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## Entry Guidance and Entry Autopilot



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Lyndon B. Johnson Space Center  
Houston, Texas

SHUTTLE PROGRAM

MCC LEVEL C FORMULATION REQUIREMENTS

ENTRY GUIDANCE AND ENTRY AUTOPILOT

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## 1.0 SUMMARY

This document provides a set of preliminary entry guidance and autopilot software formulations for use in the Mission Control Center (MCC) entry processor. These software formulations meet all level B requirements as specified in reference 1.

## 2.0 INTRODUCTION

This internal note presents the level C software formulations requirements for the entry guidance and the simplified autopilot that will be used by the MCC entry processor. Revision 2 incorporates the modifications required to functionally simulate optional TAEM targeting capability (OTT). Implementation of this logic in the MCC must be coordinated with flight software OTT implementation (CR 12848H) and MCC TAEM guidance OTT (Revision 2 to MCC Level C Formulation Requirements for TAEM Guidance and Flight Control; JSC IN 76-FM-87). The entry guidance logic is based on the Orbiter avionics entry guidance software as described in reference 2. This MCC requirements document contains a definition of coordinate systems (3.2), a list of parameter definitions for the software formulations (3.3), a description of the entry guidance detailed formulation requirements (3.4), a description of the detailed autopilot formulation requirements (3.5), a description of the targeting routine (3.6), and a set of formulation flow charts (appendixes A through C).

## 3.0 SOFTWARE FORMULATION REQUIREMENTS

### 3.1 INTRODUCTION

The entry guidance system is the source of the bank angle and angle-of-attack commands used to control the entry trajectory. The entry guidance can be called by one of two means, either in the normal mode to generate a complete entry trajectory or as a part of the iterative targeting mode in the entry target generation (ETG) subphase of the deorbit processor. This logic will be discussed in section 3.4.

The autopilot generates the Orbiter attitude response to the entry guidance commands. This is accomplished by means of a simple phase plane in the bank angle and angle-of-attack axis. The sideslip angle ( ) is always assumed to be zero. This logic is discussed in section 3.5.

The targeting logic generates the range and heading information to the targeted runway and is used by the entry guidance and the deorbit processor. This logic is described in section 3.6.

## 3.2 COORDINATE SYSTEMS

Two basic coordinate systems are assumed by the software formulations described in this document. The state vector is assumed by the targeting routine (EGRT) to be in the Greenwich true-of-date system as defined in figure 3.2-1. The runway coordinate system is defined in figure 3.2-2 and is used by EGRT. The bank command and the angle-of-attack command generated by the entry guidance and executed by the autopilot are attitudes defined with respect to the Earth relative velocity vector.

## 3.3 PARAMETER LISTS AND DEFINITIONS

A complete list of all parameters used in the entry guidance, autopilot, and targeting routine is presented with appropriate definitions. Tables 3.3-1 and 3.3-2 present the input data for the entry guidance. Table 3.3-3 presents a list of the internal parameters for entry guidance. Table 3.3-4, 3.3-5, and 3.3-6 present the same data for the autopilot and tables 3.3-7, 3.3-8, and 3.3-9 present the data for the targeting routine.

## 3.4 ENTRY GUIDANCE FORMULATION

### 3.4.1 Requirements Overview

The entry guidance is the source for bank and angle-of-attack commands that are used to control the entry trajectory. The entry guidance can be called by either of two modes. If the entry guidance flag (EGFLG) is set to zero or one, a normal entry guidance function is exercised, which will duplicate the Orbiter avionics entry guidance function. This mode will be used to simulate an entry trajectory and will also be used in the final iteration mode of the entry target generator (ETG) processor. The second mode (EGFLG=2) is used in the entry processor to simulate an entry based on a "canned" drag profile for the ETG targeting processor.

In the normal mode (EGFLG=0), the entry guidance controls the entry trajectory by bank angle modulation while using a preselected angle-of-attack profile that is a function of relative velocity. Range predictions are based on solutions to the equation of motion for a specified entry drag-velocity profile. The drag-velocity profile, the shape of which is specified by the mission constants table, consists of quadratic, pseudoequilibrium glide, linear, and constant drag segments. Downrange errors are nulled by changing the magnitude of the bank angle, and crossrange errors are nulled by bank angle reversals that limit the crossrange error within a converging deadband. This mode begins at 400 000 feet and ends at TAEM interface, relative velocity = VT<sub>AEM</sub>.

In the ETG canned mode (EGFLG=2), the entry guidance controls the entry trajectory to a predefined drag-velocity profile. The entry simulations begin at 400 000 feet and are terminated after the pullout maneuver has been completed and the flight profile stabilized on the drag velocity profile at exactly 23 000 ft/sec relative velocity (VETG).



In the normal mode, the entry guidance consists of five major phases: the preentry phase, the temperature control phase, the equilibrium glide phase, the constant drag phase, and the transition phase, as shown in figure 3.4.1-1.

The preentry phase maintains the vehicle attitude until a predetermined total load factor level is reached (ASTART). During this phase, the vehicle is maintained in a three-axis attitude hold mode. This attitude is specified by the flight controller as MM 304  $\phi$ ,  $\alpha$ , and  $\beta$ . This phase is terminated at 5.66 ft/sec<sup>2</sup> total acceleration level and the temperature control phase is entered.

The temperature control phase is designed to control the entry trajectory through pullout to a temperature profile consistent with the overall entry profile shape optimization and entry ranging requirements. This phase consists of two quadratic drag-velocity segments that are used to optimize the entry profile. Range predictions are based on analytic solution of the equations of motion for these two segments. This phase is terminated at the velocity, VB1, specified in the mission constants table, and the guidance is transferred to the equilibrium glide phase at this point.

The equilibrium glide phase produces an equilibrium glide type trajectory, consistent with the ranging solution, until the equilibrium glide trajectory intersects the constant drag trajectory required to reach the target. At this point, control is transferred to the constant drag phase, and range predictions are based on a constant drag profile until the transition phase is entered. At a specified velocity, VTRAN, (mission constants table), control is transferred to the transition phase. The transition phase is based on a linear drag profile, as a function of energy, which is required to null the range error. The transition from the entry guidance to the TAEM guidance occurs at a velocity, VTAEM, specified in the mission constants table. Presently, this transfer point is at an Earth-relative velocity of 2500 ft/sec.

The entry guidance generates bank angle and angle-of-attack commands to be used by the autopilot. The bank angle commands are designed to converge the actual drag acceleration level to the reference drag-velocity profile, described above, that is consistent with the ranging solution. The bank angle command is generated from a vertical L/D command which is a function of a reference L/D, the difference between drag and drag reference, and the difference between altitude rate and altitude rate reference. The angle-of-attack profile is a function of Earth-relative speed and consists of a series of linear and quadratic segments. The angle-of-attack profile is controlled through inputs in the mission constants table. A complete derivation of all entry guidance equations can be found in reference 3.

### 3.4.2 Entry Guidance Executive (EGEXEC)

The EGEXEC function calls the other entry guidance functions in proper sequence and controls guidance phase transitions. In the normal mode EGFLG=0 or 1, entry guidance is divided into five phases: preentry, temperature control, equilibrium glide, constant drag, and transition. Each phase, except preentry, computes a reference drag acceleration profile that is based upon the ranging requirement and the vehicle constraints.

The computations performed during each guidance cycle vary with the guidance phase. The active guidance phase is defined by the integer variable ISLECT according to the following table.

| <u>ISLECT</u> | <u>Guidance Phase</u> |
|---------------|-----------------------|
| 1             | Preentry              |
| 2             | Temperature control   |
| 3             | Equilibrium glide     |
| 4             | Constant drag         |
| 5             | Transition            |

The entry guidance phase transfer logic is summarized in table 3.4.2.

The preentry phase commands a preselected bank angle in the EGPEP function. The preentry phase (ISELECT = 1) can be terminated by any of three conditions.

- a. Normal termination: The preentry phase is normally terminated at 5.66 ft/sec<sup>2</sup> by setting the ISLECT flag to 2 when the total acceleration exceeds the threshold value of ASTART ft/sec<sup>2</sup>.
- b. Alternate termination: If, at the threshold load factor level, the current constant drag level to reach the target is greater than the desired constant drag level (ALFM), ISLECT is set to 4. This could occur for an extremely short range case.
- c. Threshold load factor level: If the current relative velocity is less than VTRAN, ISLECT is set to 5.

The temperature control phase (ISLECT = 2) computes the required drag velocity profile during the high-temperature region of entry. The functions EGRP and EGREF contain the detailed temperature control equations used by the entry guidance. During the temperature control phase, the drag-velocity reference trajectory is divided into two quadratic segments. Function EGREF determines which of these quadratics is to be used. Figure 3.4.2-2 presents example quadratics for this phase. The quadratic for the higher velocity region is used when

$V_F > VA_1$ , and

$$DRF = (DREF(2) - DREF(1)) (DREF(2) - DREF(1)) + (HDTRF(1) - HDTRF(2) GS1) > 0$$

where DREF(1), HDTRF(1), DREF(2), and HDTRF(2) are all computed in EGREF. If either test is failed, then the reference parameters RDTREF and DREFP computed for the lower velocity drag profile are used. The quadratic segment switching point is controlled by the mission load parameter GS1. The quadratic switching logic, in the EGREF function, is similar to that used for guidance phase transitions.

The temperature control phase can be terminated in four ways:

- a. Normal termination: The temperature control phase normally transfers to the equilibrium glide phase, ISLECT = 3. Transfer is planned to occur when the drag reference profiles for the temperature control phase and the equilibrium glide phase intersect, as illustrated in figure 3.4.2-3. However, if the slopes of the two intersecting profiles are different, the bank-angle command may jump at the transfer point. Bank-smoothing logic provides a smooth roll-angle command history for minimum RCS fuel usage by transferring phases when the commanded bank angle is the same for both phases. This transition occurs before the intersection point of the drag profiles and is accomplished by use of the following equation:

If  $VE < VA$ , and

$$DREFP < DREFP3$$

then:

$$ISLECT = 3$$

where  $DREFP3 = DREFP1 + GS2 (RDTREF - RDTRF1)$ , and  $DREFP3$  is computed in the EGREF function. The value of  $GS2$  determines the transfer point.

- b. Alternate termination: The guidance transfers to phase 3 when  $VE < VB1$  if the bank-smoothing logic has not been satisfied by that time. Thus, if  $VE < VB1$ , then  $ISLECT = 3$ .
- c. Alternate termination for short ranges: For very short range targets, the desired constant drag level may be reached before equilibrium glide phase initiation. In this case, control is transferred directly from the temperature control phase to the constant drag phase

(ISLECT = 4) when

$VE < VCG + DELV$ , and

$$DREFP > DREFP4$$

where  $DREFP4 = T2 + GS3 (RDTREF + 2 HS T2/VE)$ , and  $DREFP4$  is computed in EGREF. Bank command smoothing is provided through the constant  $GS3$ .

- d. Extremely short range termination: Transition to phase 4 occurs

If  $T2 > ALFM$

then:

$$ISLECT = 4$$

where  $T2$  is computed in EGCOMN.

The equilibrium glide phase (ISLECT = 3) shapes the drag velocity profile so that the constant drag level to reach the target converges on the desired constant drag level, ALFM. The functions EGRP and EGREF contain the equilibrium glide equations. There are three possible transfers from the equilibrium glide phase:

- a. Normal termination: The equilibrium glide phase transfers to the constant drag phase, ISLECT = 4. Bank-smoothing logic is provided by the constant GS3. Transfer occurs when

$$VE < VCG + DELV, \text{ and}$$

$$DREFF > DREF4$$

where  $DREF4 = T2 + GS3 (RDTREF + 2 HS T2/VE)$

and is again computed in EGREF.

- b. Alternate termination: For very long-range trajectories, the predicted velocity at the intersection of the equilibrium glide and constant drag phases is less than the transition phase initiation velocity, VTRAN. When this occurs, the equilibrium glide phase transfers directly into the transition phase, ISLECT = 5. The transition to phase 5 occurs when

$$VE < VCG + DELV, \text{ and}$$

$$VCG < VTRAN, \text{ and}$$

$$DREFF > DREF5$$

where  $DREF5 = DF + (EFF - EEF4) C1 + GS4 (RDTREF - RDTRFT)$  is computed in EGCOMN. The variables EEF, C1, and RDTRFT are also computed in EGCOMN. As in other phases, bank-smoothing logic is provided by the mission load constant GS4.

- c. Alternate termination: For extremely short ranges, as in the temperature control phase, transition to the constant drag phase (ISLECT = 4) occurs if

$$T2 > ALFM$$

where T2 is again computed in EGCOMN.

The constant drag phase (ISLECT = 4) shapes the entry profile along a constant drag velocity profile to maximize the control system margins. Function EGREF4 contains the constant drag range prediction and controller equations. The constant drag phase terminates and transfers to the transition phase (ISLECT = 5) at a predetermined time before the transition energy level, ETRAN. Transfer occurs when

VE < VTRAN + DELV, and

DREFF > DREFF5

where DREFF5 = DREFF5 in the equilibrium glide phase and the computed in EGCORN.

The transition phase is the final entry phase and is used to steer the Orbiter to the proper TAEM interface conditions. The transition phase and entry guidance are terminated at the start of the TAEM major mode. The entry-to-TAEM transition logic is defined by

If (ISLECT ≠ 1 and VE < V\_TAEM) then EG\_END = 1

To execute the entry guidance computations properly, the following functions must be called in the sequence shown:

- a. The EGSCALEHT function is called.
- b. On the first entry guidance pass (START = 0), EGINIT is then executed.
- c. The EGCORN function is called.
- d. The phase transition logic for the preentry phase (ISLECT = 1) and the first alternation termination test for the temperature control phase (if VE < VB1, then ISLECT = 3) are executed within EGEXEC. The tests to transfer to phase 4 if T2 > ALFM are also made at this time.

The functions next called depend on the value of ISLECT:

If ISLECT = 1, then perform EGPEP

If ISLECT = 2 or 3, then perform EGRP, and then EGREF

If ISLECT = 4, then perform EGREF4

If ISLECT = 5, then perform EGTRAN

After these functions have been executed, the remainder of the phase transition logic may be performed within EGEXEC at any time. The output commands are then computed by calling EGALPCMD (angle-of-attack command) and the sequence EGGNSLCT, EGLDVCMD, and EGROLCMD (bank-angle command). If ISLECT = 1, EGGNSLCT and EGLDVCMD are bypassed; and only EGALPCMD and EGROLCMD are called. For all values of ISLECT, either the angle-of-attack or bank-angle command may be computed first. The entry guidance execution sequence is summarized in figure 3.4.2-4.

In the ETG "canned" mode EGFLG = 2, ISLECT is never allowed to be greater than 2.

### 3.4.3 Entry Guidance Scale Height (EGSCALEHT)

The guidance function EGSCALEHT generates an altitude scale height (of atmospheric density) modeled on the 1962 standard atmosphere. This parameter is used in calculating the altitude rate reference term

$$RDTRF = -HS \left( \frac{2D}{VE} + \frac{\dot{D}}{D} + \frac{\dot{cd}}{cd} \right)$$

where D = drag acceleration

$\dot{D}$  = time derivative of D

cd = drag coefficient

$\dot{cd}$  = time derivative of cd

Empirical curve fits of the altitude scale height, HS, as a function of relative velocity, Ve, have been implemented into the entry guidance.

### 3.4.4 Entry Guidance Initialization (EGINIT)

The guidance function EGINIT serves as the initialization routine for entry guidance. In this routine initial values are set and parameters calculated only one time are computed.

### 3.4.5 Entry Guidance Common Computation (EGCOMN)

The entry guidance contains several parameters used continuously throughout the guidance program. These are computed in EGCOMN and are such parameters as energy, EEF, the constant drag level to reach the target (T2), and the rate of change of T2, T2DOT.

### 3.4.6 Entry Guidance Preentry Phase (EGPEP)

In the Orbiter avionics system, the purpose of EGPEP is to generate a vertical L/D command (LODV) by means of the ILCAD parameter PREBNK. However, in order for the MCC to simulate either an automatic or manual preentry phase, the LODV equation in the Orbiter avionics system should be replaced by the bank-angle input in MM 304  $\phi$  by the flight controller. Also, the angle-of-attack command issued in EGALPCMD should be overridden by MM 304 $\alpha$ . The preentry phase, ISLECT = 1, is terminated by EGEXEC at a sensed total acceleration level equal to ASTART (currently 5.66 ft/sec<sup>2</sup>).

### 3.4.7 Entry Guidance Range Prediction (EGRP)

THE EGRP function serves as the range predictor during the temperature control and equilibrium glide phases. The range prediction is then used to determine the proper drag level during phases 2 and 3 to achieve the desired range at the entry-TAEM interface is only called when ISLECT is equal to 2 or 3.

In order to determine the proper drag-velocity profile for range control, a range prediction is made of the entire entry trajectory. This is accomplished by using five drag-velocity segments; two during the temperature control phase, one during the equilibrium glide phase, one during the constant drag phase, and a constant range value during the transition phase. The temperature control, equilibrium glide, and constant drag phase range segments are computed in EGRP. The range value for transition, RPT, is computed in EGINIT and is constant in order to provide a nominal transition range at the transition interface, VTRAN. Once the transition phase is entered, the transition range prediction is modified in the EGTRAN function to meet the range requirements.

The drag-velocity segments during the temperature control, equilibrium glide, and constant drag phases are anchored at specific velocity points as illustrated in figure 3.4.7-1.

The range for the temperature control phase is predicted along two quadratic drag-velocity segments anchored at VB1 and at VA1. For the equilibrium glide segment, the range is predicted between VB1 and VCC, the computed intersection point between the equilibrium glide phase and constant drag phase; and for the constant drag segment, the range is predicted between VCG and VQ. In all cases, the entire drag-velocity profile is anchored at a drag level of D23 at a velocity of VB. During the temperature control phase, VB is defined as VB1; and during the equilibrium glide phase, VB is defined as the current relative velocity. Therefore,

If  $VE > VB1$        $VB = VB1$

If  $VE \leq VB1$        $VB = VE$

In the equilibrium glide phase, as the drag profile approaches the desired constant drag level, the locus of the equilibrium glide drag reference parameter may wander from a precise equilibrium glide profile shape trying to drive T2 to precisely ALFM, the desired constant drag level. In order to provide a more uniform equilibrium glide drag profile at the function point between the equilibrium glide and the constant drag phases, the equilibrium glide reference profile is "frozen" when the rate of change of T2 is near zero. This is illustrated in figure 3.4.7-2. This is accomplished by freezing VB at the current value of VE when T2DOT becomes less than DT2MIN and when VE is less than VCG + DELV.

If EGFLG is equal to 2, ETG canned mode, the ranging iteration of D23 is bypassed and D23 is set equal to D23C in order to provide a "canned" drag velocity profile for the ETG mode.

#### 3.4.8 Entry Guidance Reference Parameters (EGREF)

In order to control the Orbiter to the desired drag-velocity profile required for range control, a bank angle command is generated from a vertical L/D command equation. This vertical L/D command equation consists of actual and reference parameters. The function of EGREF is to generate the drag reference, the altitude rate reference, and the phase dependent part of the L/D reference parameter for the temperature control and the equilibrium glide phase. This function is only called when ISLECT is equal to 2 or 3.

#### 3.4.9 Entry Guidance Constant Drag Phase (EGREF4)

The purpose of the EGREF4 function is to generate the drag reference, the altitude rate reference, and the phase dependent part of the L/D reference for the constant drag phase. This function is called only when ISLECT is equal to 4.

#### 3.4.10 Entry Guidance Transition Phase (EGTRAN)

The transition phase function EGTRAN computes the range potential from the drag reference level at the end of the constant drag phase to the transition phase end target conditions, DF and EEF4, and then computes the correct drag-energy profile to null any range error. EGTRAN also computes the controller reference parameters: drag reference, altitude rate reference, and the phase dependent part of L/D reference. This function is called only when ISLECT is equal to 5.

#### 3.4.11 Entry Guidance Angle-Of-Attack Function (EGALPCMD)

The EGALPCMD function generates the angle-of-attack command for the flight control system. The angle-of-attack profile commanded by the entry guidance is a preselected profile established by means of mission dependent constants. The entry velocity regime is divided into NALP+1 segments, and the commanded angle of attack in each segment is defined by a quadratic function of relative velocity. Figure 3.4.11-1 shows a typical angle-of-attack command profile and illustrates the flexibility available in the profile selection.

#### 3.4.12 Entry Guidance Gain Selection Function (EGNSLCT)

THE EGGNSLCT function computes the drag error gain, C16, and the altitude rate error gain, C17, in the controller vertical L/D command equation. These gains are a function of the actual drag acceleration level and the difference between drag and drag reference.



### 3.4.13 Entry Guidance Lateral Logic and Vertical L/D Command Function (EGLODVCMD)

The purpose of the EGLODVCMD function is to:

Compute the L/D reference parameter, ALDREF

Compute a  $\dot{R}$  feedback term to correct drag error biases caused by poor navigation (DLRDOT)

Compute the vertical L/D command from the controller equation:

$$LODX = ALDREF + C16 (DRAG - DREFP) + C17 (RDTRF + DLRDOT - RDOT)$$

Perform a velocity check to see if angle-of-attack modulation should begin in order to keep drag on the drag reference profile.

Compute the bank angle limit LMN and finally to compute the bank direction, RK2ROL.

### 3.4.14 Entry Guidance Bank Command Function (EGROLCMD)

The purpose of the EGROLCMD function is to generate a bank command for the autopilot and a bank reference parameter for display. The bank command is computed from the vertical L/D command parameter and the bank reference is computed from L/D reference. If the angle-of-attack modulation flag, ICT, is equal to one, a bank command bias is computed as a function of the ALPHA difference with respect to the nominal ALPHA schedule.

### 3.4.15 Entry Guidance Data Flow Summary

The data flow charts (figs. 3.4.15-1 and 3.4.15-2) present the data flow of all computed and stored parameters within the entry guidance.

## 3.5 ENTRY AUTOPILOT FORMULATION

### 3.5.1 Requirements Overview

A simple 3-degrees-of-freedom autopilot is required to execute the bank and angle-of-attack commands generated by the entry guidance. The autopilot requirements are the same for both of the entry guidance modes.

The autopilot, by means of a simple phase plane, generates the actual bank angle and angle of attack based on a maximum acceleration and rate limit in the bank and pitch channels. The sideslip angle ( $\beta$ ) is always assumed to zero.

The entry guidance generates a bank and angle-of-attack command necessary to control the trajectory. The autopilot generates the Orbiter attitude response to

these commands over the next computer cycle (2.0 seconds) ignoring the high frequency dynamics. Based on the attitude response characteristics, the autopilot determines if the commanded attitude can be achieved during the next computer cycle, and if commanded attitudes cannot be achieved, the autopilot determines the achievable attitude at the end of the computer cycle. If the attitude can be reached within the computer cycle, a deadband attitude and rate is established about the commanded attitude. This new attitude is then used to compute the trajectory dynamics and the accelerations for the next integration step during entry.

### 3.5.2 Autopilot Executive (DAP3D)

The autopilot executive routine, DAP3D, is the driver routine for the simplified autopilot phase plane, PHSPLN. Assuming a 4-pass Runge-Kutta integrator, PHSPLN is called on the first and third pass by means of the pass counter ICTRN. ROLPLN and PCHPLN are entry points for the generalized routine PHSPLN and are called for bank attitude control and angle-of-attack control, respectively.

DAP3D also computes the Orbiter attitude with respect to the velocity vector, bank, sideslip and angle of attack. These attitudes are then used in the generation of the body to inertial coordinate system transformation matrix. Table 3.3-4 presents the inputs to the autopilot. Table 3.3-5 presents the outputs and table 3.3-6 presents the internal parameter definitions. Appendix B presents the formulation flow charts, and appendix D presents the IBM structured flow charts for the autopilot.

### 3.5.3 Autopilot Phase Plane (PHSPLN)

The PHSPLN routine is a simplified phase plane that is used to generate the Orbiter bank and angle-of-attack attitude. The routine PHSPLN has two entry points, ROLPLN and PCHPLN that update the bank and angle of attack attitudes respectively. The phase plane logic uses an acceleration level, RA or PA, a maximum rate, RRM or PRM and an attitude deadband RADB or PADB and a bank or angle-of-attack error to determine the current Orbiter attitude. A variable, ICPPLN, has been added to allow the calling frequency of the routine per integration  $\Delta t$  to be selected by the user.

### 3.5.4 Autopilot Data Flow Summary

The data flow charts (figs. 3.5.4-1 and 3.5.4-2) present the data flow of all computed and stored parameters with the autopilot.

## 3.6 TARGETING ROUTINE (EGRT)

The targeting routine, EGRT, computes the great circle range from the Orbiter to the runway threshold point via the heading alignment cone (spiral in ground plane). This is accomplished by determining the tangent point on the heading alignment cone of a vector from the vehicle to the alignment cone. This tangent

point is converted into an Earth-fixed position vector, and the great circle range to target is computed between the vehicle and this tangent point. The arc length is then computed from the tangent point around the alignment cone to WP1, the straight in approach point. The range to target is then computed as the sum of the great circle range to the tangent point, the arc length around the alignment cone, and the distance between WP1 and the runway threshold point. The azimuth error is computed as the difference between the vehicle Earth-relative azimuth and the heading to the heading alignment tangent point. Change 8 incorporates the required modifications to the targeting logic for optional TAEM targeting (OTT) capability. This capability allows selection of either an overhead (far HAC initially) or straight-in (nearest HAC) approach for both primary and secondary runways independently by MED input. The desired mode is obtained by setting the input flag OVHD to one or zero to obtain either an overhead or straight-in approach, respectively. This flag is a two-element array where the first element denotes primary runway and second element denotes secondary runway (secondary is required only for midtargeting and redesignation options). The selected runway designation flag (RWID) is required as input for proper initialization at time of redesignation. RWID = 1 if the primary runway is selected and RWID = 2 if a redesignation to the secondary runway has occurred. The velocity to switch HAC targeting overhead status is nominally zero but may be input via MED to simulate a manual HAC toggle during the entry trajectory. The midpoint targeting is needed to minimize the delta range and azimuth error for a redesignation due to low altitude winds. Midpoint targeting is accomplished by targeting to both primary and secondary runways and averaging the range and azimuth error values and is terminated when

- a. The crew selects the desired runway
- b. The relative velocity satisfies a preset velocity limit and the primary runway is selected by default

The flow charts for the targeting routine are found in appendix C and are subdivided into the following functions:

### 3.6.1 EGRT-EXEC, Targeting Executive Logic

This routine performs the necessary initialization of targeting parameters and calls the EGRT sequence controller. If midpoint targeting is active, the EGRT sequence is recycled for the secondary runway, and the resulting ranges and azimuth errors are averaged. The EGRT sequence controller executes the following subfunctions for the specified input argument list.

### 3.6.2 EGRT-CHACRC, Center of Heading Alignment Cone - Runway Coordinates

This routine computes the position of the center of the heading alignment cone in runway coordinates.

### 3.6.3 EGRT-CHACRC, Center of Heading Alinement Cone in Earth-Fixed Coordinates

This function transforms the center of the heading alinement cone vector to the Earth-fixed coordinate system.

### 3.6.4 EGRT-BV, Bearing of the Vehicle

This function computes the bearing of the vehicle based on the current vehicle Earth-fixed position vector.

### 3.6.5 EGRT-BVCHAC, Bearing to Center of the Alinement Cone

This function computes the bearing from the vehicle to the center of the heading alinement cone.

### 3.6.6 EGRT-COSTHETA, Great Circle Arc

This function computes the great circle arc between the vehicle and the center of the heading alinement cone.

### 3.6.7 EGRT-DWP1, Distance to WP1

This function computes the range to the tangency point on the heading alinement cone.

### 3.6.8 EGRT-DVNEP, Range-to-Threshold Point

This function computes the heading to the tangency point on the heading alinement cone, the distance around the alinement cone, and the final range to the runway threshold point.

### 3.6.9 EGRT-DELAZ, Azimuth Error

This function computes the azimuth error between the vehicle heading and the heading to the tangency point of the alinement cone.

#### 4.0 REFERENCES

1. SMCC Level B Formulation Requirement: Entry Guidance and Entry Autopilot, JSC IN 76-FM-77, September 23, 1976.
2. Space Shuttle Orbital Flight Test Level C Functional Subsystem Software Requirements Document Guidance, Navigation, and Control - Part A: Guidance, Rockwell International, SD76-SH-0001B, November 19, 1976.
3. Analytic Drag Control Entry Guidance System, JSC IN 74-FM-25, Revision 1, January 21, 1975.
4. Space Shuttle Orbital Flight Test Level C Functional Subsystem Software Requirements Document Guidance, Navigation, and Control - Part B: Navigation, Rockwell International SD76-SH-0005, February 1976.

TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA

(a) Input parameters

| Symbol         | Description                        | Source                    | Unit                |
|----------------|------------------------------------|---------------------------|---------------------|
| ALPHA          | Angle of attack                    | Autopilot                 | deg                 |
| DELAZ          | Current azimuth error              | EGRT                      | rad                 |
| DRAG           | Current drag acceleration          | State vector              | ft/sec <sup>2</sup> |
| EGFLG          | Guidance mode flag                 | Entry processor executive | n.d.                |
| HLS            | Altitude above runway              | State vector              | ft                  |
| LOD            | Current lift/drag ratio            | Aerodynamics              | n.d.                |
| RDOT           | Current oblate Earth altitude rate | State vector              | ft/sec              |
| ROLL           | Current bank angle                 | Autopilot                 | rad                 |
| START          | Initialization flag                | Entry processor executive | n.d.                |
| TRANGE         | Current range to runway            | EGRT                      | n. mi.              |
| VE             | Current relative velocity          | State vector              | ft/sec              |
| VI             | Current inertial velocity          | State vector              | ft/sec              |
| XLFAC          | Current load factor                | Aerodynamics              | ft/sec <sup>2</sup> |
| MM304 $\phi$   | Preentry bank angle                | Med input                 | deg                 |
| MM304 $\alpha$ | Preentry angle of attack           | Med input                 | deg                 |
| MEP            | Left-hand HAC select flag          | n.d.                      |                     |

TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA - Continued

## (b) Input constants

| Symbol   | Description   | Value     | Unit                | Range           | Class       |
|----------|---|-----------|---------------------|-----------------|-------------|
| ACLAM1   | Maximum $\alpha$ constant   | 15.0      | deg                 | 0 to $\pm$ 1000 | f           |
| ACLAM2   | Maximum $\alpha$ constant (f(VE))                                   | 0.0025    | deg-sec/ft          | 0 to $\pm$ 10   | f           |
| ACLIM1   | Minimum $\alpha$ constant   | 37.0      | deg                 | 0 to $\pm$ 1000 | f           |
| ACLIM2   | Minimum $\alpha$ constant (f(VE))                                   | 0.        | deg-sec/ft          | 0 to $\pm$ 10   | f           |
| ACLIM3   | Minimum $\alpha$ constant   | 7.6666667 | deg                 | 0 to $\pm$ 1000 | f           |
| ACLIM4   | Minimum $\alpha$ constant (f(VE))                                   | .00223333 | deg-sec/ft          | 0 to $\pm$ 10   | f           |
| ACN1     | Time constant for R feedback  | 50        | sec                 | —               | Mission (m) |
| AK       | Factor in dD/dV for temperature control guidance used to define C23 | -3.4573   | n.d.                | 0 to $\pm$ 100  | m           |
| AK1      | Factor in dD/dV for temperature control guidance used to define C23 | -4.76     | n.d.                | 0 to $\pm$ 100  | m           |
| ALPM     | Desired constant drag level   | 33.0      | ft/sec <sup>2</sup> | 0 to $\pm$ 50   | m           |
| ALIM     | Maximum sensed acceleration in transition                           | 70.84     | ft/sec <sup>2</sup> | -               | fixed (f)   |
| ALMN1    | Maximum L/D command outside of heading error deadband               | 0.7986355 | n.d.                | -               | f           |
| ALMN2    | Maximum L/D command inside of heading error deadband                | 0.9659258 | n.d.                | -               | f           |
| ALMN3    | Maximum L/D command below VELMN                                     | 0.93969   | n.d.                | -               | f           |
| ALMN4    | Maximum L/D command above VYLMAX                                    | 1.0       | n.d.                | -               | f           |
| ASTART   | Sensed acceleration to enter phase 2                                | 5.66      | ft/sec <sup>2</sup> | -               | f           |
| CALPO(1) | ALPCMD constant term in VE  | 19.455    | deg                 | 0 to $\pm$ 1000 | m           |
| CALPO(2) | ALPCMD constant term in VE  | -4.074    | deg                 | 0 to $\pm$ 1000 | m           |
| CALPO(3) | ALPCMD constant term in VE  | -4.2778   | deg                 | 0 to $\pm$ 1000 | m           |
| CALPO(4) | ALPCMD constant term in VE  | 16.398    | deg                 | 0 to $\pm$ 1000 | m           |
| CALPO(5) | ALPCMD constant term in VE  | 4.476     | deg                 | 0 to $\pm$ 1000 | m           |

TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA - Continued

(b) Input constants - Continued

| Symbol    | Description                 | Value         | Unit                                  | Range           | Class |
|-----------|-----------------------------|---------------|---------------------------------------|-----------------|-------|
| CALPO(6)  | ALPCMD constant term in VE  | -9.9339       | deg                                   | 0 to $\pm 1000$ | m     |
| CALPO(7)  | ALPCMD constant term in VE  | 40            | deg                                   | 0 to $\pm 1000$ | m     |
| CALPO(8)  | ALPCMD constant term in VE  | 40            | deg                                   | 0 to $\pm 1000$ | m     |
| CALPO(9)  | ALPCMD constant term in VE  | 40            | deg                                   | 0 to $\pm 1000$ | m     |
| CALPO(10) | ALPCMD constant term in VE  | 40            | deg                                   | 0 to $\pm 1000$ | m     |
| CALP1(1)  | ALPCMD rate term in VE      | -.776388E-2   | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(2)  | ALPCMD rate term in VE      | 8.747711E-3   | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(3)  | ALPCMD rate term in VE      | .8875002E-2   | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(4)  | ALPCMD rate term in VE      | -.3143109E-3  | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(5)  | ALPCMD rate term in VE      | 3.1875E-3     | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(6)  | ALPCMD rate term in VE      | 6.887436E-3   | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(7)  | ALDCMD rate term in VE      | 0             | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(8)  | ALDCMD rate term in VE      | 0             | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(9)  | ALDCMD rate term in VE      | 0             | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP1(10) | ALDCMD rate term in VE      | 0             | deg-sec/ft                            | 0 to $\pm 10$   | m     |
| CALP2(1)  | ALPCMD quadratic term in VE | .2152776E-5   | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |
| CALP2(2)  | ALPCMD quadratic term in VE | -7.44E-7      | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |
| CALP2(3)  | ALPCMD quadratic term in VE | -0.7638891E-6 | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |
| CALP2(4)  | ALPCMD quadratic term in VE | 0.2571456E-6  | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |
| CALP2(5)  | ALPCMD quadratic term in VE | 0             | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |
| CALP2(6)  | ALPCMD quadratic term in VE | -2.374978E-7  | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |
| CALP2(7)  | ALPCMD quadratic term in VE | 0             | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |
| CALP2(8)  | ALPCMD quadratic term in VE | 0             | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$    | m     |



TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA - Continued

(b) Input constants - Continued

| Symbol    | Description                                   | Value       | Unit                                  | Range        | Class |
|-----------|---|-------------|---------------------------------------|--------------|-------|
| CALP2(9)  | ALPCMD quadratic term in VE                   | 0           | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$ | m     |
| CALP2(10) | ALPCMD quadratic term in VE                   | 0           | deg-sec <sup>2</sup> /ft <sup>2</sup> | 0 to $\pm 1$ | m     |
| CDDOT1    | CD velocity coefficient                       | 1500        | ft/sec                                | -            | f     |
| CDDOT2    | CD velocity coefficient                       | 2000        | ft/sec                                | -            | f     |
| CDDOT3    | CD velocity coefficient                       | 0.15        | n.d.                                  | -            | f     |
| CDDOT4    | CD alpha coefficient                          | 0.0783      | n.d.                                  | -            | f     |
| CDDOT5    | CD alpha coefficient                          | -8.165E-3   | 1/deg                                 | -            | f     |
| CDDOT6    | CD alpha coefficient                          | 6.833E-4    | 1/deg <sup>2</sup>                    | -            | f     |
| CDDOT7    | CD coefficient                                | 7.5E-5      | sec/ft                                | -            | f     |
| CDDOT8    | CD coefficient                                | 13.666E-4   | 1/deg <sup>2</sup>                    | -            | f     |
| CDDOT9    | CD coefficient                                | -8.165E-3   | 1/sec                                 | -            | f     |
| CNMFS     | Conversion factor from feet to nautical miles | 1.645788E-4 | n.mi./ft                              | -            | f     |
| CRDEAF    | Gain on roll bias for $\alpha$ modulation     | 4.0         | n.d.                                  | 0 to 10      | m     |
| CT16(1)   | C16 coefficient                               | 0.1354      | sec <sup>2</sup> /ft                  | -            | f     |
| CT16(2)   | C16 power coefficient                         | -0.10       | n.d.                                  | -            | f     |
| CT16(3)   | C16 drag error coefficient                    | 0.006       | sec <sup>2</sup> /ft                  | -            | f     |
| CT17(1)   | C17 coefficient                               | 1.537E-2    | sec/ft                                | -            | f     |
| CT17(2)   | C17 power coefficient                         | -5.8146E-1  | n.d.                                  | -            | f     |
| CT16MN    | Minimum value of C16                          | 0.025       | sec <sup>2</sup> /ft                  | -            | f     |
| CT16MX    | Maximum value of C16                          | 0.35        | sec <sup>2</sup> /ft                  | -            | f     |
| CT17MN    | Minimum value of C17                          | 0.0025      | sec/ft                                | -            | f     |
| CT17MX    | Maximum value of C17                          | 0.014       | sec/ft                                | -            | f     |
| CT17M2    | Value of CT17MN when ICT = 1                  | 0.00133     | sec/ft                                | -            | f     |

TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA - Continued

(b) Input constants - Continued

| Symbol | Description  | Value        | Unit                       | Range           | Class |
|--------|--|--------------|----------------------------|-----------------|-------|
| CY0    | Constant term in heading error deadband                                | -0.1309      | rad                        | -               | f     |
| CY1    | Slope of heading error deadband wrt VE                                 | 1.0908E-4    | rad-sec/ft                 | -               | f     |
| C17MP  | Mult. factor on C17<br>when ICT = 1                                    | 0.75         | n.d                        | 0 to 2.         | f     |
| C21    | C20 constant value   | 0.06         | 1/deg                      | 0 to $\pm 1000$ | m     |
| C22    | C20 constant value in linear term                                      | -0.001       | 1/deg                      | 0 to $\pm 1000$ | m     |
| C23    | C20 linear term  | 4.25E-6      | sec/ft-deg                 | 0 to $\pm 10$   | m     |
| C24    | C20 constant value   | 0.01         | 1/deg                      | 0 to $\pm 1000$ | m     |
| C25    | C20 constant value in linear term                                      | 0.           | 1/deg                      | 0 to $\pm 1000$ | m     |
| C26    | C20 linear value   | 0.           | sec/ft-deg                 | 0 to $\pm 10$   | m     |
| C27    | C20 constant value   | 0.           | 1/deg                      | 0 to $\pm 1000$ | m     |
| DDLIM  | Maximum $\Delta$ drag for H feedback                                   | 2.0          | ft/sec <sup>2</sup>        | 0 to 10         | m     |
| DDMIN  | Maximum drag error   | 0.15         | ft/sec <sup>2</sup>        | -               | f     |
| DELV   | Phase transfer velocity bias   | 2300         | ft/sec                     | -               | f     |
| DF     | Final drag value in transition phase                                   | 21.0         | ft/sec <sup>2</sup>        | 0 to 50         | m     |
| DLALLM | Maximum $\alpha$ constant  | 43.0         | deg                        | -               | f     |
| DLAPLM | Limit value for DELALP   | 2.0          | deg                        | -               | f     |
| D23C   | ETG canned D23   | 19.8         | ft/sec <sup>2</sup>        | 0 to 50         | m     |
| D230   | Initial value of D23   | 19.8         | ft/sec <sup>2</sup>        | 0 to 50         | m     |
| DRDDL  | Minimum value of DRDD  | -1.5         | n.mi./sec <sup>2</sup> /ft | -               | f     |
| DTEGD  | Entry guidance computation interval<br>(value may change for ETG mode) | 1.92         | sec                        | -               | f     |
| DT2MIN | Minimum value of T2DOT   | 0.008        | ft/sec <sup>3</sup>        | -               | f     |
| DTR    | Degrees to radians   | 0.0174532925 | rad/deg                    | -               | f     |

TABLE 3.3-1.-- ENTRY GUIDANCE INPUT DATA - Continued

(b) Input constants - Continued

| Symbol | Description   | Value      | Unit                              | Range     | Class |
|--------|---|------------|-----------------------------------|-----------|-------|
| EEF4   | Final reference energy level in transition phase          | 2.0E-6     | ft <sup>2</sup> /sec <sup>2</sup> | 0 to 1.E7 | m     |
| ETRAN  | Energy level at start of transition                       | 6.002262E7 | ft <sup>2</sup> /sec <sup>2</sup> | 0 to 2.E8 | m     |
| E1     | Minimum value of DREFP and  DREFP-DF  in transition phase | 0.01       | ft/sec <sup>2</sup>               | -         | f     |
| GS     | Earth gravitational constant                              | 32.174     | ft/sec <sup>2</sup>               | -         | f     |
| GS1    | Factor in smoothing roll command                          | 0.02       | sec <sup>-1</sup>                 | 0 to 10   | m     |
| GS2    | Factor in smoothing roll command                          | 0.02       | sec <sup>-1</sup>                 | 0 to 10   | m     |
| GS3    | Factor in smoothing roll command                          | 0.03767    | sec <sup>-1</sup>                 | 0 to 10   | m     |
| GS4    | Factor in smoothing roll command                          | 0.03       | sec <sup>-1</sup>                 | 0 to 10   | m     |
| HSMIN  | Minimum value of scale height                             | 20 500.    | ft                                | -         | f     |
| HS01   | Scale height constant term                                | 18 075.    | ft                                | -         | f     |
| HS02   | Scale height constant term                                | 27 000.    | ft                                | -         | f     |
| HS03   | Scale height constant term                                | 45 583.5   | ft                                | -         | f     |
| HS11   | Scale height slope wrt VE                                 | 0.725      | sec                               | -         | f     |
| HS13   | Scale height slope wrt VE                                 | -0.9445    | sec                               | -         | f     |
| LODMIN | Minimum L/D ratio   | 0.5        | n.d.                              | -         | f     |
| NALP   | Number of ALPCMD velocity segment boundaries              | 9          | n.d.                              | -         | f     |
| MM304b | Preentry bank angle command                               | 0.0        | deg                               | 0 to +180 | m     |
| MM304c | Preentry angle-of-attack command                          | 40         | deg                               | 0 to 60   | m     |

TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA - Continued

(b) Input constants - Continued

| Symbol  | Description   | Value    | Unit       | Range       | Class |
|---------|---|----------|------------|-------------|-------|
| RADEG   | Radian-to-degree conversion factor  | 57.29578 | deg/rad    | -           | f     |
| RDMAX   | Maximum roll bias   | 12.0     | deg        | -           | f     |
| RLMC1   | Maximum value of RLM  | 70.      | deg        | -           | f     |
| RLMC2   | Coefficient in first RLM segment  | 70.      | deg        | -           | f     |
| RLMC3   | Coefficient in first RLM segment  | 0.       | deg/ft/sec | -           | f     |
| RLMC4   | Coefficient in second RLM segment   | 70.      | deg        | -           | f     |
| RLMC5   | Coefficient in second RLM segment   | 0.       | deg/ft/sec | -           | f     |
| RLMC6   | Minimum value of RLM  | 70.      | deg        | -           | f     |
| RPT1    | Range bias term   | 22.4     | n.mi.      | 0 to 1 000  | m     |
| VA      | Initial velocity for temperature quadratic, $dD/dV=0$                     | 27 637.  | ft/sec     | 0 to 50 000 | m     |
| VALMDD  | $\alpha$ modulation start flag for nonconvergence                         | 23 000.  | ft/sec     | 0 to 50 000 | m     |
| VALP(1) | ALPCMD vs VE boundary   | 2 850.   | ft/sec     | 0 to 50 000 | m     |
| VALP(2) | ALPCMD vs VE boundary   | 3 200.   | ft/sec     | 0 to 50 000 | m     |
| VALP(3) | ALPCMD vs VE boundary   | 4 500.   | ft/sec     | 0 to 50 000 | m     |
| VALP(4) | ALPCMD vs VE boundary   | 6 609.   | ft/sec     | 0 to 50 000 | m     |
| VALP(5) | ALPCMD vs VE boundary   | 7 789.4  | ft/sec     | 0 to 50 000 | m     |
| VALP(6) | ALPCMD vs VE boundary   | 14 500.  | ft/sec     | 0 to 50 000 | m     |
| VALP(7) | ALPCMD vs VE boundary   | 14 500.  | ft/sec     | 0 to 50 000 | m     |
| VALP(8) | ALPCMD vs VE boundary   | 14 500.  | ft/sec     | 0 to 50 000 | m     |
| VALP(9) | ALPCMD vs VE boundary   | 14 500.  | ft/sec     | 0 to 50 000 | m     |
| VA1     | Boundary velocity between quadratic segments in temperature control phase | 22 000.  | ft/sec     | 0 to 50 000 | m     |

TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA - Continued

(b) Input constants - Continued

| Symbol | Description   | Value    | Unit   | Range       | Class |
|--------|---|----------|--------|-------------|-------|
| VA2    | Initial velocity for temperature quadratic, $dD/dV=0$                     | 27 637.  | ft/sec | 0 to 50 000 | m     |
| VB1    | Temperature control - equilibrium glide phase boundary velocity           | 19 000.  | ft/sec | 0 to 50 000 | m     |
| VC16   | Velocity to start C16 drag error term                                     | 23 000   | ft/sec | -           | f     |
| VC20   | C20 velocity break point  | 2 500.   | ft/sec | 0 to 50 000 | m     |
| VELMN  | Maximum velocity for limiting LMN by ALMN3                                | 8 000    | ft/sec | 0 to 50 000 | f     |
| VEROLC | Maximum velocity for limiting bank angle command                          | 8 000    | ft/sec | 0 to 50 000 | f     |
| VHS1   | Scale height vs VE boundary   | 12 310   | ft/sec | 0 to 50 000 | f     |
| VHS2   | Scale height vs VE boundary   | 19 675.5 | ft/sec | 0 to 50 000 | f     |
| VNOALP | $\alpha$ modulation start flag (VNOALP will always equal 0. for ETG mode) | 0.       | ft/sec | 0 to 50 000 | m     |
| VQ     | Predicted end velocity for constant drag phase                            | 5 000    | ft/sec | 0 to 50 000 | m     |
| VRLMC  | Velocity to switch RLM segments   | 2 500.   | ft/sec | -           | f     |
| VSAT   | Local circular orbit velocity   | 25 766.2 | ft/sec | 0 to 50 000 | f     |
| VS1    | Reference velocity for equilibrium glide                                  | 23 283.5 | ft/sec | 0 to 50 000 | m     |
| VRDT   | Velocity to start H feedback  | 23 000   | ft/sec | 0 to 50 000 | m     |
| V_TAEM | Reference velocity at entry-TAEM interface                                | 2 500    | ft/sec | 0 to 50 000 | m     |
| VTRAN  | Nominal velocity at start of transition phase                             | 10 500.  | ft/sec | 0 to 50 000 | m     |
| VYLMAX | Minimum velocity at start of LMN by ALMN4                                 | 23 000   | ft/sec | 0 to 50 000 | f     |
| YLMIN  | YL bias used in test for LMN  | 0.03     | rad    | -           | f     |

TABLE 3.3-1.- ENTRY GUIDANCE INPUT DATA - Concluded

## (b) Input constants - Concluded

| Symbol | Description  | Value     | Unit | Range    | Class |
|--------|--|-----------|------|----------|-------|
| YLMN2  | Minimum YL bias                                      | 0.07      | rad  | -        | f     |
| Y1     | Maximum heading error deadband before first reversal | 0.3054326 | rad  | -        | f     |
| Y2     | Minimum heading error deadband                       | 0.1745329 | rad  | -        | f     |
| Y3     | Maximum heading error deadband after first reversal  | 0.3054326 | rad  | -        | f     |
| ZK1    | Gain for H feedback                                  | 1.0       | sec  | 0 to 100 | m     |

TABLE 3.3-2.- ENTRY GUIDANCE OUTPUTS

| Symbol | Description                                 | Unit                | Destination |
|--------|---|---------------------|-------------|
| ALPCMD | Angle-of-attack command                     | rad                 | Autopilot   |
| ROLLC  | Bank command                                | rad                 | Autopilot   |
| DREFP  | Drag reference                              | ft/sec <sup>2</sup> | Display     |
| DRAG   | Actual drag                                 | ft/sec <sup>2</sup> | Display     |
| ROLREF | Bank reference                              | deg                 | Display     |
| ISLECT | Guidance phase indicator<br>relative        | n.d.                | Display     |
| VCG    | Velocity at start of constant<br>drag phase | ft/sec              | Display     |
| VRR    | Velocity at first bank<br>reversal          | ft/sec              | Display     |
| EOWD   | Energy overweight                           | ft                  | Display     |
| EEL    | Entry evaluation indicator                  | n.d.                | Display     |
| RC176G | First roll command after 0.176g             | deg                 | Display     |

TABLE 3.3-3.- ENTRY GUIDANCE INTERNAL PARAMETER DEFINITIONS

| Symbol   | Description   |
|----------|---|
| ACLAM    | Maximum allowable alpha   |
| ACLIM    | Minimum allowable alpha   |
| ACMD1    | Scheduled angle of attack   |
| ALDCO    | Temporary variable in phase 3 reference parameters                    |
| ALDREF   | Vertical L/D reference  |
| ALPCMD   | Angle-of-attack command   |
| ALPDOT   | Rate of change of ALPCMD  |
| ARG(1)   | Cosine of commanded bank angle  |
| ARG(2)   | Cosine of unlimited bank command                                      |
| ARG(3)   | Cosine of bank reference angle  |
| A2       | Temporary variable used in computing range and updating D23           |
| CAG      | Pseudoenergy/mass used in transition (L/D) reference                  |
| CQ1(1,2) | Constants in Ith temperature control D-V quadratic                    |
| CQ2(1,2) | VE coefficients in Ith temperature control D-V quadratic              |
| CQ3(1,2) | VE <sup>2</sup> coefficients in Ith temperature control D-V quadratic |
| C1       | dD/dE in transition   |
| C16      | d(L/D)/dD   |
| C17      | d(L/D)/dH   |
| C2       | Component of L/D reference  |
| C4       | Reference altitude rate term  |
| C20      | d ALPHA/dCd gain  |
| DD       | Drag - DREFF  |
| DDS      | Limited value of DD   |



TABLE 3.3-3.- Continued

| Symbol    | Description   |
|-----------|---|
| DDP       | Past value of DD  |
| DELALF    | Delta ALPHA from schedule   |
| DELALP    | Command ALPHA increment   |
| DLRDOT    | R feedback term   |
| DLIM      | Maximum value of DREFP in transition                                |
| DLZRL     | Test variable in bank angle computation                             |
| DRDD      | Derivative of range wrt drag  |
| DREF(1,2) | DREFP for Ith temperature control D-V quadratic                     |
| DREFP     | Drag reference used in controller                                   |
| DREFPT    | DREFP-DF in transition phase  |
| DREFP1    | DREFP in equilibrium glide  |
| DREFP3    | DREFP test value for transition to phase 3                          |
| DREFP4    | DREFP test value for transition to phase 4                          |
| DREFP5    | DREFP test value for transition to phase 5                          |
| DRF       | Test value for transition to D23-VB1 quadratic reference parameters |
| DX(1,2)   | Normalized values of DREFP  |
| DZOLD     | Previous value of DELAZ   |
| DZSGN     | Change in DELAZ   |
| D231      | First updated value of D23  |
| EEF       | Energy/mass   |
| HDTRF(1)  | Intermediate calculation of temperature control $\dot{R}$ ref       |
| IALP      | ALPCMD segment counter  |

TABLE 3.3.-3.- Continued

| Symbol    | Description   |
|-----------|---|
| DDP       | Past value of DD  |
| DELALF    | Delta ALPHA from schedule   |
| DELALP    | Command ALPHA increment   |
| DLRDOT    | R feedback term   |
| DLIM      | Maximum value of DREFP in transition                                |
| DLZRL     | Test variable in bank angle computation                             |
| DRDD      | Derivative of range wrt drag  |
| DREF(1,2) | DREFP for Ith temperature control D-V quadratic                     |
| DREFP     | Drag reference used in controller                                   |
| DREFPT    | DREFP-DF in transition phase  |
| DREFP1    | DREFP in equilibrium glide  |
| DREFP3    | DREFP test value for transition to phase 3                          |
| DREFP4    | DREFP test value for transition to phase 4                          |
| DREFP5    | DREFP test value for transition to phase 5                          |
| DRF       | Test value for transition to D23-VB1 quadratic reference parameters |
| DX(1,2)   | Normalized values of DREFP  |
| DZOLD     | Previous value of DELAZ   |
| DZSGN     | Change in DELAZ   |
| D231      | First updated value of D23  |
| EEF       | Energy/mass   |
| HDTRF(1)  | Intermediate calculation of temperature control $\dot{R}$ ref       |
| IALP      | ALPCMD segment counter  |

TABLE 3.3.-3.- Continued

| Symbol   | Description                                   |
|----------|---|
| ICT      | Alpha modulation flag                         |
| ISLECP   | Past value of ISLECT                          |
| ISLECT   | Entry guidance subphase counter               |
| ITRAN    | Transition initialization flag                |
| LMFLG    | Saturated roll command flag                   |
| LMN      | Maximum value of LODV                         |
| LODV     | Vertical L/D command                          |
| LODX     | Unlimited vertical L/D command                |
| Q(1,2,3) | DREFP/VE in temp control phase                |
| RCG      | Constant drag phase range                     |
| RCG1     | Constant component of RCG                     |
| RDEALF   | Roll bias for alpha modulation                |
| RDTRF    | Altitude rate reference                       |
| RDTRF1   | RDTRF Phase 3                                 |
| REQ1     | Equilibrium glide range x D23                 |
| RER1     | Transition phase range                        |
| RF(1,2)  | Ith range segment in temp control phase x D23 |
| RFF1     | Temperature control range x D23               |
| RDTRF    | Altitude rate reference corrected for Cd      |
| ROLLC(1) | Roll angle command about body axis            |
| ROLLC(2) | Unlimited roll command                        |
| ROLLC(3) | Rollref                                       |
| RPT      | Desired range at VQ                           |

TABLE 3.3-3.- Concluded

| Symbol   | Description  |
|----------|--|
| R231     | Phase 2 and 3 range x D23  |
| START    | Entry guidance first pass flag                                       |
| T1       | Equilibrium glide vertical lift acceleration                         |
| T2       | Constant drag level to reach target                                  |
| T2DOT    | Rate of change of T2   |
| T2OLD    | Old T2 value   |
| V(1,2,3) | Velocity sampling points for temp control numerical range prediction |
| VB2      | $VB^2$   |
| VCG      | Phase 3-4 boundary velocity  |
| VE2      | $VE^2$   |
| VF(1,2)  | Upper velocity bounds for Ith temperature control range segment      |
| VSAT2    | $VSAT^2$   |
| VTRB     | $\dot{R}$ feedback velocity lockout                                  |
| VX(1,2)  | Velocities where $dD/dV=0$ in Ith temp control D-V quadratic         |
| XLOD     | Limited left/drag ratio  |
| YL       | Maximum heading error absolute value                                 |
| ZK       | $\dot{R}$ feedback gain  |

TABLE 3.3-4.- AUTOPILOT INPUT DATA

(a) Input parameters

| Symbol         | Description                        | Source           | Unit    |
|----------------|------------------------------------|------------------|---------|
| ALPWARD        | Angle of attack with winds         | Integrator       | rad     |
| ALPHAP         | Previous pass angle of attack      | Entry integrator | rad     |
| ALPCMD         | Angle-of-attack command            | Entry guidance   | rad     |
| PQR(IV1)       | Initial bank rate                  | Entry integrator | rad/sec |
| PQR(IV+2)      | Initial alpha rate                 | Entry integrator | rad/sec |
| ROLLC          | Bank command                       | Entry guidance   | rad     |
| ROLLP          | Previous pass bank angle           | Entry integrator | rad     |
| RRPAST         | Previous pass bank rate            | Entry integrator | rad/sec |
| PRPAST         | Previous pass angle-of-attack rate | Entry integrator | rad/sec |
| EGFLG          | Guidance mode flag                 | Executive        | n.d.    |
| MM304 $\phi$   | Preentry bank command              | Med input        | rad     |
| MM304 $\alpha$ | Preentry angle-of-attack command   | Med input        | rad     |
| ROLL           | Current bank angle                 | Integrator       | rad     |
| DELTT          | Integration time step              | Executive        | sec     |

TABLE 3.3-4.- AUTOPILOT INPUT DATA

(b) Input constants

| Symbol  | Description                          | Value       | Unit                 | Class |
|---------|--------------------------------------|-------------|----------------------|-------|
| DTR     | Degrees to radians                   | 0.017453292 | rad                  | f     |
| KONTROL | Initialization flag                  | 15          | n.d.                 |       |
| PA      | Maximum angle-of-attack acceleration | 0.0174533   | rad/sec <sup>2</sup> | f     |
| PADB    | Angle-of-attack attitude deadband    | 0.00174533  | rad                  | f     |
| PRM     | Maximum angle-of-attack rate         | 0.0872665   | rad/sec              | f     |
| RA      | Maximum bank acceleration            | 0.029671    | rad/sec <sup>2</sup> | f     |
| RADB    | Bank attitude deadband               | 0.043633    | rad                  | f     |
| RADB2   | Bank attitude deadband for EGFLG=2   | 0.00174533  | rad                  | f     |
| RAD160  | 160 degrees converted to radians     | 2.7925268   | rad                  | f     |
| RAD180  | 180 degrees converted to radians     | 3.1415927   | rad                  | f     |
| RAD360  | 360 degrees converted to radians     | 6.2831853   | rad                  | f     |
| RRM     | Maximum bank rate                    | 0.0872665   | rad/sec              | f     |

TABLE 3.3-5.- AUTOPILOT OUTPUTS

| Symbol | Description                        | Unit    | Destination |
|--------|------------------------------------|---------|-------------|
| ALPWND | Updated angle of attack with winds | rad     | Integrator  |
| BANK   | Updated bank angle                 | rad     | Integrator  |
| PR     | Updated angle-of-attack rate       | rad/sec | Integrator  |
| RR     | Updated bank rate                  | rad/sec | Integrator  |

TABLE 3.3-6.- AUTOPILOT INTERNAL PARAMETER DEFINITIONS

| Symbol | Description                        |
|--------|------------------------------------|
| BANK   | Bank about the velocity vector     |
| DIFF   | Difference between ROLLC and ROLL  |
| DIR    | Direction of acceleration          |
| DTIM   | DAP3D time step                    |
| EFRATE | Average value of EFRAT1 and EFRAT2 |
| EFRAT1 | DIFF rate                          |
| EFRAT2 | Past value of EFRAT1               |
| ICPPLN | Cycle frequency of DAP3D           |
| ICTTRN | First and third pass flag          |
| INTRY  | Flag to establish constant set     |
| KONTRL | PHSPLN initialization flag         |
| RR1    | Current bank rate                  |
| ROLL   | Current bank angle                 |



TABLE 3.3-7.- TARGETING ROUTINE INPUT DATA

(a) Input parameters

| Symbol              | Description                                   | Source             | Unit   |
|---------------------|---|--------------------|--------|
| AZRW                | Bearing from true north of runway + X axis    | Landing site table | rad    |
| XYZE                | Vehicle position vector                       | Integrator         | ft     |
| XYZED               | Vehicle velocity vector                       | Integrator         | ft/sec |
| SRAZ                | Secondary runway azimuth                      | Landing site table | rad    |
| M                   | Vehicle mass                                  | AERO               | slugs  |
| (OVHD) <sup>a</sup> | Runway approach mode flags                    | MED                | n.d.   |
| RWID                | Selected runway ID flag<br>(pri = 1, sec = 2) | site selection     | n.d.   |
| (REC) <sup>b</sup>  | Greenwich to runway transformation matrices   | site selection     | n.d.   |
| (RLS) <sup>c</sup>  | Runway position vectors<br>(Greenwich coord.) | site selection     | ft     |
| IFP                 | First pass flag (= 0 initially)               | EXEC               | --     |
| VTOGL <sup>d</sup>  | Velocity to toggle OVHD/STRT HAC status       | MED                | ft/sec |

<sup>a</sup>MED input to select approach mode (overhead = 1, straight in = 0)(dimensioned (2) where subscript is runway ID flag). Initialized to 1 in mission constants table.

