80-FM-23
(Supersedes 76-FM-98, Rev. 1)

JSC-16515
(Supersedes JSC-11746)

MCC Level C Formulation Requirements

Entry Guidance and Entry Autopilot (STS-1 Baseline)

(NASA-TM-81034) ENTRY GUIDANCE AND ENTRY AUTOPILOT (STS-1 BASELINE) (NASA) 125 p HC A07/MF A01 CSCL 22A

N80-29383

Unclas
G3/13 26923

Mission Planning and Analysis Division

August 1980

NASA
National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

80FM23

80-FM-23
(Supersedes 76-FM-98, Rev. 1)

JSC-16515
(Supersedes JSC-11746)

SHUTTLE PROGRAM

MCC LEVEL C FORMULATION REQUIREMENTS

ENTRY GUIDANCE AND ENTRY AUTOPILOT
(STS-1 BASELINE)

By J. C. Harpold and Oliver Hill
Flight Analysis Branch

Approved:
Claude A. Graves, Jr., Assistant Chief
Flight Analysis Branch

Approved:
Ronald L. Berry, Chief
Mission Planning and Analysis Division

Mission Planning and Analysis Division

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center

Houston, Texas

August 1980

CONTENTS

Section Page

TABLES

FIGURES

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 formulation requirements for the entry guidance and the simplified autopilot that will be used by the MCC entry processor. 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 (sec. 3.2), a list of parameter definitions for the software formulations (sec. 3.3), a description of the entry guidance detailed formulation requirements (sec. 3.4), a description of the detailed autopilot formulation requirements (sec. 3.5), a description of the targeting routine (sec. 3.6), and a set of formulation flow charts (appendixes A through C).

3.0 SOFTWARE FORMULATION REQUIREMENTS

3.1 INTRODUCTION

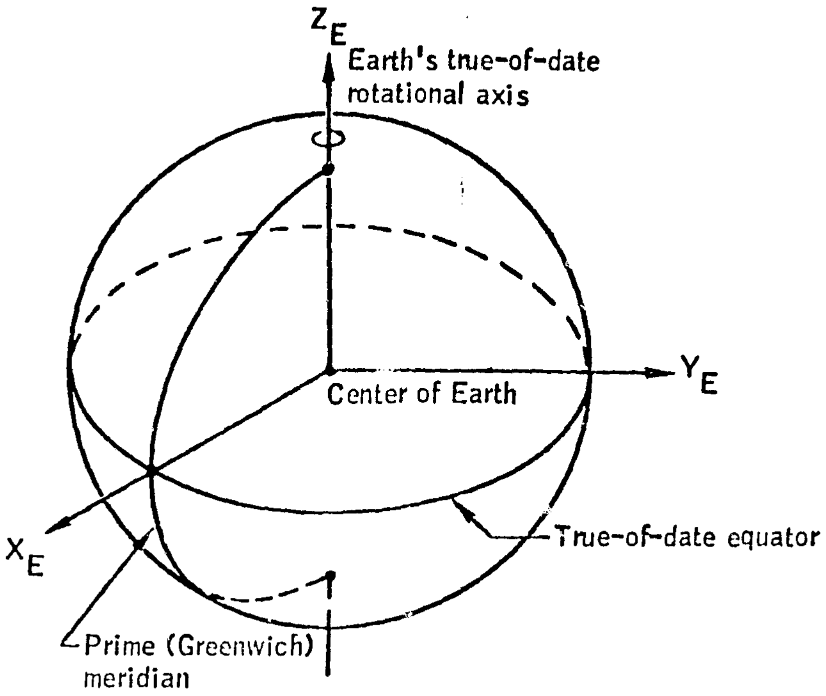
The entry guidance system is the source of the bank-angle and angle-of-attack commands used to control the entry trajectory. The entry guidance can be called by one of two means: either in the normal mode to generate a complete entry trajectory, or as a part of the iterative targeting mode in the entry 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 (β) 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-angle and angle-of-attack commands generated by the entry guidance and executed by the autopilot are attitudes defined with respect to the Earth-relative velocity vector.



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.

