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RTCC REQUIEMENTS FOR MISSIONS D, E, AND F: REENTRY PHASE

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MISSION PLANNING AND ANALYSIS DIVISION

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HOUSTON, TEXAS

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PROJECT APOLLO

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RTCC REQUIREMENTS FOR MISSIONS D, E, AND F: REENTRY PHASE

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and Joseph E. Rogers

SUMMARY AND INTRODUCTION

Presented in this internal note are the real-time program requirements for the reentry phases of the Apollo Missions D, E, and F. This revision supersedes reference 1. The primary mode of reentry trajectory control will utilize the guidance and navigation (G&N) system onboard the spacecraft. However, should there be a G&N failure, there are several backup reentry modes available.

The backup modes may utilize the entry monitoring system (EMS) for ranging or may be based on manual open-loop control of the spacecraft bank angle by the flight crew. The real-time computations required to support these reentry modes for Missions D, E, and F, and subsequent missions are presented in this document. The recommendations for the Real-Time Computer Complex (RTCC) displays are currently being redefined and will be published in a subsequent document.

PRIMARY GUIDANCE REQUIREMENTS

The basic Apollo reentry guidance and navigation is presented in reference 2. Some phases of the reentry guidance flow logic of reference 2 are still in the developmental stages and will be updated at a later date. The current Apollo reentry guidance flow logic is presented in figures 1 through 13 of this internal note. Changes to the flow charts (fig. 1 - 13) which have been made since the publication of reference 1 are outlined in dashed lines. The definitions of the reentry guidance variables are presented in table I. The guidance gains and constants are presented in table II, and the final phase reference trajectory is presented in table III.

The navigation for the real-time program is to be obtained from the real-time processor integration package. The total aerodynamic acceleration, D, used in the targeting phase (fig. 4) is also to be obtained from this integration package. The average g navigation computation (fig. 2) and the D computation are included in order to present a more complete document.

The initialization phase of the program is presented in figure 3. The parameters Q7 and L/D must be initialized to accommodate a branch to KEPL from INITROLL (fig. 5) for a slow-speed reentry. Q7 is set equal to Q7F, and L/D is equated to LAD (cos C10), where C10 is the command module (CM) bank angle at reentry interface. The parameter FACTOR must be initialized at 1.0 to insure the correct computation of L/D in the UPCONTROL phase in the event of shallow, high-speed reentries. The unit target vector, $\bar{U}$RTO, is the initial target unit vector and must be computed from the longitude and geodetic latitude of the desired splash point. The time increment, TN, is a constant added to the current flight time in order to obtain a nominal time of flight from lift-off through reentry.

The RTCC must have the capability of receiving an update of the targets, trim aerodynamic characteristics, guidance gain LAD, guidance gain LOD, CM weight, and lateral bias during the missions. The flight controllers must have the option of selecting the initial reentry bank angle of the CM, C10. He must also have the capability of maintaining this initial bank angle until a prescribed g level, g_c, is obtained; at which time the roll commands from the guidance logic are utilized. These manual entry devices (MED) are further defined in table IX. This table also contains a column labeled "system value". For those parameters where a value is specified, this value will be used if no MED is inserted into the system.

The function of the lateral bias term is to simulate the aerodynamic rotation of the lift vector which results from a lateral center-of-gravity offset. The magnitude of the lateral bias (CGBIAS) term is computed from the equation

$$\text{CGBIAS} = \tan^{-1} \left| \frac{\text{Ycg}}{\text{Zcg}} \right| \text{ sign (Ycg)}$$

where Ycg and Zcg are given in CM body coordinates. (Note that the sign of CGBIAS is the sign of Ycg.) The positive X-body axis is along the center line and through the apex of the CM, the positive Z-body axis is normal to X-body and in the general direction of the lift vector, and the positive Y-body completes the orthogonal set of a right-hand system. The calculated bank angle (β) which goes to the integrator must reflect the CGBIAS term; i.e., β = β + CGBIAS.

The RTCC must be able to compute a guided reentry simulation for state vectors obtained after reentry interface, 400 000-ft altitude. This computation may be accomplished by generating two simulations, the first using a vector obtained prior to reentry, and the second using the vector obtained after reentry and certain parameters generated by the first simulation.

The parameters generated by the first simulation which are necessary input for the second simulation are defined in table IV. The flow diagrams presented in figures 1 through 13 include the logic necessary to generate the above parameters and use such for the "vector below reentry interface" case.

DIGITAL AUTOPILOT SIMULATION

Figure 14 presents the detailed flow logic for the roll channel of the CM reentry digital autopilot (DAP). The DAP is explained more fully in reference 3, from which the basic flow was taken.

The DAP simulation implements the roll commands issued by the reentry guidance logic every 2 seconds. The only inputs necessary are the roll command from the reentry guidance (delayed by 1 second), the trim angle of attack, the value of SWTCH2, and the initial spacecraft bank angle. Since the roll command to the DAP is delayed by 1 second, the logic implements the command generated at time (T) during the time interval (T + 1) to (T + 3). The spacecraft bank angle is the same as specified in the previous section. The flow, as shown in figure 14, will process the logic at 0.1-second intervals and, as such, will make 10 individual calculations of the pertinent variables during the first second of each 2-second interval before exiting the routine, going to the integrator, and then returning for the second second of the 2-second time interval. The minimum time interval that can be processed is 3 centiseconds, which accounts for the truncation of time intervals T1, T2, and TOFF to 2 decimal places, as shown on page 4 of the six pages of DAP flow logic. Outputs from the routine include bank angle, body roll rate, stability roll rate, and CM-RCS fuel usage.

All switches have initial values as shown on page 18. As indicated in the flow, SWTCH2 must be set equal to zero each time a new roll command is generated by the reentry guidance in order that the parameters be reinitialized.

The DAP roll logic is designed to calculate a delta time interval (T1) to fire the CM-RCS engines to drive the spacecraft to the commanded attitude. This value of T1 that is calculated is based on a roll rate that is proportional to roll attitude error. In addition, time intervals TOFF and T2 are calculated which, respectively, represent a coast time and a time to fire the opposing jets to reduce the roll rate to approximately zero as the spacecraft attitude approaches the roll command.

All constants were taken from reference 3 with the exception of the acceleration about the CM X-body axis which was taken from reference 4. Table V presents the definition of variables used in the DAP simulation, and table VI shows the DAP gains and constants.

ENTRY MONITORING SYSTEM

The entry monitoring system (EMS) provides the crew with the capability for reentry monitoring and backup ranging. It provides a display of load factor (g) versus inertial velocity (V) on a scroll marked with offset and onset curves which enables the crew to monitor the reentry trajectory and aid in performing a safe manual entry. In case there is a failure in the primary G&N system either before or during reentry, the EMS can be used as a reentry display for the backup mode.

The EMS is initialized by the flight crew inserting the inertial velocity and the inertial range-to-go values into the EMS prior to reentry. The inserted data corresponds to the 0.05g point or an arbitrary altitude in the reentry trajectory. These quantities are made available to the crew by voice communications from the ground. The primary method for initialization is to compute the inertial velocity and inertial range-to-go using the RTCC reentry simulation program. The EMS begins operating when it senses a load factor of 0.05g $\pm$ 0.005g or when the crew manually starts the system at a time corresponding to an arbitrary altitude. The following procedure is to be used to determine the initial conditions:

1. Determine the inertial position and velocity at the 0.05g point or an MED altitude (H_{EMS}) in the reentry trajectory. If an MED altitude is not input into the RTCC, the simulation will automatically use the 0.05g point.

2. Using the state vectors at 0.05g or the MED altitude, continue the velocity integration for guided and backup entry trajectories with:

$$V = V_o - K_D \int_{t_i}^{t_f} A_X dt$$

where

V_o = velocity at 0.05g or H_{EMS}

V = inertial velocity

K_D = 0.948 (resolution factor) for Missions E and F; 0.935 for Mission D

A_X = sensed aerodynamic acceleration along the longitudinal body axis

t_f = time when the altitude decreases to 25 000 ft

t_i = time at 0.05g or H_{EMS}

$g = 32.174 \text{ ft/sec}^2$

3. Using the velocity from the above equation, calculate the inertial range-to-go by

$$R_f = 0.000162 \int_{t_i}^{t_f} V dt$$

where

R_f = inertial range from t_i to t_f above an oblate earth and 0.000162 is the conversion factor to obtain range-to-go in nautical miles.

The quantities V_o and R_f are transmitted by voice link to the flight crew for EMS initialization. Figure 15 presents a block diagram of the initialization steps. The inertial velocity will be calculated in feet per second, and the inertial range-to-go in nautical miles. These quantities and t_i will be displayed in the Mission Control Center (MCC) to the flight controller for relay to the crew.

BACKUP ENTRY MODES

The mission support for the Missions D, E, and F reentry phases is to be designed to encompass all reentry speeds from earth orbital to lunar return and time-critical abort reentry speeds. Therefore, it is necessary to devise a backup entry mode which will satisfy the safe entry requirements for this range of velocities. The RTCC must be programed to provide the flight controllers with the option of selecting a backup reentry mode as opposed to a guided (closed-loop) mode. The basis for these backup modes is manual attitude control of the CM lift-vector orientation. The selection of the proper routine to be used is basically a function of three parameters:

1. Degree of degradation of the spacecraft systems.

2. Inertial velocity at reentry.

3. Inertial flight-path angle at reentry.

Figure 16 presents a flow diagram containing five possible backup modes that must be provided for in the RTCC. At entry interface, the spacecraft is banked to an angle defined by K1, an MED quantity. The bank angle is then held constant until the "g" level is equal to g_c. The parameter g_c

may be defined in one of two ways:

1. An MED quantity.

2. A quantity which may be set automatically in the program if option 2, 3, or 4 illustrated in figure 16 are used.

The subroutines which may be selected by setting KSWCH to a value of 1 through 5 are described below:

Subroutine 1 is a constant bank angle routine. The bank angle K1 is flown until the g level is equal to g_c, at which time the spacecraft is rolled to a second bank angle, K2.

Subroutine 2 is a rolling entry mode. A constant bank angle K1 is held until the g level is greater than g_c. At this time, the CM is rolled about the X-body axis at a rate of 20 deg/sec. The value of g_c should be set automatically at .05g unless it is overridden by a MED value. This subroutine is selected by setting KSWCH equal to 2.

Subroutine 3 is a constant g entry. When KSWCH = 3, g_c should be set to .05g unless overridden by a MED value. Figure 17 gives the flow logic for this mode, and table VII lists the definitions for the parameters used in the flow logic. Besides KSWCH, g_c, and K1, the desired constant g level (DO), LAD, and the roll direction (RLDIR) should be MED quantities. A constant bank angle K1 should be flown until g = g_c at which time the constant g logic is used to control the roll angle of the CM.

Subroutine 4 is used to iterate on the constant g level to be flown so that the longitude of impact (λ_{IP}) is equal to the longitude of the target (λ_t). Figure 18 gives the flow logic for this mode and table VIII defines the parameters used in the flow logic. KSWCH is equal to 4 and g_c is set equal to .05g unless overridden by a MED. A constant bank angle (K1) is flown until g = g_c at which time the constant g logic is used to control the CM roll attitude. Besides KSWCH, g_c, and K1, λ_t, LAD, DO, and RLDIR should be MED quanities.

Subroutine 5 shapes the trajectory by iterating on a bank angle and time-to-reverse bank angle in order to reach the desired target (λ_t, ϕ_t).

The entry processor can also be used to generate an entry footprint by the use of subroutines 1 and 2.

The MED's required for the backup modes are summarized in table X. This table contains a column marked "system value". For those parameters where a value is specified, this value will be used if no MED is inserted into the system.