<sup>b</sup>Dimensioned (3 x 3 x 2) where last index is runway ID.

<sup>c</sup>Dimensioned (3 x 2) where last index is runway ID.

<sup>d</sup>MED input to simulate manual HAC toggle. Initialized to zero in mission constants table.

TABLE 3.3-7.- Concluded

## (b) Input constants

| Symbol | Description   | Value        | Unit                | Class |
|--------|---|--------------|---------------------|-------|
| RX22   | Polar radius <sup>2</sup> /equatorial radius <sup>2</sup> | 0.9933065782 | n.d.                | f     |
| VMIDPT | Velocity limit for midpoint targeting                     | TBD          | fps                 | m     |
| XHACL  | Low mass RW to HAC distance                               | -35245.      | ft                  | m     |
| XHACH  | High mass RW to HAC distance                              | -35245.      | ft                  | m     |
| WTGS1  | Mass threshold value                                      | 8000.        | slugs               | m     |
| RI     | Initial HAC radius  | 20000.       | ft                  | f     |
| PSHARS | Initial HAC turn angle                                    | 270.         | deg                 | f     |
| RFO    | HAC radius on final                                       | 14000.       | ft                  | f     |
| R1     | Linear term in spiral radius eqn.                         | 0.           | ft/deg              | f     |
| R2     | Quadratic term in spiral radius eqn.                      | .093         | ft/deg <sup>2</sup> | f     |
| A3TOL  | HAC turn angle tolerance value                            | -.003        | deg                 | f     |
| DTR    | Deg to rad conversion const.                              | .01745329    | rad/deg             | f     |
| RTD    | Rad to deg conversion const.                              | 57.29578     | deg/rad             | f     |

TABLE 3.3-8.- TARGETING ROUTINE OUTPUTS

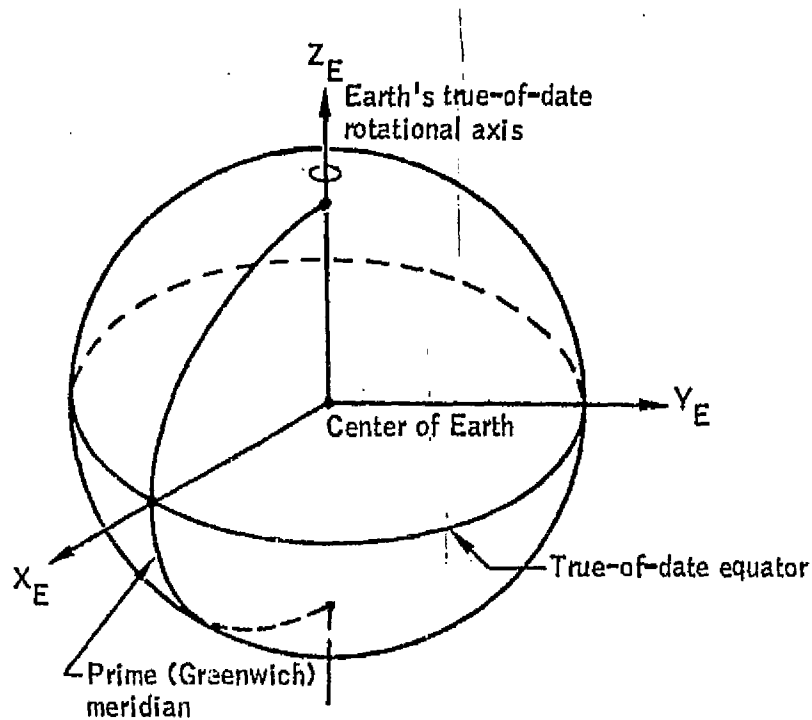
| Symbol | Description            | Unit   | Destination       |
|--------|------------------------|--------|-------------------|
| TRANGE | Range to target        | n. mi. | Entry guidance    |
| DELAZ  | Azimuth error          | rad    | Entry guidance    |
| RCHMAG | Radius of landing site | ft     | Deorbit processor |
| PSHAT  | HAC turn angle         | deg    | TAEM guidance     |
| RTURNT | HAC radius             | ft     | TAEM guidance     |
| YSGNT  | R/L HAC indicator      | n.d.   | TAEM guidance     |

TABLE 3.3-9.- TARGETING ROUTINE INTERNAL PARAMETER DEFINITIONS

| Symbol | Description   |
|--------|---|
| RLS    | Landing site in Earth-fixed coordinates                       |
| RC     | Center of heading alinement circle in runway coordinates      |
| HACEF  | Center of heading alinement circle in Earth-fixed coordinates |
| BARCC  | Heading to center of alinement circle                         |
| CTHVC  | Cosine (angle between vehicle and HAC)                        |
| BARWPI | Heading to tangent point on HAC                               |
| DARC   | Distance around heading alinement cone                        |
| PSI    | Heading of vehicle  |
| REC    | Runway to Earth-fixed matrix                                  |

TABLE 3.4-2.- GUIDANCE PHASE SELECTION LOGIC

| Guidance phase          | Preentry   | Temperature control  | Equilibrium glide  | Constant drag   | Transition   |
|-------------------------|--|--|--|---|--|
| ISLECT                  | 1  | 2  | 3  | 4   | 5  |
| Previous possible phase | NA<br>Crew selects entry program   | Preentry   | Temperature control  | Preentry<br>Temperature control<br>Equilibrium glide                    | Preentry<br>Equilibrium glide<br>Constant drag           |
| Possible phase transfer | Temp control<br>Constant drag<br>Transition  | Equilibrium glide<br>Constant drag   | Constant drag<br>Transition  | Transition  | NA<br>TAEM logic called at end of transition             |
| Transfer logic          | $XLFAC > ASTART$<br>$ISLECT = 2$<br><hr/> $XLFAC > ASTART$<br>and<br>$T2 > ALFV$<br>$ISLECT = 4$<br><hr/> $XLFAC > ASTART$<br>and<br>$VE < VTRAN$<br>$ISLECT = 5$<br><hr/> | $VE < VA$<br>and<br>$DREFP < DREFP3$<br>$ISLECT = 3$<br><hr/> $VE < VB1$<br>$ISLECT = 3$<br><hr/> $VE < VCG + DELV$<br>and<br>$DREFP > DREFP4$<br>$ISLECT = 4$<br><hr/> $T2 > ALFM$<br>$ISLECT = 4$<br><hr/> Temperature control phase internally transfer quadratic D-V segments when<br>$VE > VA1$<br>and<br>$DRF < 0$ | $VE < VCG + DELV$<br>and<br>$DREFP > DREFP4$<br>$ISLECT = 4$<br><hr/> $VE < VTRAN + DELV$<br>and<br>$VCG < VTRAN$<br>and<br>$DREFP > DREFP5$<br>$ISLECT = 5$<br><hr/> $T2 > ALFM$<br>$ISLECT = 4$<br><hr/> | $VE < VTRAN + DELV$<br>and<br>$DREFP > DREFP5$<br>$ISLECT = 5$<br><hr/> | NA<br>TAEM guidance logic called when<br>$VE < V_{TAEM}$ |



Name: Greenwich true of date (geographic).

Origin: The center of the Earth.

Orientation: The  $X_E$ - $Y_E$  plane is the Earth's true-of-date equator.

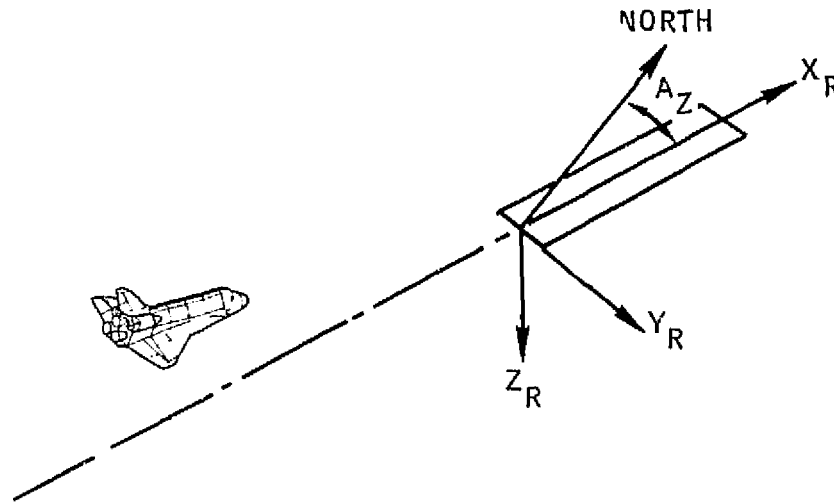
The  $Z_E$ -axis is directed along the Earth's true-of-date rotational axis and is positive north.

The  $+X_E$ -axis is directed toward the prime meridian.

The  $Y_E$ -axis completes a right-handed system.

Characteristics: Rotating, right-handed, Cartesian. Velocity vectors expressed in this system are relative to a rotating reference frame fixed to the Earth, whose rotation rates are expressed relative to the Aries-mean-of-1950 system.

Figure 3.2-1.- Greenwich true of date (geographic).



Name: Runway coordinate system.

Origin: Runway center at approach threshold.

Characteristics: Rotating, Earth-referenced.

Description:  $Z_R$ -axis is normal to the ellipsoid model through the runway centerline at the approach threshold and positive toward the center of the Earth.  $X_R$ -axis is perpendicular to the  $Z_R$ -axis and lies in a plane containing the  $Z_R$ -axis and the runway centerline (positive in the direction of landing).

$Y_R$ -axis completes the right-handed system.

$A_Z$  is the runway azimuth, measured in the  $X_R$ - $Y_R$  plane from true north to the  $+X_R$ -axis (positive clockwise).

Figure 3.2-2.- Runway coordinates.

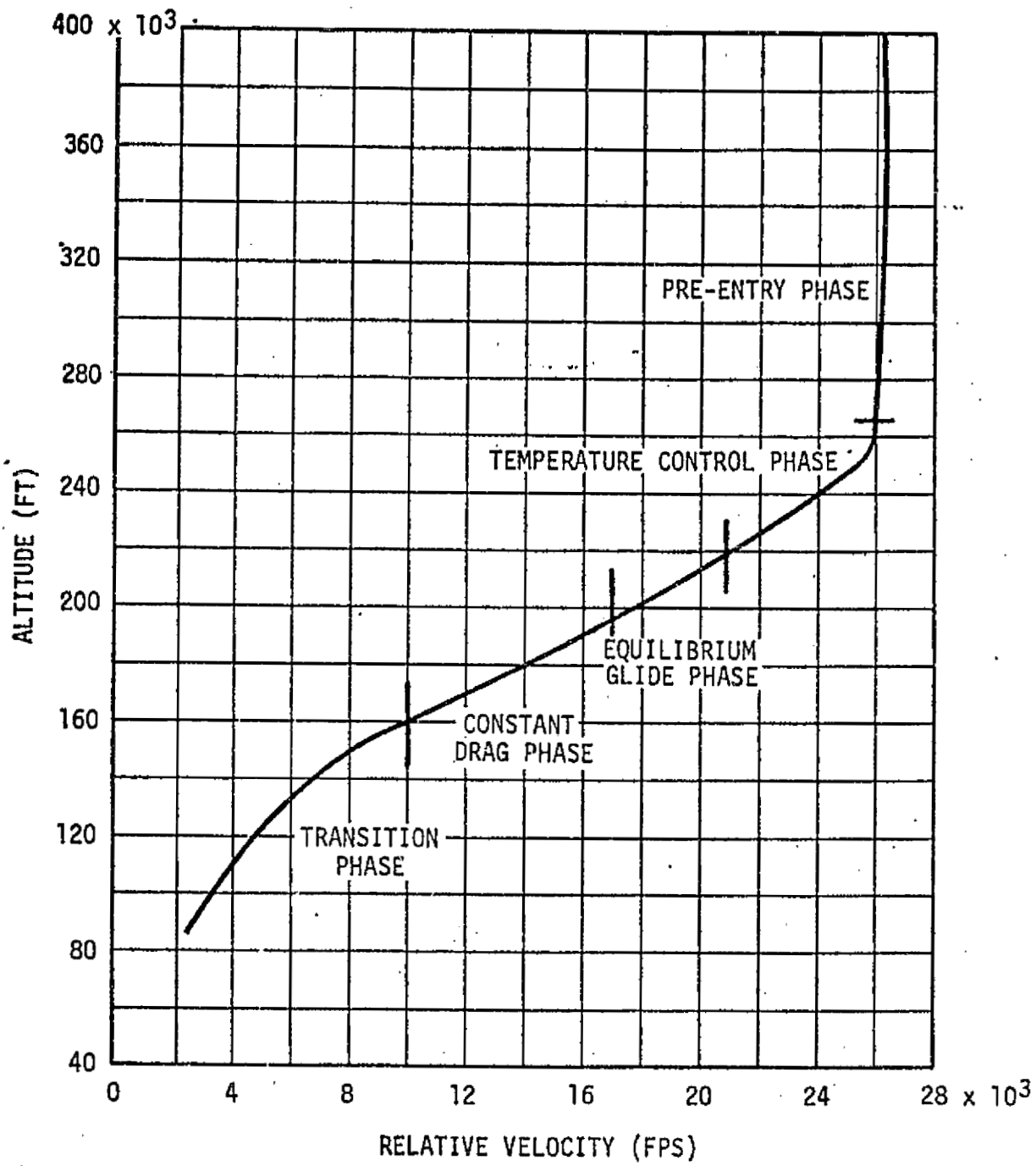


Figure 3.4.1-1.- Entry guidance phases.



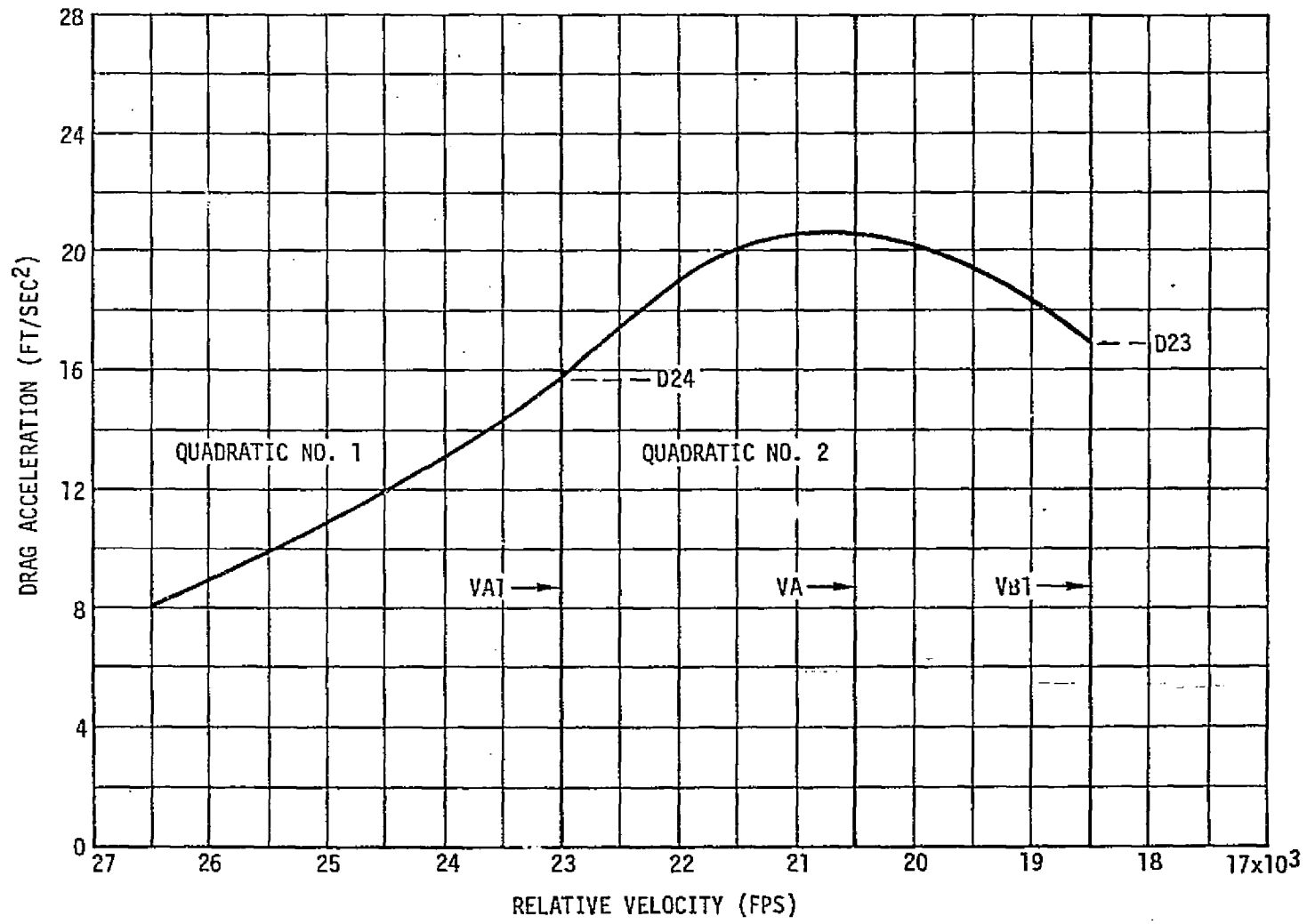


Figure 3.4.2-2.- Temperature control phase quadratic definition.

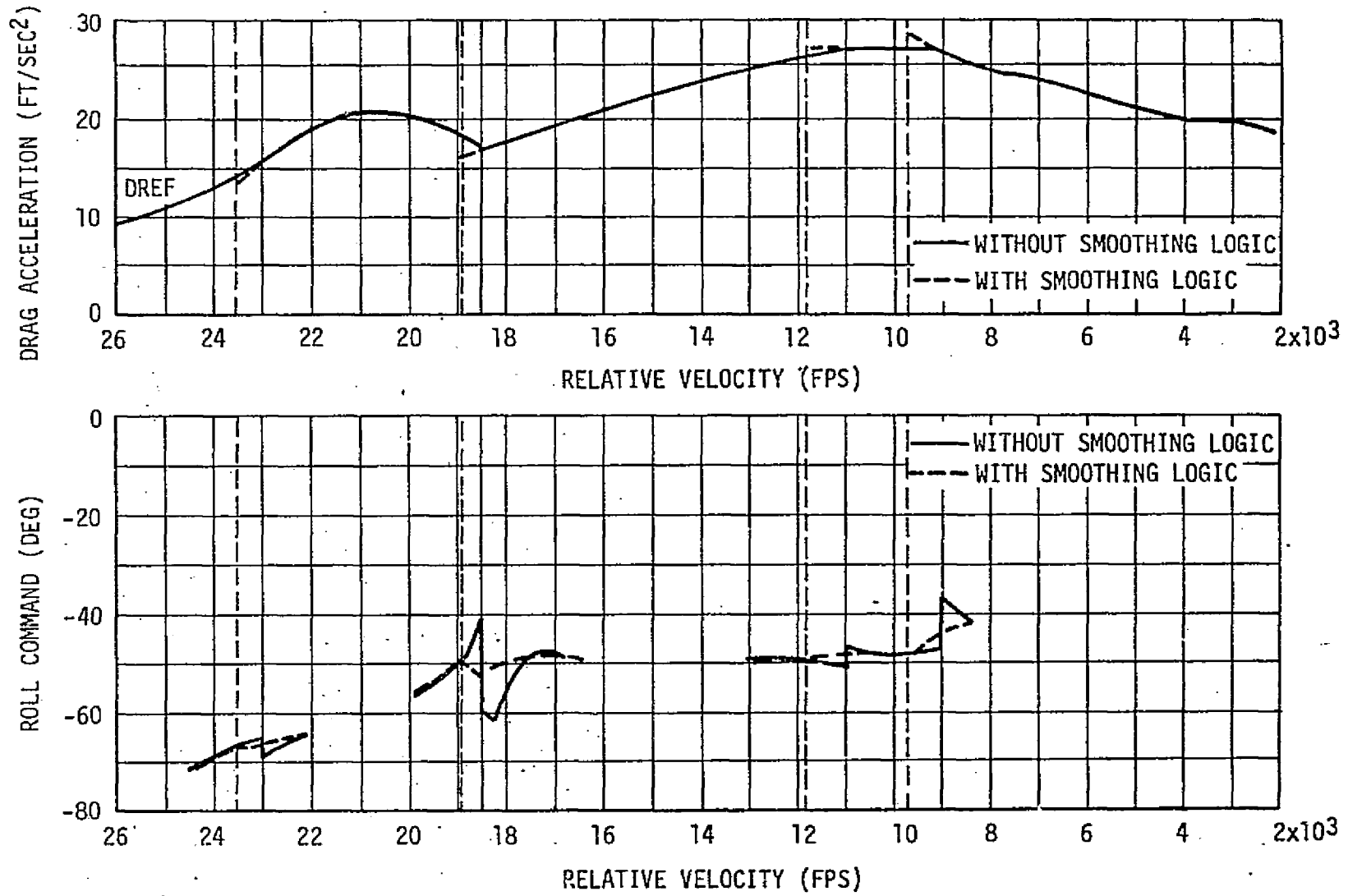


Figure 3.4.2-3.- Bank-angle smoothing logic between guidance phases.

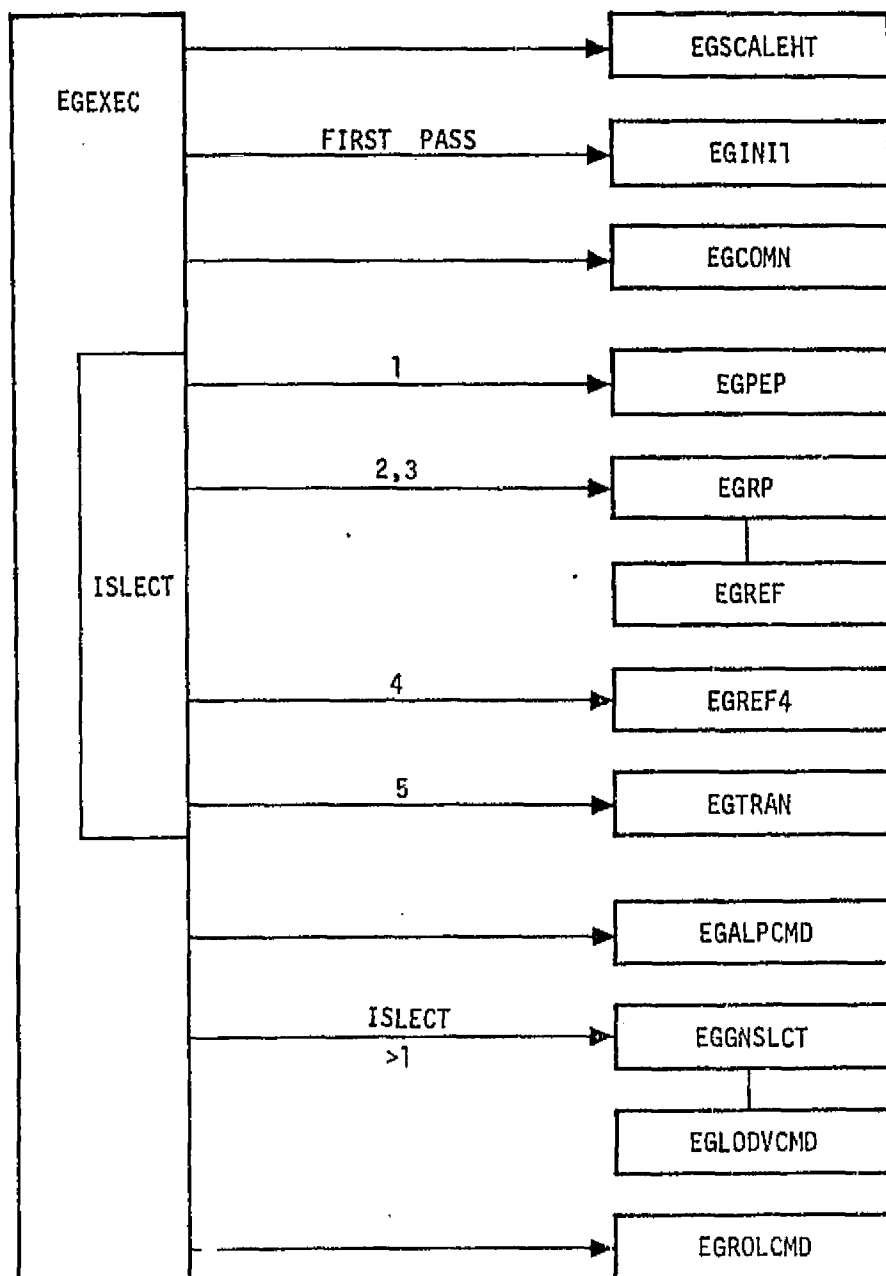


Figure 3.4.2-4.- Entry guidance sequence.

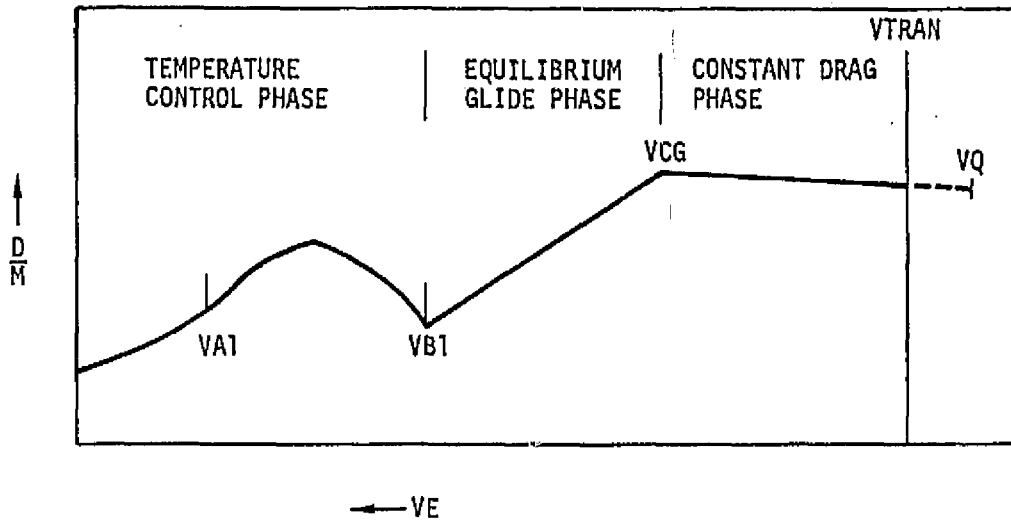


Figure 3.4.7-1.- Drag-velocity segments used in range predictions.

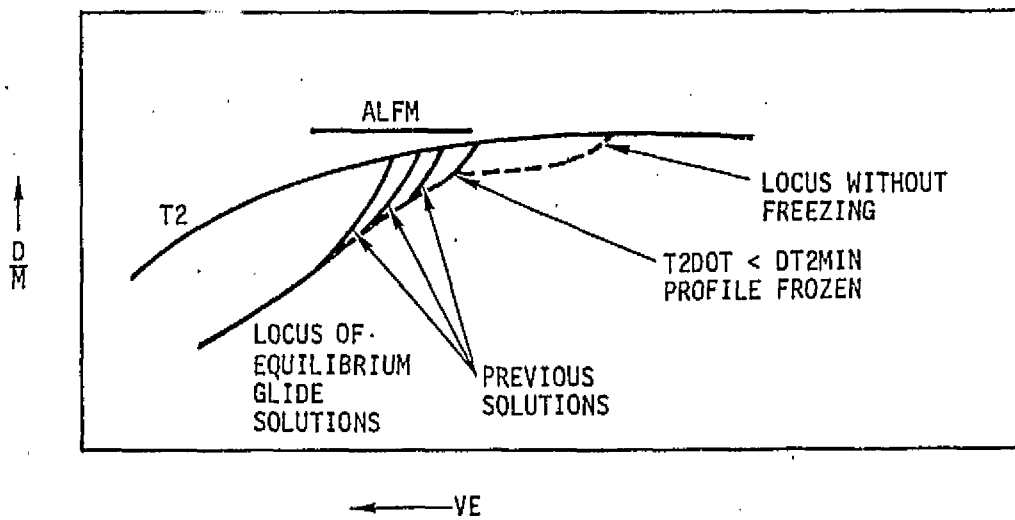


Figure 3.4.7-2.- Freezing of equilibrium glide profile.