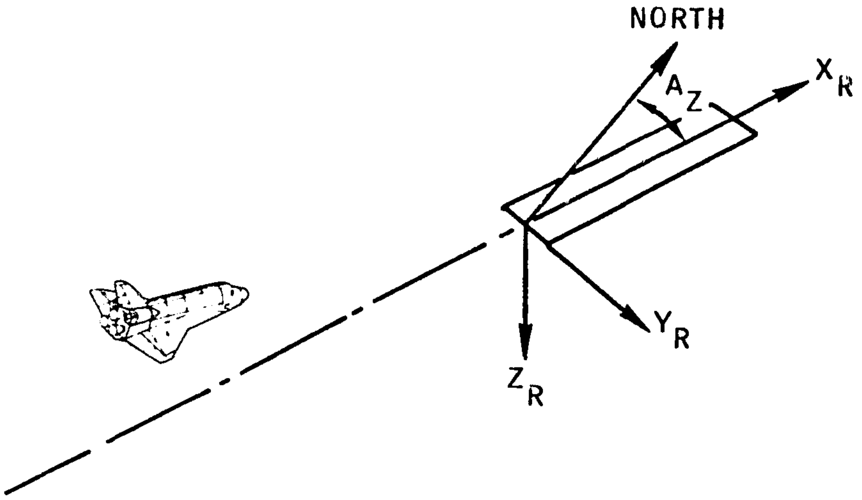
The Z_E-axis is directed along the Earth's true-of-date rotational axis and is positive north.

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.

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 and output data for the entry guidance. Table 3.3-3 presents a list of internal parameters for entry guidance. Tables 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. The data in these tables represent STS-1 cycle 3 trajectory data. This document will not be updated for constant changes. These changes are documented in system parameter lists by the Ground Data Systems Division (GDSD).

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^2
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^2
MM304	Preentry bank angle	Med input	deg
MM304	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 α constant	7.5	deg	0 to ± 1000	f
ACLAM2	Maximum α constant (f(VE))	0.0035	deg-sec/ft	0 to ± 10	f
ACLIM1	Minimum α constant	37.0	deg	0 to ± 1000	f
ACLIM2	Minimum α constant (f(VE))	0.	deg-sec/ft	0 to ± 10	f
ACLIM3	Minimum α constant	7.6666667	deg	0 to ± 1000	f
ACLIM4	Minimum α constant (f(VE))	.00223333	deg-sec/ft	0 to ± 10	f
ACN1	Time constant for $\dot{H}$ feedback	50	sec	--	Mission (m)
AK	Factor in dD/dV for temperature control guidance used to define C23	-.4612777	n.d.	0 to ± 100	m
AK1	Factor in dD/dV for temperature control guidance used to define C23	-4.176825	n.d.	0 to ± 100	m
ALFM	Desired constant drag level	33.0	ft/sec^2	0 to ± 50	m
ALIM	Maximum sensed acceleration in transition	70.84	ft/sec^2	-	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^2	-	f
CALPO(1)	ALPCMD constant term in VE	5.424505	deg	0 to ± 1000	m
CALPO(2)	ALPCMD constant term in VE	5.424505	deg	0 to ± 1000	m