TABLE I.- VARIABLES FOR REENTRY GUIDANCE

Variable	Definition
$\overline{\text{URTO}}$	initial unit target vector
$\overline{\text{UZ}}$	unit vector north
$\overline{\text{V}}$	velocity vector
$\overline{\text{R}}$	position vector
$\overline{\text{VI}}$	inertial velocity vector
$\overline{\text{RTE}}$	vector east at initial target
$\overline{\text{UTR}}$	vector normal to $\overline{\text{RTE}}$ and $\overline{\text{UZ}}$
$\overline{\text{URT}}$	target vector
$\overline{\text{UNI}}$	unit vector normal to trajectory plane
$\overline{\text{DELV}}$	integrated acceleration from PIPAS
$\overline{\text{G}}$	gravity vector
AHOOK	term in GAMMAL calculation
AO	initial drag for upcontrol
ALP	constant for upcontrol
ASKEP	Kepler range
ASP1	final phase range
ASPUP	up-range
ASP3	gamma correction
ASPDWN	range down to pull up
ASP	predicted range
COSG	cosine of GAMMAL
C10	initial CM bank angle

TABLE I.- VARIABLES FOR REENTRY GUIDANCE - Continued

Variable	Definition
D	total aerodynamic acceleration
DO	controlled constant drag
DHOOK	term in GAMMAL computation
DIFF	THETNM-ASP (range difference)
DIFFOLD	previous value of DIFF
DR	reference drag for down control
DLEWD	change in LEWD
DREFR	reference drag
DVL	VS1 - VL
E	eccentricity
F1	∂ range/∂ drag (final phase)
F2	∂ range/∂ RDOT (final phase)
F3	∂ range/∂ L/D
FACT1	constant for upcontrol
FACT2	constant for upcontrol
FACTOR	used in upcontrol
GAMMAL	flight-path angle at VL
GAMMAL1	simple form of GAMMAL
KA	drag level to initiate constant drag steering
K2ROLL	parameter used in calculation of roll command
LATANG	lateral range
LEQ	excess centrifugal force over gravity: = (VSQ - 1) GS
LEWD	upcontrol reference L/D

TABLE I.- VARIABLES FOR REENTRY GUIDANCE - Continued

Variable	Definition
L/D	desired lift-to-drag ratio (osculating plane)
L/D1	temporary storage for L/D in lateral logic
P	partial derivative of range with respect to L/D
PREDANG1	reference range from final phase table
PREDANG2	final phase range perturbation due to drag
PREDANG3	final phase range perturbation due to RDOT
PREDANGL	predicted range (final phase)
Q7	minimum drag for upcontrol
RDOT	altitude rate
RDOTREF	reference RDOT for upcontrol
RDTR	reference RDOT for downcontrol
RDTRF	reference RDOT from final phase table
ROLLC	roll command
RTOGO	range-to-go (final phase)
SL	sine of latitude
T	elapsed time from lift-off
TEMIB	incremental value of L/D for upcontrol
THETA	desired great circle range (radians)
THETNM	desired great circle range (nautical miles)
V	velocity magnitude
V1	initial velocity for upcontrol
VL	exit velocity for upcontrol

TABLE I.- VARIABLES FOR REENTRY GUIDANCE - Concluded

Variable	Definition
VREF	reference velocity for upcontrol
VS1	VSAT or V1, whichever is smaller
VBARS	$(VL/VSAT)^2$
VSQ	normalized velocity squared: $= (V/VSAT)^2$
WT	earth rate times time
X	intermediate variable in G-limiter
Y	lateral miss limit

TABLE II.- GUIDANCE GAINS AND CONSTANTS

(a) Entry constants and gains

Constant or gain	Symbol	Value	Units
Factor in ALP computation	C1	1.25	n.d.
Constant gain on drag	C16	0.01	1/fpss
Constant gain on RDOT	C17	0.001	1/fps
Bias velocity for final phase start	C18	500.	fps
Maximum drag for down-lift	C20	175.	fpss
Factor in AHOOK computation	CHOOK	0.25	n.d.
Factor in GAMMAL computation	CH1	1.0	n.d.
cos 15°	cos 15	0.965	n.d.
Initial variation in LEWD	DLEWDO	-0.05	n.d.
Computation cycle-time interval	DT	2.	sec
Maximum acceleration	GMAX	257.6	fpss
Factor in KA computation	KA1	1.3	GS
Factor in KA computation	KA2	$\frac{Q7F}{GS}$	GS
Factor in DO computation	KA3	90.	fpss
Factor in DO computation	KA4	40.	fpss
Optimized upcontrol gain	KB1	3.4	n.d.
Optimized upcontrol gain	KB2	0.0034	1/fps
Increment on Q7 to detect end of Kepler phase	KDMIN	0.5	fpss
Lateral switch gain	KLAT1	$\frac{1}{24}$	rad
Time of flight constant	KTETA	1000.	sec

TABLE II.- GUIDANCE GAINS AND CONSTANTS - Continued

(a) Entry constants and gains - Continued

Constant or gain	Symbol	Value	Units
Nominal time of flight	TN	700.	sec
Constant in FINAL PHASE	K13P	4.	n.d.
Nominal upcontrol L/D:	LEWD1	0.15	n.d.
Factor to reduce upcontrol gain	POINT1	0.1	n.d.
Final phase D range/DV	Q3	0.07	n. mi./fps
Final phase D range/D GAMMA	Q5	7050.	n. mi./rad
Final phase initial flight-path angle	Q6	0.0349	rad
Constant in factor	Q7MIN	40.	fpss
Minimum drag for upcontrol	Q7F	6.	fpss
Constant in GAMMAL1	Q19	0.5	n.d.
Minimum VL	VLMIN	18 000	fps
Velocity to switch to relative velocity	VMIN	VSAT/2	fps
RDOT to start into HUNTEST	VRCONTRL	700.	fps
Tolerance to stop range iteration	25NM	25.	n. mi.
Lateral switch bias term	LATBIAS	.00012	rad
Velocity to stop steering	VQUIT	1000.	fps
Initial attitude gain	K44	19 749 550.	fps

TABLE II.- GUIDANCE GAINS AND CONSTANTS - Continued

(a) Entry constants and gains - Concluded

Constant or gain	Symbol	Value	Units
Velocity to start final phase on INITENTRY	VFINAL1	27 000.	fps
Factor in initial attitude	VFINAL	26 600.	fps
Entry conversion factors and scaling constants			
Angle in RAD to NM	ATK	3437.7468	n. mi./rad
Nominal G value for scaling	GS	32.2	fpss
Atmosphere scale height	HS	28 500.	ft
Earth radius	RE	21 202 900.	ft
Earth equatorial radius	REQ	20 925 738.2	ft
Satellite velocity at RE	VSAT	25 766.1973	fps
Earth rate	WIE	$72.9211505 \times 10^{-6}$	rad/sec
Equatorial earth rate	KWE	1546.70168	fps
Gravity harmonic coefficient	J	.00162346	n.d.
Earth gravitational constant	MUE	$3.986032233 \times 10^{14}$	m^3/sec^3

TABLE II.- GUIDANCE GAINS AND CONSTANTS - Concluded

(b) Switches

Switch	Symbol	Initial value
Final phase switch	EGSW	0
Indicates overshoot of target	GONEPAST	1
Overshoot indicator	GONEBY	0
Indicates iteration in HUNTEST	HIND	0
Indicates initial roll attitude set	INRLSW	0
Relative velocity switch	RELVELSW	0
Inhibit downlift switch in DAP if set = 0	LATSW	1
.05 g switch	.05GSW	0
Inhibits roll switch during upcontrol	NOSWITCH	0
Indicates program has started utilizing guidance commands	ROLLSW	0

TABLE III.- FINAL PHASE REFERENCE TRAJECTORY

N	VREF, fps	RDTR (RDTRF), fps	AREF, fpss	FRDT F2 DR/DRDOT, n. mi./fps	FA F1 DR/DA, n. mi./fpss	RTOGO, n. mi.	PP (DR/DL/D), n. mi.
1	994	-690.9	41.15	0.002507	-0.0346	2.2	12.20
2	2103	-719	60.0	0.003582	-0.05551	8.9	21.82
3	3922	-694	81.5	0.007039	-0.09034	22.1	43.28
4	6295	-609	93.9	0.01446	-0.1410	46.3	96.70
5	8531	-493	98.5	0.02479	-0.1978	75.4	187.44
6	10 101	-416	102.3	0.03391	-0.2372	99.9	282.2
7	14 014	-352	118.7	0.06139	-0.3305	170.9	329.4
8	15 951	-416	125.2	0.07683	-0.3605	210.3	465.5
9	18 357	-566	120.4	0.09982	-0.4956	266.8	682.7
10	20 829	-781	95.4	0.1335	-0.6483	344.3	980.5
11	23 090	-927	28.1	0.2175	-2.021	504.8	1385.
12	23 500	-820	6.4	0.3046	-3.354	643.0	1508.
13	35 000	-820	6.4	0.3046	-3.354	794.3	1508.

TABLE IV.- PARAMETERS FOR "BELOW REENTRY INTERFACE INITIALIZATION"

TIME (1)	time of start "UPCONTROL"
TIME (2)	time of end UPCONTROL
VISAVE	initial velocity for UPCONTROL
AOSAVE	initial drag for UPCONTROL
A1SAVE	drag for UPCONTROL
ALPSAV	constant for UPCONTROL
FACT1SAV	constant for UPCONTROL
FACT2SAV	constant for UPCONTROL
VLSAVE	exit velocity for UPCONTROL
VS1SAVE	VSAT or V1 which ever is smaller
DHOOKSAV	term in GAMMAL computation
AHOOKSAV	term in GAMMAL computation
GAMMALISAV	simple form of GAMMAL
GAMMALSAV	flight-path angle at VL
LEWDSAV	UPCONTROL reference L/D
Q7SAVE	minimum drag for UPCONTROL

TABLE V.- DEFINITION OF VARIABLES FOR FIGURE 16

Variable	Definition
BACC	body acceleration
BETA	spacecraft bank angle
BRATE	body roll rate
BRR	pseudo body roll rate
FUEL	fuel used by CM during reentry
ITEM	temporary integer storage
JNDX, JNDX1	direction of roll flags
RAE	roll attitude error
RAEDES	desired roll attitude error
ROLLCD	roll command
ROLLCD1	roll command storage
SACC	stability acceleration
SRATE	stability roll rate
TEM	temporary storage
TOFF	coast time
T1	time to fire jets
T2	time to reverse firing
T3	temporary storage
T4	temporary storage
T5	temporary storage
TUSED	temporary storage
VDRIF	drift roll rate

TABLE VI.- DAP GAINS AND CONSTANTS FOR FIGURE 16

(a) Gains and constants

Symbol	Value	Units
ANGMAX	20.0	deg/sec
A1	9.10	deg/sec^2
A2	4.55	deg/sec^2
M	0	--
RAEMIN	4.0	deg
SLOPE	0.25	sec^{-1}
TIMINT	2.0	sec
TMAX	0.1	sec
VZ	2.0	deg/sec
XBUF	4.0	deg
XS	2.0	deg

(b) Switches

Symbol	Value	Units
KLAG1	1	--
KLAG2	1	--
KLAG3	1	--
SWTCH1	0.0	--
SWTCH2	0.0	--
SWTCH3	1.0	--

TABLE VII.- PARAMETERS FOR CONSTANT g LOGIC

(a) Constants for constant g logic

Symbol	Constant	Value
VSAT	satellite velocity at earth radius	25766.1973 fps
VMIN	velocity to switch to relative velocity	VSAT/2, fps
KWE	equatorial earth rate	1546.70168 fps
C16	constant gain on drag	0.01
C17	constant gain on RDOT	0.001
HS	atmospheric scale height	28500 ft
GS	nominal g value for scaling	32.2 fps

(b) Variables for constant g logic

Symbol	Variable
$\overline{\text{UZ}}$	unit vector North
UNIT ($\overline{\text{R}}$)	unit radius vector
D	total aerodynamic acceleration
$\overline{\text{VI}}$	inertial velocity vector
DO	controlled constant drag
LAD	maximum L/D of vehicle
RLDIR	desired roll direction

TABLE VIII.- DEFINITION OF VARIABLES FOR CONSTANT g ITERATION LOGIC

Variable	Definition
DO	constant g level
g_{min}	minimum exceptable g level ("go tape" variable)
g_{max}	maximum acceptable g level ("go tape" variable)
λ_{IP}	longitude of impact
λ_{T}	longitude of target (MED)

TABLE IX.- MED PARAMETERS FOR G&N SIMULATION

MED	System value	Purpose
ϕ_T, λ_T	--	Used to provide real-time update capability of the reentry target.
g_c	0.05	To maintain a constant bank angle until a prescribed g level, at which time reentry guidance roll commands are utilized.
LAD	0.25	Necessary to provide update capability of the maximum L/D reference. Made necessary by changes in vehicle aerodynamics during the mission.
LOD	0.225	Provides capability for updating final phase reference L/D. Made necessary by aerodynamic changes during the mission.
CGBIAS	0.	Provides update of lateral bias needed due to changes in aerodynamics.
Trim aero-dynamics	--	Used to provide real-time update of aerodynamics which may change during the mission.
C10	0.	Provides capability of selecting the initial reentry bank angle.
CM wt	--	Provides update capability of changing the command module weight.
H_{EMS}	--	EMS initialization altitude.

TABLE X.- MED PARAMETERS REQUIRED FOR THE REENTRY BACKUP MODES

Parameter	System value	Backup modes	Purpose
g_c	0.05	1,2,3,4,5	To maintain a constant bank angle until a prescribed g level at which time one of the six backup modes is entered.
H_{EMS}	--	1,2,3,4,5	EMS initialization altitude.
KSWCH	--	1,2,3,4,5	Determines which backup mode will be used.
K1	--	1,2,3,4,5	To provide capability of selecting initial reentry bank angle.
K2	--	1	Provides option of selecting second bank angle to be flown after $g = g_c$.
DO	128.8	3,4	Provides ability to select desired constant g level, ft/sec^2.
LAD	0.25	3,4	Provides update capability of reference maximum L/D.
RLDIR	+1.	3,4	Provides capability of selecting roll direction for the constant g mode.
λ_T	--	4,5	Provides ability to select longitude of target.
ϕ_T	--	5	Provides ability to select latitude of target.

