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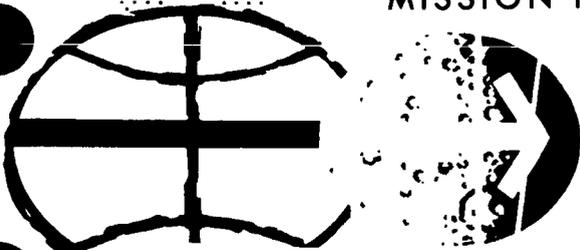
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RTCC REQUIREMENTS FOR THE LOI BURN GO/NO-GO PROCEDURE

Guidance and Performance Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS



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THE LOI BURN GO/NO-GO PROCEDURE (NASA)
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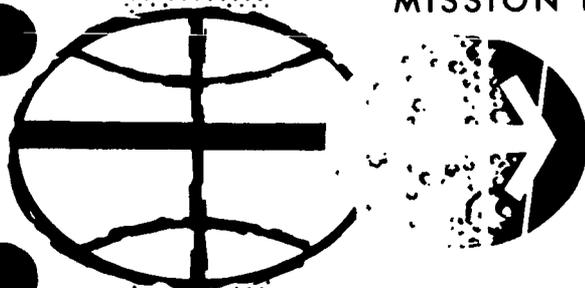
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PROJECT APOLLO

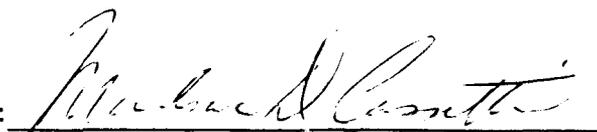
RTCC REQUIREMENTS FOR THE LOI BURN
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By H.S. Estes
Guidance and Performance Branch

October 23, 1969

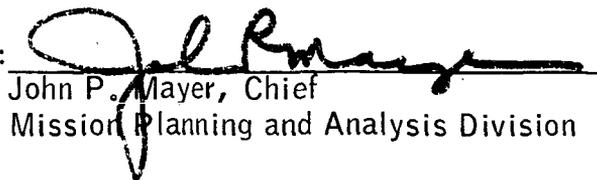
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RTCC REQUIREMENTS FOR THE LOI BURN

GO/NO-GO PROCECURE

By H. S. Estes

1.0 SUMMARY AND INTRODUCTION

The purpose of this document is to define the equations and logic required to develop a computer program to compare the Saturn instrument unit (IU) and spacecraft inertial measurement unit (IMU) velocity vectors during the translunar injection burn. The comparisons are part of the LOI GO/NO-GO decision defined in reference 1. This function was the responsibility of the Real-Time Auxiliary Computer Facility for previous missions and should be available in the Real-Time Computer Complex (RTCC) for use on Apollo 12 (Mission H-1) and subsequent missions.

For every computational cycle, the program accepts a Saturn state vector and a spacecraft (SC) state vector with their associated down-linked time tags from the real-time program. These state vectors have previously been resolved into earth-centered true (ECT) coordinates by the RTCC. The vectors are then time synchronized and resolved into IMU stable member (SM) coordinates; the gravity and SC initial azimuth misalignment effects are removed; and the resultant vectors are differenced. The component and total velocity differences should be produced as output on strip chart recorders or on equivalent displays. The logic flow of the program is shown in figure 1. Equations pertaining to each block are shown in figures 2 through 8. A description of each block follows. Input required for the program is listed in table I. All symbols are defined in table II.

2.0 PROGRAM DESCRIPTION

Processing of data begins when the time tags associated with the input Saturn and SC state vectors exceed a time which is controlled by input. The input time should correspond closely to 10 seconds before translunar injection (TLI) burn ignition time expressed in ground elapsed time (g.e.t.). Immediately after data processing begins, the state vectors from both the Saturn and the SC must be edited to eliminate the possibility of initializing the gravity correction computations on a bad data point. An existing editing routine which compares position and velocity components of several successive state vectors is recommended. By appropriate comparisons, an inconsistent vector can be found. The initial state vector to be processed

for both the Saturn and the SC should be the earliest vector which has been determined to be valid. Bad vectors which occur after the initial vector should not be eliminated from the computations. Other proven methods used to edit the initial state vectors are acceptable if it is impractical to implement the one discussed.

The initial function of the interpolation routine is to determine the leading vector by comparison of the Saturn and SC time tags on each data point. The time tag on the lagging vector is bracketed as a result of cycling through a table of leading vectors which have been stored in tabular form. After the lagging vector is bracketed, the leading vector is interpolated linearly to determine a state vector at the lagging vector time. The lagging vector and the interpolated vector are processed through the remainder of the program for comparison of the velocities. The leading and lagging vectors must be labeled Saturn or SC prior to the interpolation. An alternate interpolation method may be used if this program is not included in the real-time system.