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

(b) Input constants - Continued

Symbol	Description	Value	Unit	Range	Class
CALPO(3)	ALPCMD constant term in VE	-4.2778	deg	0 to ± 1000	m
CALPO(4)	ALPCMD constant term in VE	16.398	deg	0 to ± 1000	m
CALPO(5)	ALPCMD constant term in VE	4.476	deg	0 to ± 1000	m
CALPO(6)	ALPCMD constant term in VE	-9.9339	deg	0 to ± 1000	m
CALPO(7)	ALPCMD constant term in VE	40	deg	0 to ± 1000	m
CALPO(8)	ALPCMD constant term in VE	40	deg	0 to ± 1000	m
CALPO(9)	ALPCMD constant term in VE	40	deg	0 to ± 1000	m
CALPO(10)	ALPCMD constant term in VE	40	deg	0 to ± 1000	m
CALP1(1)	ALPCMD rate term in VE	0.003430198	deg-sec/ft	0 to ± 10	m
CALP1(2)	ALPCMD rate term in VE	0.003430198	deg-sec/ft	0 to ± 10	m
CALP1(3)	ALPCMD rate term in VE	.8875002E-2	deg-sec/ft	0 to ± 10	m
CALP1(4)	ALPCMD rate term in VE	-.3143109E-3	deg-sec/ft	0 to ± 10	m
CALP1(5)	ALPCMD rate term in VE	3.1875E-3	deg-sec/ft	0 to ± 10	m
CALP1(6)	ALPCMD rate term in VE	6.887436E-3	deg-sec/ft	0 to ± 10	m
CALP1(7)	ALDCMD rate term in VE	0	deg-sec/ft	0 to ± 10	m
CALP1(8)	ALDCMD rate term in VE	0	deg-sec/ft	0 to ± 10	m
CALP1(9)	ALDCMD rate term in VE	0	deg-sec/ft	0 to ± 10	m
CALP1(10)	ALDCMD rate term in VE	0	deg-sec/ft	0 to ± 10	m
CALP2(1)	ALPCMD quadratic term in VE	0.0	deg-sec^2/ft^2	0 to ± 1	m
CALP2(2)	ALPCMD quadratic term in VE	0.0	deg-sec^2/ft^2	0 to ± 1	m

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

(b) Input constants - Continued

Symbol	Description	Value	Unit	Range	Class
CALP2(3)	ALPCMD quadratic term in VE	-0.7638891E-6	deg-sec^2/ft^2	0 to ± 1	m
CALP2(4)	ALPCMD quadratic term in VE	0.2571456E-6	deg-sec^2/ft^2	0 to ± 1	m
CALP2(5)	ALPCMD quadratic term in VE	0	deg-sec^2/ft^2	0 to ± 1	m
CALP2(6)	ALPCMD quadratic term in VE	-2.374978E-7	deg-sec^2/ft^2	0 to ± 1	m
CALP2(7)	ALPCMD quadratic term in VE	0	deg-sec^2/ft^2	0 to ± 1	m
CALP2(8)	ALPCMD quadratic term in VE	0	deg-sec^2/ft^2	0 to ± 1	m
CALP2(9)	ALPCMD quadratic term in VE	0	deg-sec^2/ft^2	0 to ± 1	m
CALP2(10)	ALPCMD quadratic term in VE	0	deg-sec^2/ft^2	0 to ± 1	m
CDDOT1	CD velocity coefficient	1500	ft/sec	-	f
CDDOT2	CD velocity coefficient	2000	ft/sec	-	f
CDDOT3	CD velocity coefficient	0.18	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^2	-	f
CDDOT7	$\dot{\mathrm{C}}$D coefficient	.9E-4	sec/ft	-	f
CDDOT8	$\dot{\mathrm{C}}$D coefficient	13.666E-4	1/deg^2	-	f
CDDOT9	$\dot{\mathrm{C}}$D 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 α modulation	4.0	n.d.	0 to 10	m
CT16(1)	C16 coefficient	0.1354	sec^2/ft	-	f

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

(b) Input constants - Continued

Symbol	Description	Value	Unit	Range	Class
CT16(2)	C16 power coefficient	-0.10	n.d.	-	f
CT16(3)	C16 drag error coefficient	0.006	sec^2/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^2/ft	-	f
CT16MX	Maximum value of C16	0.35	sec^2/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
CYO	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	Multiplication factor on C17 when ICT = 1	0.75	n.d.	0 to 2.	f
C21	C20 constant value	0.06	1/deg	0 to ± 1000	m
C22	C20 constant value in linear term	-0.001	1/deg	0 to ± 1000	m
C23	C20 linear term	4.25E-6	sec/ft-deg	0 to ± 10	m
C24	C20 constant value	0.01	1/deg	0 to ± 1000	m
C25	C20 constant value in linear term	0.01	1/deg	0 to ± 1000	m
C26	C20 linear value	0.	sec/ft-deg	0 to ± 10	m
C27	C20 constant value	0.	1/deg	0 to ± 1000	m
DDLIM	maximum Δ drag for $\dot{H}$ feedback	2.0	ft/sec^2	0 to 10	m

