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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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September 25, 1970

RTCC REQUIREMENTS FOR APOLLO 14 (MISSION H-3): LOI TARGETING REVISION 1

Lunar Mission Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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IN REPLY REFER TO: 70-FM54-217

SEP 24 1970

MEMORANDUM TO: See attached list

FROM : FM5/Chief, Lunar Mission Analysis Branch

SUBJECT : RTCC requirements for Apollo 14 (H-3): LOI targeting

The enclosed MSC Internal Note 70-FM-145 updates and supercedes MSC Internal Notes 69-FM-11, 69-FM-327, and 70-FM-81. The enclosed internal note specifies the RTCC LOI targeting processor logic for Apollo 14. The enclosed internal note corrects mistakes and documents necessary formulation changes found in programming and using the LOI targeting processor, and reflects the RTCC LOI processor as it currently exists.

Major formulation changes were made to subroutine DELV2 which computes the LOI-2 ΔV. Minor formulation changes were made to subroutines DELTAT, MINTHT, CANS, and INTER.

Ronald L. Berry

APPROVED BY:

for John P. Mayer
Chief, Mission Planning
and Analysis Division

The Flight Software Branch concurs with the above recommendations.

James C. Stokes, Jr.

Enclosure

NASA - Manned Spacecraft Center RELEASE APPROVAL	1. Type of Document: Internal note 2. Identification: 70-FM-145 Page 1 of 1 Pages

TO:	3. FROM: Division: Mission Planning and Analysis Branch: Lunar Mission Analysis Section

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Revision 1

MSC INTERNAL NOTE NO. 70-FM-145

PROJECT APOLLO

RTCC REQUIREMENTS FOR APOLLO 14 (MISSION H-3): LOI TARGETING REVISION 1

By Robert F. Wiley
Lunar Mission Analysis Branch

September 25, 1970

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: Ronald L. Berry
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Mission Planning and Analysis Division

RTCC REQUIREMENTS FOR APOLLO 14 (MISSION H-3):

LOI TARGETING

By Robert F. Wiley

1.0 SUMMARY AND INTRODUCTION

Because of experience gained from previous lunar missions, new logic for the RTCC lunar orbit insertion targeting processor was specified for Apollo 14 (Mission H-3). Several things which were being done preflight or in real time through use of graphs needed to be automated. Some of this occurred because the emphasis had been changed from automatic computation of solutions for a range of azimuths at the landing site to computation of solutions to achieve a specified orbit at some point past LOI.

This new logic was specified in reference 1. Because of RTCC program priorities, this logic was slipped to Apollo 15 (Mission H-4), and an update to the existing RTCC LOI targeting processor was made for Apollo 14 (Mission H-3). Reference 2 was the updated version of reference 1 for Apollo 15. However, because the Apollo 14 launch has been slipped, this Apollo 15 logic has been incorporated in the RTCC for Apollo 14. This internal note updates reference 2 to correct the errors detected in programing the inhouse and RTCC versions of the program and to improve some formulation.

2.0 GENERAL DISCUSSION

The LOI targeting logic for H-2 and previous missions computed several types of maneuvers (which are referred to as solutions to the LOI problem or just as solutions in this internal note) corresponding to a range of azimuths at the landing site. That logic also propagated in only a circular orbit, propagated with the AEG, and depended on some preflight data for certain calculations. This pre-H-3 LOI targeting logic rotated for the LOI ellipse in only one direction which can sometimes make the DOI maneuver farther from nominal than is necessary. However, both lunar orbit rotations are provided for in the program logic specified in this internal note; also, propagation in a high ellipse (e.g., the one that would be used for a DPS LOI) is considered; the integrator is used to predict the lunar orbit; preflight data are eliminated; and a solution to intersect with another specified lunar orbit is computed.

Some capabilities have been added to the program but some also have been given up. No fuel reserves after TEI are calculated for two reasons. First, the lunar orbit profiles are very uncertain; thus, much preflight work or much programing would have to be done to retain this function. Second, there are ways in the RTCC to estimate the reserves associated with various LOI solutions to sufficient accuracy if the nominal is known and if there is little or no landing site azimuth change. The capability to compute various solutions within a specified azimuth range over the site also has been given up because the work to program this capability cannot be justified for three reasons. First, the desire to return to the nominal is very strong. Second, an azimuth change very seldom would be required. Third, if it is ever necessary that the azimuth be changed, the flight controller should be able to iterate on azimuth and easily find an acceptable solution.

The same philosophy that was used for the present program is used in this new program (ref. 3). This philosophy consists of three things. First, the functions now known are programed, but enough information is computed and displayed and enough degrees of freedom to the problem are specified as input to permit the accomplishment of other functions, even though it may require much real-time effort. Second, the problem of the sensitive node between the hyperbola and the lunar orbit caused by very small plane differences is solved in the same manner. Third, because it is impossible to obtain all of the desired end conditions of the LOI burn in some cases (e.g., if the nodal altitude is less than the desired lunar orbit perilune altitude, the desired lunar orbit perilune cannot be obtained), certain end conditions are relaxed one at a time to give various solutions.

3.0 LOI SOLUTIONS

Some terminology must be defined. A positive solution is one whose perilune is rotated ahead (i.e., in the direction of motion); a negative solution is one whose perilune is rotated behind (i.e., opposite to the direction of motion). Eight solutions are computed. There are four solution types, each with a positive-negative solution. The four types are as follows.

a. Plane solutions: obtain the desired azimuth at the landing site, giving up the lunar orbit perilune altitude if necessary.

b. Coplanar solutions: obtain the desired lunar orbit shape in the plane of the approach hyperbola with a pre-hyperbolic perilune impulsive point for the positive solution and a post-hyperbolic perilune impulsive point for the negative solution.

c. Minimum θ solutions: obtain the desired lunar orbit shape and minimize the wedge angle between the actual and desired lunar orbit within an input maximum allowable ΔV.

d. Intersection solutions: adjust the first lunar orbit perilune altitude to obtain a specified altitude difference between it and the altitude on the post-DOI lunar orbit.

Note that this logic is like the one-azimuth logic of the pre-H-3 programs with intersection and positive-negative solutions added and with a more sophisticated method of lunar orbit propagation.

4.0 DISCUSSION OF THE TARGETING LOGIC

The LOI-1 maneuver is targeted based on the following assumed trajectory profile to the landing site. All plane change is accomplished with the first burn. A second burn adjusts the inplane orbital elements so that a specified orbit occurs at the landing site. It is not always possible to meet all desired end conditions; thus, the various solutions mentioned previously are computed.

The time at the landing site is estimated from the two parking orbits (LPO-1 and LPO-2) and the number of revolutions in each, all of which are MED inputs. Because perturbations are dependent on the orientation of the orbit relative to the moon, a true anomaly at which to transfer from the hyperbola to the first LPO is entered. (This input affects only the estimated time at the landing site and the orientation of LPO-1 when it is moved back to LOI.) Two-body equations are used; therefore, the error in time estimate will be caused by the perturbations of the lunar orbit perilune position in inertial space.

The backward integration from the landing site is done with the integrator to obtain the inplane elements of LPO-2 used to compute intersection solutions and the plane used to determine the node between the hyperbola and LPO-1. This integration is done twice. The first time, an estimate of the error in the time at the landing site is made and the time at the landing site is corrected. The second backward integration starts at this corrected time.

A maximum allowable LOI ΔV for both positive and negative solutions is entered (ΔV_{max+} and ΔV_{max-}) to calculate minimum θ solutions. Unlike the old program, solutions will be computed here even if ΔV is less than ΔV_{max}.

The logic is divided into two major parts after the orbit has been backed up from the landing site and the coplanar solutions have been calculated. On one path, the LPO-1 plane and hyperbola plane are within some specified small angle of each other; on the other path, they are farther apart.

To compute solutions for small plane changes, the capability is provided to compute intersection solutions in the minimum θ solutions' planes. This capability is used when the planes of the minimum θ solutions are so close to the desired lunar orbit plane that the difference is negligible.

For the intersection solutions, the amount that perilune of the first lunar orbit should be above or below the second lunar orbit at perilune of the first is specified by a MED. The angle between the node and perilune of the first lunar orbit is minimized. If the perilune altitude is less than the altitude on the second LPO minus the Δh_{BIAS} when the lunar orbit perilune altitude is equal to the nodal altitude, perilune is placed at the node and no further computations are done.

The computation of the intersection solutions requires solving a fourth-order equation for the LPO-1 perilune radius. Because numerical problems were encountered in solving for the radius, a change was necessary to the routine that solves up to fourth-order equations, PCAQRE. That change was to remove the epsilon test on the resolvent cubic equation, as is discussed in reference 4. The RTCC LOI program has its own version of PCAQRE with this change.

The backward integration of LPO-1 from the landing site provides an estimate of the amount that the apolune and perilune altitudes and perilune position will change. These differences are used in computing intersection solutions so that Δh_{BIAS} is achieved at the time of the transfer from LPO-1 to LPO-2.

The ΔV for the maneuver after LOI-1 is computed for each solution. If there is no intersection or LPO-1 is the same as LPO-2, no ΔV will be computed. The nodal altitude and true anomaly for the ψ_{MX} and ψ_{MN} lunar orbits are computed to provide information about which way to change the landing site azimuth to improve the solution and to give an estimate of the size of the change.

The flow charts at the end of this internal note give the detailed computations discussed above. There is a functional flow chart (flow chart 1) followed by detailed flow charts (flow charts 2 through 12) which give the equations and logic routes.

5.0 MED INPUTS

LOI targeting will require an initialization MED to enter the quantities that normally would not change and a computational MED to tell the program to execute. All data the program needs to run are specified by MED for flexibility. The initialization MED should have the following information.

a. The lunar orbit parameters at the landing site (except for azimuth): ϕ, λ, R of surface; h_a, h_p, angle of perilune from the site, $\Delta\omega$ ($\Delta\omega$ is negative if the site is post-perilune.)

b. Number of revolutions in the first (revs 1) and second lunar orbits (revs 2). (Revs 1 may have a fractional part.)

c. True anomaly on LPO-1 for transferring from the hyperbola to LPO-1, η_1

d. Altitude constraint of the intersection solutions, Δh_{BIAS}. The Δh_{BIAS} is negative if LPO-2 is to be below the LPO-1 perilune. The Δh_{BIAS} and η_1 should revert to zero.

e. A flag to specify if plane or minimum θ nodes should be used to compute intersection solutions. This should revert to plane solutions.

The computational MED should have the following information.

a. Apolune and perilune altitudes of the first LPO

b. A maximum allowable ΔV for the positive solutions and a maximum allowable ΔV for the negative solutions

c. The maximum, desired, and minimum azimuths at the landing site

d. From where and at what time to obtain the pre-LOI state vector

6.0 FLOW CHART NOTATION

a	semimajor axis (except when used in INTER and DELV2); value redefined at several places in the program
a_H	semimajor axis of the hyperbola at perilune

e	eccentricity (except when used in INTER and DELV2); values redefined at several places in the program
e_H	eccentricity of the hyperbola at perilune
H_{ALPO}, H_{PLPO}	input apolune and perilune altitudes of the first LPO
LLS	lunar landing site
LPO	lunar parking orbit
R, V, $\hat{R}$, $\vec{R}$, $\vec{V}$	state vector positions and velocities; values redefined at several places in the program
REVS 1, REVS 2	revs in the first and second LPO's
R_{ALPO}, R_{PLPO}	apolune and perilune radii of the first LPO
R_N, R_{NODE}, $\hat{R}_N$, $\hat{R}_{NODE}$	nodal radius magnitude and unit vector to the node
SOLN	denotes a positive solution (value is +1) or a negative solution (value is -1)
$\vec{SPH}$	hyperbolic perilune state vector
$\hat{U}_H$	unit angular momentum vector to $\vec{SPH}$
$\hat{U}_L$	unit inertial vector to LPO-2 perilune used in INTER. Equal to $\hat{U}_{PL}$ or the projection of $\hat{U}_{PL}$ into the minimum θ solutions' planes
$\hat{U}_{LLS}$	unit inertial position vector to the LLS at the estimated time at the LLS
$\hat{U}_{MX}$, $\hat{U}_{DS}$, $\hat{U}_{MN}$	unit angular momentum vectors to the ψ_{MX}, ψ_{DS}, and ψ_{MN} LPO's, respectively
$\hat{U}_N$	unit $(\hat{U}_{DS} \times \hat{U}_{XTRA})$
$\hat{U}_{PC}$	unit position vector to hyperbolic perilune
$\hat{U}_{PL}$	unit inertial vector to LPO-2 perilune at LOI-2 time
$\hat{U}_S$	unit angular momentum vector to the plane of the solution

$\hat{U}_{XTRA}$	unit angular momentum vector to an LPO at the LLS made from ψ_{DS} - 5° and backed up to LOI
Δh_a, Δh_p, Δw_p	estimate of the change of apolune altitude, perilune altitude, and perilune position due to propagation in LPO-1
Δh_{BIAS}	difference between the perilune of the first LPO and the corresponding position on the second LPO
Δt_{CORR}	error in the estimated time at the LLS
ΔV_{max+}	maximum allowable LOI ΔV for the positive solution
ΔV_{max-}	maximum allowable LOI ΔV for the negative solution
ΔV_+, ΔV_-	ΔV's for the positive and negative selections
ψ_{MX}, ψ_{DS}, ψ_{MN}	maximum, desired, and minimum azimuths at the LLS
η_1	true anomaly at which to get on LPO-1. Used only for the T_{LLS} estimate and in backing up the lunar orbit to LOI
$\hat{\nu}$	unit vector; value redefined at several places in the program

Operations

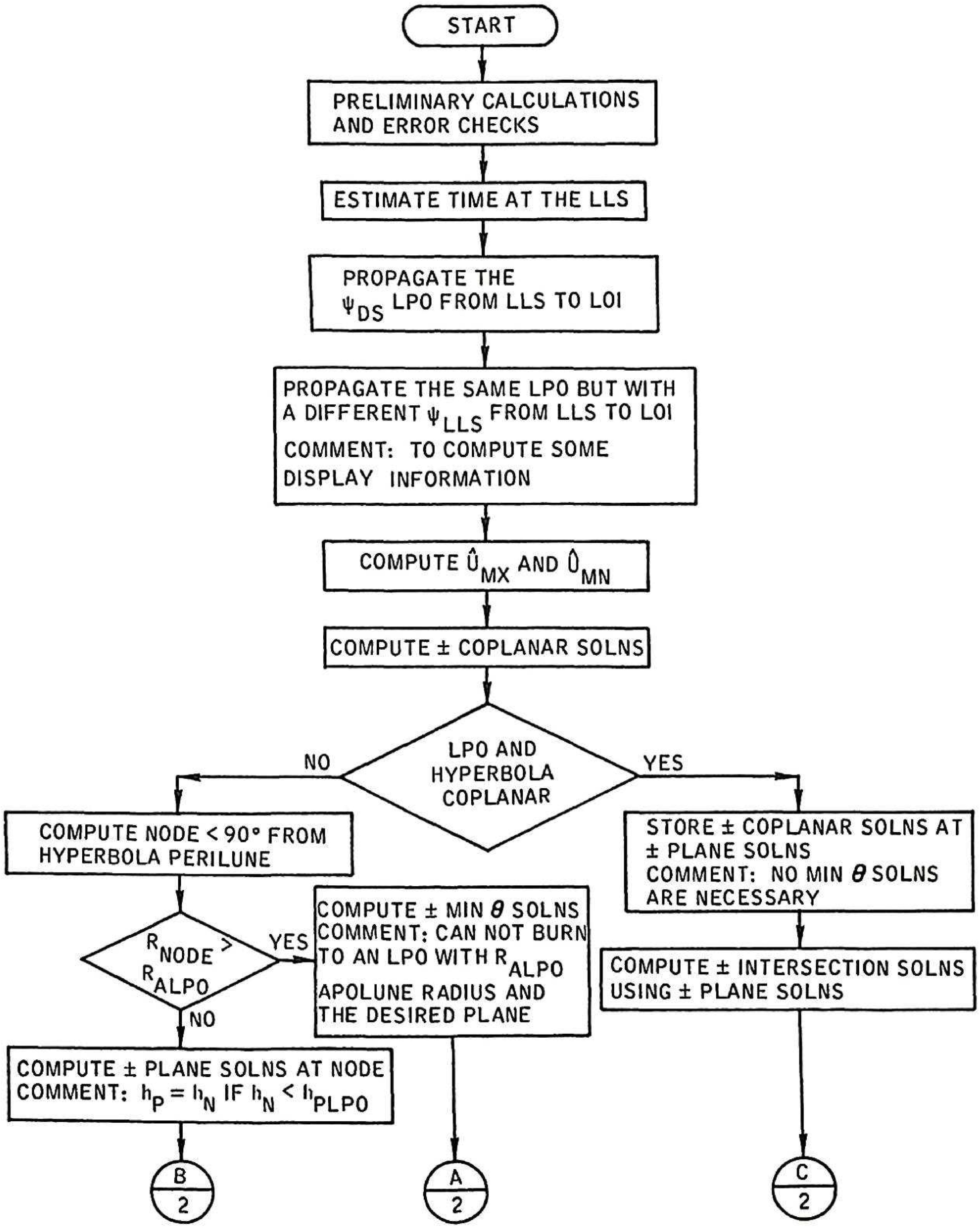
SIGN(x)y	multiply y by ±1, where the sign of the ±1 is the sign of x

Subscripts

+	denotes the positive solution
-	denotes the negative solution

Superscripts

^	denotes a unit vector



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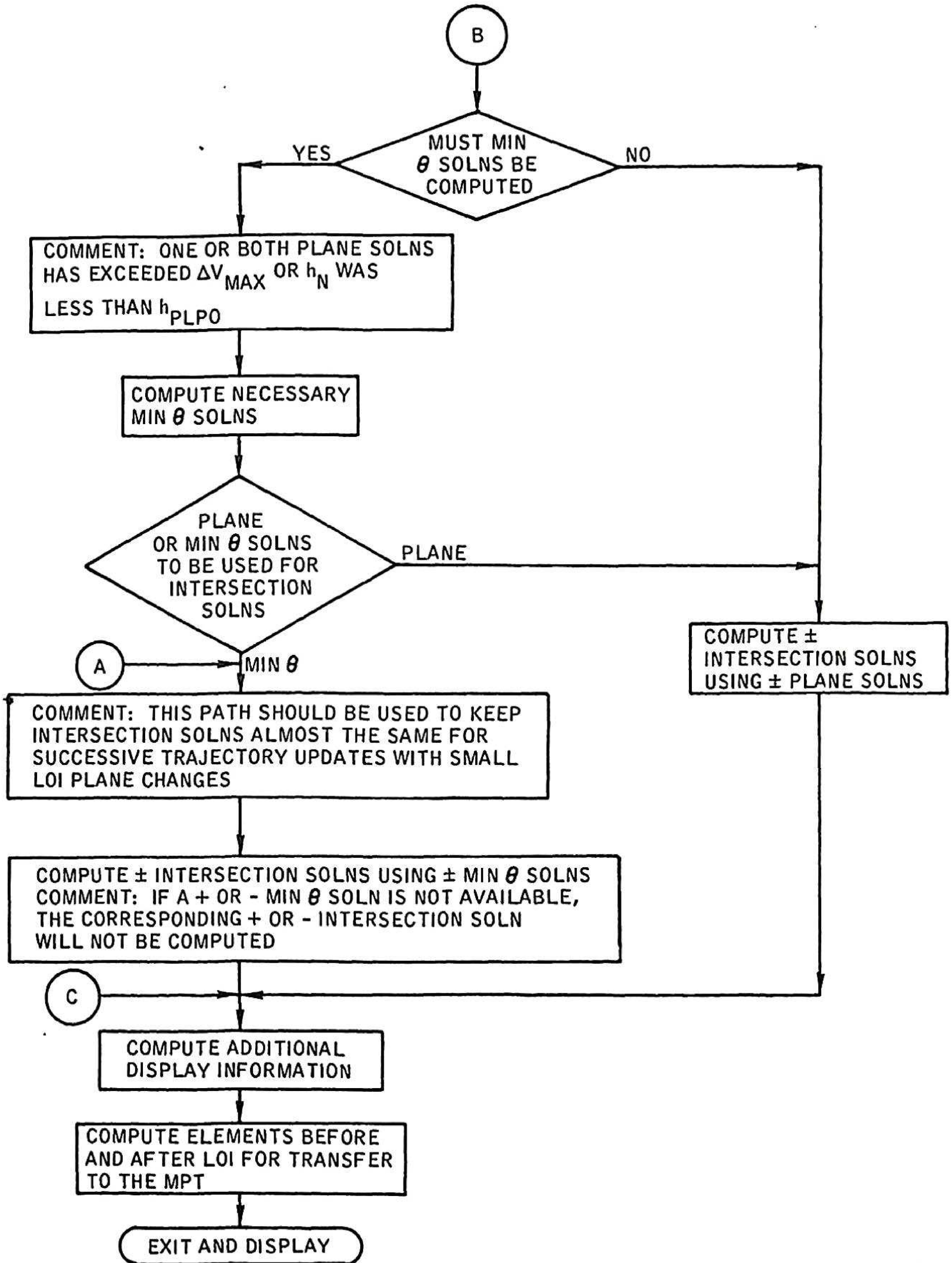
Flow chart 1.- Functional flow.