After interpolation, the state vectors are transformed from ECT into IMU stable member coordinates. Both coordinate systems are inertial earth centered and are defined as follows.

a. ECT - X-axis is in the equatorial plane directed through the Greenwich meridian at midnight prior to launch. The Z-axis is directed along the earth's rotation axis through the north pole. The Y-axis completes a right-handed coordinate system.

b. SM - The X-axis is parallel to the flight azimuth and is positive down range. The Z-axis is parallel to the local gravity vector and is positive down. The Y-axis completes a right-handed coordinate system.

The transformation operation requires three rotations defined by the following.

a. A rotation by the angle θ about the Z ECT axis (θ = longitude of launch pad plus the product of the time interval from midnight prior to launch and the earth rotational rate)

b. A negative rotation by the geodetic latitude plus 90° about the new Y ECT axis

c. A rotation by the initial flight azimuth about the new Z ECT axis

The velocity change caused by gravity is calculated for both sources by summation of the incremental velocity changes which can be attributed to gravity. An average gravity is assumed over each time increment. A spherical earth is assumed for the gravity acceleration at each position. The SC velocity vector is corrected by subtraction of the total gravity

velocity change of the SC followed by addition of the total gravity velocity change of the Saturn. These computations remove the effect of the initial position difference between the Saturn and the SC from the velocity differences.

If no IMU alinement is made in earth orbit, the initial azimuth misalignment computed during launch must be manually entered as input into the program. The SC velocity vector is corrected for the initial azimuth misalignment by rotation through the input angle. This operation is performed by the same equations which correct for Saturn and SC gravity differences.

A velocity component bias is applied to each Saturn/SC velocity component comparison. These biases are determined by computation of the difference between the Saturn and SC velocity vector components at the first synchronized vectors after program start. Once computed, the biases remain constant.

The desired total and component velocity comparisons are made by subtraction of the gravity- and azimuth-corrected SC total and component velocities from the corresponding Saturn total and component velocities. The velocity component biases are then added to establish the final velocity differences to be produced as output in appropriate digital and graphical form.

3.0 CONCLUSION

By use of the program described in this internal note, the parameters required to evaluate SC performance relative to Saturn performance can be computed. When these parameters are combined with other parameters computed by the RTCC, a basis is formed for making the LOI GO/NO-GO decision for the SC.

TABLE I.- REQUIRED PROGRAM INPUT

Symbol	Definition
AZ_0	Initial flight azimuth
TSTART	G.m.t. to start processing data
tx	Maximum time interval over which linear interpolation is permitted
ΔAZ	Initial azimuth misalignment (= 0 if IMU alignment is performed in earth orbit)
Δt_m	Time from previous midnight to lift-off
λ	Longitude of the launch site
μ	Gravity constant for spherical earth
ϕ	Geodetic latitude of the launch site
ω_E	Earth rotational rate

TABLE II.- DEFINITION OF TERMS

A	ECT to SM transformation matrix
AZ_0	Input initial flight azimuth
a_{ij}	Elements of ECT to SM transformation matrix
ECT	Earth-centered true coordinate subscript
P	Leading vector time rate of change over the interpolation interval
R	Radius
SM	Stable member coordinate subscript
TSTART	Input G.m.t. time to start processing data
t_n	Time of current vector
t_{n-1}	Time of previous vector
$t_n, X_n, Y_n, Z_n, \dot{X}_n, \dot{Y}_n, \dot{Z}_n$ $t_{n-1}, X_{n-1}, Y_{n-1}, Z_{n-1},$ $\dot{X}_{n-1}, \dot{Y}_{n-1}, \dot{Z}_{n-1}$	Leading source latest and succeeding state vectors for times which bracket the lagging vector time, t_s
$t_s, X_s, Y_s, Z_s,$ $\dot{X}_s, \dot{Y}_s, \dot{Z}_s$	Leading source interpolated state vector at lagging source time, t_s
X, Y, Z	Subscripted position vector
$\dot{X}, \dot{Y}, \dot{Z}$	Subscripted velocity vector
$\ddot{X}, \ddot{Y}, \ddot{Z}$	Subscripted acceleration vector
$\dot{X}_{t=0}$	SM X component of velocity at lift-off

$\dot{Y}_{t=0}$	SM Y component of velocity at lift-off
ΔAZ	Input initial azimuth misalignment
Δt_m	Input time to lift-off from midnight prior to launch
$\dot{\Delta X}_g, \dot{\Delta Y}_g, \dot{\Delta Z}_g$	Total delta velocity caused by gravity at time indicated.
$\dot{\Delta X}, \dot{\Delta Y}, \dot{\Delta Z}, \Delta V$	Component and total velocity differences between Saturn and corrected SC at time, t_s
$\dot{\Delta X}_{BIAS}, \dot{\Delta Y}_{BIAS}, \dot{\Delta Z}_{BIAS}$	Saturn/SC velocity difference at time of first pass only
λ	Input longitude of launch pad
ω_E	Input rotational rate of earth

