

CR-134152

SPACE SHUTTLE GN&C EQUATION DOCUMENT
No. 15
(REVISION 2)
RENDEZVOUS TERMINAL PHASE
AUTOMATIC BRAKING SEQUENCING AND TARGETING
BY
PETER M. KACHMAR
July 1973

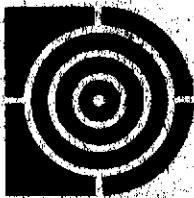
(NASA-CR-134152) RENDEZVOUS TERMINAL
PHASE AUTOMATIC BRAKING SEQUENCING AND
TARGETING (Draper (Charles Stark) Lab.,
Inc.) 42 p HC \$4.25
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Cambridge, Massachusetts 02139

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Rendezvous Terminal Phase
Automatic Braking Sequencing and Targeting

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Peter M. Kachmar

Charles Stark Draper Laboratory

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NAS9-10268

for

National Aeronautics and Space Administration
Guidance and Control Systems Branch
Avionics Systems Engineering Division
Lyndon B. Johnson Space Center, Houston, Texas

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ACKNOWLEDGEMENT

This report was prepared under DSR Project 55-40800, sponsored by the Manned Spacecraft Center of the National Aeronautics and Space Administration through Contract NAS9-10268.

The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

REVISION 2 CHANGES

This document is a revised version of the previous one dated November 1972. The following is a summary of the major technical changes included in this revision.

- Revision of Terminal Phase Targeting Routine,
Detailed Flow Diagram

FOREWORD

This document is one of a series of candidates for inclusion in a future revision of JSC-04217, "Space Shuttle Guidance, Navigation and Control Design Equations." The enclosed has been prepared under NAS9-10268, Task No. 15-A, "GN&C Flight Equation Specification Support", and applies to function 7 of the Rendezvous Targeting Module (OG3), as defined in JSC-03690, Rev. D, "Space Shuttle Orbiter Guidance, Navigation and Control Software Functional Requirements", dated January 1973.

Gerald M. Levine
Division Leader, Guidance Analysis
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NOMENCLATURE

f_{ACS} , f_{OMS}	Thrust of the engine selected for the maneuver, either the reaction control system jets or the OMS engine
g	Gravitational acceleration
ISPACS, ISPOMS	Specific impulse of the reaction control jets, or the OMS engine respectively
i	Indicates current value of the braking gate, and range rate profile levels
\underline{i}_N	Unit normal to the transfer plane, obtained from precision required velocity determination routine
\underline{i}_ρ	Unit vector in direction of relative position vector, $\underline{\rho}$
\underline{i}_s	Unit vector which defines center of station-keeping boundary, relative to target vehicle
\underline{i}_{pole}	Unit vector in direction of earth's polar axis
J_2, J_3, J_4	Second, third and fourth zonal harmonic coefficients of the earth's gravitational acceleration
k_1	Constant used to determine the range at which each range gate search starts when approaching that particular range gate
k_2	Constant used to determine how often the line-of-sight targeting loop is entered; integer number of terminal phase sequencer program cycles
k_3	Constant multiplication factor applied to the minimum range rate at a given range to insure primary vehicle intercept of target vehicle
k_4	Constant used to determine how often the range-rate correction targeting loop is entered

k_5	Constant multiplication factor used in checking range rate limits in "Lambert" targeting option
m	Current estimated primary vehicle mass
MINMAX	Switch used in the Terminal Phase Targeting program to indicate vehicle is "between" braking gates in terminal range range-rate profile
MKGIM	If non-zero, indicates intercept maneuver will be performed after MKGIM number of marks have been processed by on-board filter in terminal phase
MRKCNT	Number of marks processed by on-board filter since entering terminal phase
M_{R-B}	Transformation matrix from reference coordinate frame to body axes coordinate frame
M_{R-LV}	Transformation matrix from reference coordinate frame to local vertical coordinate frame
M_{R-LOS}	Transformation matrix from reference coordinate frame (in which vehicle states are expressed) to LOS coordinate frame axes
M_{R-SM}	Transformation matrix from reference coordinate frame to stable member coordinate frame
M_{NB-B}	Transformation matrix from navigation base frame to body axes
n	Number of discrete braking gates in the range/range rate correction schedule
\underline{r}	Precision target vector used in Precision Required Velocity Determination Routine
r_{eq}	Mean equatorial radius of the earth
\underline{r}_L	Local vertical relative position vector (target vehicle local vertical)

\underline{r}_P	Primary vehicle position vector
$\underline{r}_P(t_{ig})$	Primary vehicle position vector at maneuver ignition
\underline{r}_T	Target vehicle position vector
$\underline{r}_T(t_{ig})$	Target vehicle position vector at maneuver ignition
$\underline{r}_T(t_A)$	Position of target vehicle at intercept time. Used as aimpoint vector in Lambert targeting calculations
\underline{r}_{lc}	Offset aimpoint vector obtained from Precision Required Velocity Determination Routine and used in Powered Flight Routine
s_B	Switch which controls braking gate targeting cycle
s_{ENG}	Engine select switch; if it is negative, indicates reaction control system jets will be used for the maneuver; magnitude then indicates number of RCS jets to be used. Positive number indicates OMS engine will be used.
SENGBRAK	Engine select switch value (sign and magnitude) for braking maneuvers
SENGLOS	Engine select switch for LOS correction
SENGIM	Engine select switch for intercept maneuver
s_{freq}	Switch which controls measurement processing (navigation) cycle
s_{GIM}	Switch which indicates if an intercept maneuver is to be performed or not (needed in a rendezvous which does not have an intercept maneuver preceding the terminal phase sequence)
s_{GM}	Switch which indicates guidance mode to be used in Powered Flight Guidance Routine; "2" - two axis thrusting; "3" - modified Delta-v mode; "4" - modified Lambert mode
s_{LAM}	Switch used to select type of targeting scheme used in the Terminal Phase Braking Targeting Program
s_{MK}	Switch which controls measurement cycle

s_{LOS}	Switch which controls line-of-sight targeting cycle
s_{pert}	Switch indicating the perturbing accelerations to be included in the state vector integrations
$s_{RELPARAM}$	Switch used in Terminal Phase Targeting Routine
s_{search}	Indicates target search routine is needed in the Unified Navigation Filter program
s_{mk}	Switch which controls navigation cycle
$s_{\Delta v}$	Switch which indicates if a velocity correction is to be made or not
$s_{\Delta vB}$	Switch which indicates a braking correction is to be made
$s_{\Delta vLOS}$	Switch which indicates LOS correction is to be made
t_A	Time of target intercept
t_c	Current time
t_{ig}	Maneuver ignition time
t_m	Measurement time
t_{NOM} t_{INT}	Nominal time of target intercept of no braking is done; used in intercept maneuver calculations
t_P, t_T	Time associated with primary and target vehicle state vectors respectively.
TGIM	If non-zero, indicates intercept maneuver will be performed after TGIM seconds have elapsed since initiation of the terminal phase

\underline{v}_L	Relative velocity vector in target vehicle local vertical frame
\underline{v}_P	Primary vehicle velocity vector
$\underline{v}_P(t_{ig})$	Primary vehicle velocity vector at maneuver ignition
\underline{v}_T	Target vehicle velocity vector
$\underline{v}_T(t_{ig})$	Target vehicle velocity vector at maneuver ignition
$\underline{v}_T(t_A)$	Target vehicle velocity vector at intercept time , t_A
WGT	Current primary vehicle estimated weight
δt_B	Delta time to ignition for a range-rate correction maneuver
δt_{LOS}	Delta time to ignition for a line-of-sight correction
Δt_m	Basic sequencing cycle time
$\Delta \underline{v}$	Inertial velocity change required at braking, LOS or intercept maneuver
$\Delta \underline{v}_B$	Velocity change expressed in the body coordinate frame
Δv_{LIM}	Magnitude of velocity change below which no maneuver will be applied
$\Delta \underline{v}_{LOS}$	Velocity change expressed in line-of-sight coordinate frame
$\Delta \underline{v}_{LV}$	Velocity change expressed in local vertical coordinate frame
μ	Gravitational constant of the earth
ν	Magnitude of relative velocity vector
$\underline{\nu}$	Relative velocity vector

v_u	Upper bound on station-keeping velocity
v_l	Lower bound on station-keeping velocity
ω_{LIM}	Angular velocity lower limit below which no line-of-sight correction is made; value to which line-of-sight angular velocity is driven if a line-of-sight correction is made at ranges greater than ρ_{LOS_LIM}
$\underline{\omega}_{LOS}$	Angular velocity vector of the line-of-sight between the primary and target vehicle
ω_{LOS_LIM}	Value of line of sight rate to which the line of sight corrections drive the line of sight rate
ω_{LOS}	Magnitude of $\underline{\omega}_{LOS}$
ρ	Magnitude of relative position vector, $\underline{\rho}$
$\dot{\rho}$	Range rate between the primary and target vehicles
$\dot{\rho}_{DES}$	Desired range rate between the primary and target vehicle; used in braking correction calculations
$\underline{\rho}$	Relative position vector
ρ_{Bi}	Range of the i^{th} braking gate
ρ_l	Lower bound on station-keeping position
ρ_{LOS_LIM}	Relative range below which line-of-sight rate is driven to zero instead of ω_{LIM} at a line-of-sight correction
$\dot{\rho}_{max_i}$	Maximum range rate desired at i^{th} braking gate
$\dot{\rho}_{min_i}$	Minimum range rate desired between braking gates i and $i + 1$
$\underline{\rho}_{off(LV)}$	Offset aimpoint relative to target point expressed in target local vertical frame
$\underline{\rho}_{off}$	Offset aimpoint vector in inertial coordinates

ρ_{store}	Current value of relative range
$\dot{\rho}_{\text{store}}$	Current value of relative range rate
ρ_{μ}	Upper bound on station-keeping position
$[\]_m$	Vector expressed in measurement coordinate frame
$(\)'$	Prime indicates previous values of a variable, e.g. prior measurement parameters, prior measurement time, etc.
$(\underline{\alpha})$	Bar indicates vector variable with components $\alpha_0, \alpha_1, \alpha_2$

1. INTRODUCTION

The purpose of the Rendezvous Terminal Phase Braking Program is to provide the means of automatically bringing the primary vehicle (Orbiter) within desired station-keeping boundaries relative to the target vehicle (or satellite). To accomplish this task, the program of necessity contains navigation, targeting and guidance functions.

The program is normally initiated in one of two ways: either following the final (usually the second) midcourse correction of a rendezvous targeting sequence which contained a terminal phase initiation (intercept) maneuver or upon orbiter insertion for a one revolution rendezvous mission (Mission 3B). In the former case the intercept trajectory is "good" enough post midcourse corrections to insure arrival at the first braking gate. In the latter case, insertion guidance has attempted to place the orbiter on an intercept trajectory. To correct the ascent dispersions which cause a miss trajectory, the program has the capability of performing an intercept maneuver (similar to a midcourse correction) so that the desired terminal phase intercept trajectory is obtained.