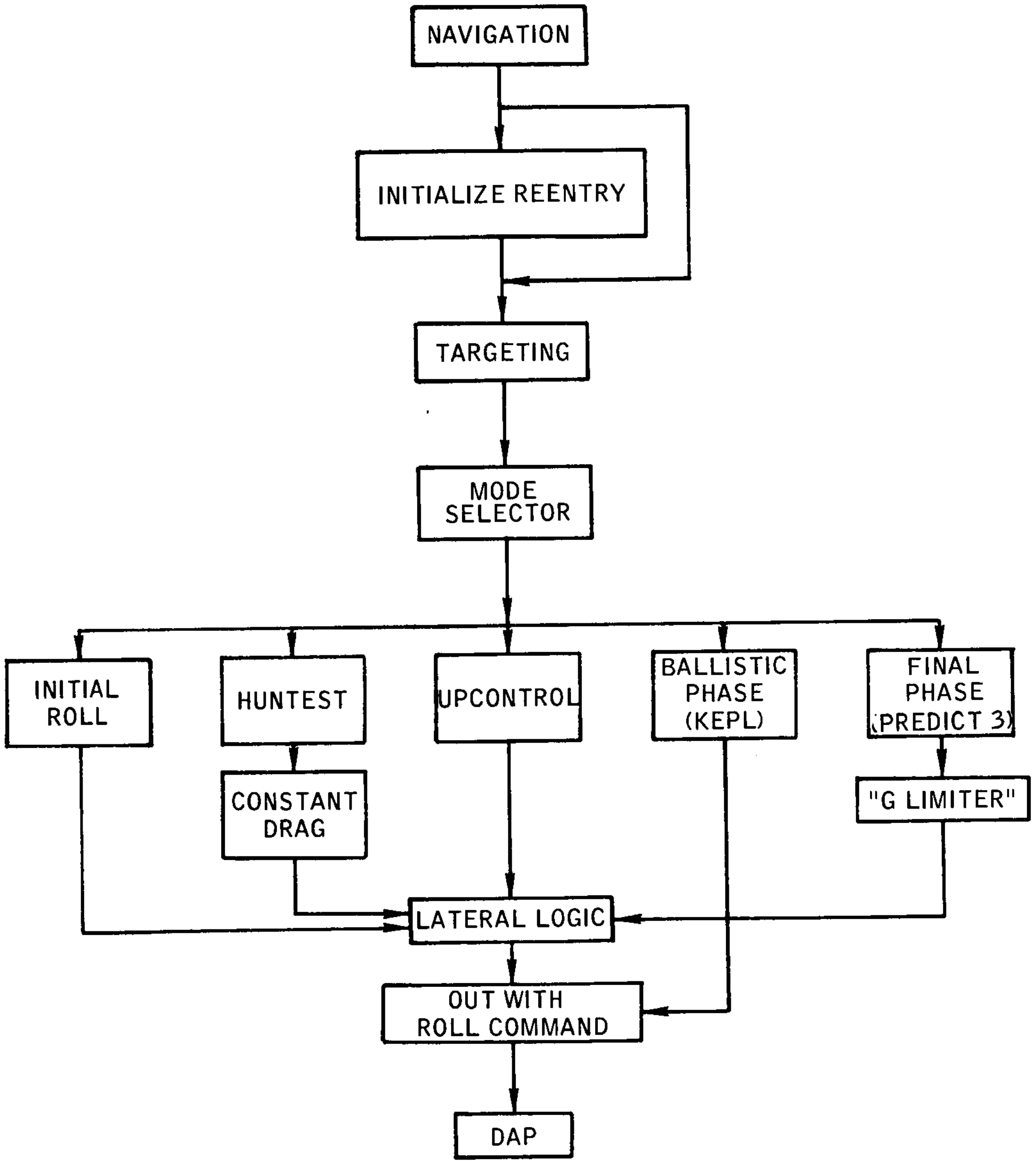

Figure 1.- Reentry steering.

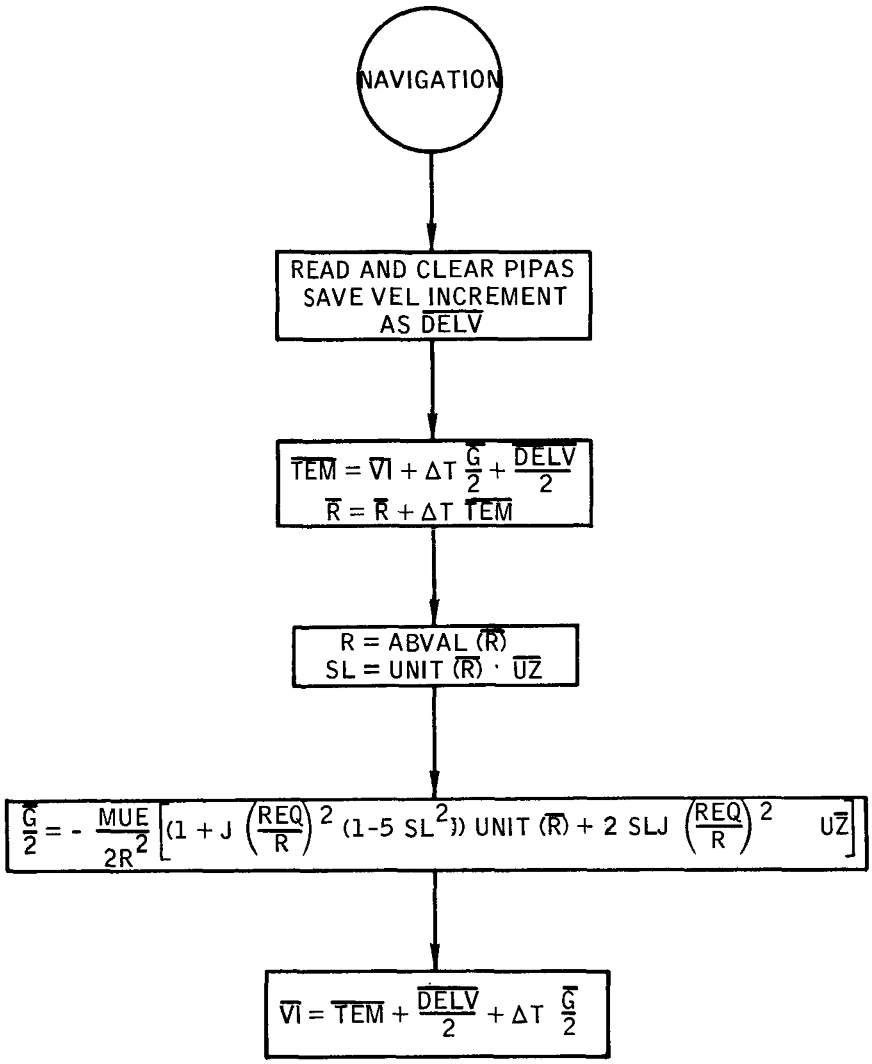

Figure 2.- "Average - g" navigation.

INITIALIZATION

$$\overline{RTE} = \overline{UZ} * \overline{URTO}$$
$$\overline{UTR} = \overline{RTE} * \overline{UZ}$$
$$WT = WIE(TN + T)$$
$$\overline{RTINT} = \overline{URTO} + \overline{UTR}\,(COS(WT) - 1) + \overline{RTE}\ SIN\ (WT)$$
$$THETA = COS^{-1}\,(UNIT\ (\bar{R}) \cdot UNIT\ (\overline{RTINT}))$$
$$K2ROLL = -UNIT\ (\overline{RTINT}) \cdot UNIT\ (\bar{V}) * UNIT\ (\bar{R})$$
$$K2ROLL = 1\ SGN\ (K2ROLL)$$
$$KLAT = KLAT1\ LAD$$
$$L/D\ CMINR = LAD\ COS\ 15$$
$$FACTOR = 1.0$$
$$Q7 = Q7F$$
$$L/D = LAD\ COS\ (C10)$$
$$ROLLC = C10$$
$$DIFFOLD = 0$$
$$DLEWD = DLEWD0$$
$$LEWD = LEWDI$$
$$\boxed{Q2 = -1152 + 500 \cdot LAD}$$

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2

* INDICATES VECTOR CROSS PRODUCTS

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Figure 3.- Initialization.

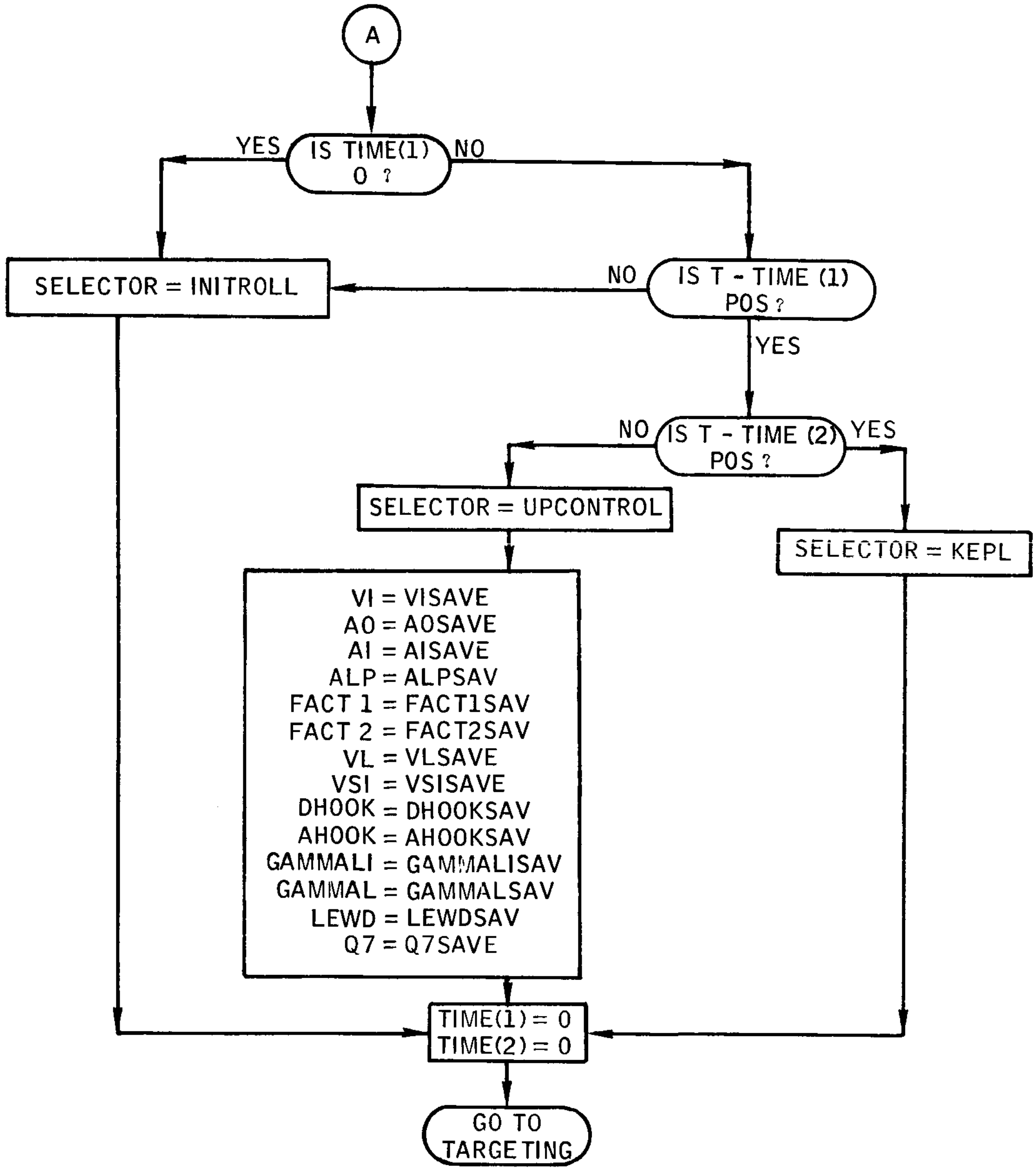

Figure 3.- Concluded.

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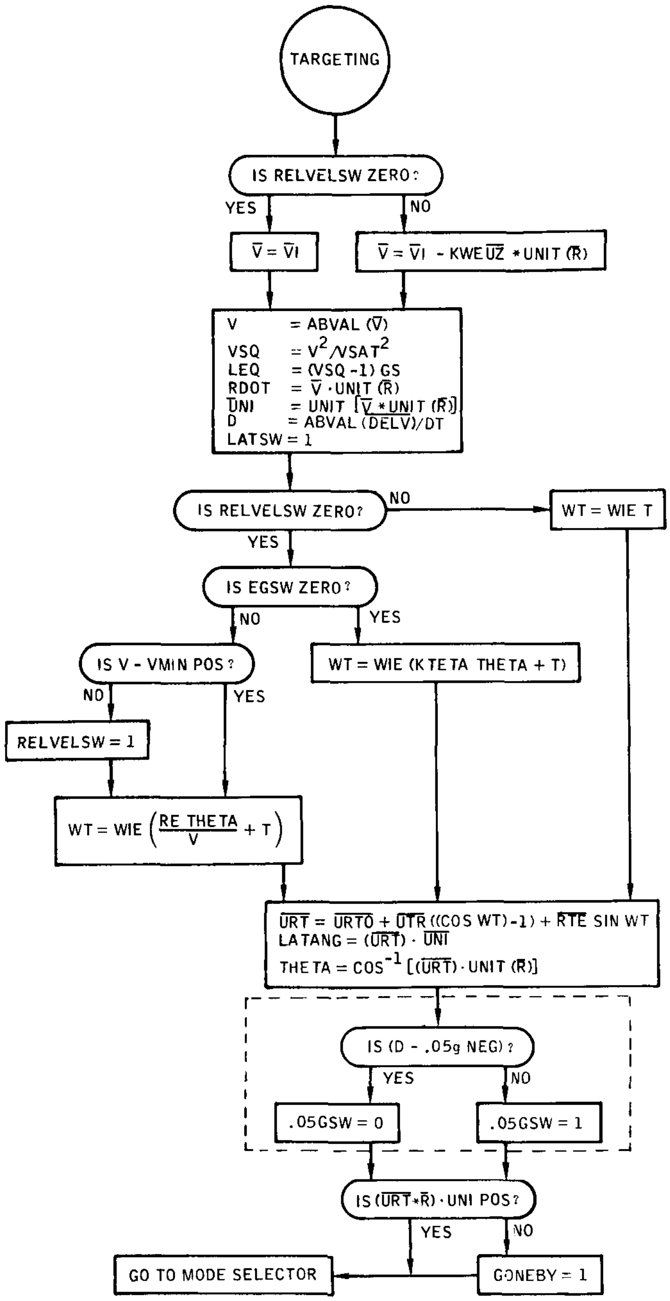

Figure 4.- Targeting.