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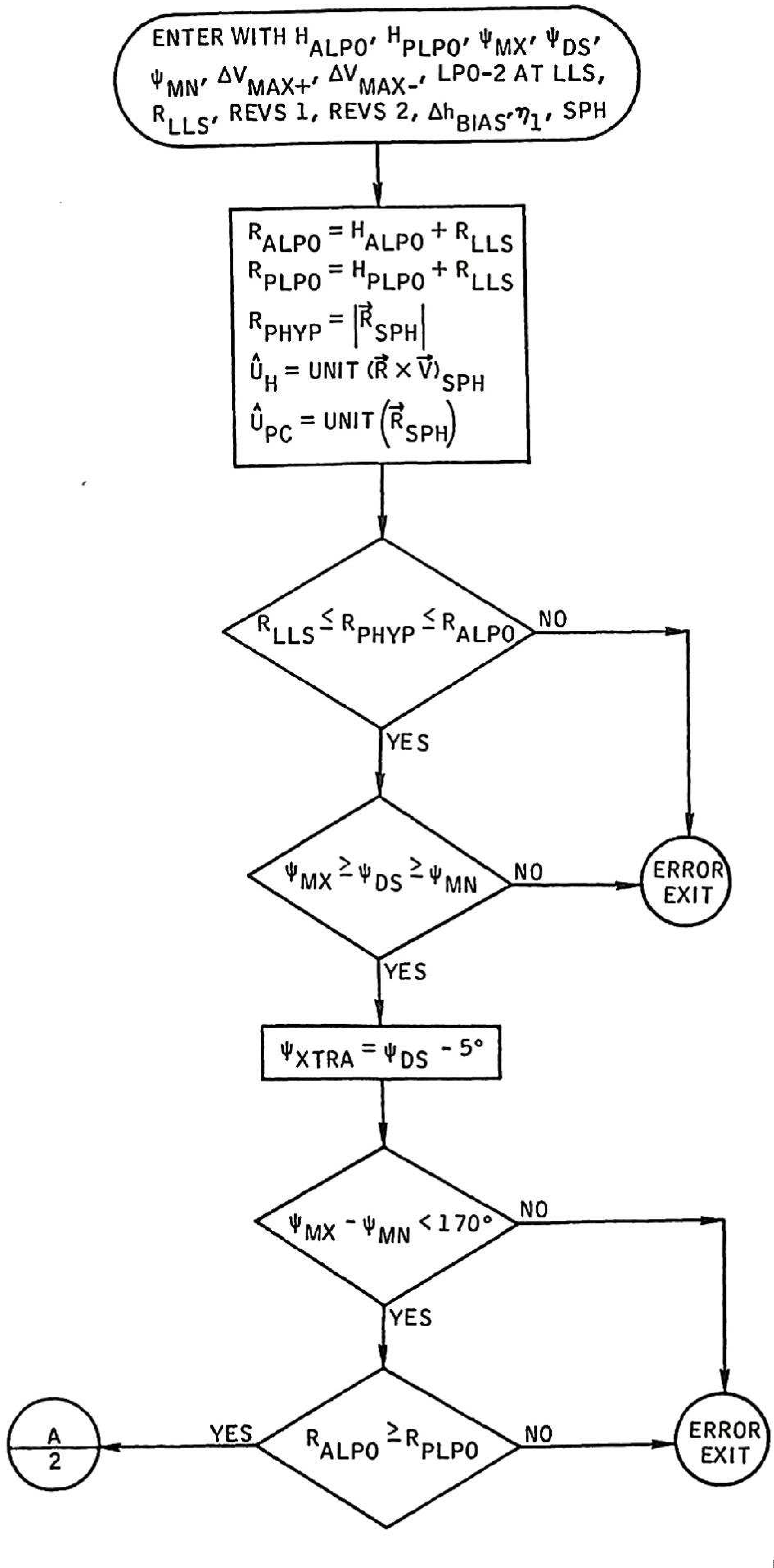
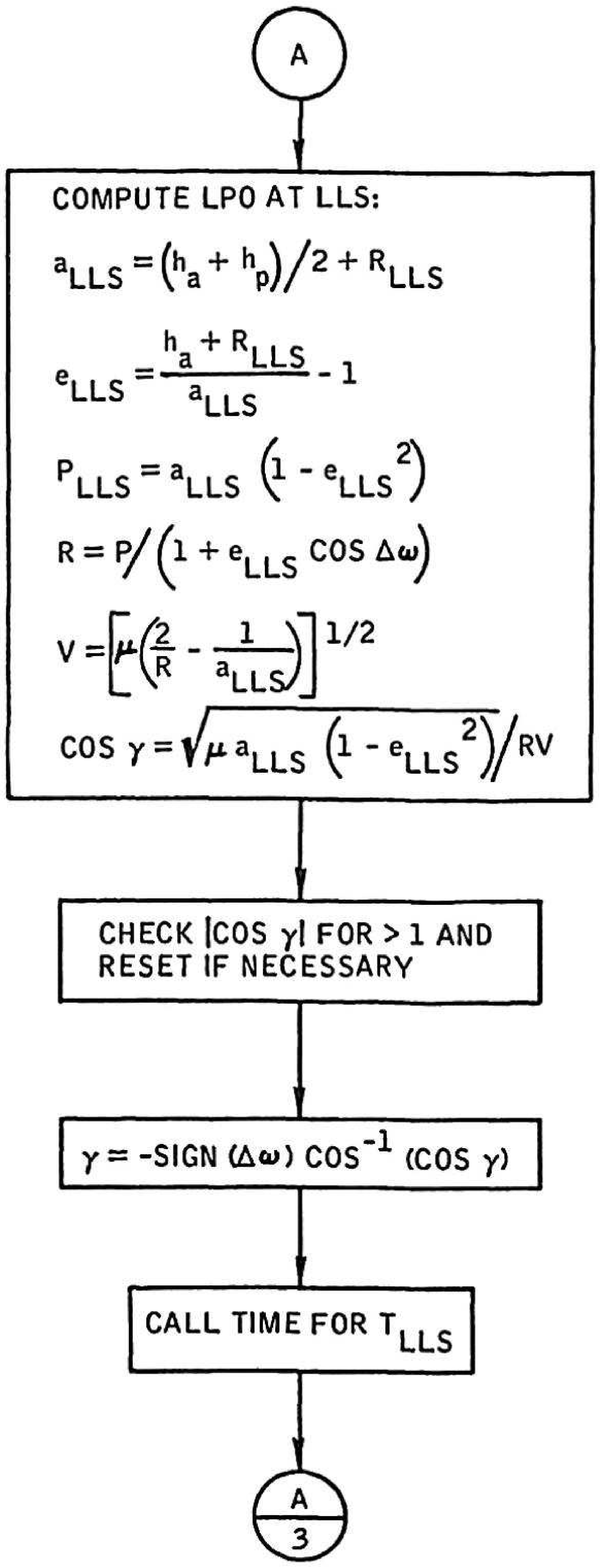
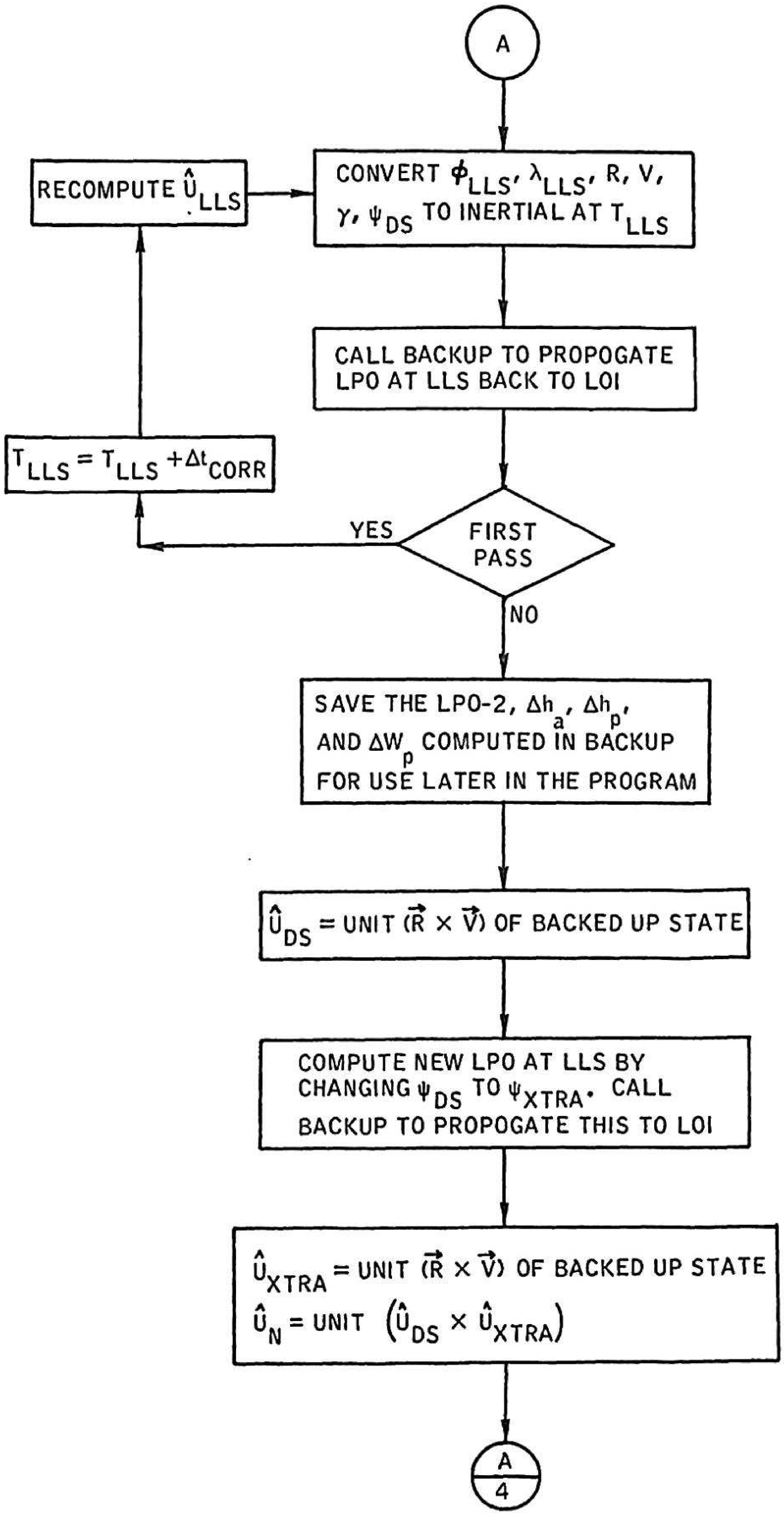
Flow chart 1.- Functional flow - Concluded.



Flow chart 2.- Detailed flow.



Flow chart 2.- Detailed flow - Continued.



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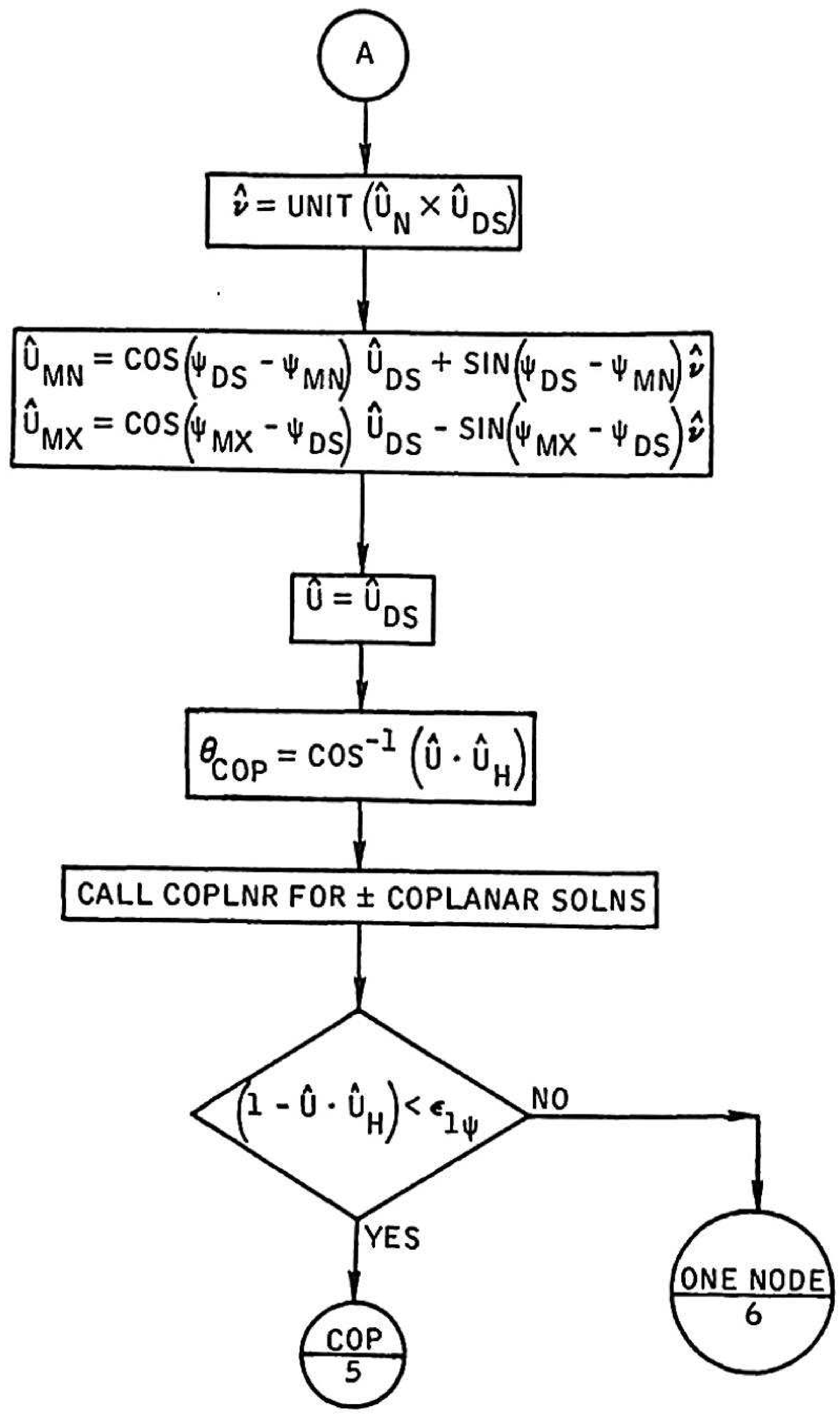
Flow chart 2.- Detailed flow - Continued.