When the primary vehicle has achieved a position (and velocity) relative to the target which places it within the desired station-keeping boundaries so that the station-keeping function can be initiated and maintained, the program is terminated.

2. FUNCTIONAL FLOW DIAGRAM

The functional flow diagram for the Rendezvous Terminal Phase Braking Program is shown in Figure 1. If the program is initiated after the last midcourse correction maneuver of a rendezvous targeting sequence the relative range between the primary and target vehicle at this point is on the order of three to five miles and closing. The previous midcourse corrections have reduced the miss distance at the nominal intercept time to a point where the desired terminal phase braking gates will be intercepted and no intercept maneuver need be performed in the Terminal Phase Braking program itself.

When the program is entered following orbiter insertion for a one-revolution rendezvous retrieval mission, however, the orbiter will not necessarily be on an intercept trajectory which insures arrival at the desired terminal phase braking gates due to ascent trajectory dispersions. In this case (and in similar ones) it is necessary to perform an intercept maneuver (same as a midcourse correction in a normal rendezvous sequence) after insertion to guarantee arrival at the desired terminal phase braking gates and hence maintain the desired characteristics of the rendezvous trajectory.

The relative range in this case is approximately 8-12 nautical miles.

The program sequencing begins with the updating of the on-board navigation filter with the appropriate sensor data.

The relative state parameters obtained from the navigation filter state estimates are then used in the Terminal Phase Targeting Program where the necessary calculations are performed to determine if an intercept maneuver is to be done.

After the intercept maneuver has been done, if needed, line-of-sight and/or braking corrections are done as required to maintain the desired characteristics of the closing trajectory. The line-of-sight corrections maintain the desired intercept by nulling out line-of-sight rates which exceed a desired rate. At selected ranges between the primary and target vehicles, braking corrections are performed to reduce the closing rate to that specified in the terminal range/range rate profile, if the closing rate exceeds the desired value. During the program sequencing a continuous check is made to insure that the closing rate is sufficiently high so that the primary vehicle will intercept the target.

If either a line-of-sight correction and/or range-rate correction is necessary, the velocity correction is applied using the appropriate guidance mode.

The program sequencing is then repeated. The program is terminated when the desired relative position and velocity conditions are achieved so that the station-keeping mode can be initiated and maintained.

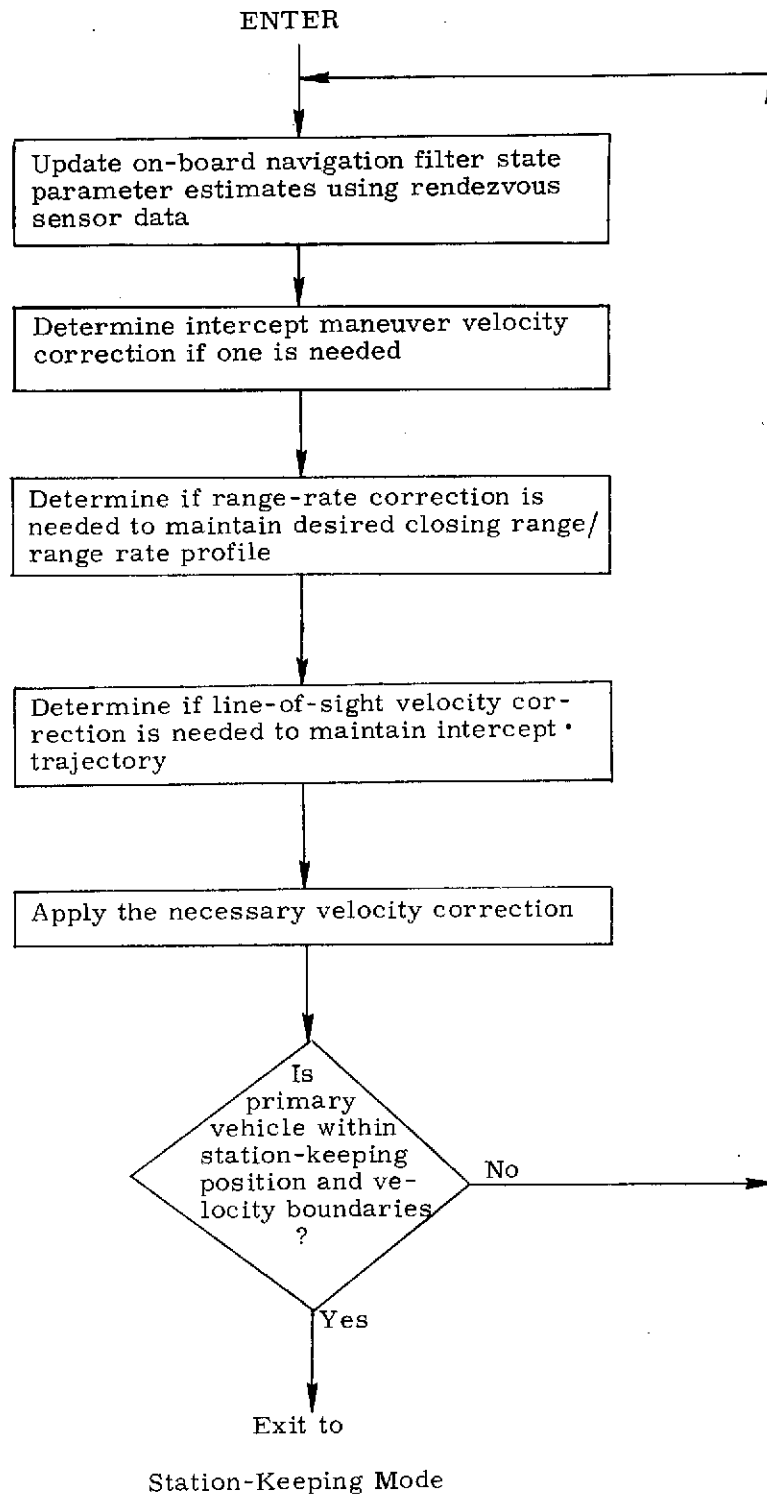


Figure 1. Rendezvous Terminal Phase Braking Program, Functional Flow Diagram

3. INPUT AND OUTPUT VARIABLES

The Terminal Phase Braking Program consists of three basic functions- navigation, targeting and guidance and a sequencer which ties these functions together. The following is a description of the input and output variables for the basic sequencing program, and the targeting program. The Powered Flight Guidance Program is described in Ref. 2 and the Unified Navigation Filter in Ref. 1.

3.1 Terminal Phase Braking Sequencing Program

Input Variables

$\underline{r}_P, \underline{v}_P$	Estimated primary vehicle state vector at time t_P
$\underline{r}_T, \underline{v}_T$	Estimated target vehicle state vector at time t_T
n	Number of discrete range gate corrections
$\rho_{B0}, \dots, \rho_{Bn}$	Range values of the n braking gates
$\dot{\rho}_{B0}, \dots, \dot{\rho}_{Bn}$	Range rates desired at the n braking gates
$\underline{\rho}_{OFF(LV)}$	Offset distance relative to target position in target local vertical coordinates
s_{freq}	Switch which controls navigation cycle
s_{LAM}	Switch used to select type of targeting scheme used in the Terminal Phase Braking Program

Output Variables

$\underline{r}_P, \underline{v}_P$	Primary vehicle state vector for use in station-keeping phase
$\underline{r}_T, \underline{v}_T$	Target vehicle state vector for use in station-keeping phase
t_P, t_T	Time tag of above state vectors

3.2 Terminal Phase Targeting Routine

Input Variables

$\underline{r}_P, \underline{v}_P$	Primary vehicle state vector
$\underline{r}_T, \underline{v}_T$	Target vehicle state vector
ρ	Relative range between primary and target vehicle
$\dot{\rho}$	Range rate between primary and target vehicle
\underline{i}_ρ	Unit vector in direction of relative range vector
$\underline{\omega}_{LOS}$	Angular velocity vector of the line-of-sight between primary and target vehicles
ω_{LOS}	Magnitude of $\underline{\omega}_{LOS}$
M_{R-LOS}	Matrix transformation between the reference coordinate frame and the line-of-sight coordinate frame
s_{LAM}	Switch used to select type of targeting scheme
t_c	Current time
t_P, t_T	Time tag of primary and target vehicle states
$t_{NOM INT}$	Nominal time of target intercept if no braking is done
TGIM	Time into the terminal phase at which intercept maneuver will be performed
MKGM	Number of marks in the terminal phase after which vehicle intercept maneuver will be done
MRKCNT	Number of marks processed by on-board filter in the terminal phase

WGT Current estimated primary vehicle weight

f_{ACS} ,
 f_{OMS} Thrust of reaction control jet or OMS engine respectively

ISPACS,
ISPOMS Specific impulse of reaction control jets or OMS engine respectively

SENGBRAK,
SENGLOS,
SENGIM Engine select switches for braking, LOS and intercept maneuvers respectively

$s_{LOS2AXIS}$ Switch which indicates is LOS correction is to be done in two axes or combined into a "single axis" correction

Output Variables

\underline{i}_N Unit normal to the trajectory plane (in the direction of the angular momentum at ignition)

\underline{r}_{1c} Offset target position

t_{ig} Time of upcoming maneuver

Δv_{LOS} Velocity change of upcoming maneuver in line-of-sight coordinates

Δv_{LV} Velocity correction in local vertical coordinates

s_{eng} Engine select switch

$s_{\Delta v}$ Switch which indicates if velocity correction is to be performed during this sequencing of the Terminal Phase Braking Program

s_{proj} Switch set when the target vector must be projected into the plane defined by \underline{i}_N

s_{GM} Switch which indicates guidance mode to be used in the Powered Flight Guidance Sequencing Program

4. DESCRIPTION OF EQUATIONS

4.1 Terminal Phase Braking Sequencing Program

The Terminal Phase Braking Sequencing Program (Figure 4) which is the main sequencing program for the terminal phase is initiated either after the last midcourse correction in the rendezvous targeting sequence or upon orbit insertion for a one revolution rendezvous case.

In the latter case it is necessary to do an intercept maneuver to put the orbiter on an intercept with the target. This maneuver is done either at a given time into the mission or is based on the number of rendezvous sensor marks processed in the navigation filter during this phase. (The mode used is chosen before liftoff). The primary consideration is that enough sensor marks have been processed so that the intercept maneuver can be computed with a high degree of confidence.