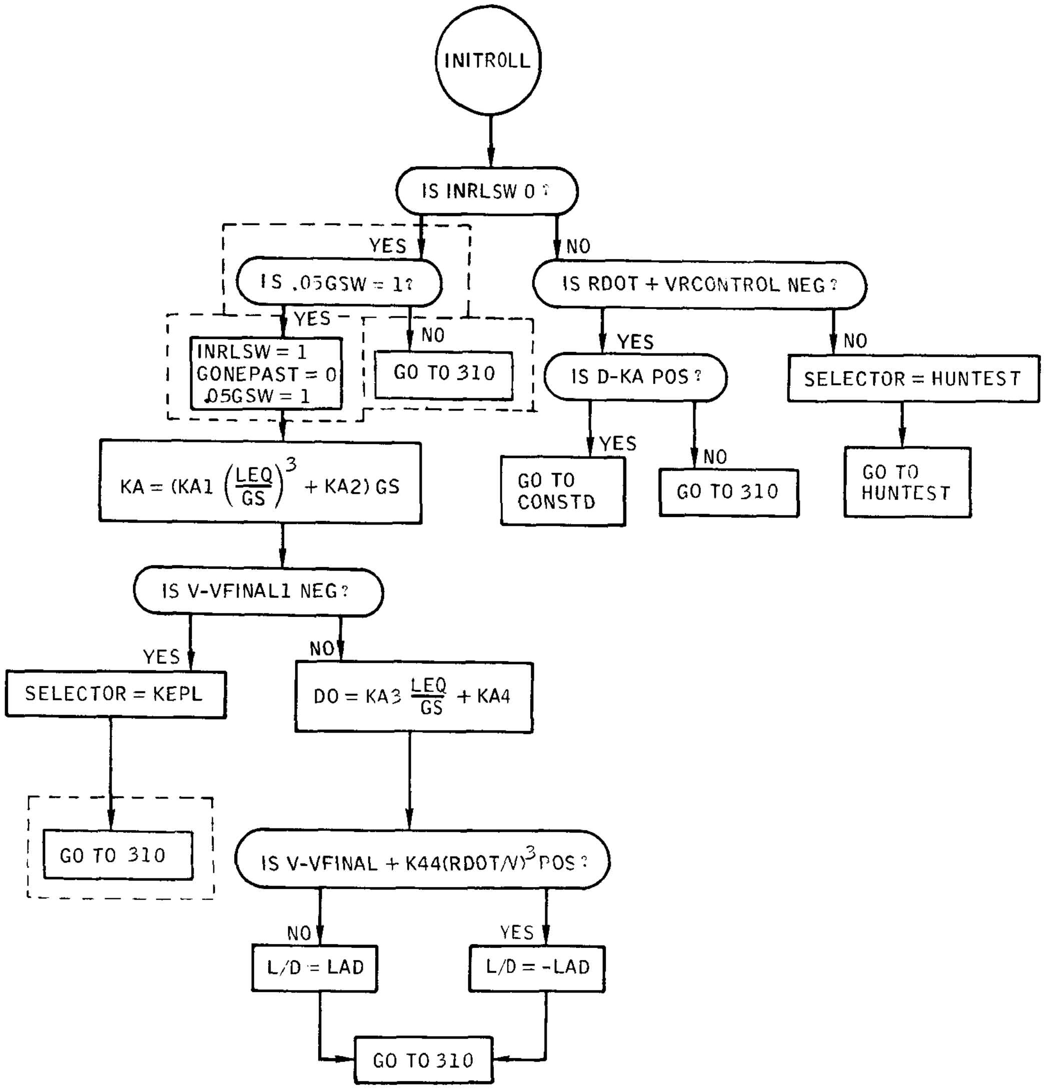

Figure 5. - Initial roll.

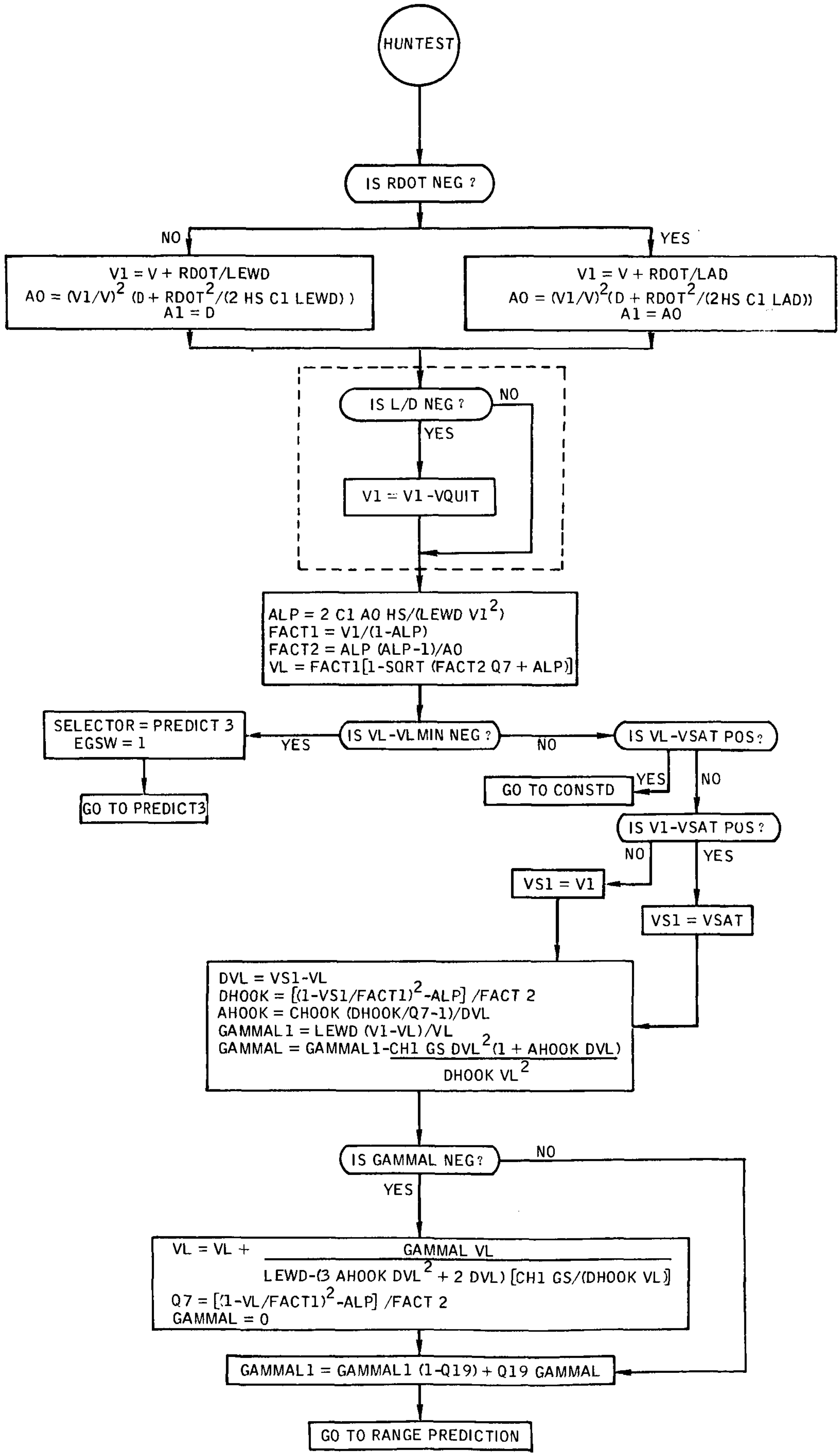

Figure 6.- Huntest.

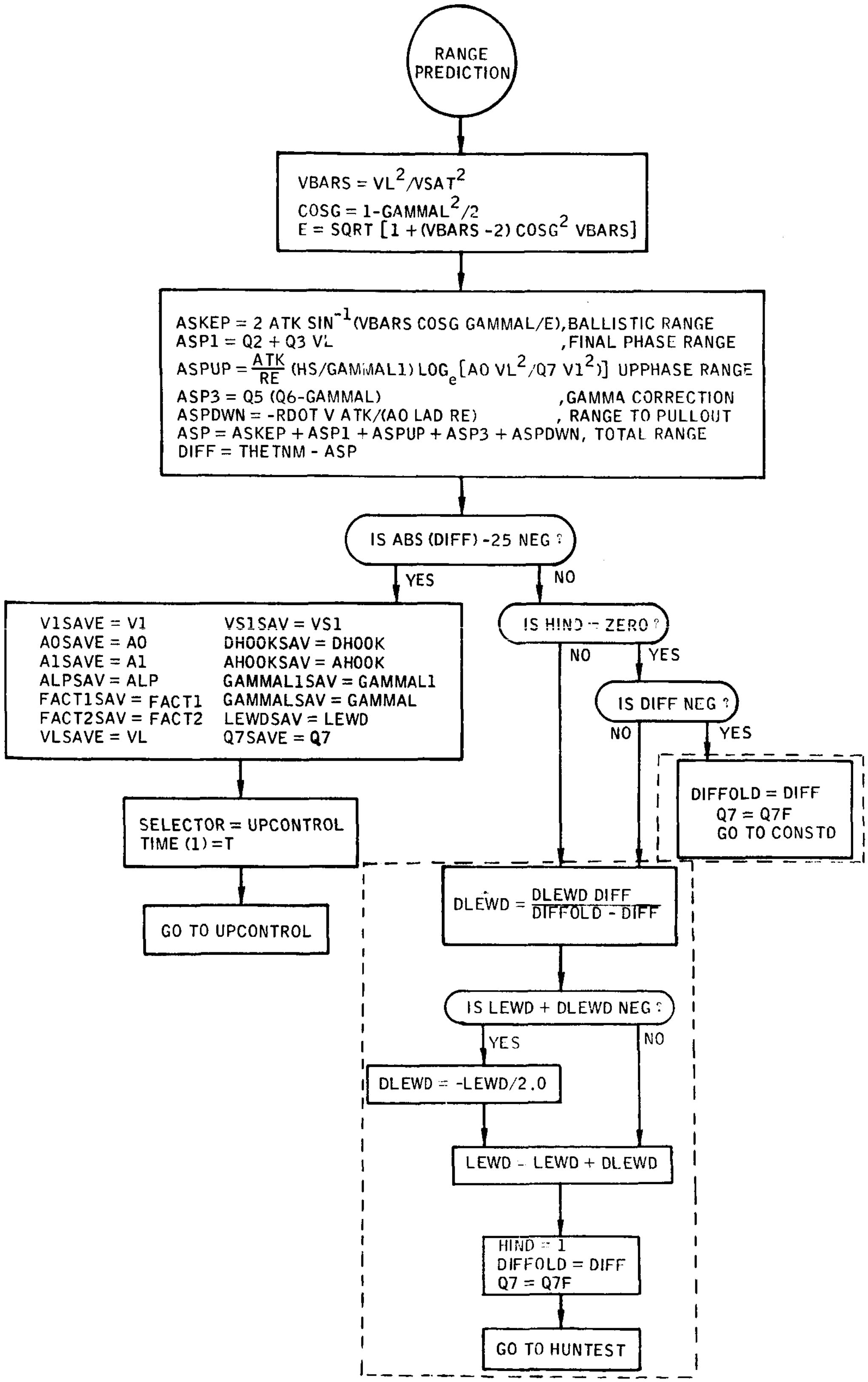

Figure 7.- Range prediction.

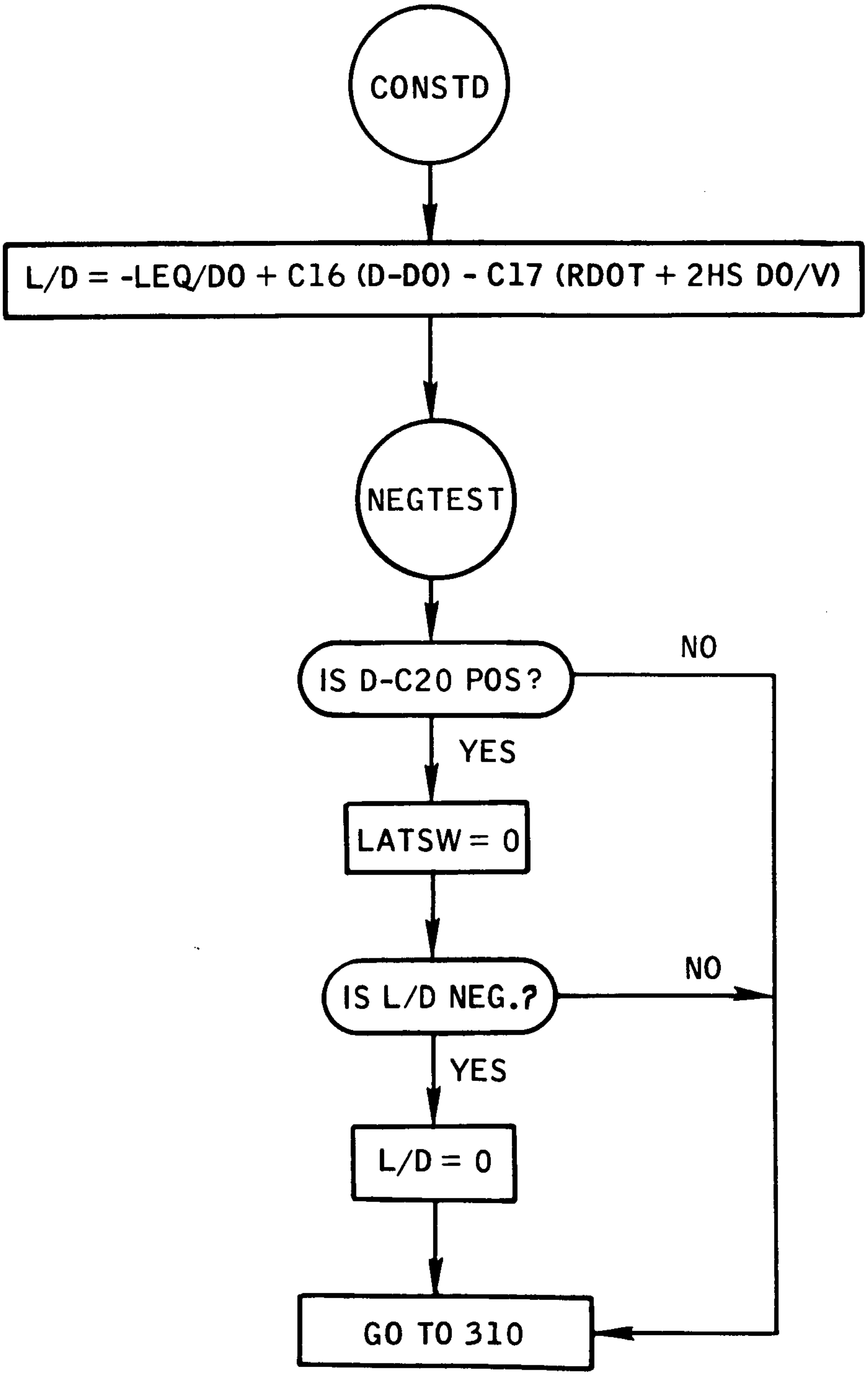

Figure 8. - Constant drag.