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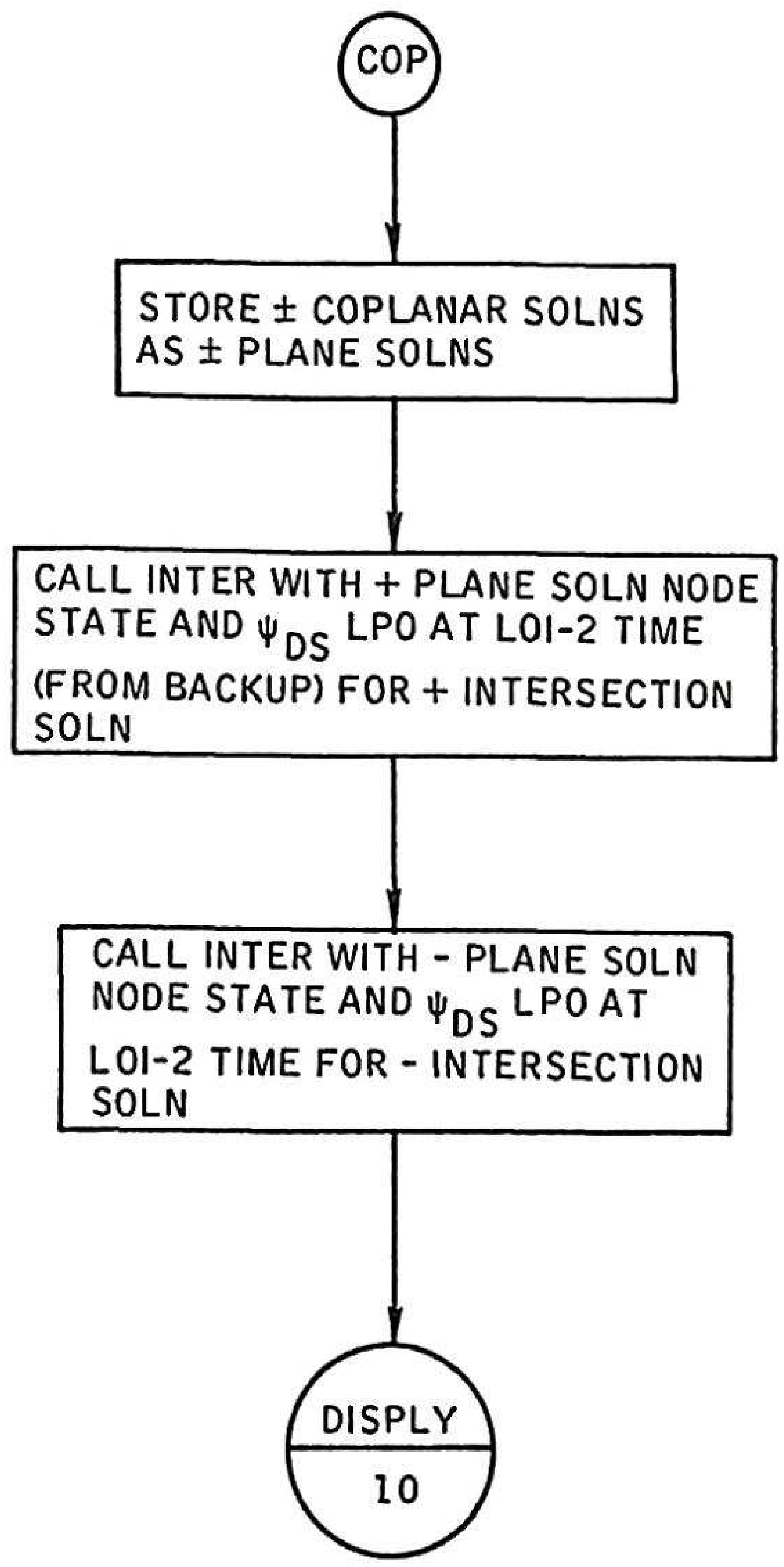
Flow chart 2.- Detailed flow - Continued.



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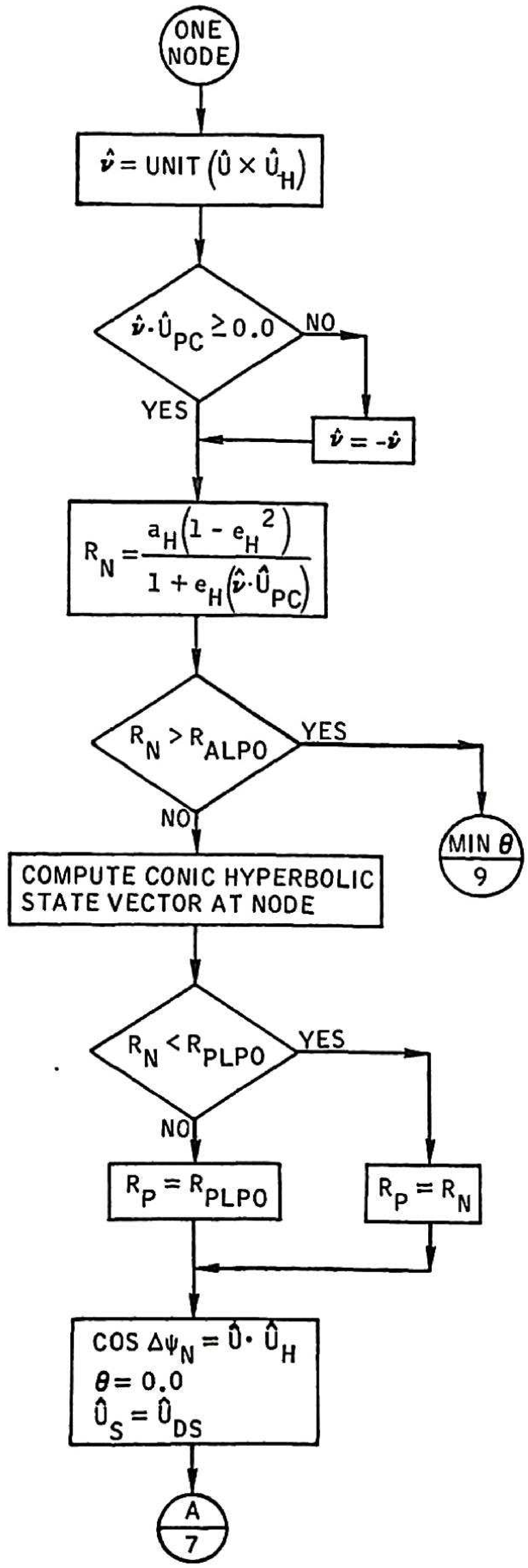
Flow chart 2.- Detailed flow - Continued.



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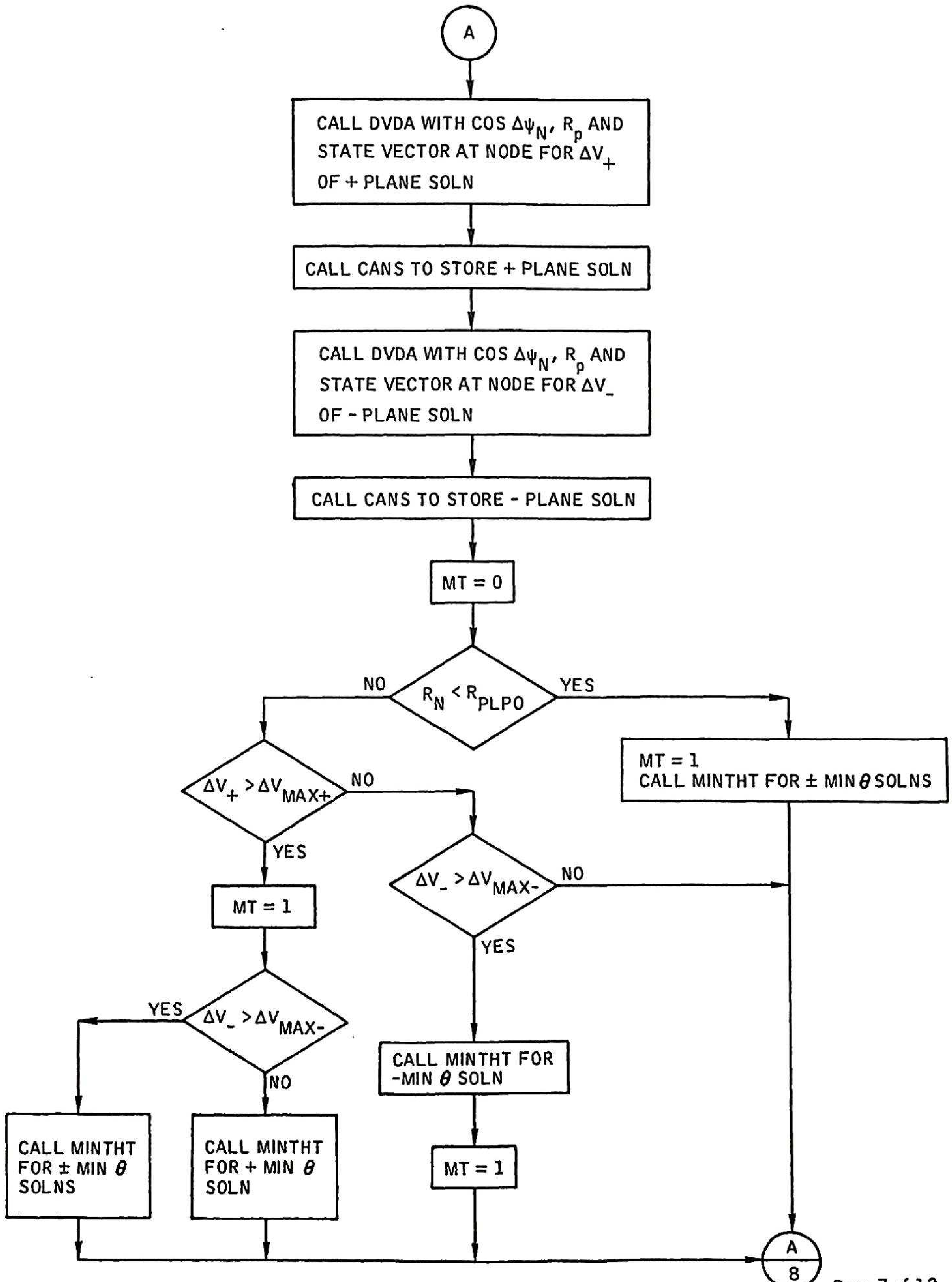
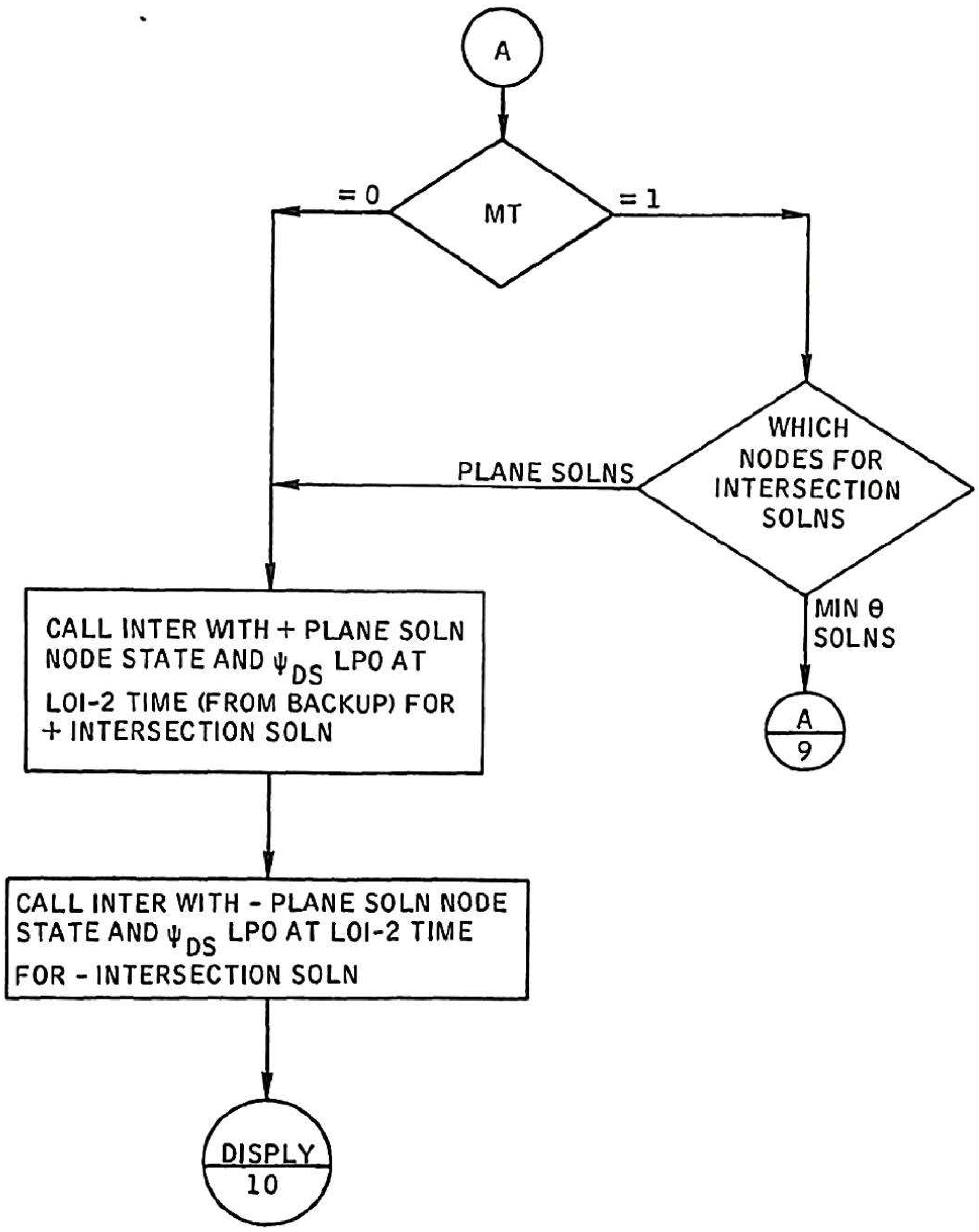


Flow chart 2.- Detailed flow - Continued.



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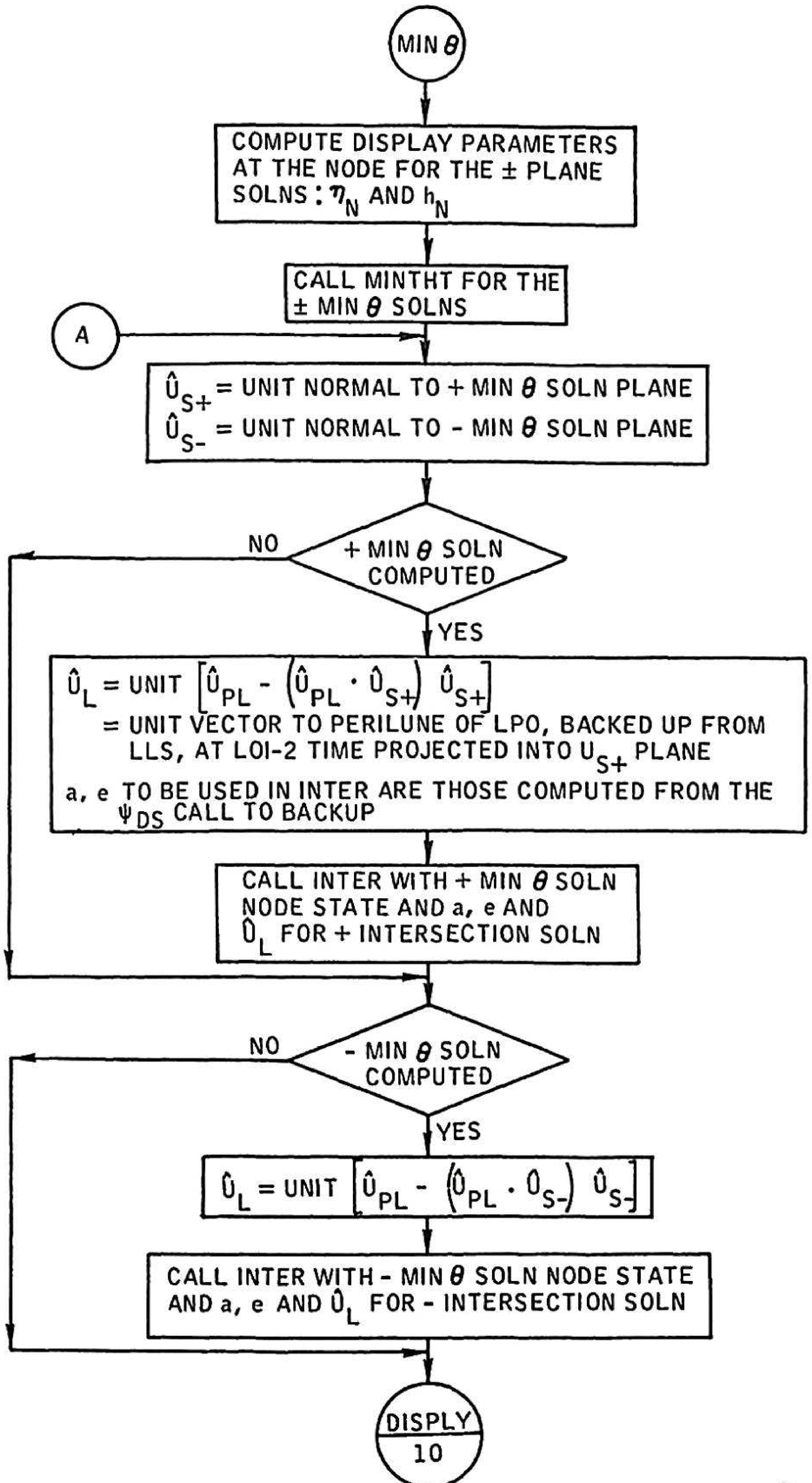
Flow chart 2.- Detailed flow - Continued.