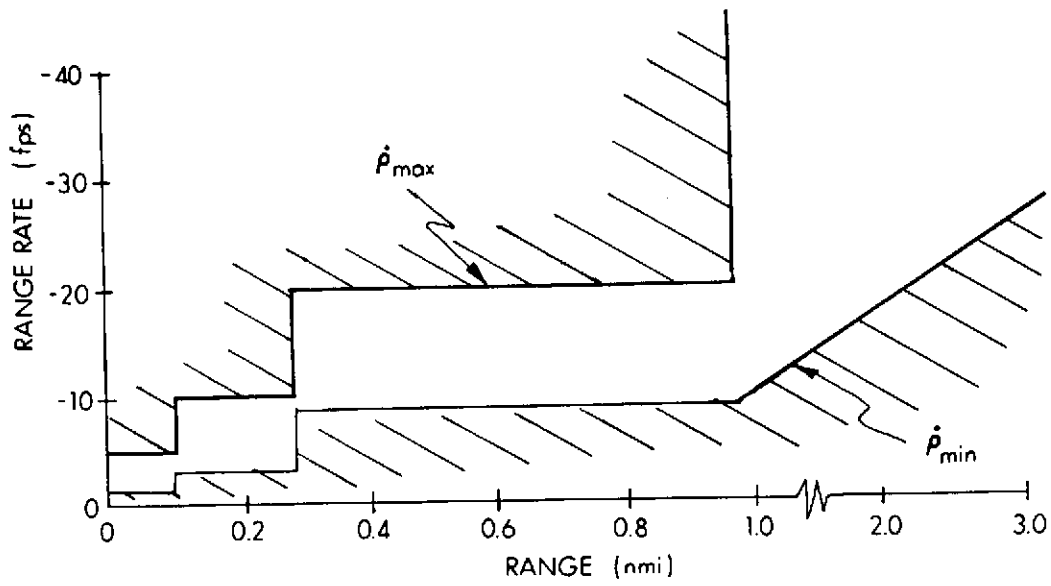
The range/range rate terminal braking schedule used in the program is determined prior to the initiation of the program and consists of discrete range gates and their associated desired range rates. A minimum range rate is also specified throughout the terminal phase to insure primary vehicle intercept of the target vehicle. An example of such a braking schedule is shown in Figure 2.

The sequencing begins with the processing of rendezvous sensor data to obtain estimates of range, range rate, line-of-sight rates, etc. These estimates are derived from processing the sensor data in the Relative State Updating Routine (which is also used throughout the rendezvous sequence, and is described in Ref. 2).

These relative parameter estimates are then used in the Terminal Phase Targeting Routine to determine if a maneuver (either an intercept maneuver, a braking maneuver, a line-of-sight correction or a combination of the last two) is to be performed. The associated maneuver time and guidance parameters are also computed.

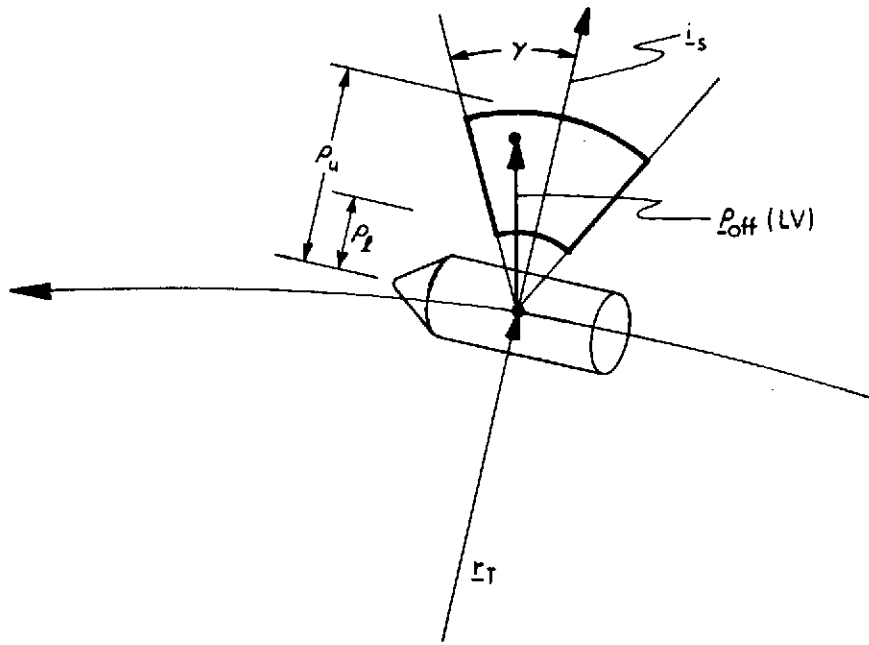
If a maneuver is to be performed, the Powered Flight Guidance Sequencing Program (similar to the Servicer Routine in Apollo) is entered with the appropriate inputs to accomplish the maneuver.

This basic sequencing is repeated until the primary vehicle is within desired station-keeping boundaries relative to the target vehicle (Figure 3).



NOTE: Change of scale on range axis.

Figure 2. Typical Range/Range Rate Schedule



- γ - Cone angle of station-keeping zone
- ρ_u, ρ_l - Upper and lower values of station-keeping boundaries
- $\rho_{\text{off}}(\text{LV})$ - Relative offset vector in target vehicle local vertical, used to target Lambert braking corrections; primary vehicle will intercept this point in the station-keeping zone

Figure 3. Station-Keeping Boundaries—Station-Keeping Above

4.2 Terminal Phase Targeting Routine

The Terminal Phase Targeting Routine (Figure 5) computes the necessary maneuvers to first establish an intercept trajectory between the primary and target vehicles (if one is needed, such as in a once-around rendezvous mission) and second to maintain the intercept trajectory while keeping the range/range rate profile within the desired boundaries.

If it is necessary to do the maneuver to initiate or improve the intercept trajectory (such as correcting ascent dispersions on the one revolution rendezvous mission) the maneuver can be performed either at a set time into the mission or based on a given number of marks processed by the on-board navigation filter in the terminal phase.

Once this maneuver has been performed, line-of-sight control and range-rate control is initiated. If the maneuver is not necessary, line-of-sight control and range-rate control are initiated immediately.

Two modes of operation are then available. The first mode is referred to as automatic line-of-sight control braking and the second automatic Lambert braking.

When s_{LAM} is set to zero, the automatic line-of-sight control braking mode is used. If the line-of-sight rate, as determined from processing the sensor data is above a set limit (typically 0.2 mr/sec), the line-of-sight correction necessary to drive the line-of-sight rate to a desired level is computed and the appropriate ignition time, engine selection and guidance mode switches are set. The RCS thrusters are used to effect the maneuver. The maneuver is accomplished by using either two-axis thrusting normal to the line-of-sight, or rolling the spacecraft to align the delta-v with one of the body axes, thus enabling a one axis velocity correction.

The line-of-sight correction check is typically made every two cycles of the main program. (Line-of-sight cycling is determined by k_2).

The range/range rate checks, to insure that the desired terminal profile is being followed, are made prior to the line-of-sight checks. If the range rate at certain pre-selected ranges exceeds the desired range rate a braking maneuver is performed to reduce the closing rate. Continuous checks are made to insure that the closing rate is above the minimum value to maintain intercept. If it is not, then the closing rate is increased.

The ignition time which is set δt_B seconds from the present time for a braking correction and δt_{LOS} seconds for an LOS correction allows the necessary burn preparations to be made before ignition.

The second mode of operation, the automatic Lambert braking, targets for an intercept point (either the target vehicle or a point offset from the target vehicle indicated by \underline{p}_{off} , Figure 3) at each pre-selected braking gate. Line-of-sight rate is implicitly corrected at each gate to maintain the intercept trajectory when using this mode of operation.

When the range between the vehicles reaches $(1 + k_1)$ times the pre-selected range gate, the time of arrival at the range gate is computed. The calculation assumes the present range-rate remains constant until the range gate is reached. The primary and target vehicle state vectors are then advanced to this ignition time.

The time of arrival at the intercept point is redefined by the equation

$$t_{go} = \frac{(\text{Range at ignition})}{(\text{Desired range rate at this range gate})}$$

This t_{go} is then used in the precision state extrapolation routine to calculate a new target vector for use in the Lambert routine to determine the necessary velocity correction.

By redefining the intercept point in this manner, the Lambert solution forces a reduction in range rate to the desired range rate, insuring intercept in a length of time equivalent to the time it would take to travel the present range at the constant desired range rate. The line-of-sight rate is automatically corrected in the Lambert solution to assure intercept.

The new target vector, time-of-arrival, ignition time and guidance mode switches are then used in the Powered Flight Guidance Routines (Ref. 3) to effect the maneuver.

Between the discrete braking gates, line-of-sight corrections are made when necessary (as in the first mode of operation) to insure arrival at subsequent braking gates and to insure intercept, based on the latest navigated state estimates. (These additional line-of-sight corrections are not normally needed until the last braking gates have been passed since the Lambert targeted corrections at each gate are usually adequate to maintain rendezvous intercept.)

In addition the range-rate is kept above a minimum value to insure intercept.

5. DETAILED FLOW DIAGRAMS

This section contains detailed flow diagrams of the Terminal Phase Braking Sequencing Program, and the Terminal Phase Targeting Routine.

Each input and output variable in the routine and subroutine call statements can be followed by a symbol in brackets. This symbol identifies the notation for the corresponding variable in the detailed description and flow diagrams of the called routine. When identical notation is used, the bracketed symbol is omitted.