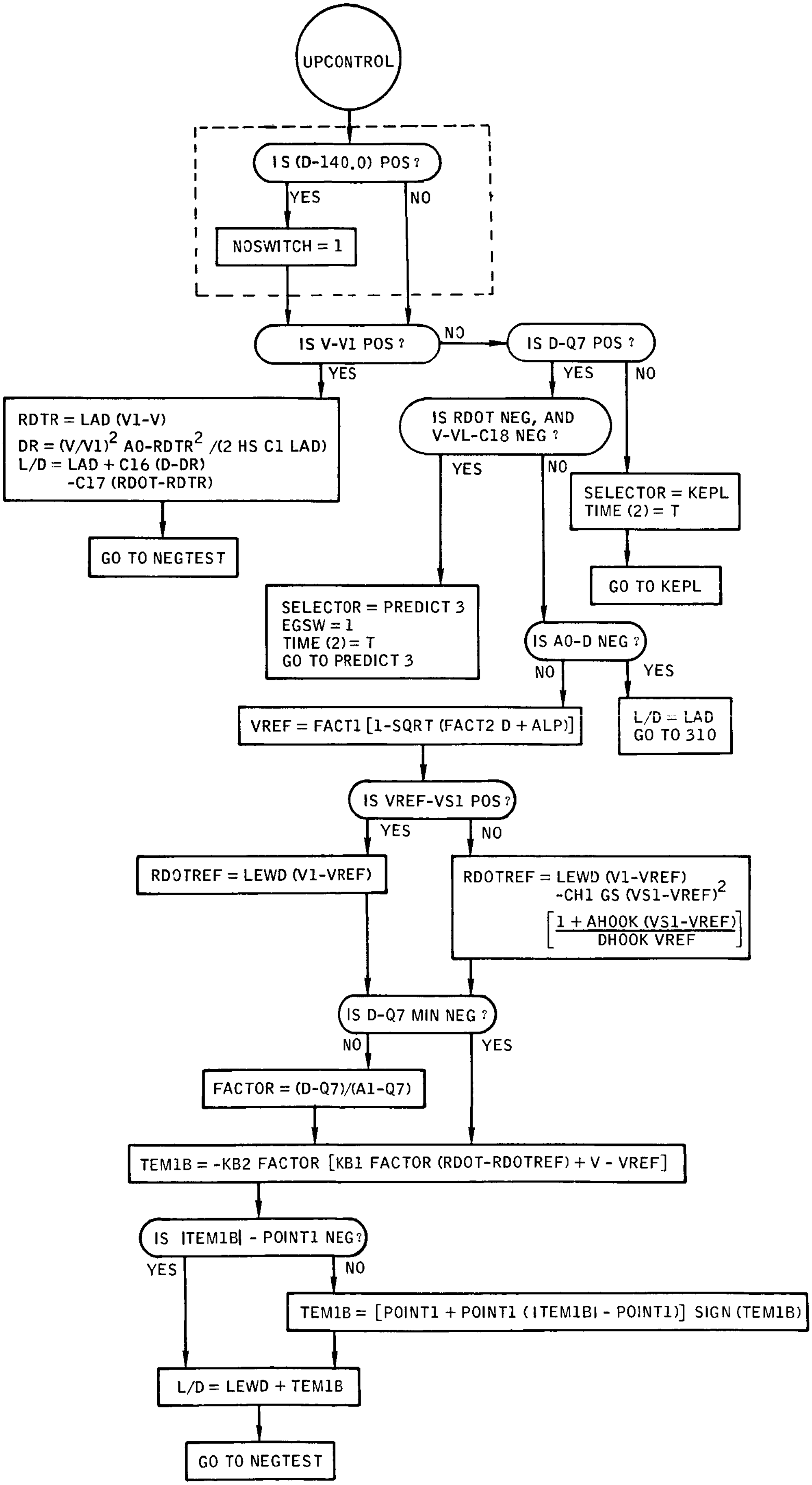

Figure 9.- Upcontrol.

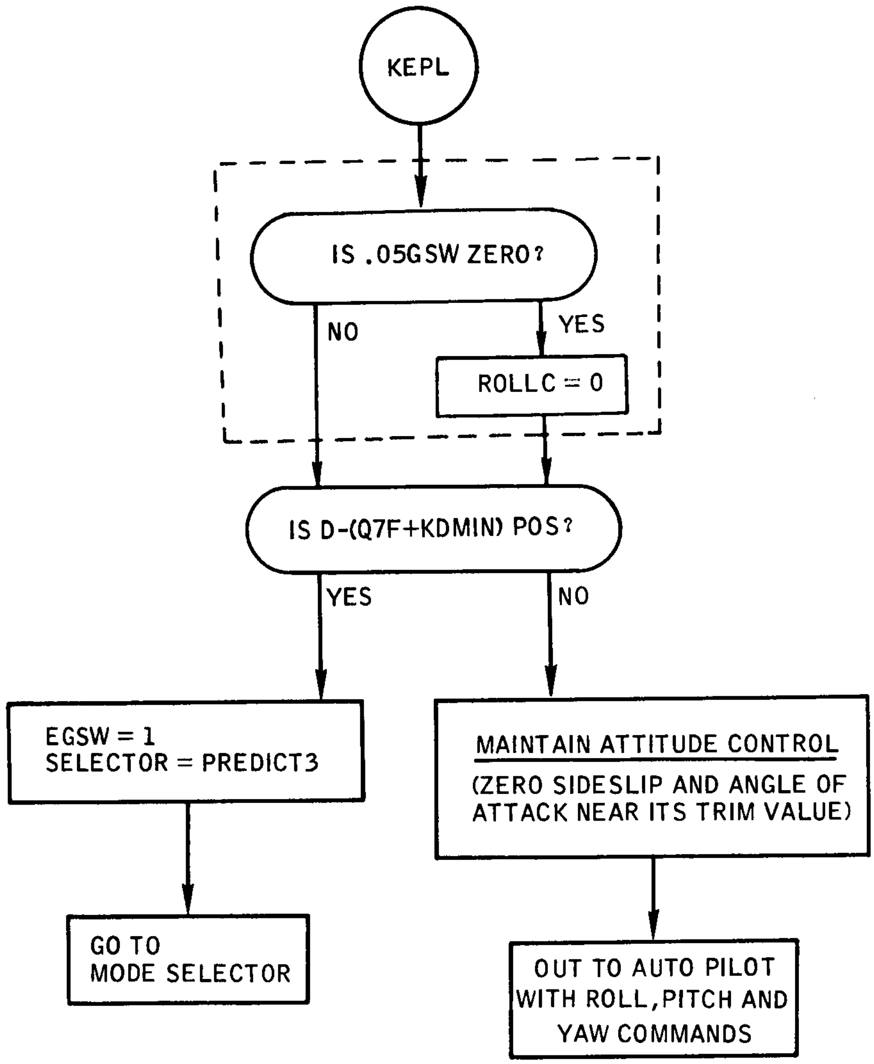

Figure 10.- Ballistic phase.

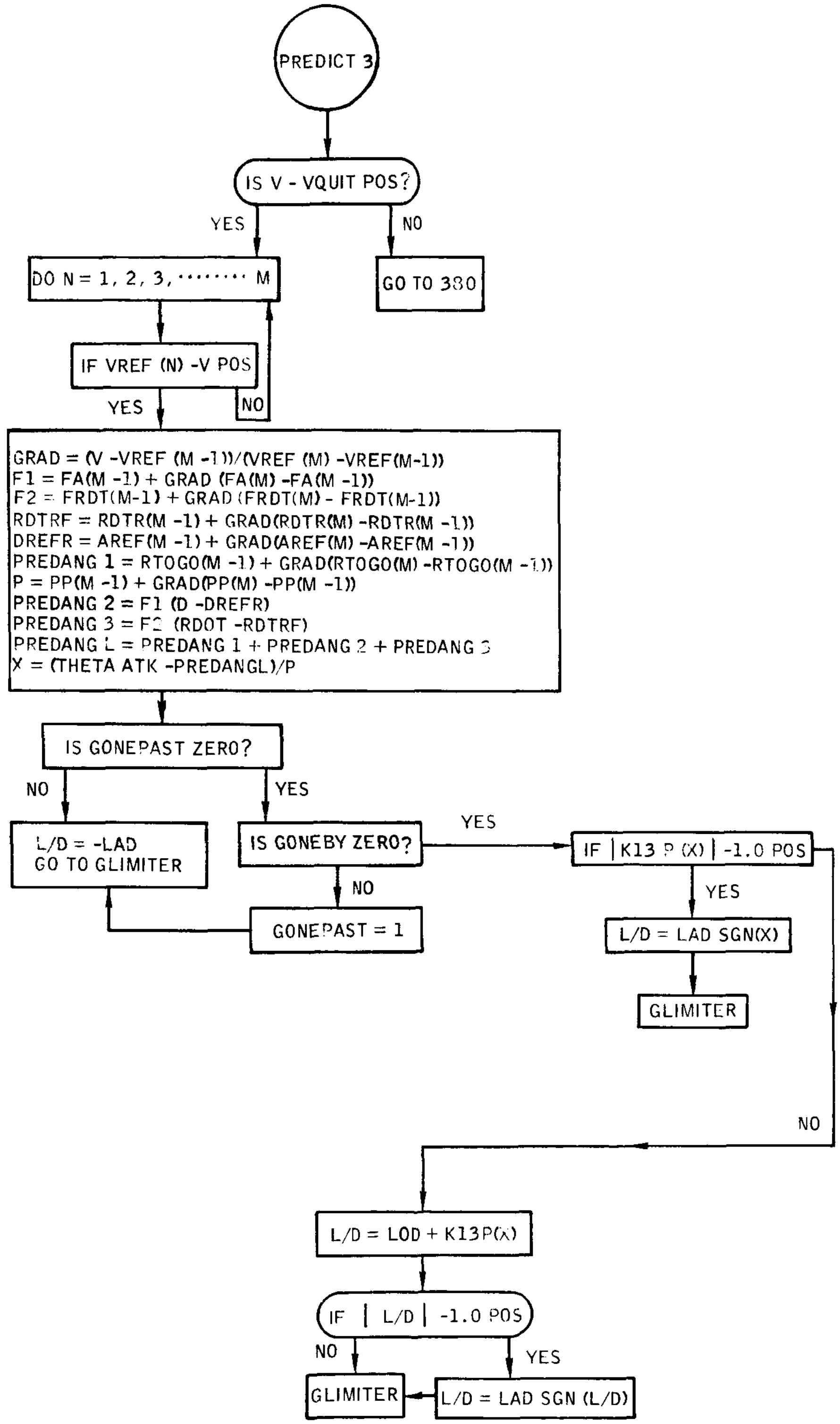

Figure 11.- Predict 3.

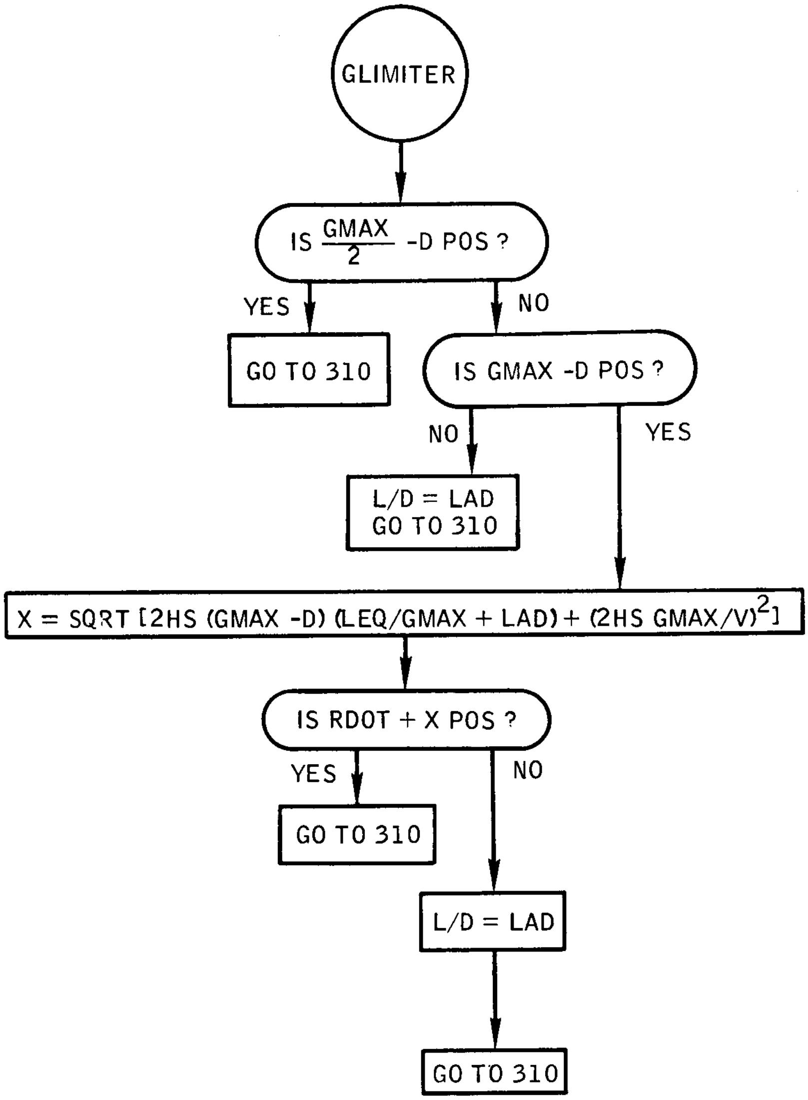

Figure 12. - G-Limiter.