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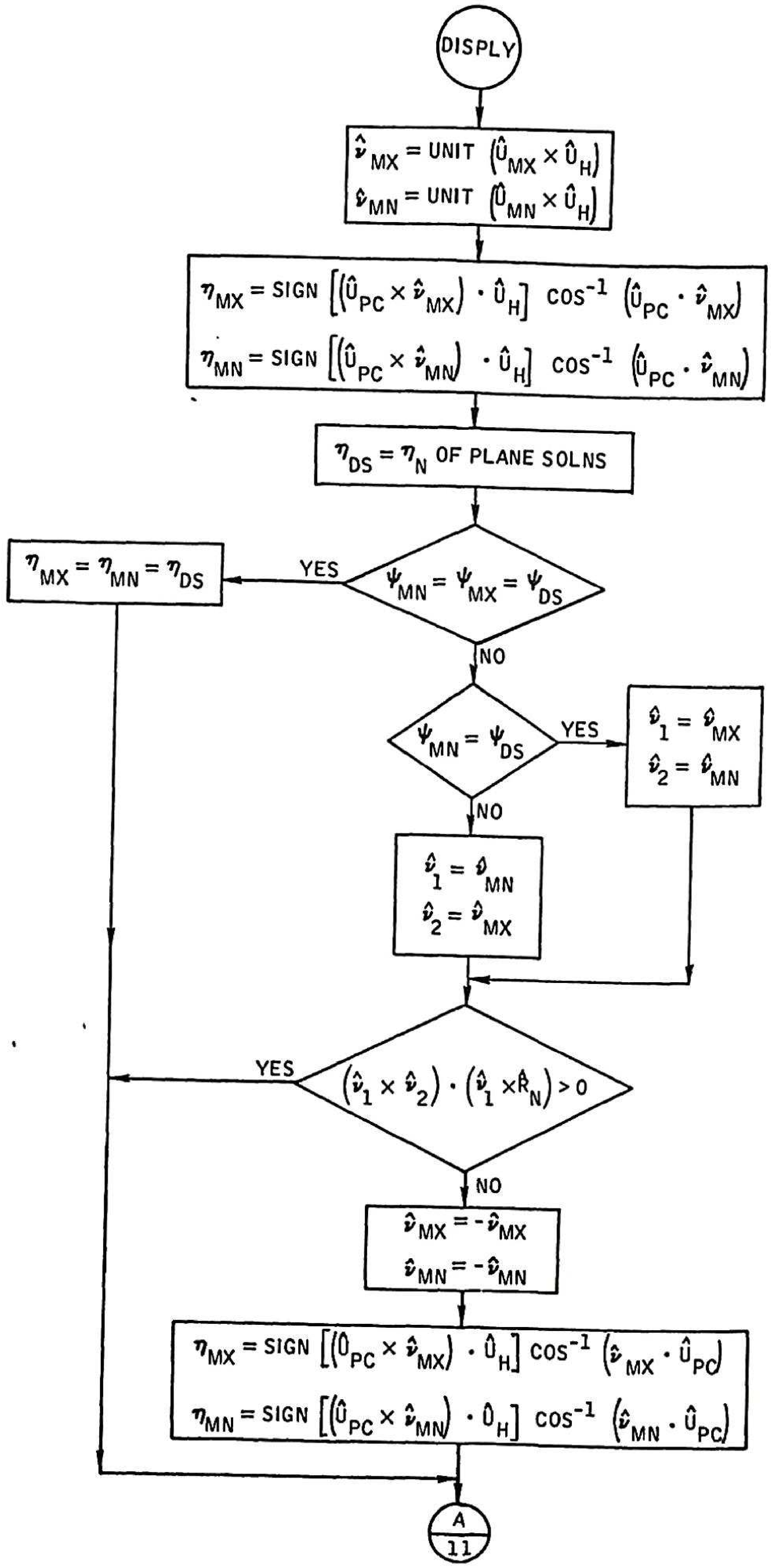
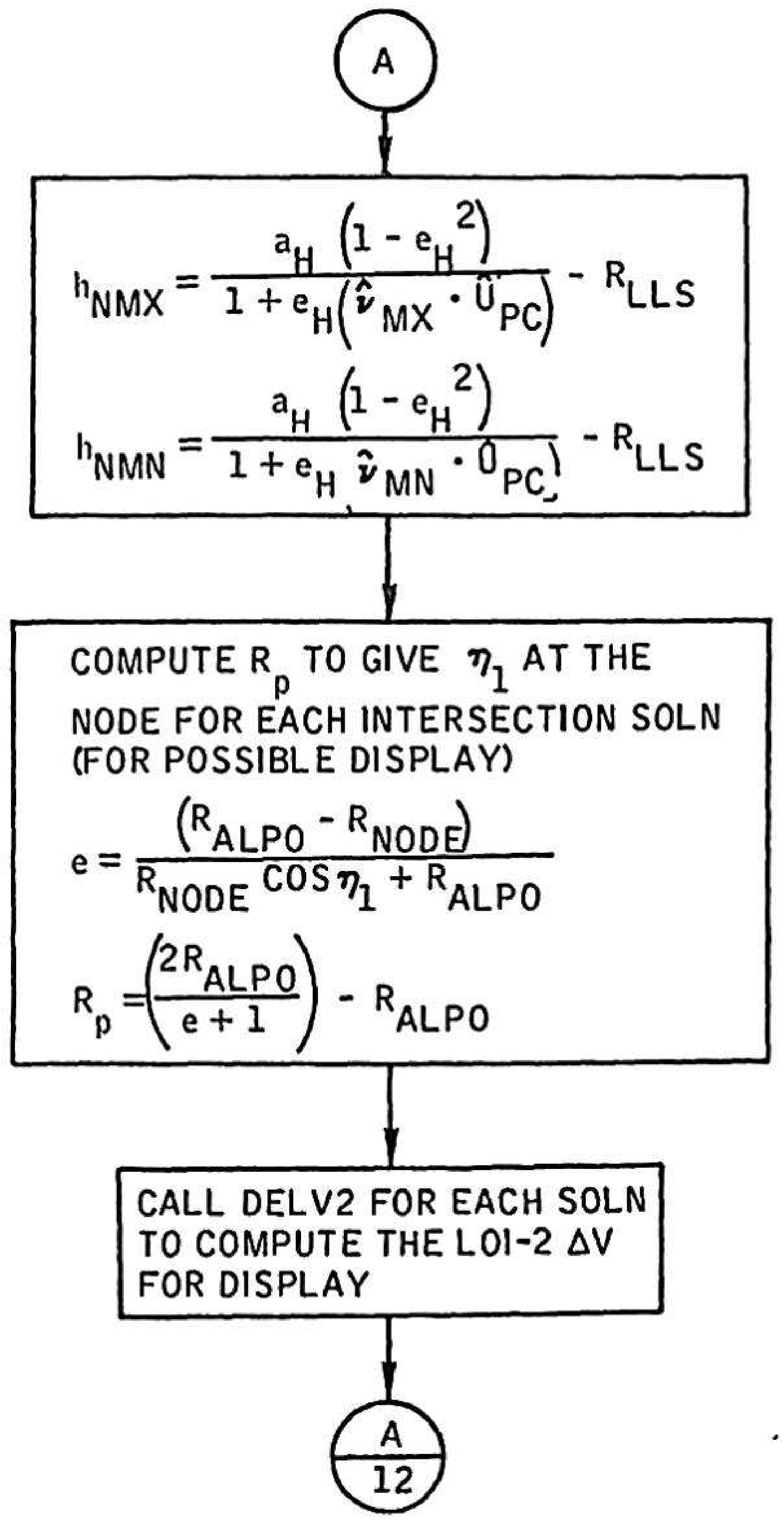


Flow chart 2.- Detailed flow - Continued.



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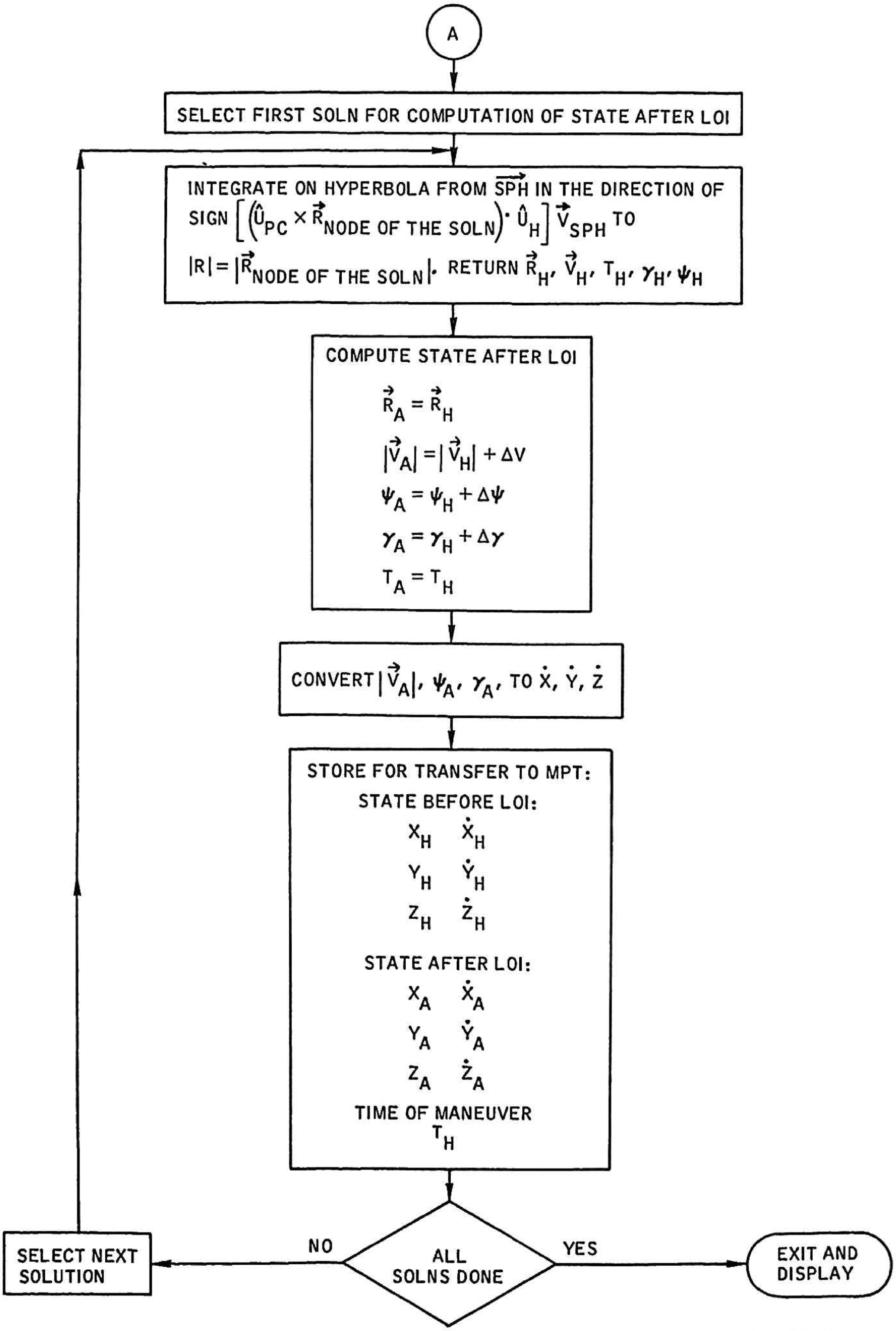
Flow chart 2.- Detailed flow - Continued.



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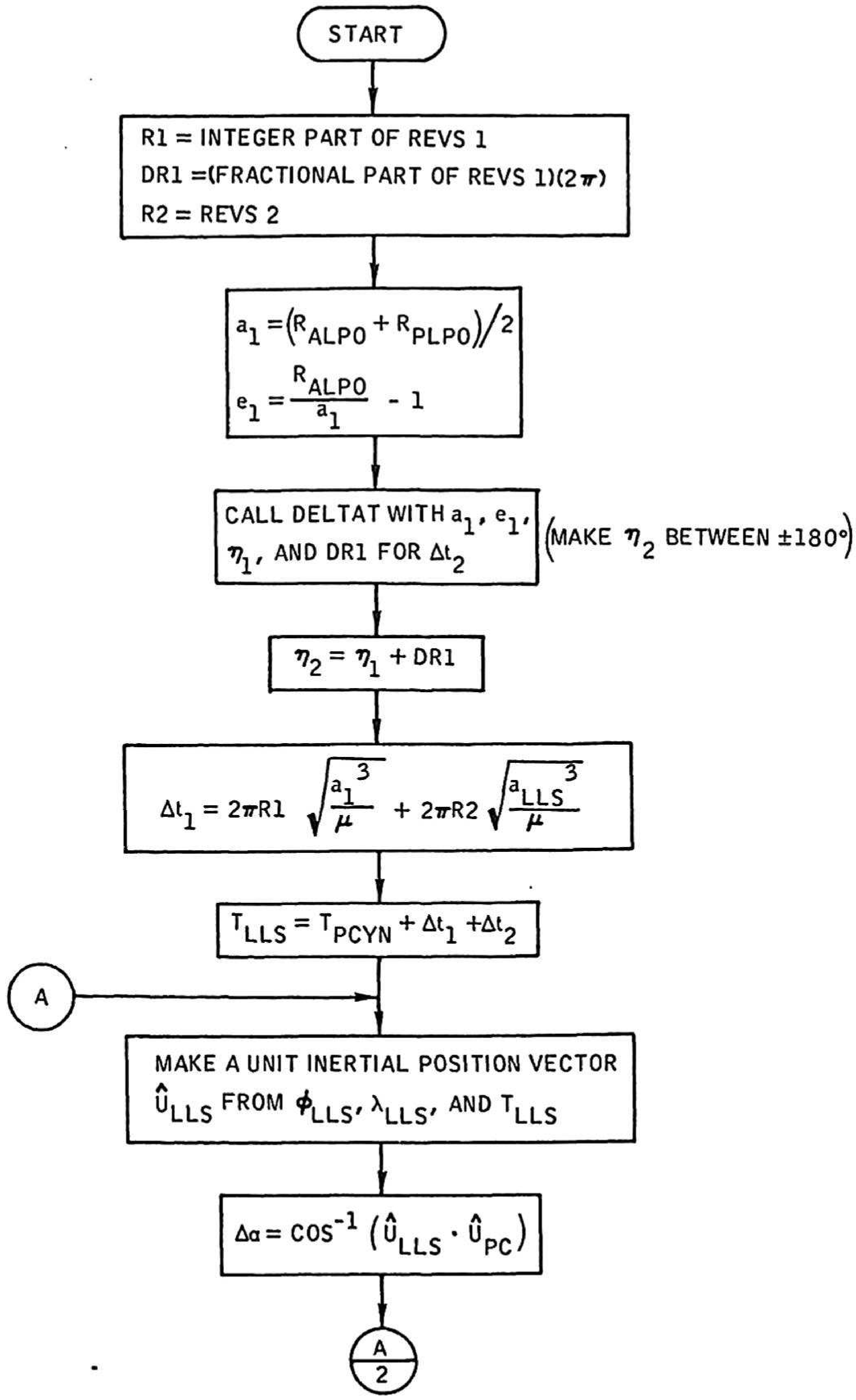
Flow chart 2.- Detailed flow - Concluded.



PURPOSE: TO ESTIMATE THE TIME AT THE LLS.
COMMENT: CONIC ESTIMATE.

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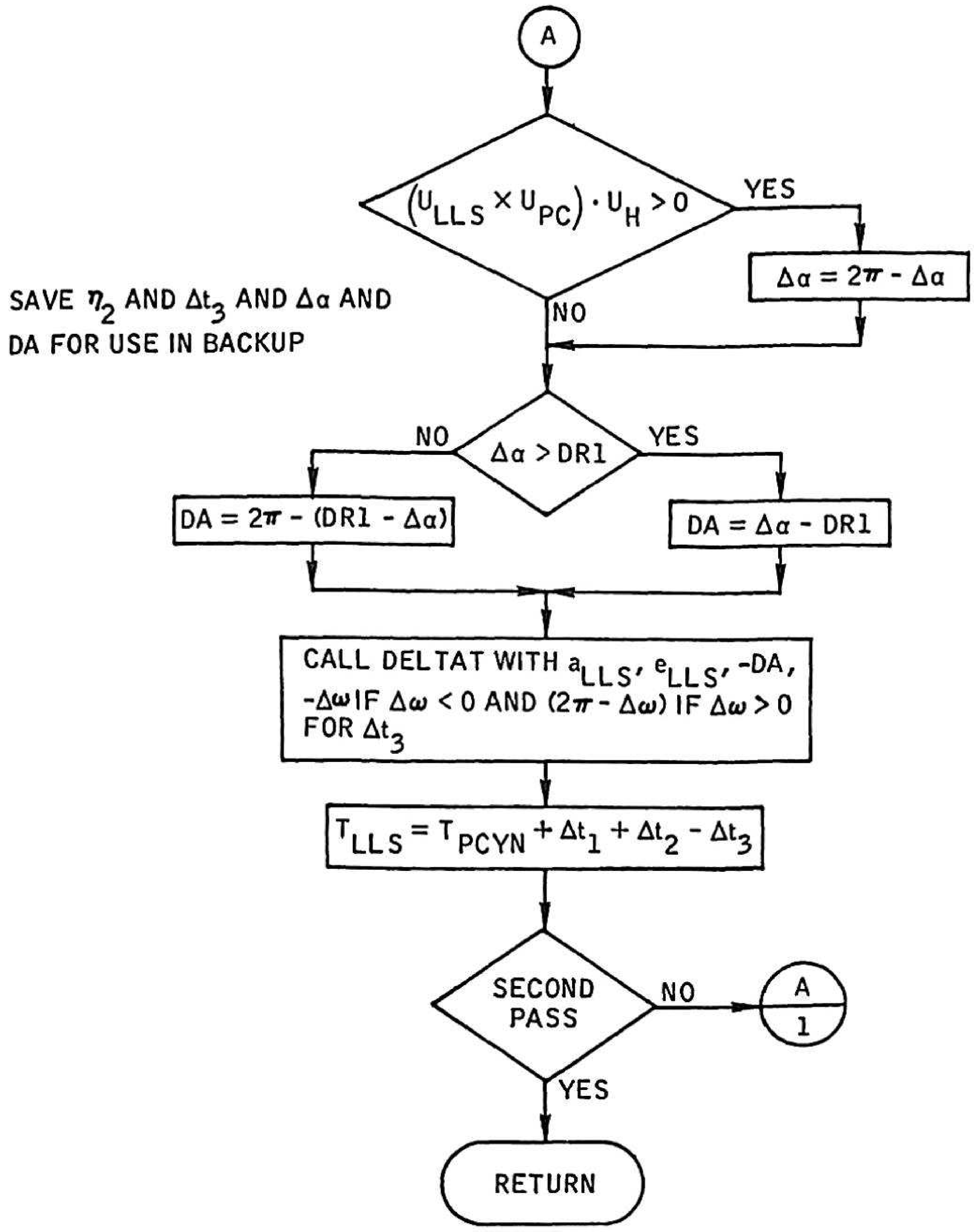
Flow chart 3.- Subroutine TIME.