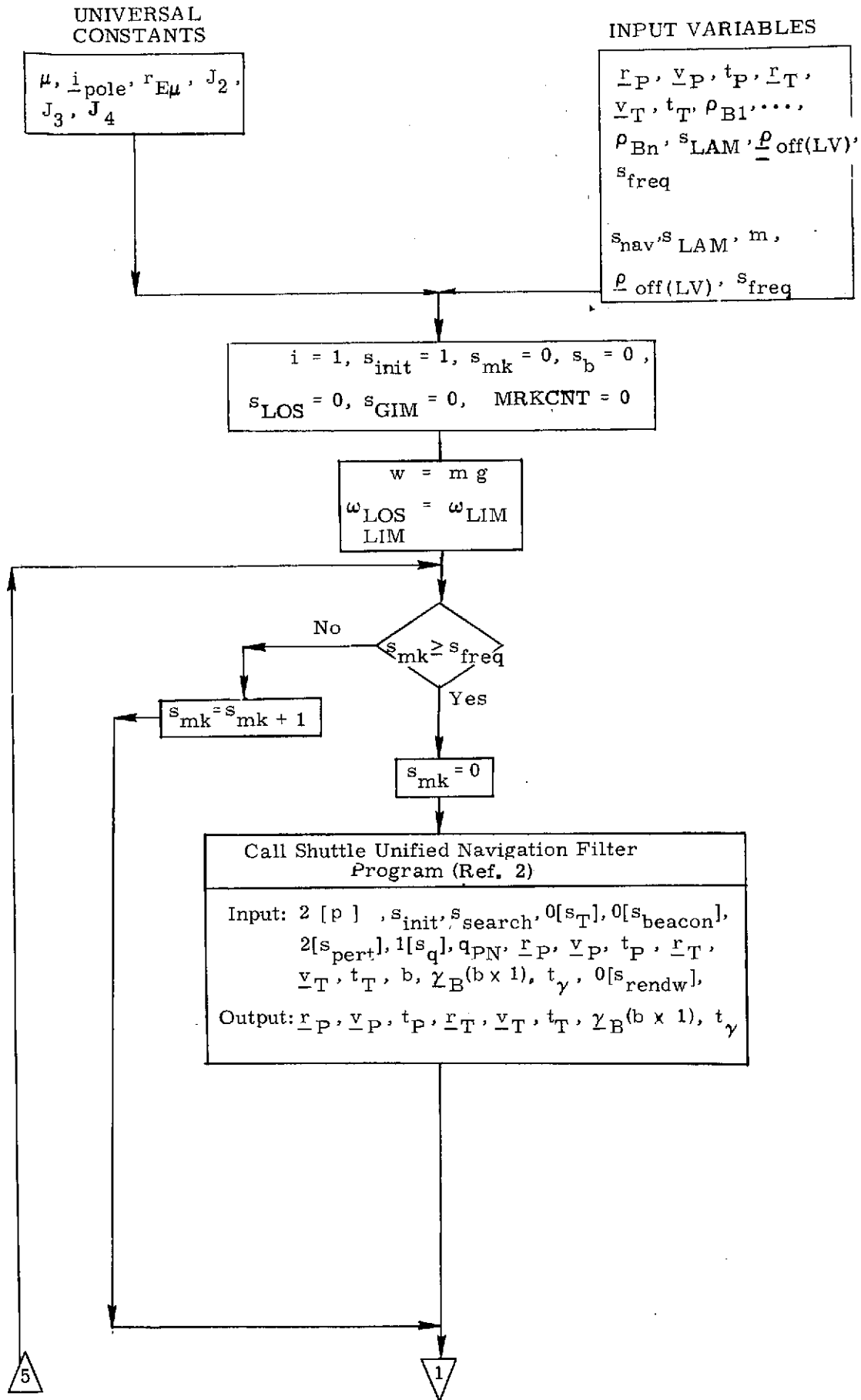


Figure 4a. Terminal Phase Braking Sequencing Program, Detailed Flow Diagram

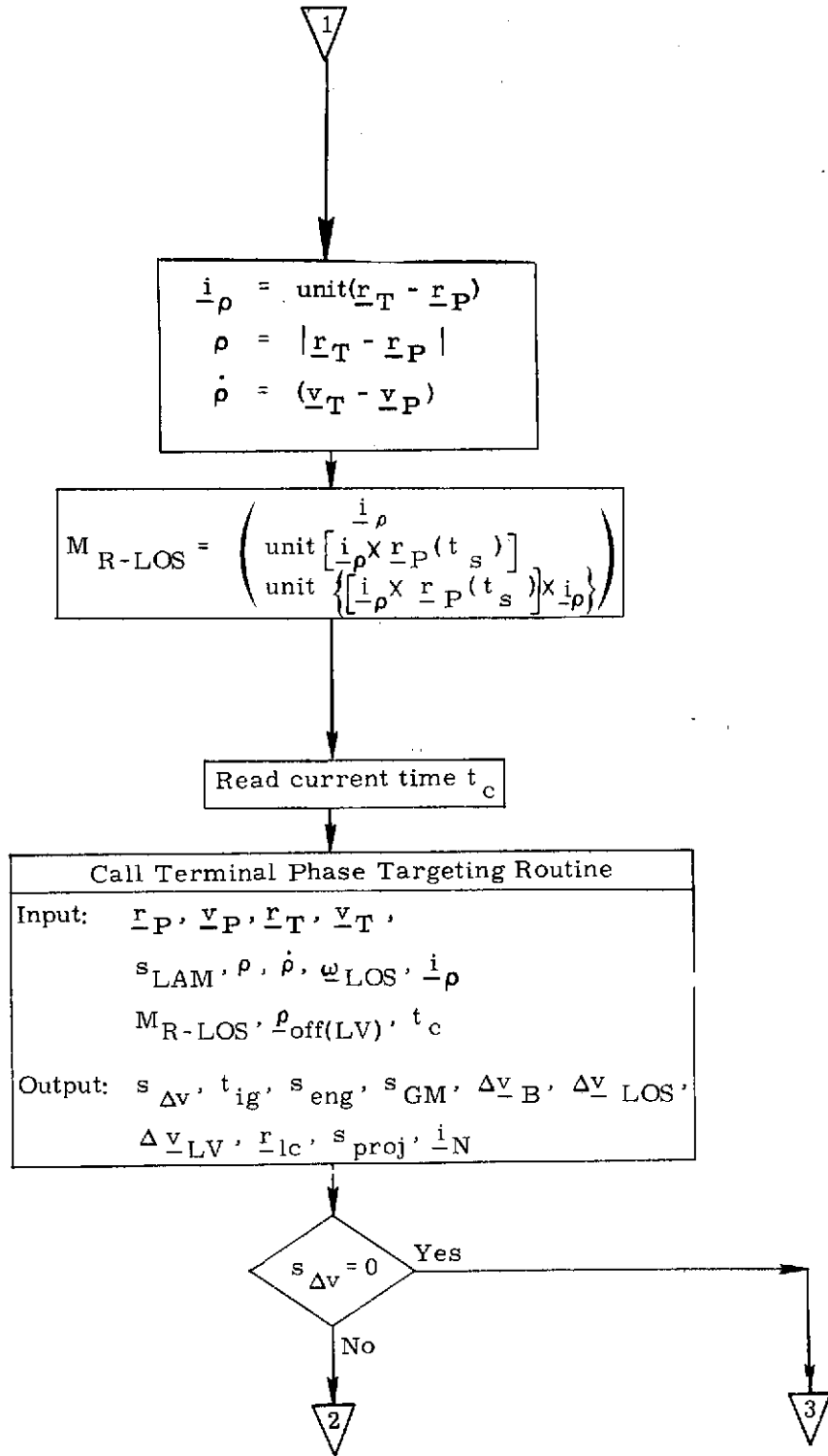


Figure 4b. Terminal Phase Braking Sequencing Program, Detailed Flow Diagram

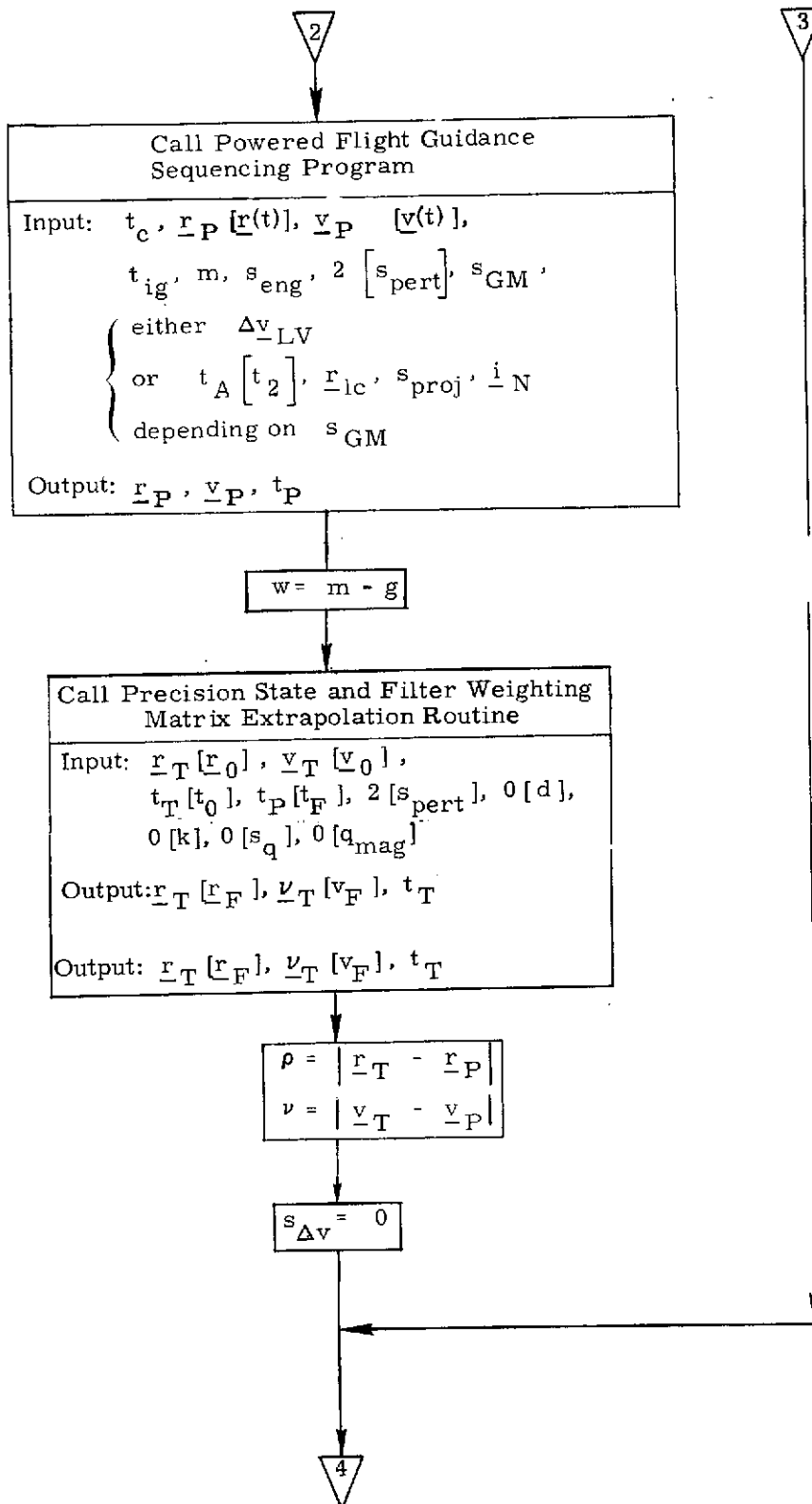


Figure 4c. Terminal Phase Braking Sequencing Program, Detailed Flow Diagram

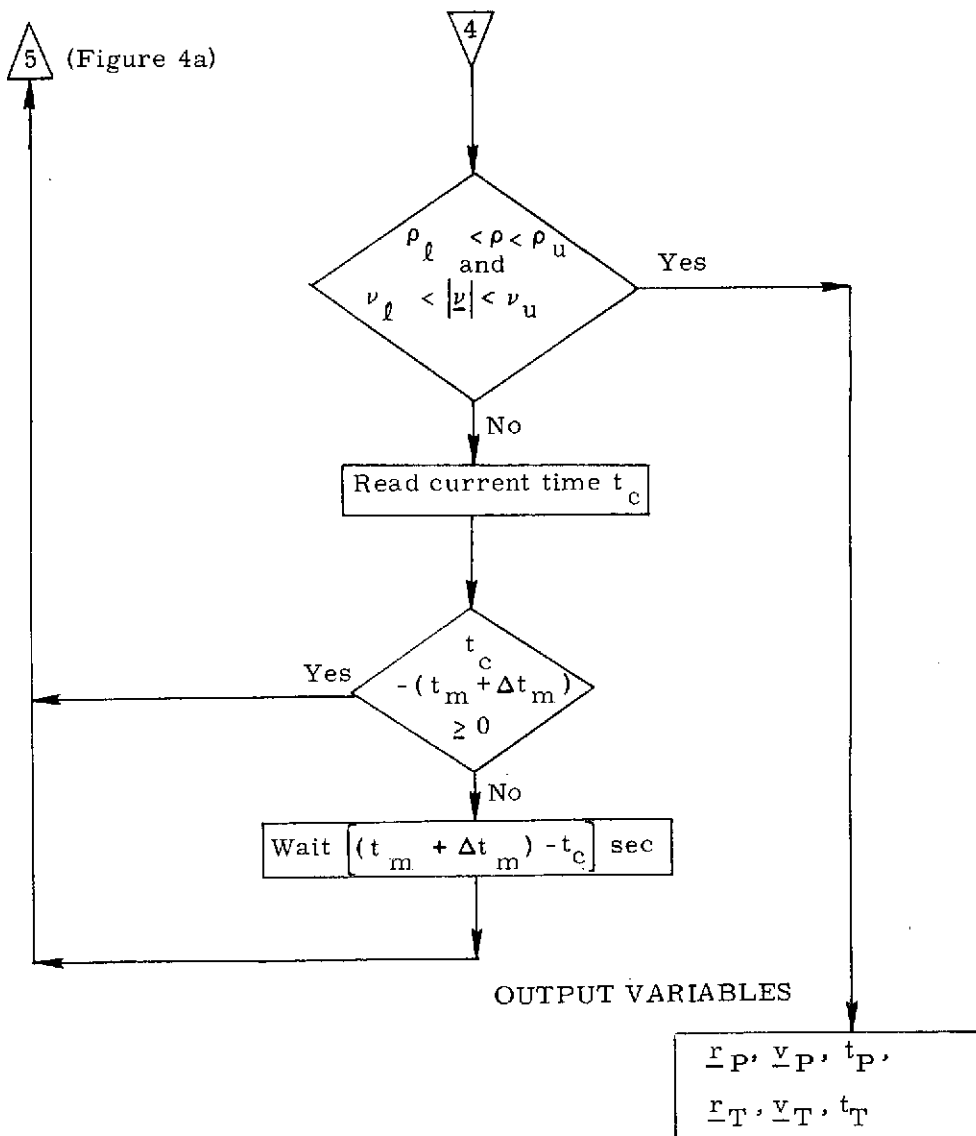


Figure 4d. Terminal Phase Braking Sequencing Program, Detailed Flow Diagram

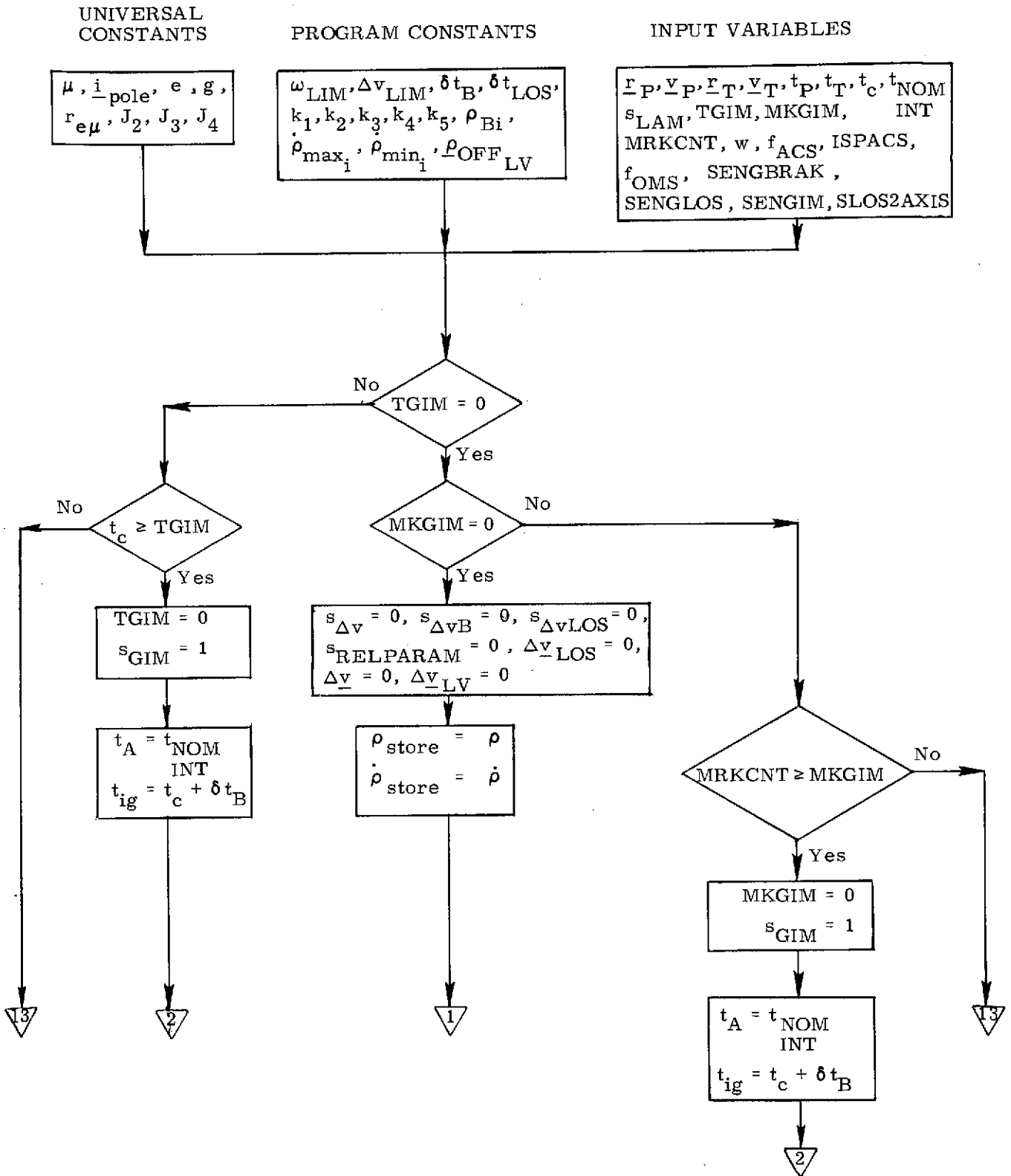


Figure 5a. Terminal Phase Targeting Routine, Detailed Flow Diagram

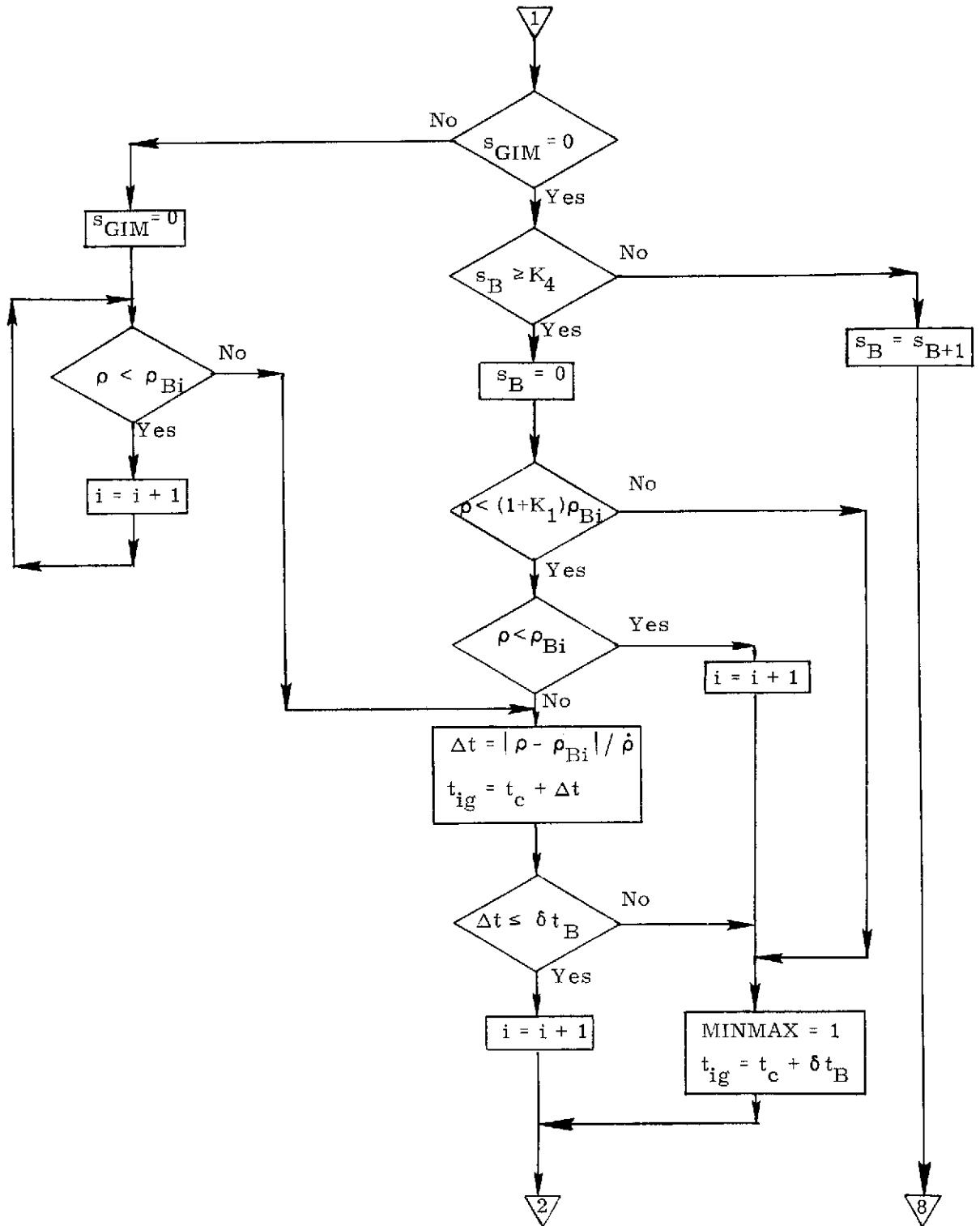


Figure 5b. Terminal Phase Targeting Routine, Detailed Flow Diagram

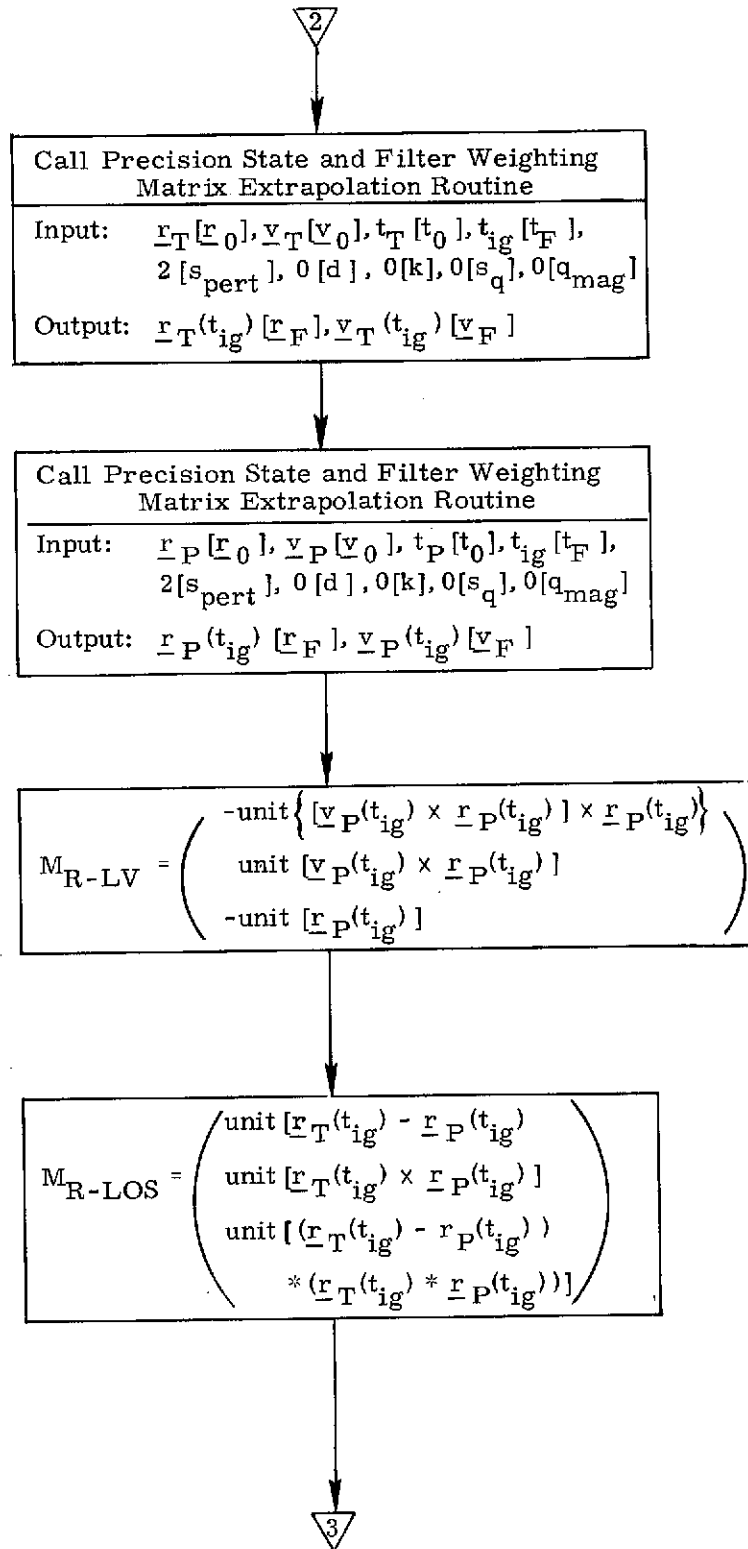


Figure 5c. Terminal Phase Targeting Routine, Detailed Flow Diagram

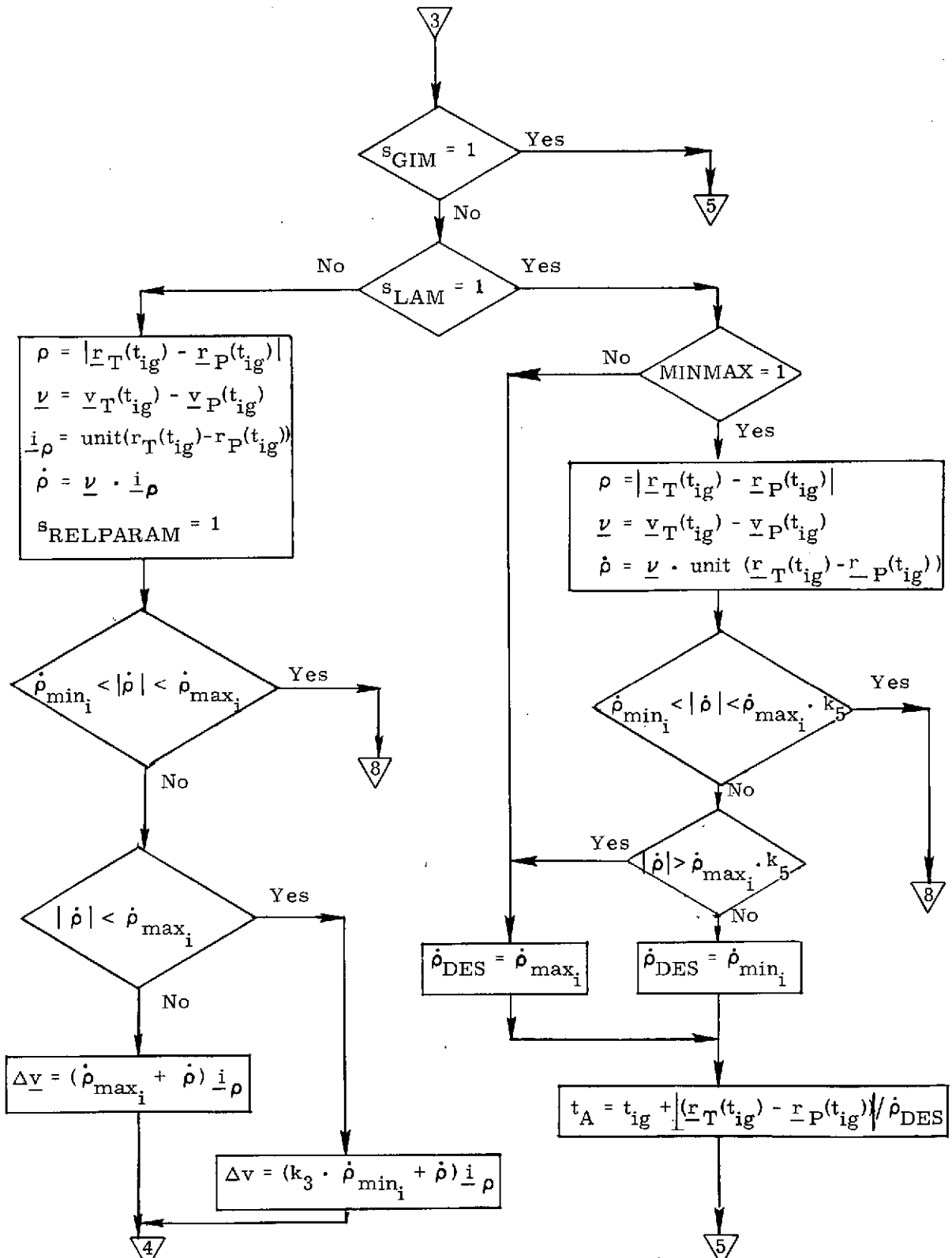