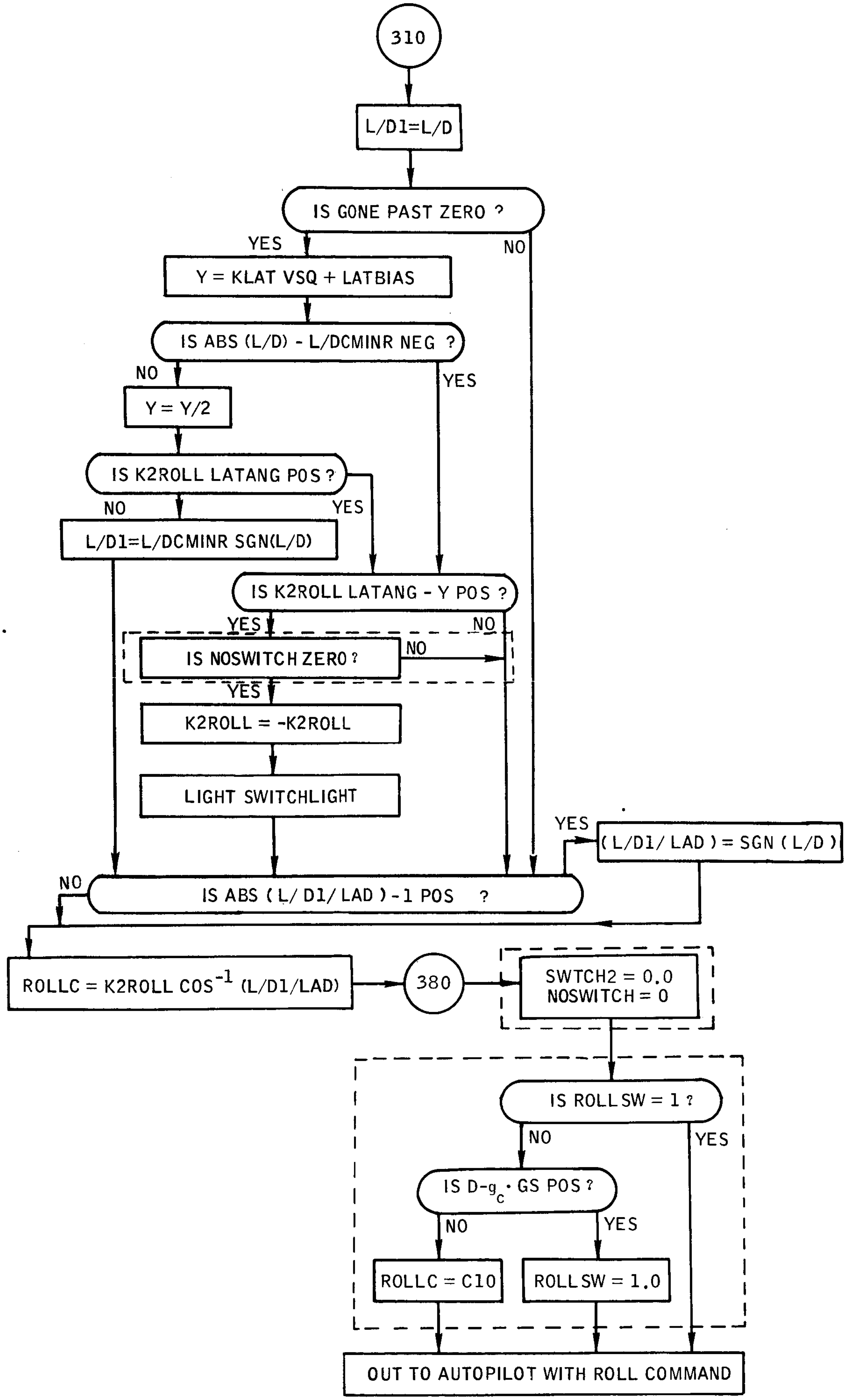

Figure 13. - Lateral control.

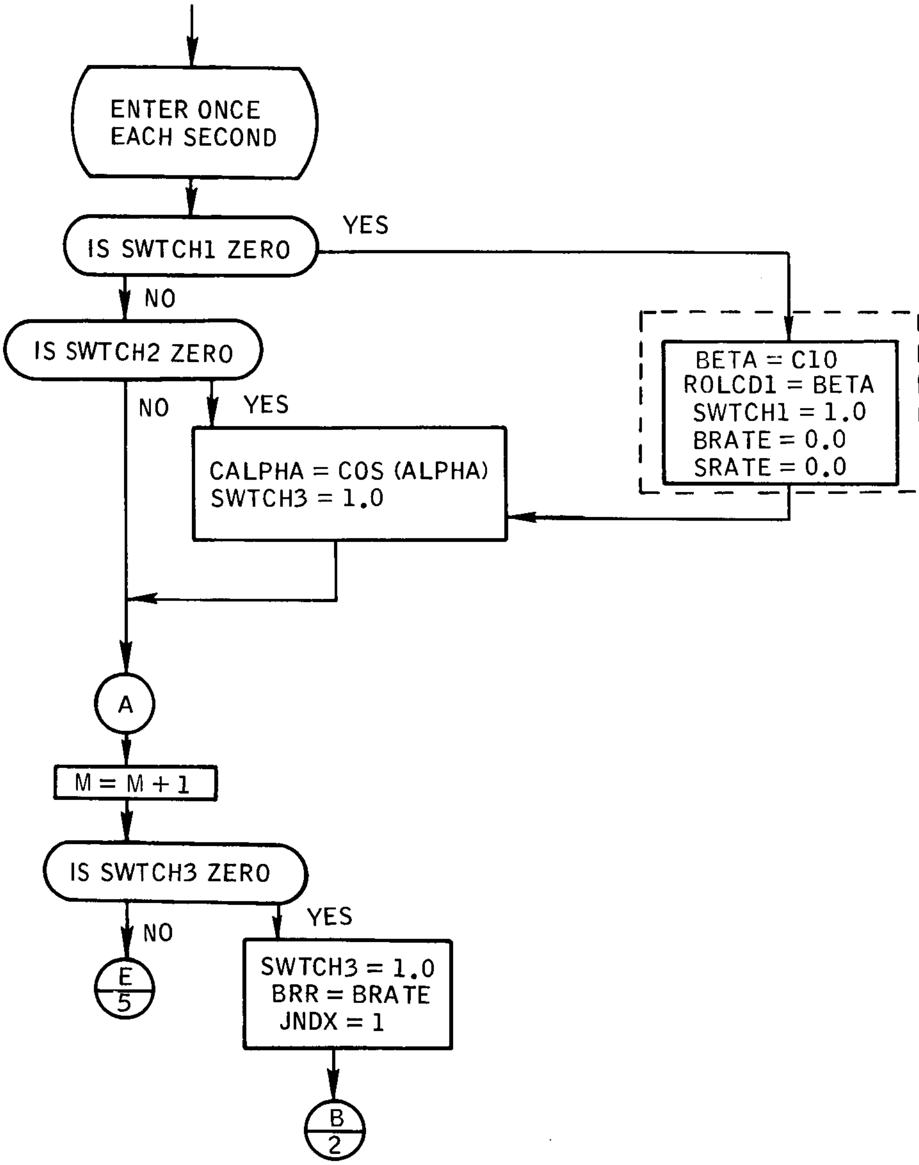

Figure 14. - Atmospheric roll DAP flow logic.

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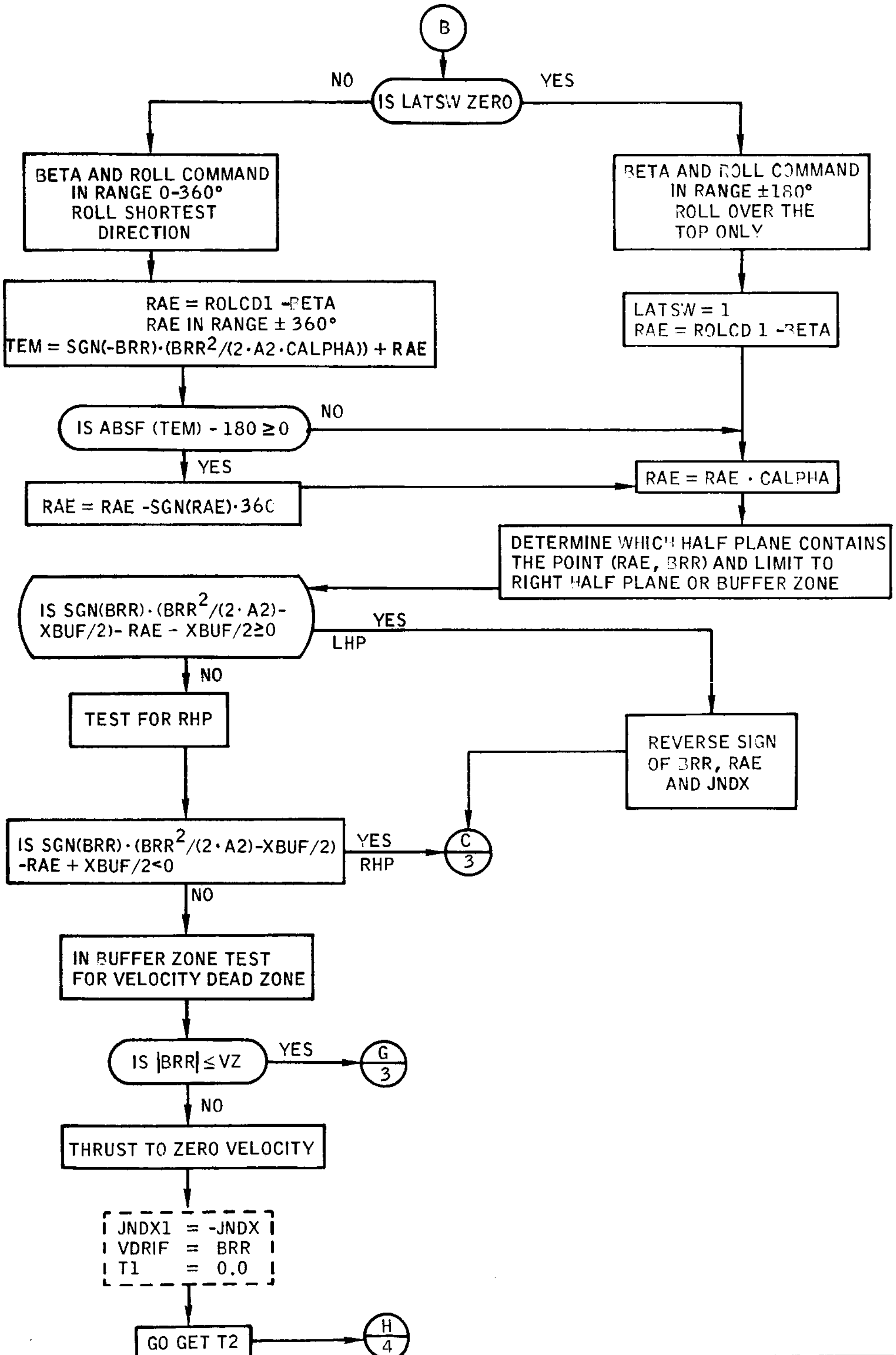

Figure 14. - Continued.