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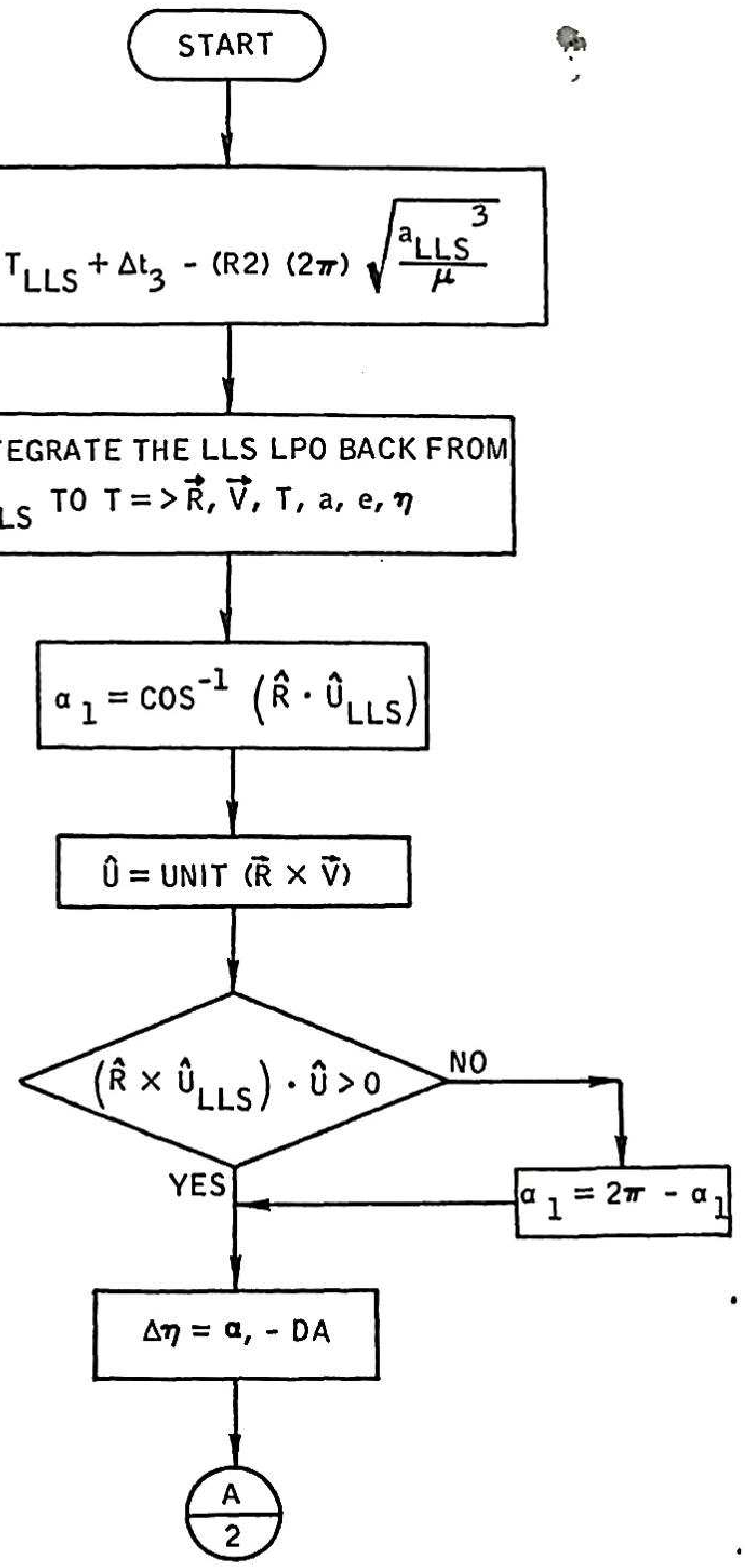
Flow chart 3.- Subroutine TIME - Concluded.



PURPOSE: TO BACKUP AN INERTIAL LPO AT THE LLS THROUGH REVS 1 AND REVS 2 TO LOI, PROPOGATING IN AN APPROXIMATION TO THE INITIAL LPO AND USING THE INTEGRATOR.

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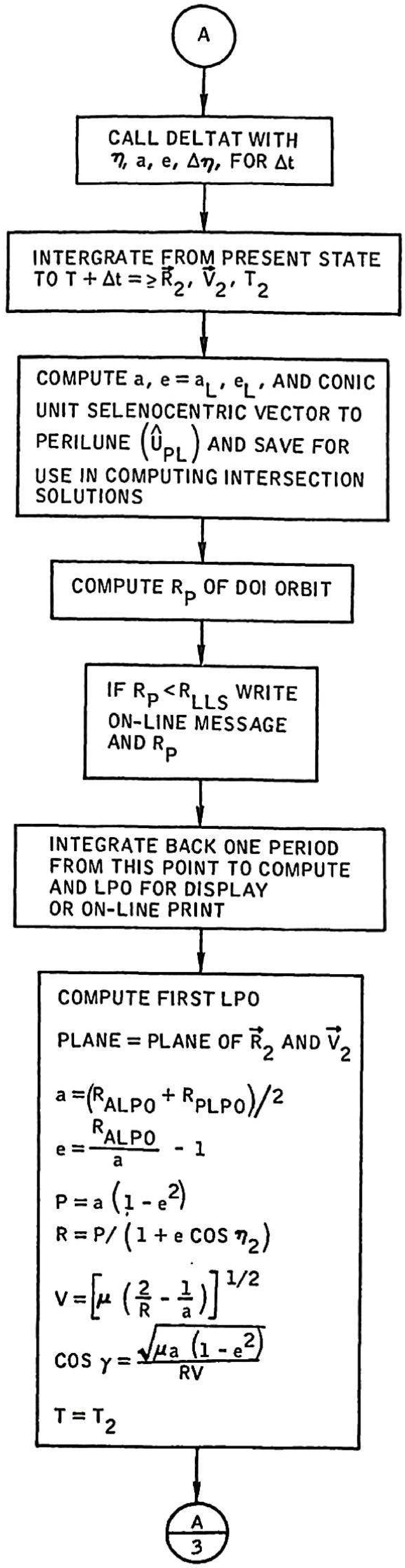
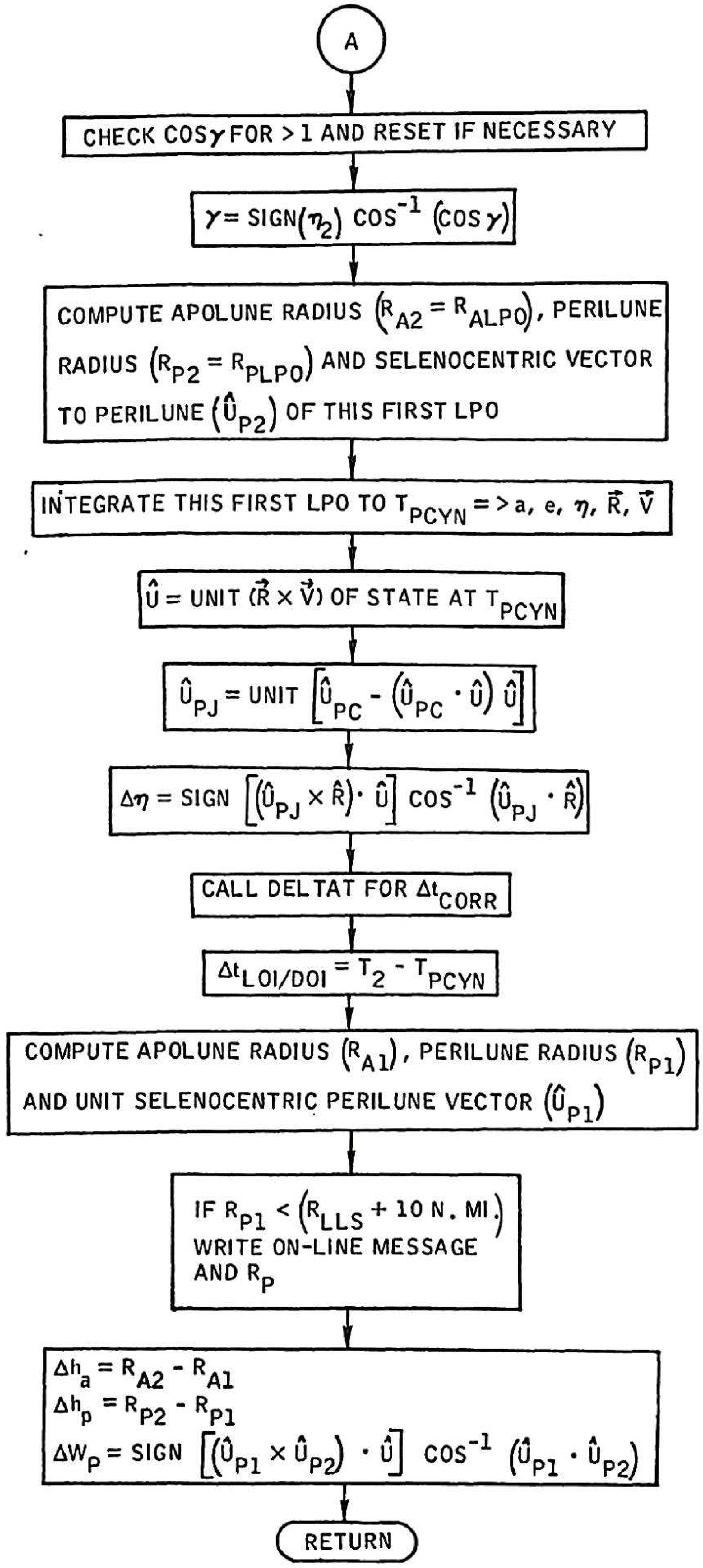
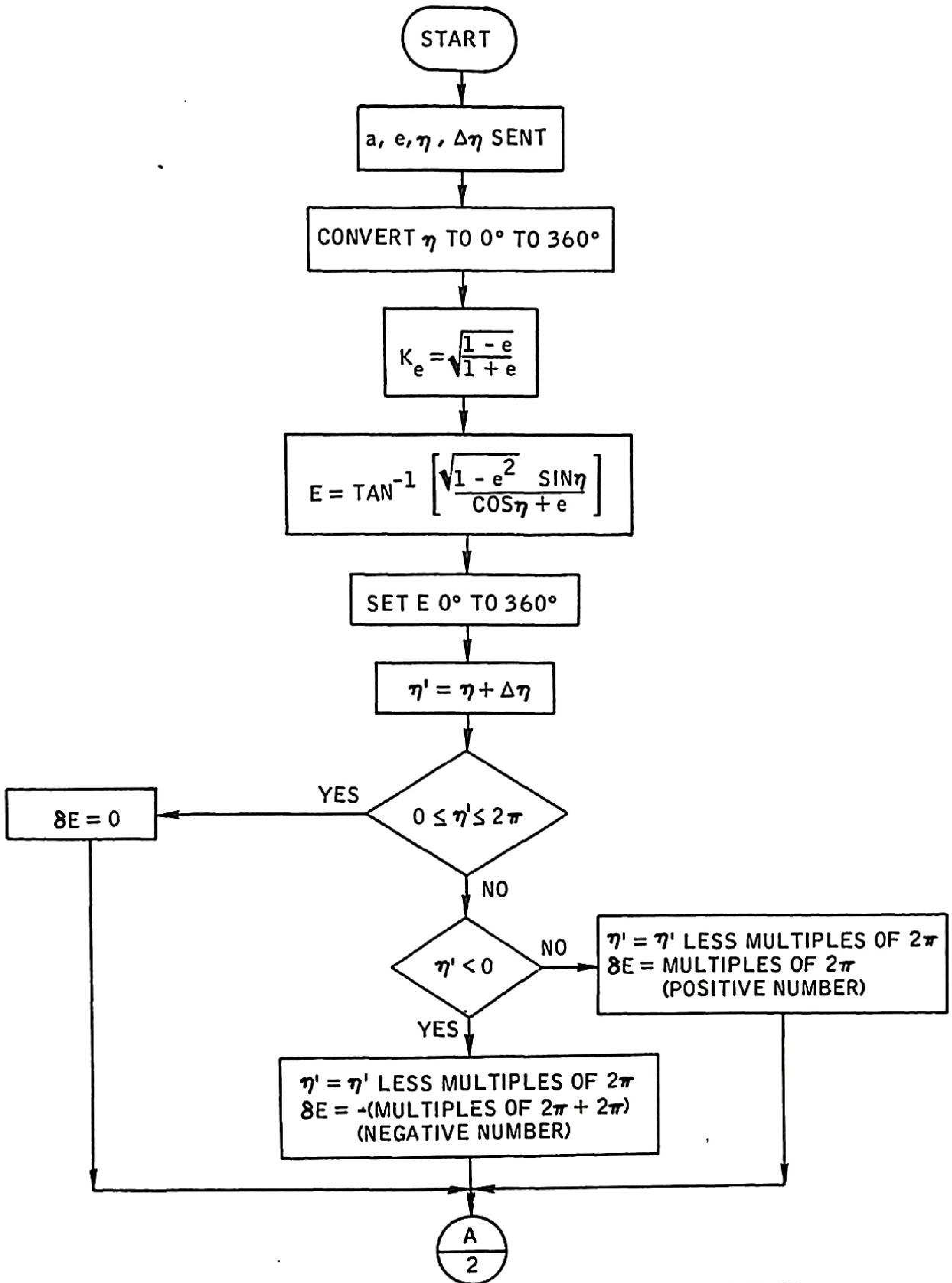
Flow chart 4.- Subroutine BACKUP.



Flow chart 4.- Subroutine BACKUP - Continued.

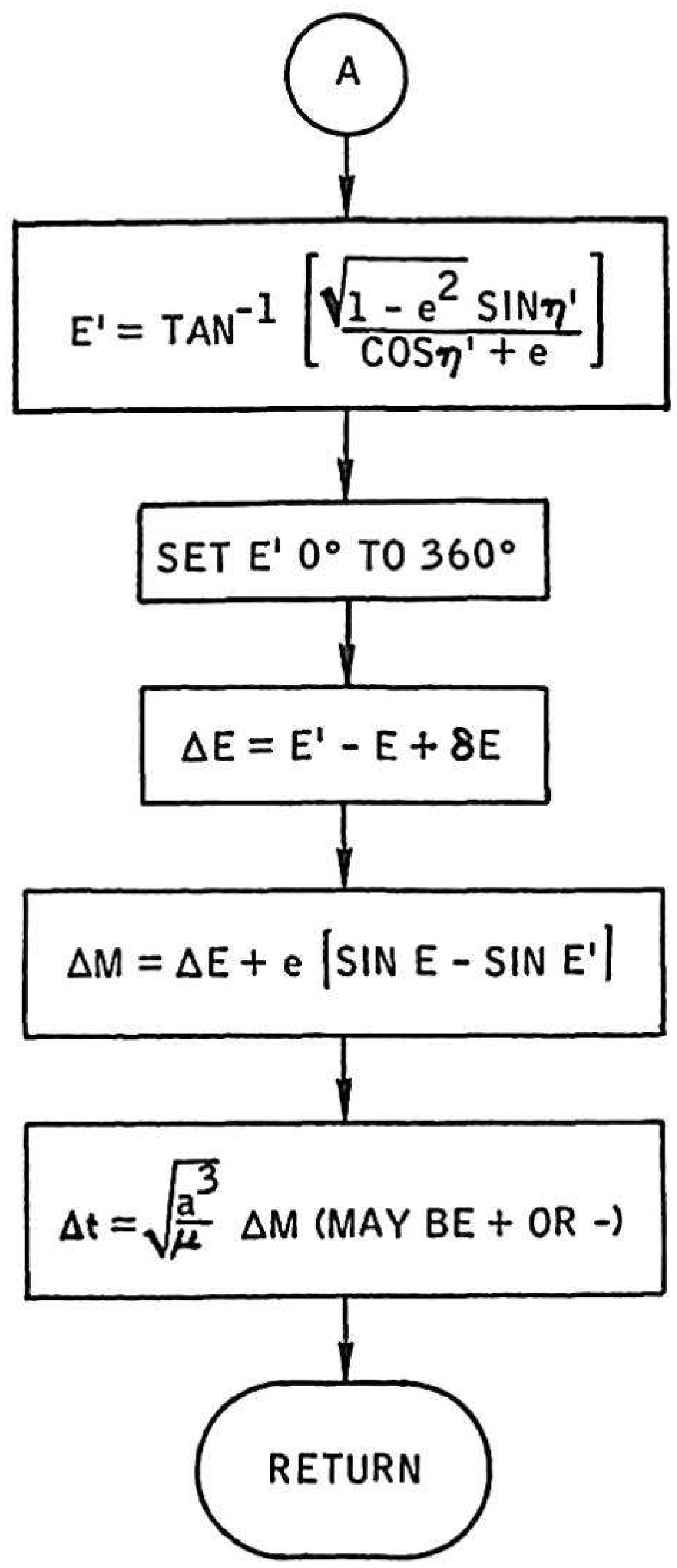


Flow chart 4.- Subroutine BACKUP - Concluded.



PURPOSE: TO COMPUTE A CONIC Δt TO GO FROM AN INPUT TRUE ANOMALY IN AN ELLIPSE THROUGH A DELTA TRUE ANOMALY

Flow chart 5.- Subroutine DELTAT.



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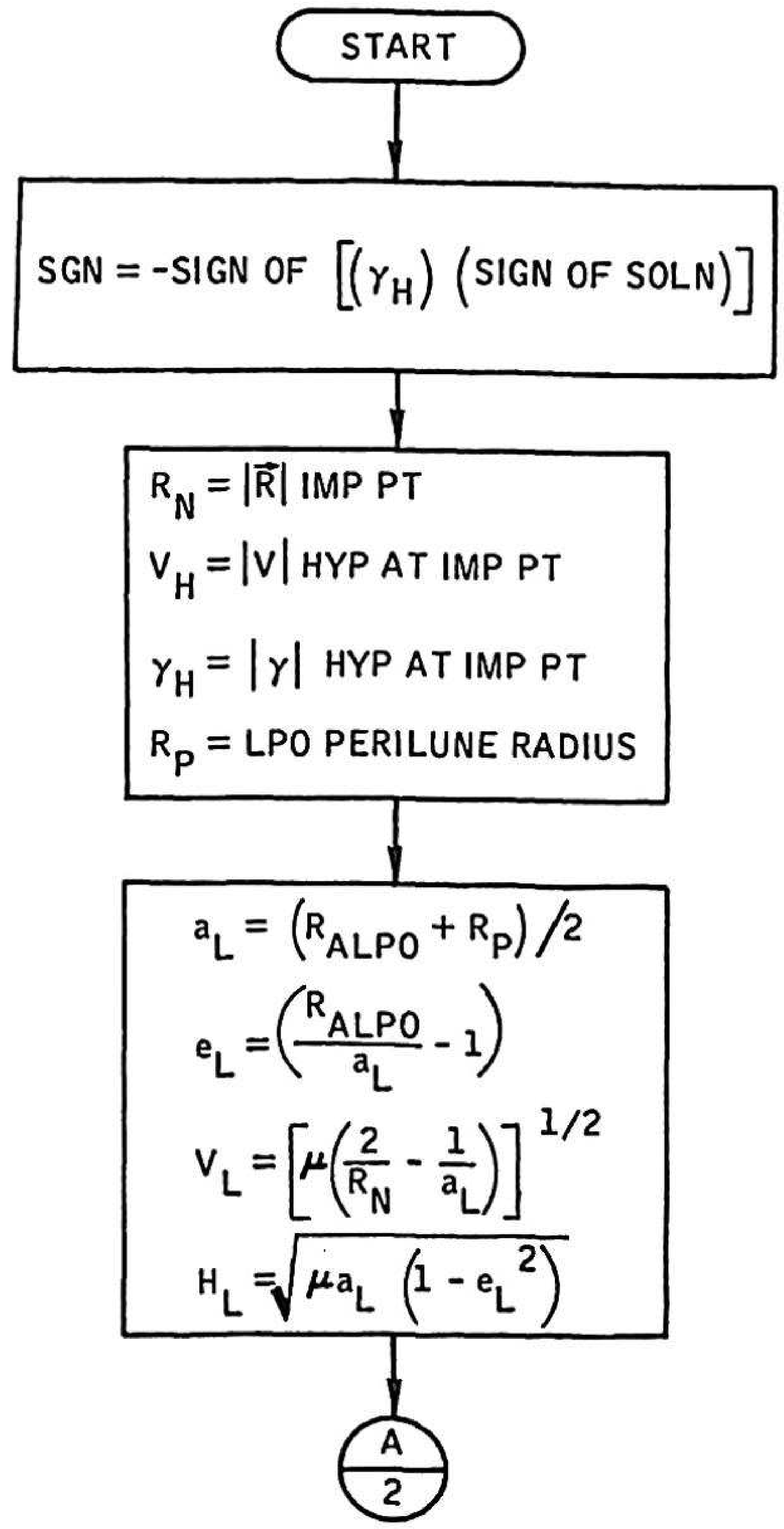
Flow chart 5.- Subroutine DELTAT - Concluded.