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

(b) Input constants - Continued

Symbol	Description	Value	Unit	Range	Class
DDMIN	Maximum drag error	0.15	ft/sec^2	-	f
DELV	Phase transfer velocity bias	2300	ft/sec	-	f
DF	Final drag value in transition phase	20.80031	ft/sec^2	0 to 50	m
DLALLM	Maximum α constant	43.0	deg	-	f
DLAPLM	Limit value for DELALP	2.0	deg	-	f
D23C	ETG canned D23	19.38	ft/sec^2	0 to 50	m
D230	Initial value of D23	19.38	ft/sec^2	0 to 50	m
DRDDL	Minimum value of DRDD	-1.5	n.mi./sec^2/ft	-	f
DTEGD	Entry guidance computation interval (value may change for ETG mode)	1.92	sec	-	f
DT2MIN	Minimum value of T2DOT	0.008	ft/sec^3	-	f
DTR	Degrees to radians	0.0174532925	deg/rad	-	f
EEF4	Final reference energy level in transition phase	2.0E-6	ft^2/sec^2	0 to 1.E7	m
ETRAN	Energy level at start of transition	.5998473E8	ft^2/sec^2	0 to 2.E8	m
E1	Minimum value of DREFP and $\lvert$DREFP-DF$\rvert$ in transition phase	0.01	ft/sec^2	-	f
GS	Earth-gravitational constant	32.174	ft/sec^2	-	f
GS1	Factor in smoothing roll command	0.0	sec^{-1}	0 to 10	m
GS2	Factor in smoothing roll command	0.0001	sec^{-1}	0 to 10	m
GS3	Factor in smoothing roll command	0.0	sec^{-1}	0 to 10	m
GS4	Factor in smoothing roll command	0.0	sec^{-1}	0 to 10	m

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

(b) Input constants - Continued

Symbol	Description	Value	Unit	Range	Class
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
MM304ϕ	Preentry bank-angle command	0.0	deg	0 to ±180	m
MM304α	Preentry angle-of-attack command	40	deg	0 to 60	m
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	-370.	deg	-	f
RLMC5	Coefficient in second RLM segment	0.16	deg/ft/sec	-	f
RLMC6	Minimum value of RLM	30.0	deg	-	f
RPT1	Range bias term	29.44	n.mi.	0 to 1 000	m

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

(b) Input constants - Continued

Symbol	Description	Value	Unit	Range	Class
VA	Initial velocity for temperature quadratic, dD/dV=0	23 163.7	ft/sec	0 to 50 000	m
VALMOD	α 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	3 563.87	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	6 809.	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	21 000.	ft/sec	0 to 50 000	m
VA2	Initial velocity for temperature quadratic, dD/dV=0	27 197.46	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	9 500.	ft/sec	0 to 50 000	f

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

(b) Input constants - Concluded

Symbol	Description	Value	Unit	Range	Class
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	α modulation start flag (VNOALP will always equal 0. for ETG mode)	25 000.	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	2 750.	ft/sec	-	f
VSAT	Local circular orbit velocity	25 766.2	ft/sec	0 to 50 000	f
VS1	Reference velocity for equilibrium glide	23 271.87	ft/sec	0 to 50 000	m
VRDT	Velocity to start $\dot{H}$ 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
YLMN2	Minimum YL BIAS	.07	rad	-	f
Y1	Maximum heading error deadband before first reversal	0.1832596	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 $\dot{H}$ feedback	0.6	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^2	Display
DRAG	Actual drag	ft/sec^2	Display
ROLREF	Bank reference	deg	Display
ISLECT	Guidance phase indicator relative	n.d.	Display
VCG	Velocity at start of constant drag phase	ft/sec	Display
VRR	Velocity at first bank reversal	ft/sec	Display
EOWD	Energy overweight	ft	Display
EEI	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^2 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 - DREFP
DDS	Limited value of DD

TABLE 3.3-3.- ENTRY GUIDANCE INTERNAL PARAMETER DEFINITIONS - Continued

Symbol	Description
DDP	Past value of DD
DELALF	Delta ALPHA from schedule
DELALP	Command ALPHA increment
DLRDOT	$\dot{R}$ 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.- ENTRY GUIDANCE INTERNAL PARAMETER DEFINITIONS - 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 temperature control phase
RCG	Constant drag phase range
RCG1	Constant component of RCG
RDEALF	Roll bias for alpha modulation
RDTREF	Altitude rate reference
RDTRF1	RDTREF in Phase 3
REQ1	Equilibrium glide range x D23
RER1	Transition phase range
RF(1,2)	Ith range segment in temperature 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)	Rolref
RPT	Desired range at VQ