Figure 5d. Terminal Phase Targeting Routine, Detailed Flow Diagram

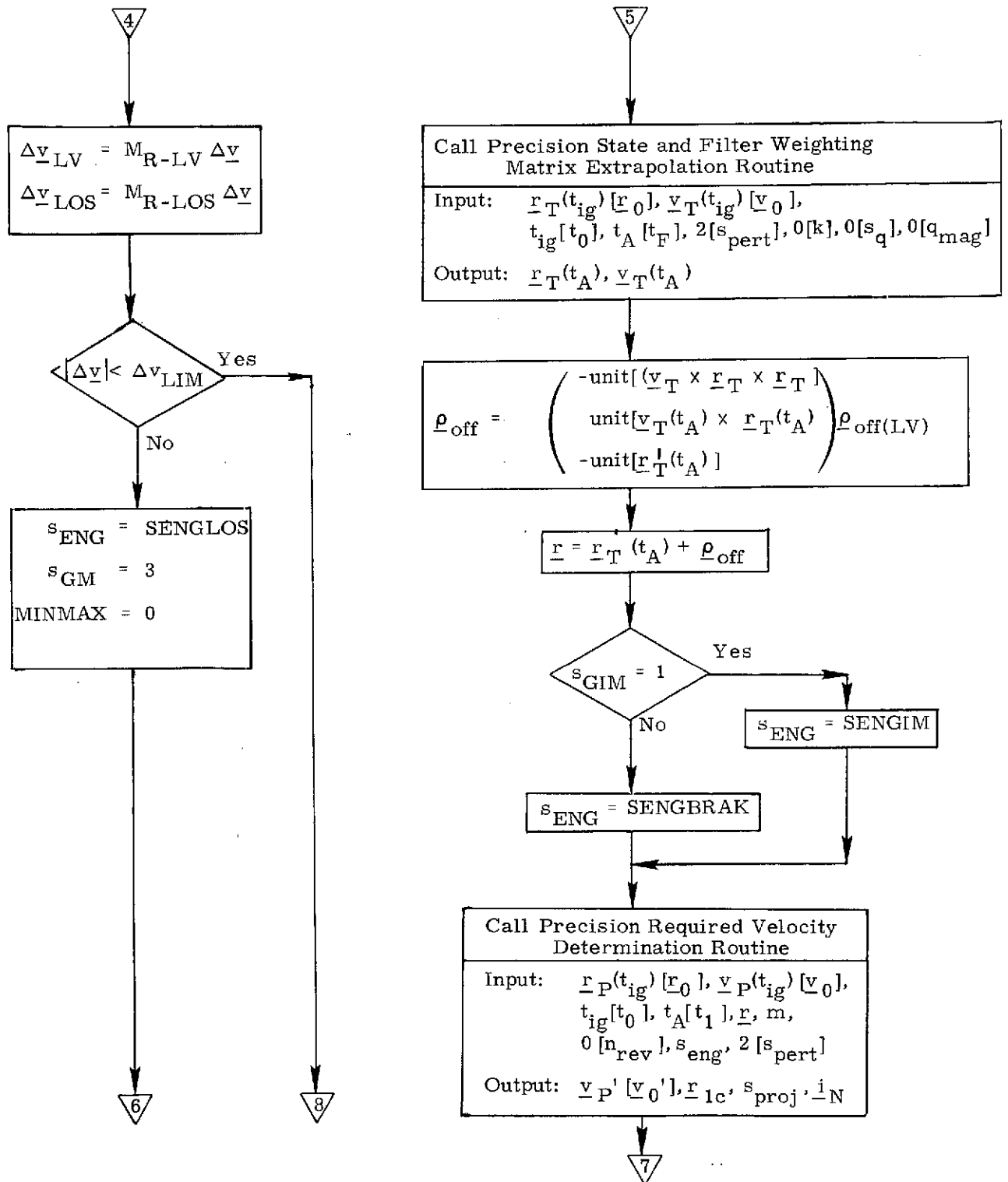


Figure 5e. Terminal Phase Targeting Routine, Detailed Flow Diagram

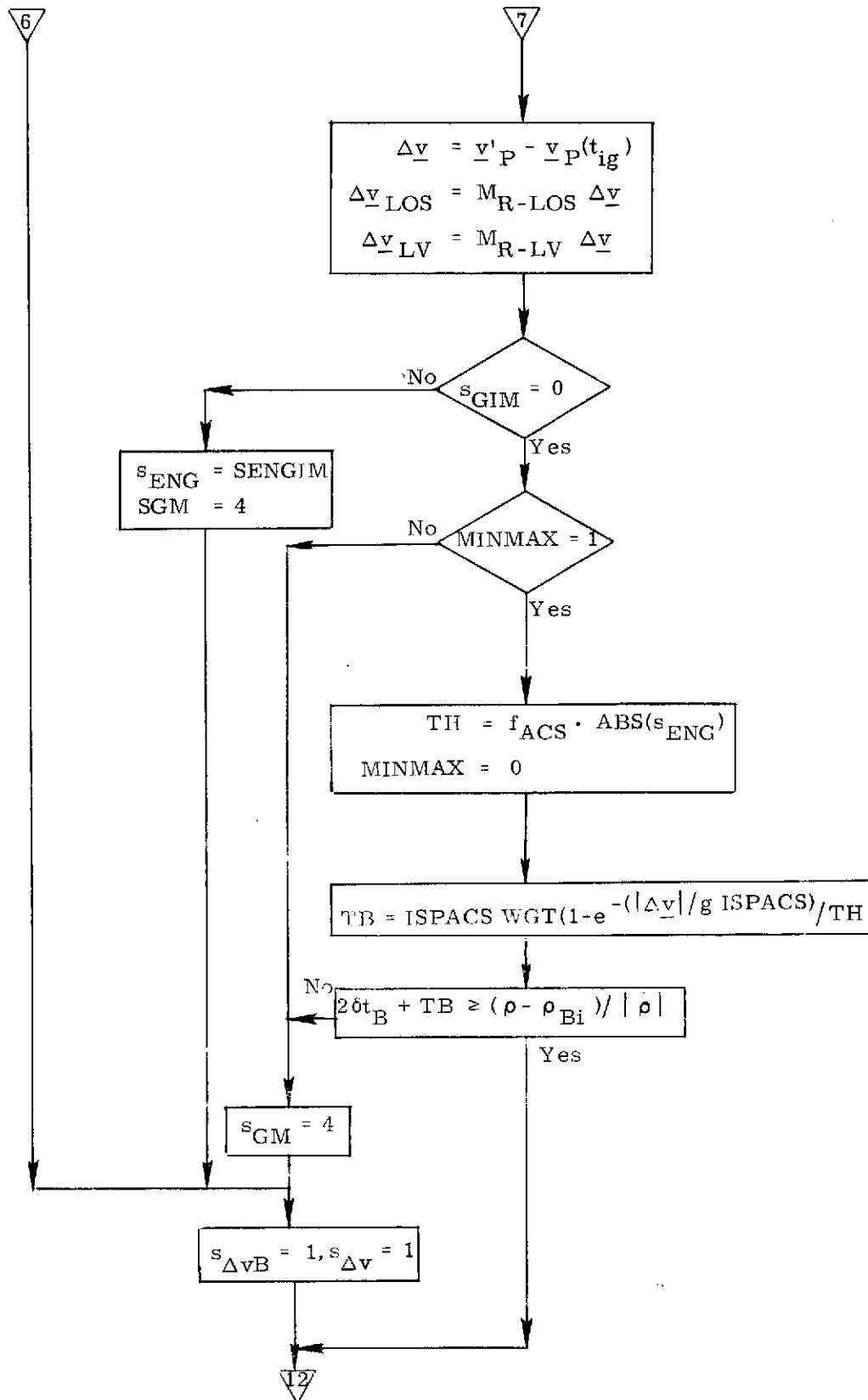


Figure 5f. Terminal Phase Targeting Routine, Detailed Flow Diagram

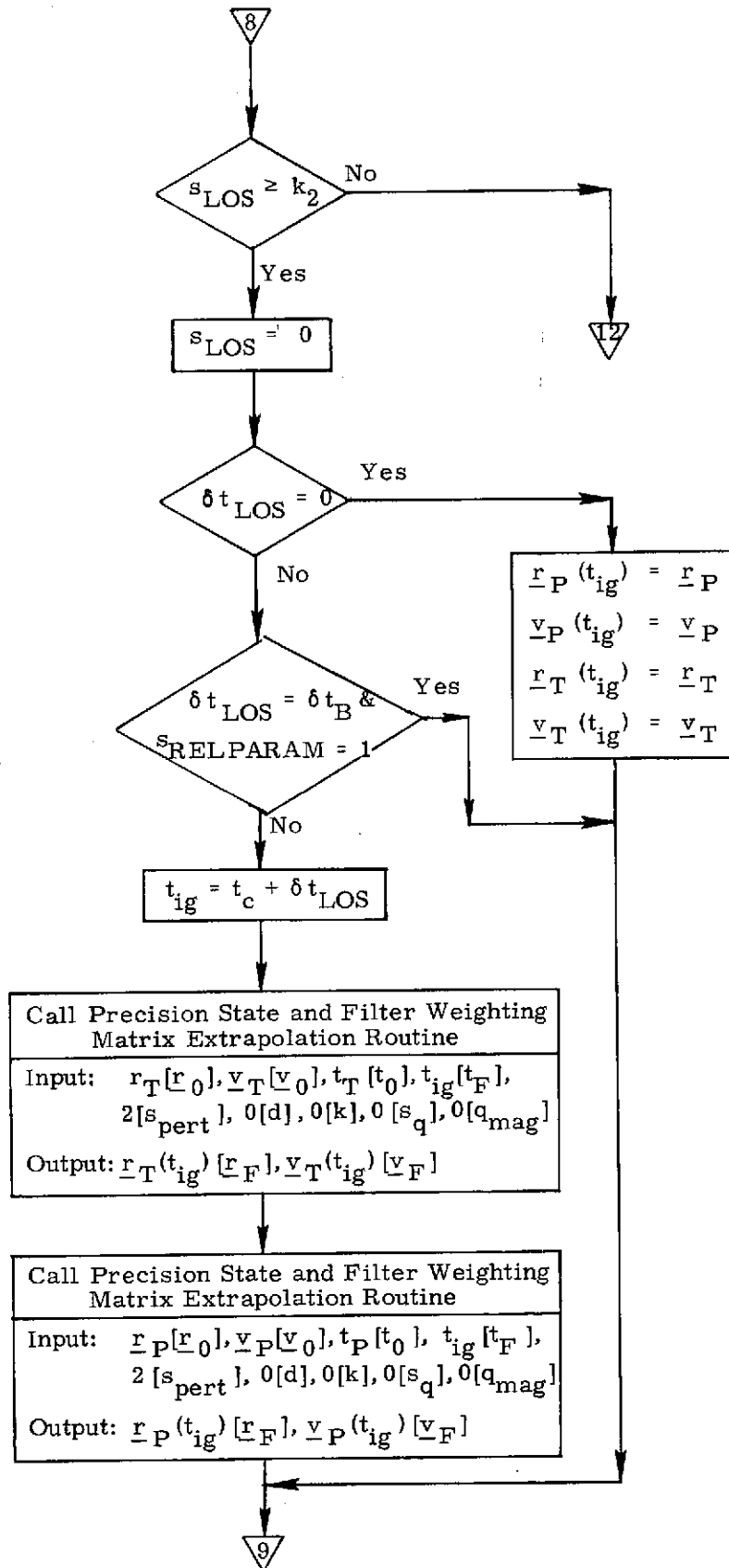


Figure 5g. Terminal Phase Targeting Routine, Detailed Flow Diagram

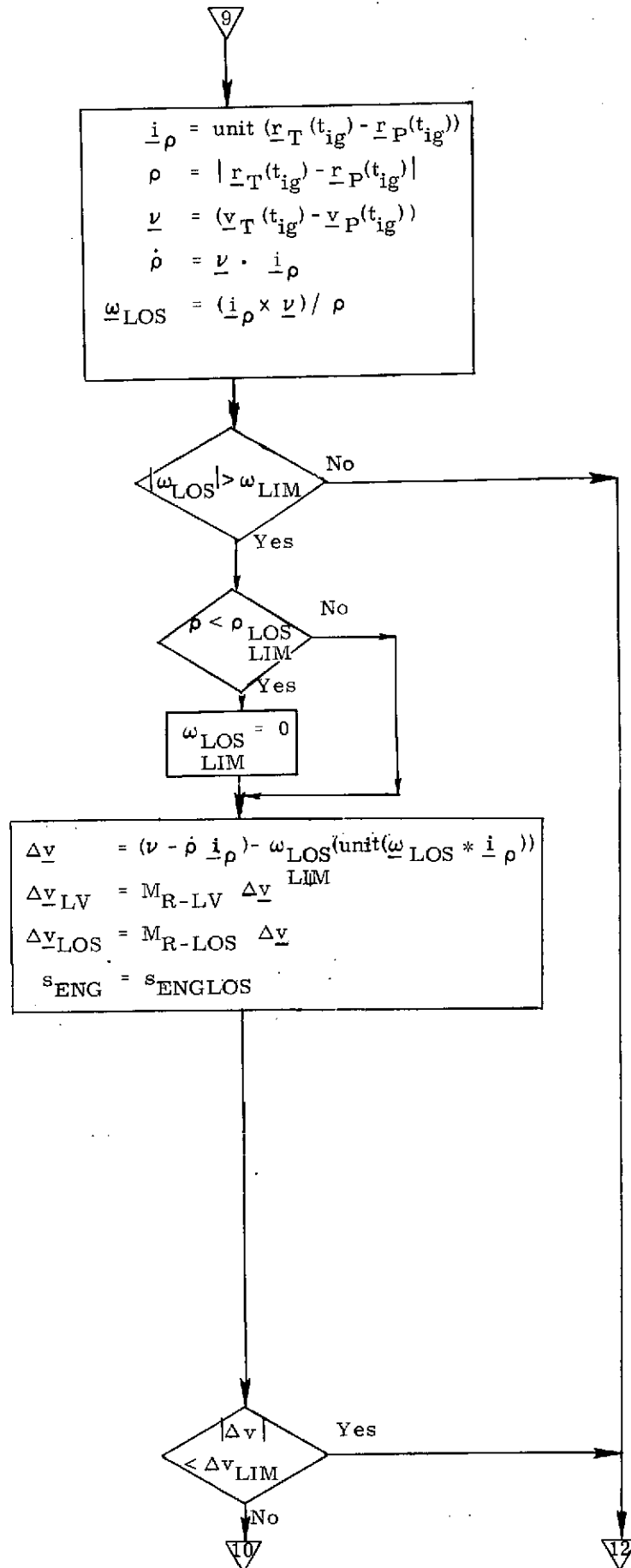


Figure 5h. Terminal Phase Targeting Routine, Detailed Flow Diagram

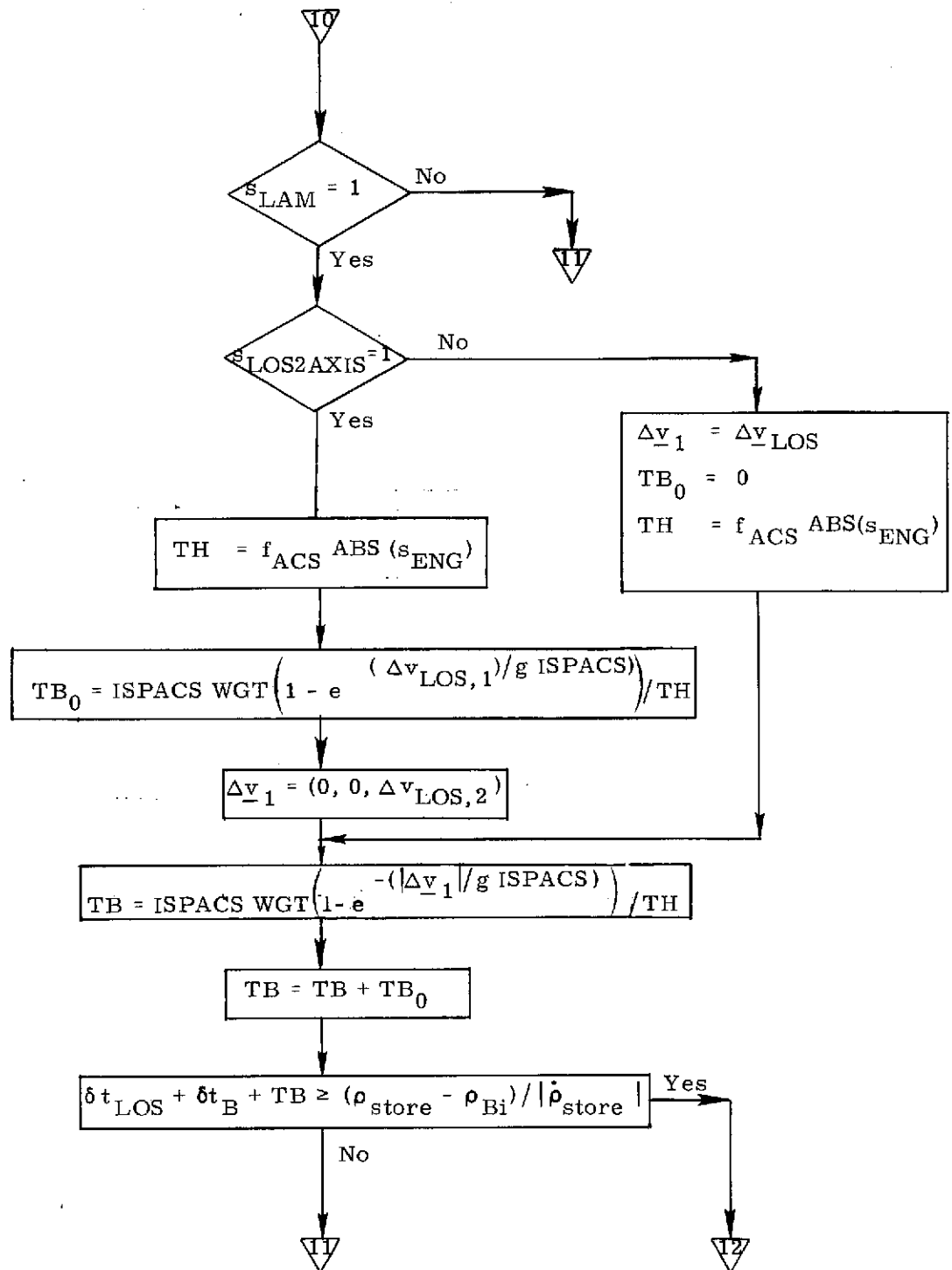


Figure 5i. Terminal Phase Targeting Routine, Detailed Flow Diagram

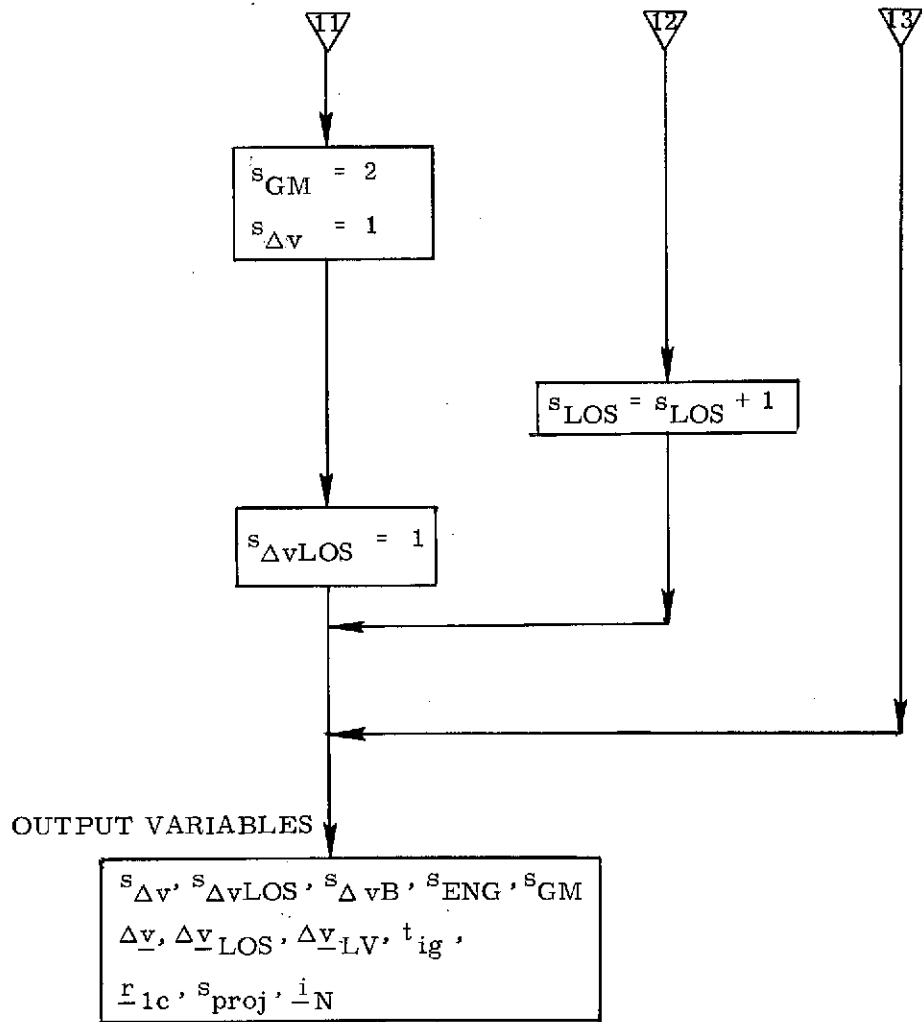


Figure 5j. Terminal Phase Targeting Routine, Detailed Flow Diagram

6. SUPPLEMENTARY INFORMATION

The Rendezvous Terminal Phase Targeting and Sequencing Programs utilize an inertial state vector formulation for both the target and primary vehicles. This