PURPOSE: TO COMPUTE A MANEUVER ΔV OR THE COSINE OF THE ALLOWABLE PLANE CHANGE WITHIN A GIVEN ΔV

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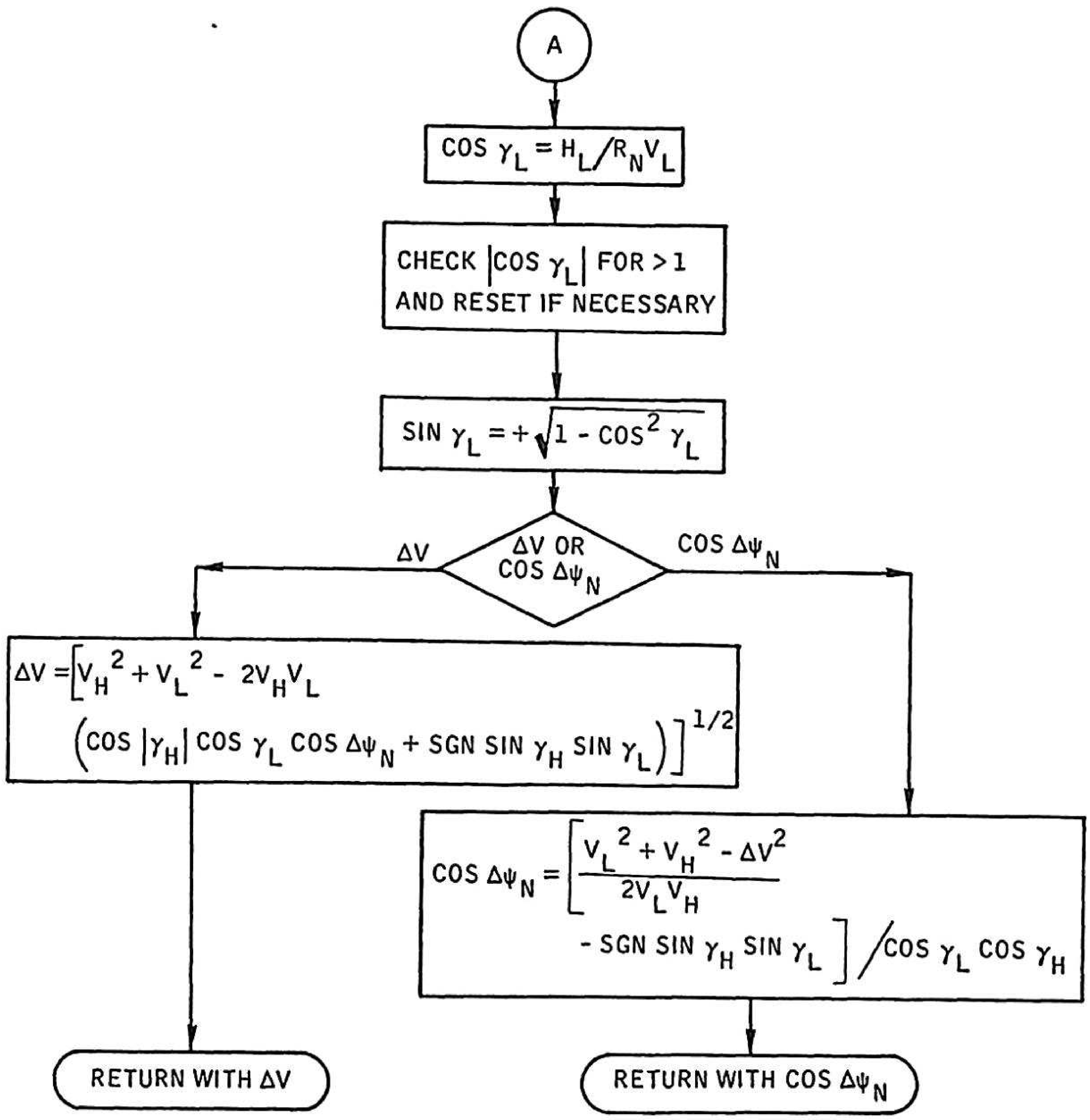
Flow chart 6.- Subroutine DVDA.



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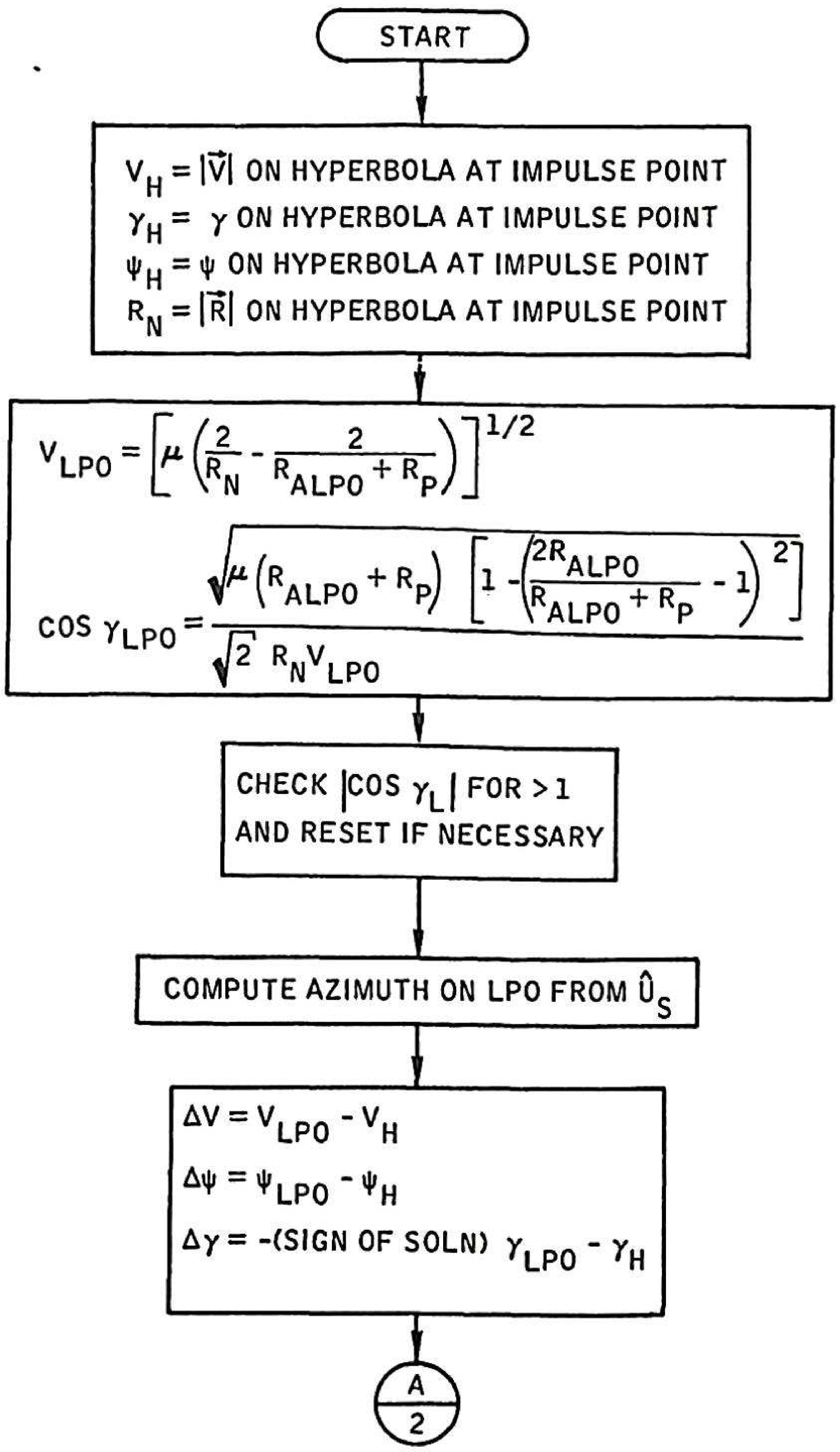
Flow chart 6.- Subroutine DVDA - Concluded.



PURPOSE: TO COMPUTE $\Delta|V|$, $\Delta\gamma$, $\Delta\psi$ OF THE SOLUTION AND CERTAIN DISPLAY QUANTITIES

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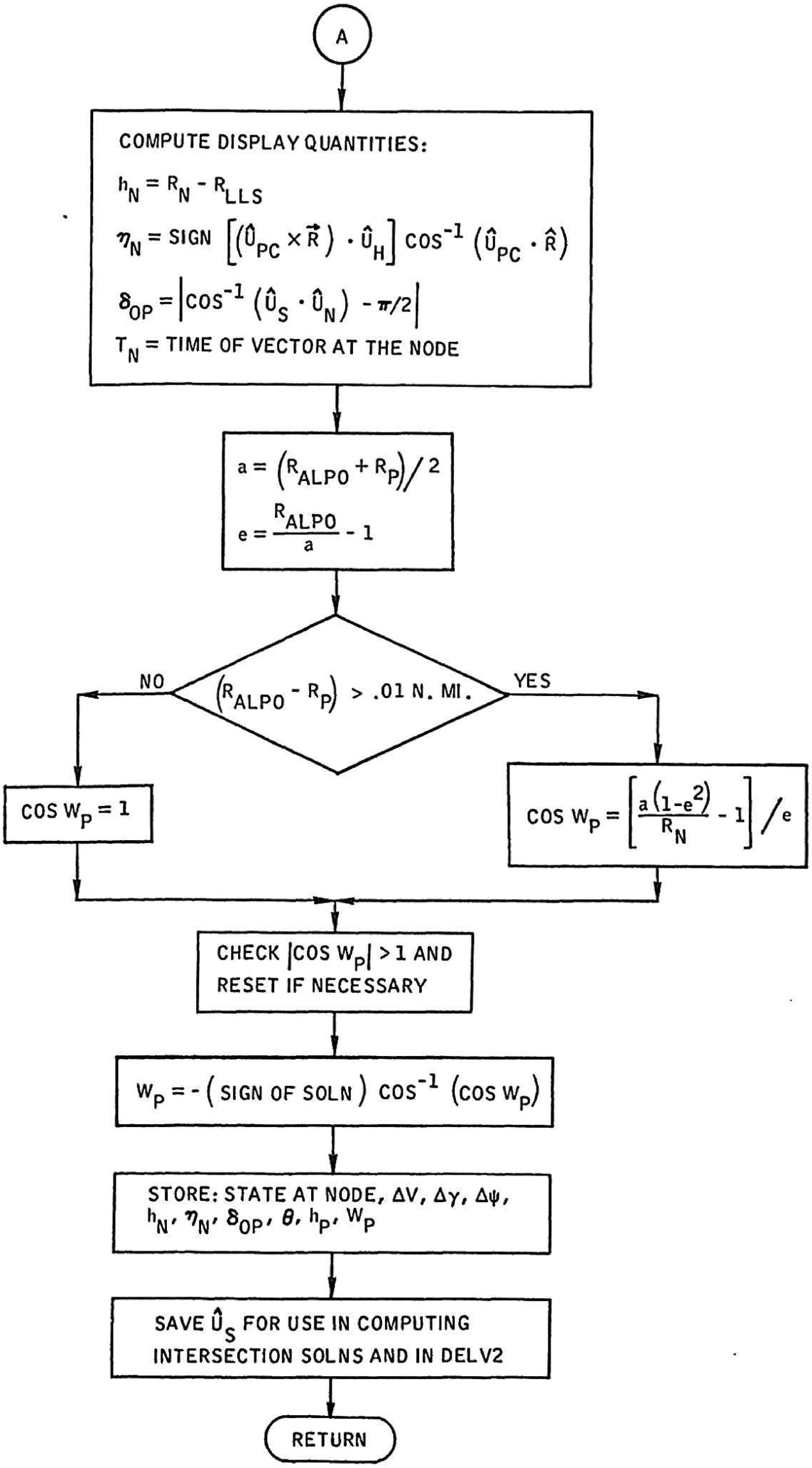
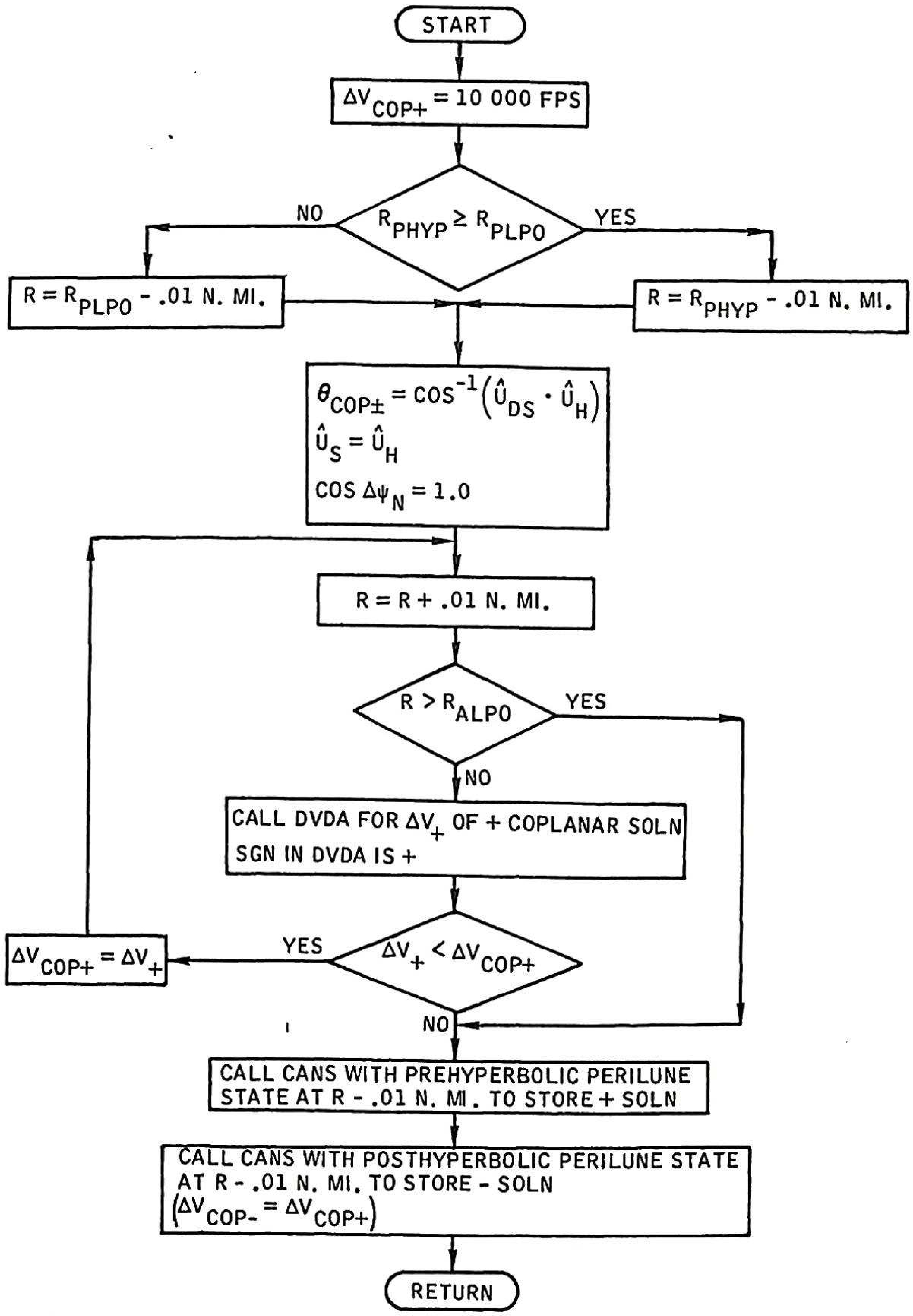
Flow chart 7.- Subroutine CANS.