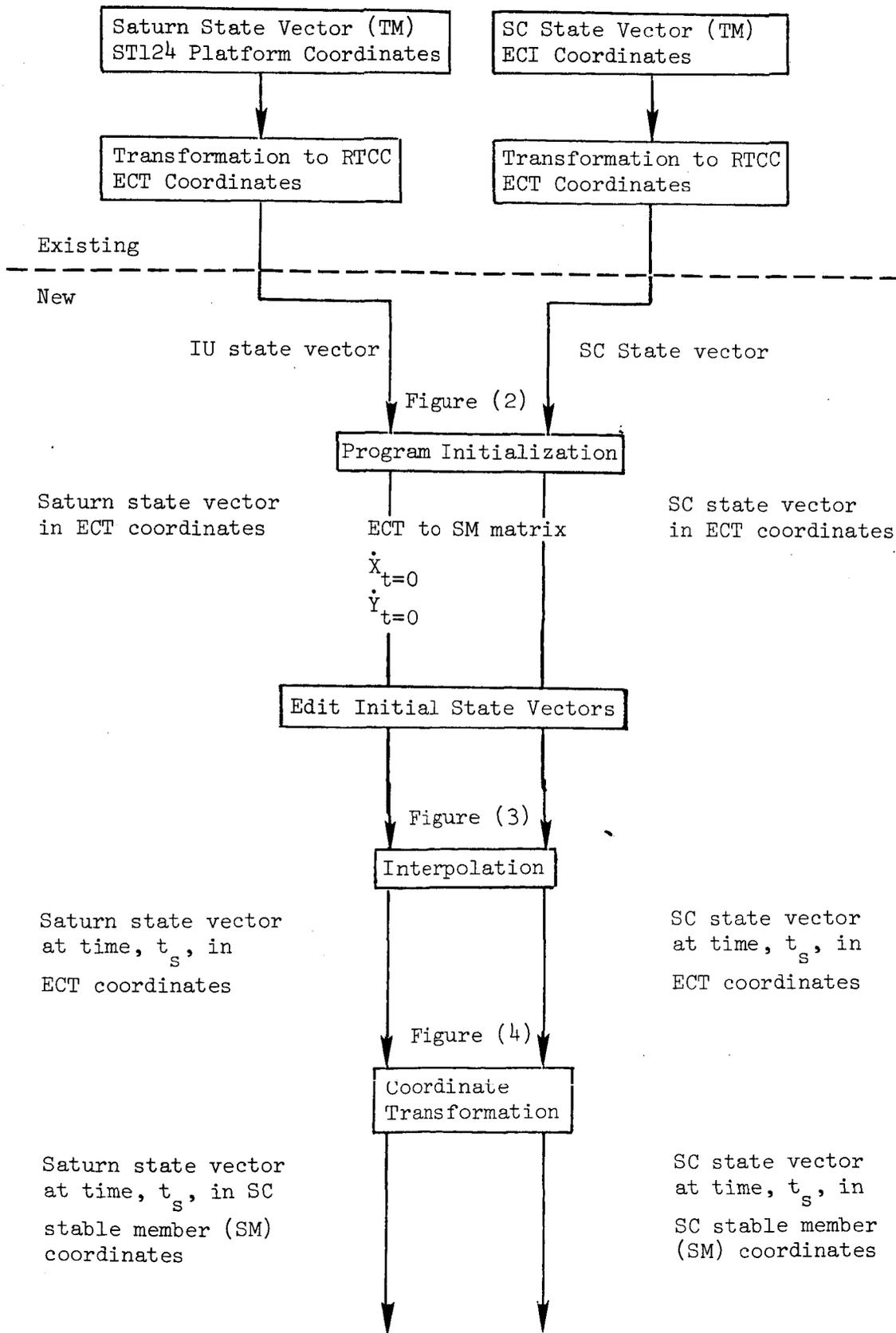


Figure 1.- Logic flow for LOI GO/NO-GO velocity difference program.

