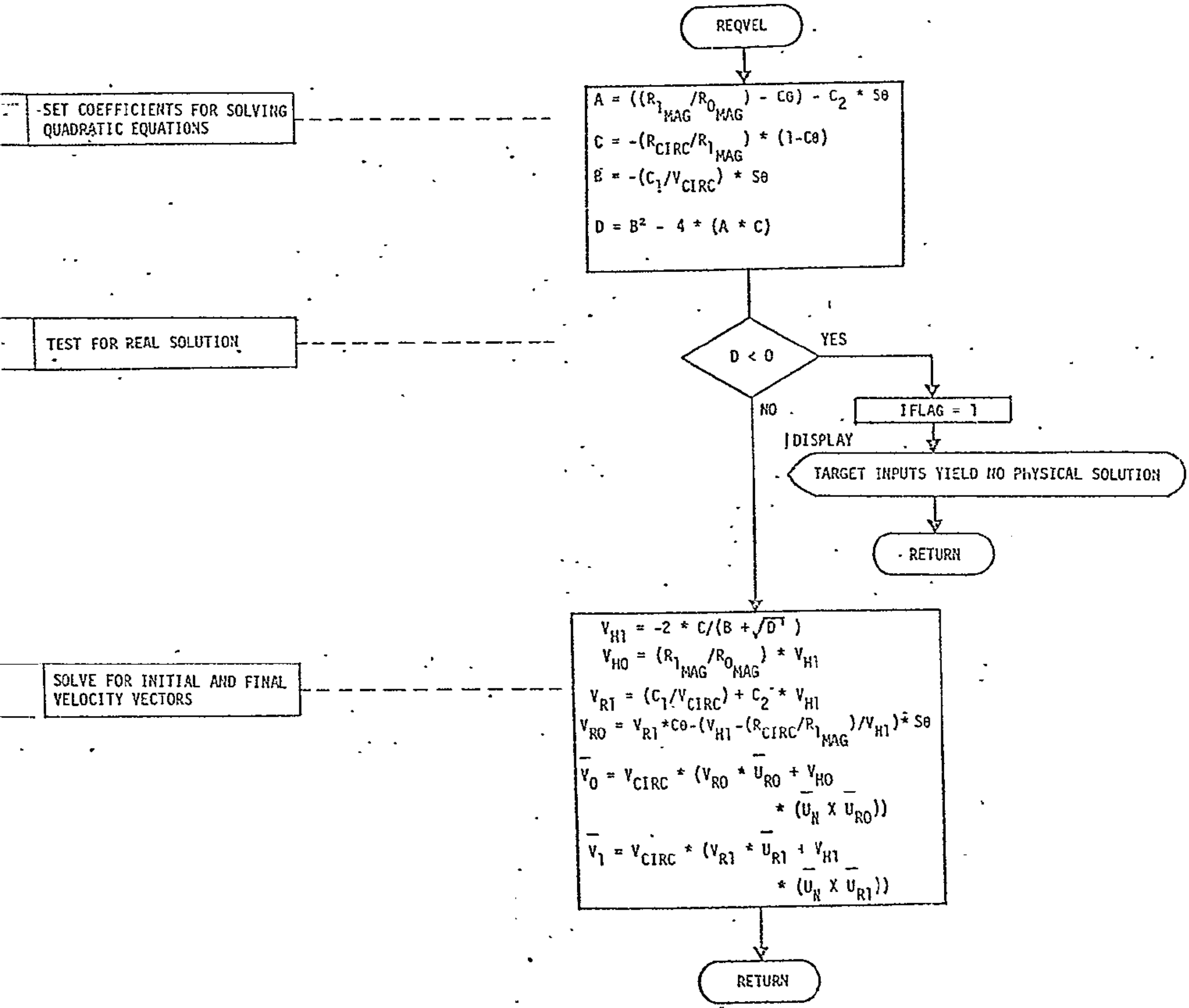

FIGURE 16 - REQVEL LOGIC FLOW

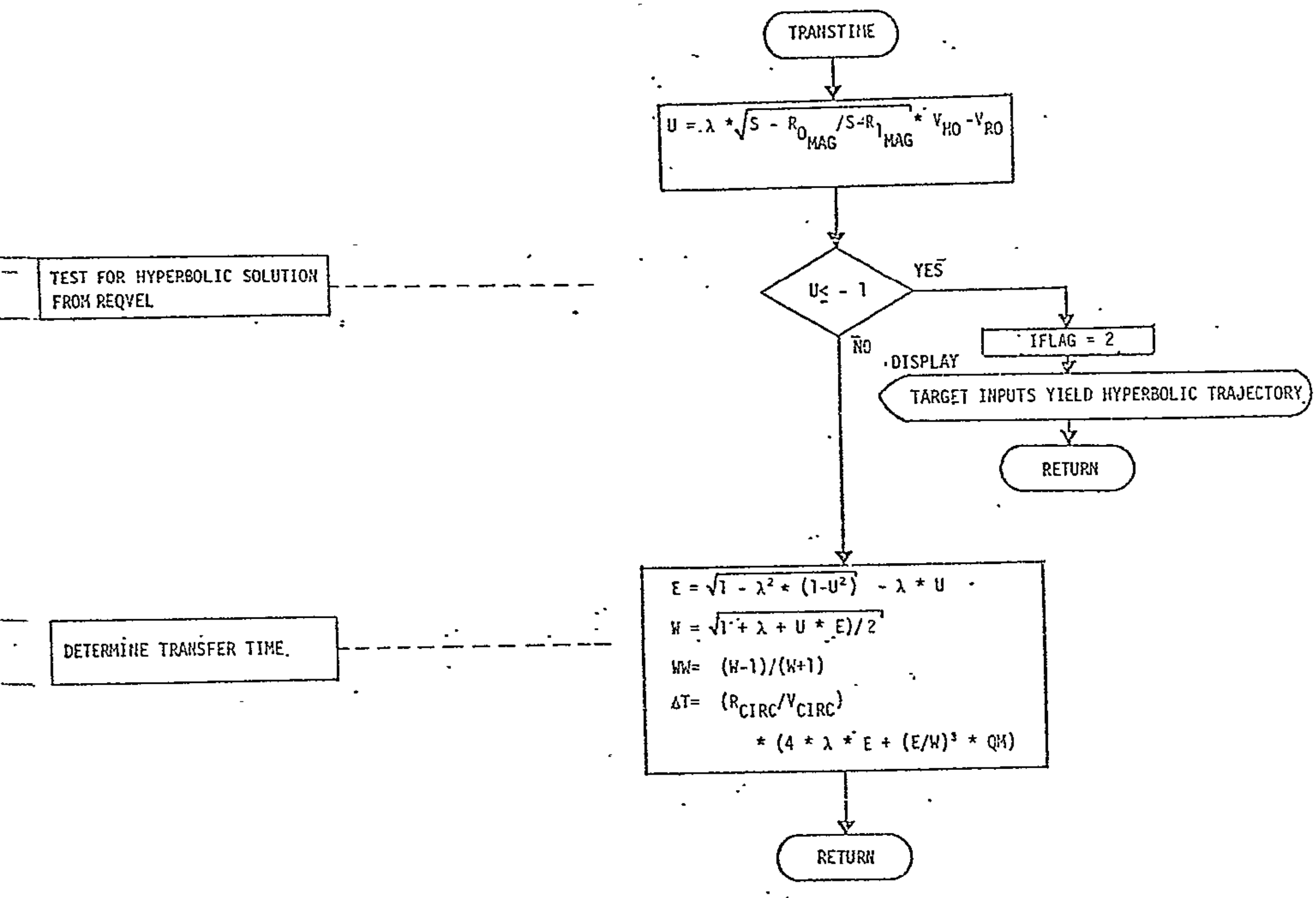

FIGURE 17 - TRANSTIME LOGIC FLOW

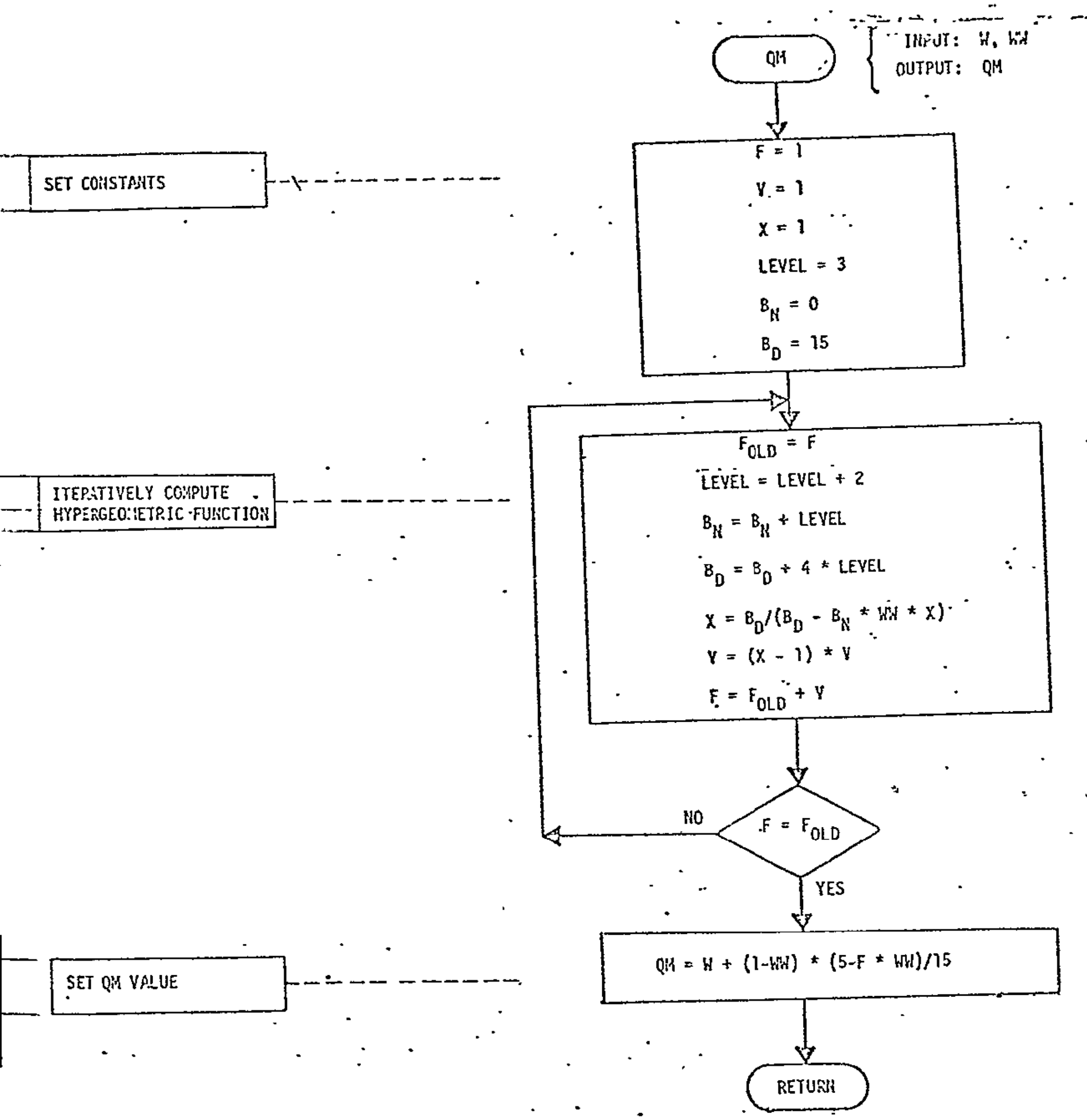

FIGURE 18 - FUNCTION QM LOGIC FLOW

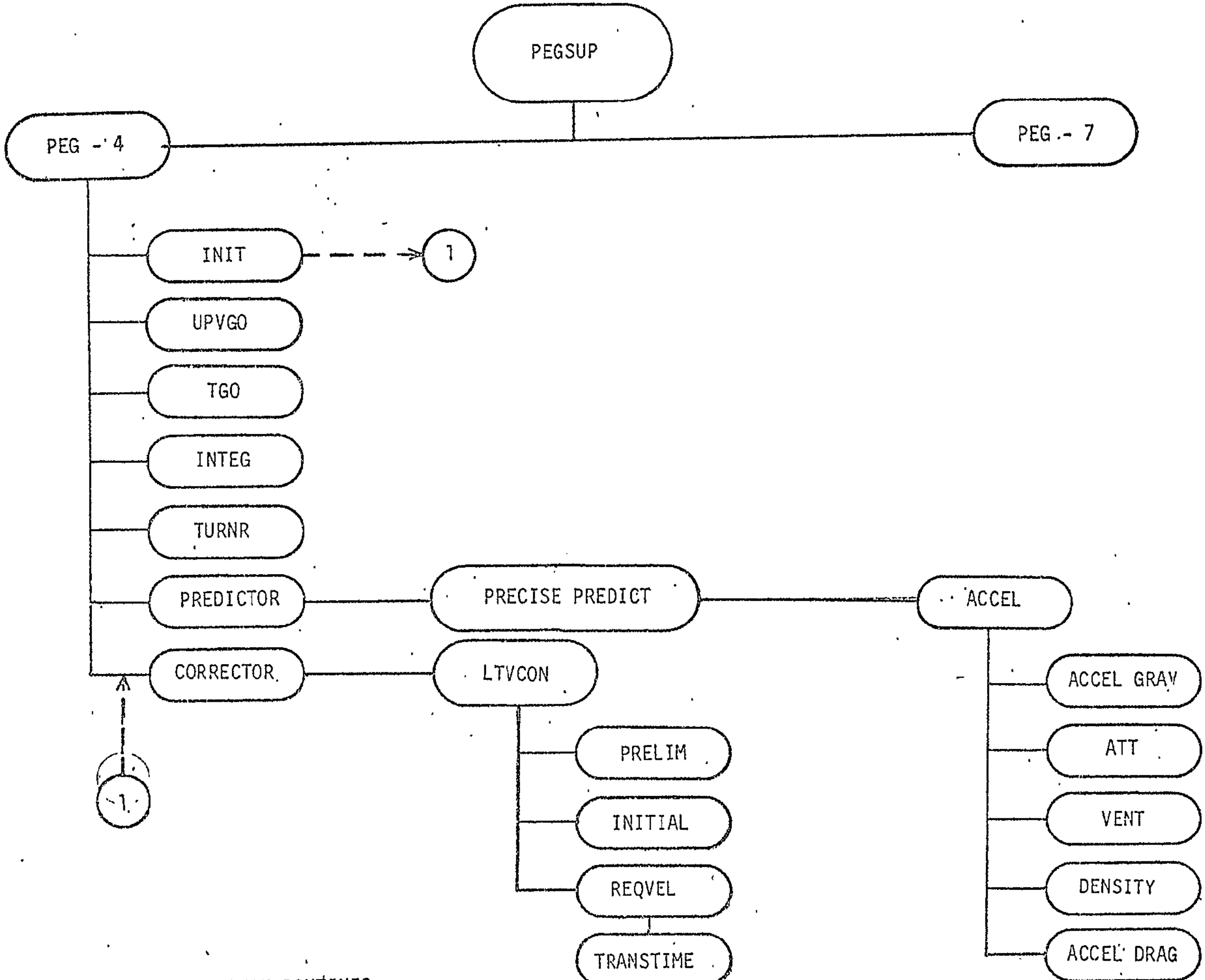

FIGURE 19 - ORBITAL GUIDANCE ROUTINES

LYNDON B. JOHNSON SPACE CENTER MEMORANDUM

REFER TO: LC-5-363

INITIATOR: LC/R. Merrifield:rl:5-19-76:2091

DATE: MAY 20 1976

TO: JM6/E. Robinson

CC:

ENCL:

FROM: LA3/Manager for Management Integration

SIGNATURE: Reginald M. Machell

SUBJ: Document Release Authorization

On September 23, 1975, by memorandum LC-5-260 from this office, you were requested to process document release authorizations for documents generated by the Space Shuttle Engineering and Operations Support Contract NAS 9-13970 according to the following criteria:

a. "May be announced in STAR (or CSTAR if classified)."

b. "May be made publicly available, except (1) classified material which should be released to security qualified requestors only, and (2) documents which may be released overseas that come under the jurisdiction of the Federal Early Domestic Dissemination Program."

The above referenced contract has been superseded by NAS 9-14960, but the processing of document release authorizations should continue to be guided by the same criteria. If any additional clarification of this criteria is needed, such requests should be addressed to LC/R. B. Merrifield, extension 2091.