A
COMPUTE DISPLAY QUANTITIES:
$h_N = R_N - R_{LLS}$
$\eta_N = \text{SIGN}\left[(\hat{U}_{PC} \times \vec{R}) \cdot \hat{U}_H\right] \cos^{-1}(\hat{U}_{PC} \cdot \hat{R})$
$\delta_{OP} = \left|\cos^{-1}(\hat{U}_S \cdot \hat{U}_N) - \pi/2\right|$
T_N = TIME OF VECTOR AT THE NODE
$a = (R_{ALPO} + R_P)/2$
$e = \frac{R_{ALPO}}{a} - 1$
$(R_{ALPO} - R_P) > .01$ N. MI.
NO
YES
$\cos W_P = 1$
$\cos W_P = \left[\frac{a(1-e^2)}{R_N} - 1\right] / e$
CHECK $|\cos W_P| > 1$ AND RESET IF NECESSARY
$W_P = -(\text{SIGN OF SOLN}) \cos^{-1}(\cos W_P)$
STORE: STATE AT NODE, ΔV, $\Delta\gamma$, $\Delta\psi$, h_N, η_N, δ_{OP}, θ, h_P, W_P
SAVE $\hat{U}_S$ FOR USE IN COMPUTING INTERSECTION SOLNS AND IN DELV2
RETURN



PURPOSE: TO COMPUTE ± COPLANAR SOLNS

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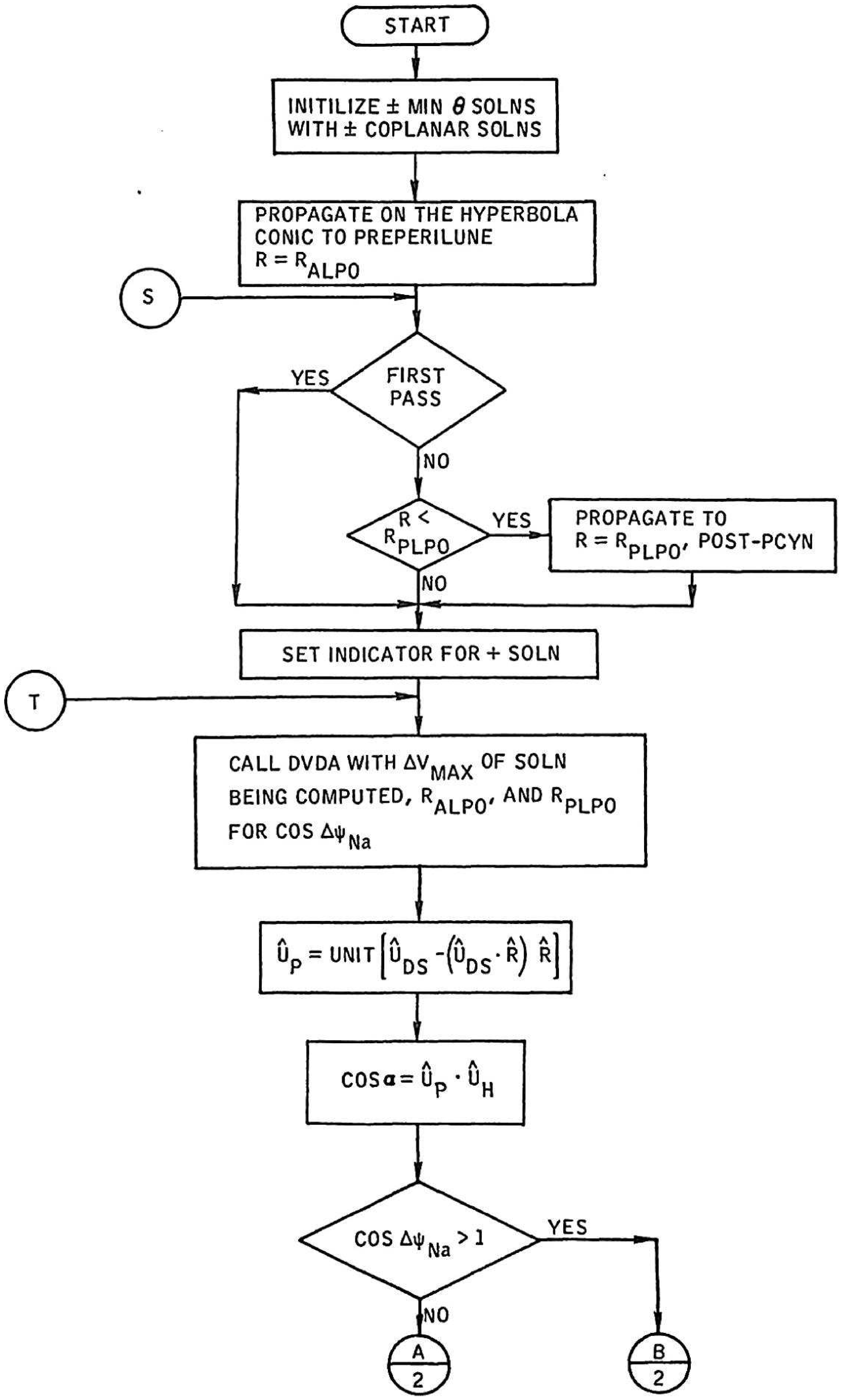
Flow chart 8.- Subroutine COPLNR.



PURPOSE: TO COMPUTE + AND - MINIMUM θ SOLNS

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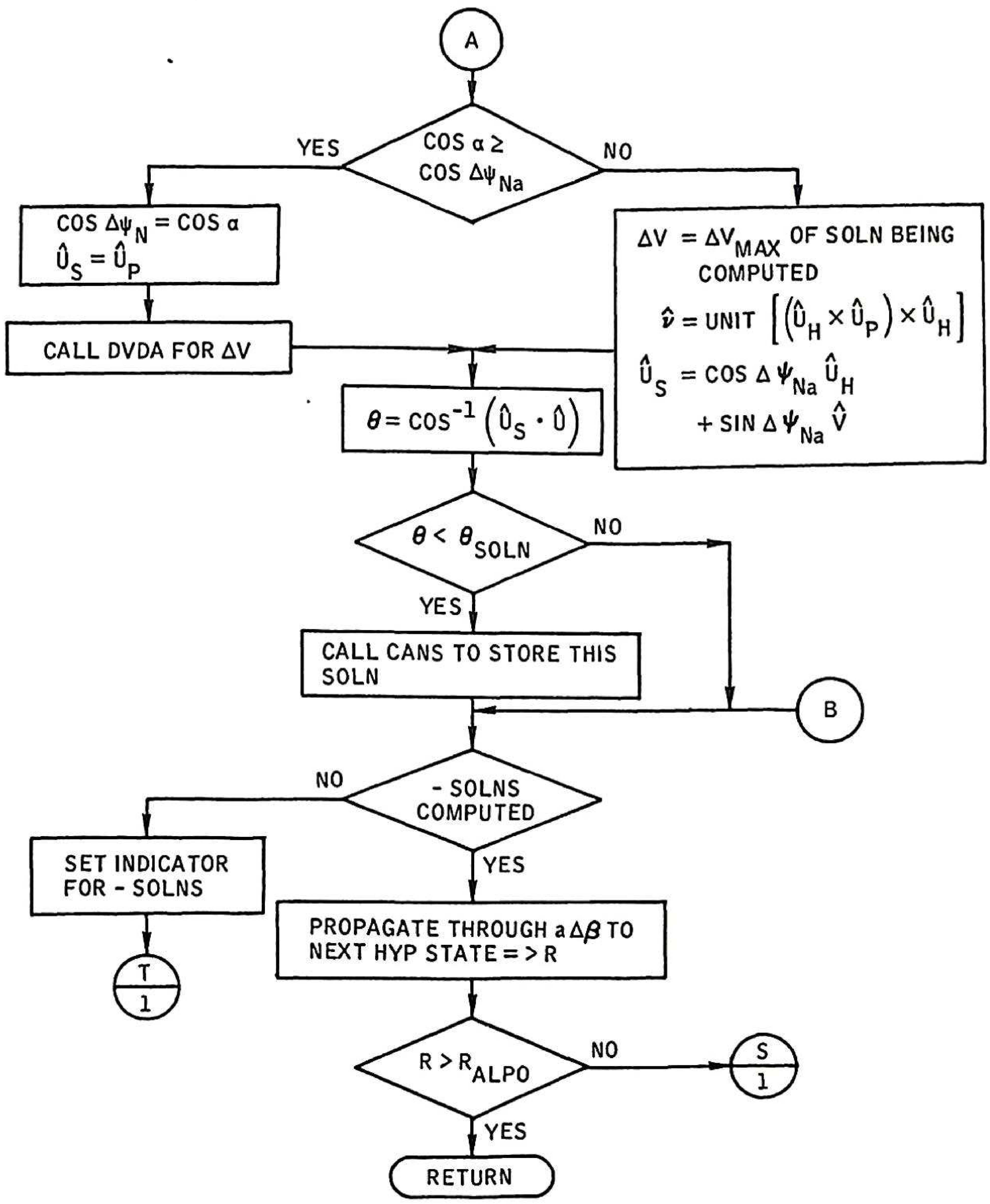
Flow chart 9.- Subroutine MINTHT.



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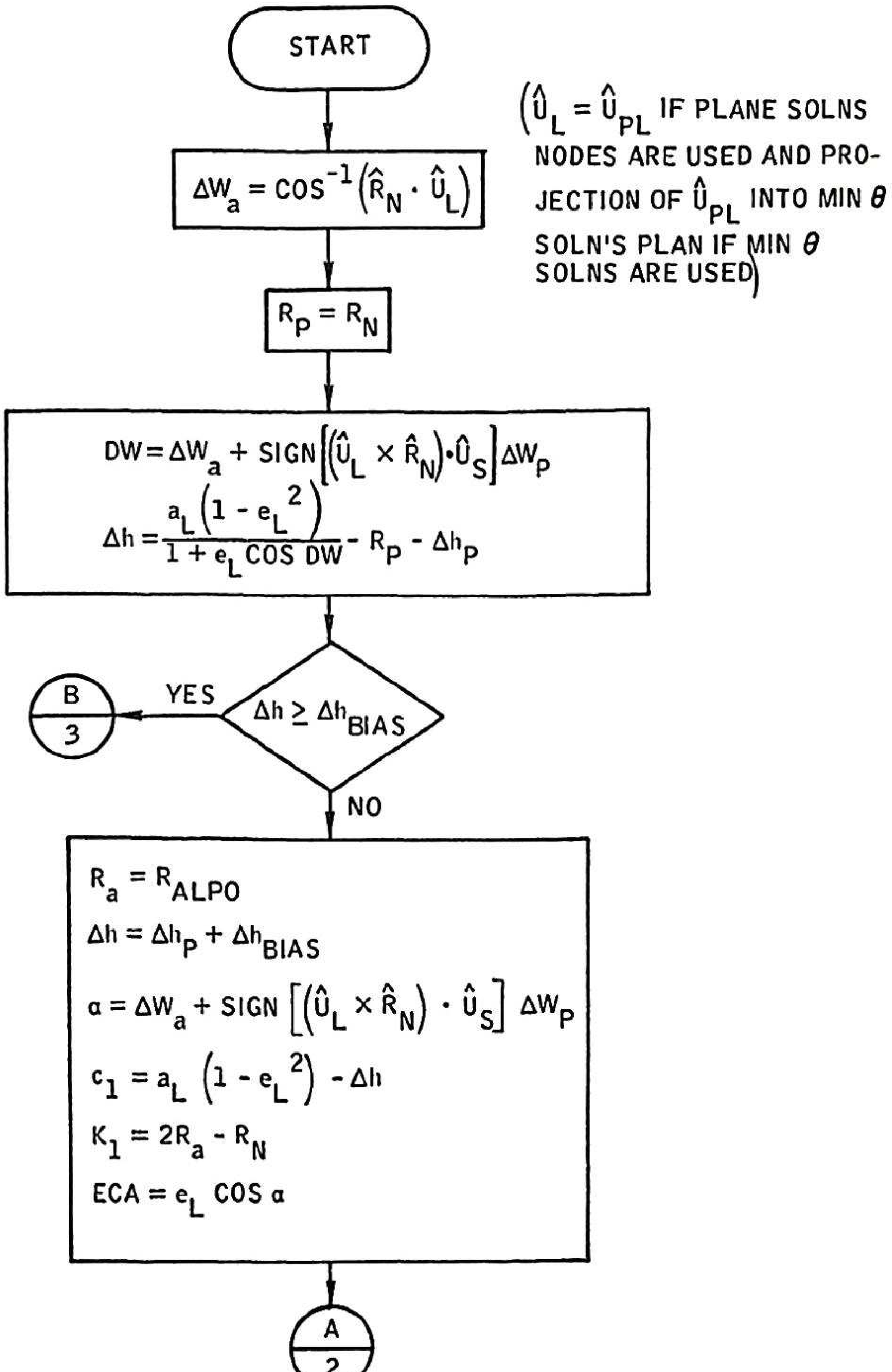
Flow chart 9.- Subroutine MINTHT - Concluded.



PURPOSE: TO COMPUTE + OR - INTERSECTION SOLUTIONS

Flow chart 10.- Subroutine INTER.

(A)

COMPUTE EQUATION COEFFICIENTS

$$a = R_N^2\left(1 + ECA^2\right) + e_L^2\left(K_1^2 - R_N^2\right) - 2K_1 R_N ECA$$

$$b = 2R_N^2\left[ECA^2\left(\Delta h - R_a\right) - R_a - c_1\right] + 2e_L^2\left[K_1^2 \Delta h - K_1 R_N R_a - R_N^2\left(\Delta h - R_a\right)\right] + 2ECA\, R_N\left[K_1\left(R_a - \Delta h + c_1\right) + R_a R_N\right]$$

$$c = R_N^2\left[R_a^2 + c_1^2 + 4c_1 R_a + ECA^2\left(R_a^2 + \Delta h^2 - 4R_a \Delta h\right)\right] + e_L^2\left(\Delta h^2 K_1^2 - 4K_1 R_a R_N \Delta h + R_N^2\left(4R_a \Delta h - \Delta h^2\right)\right) - 2ECA\left[R_a R_N\left(K_1 c_1 - K_1 \Delta h - R_N \Delta h + R_N R_a\right) + R_N^2 c_1 R_a - c_1 \Delta h R_N K_1\right]$$

$$d = 2e_L^2 \Delta h^2 R_a R_N\left(R_N - K_1\right) - 2R_N^2 R_a\left[c_1^2 + ECA^2\left(\Delta h^2 - R_a \Delta h\right) + c_1 R_a\right] + 2ECA\left[R_N^2 R_a^2\left(c_1 - \Delta h\right) - c_1 \Delta h R_a R_N\left(K_1 + R_N\right)\right]$$

$$e = R_N^2 R_a^2\left[c_1^2 + 2ECA\, c_1 \Delta h + ECA^2 \Delta h^2\right]$$

SOLVE $aR_p^4 + bR_p^3 + cR_p^2 + dR_p + e = 0$
FOR R_p WITH PCAQRE

REAL SOLNS? — NO → ERROR

YES ↓

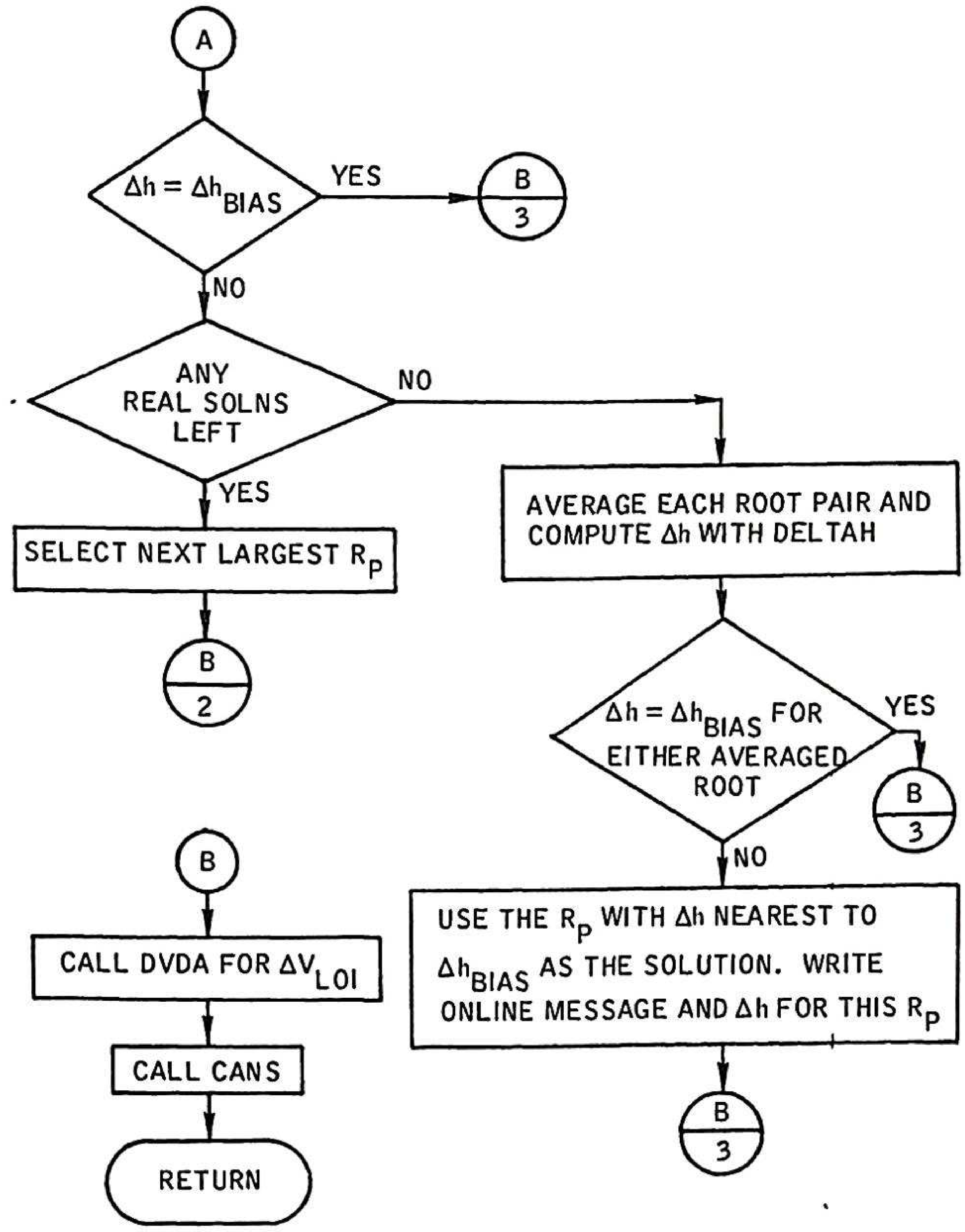
SELECT LARGEST REAL R_P

(B) →

CALL DELTAH FOR Δh

(A / 3)

Flow chart 10.- Subroutine INTER - Continued.