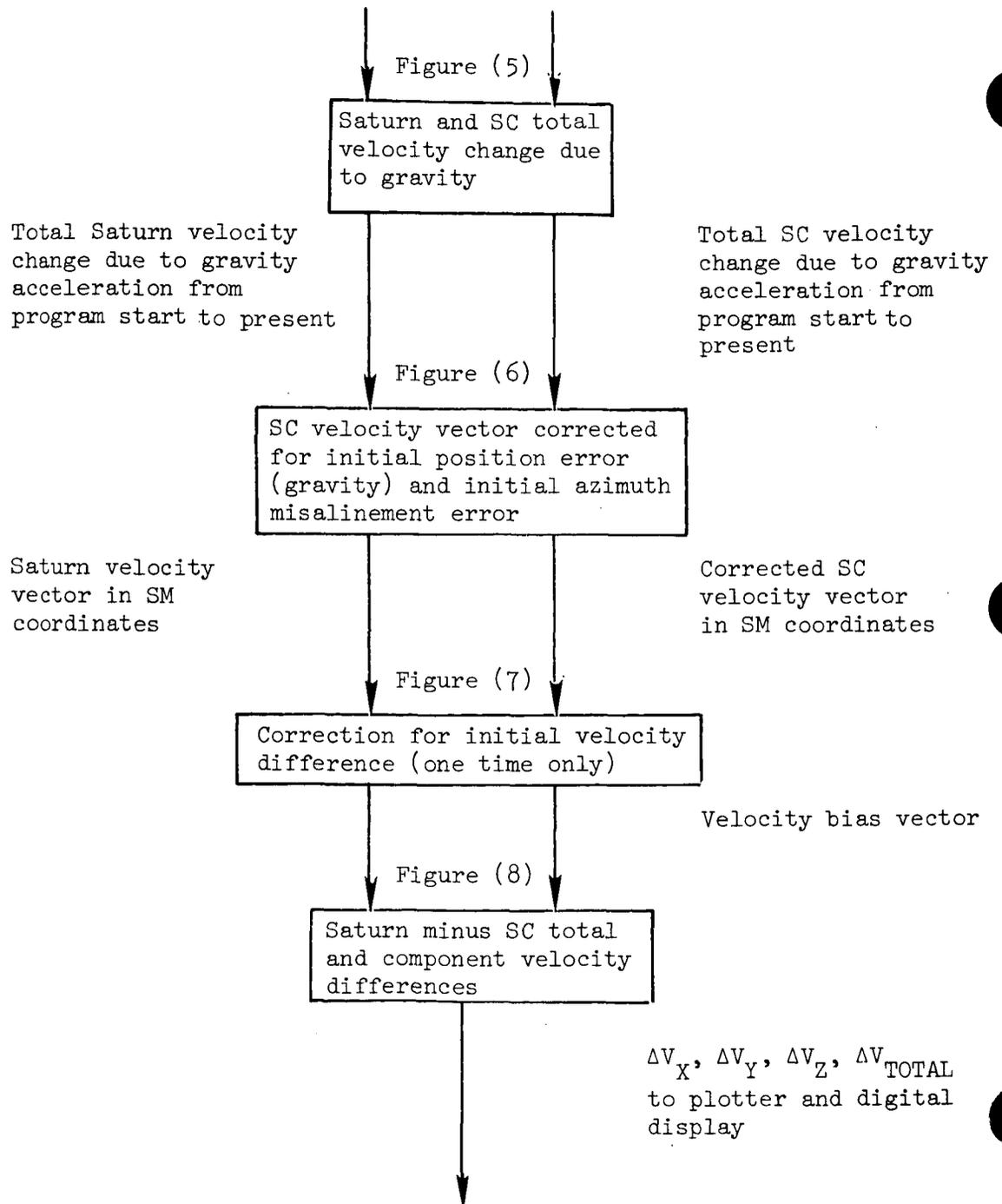


Figure 1.- Concluded