TABLE 3.3-3.- ENTRY GUIDANCE INTERNAL PARAMETER DEFINITIONS - 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 temperature 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 temperature control D-V quadratic
XLOD	Limited lift/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
ALPWWD	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.
MM304ϕ	Preentry bank command	Med input	rad
MM304α	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 - Concluded

(b) Input constants

Symbol	Description	Value	Unit	Class
RA	Maximum bank acceleration	0.029671	rad/sec^2	f
RADB	Bank attitude deadband	0.00174533	rad	f
RADB2	Bank attitude deadband for EGFLG=2	0.00174533	rad	f
RRM	Maximum bank rate	0.0872665	rad/sec	f
PA	Maximum angle-of-attack acceleration	0.0174533	rad/sec^2	f
PADB	Angle-of-attack attitude deadband	0.00174533	rad	f
PRM	Maximum angle-of-attack rate	0.0872665	rad/sec	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
DTR	Degrees to radians	0.017453292	rad	f
KONTROL	Initialization flag	15	n.d.	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
ALTD	Altitude of runway	Landing site table	ft
RLAT	Redesignation runway latitude	Landing site table	rad
RLONG	Redesignation runway longitude	Landing site table	rad
RALTD	Redesignation runway altitude	Landing site table	ft
RAZRW	Redesignation runway azimuth	Landing site table	rad
TLONG	Runway longitude	Landing site table	rad
TLATD	Runway latitude	Landing site table	rad
VREDS	Redesignation velocity	Landing site table	ft/sec
XYZE	Vehicle position vector	Integrator	ft
XYZED	Vehicle velocity vector	Integrator	ft/sec
SLATD	Secondary runway latitude	Landing site table	rad
SLONG	Secondary runway longitude	Landing site table	rad
SRTE1	Secondary runway altitude	Landing site table	ft
SRAZ	Secondary runway azimuth	Landing site table	rad

TABLE 3.3-7.- TARGETING ROUTINE INPUT DATA - Concluded

(b) Input constants

Symbol	Description	Value	Units	Class
RTURN	Radius of heading alinement circle	20 000	ft	m
XNEP	Distance between HAC center and threshold point	-39 519	ft	m
RX22	Polar radius^2/equatorial radius^2	0.9933065782	n.d	f
VMIDPT	Velocity limit for midpoint targeting	30 000.	fps	

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

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 circle
TT2DIN	Earth-fixed to topodetic matrix
PSI	Heading of vehicle
REC	Runway to Earth-fixed matrix
IPASS1	Midpoint targeting flag to denote computation of primary runway range and delta azimuth
XLAT	Primary runway latitude save parameter
XLONG	Primary runway longitude save parameter
XRTE1	Primary runway altitude save parameter
XRAZ	Primary runway azimuth save parameter

3.4 ENTRY GUIDANCE FORMULATION

3.4.1 Requirements Overview

The entry guidance is the source for bank-angle and angle-of-attack commands, which 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 that 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, which 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, which limit the crossrange error within a converging deadband. This mode begins at 400 000 ft and ends at TAEM interface, relative velocity = VTAEM.

In the ETB "canned" mode (EGFLG=2), the entry guidance controls the entry trajectory to a predefined drag-velocity profile. The entry simulations begin at 400 000 ft 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 MM304ϕ, MM304α, and MM304β. This phase is terminated at 5.66 ft/sec^2 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, which are used to optimize the entry profile. Range predictions are based on analytic solutions 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.