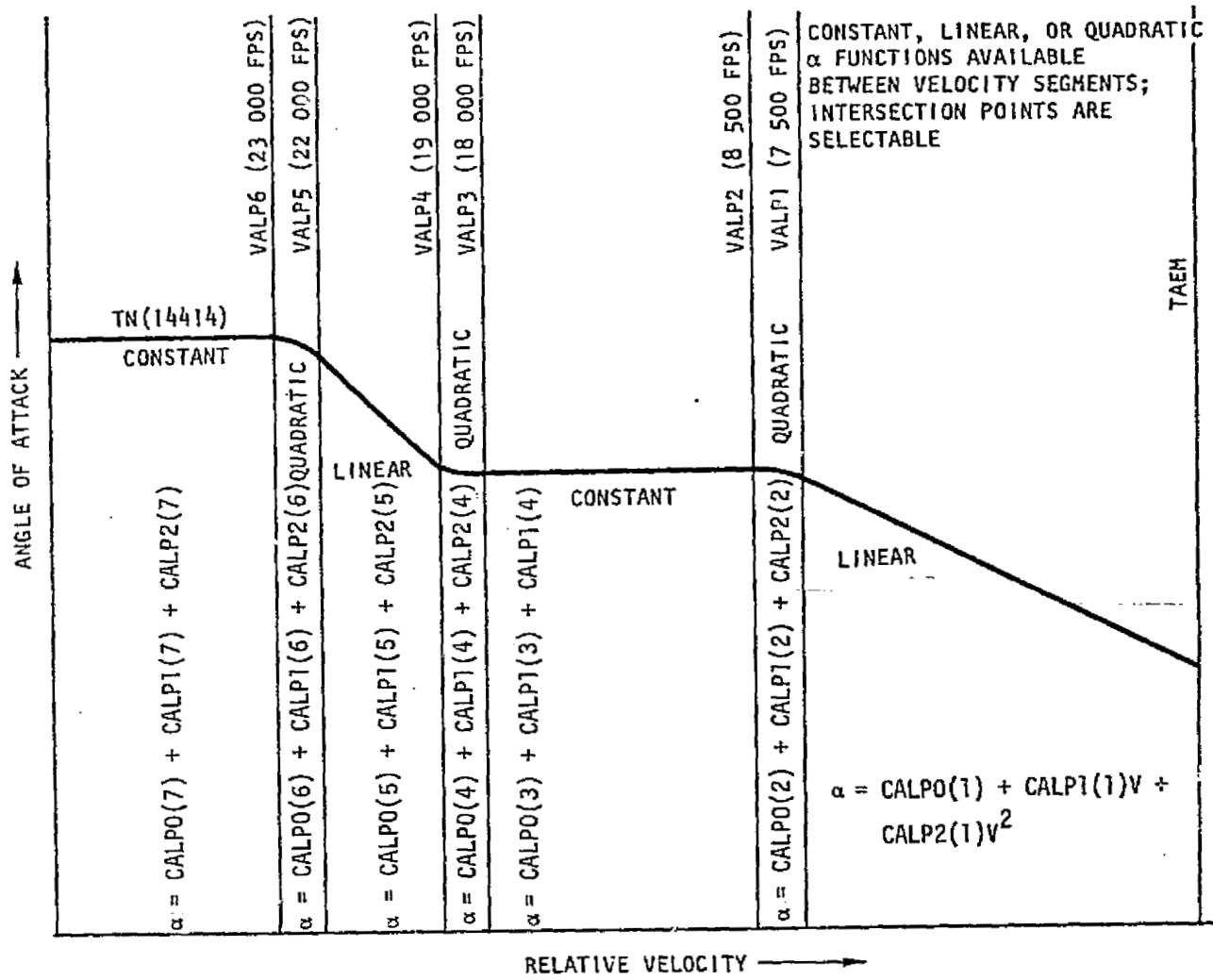


Figure 3.4.11-1.- Angle-of-attack selection capability.

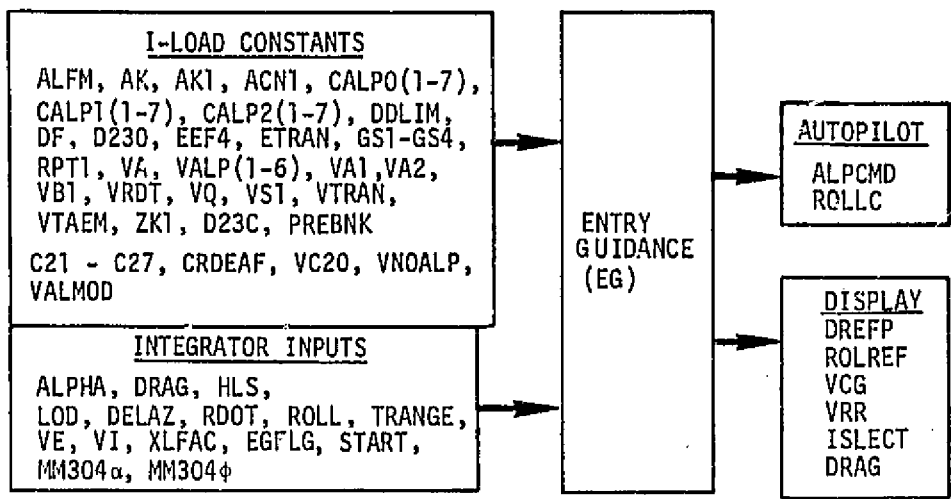


Figure 3.4.15-1.- Entry guidance external data flow summary.

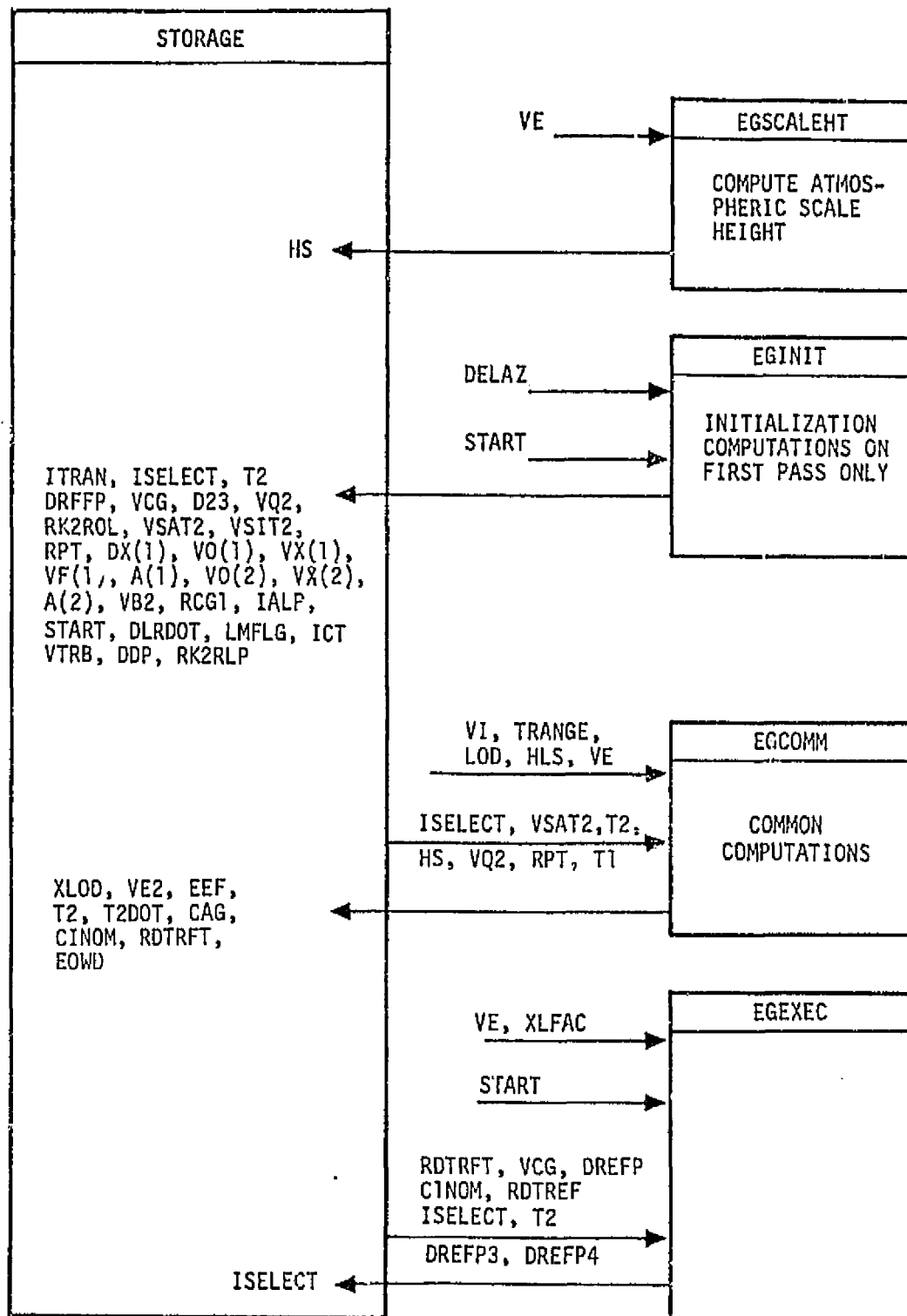


Figure 3.4.15-2.- Entry guidance internal data flow.

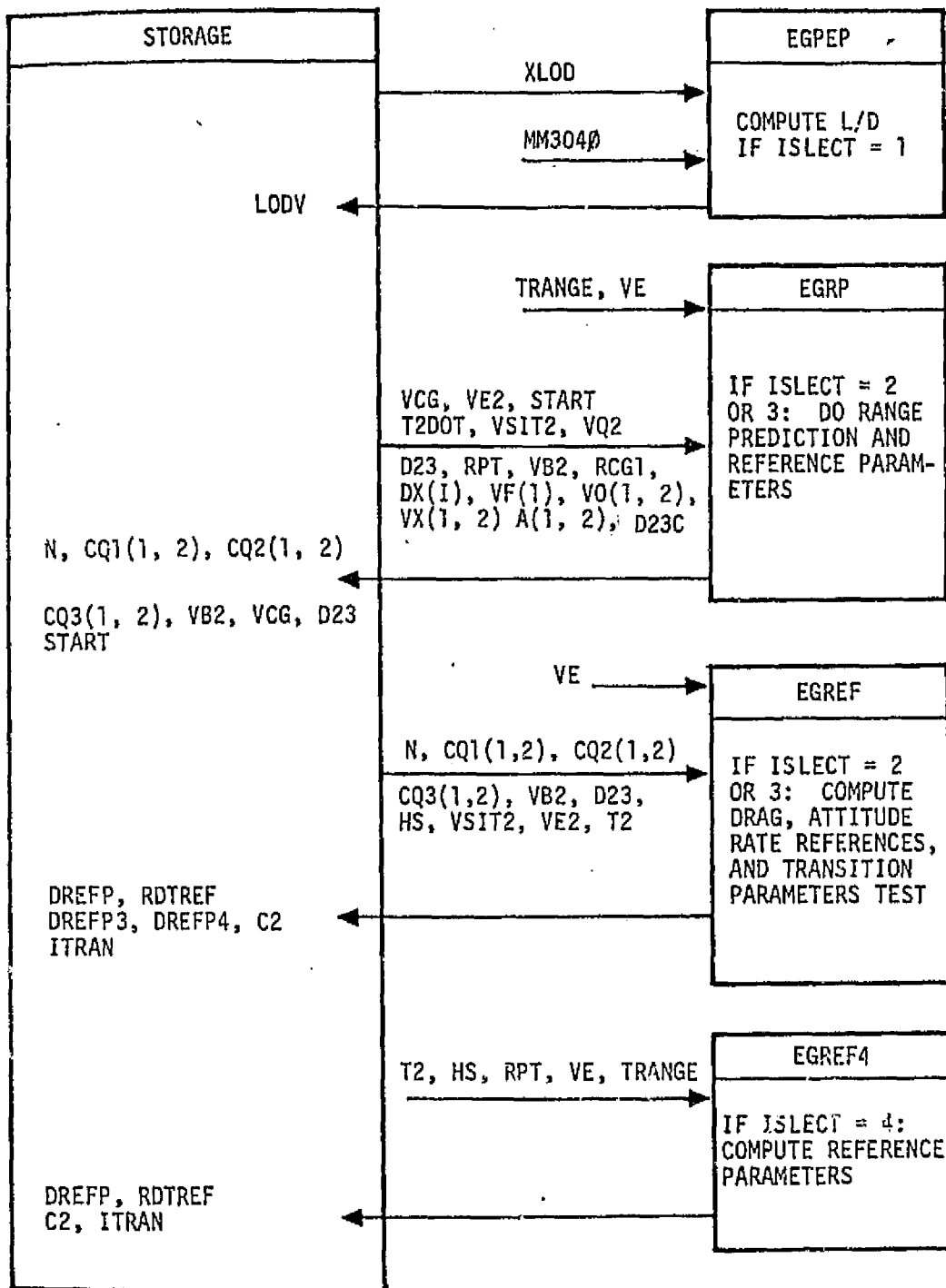


Figure 3.4.15-2.- Continued.

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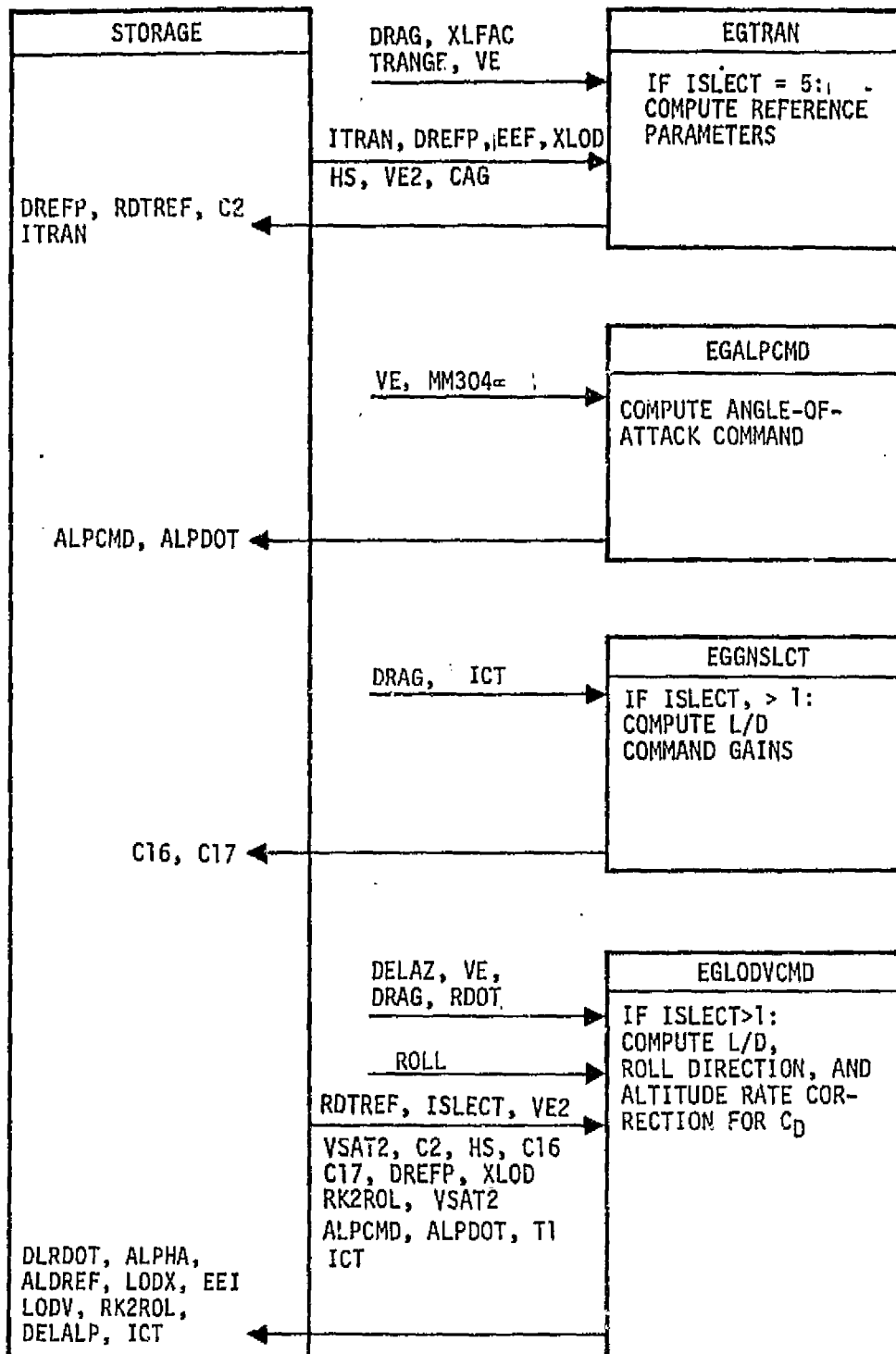


Figure 3.4.15-2.- Continued.

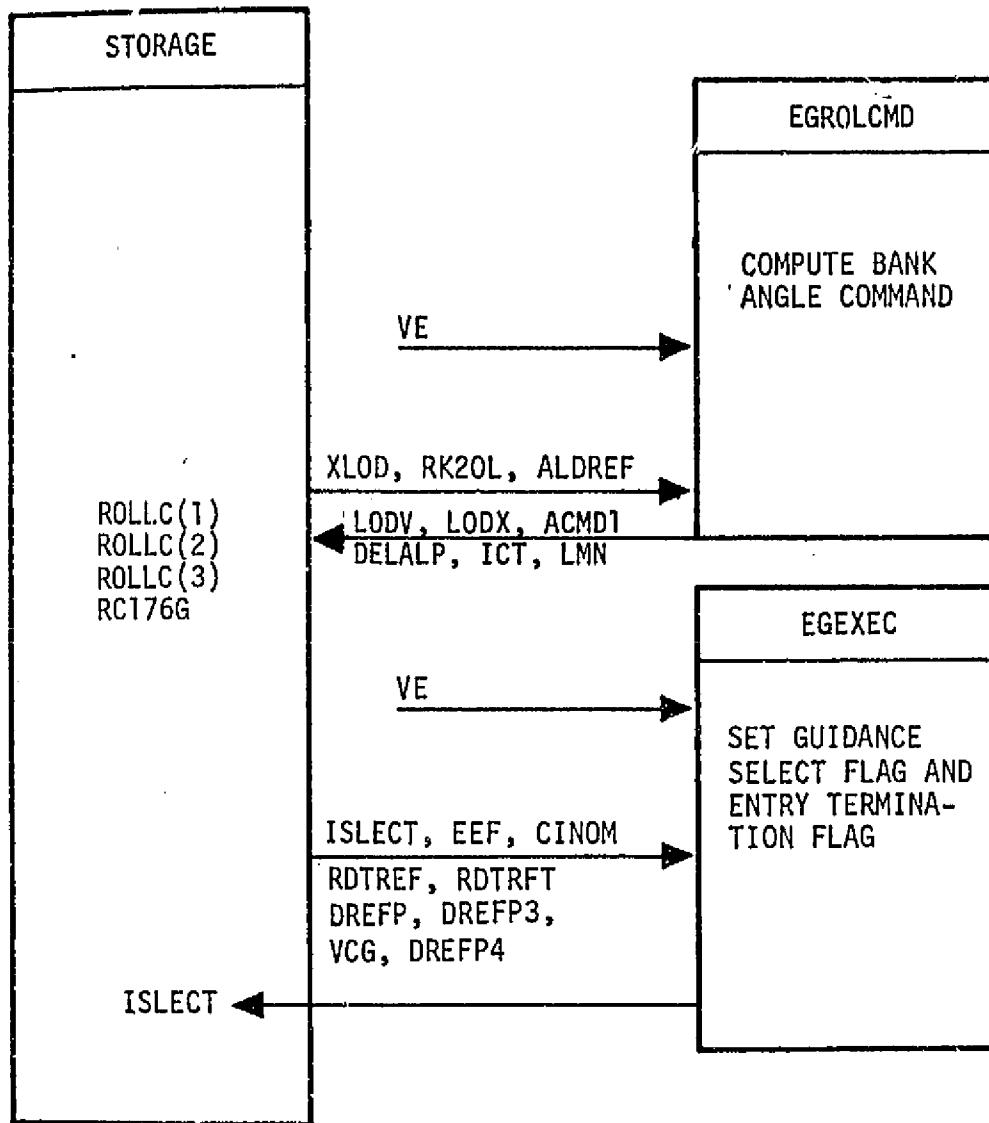


Figure 3.4.15-2.- Concluded.

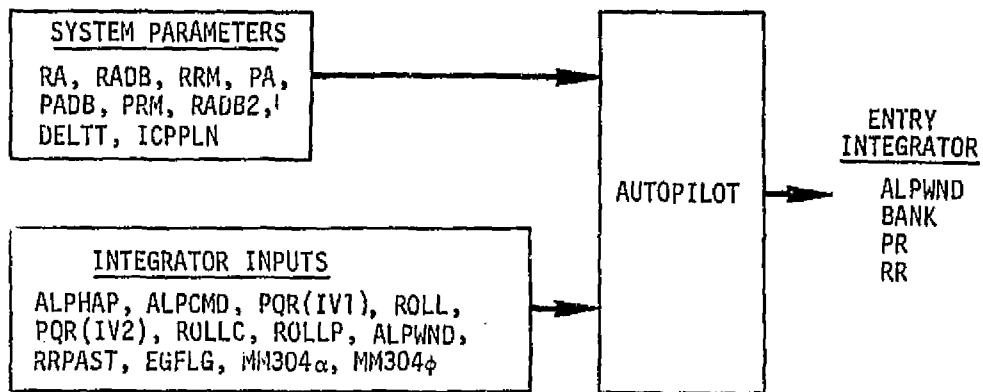


Figure 3.5.4-1.- Autopilot external data flow.

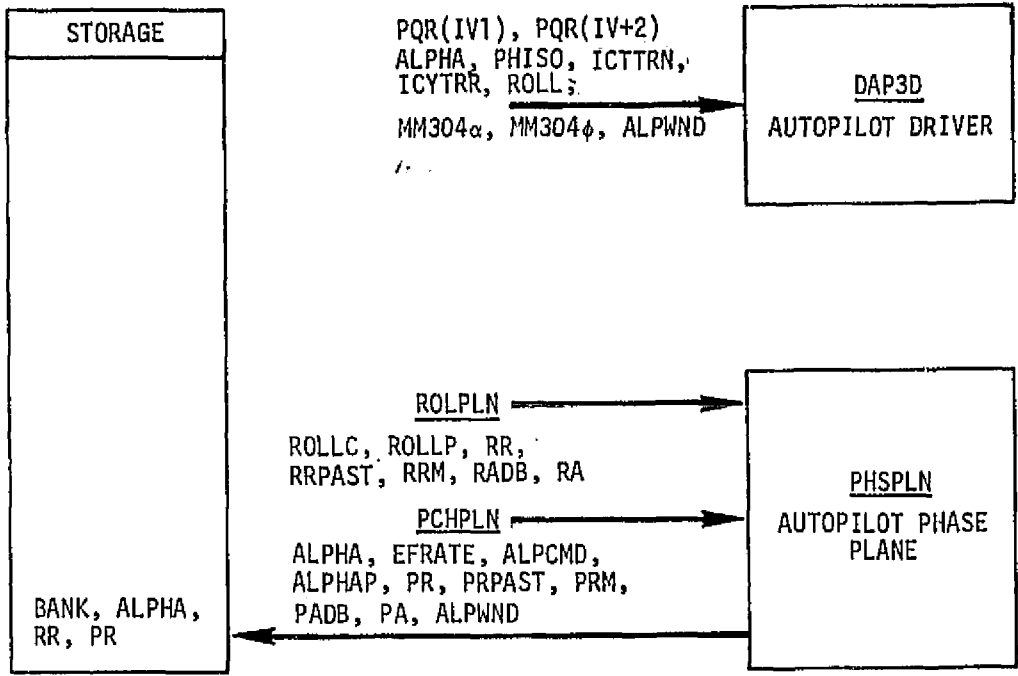


Figure 3.5.4-2.- Autopilot internal data flow.

## APPENDIX A: ENTRY GUIDANCE FLOW CHARTS

The following flow charts define the entry guidance formulations.

| <u>Function</u>    | <u>Figure</u> | <u>Number of flow charts</u> |
|--------------------|---------------|------------------------------|
| EGEXEC             | A-1           | 4                            |
| EGSCALHT           | A-2           | 1                            |
| EGINIT             | A-3           | 2                            |
| EGCOMN             | A-4           | 1                            |
| EGPEP              | A-5           | 1                            |
| EGRP               | A-6           | 3                            |
| EGREF              | A-7           | 2                            |
| EGREF <sup>4</sup> | A-8           | 1                            |
| EGTRAN             | A-9           | 2                            |
| EGALPCMD           | A-10          | 1                            |
| EGGNSLCT           | A-11          | 1                            |
| EGLODVCMD          | A-12          | 2                            |
| EGROLCMD           | A-13          | 1                            |

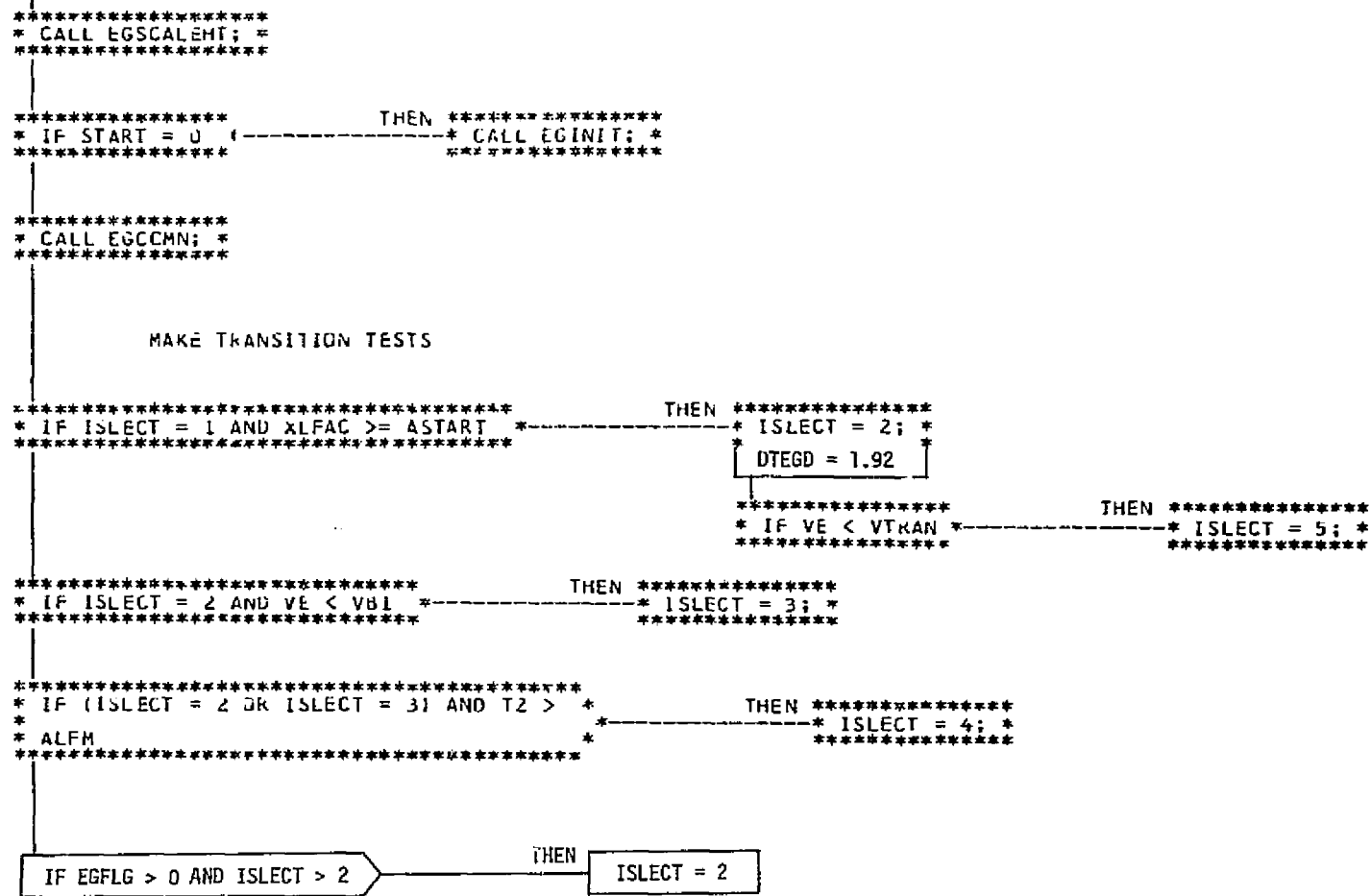


Figure A-1.- EGEXEC, entry guidance executive.