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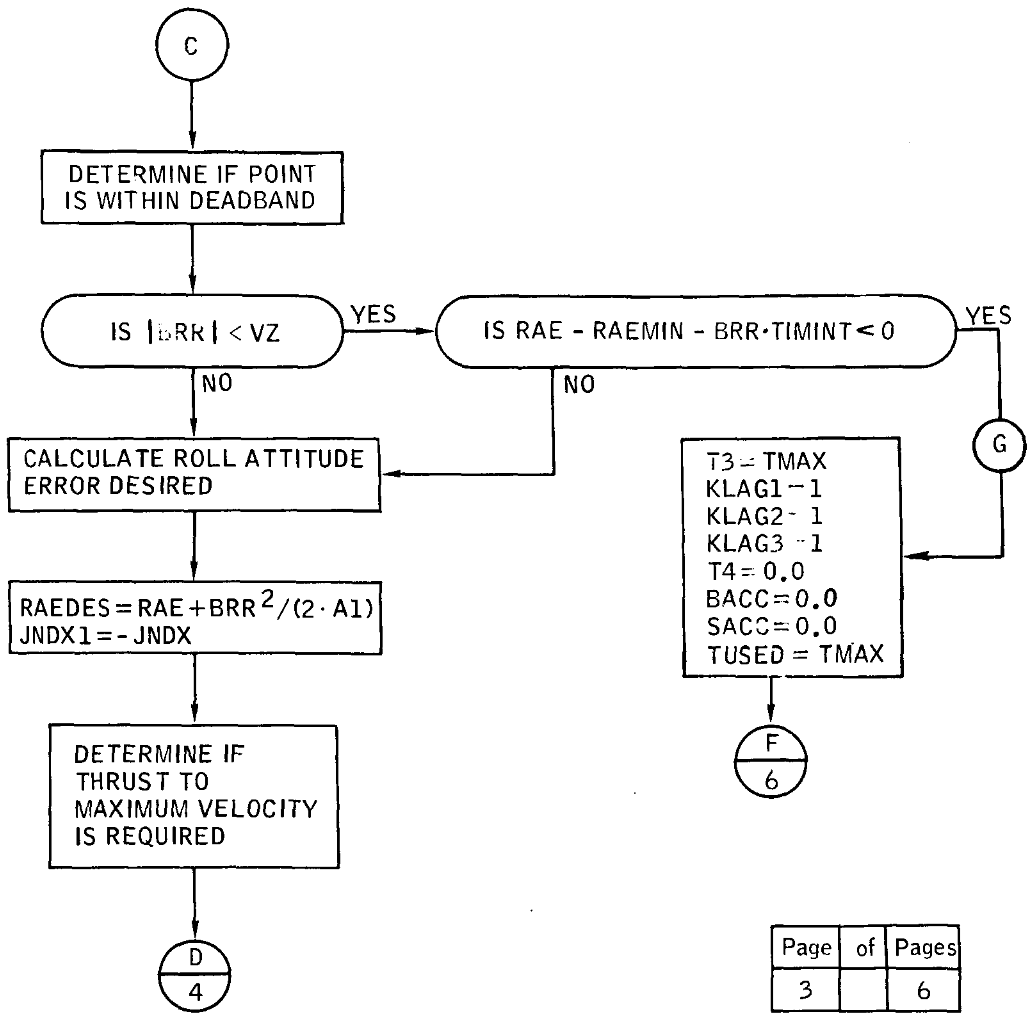

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Figure 14. - Continued.

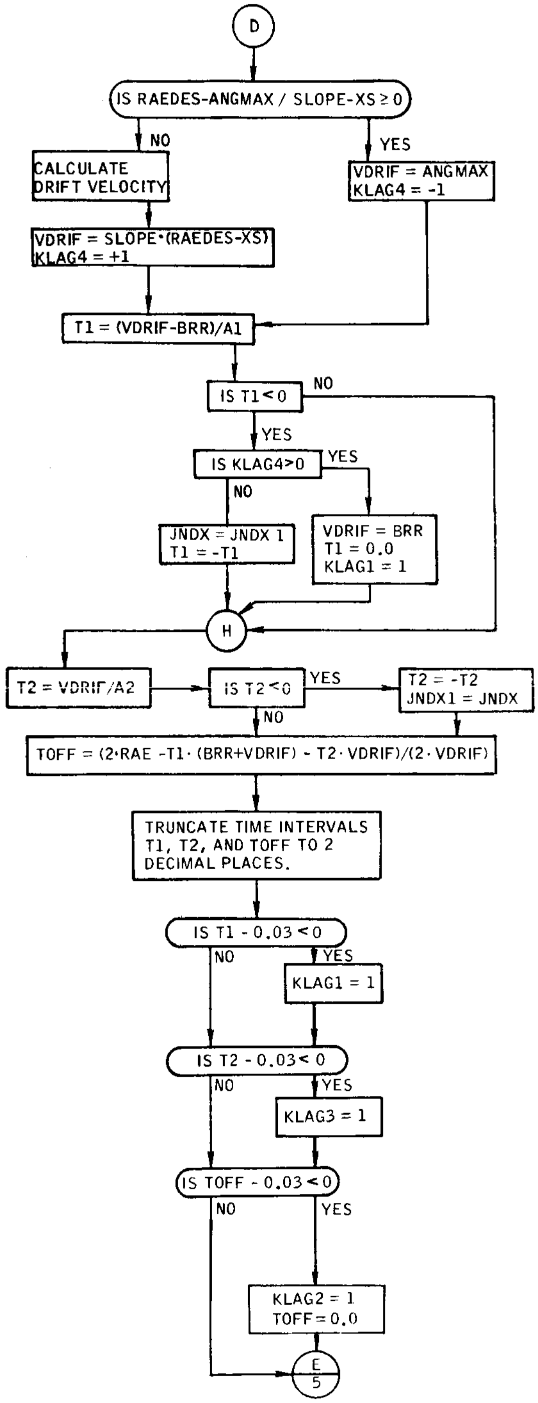

Figure 14.-Continued.

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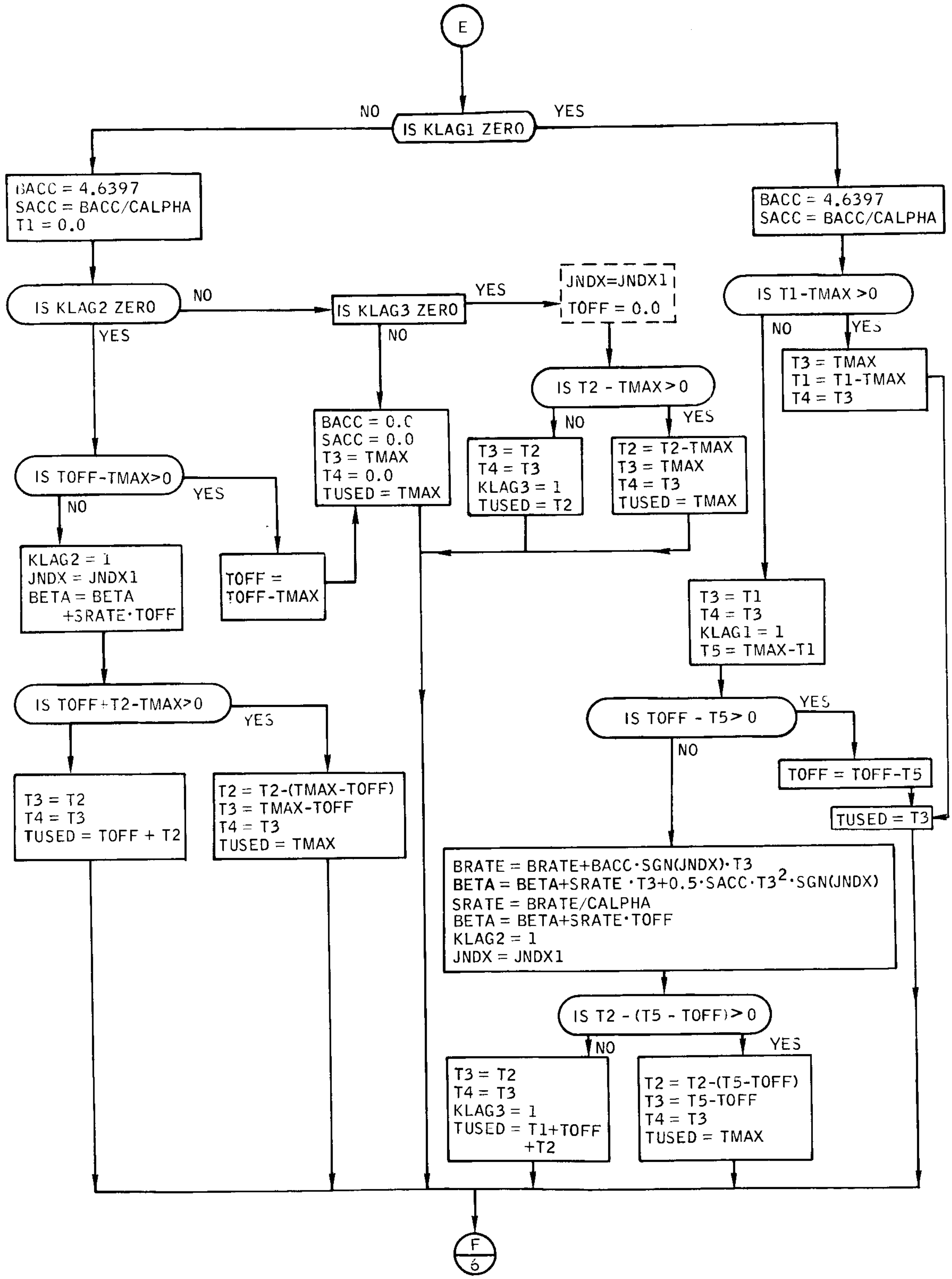

Figure 14. - Continued.

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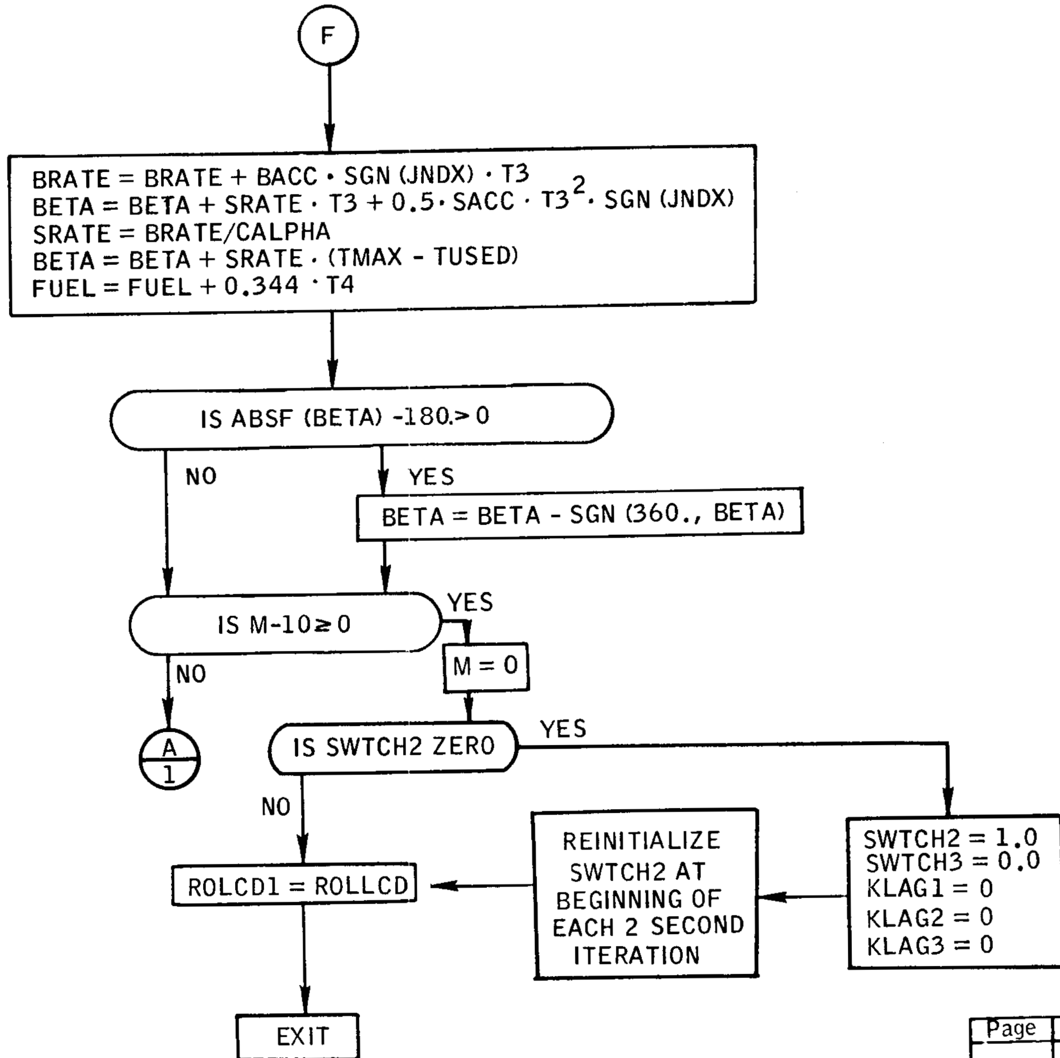

Figure 14. - Concluded.