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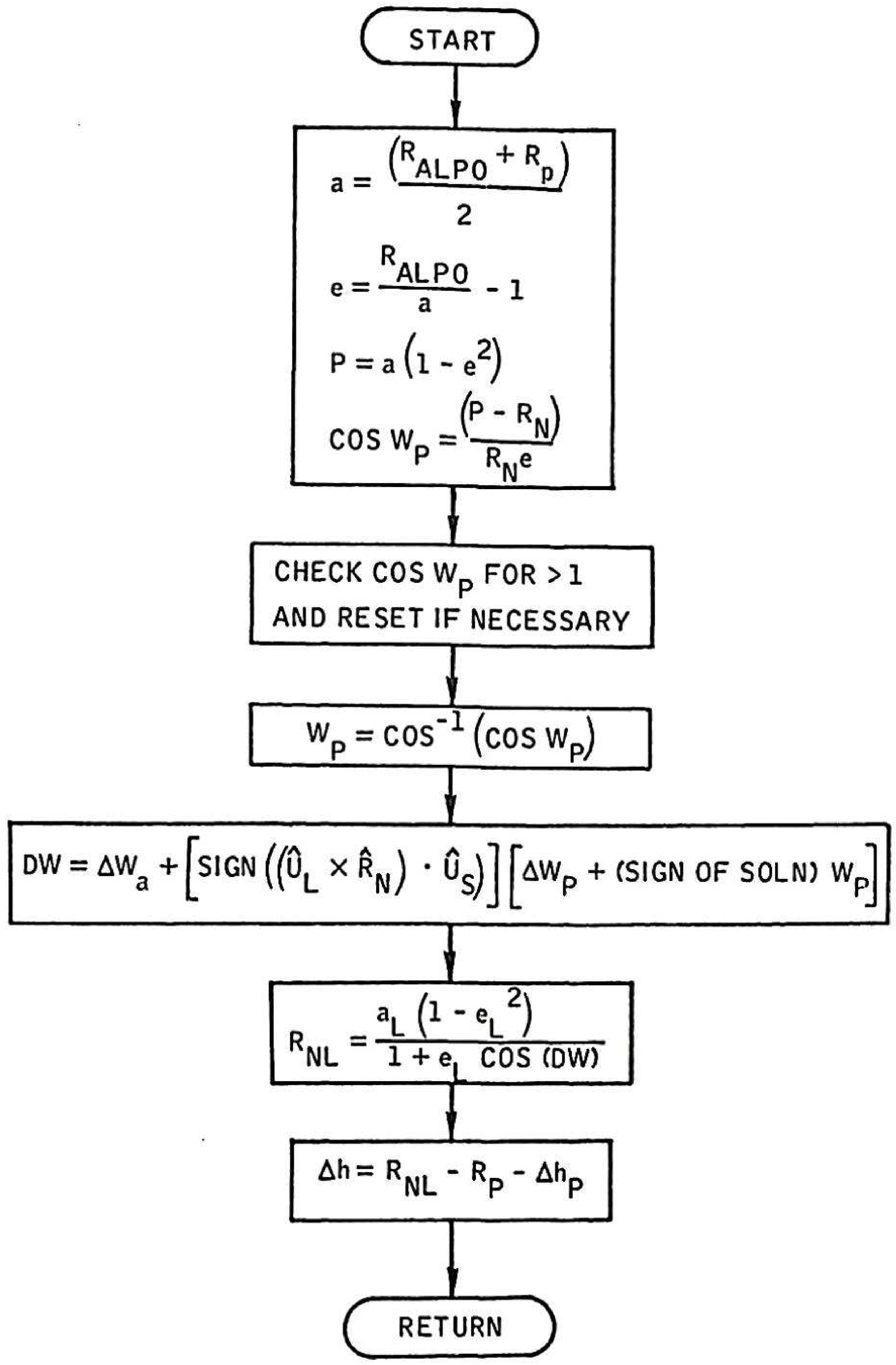
Flow chart 10.- Subroutine INTER - Concluded.



PURPOSE: TO COMPUTE THE Δh BETWEEN R_p OF THE FIRST LPO AT DOI TIME AND THE R ON THE SECOND LPO

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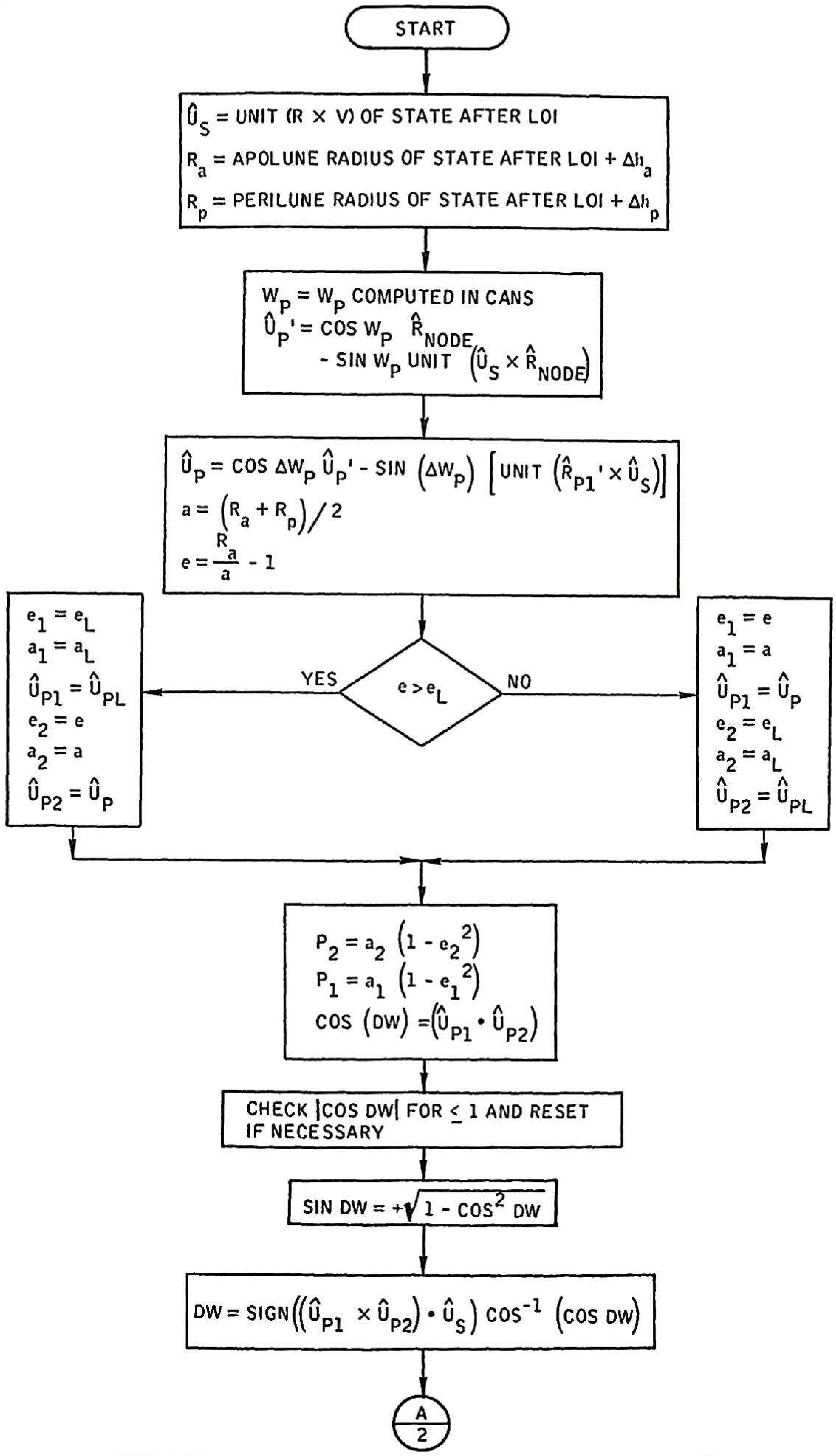
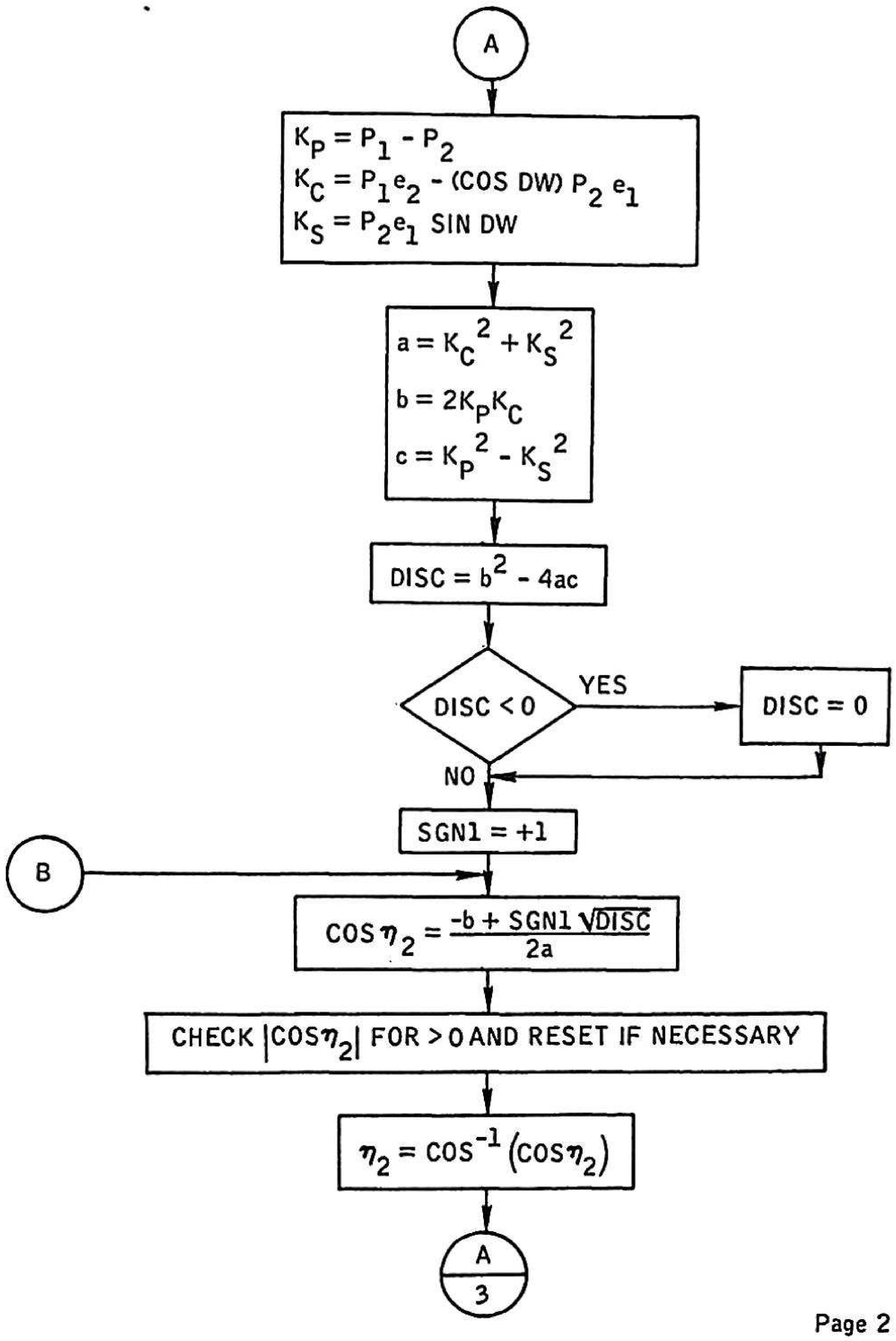
Flow chart 11.- Subroutine DELTAH.

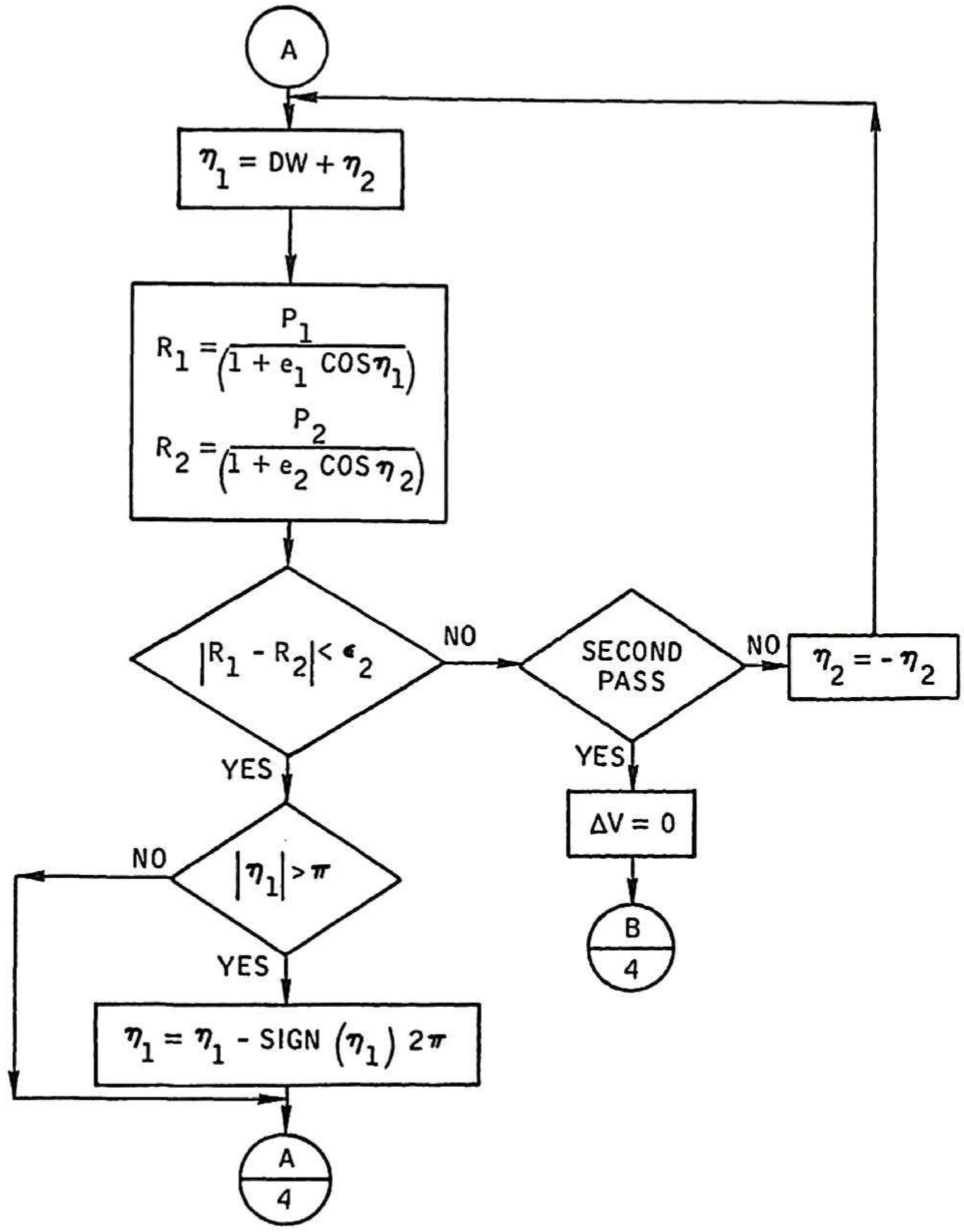


PURPOSE: TO COMPUTE THE ΔV FOR THE MANEUVER AFTER LOI

Flow chart 12.- Subroutine DELV2.



Flow chart 12.- Subroutine DELV2 - Continued.



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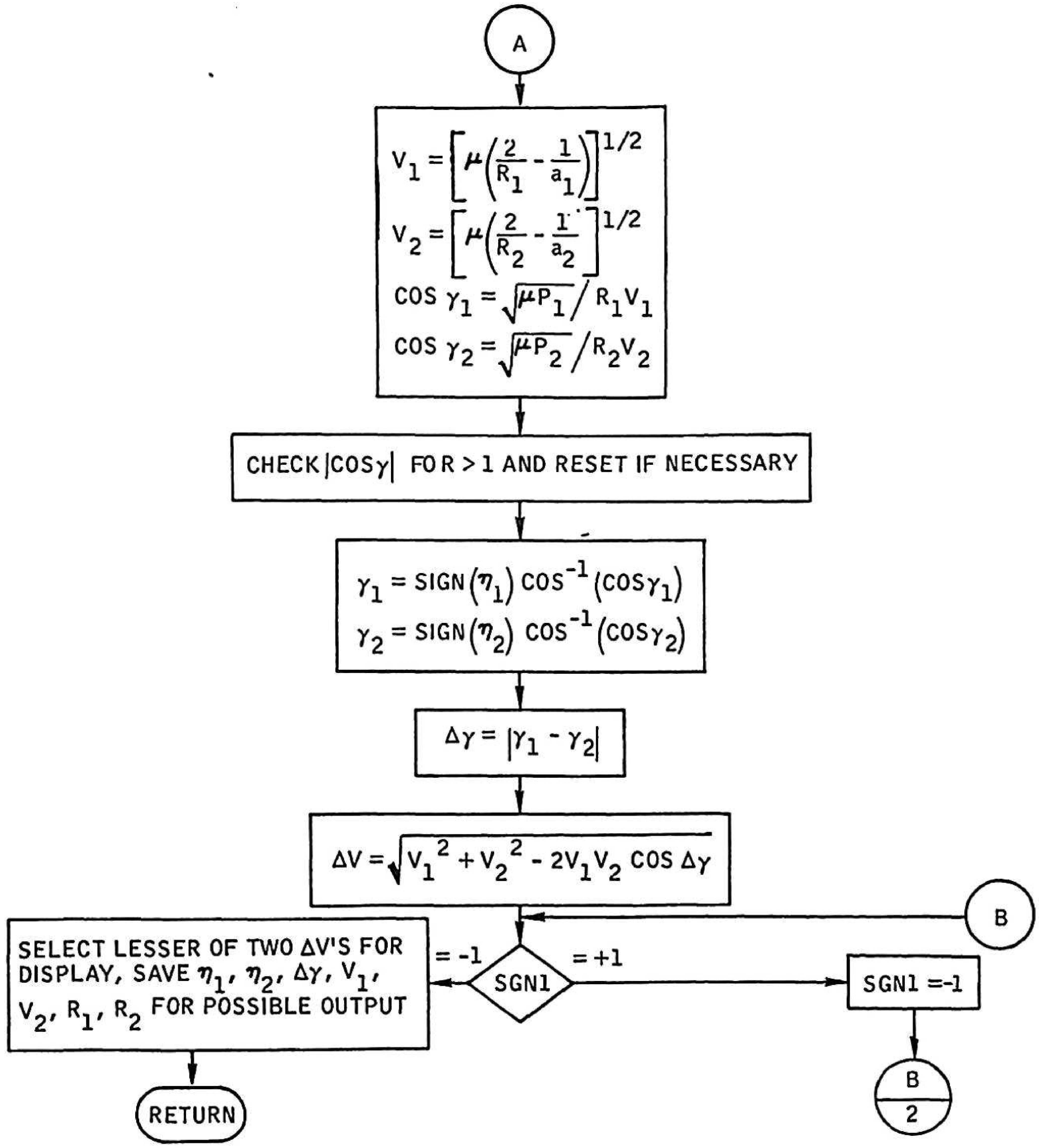
Flow chart 12.- Subroutine DELV2 - Continued.



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Flow chart 12.- Subroutine DELV2 - Concluded.

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4. Notes on the Quartic Problem Encountered While Computing the Intersection Solutions in the LOI Processor. TRW IOC 70-5521.4-59, Sept. 8, 1970.