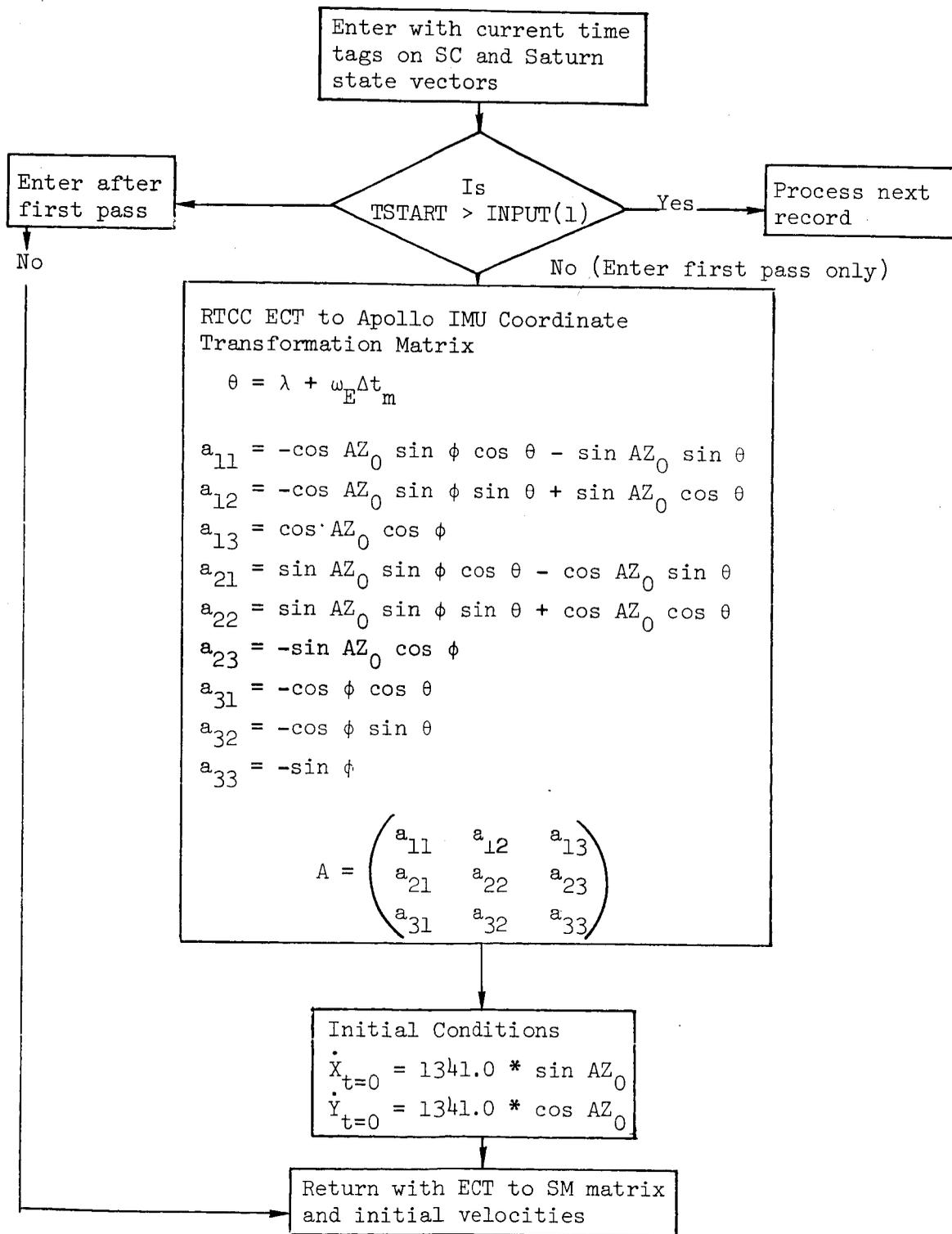


Figure 2.- Program initialization.