\*\*\*\*\*  
\* DU CASE ISLECT; \*  
\*\*\*\*\*

1

COMPUTE VERTICAL ( L/D ) DURING PREENTRY PHASE

\*\*\*\*\*  
\* CALL EGPEP; \*  
\*\*\*\*\*

2

COMPUTE REFERENCE PARAMETERS DURING TEMPERATURE CONTROL PHASE

\*\*\*\*\*  
\* CALL EGRP; \*  
\* CALL EGREF; \*  
\*\*\*\*\*

3

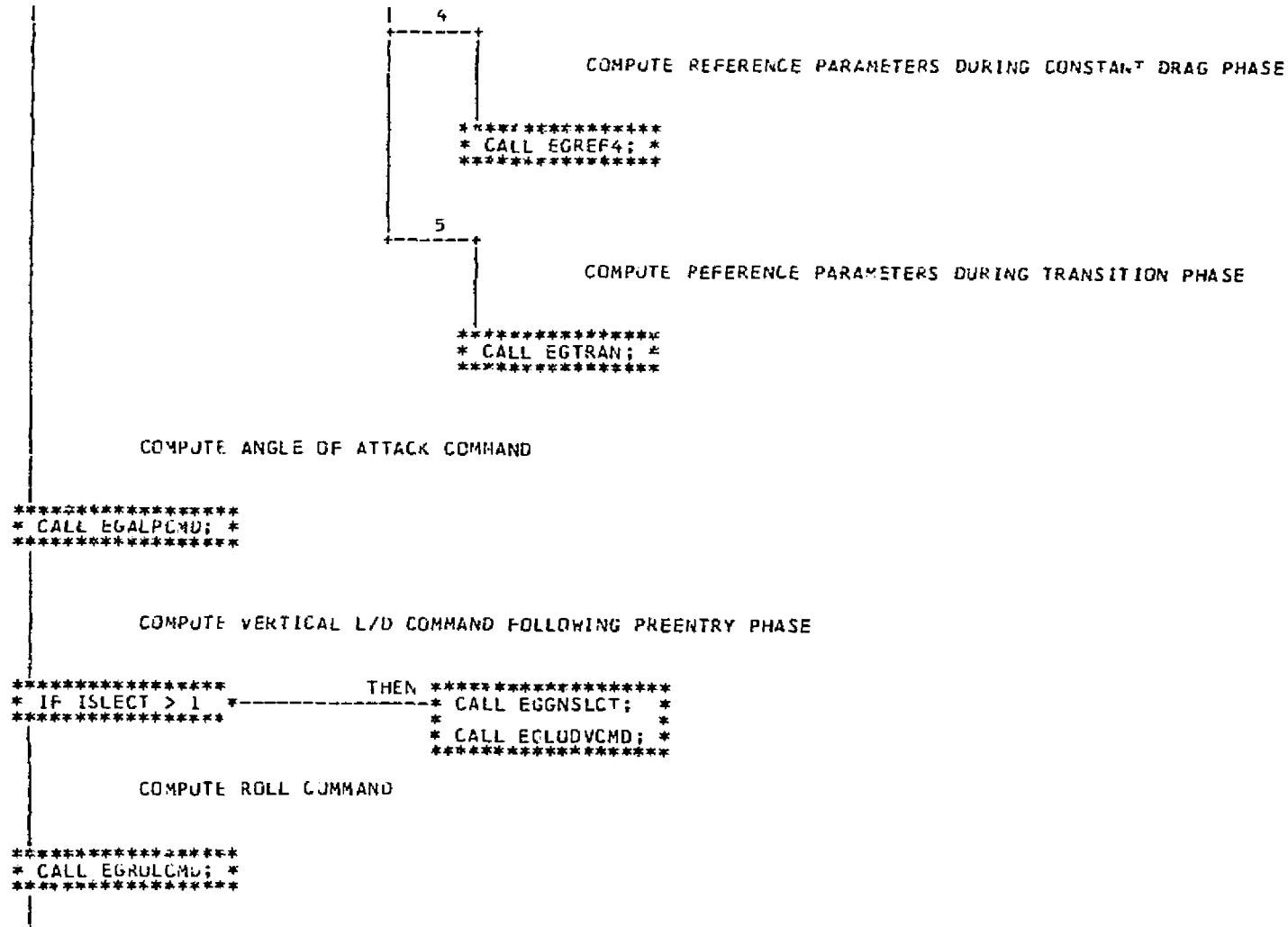
COMPUTE REFERENCE PARAMETERS DURING EQUILIBRIUM GLIDE PHASE

\*\*\*\*\*  
\* CALL EGRP; \*  
\* CALL EGREF; \*  
\*\*\*\*\*

A-3

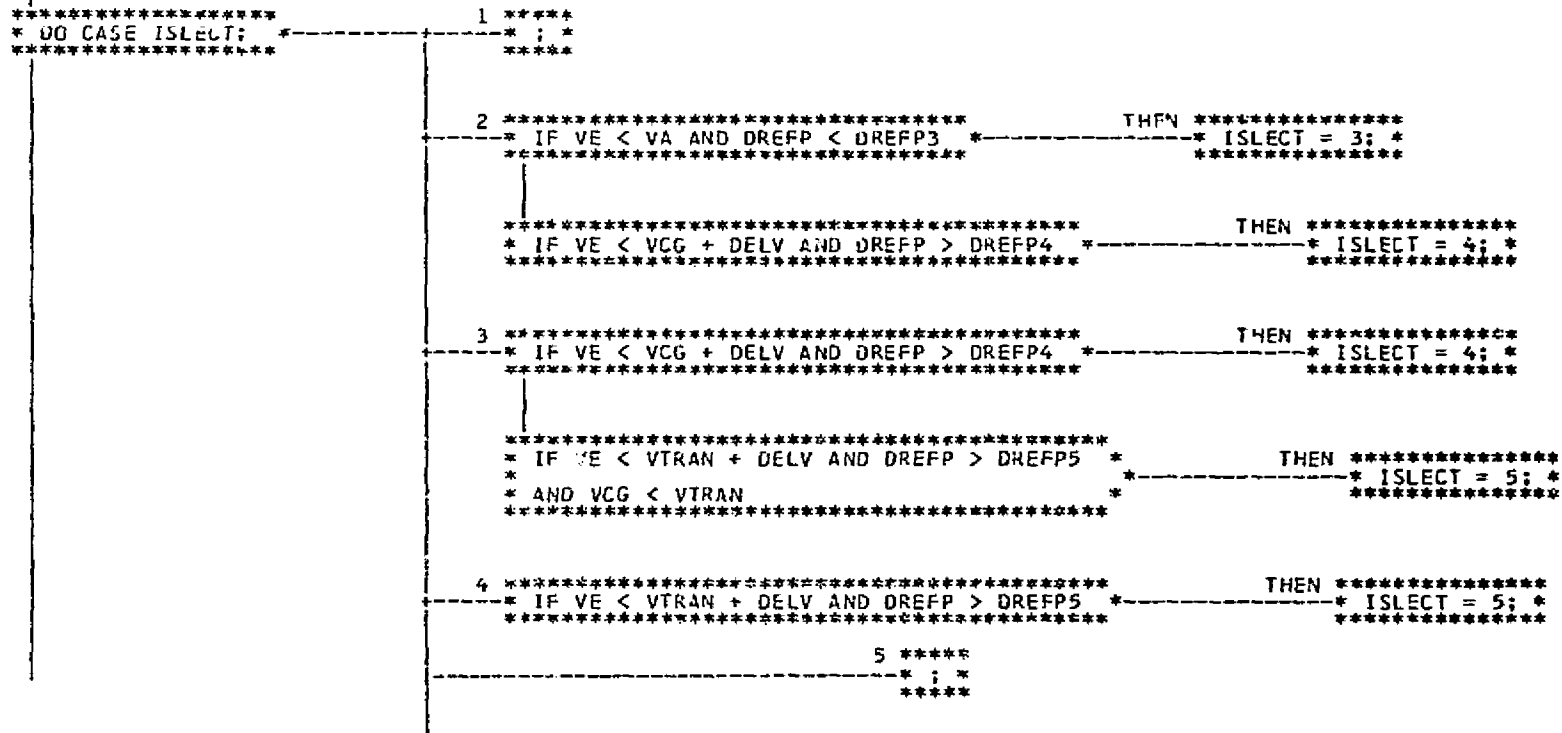
ORIG  
DU CASE ISLECT  
QUALITY

Figure A-1.- Continued.





MAKE TRANSITION TESTS



A-5

Figure A-1.- Concluded.

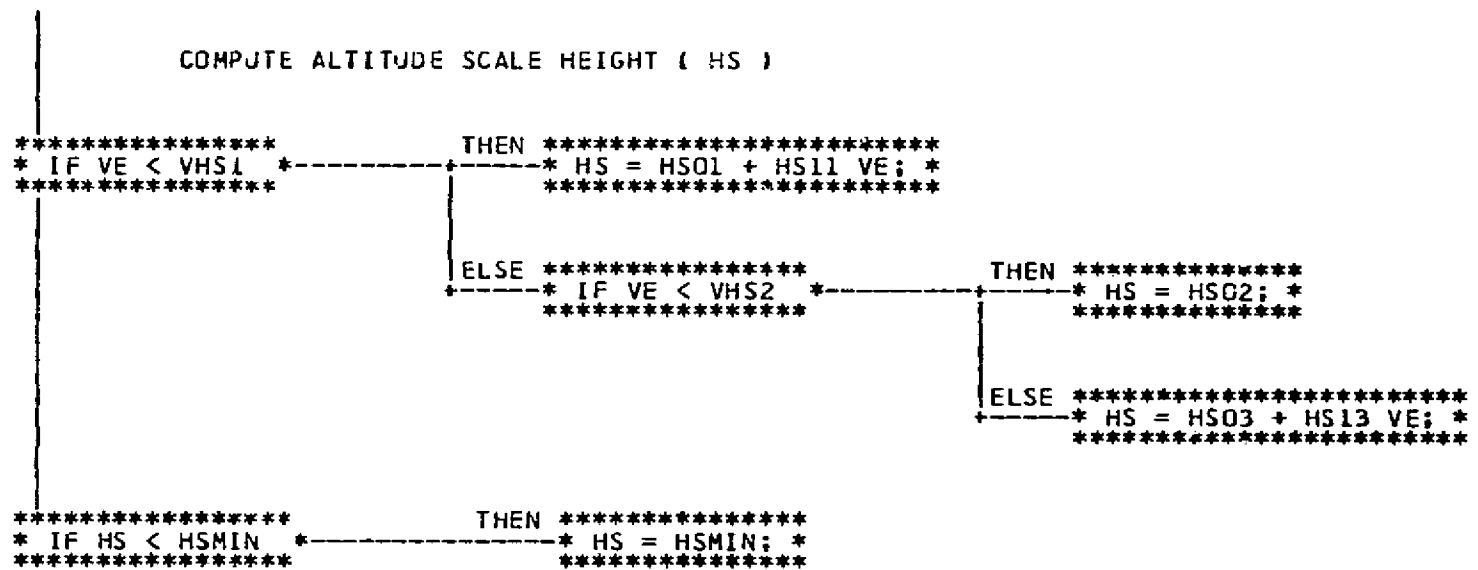


Figure A-2.- EGSCALHT, scale height.

INITIALIZE VARIABLES AND FLAGS

```

*****
* CZOLD = 0.;
* IVRR = 0
* ITRAN = OFF;
* ISLECT = 1;
* ICT = 0
* IDBCHG = 0
* T2 = 0.;
* DREFP = 0.;
* VQ2 = VQ VQ;
* RK2ROL = -SIGN(DELAZ);
* DLROOT = 0.;
* LMFLG = 0;
* VTRB = 60000.;
* DDP = 0.;
* RK2RLP = RK2R JL;
*****

```

COMPUTE DESIRED TRANSITION RANGE ( RPT )

```

*****
* RPT = -((ETRAN - EEF4) LOG(DF / ALFM) / (
* ALFM - DF) + (VTRAN VTRAN - VQ2) / (
* 2. ALFM)) CNMFS + RPT1;
*****
* VSAT2 = VSAT VSAT;
* VSIT2 = VS1 VS1;
* VCG = VQ;
* D23 = D230;
* DX = 1.;
*
*****

```

Figure A-3.- EGINIT, initialization.

```

*****
* VO = VB1;
* 1
* VX = VA;
* 1
* VF = VA1;
* 1
* A = AK;
* 1
* VO = VA1;
* 2
* VX = VA2;
* 2
* A = AK1;
* 2
* VB2 = VB1 VB1;
*****

```

COMPUTE COMPONENT OF CONSTANT DRAG PHASE RANGE, RCG

```

*****
* RCG1 = CNMFS (VSIT2 - VQ2) / (2. ALFM);
*****
*****
* IALP = NALP;
* START = 1;
*
*
*
*****

```

6-7

```

      COMPUTE COMMON VARIABLES
*****
* XLCD = MAX(SCALAR(LCD), LUDMIN);
* T1 = GS (VI VI / VS*T2 - 1.);
* T2GLC = T2;
* VE2 = VE VE;
* EEF = GS HLS + VE2 / 2.;
* EOWD = EEF/GS
* CAG = 2. GS HS + VE2;
*****
*****
* IF ISLECT < > THEN *****
* T2 = CNMFS (VE2 - VQ2) / T2, (TRANGE -
* RPT);
* T2JUT = (T2 - T2JLD) / DTJGD;
*****
      COMPUTE ALTITUDE RATE REFERENCE FOR TRANSITION
*****
* IF VE < VTRAN + DELV ***** THEN *****
* C1 = (T2 - DF) / (ETRAN - EEF4);
* RDTAFT = -(C1 (GS HLS - EEF4) + DF) 2.
* VE HS / CAG;
* DREFPS = DF + (EEF - EEF4) C1 + GS4 (
* RDTREF = RDTAFT);
*****

```

Figure A-4.- EGCOMN, common.

```

      COMPUTE VERTICAL L/D DURING PREENTRY PHASE
*****
* LODX = XLOD COS(MM304φ / RADEG)      *
*                                       *
* LODV = LODX;                         *
*****
```

Figure A-5.- EGPEP, preentry phase.

COMPUTE REFERENCE PARAMETERS FOR TEMPERATURE CONTROL AND  
EQUILIBRIUM GLIDE PHASES ( ISLECT = 2 OR 3 )

```

*****
* IF VE > VAL THEN *****
*****
* K = 2; *
* N = 2; *
*****
ELSE *****
* K = 1; *
* N = 1; *
* RF = 0.; *
* 2 *
*****

*****
* VF = VE; *
* N *
*****

***** THEN *****
* IF START = 1 *****
*****
* K = 1; *
* START = 2; *
*****

***** ,HEN *****
* DO FOR I = 1 TO 2; *****
*****
***** IF I = 2 *****
*****
***** DX = CQ1 + VAL (CQ2 + CQ3 VAL); *****
*****
*****
***** CQ3 = -A DX / (2. (VX - VO ) VO ); *****
*****
***** CQ2 = -2. VX CQ3 ; *****
*****
***** DX - VO (CQ2 + CQ3 VO ); *****
*****
***** *****

```

II-V

Figure A-6.- EGRP, range prediction.







A-14

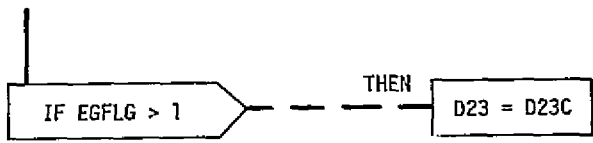


Figure A-6.- Concluded.

COMPUTE REFERENCE PARAMETERS FOR TEMPERATURE CONTROL AND  
EQUILIBRIUM GLOW PHASES ( ISELECT = 2 OR 3 )

DURING TEMPERATURE CONTROL PHASE

```

*****
* IF VE > VB1 *----- THEN *****
*****
* DO FOR I = 1 TO N; *----- *****
*****
* DREF = CQ1 + VE (CQ2 + CQ3 VE); *
*      I      I      I      I      I *
* HDTRF = -HS (2. DREF / VE - CQ2 - 2. *
*      I      I      I      I      I *
*      CQ3 VE); *
*****
*****
* IF VE > VA1 *----- THEN *****
*****
* DRF = DREF - DREF ; *
*      2      I *
* DRF = DRF (DRF + (HDTRF - HDTRF ) GS1); *
*      I      I      2 *
*****
*****
* IF DRF < 0. *----- THEN *****
*****
*****
*****
* DREFP = D23 DREF ; *
*      N *
* RDTRF = D23 HDTRF ; *
*      N *
* C2 = CQ2 D23; *
*      N *
*****

```

A-15

Figure A-7.- EGREF, reference parameters.

```

DURING EQUILIBRIUM GLIDE PHASE

*****
* IF VE < VA *----- THEN *****
*****
* ALDCO = (1. - VB2 / VSIT2) / D23; *
* DREFP1 = (1. - VE2 / VSIT2) / ALDCO; *
* ROTRF1 = -2. HS / (VE ALDCO); *
* DREFP3 = DREFP1 + GS2 (ROTFREF - ROTRF1); *
*****
*----- THEN *****
* IF DREFP3 > DREFP OR VE < VB1 *-----
*****
* DREFP = DREFP1; *
* ROTREF = ROTRF1; *
* C2 = 0.; *
*****

COMPUTE TEST VALUE FOR DREFP FOR TRANSITION TO CONSTANT
DRAG PHASE ( ISLECT = 4 )

*****
* DREFP4 = GS3 (ROTFREF + 2. HS T2 / VE) + *
* T2; *
* ITRAN = ON; *
*****

```

```
COMPUTE REFERENCE PARAMETERS DURING CONSTANT DRAG PHASE

*****
* DREFP = T2;
* RDTREF = -2. HS T2 / VE;
* DRDD = -(TRANGE - RPT) / T2;
* C2 = 0.;
*
* ITRAN = ON;
*****
```

Figure A-8.- EGRAF4, constant drag phase.

COMPUTE REFERENCE PARAMETERS DURING TRANSITION PHASE

```

*****
* IF ITRAN = OFF *----- THEN *****
*                   * DREFP = ALFM; *
*                   *                   *
*                   * ITRAN = ON; *
*****

*****
* DREFPT = DREFP - DF; *
*****

*****
* IF ABS(DREFPT) < E1 *----- THEN *****
*                   * DREFP = DF + E1 SIGN(DREFPT); *
*****

*****
* IF DREFP < E1 *----- THEN *****
*                   * DREFP = E1; *
*****

*****
* DREFPT = DREFP - DF; *
* C1 = DREFPT / (EEF - EEF+); *
* RER1 = CNMFS LOG(DREFP / DF) / C1; *
* DRDD = MIN(SCALAR(CNMFS / (C1 DREFP) - *
* RER1 / DREFPT, DRDDL)); *
* DREFP = DREFP + (TRANGE - RER1 - RPT1) / *
* DRDD; *
* DLIM = ALIM DRAG / XLFAC; *
*****

```

A-18

Figure A-9.- EGTRAN, transition phase.

```

*****
* IF DREFP > DLIM *----- THEN *****
*****
* DREFP = DLIM; *
* C1 = 0.0; *
*****

*****
* IF DREFP < E1 *----- THEN *****
*****
* DREFP = E1; *
*****

*****
* RDTREF = -HS VE (2. DREFP - C1 VE2) / *
* *
* CAG; *
* *
* C2 = 4. VE DREFP (1. - (VE2 / CAG)2) *
* *
* CAG; *
*****

```

Figure A-9.- Concluded.





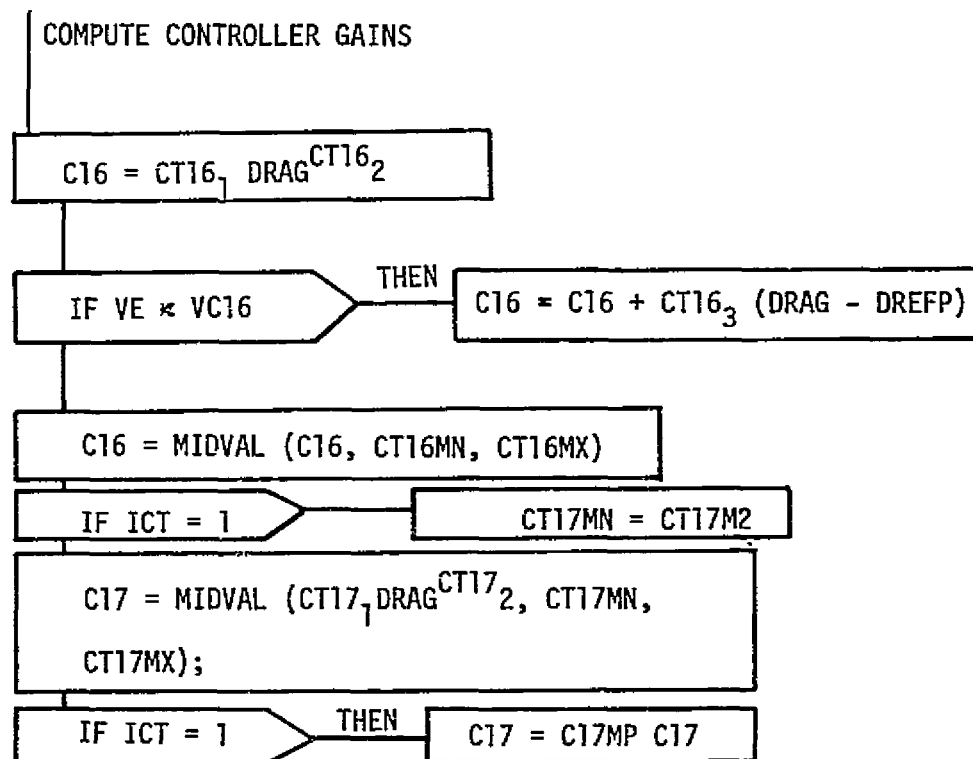


Figure A-11.- EGGNSLCT, gain select.

COMPUTE VERTICAL L/D COMMAND (L/DV)

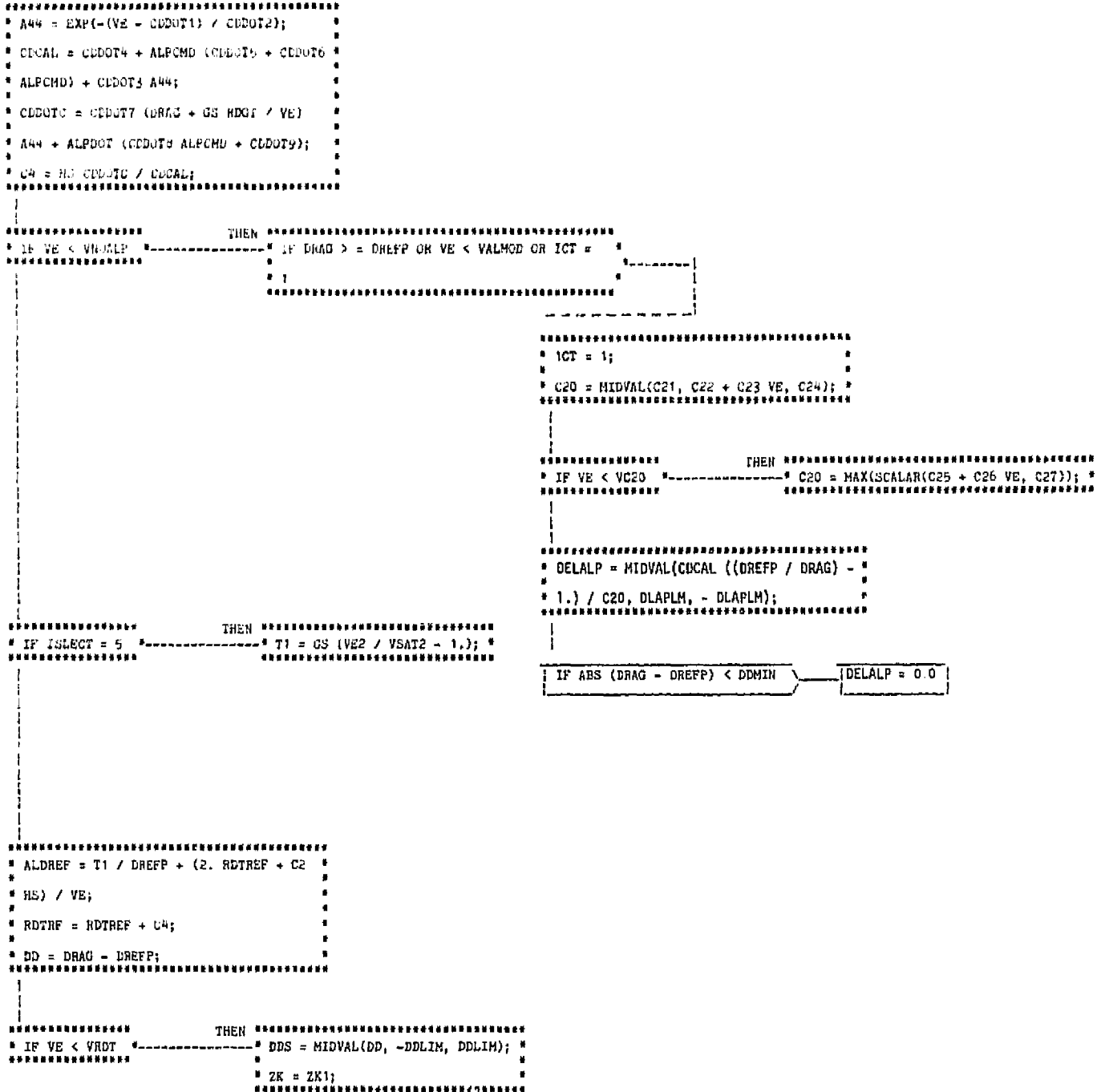


Figure A-12.- EGLDVCMD, lateral logic and vertical L/D command.

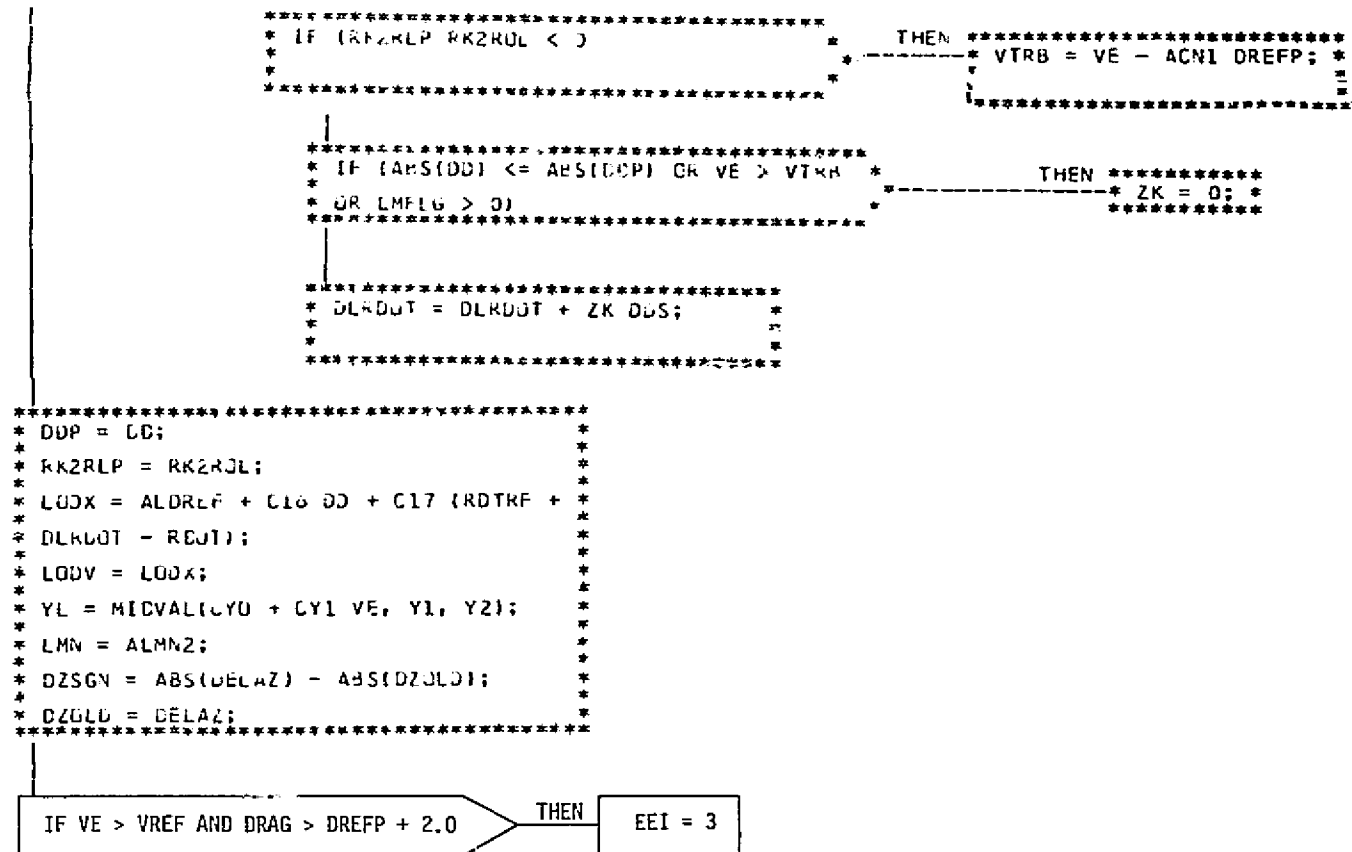
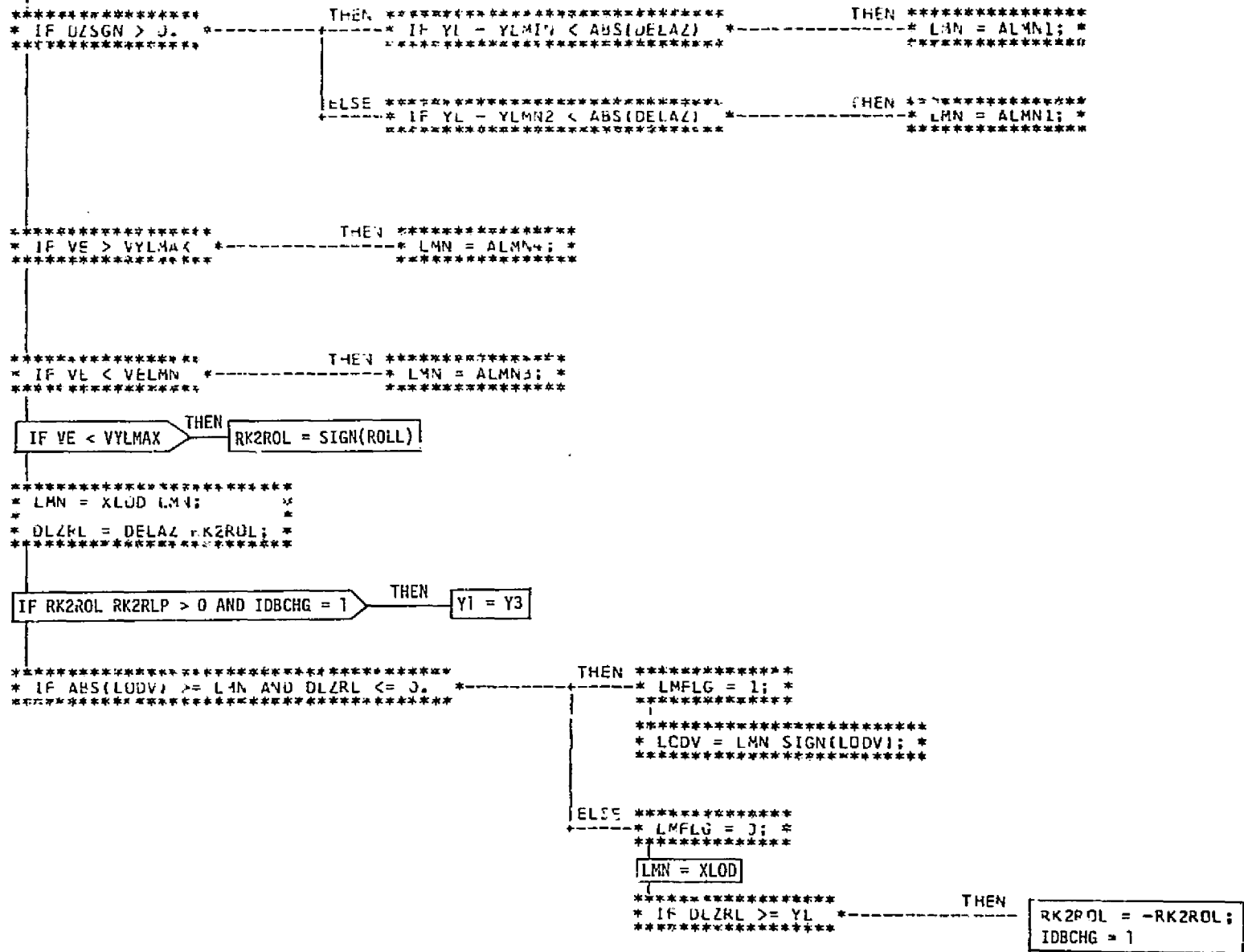


Figure A-12.- Continued.