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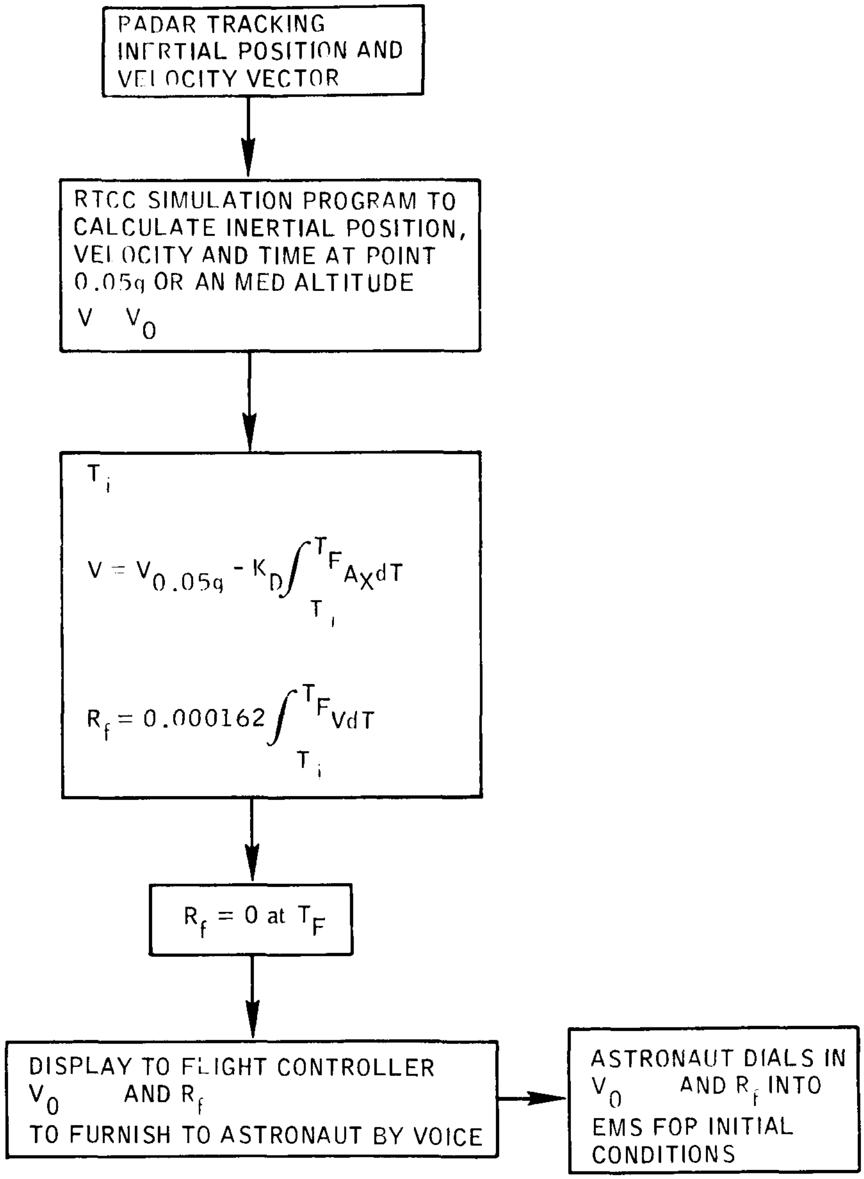


Figure 15. - Ground initialization flow for EMS initialization.

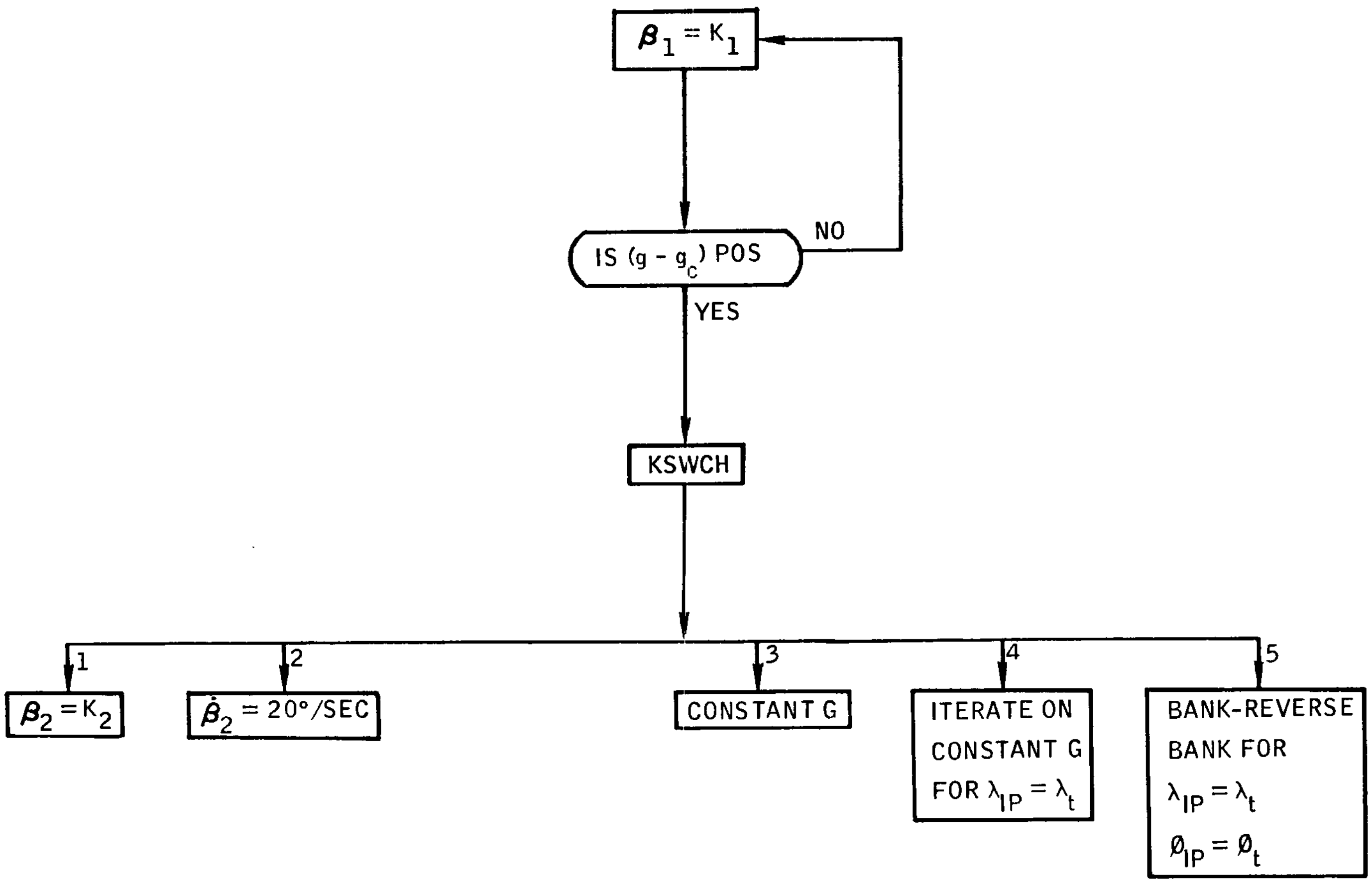
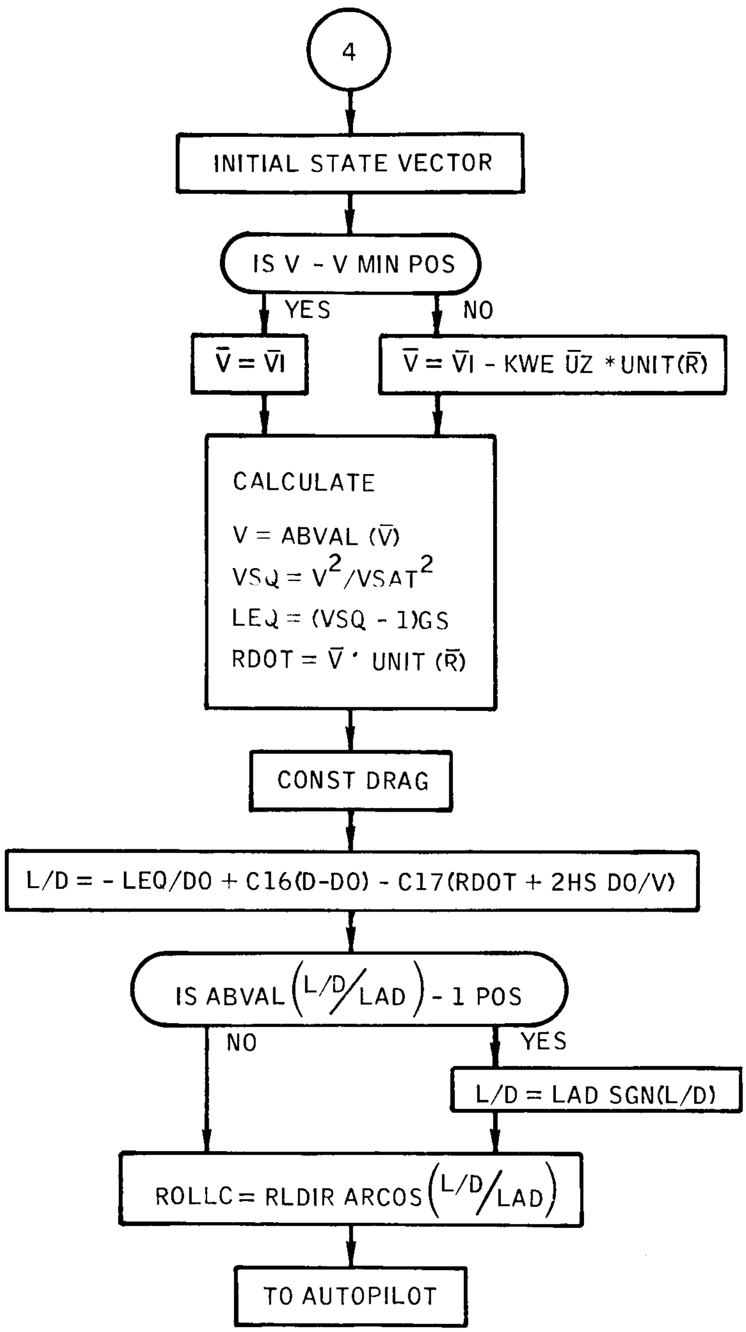


Figure 16. - Backup entry mode control logic.



*DENOTES VECTOR CROSS-PRODUCT

Figure 17.- Constant g logic.

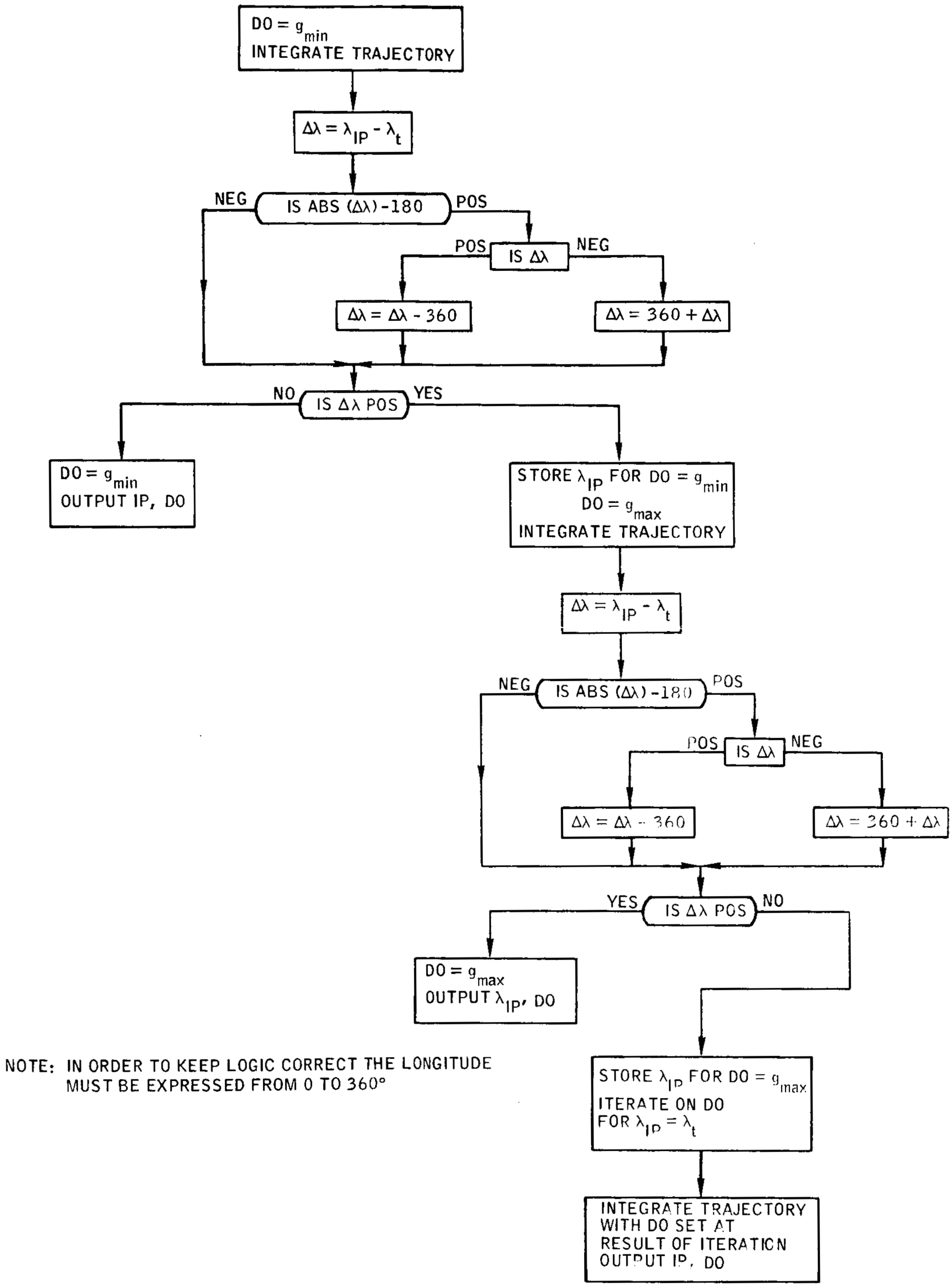


Figure 18.- Iteration logic for constant g level at which $\lambda_{IP} = \lambda_t$.

REFERENCES

1. Tolin, James W., Jr.; Fulkerson, Grover D.; Harpold, Jon C.; Adams, James C.; and Rogers, Joseph E.: RTCC Requirements for Missions D, E, and F: Reentry Phase. MSC IN 68-FM-102, April 24, 1968.

2. MIT: Guidance System Operations Plan for Manned CM Earth Orbital and Lunar Missions Using Program Colossus Section 5, Guidance Equations, Revision 2. MIT, July 1968.

3. MIT: Guidance System Operations Plan for Manned CM Earth Orbital Missions and Lunar Missions Using Program COLOSSUS Section 3. Revision 1. MIT Instrumentation Laboratory Report No. R-577, June 1968.

4. Nunn, James R.: Block II Command Module RCS Force and Moment Components. MSC Memorandum 67-FM53-146, 1967.