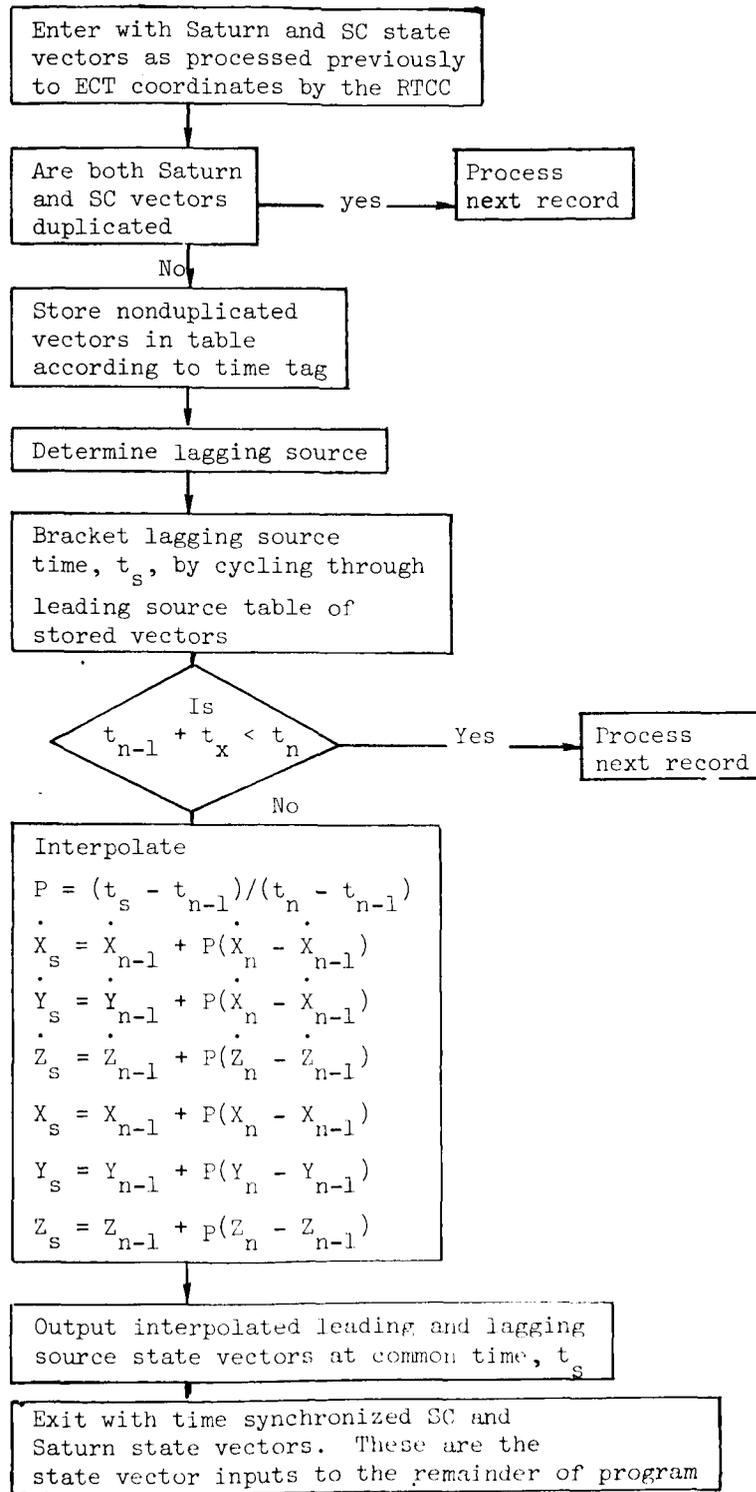


Figure 3.- Interpolation routine.

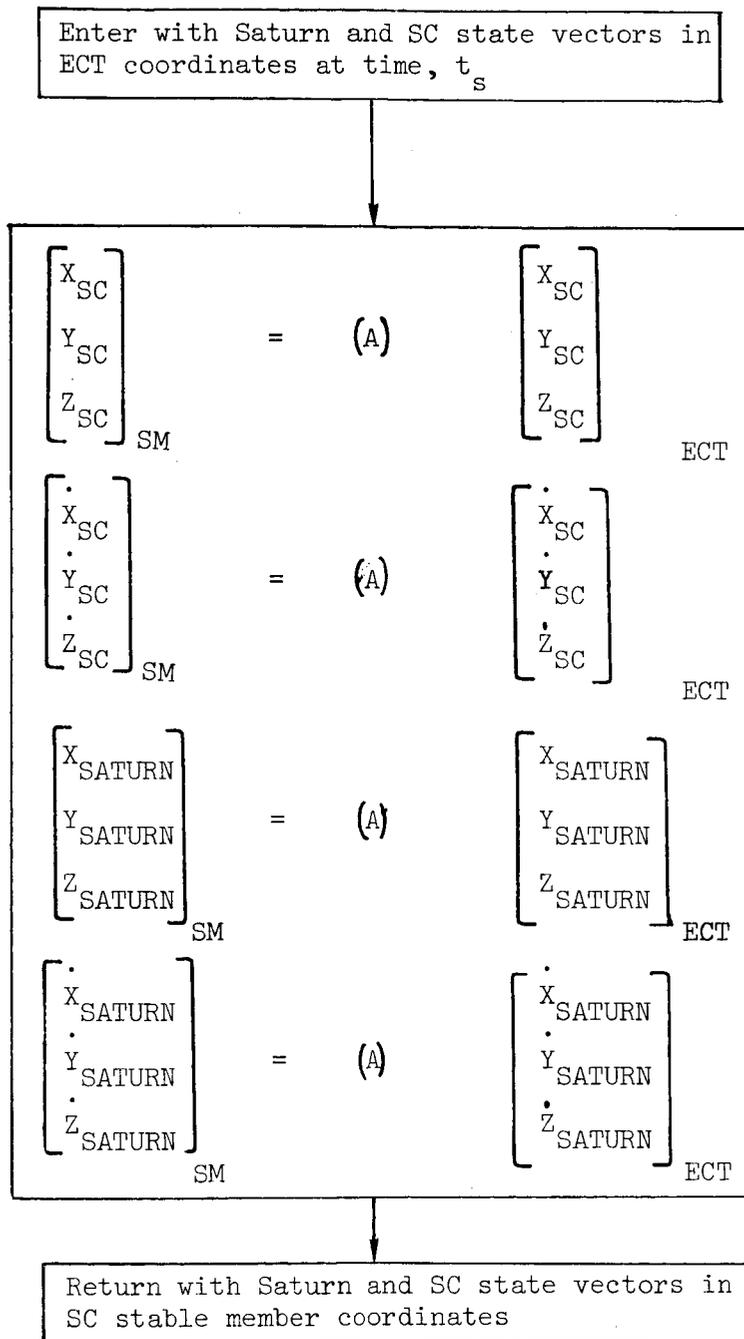


Figure 4.- ECT to SC stable member coordinate transformation routine.