A-24

Figure A-12.- Concluded.

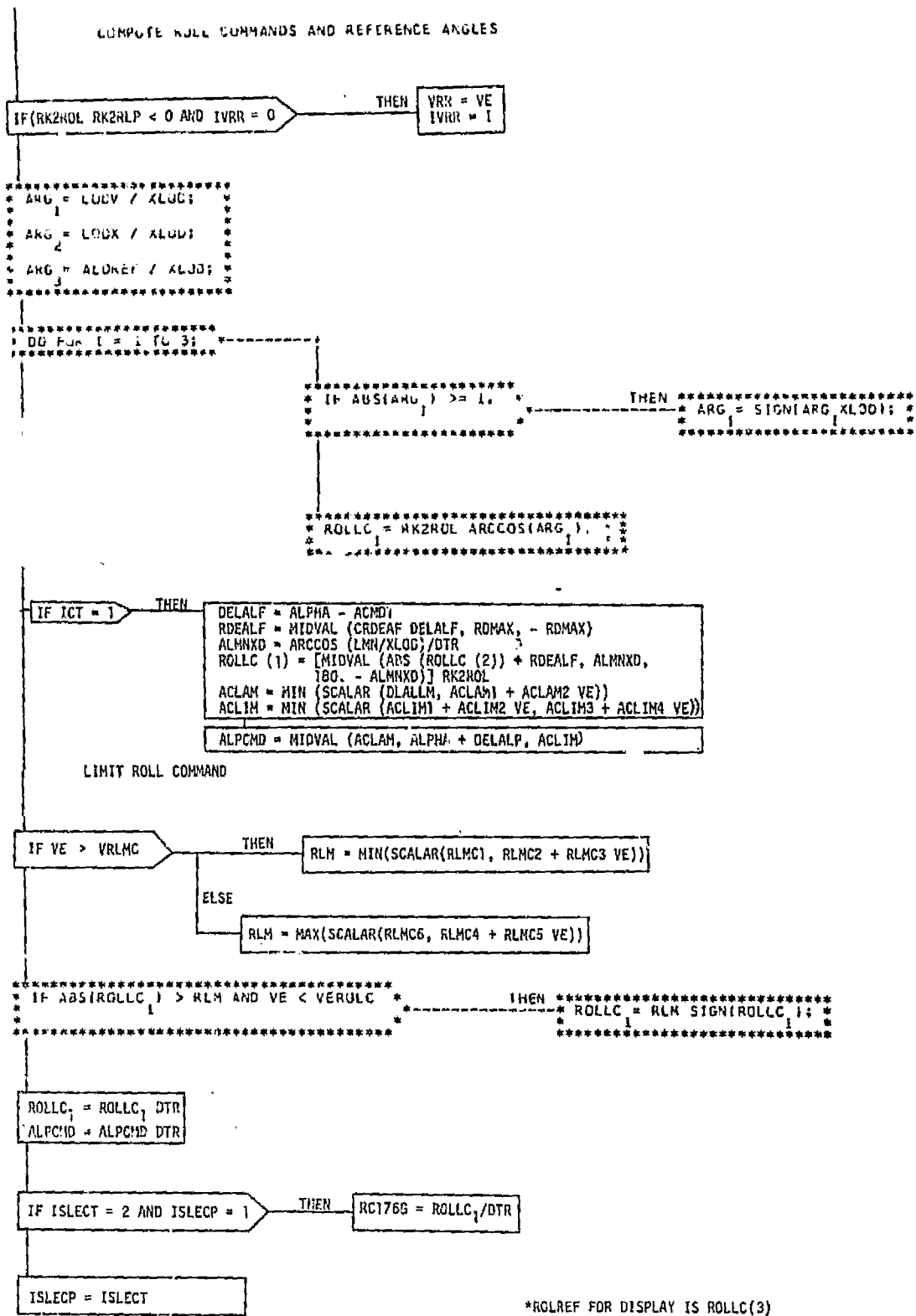
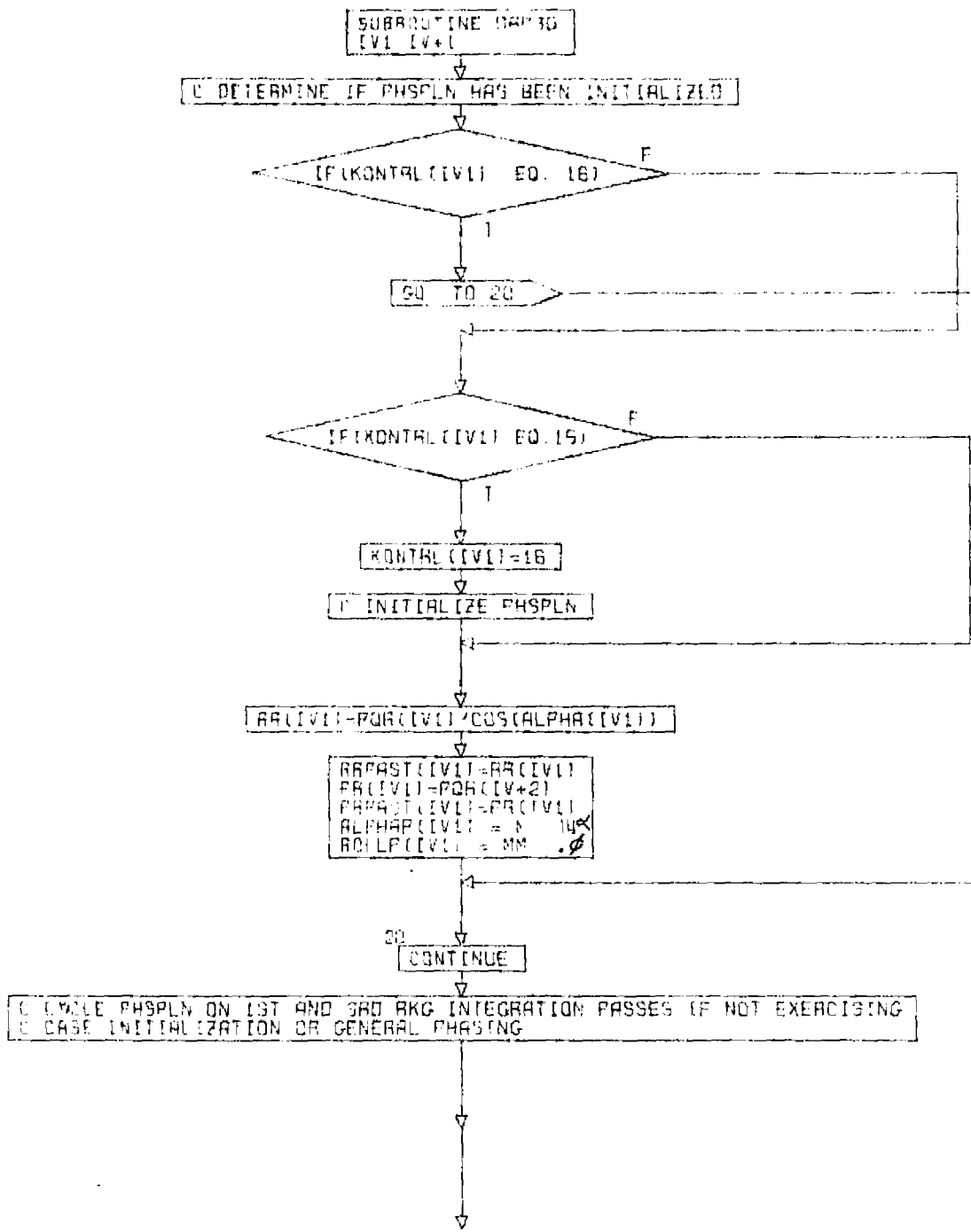


Figure A-13.- EGROLCHD, roll command.

## APPENDIX B: ENTRY AUTOPILOT FLOW CHARTS

The following flow charts define the entry autopilot formulations.

| <u>Function</u> | <u>Figure</u> | <u>Number of flow charts</u> |
|-----------------|---------------|------------------------------|
| DAP3D           | B-1           | 2                            |
| PHSPLN          | B-2           | 10                           |



CONT. ON PG 2

DAP3D  
PG 1 OF 2

Figure B-1.- DAP3D.

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 OF POOR QUALITY

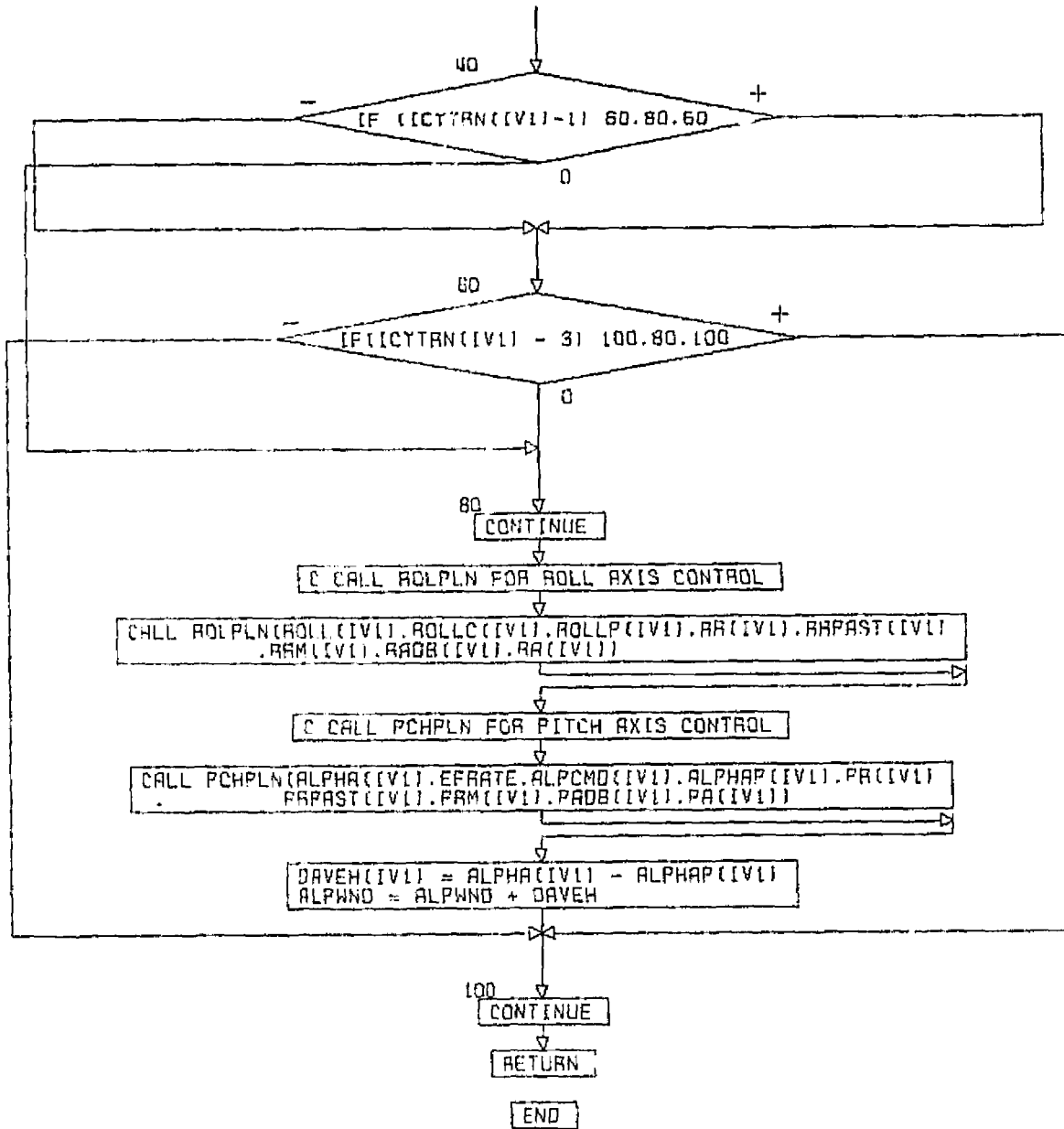


Figure B-1.- Concluded.

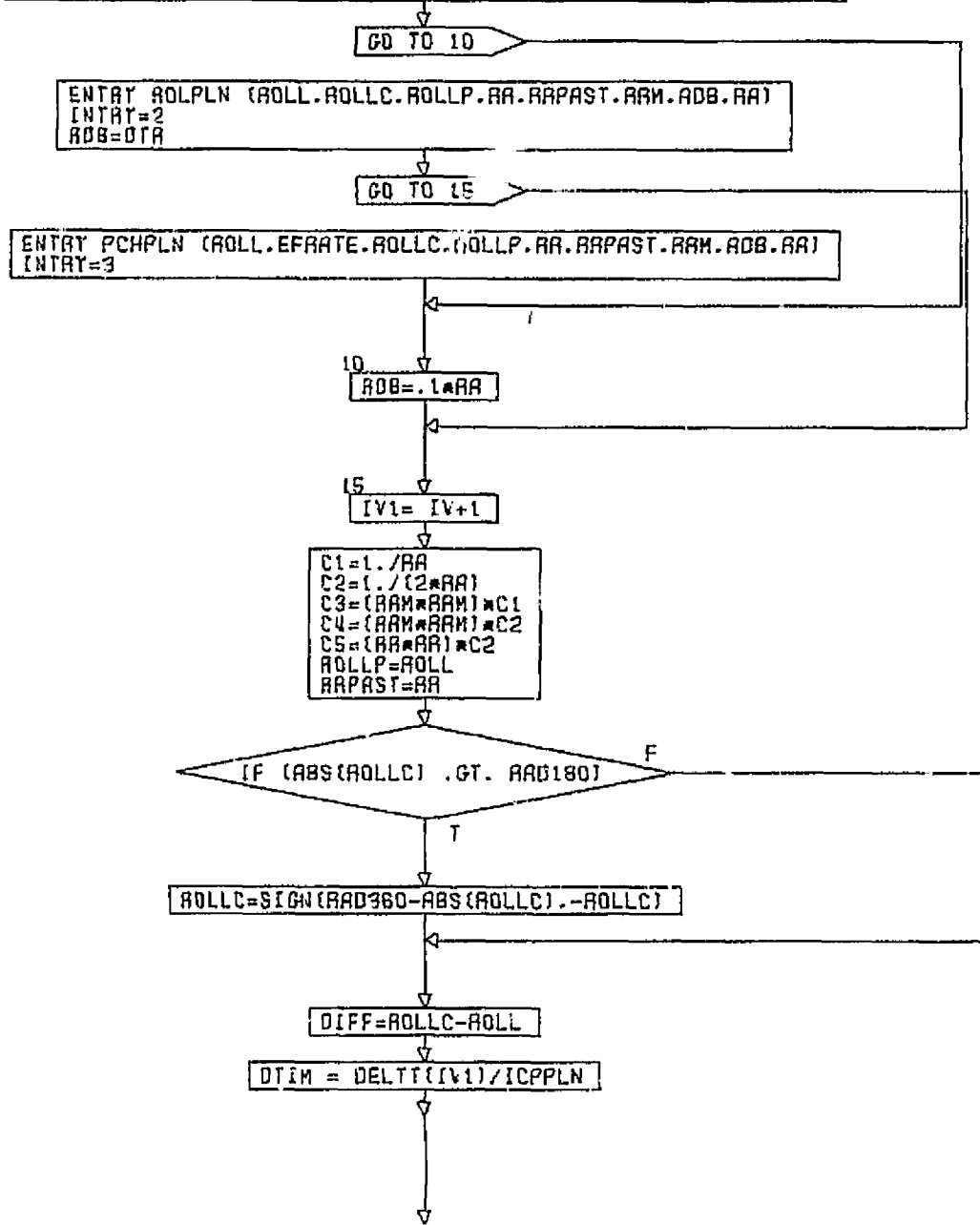
DAP30  
 PG 2 E16PL



```

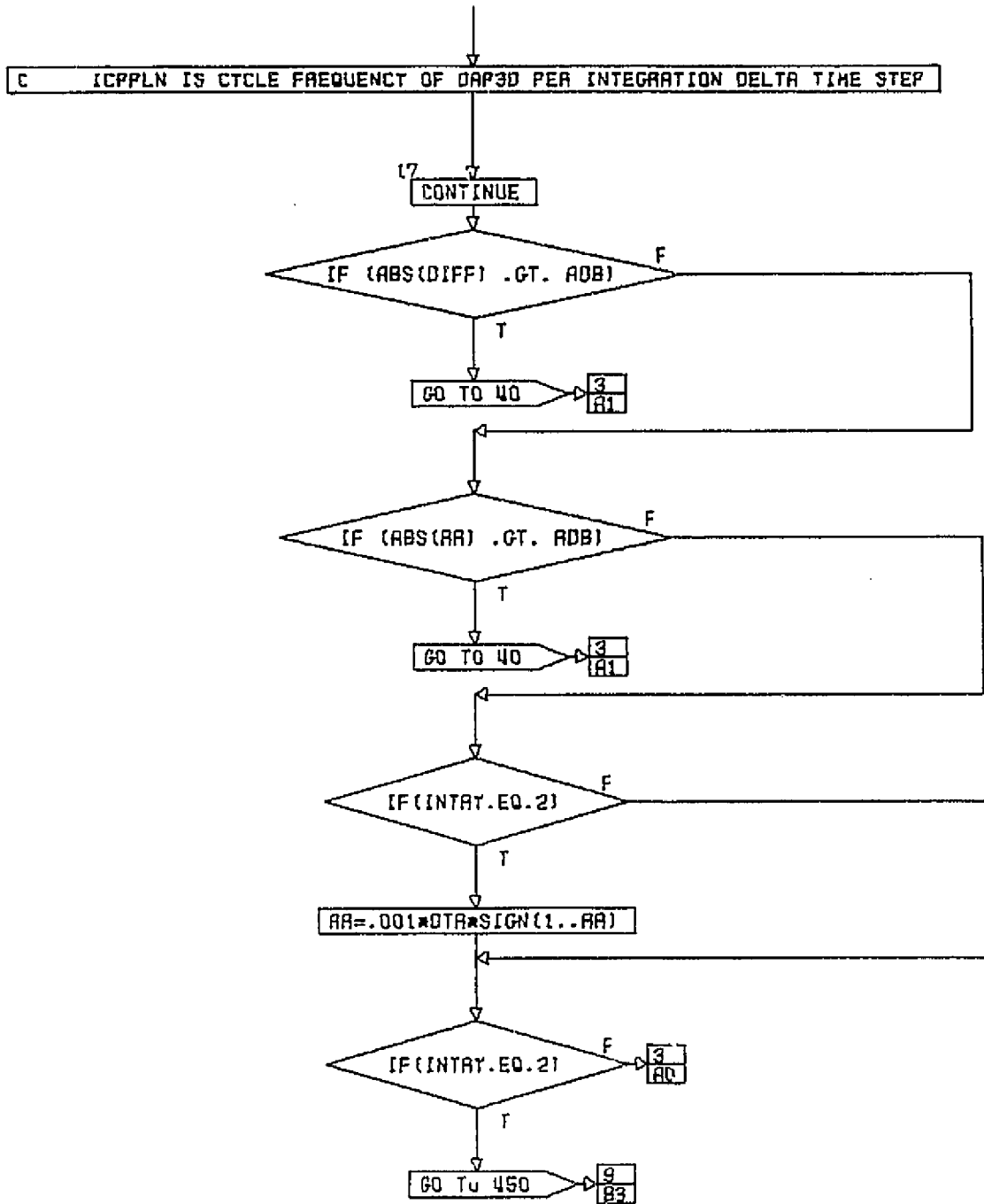
SUBROUTINE PHSPLN(ROLL,ROLLC,ROLLP,RA,RPAST,ARM,ADB,RA)
DATA RAD160/2.7925268/, RAD180/3.1415927/, RAD360/6.2831853/
DATA DTA/.017453292/
INTRY=1

```



PHSPLN  
PG 1 OF 10

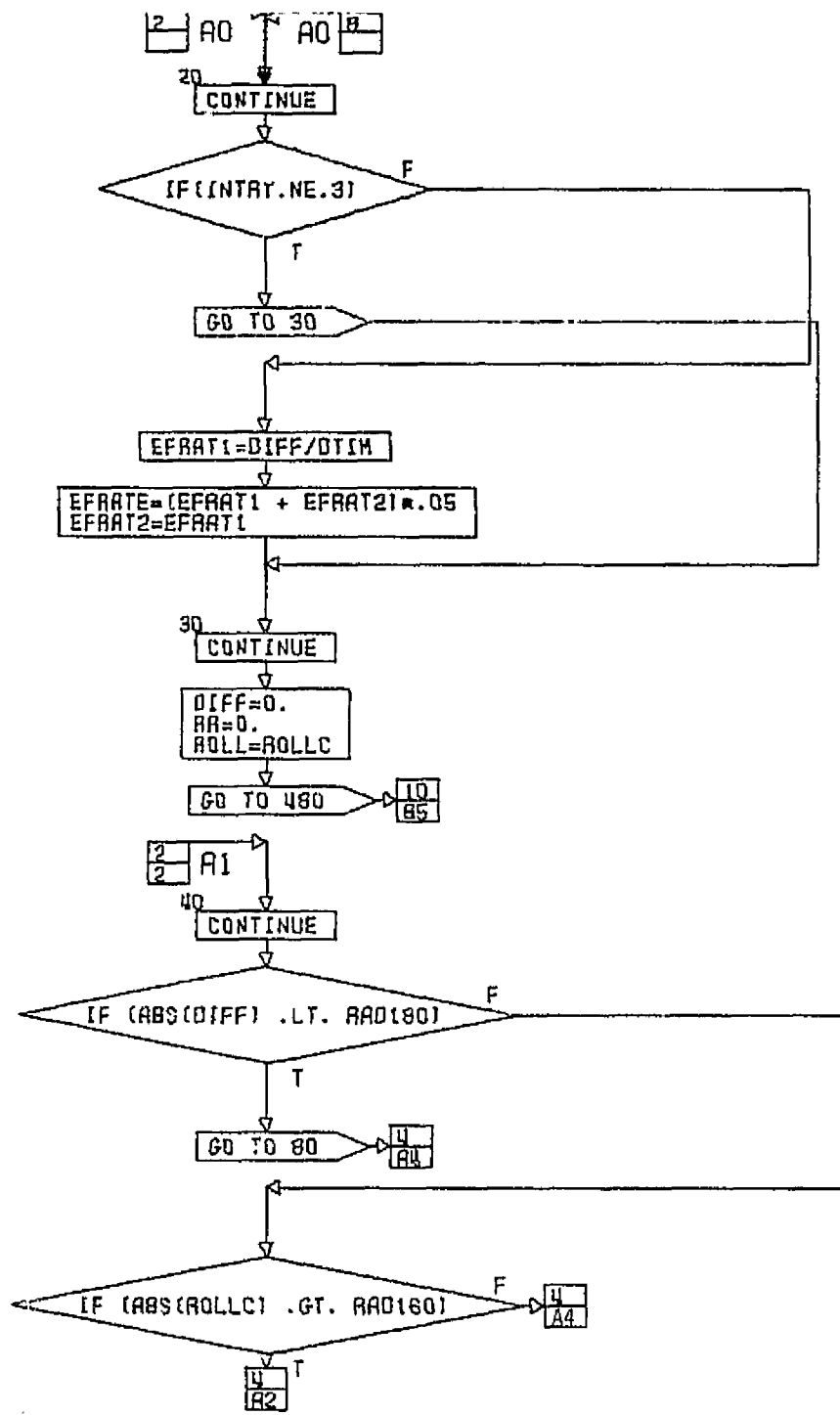
Figure B-2.- PHSPLN.



CONT. ON PG 3

PHSPLN  
PG 2 OF 10

Figure B-2.- Continued.



CONT. ON PG 4

PHSPLN  
PG 3 OF 10

Figure B-2.- Continued.

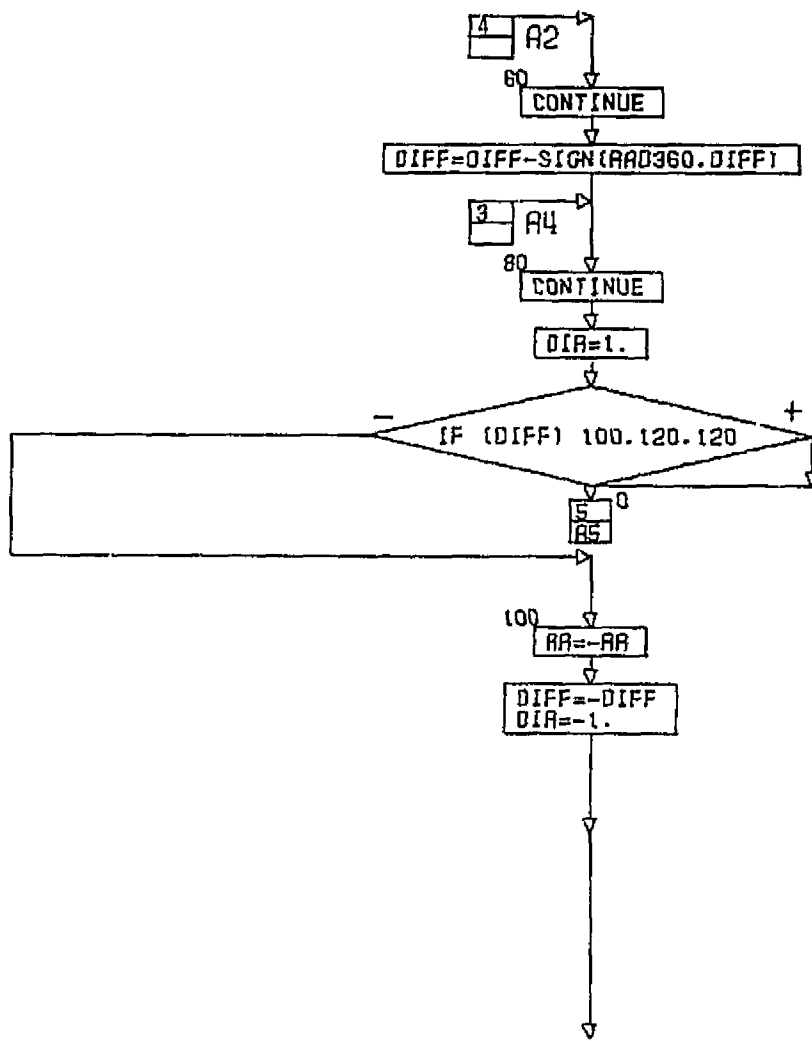
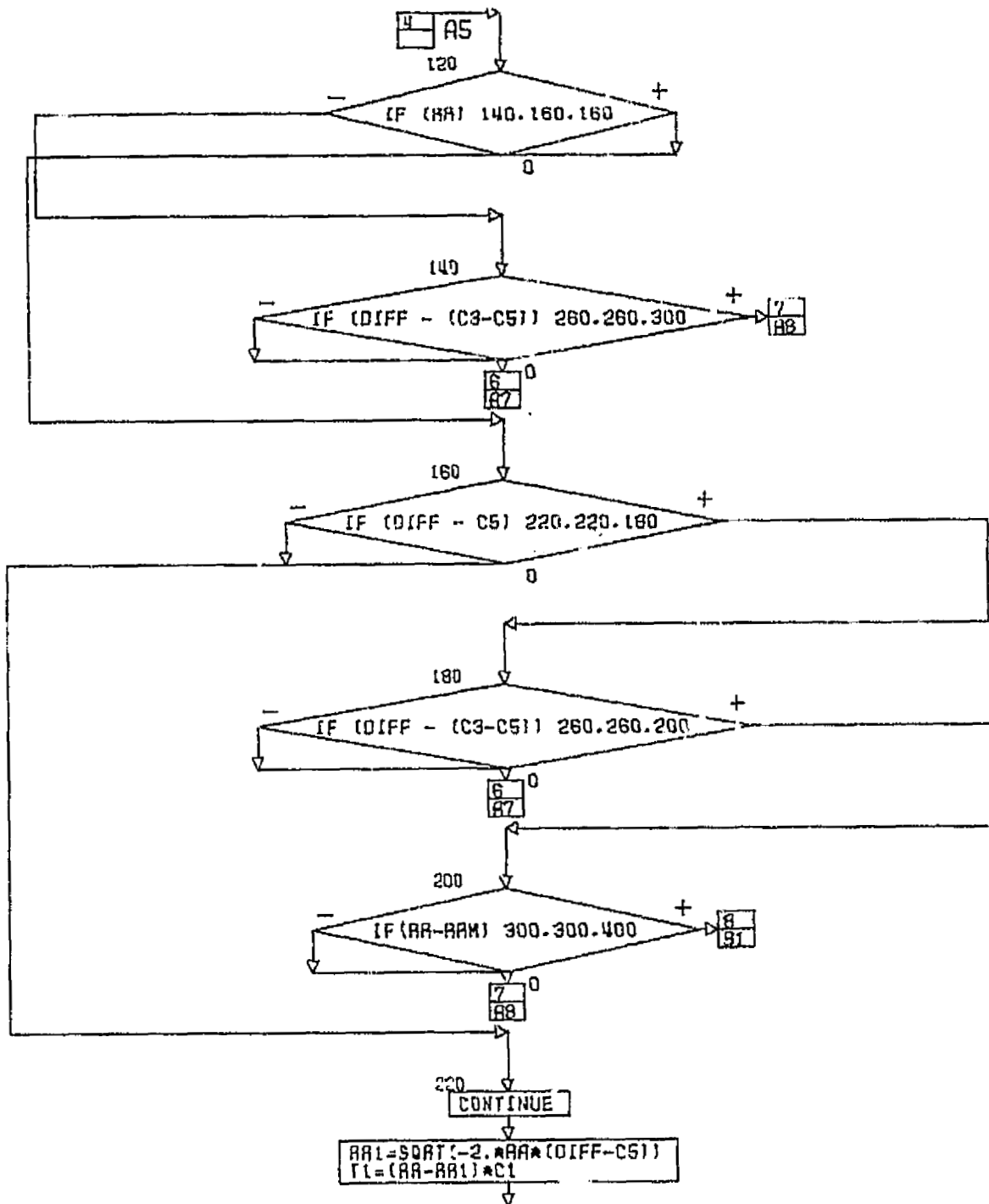


Figure B-2.- Continued.