formulation is the same as that employed throughout the rendezvous phase and therefore the navigation filter used to process the relative measurements is essentially the same for both phases. (See Ref. 1.)

The targeting program presently uses an inertial extrapolation of the state vectors to maneuver ignition at which point the necessary relative state information to compute the velocity correction is obtained by differencing the two inertial state vectors. This inertial extrapolation could be replaced by a relative state extrapolation (as well as a relative state formulation in the navigation filter) if required due to integration accuracy limitations but simulations to date have not shown the need to do this.

The Targeting Program contains two options as described previously: (1) "Lambert" maneuvers at the discrete braking gates with line-of-sight corrections performed as needed and (2) corrections down the line-of-sight at the discrete braking gates with line-of-sight corrections as needed.

When using mode two, the powered flight guidance routine holds the vehicle in inertial attitude from maneuver ignition until the completion of the burn.

In mode one operation, at each braking correction the powered flight guidance is such as to maintain essentially constant vehicle attitude burns which, however, are not in the direction of the estimated line-of-sight at maneuver ignition, since LOS rate is also implicitly corrected during the maneuver. The maneuver attitude is within 9° of the true line-of-sight throughout the duration of the burn.

Since the time of flight calculation used in this Lambert mode of operation assumes that the range-rate is constant from maneuver ignition to intercept, the estimated (as well as actual) range rate immediately following the maneuver will be higher than that desired by several feet per second. This is because the Lambert maneuver calculation takes into account the fact that the closing range rate between the vehicles will be gradually reduced due to differential gravity effects. This negates the need to use the multiplicative constant k_3 with the $\dot{\rho}_{\min}$ checks and requires a similar constant k_5 in the $\dot{\rho}_{\max}$ check loop when using mode 1.

Since the line-of-sight rate on an intercept trajectory is non-zero except for the last portion of the intercept the targeted line-of-sight rate corrections drive the line-of-sight rate to ω_{LIM} (0.2 mr/sec) at ranges greater than $\rho_{\text{LOS}} \cdot \text{LIM}$.

When the range decreases to below $\rho_{\text{LOS}} \cdot \text{LIM}$, the line-of-sight rate is driven to zero at each correction.