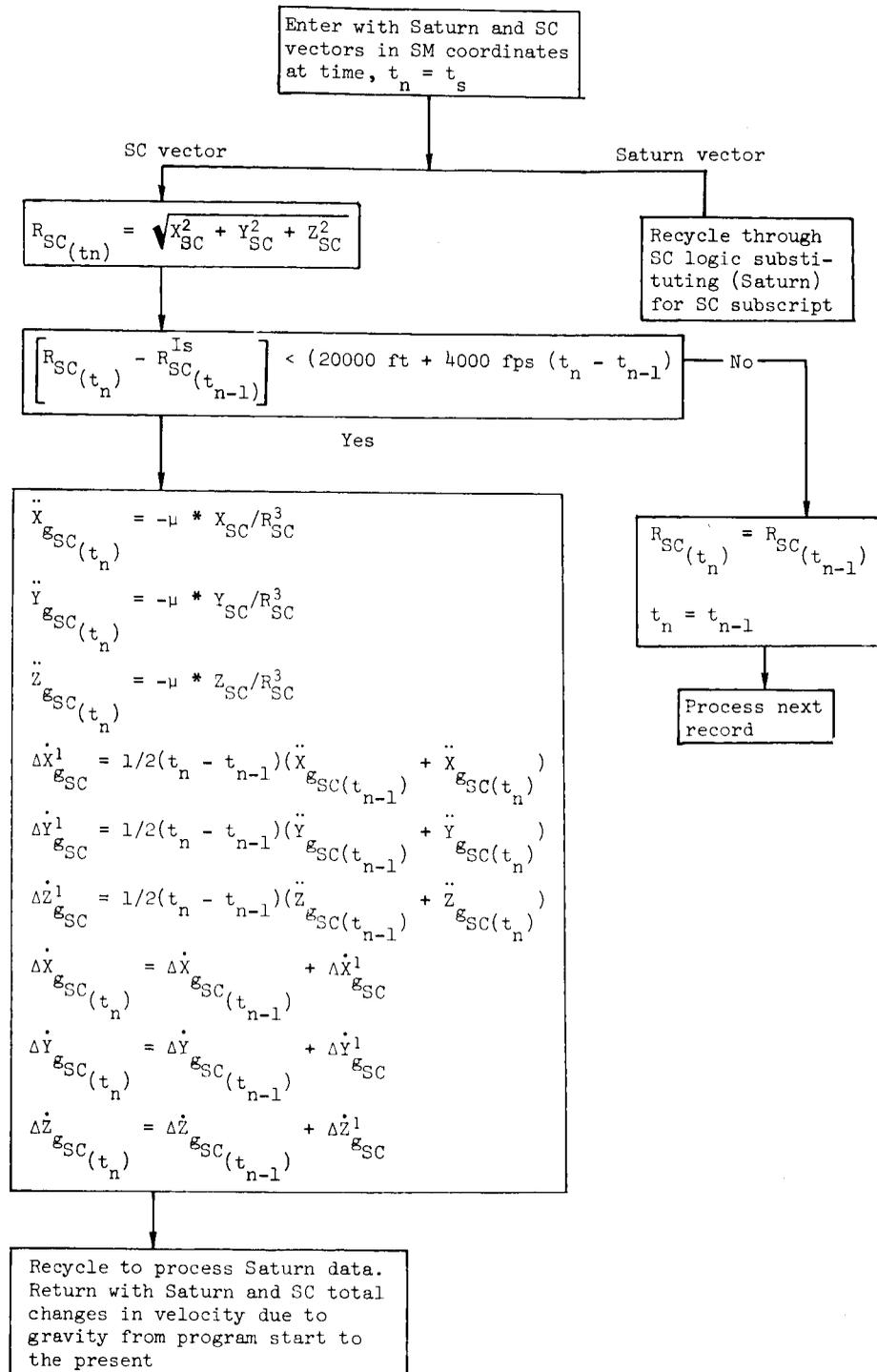


Figure 5.- Gravity correction computations.

Enter with velocities at $t = 0$ sec,
 uncorrected SC velocity vector in
 SC SM coordinates, Saturn and SC
 total velocity change due to gravity
 and the initial azimuth misalignment

$$\begin{aligned} \dot{X}_{SC}^{\text{corrected}} &= \dot{X}_{t=0} + \Delta \dot{X}_{g_{\text{Saturn}}} + \sin(\Delta \text{AZ}) \left(\dot{Y}_{SC} - \dot{Y}_{t=0} - \Delta \dot{Y}_{g_{SC}} \right) \\ &\quad + \cos(\Delta \text{AZ}) \left(\dot{X}_{SC} - \dot{X}_{t=0} - \Delta \dot{X}_{g_{SC}} \right) \\ \dot{Y}_{SC}^{\text{corrected}} &= \dot{Y}_{t=0} + \Delta \dot{Y}_{g_{\text{Saturn}}} - \sin(\Delta \text{AZ}) \left(\dot{X}_{SC} - \dot{X}_{t=0} - \Delta \dot{X}_{g_{SC}} \right) \\ &\quad + \cos(\Delta \text{AZ}) \left(\dot{Y}_{SC} - \dot{Y}_{t=0} - \Delta \dot{Y}_{g_{SC}} \right) \\ \dot{Z}_{SC}^{\text{corrected}} &= \dot{Z}_{SC} + \Delta \dot{Z}_{g_{\text{Saturn}}} - \Delta \dot{Z}_{g_{SC}} \end{aligned}$$

Return with corrected SC
 velocity components

Figure 6.- Initial azimuth misalignment and gravity
 correction to SC velocity vector.