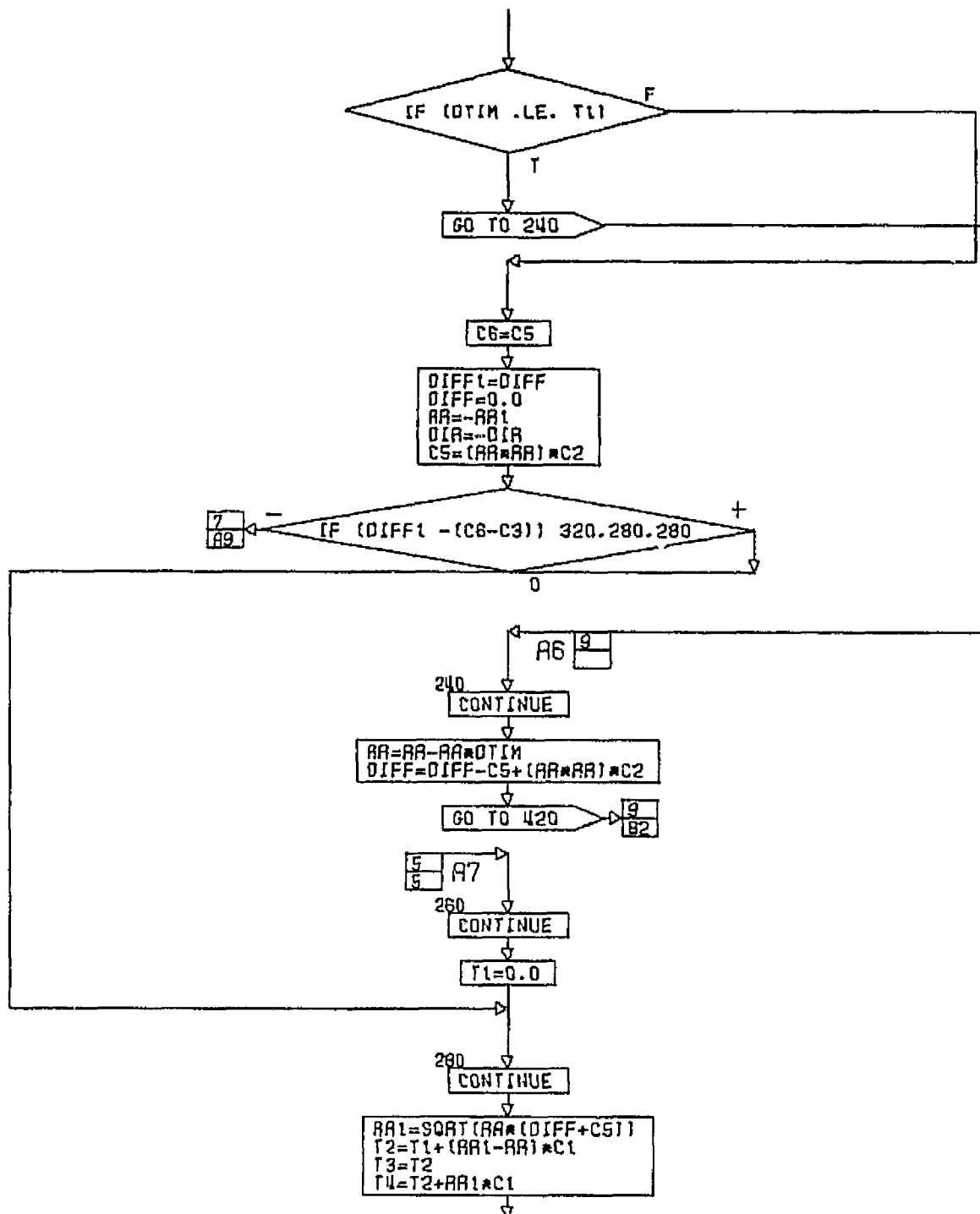
PHSPLN  
PG 4 OF 10



CONT. ON PG 6

PHSPLN  
PG. 5 OF 10

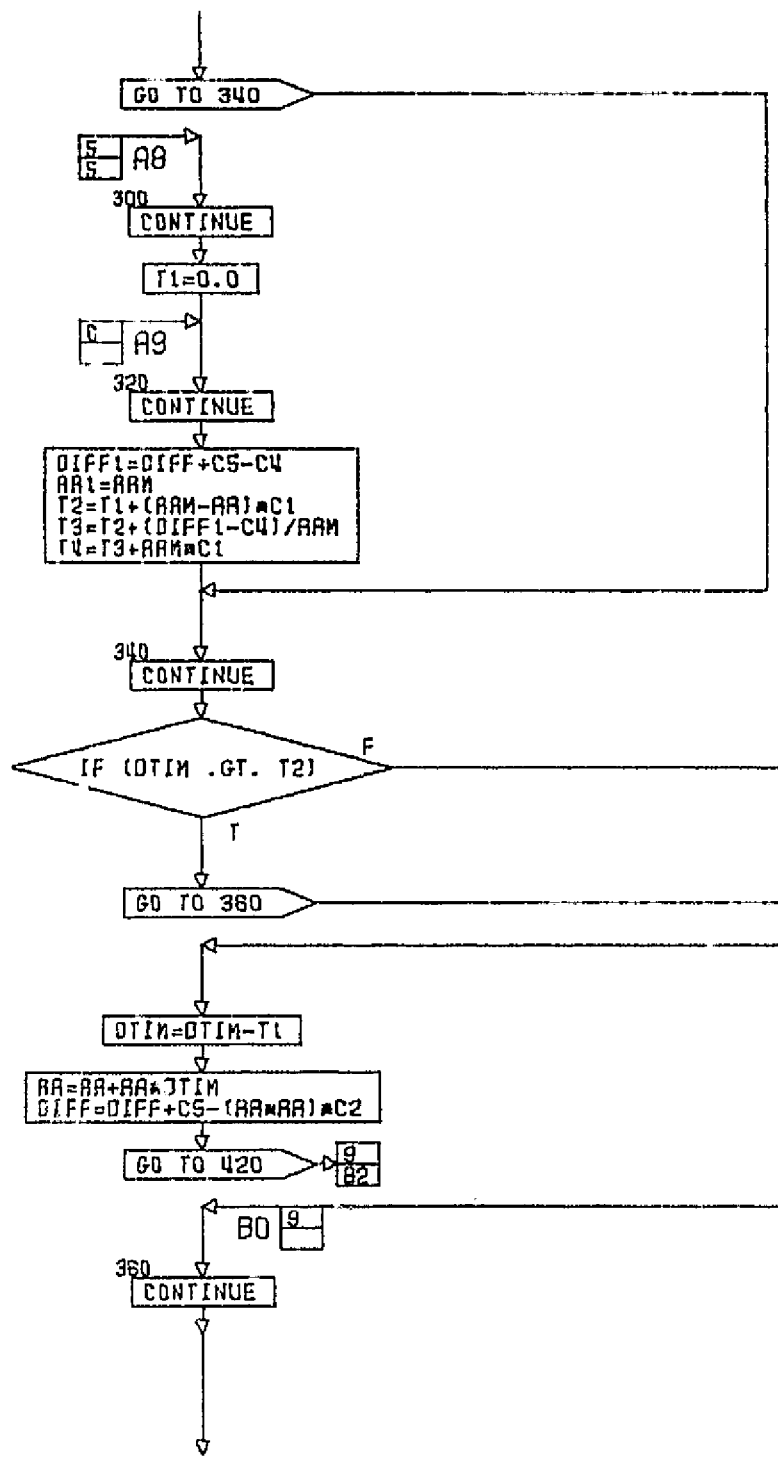
Figure B-2.- Continued.



CONT. ON PG 7

PHSPLN  
PG 6 OF 10

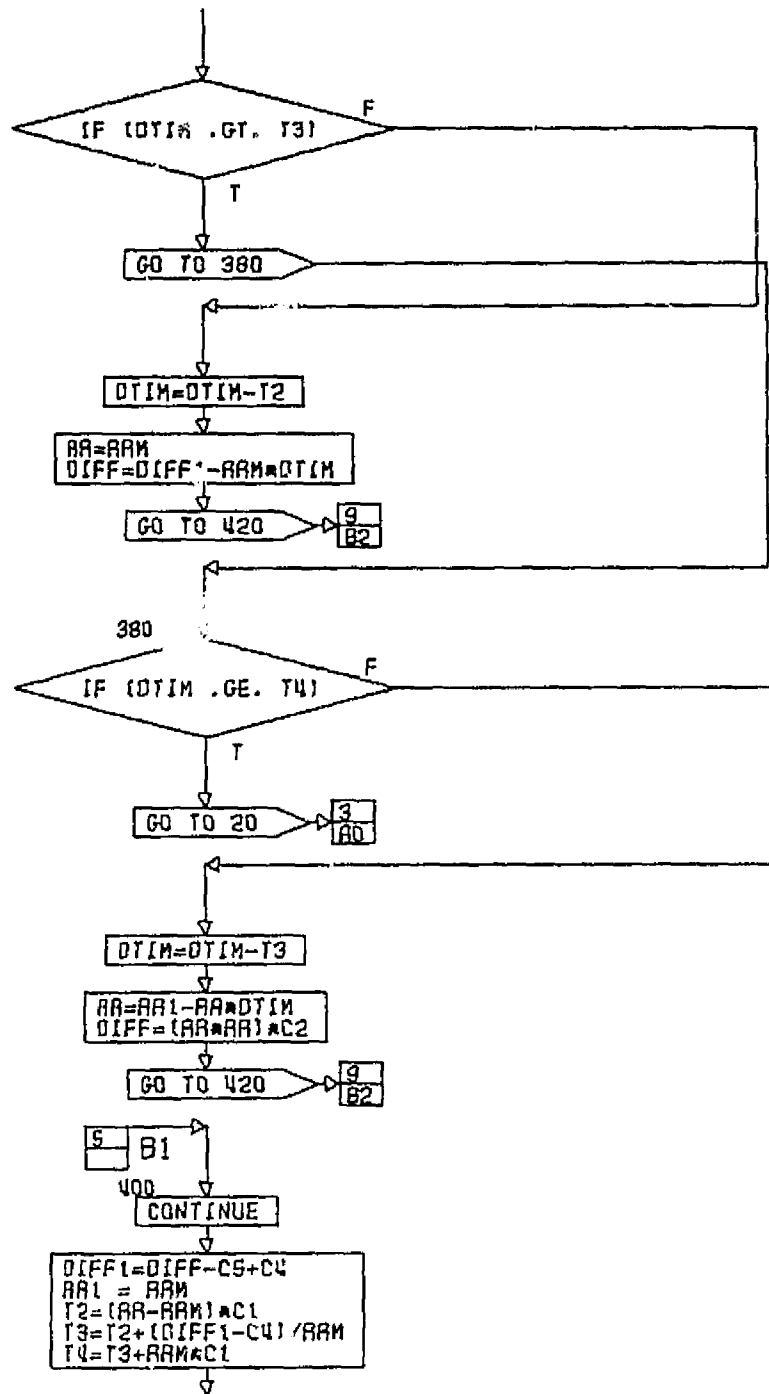
Figure B-2.- Continued.



CONT. ON PG 8

PHSPLN  
PG 7 OF 10

Figure B-2.- Continued.

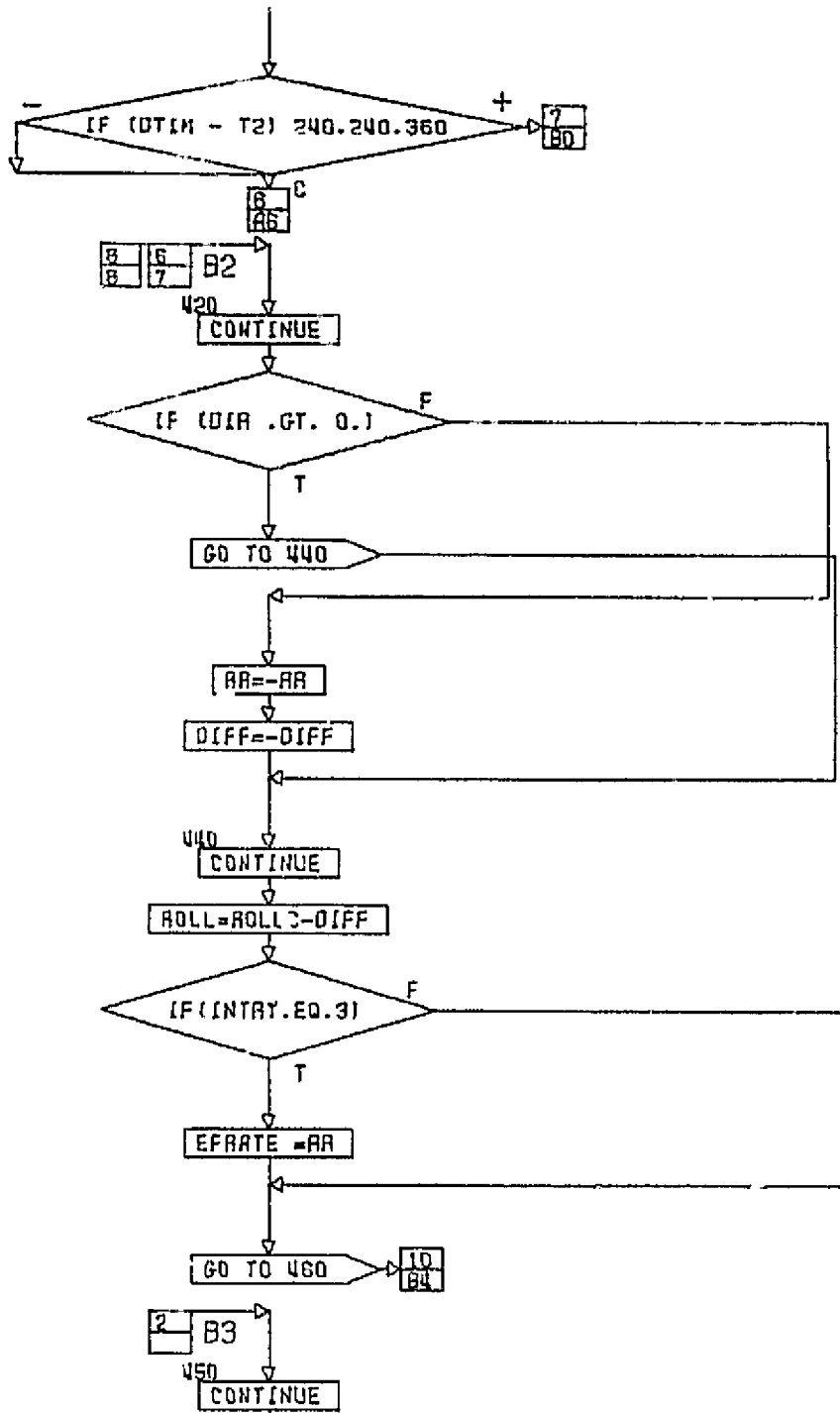


CONT. ON PG 9

PHSPLN  
PG 8 OF 10

Figure B-2.- Continued.



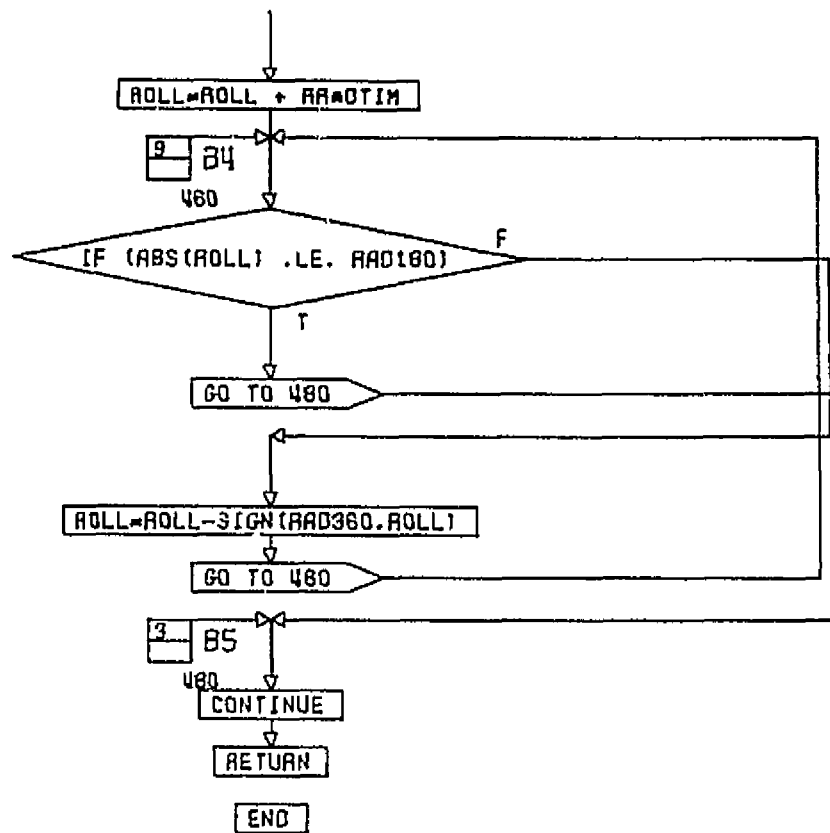


CONT. ON PG 10

PHSPLN  
PG 9 OF 10

Figure B-2.- Continued.

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PHSPLN  
PG 10 FINAL

Figure B-2.- Concluded.

## APPENDIX C: TARGETING FLOW CHARTS

The following flow charts define the targeting function for the entry processor.

| <u>Function</u> | <u>Figure</u> | <u>Number of flow charts</u> |
|-----------------|---------------|------------------------------|
| EGRT-EXEC       | C-1           | 1                            |
| EGRT-SEQ        | C-2           | 1                            |
| EGRT-CHACRC     | C-3           | 1                            |
| EGRT-CHACEFC    | C-4           | 1                            |
| EGRT-BV         | C-5           | 1                            |
| EGRT-BVCHAC     | C-6           | 1                            |
| EGRT-COSTHETA   | C-7           | 1                            |
| EGRT-DWP1       | C-8           | 1                            |
| EGRT-DVNEP      | C-9           | 1                            |
| EGRT-DELAZ      | C-10          | 1                            |

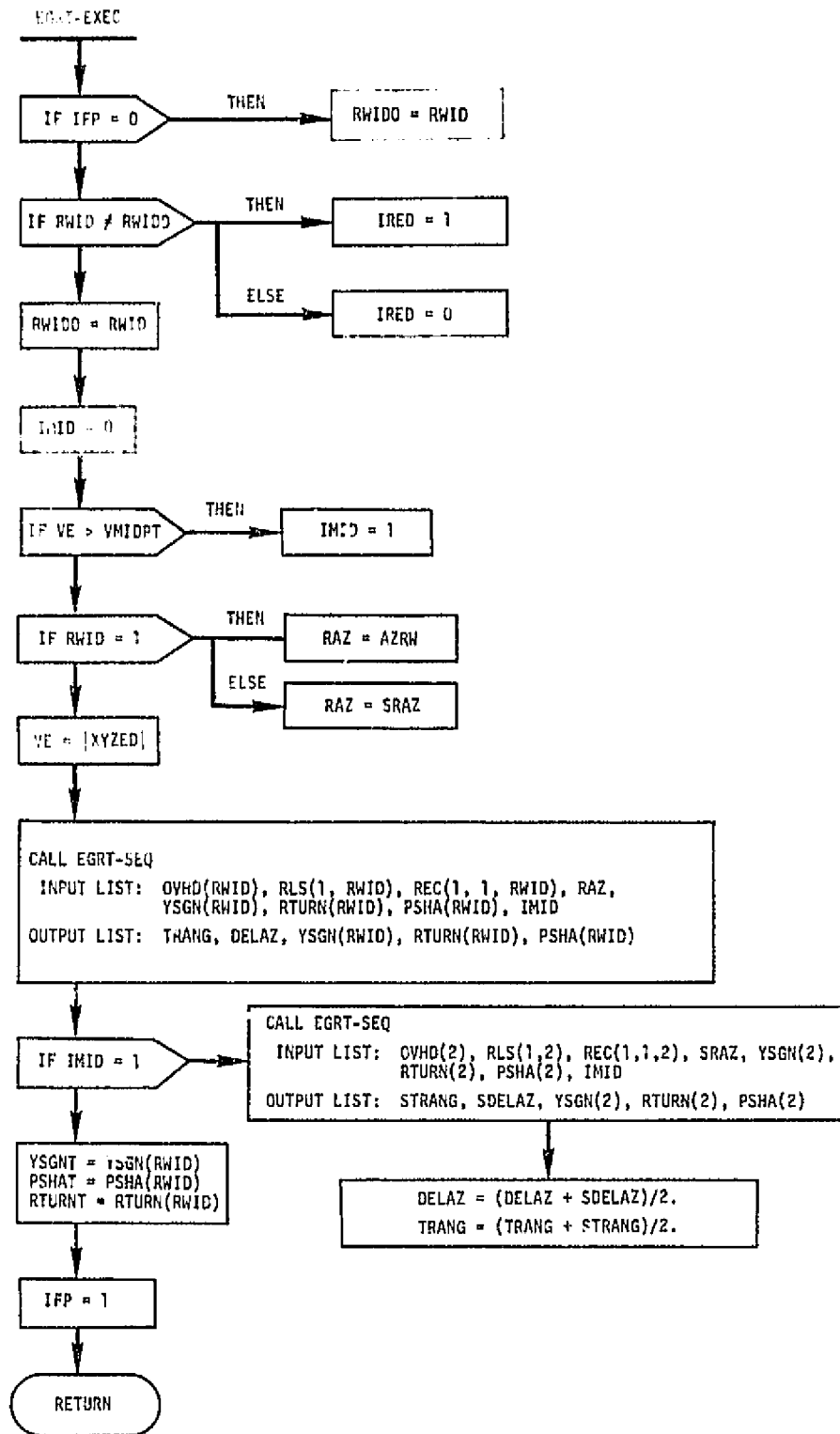


Figure C-1.- EGRT-EXEC, targeting executive logic.

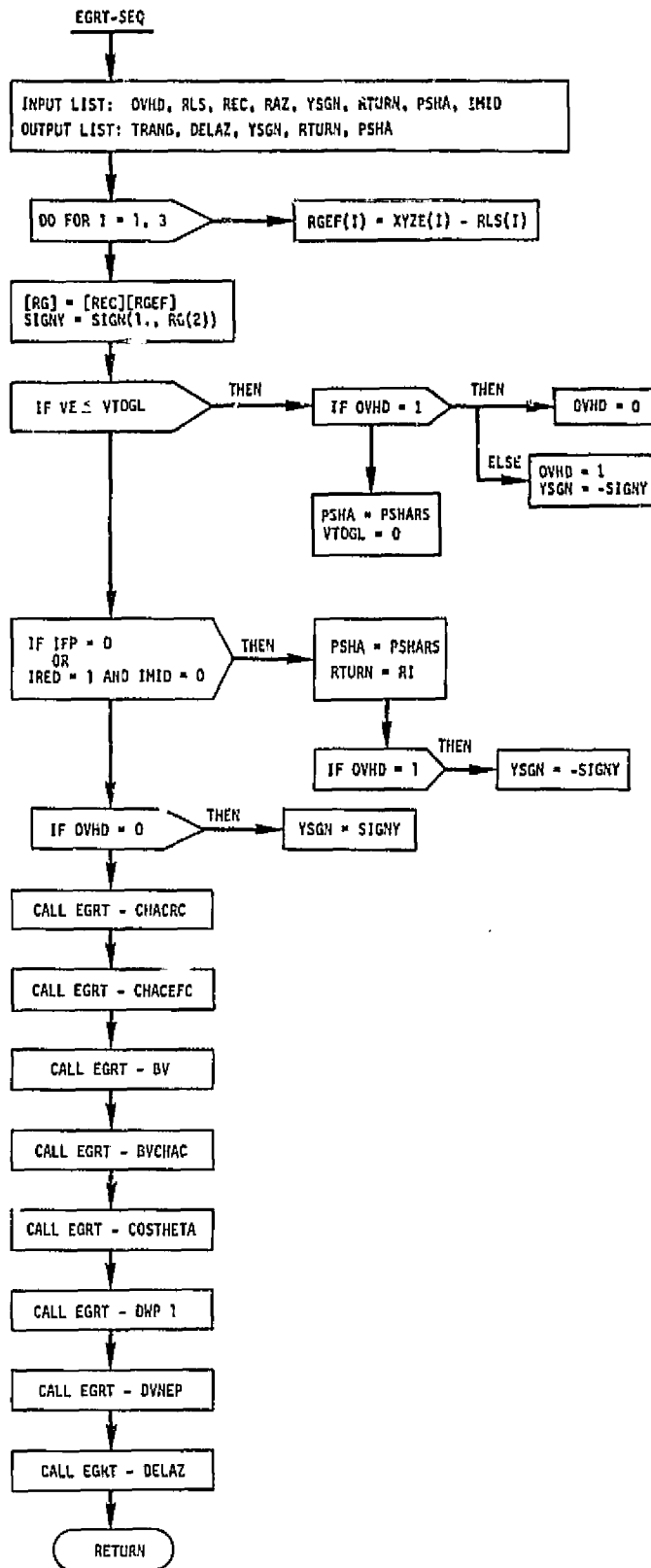


Figure C-2.- EGRT-SEQ, targeting logic sequence controller.

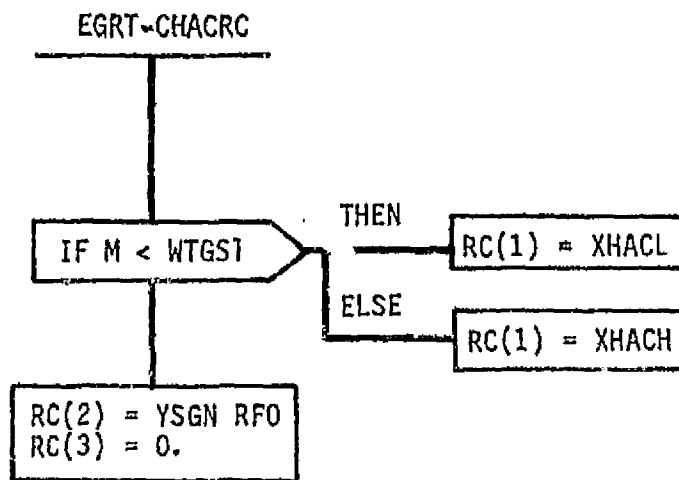


Figure C-3.- EGRT-CHACRC, center heading alignment cone - runway coordinate system.