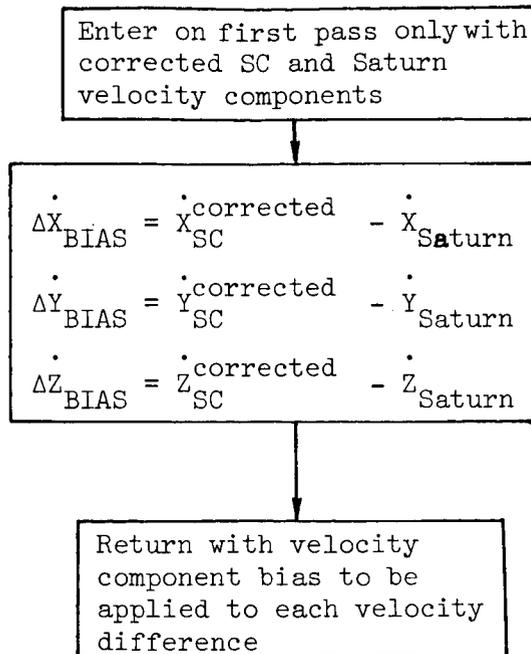


Figure 7.- Velocity difference initialization routine.

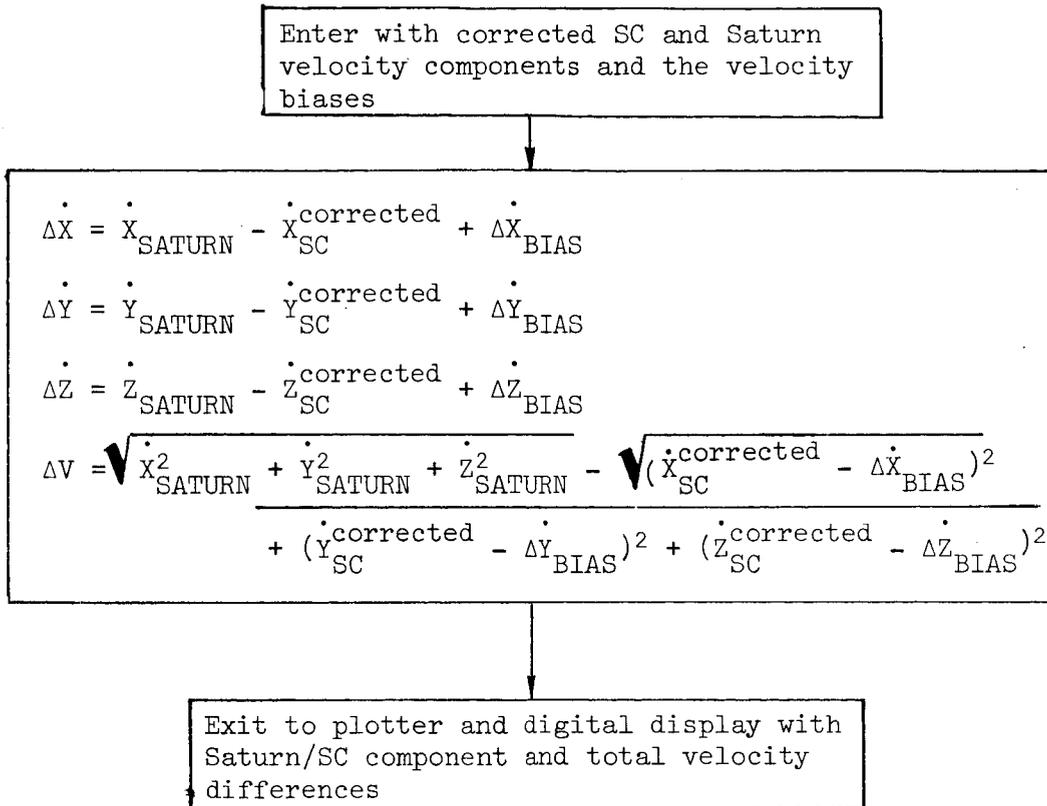


Figure 8.- Velocity component and total velocity difference routine.

REFERENCE

1. Estes, H. S.: LOI GO/NO-GO Procedure. MSC memo 68-FM73-452, October 4, 1968.