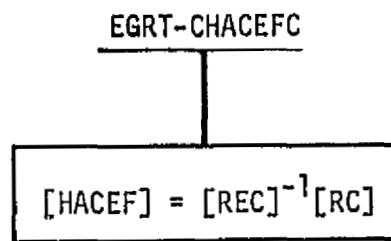


Figure C-4.- EGRT-CHACEFC, center heading alignment circle -  
Earth-fixed coordinates.

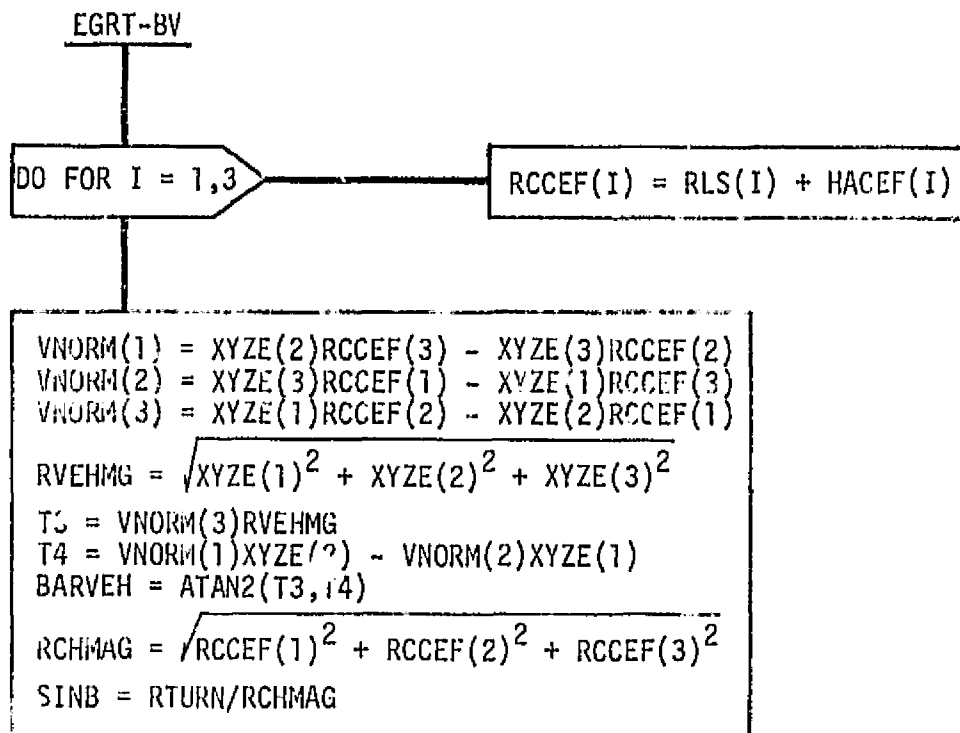


Figure C-5.- EGRT-BV, bearing of vehicle.



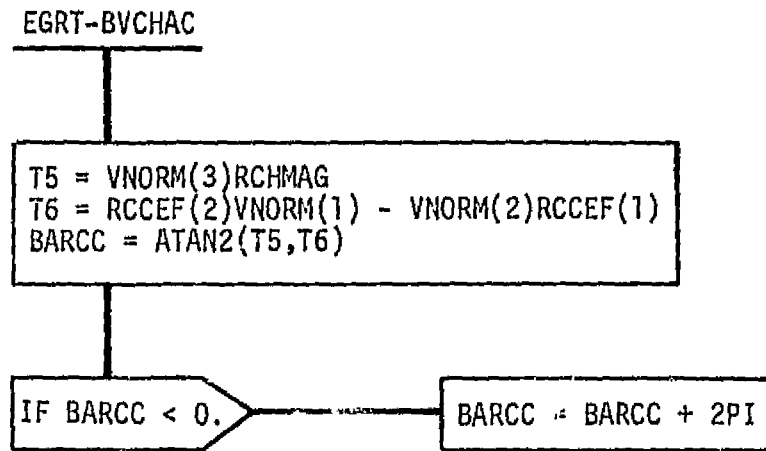


Figure C-6.- EGRT-BVCHAC, bearing to center of alignment circle.

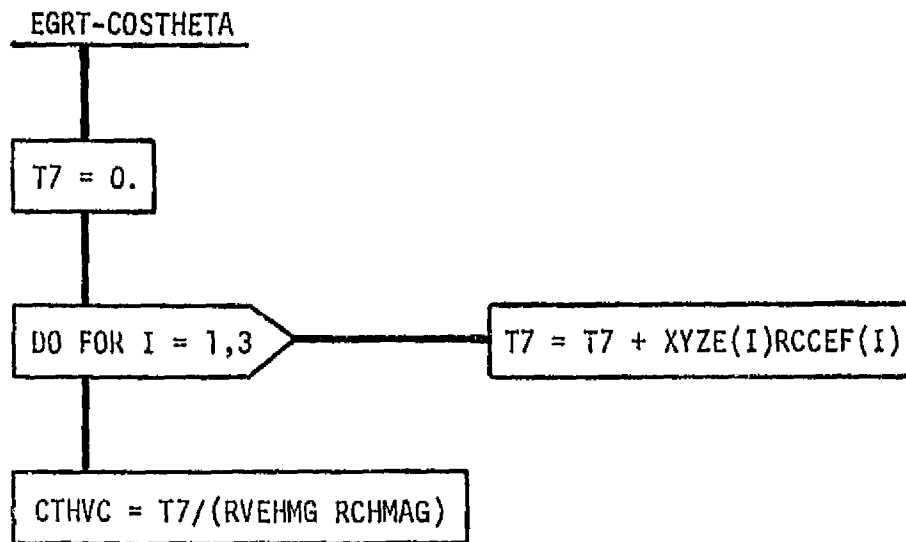


Figure C-7.- EGRT-COSTHETA, great circle arc.

EGRT-DWP1

```
STHVC =  $\sqrt{\text{MCRT01} - \text{CTHVC}^2}$ 
CTVWP1 = CTHVC + MCRT02 CTHVC SINB2
SBARCR = SINB/STHVC
TEMP = CTVWP1 SBARCR
TEMP = AMIN1(1.,AMAX1(TEMP,-1.))
A2 = ACOS(TEMP)
TEMP = CTVWP1
TEMP = AMIN1(1.,AMAX1(TEMP,-1.))
DVEWP1 = ACOS(TEMP)RCHMAG
```

Figure C-8.- EGRT-DWP1, distance to WP1.

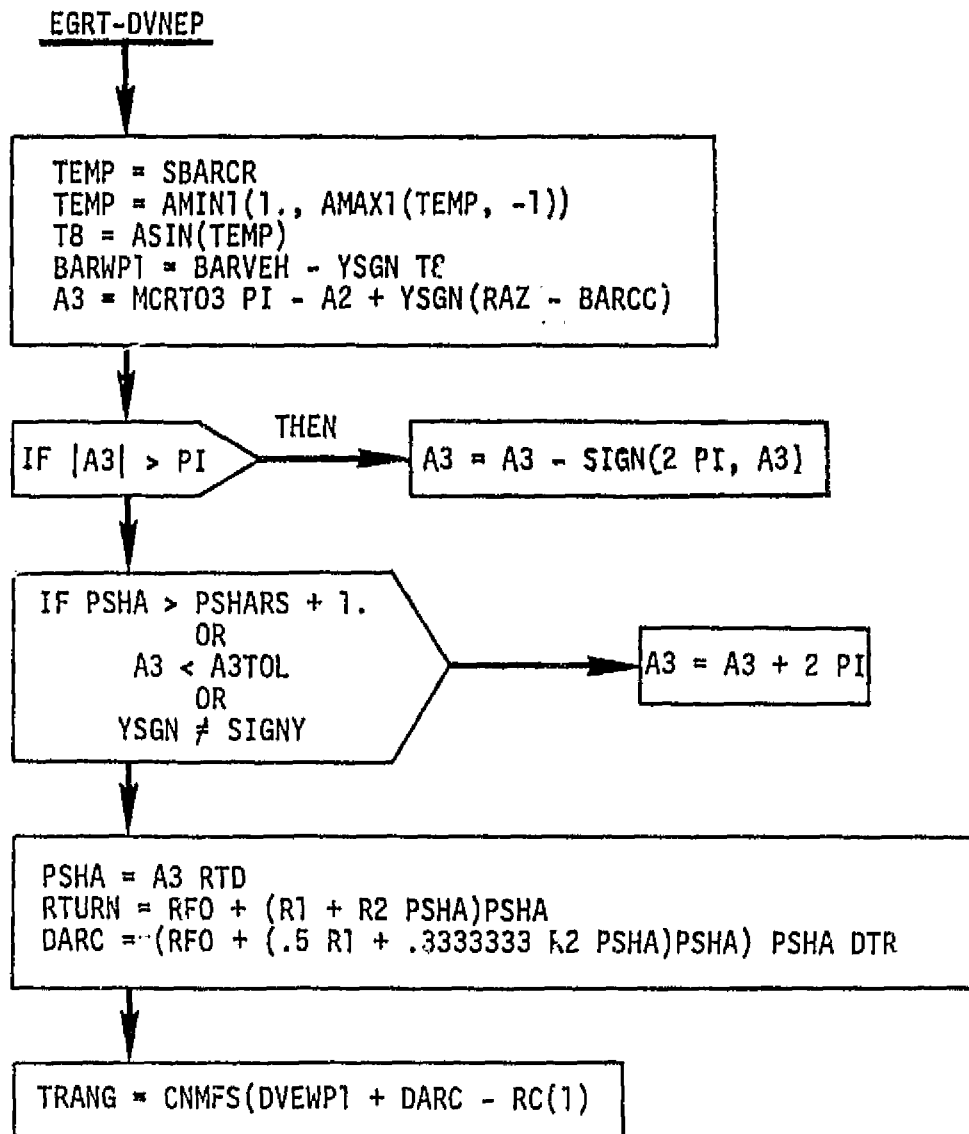


Figure C-9.- EGRT-DVNEP, range-to-threshold point.

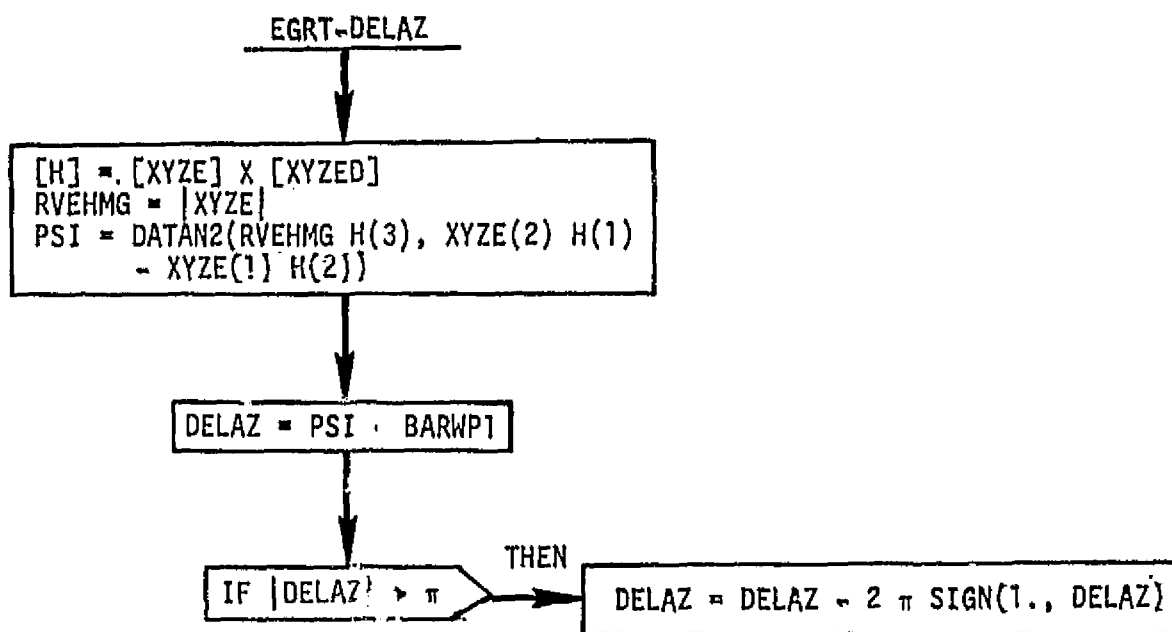


Figure C-10.- EGRT-DELAZ, azimuth error.

76FM98

APPENDIX D: IBM AUTOPILOT FLOW CHARTS

The flow charts presented in this appendix represents IBM's response to the requirements set forth in this document. The autopilot model for the MCC will be programed by IBM from the flow charts contained in this appendix.

### Input

ROLL -- Current Bank Angle  
ROLLC -- Bank Command  
ALPHA -- Current Angle-Of-Attack  
ALPCMD -- Angle-Of-Attack Command

DELTT -- Time Step (Sec)  
EGFLG -- Guidance Mode Flag

RR -- Current Bank Rate  
PR -- Current Angle-Of-Attack Rate

RA -- Max Bank Acceleration  
PA -- Max Angle-Of-Attack Acceleration

RRM -- Bank Rate Max  
PRM -- Angle-Of-Attack Rate Max  
RADB -- Bank Deadband  
RADB2 -- ETG Special Bank Deadband  
PADB -- Angle-Of-Attack Deadband  
RAD180 -- 180° In Radian Measure  
RAD180 -- 180° In Radian Measure  
RAD360 -- 360° In Radian Measure  
DTR -- Degrees To Radian Conversion

### Process

Compute New Bank And Angle-Of-Attack Angles For Current Time Based On Previous Bank And Bank Angle Rates, And Previous Angle-Of-Attack And Angle-Of-Attack Rates

### Output

ROLL -- New Current Bank  
ALPHA -- New Current Angle-Of-Attack  
RR -- New Current Bank Rate  
PR -- New Current Angle-Of-Attack Rate

Figure D-1.- Entry autopilot.

DAF3D

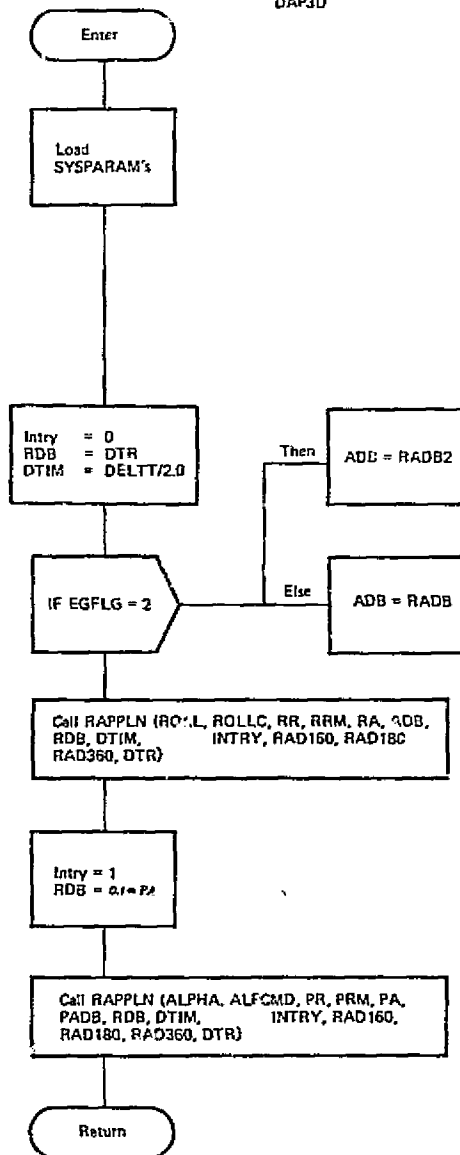
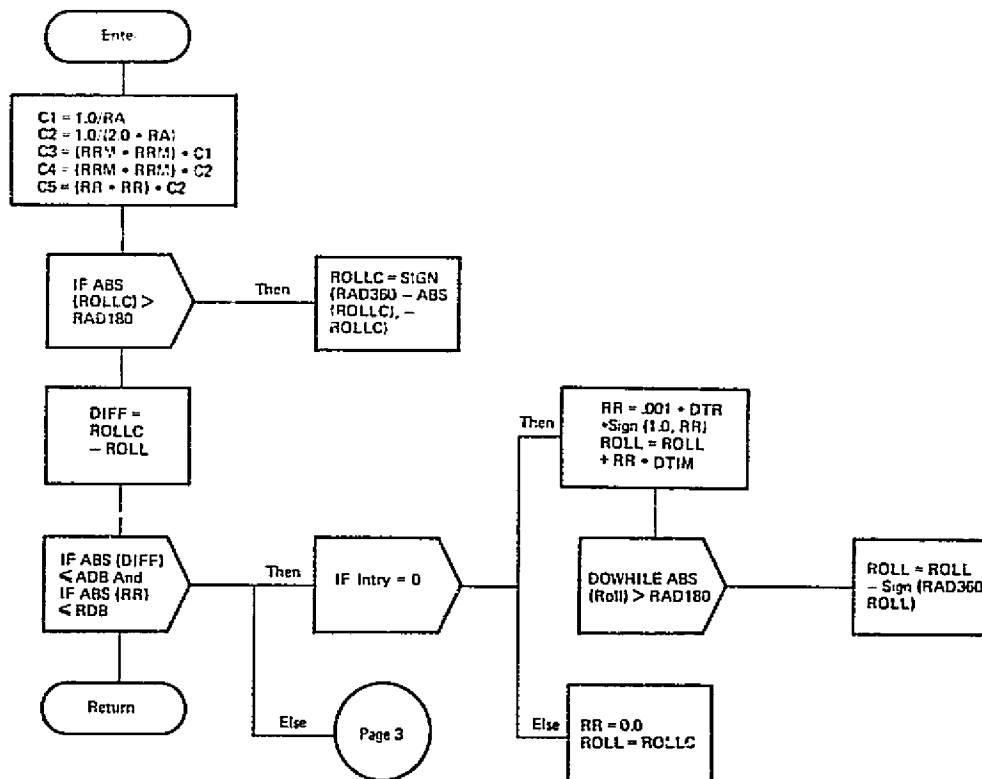


Figure D-1.- Continued.





SUBROUTINE RAPPLN (ROLL, ROLLC, RR, RRM, RA, ADB, RDB, DTIM,  
INTRY, RAD160, RAD180, RAD360, DTR)

Figure D-1.- Continued.

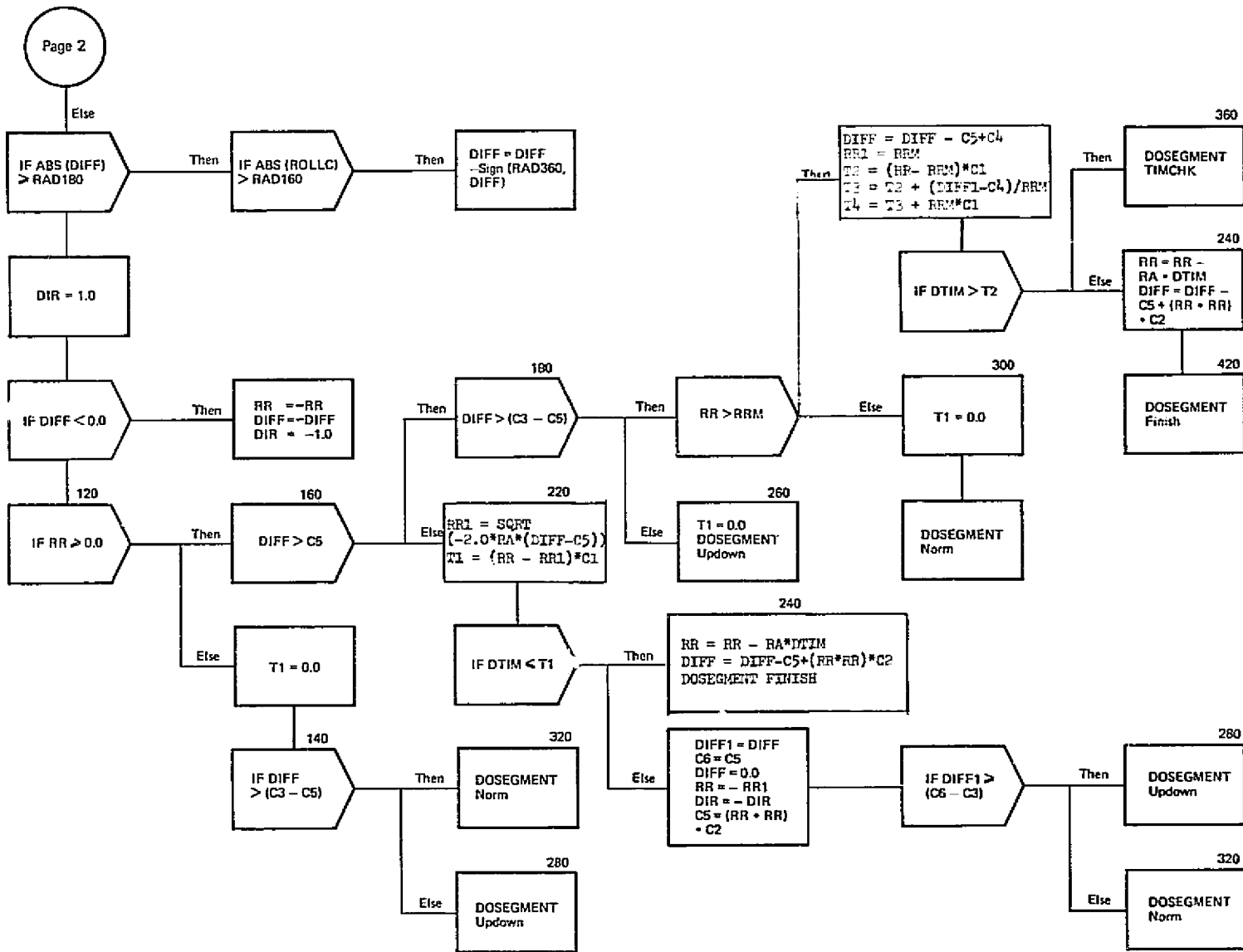
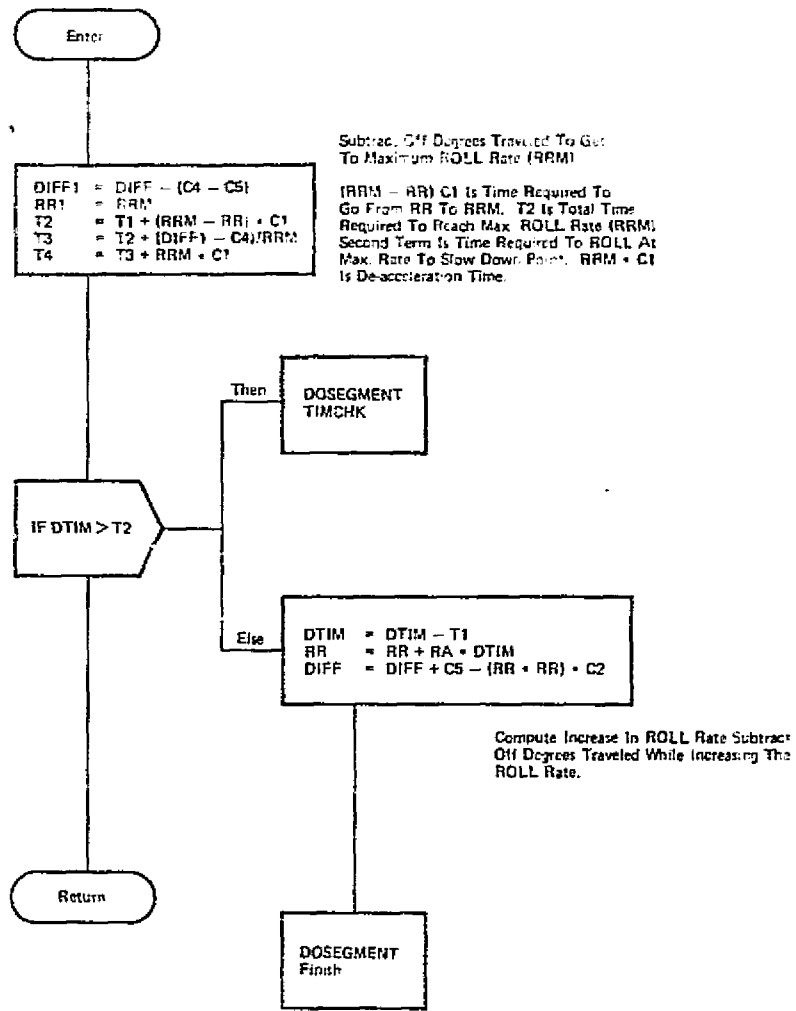
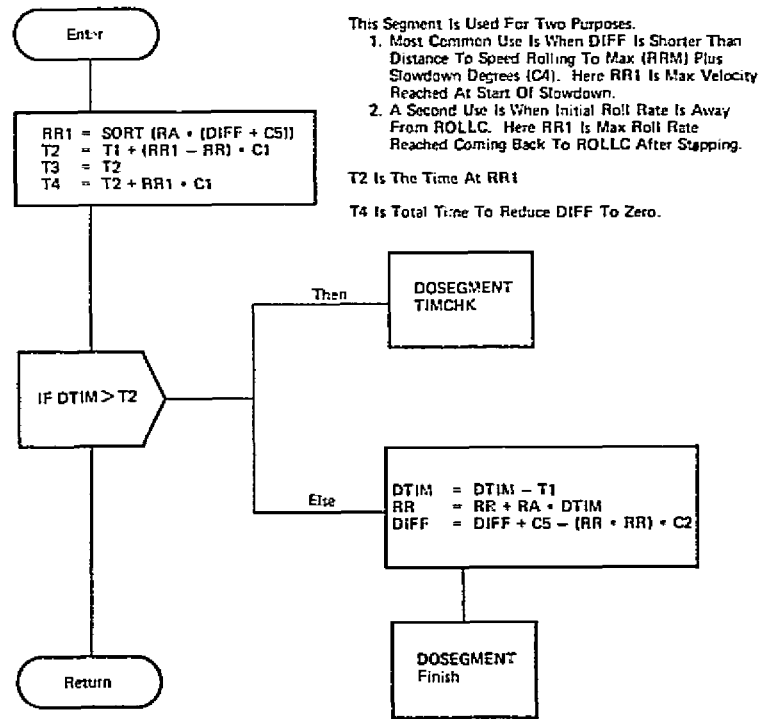


Figure D-1.- Continued.



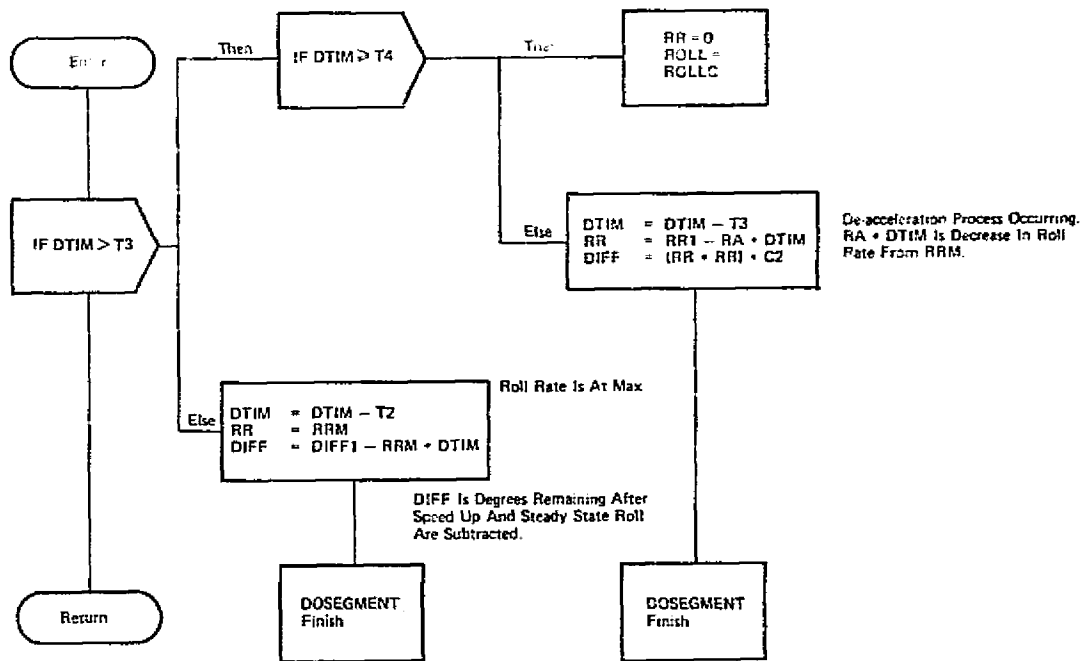
SEGMENT NORM

Figure D-1.- Continued.



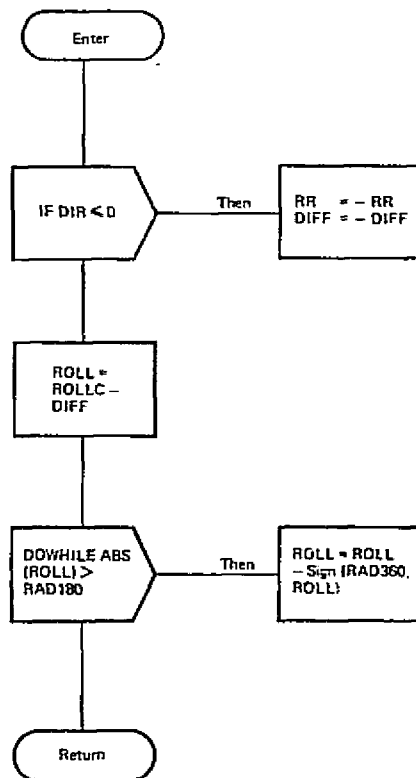
SEGMENT UPDOWN

Figure D-1.- Continued.



SEGMENT TIMCHK

Figure D-1.- Continued.



SEGMENT FINISH

Figure D-1.- Concluded.