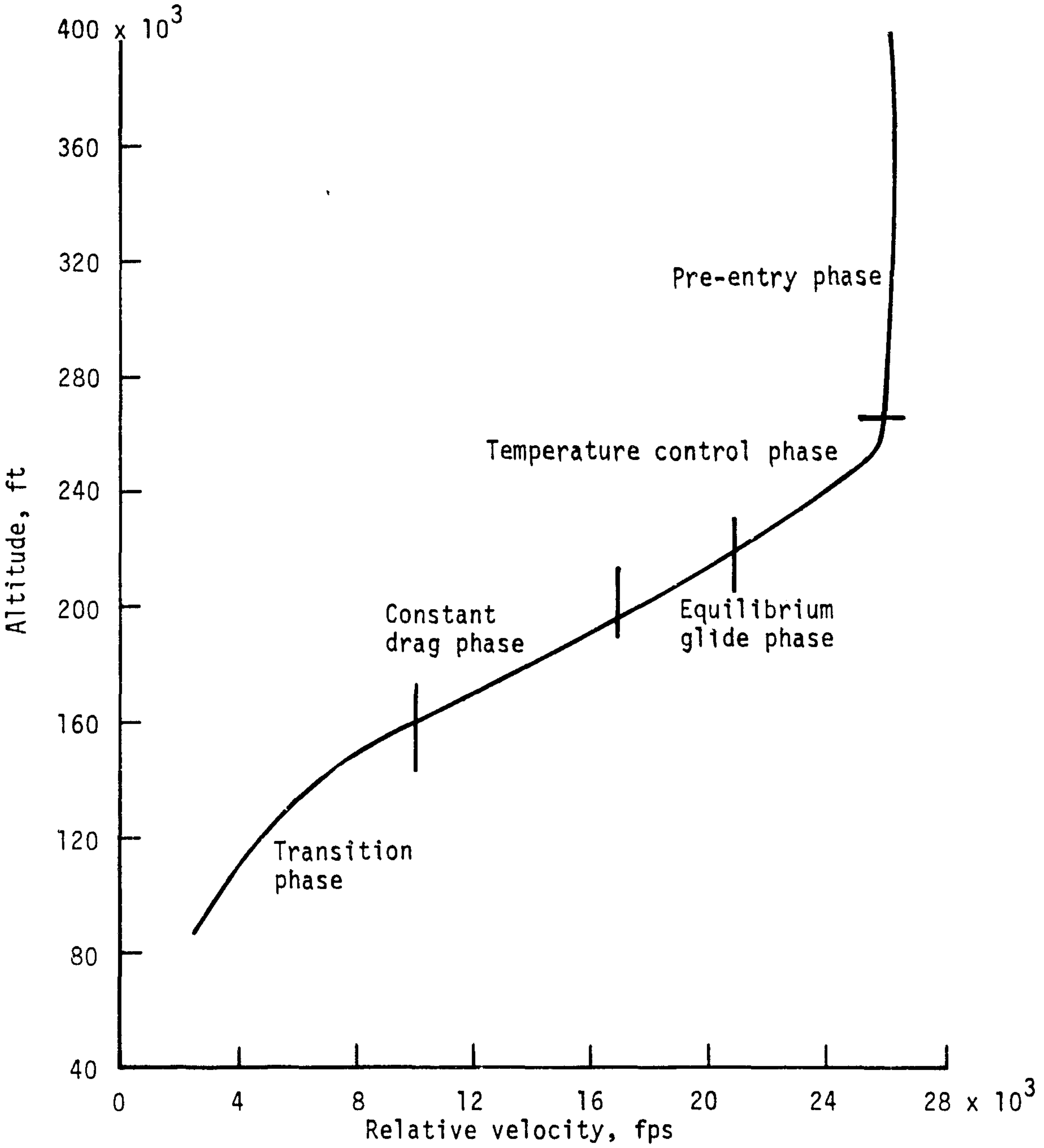


Figure 3.4.1-1.- Entry guidance phases.

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, which 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.

ISLECT	Guidance Phase
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.

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

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^2 by setting the ISLECT flag to 2 when the total acceleration exceeds the threshold value of ASTART ft/sec^2.

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

$$\mathrm{VE} > \mathrm{VA1}$$

and

$$\mathrm{DRF} = (\mathrm{DREF}(2) - \mathrm{DREF}(1))\ (\mathrm{DREF}(2) - \mathrm{DREF}\ (1)) + (\mathrm{HDTRF}(1) - \mathrm{HDTRF}(2)\ \mathrm{GS1}) > 0$$

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 reaction control system (RCS) fuel usage by transferring phases when the commanded bank angle is the same

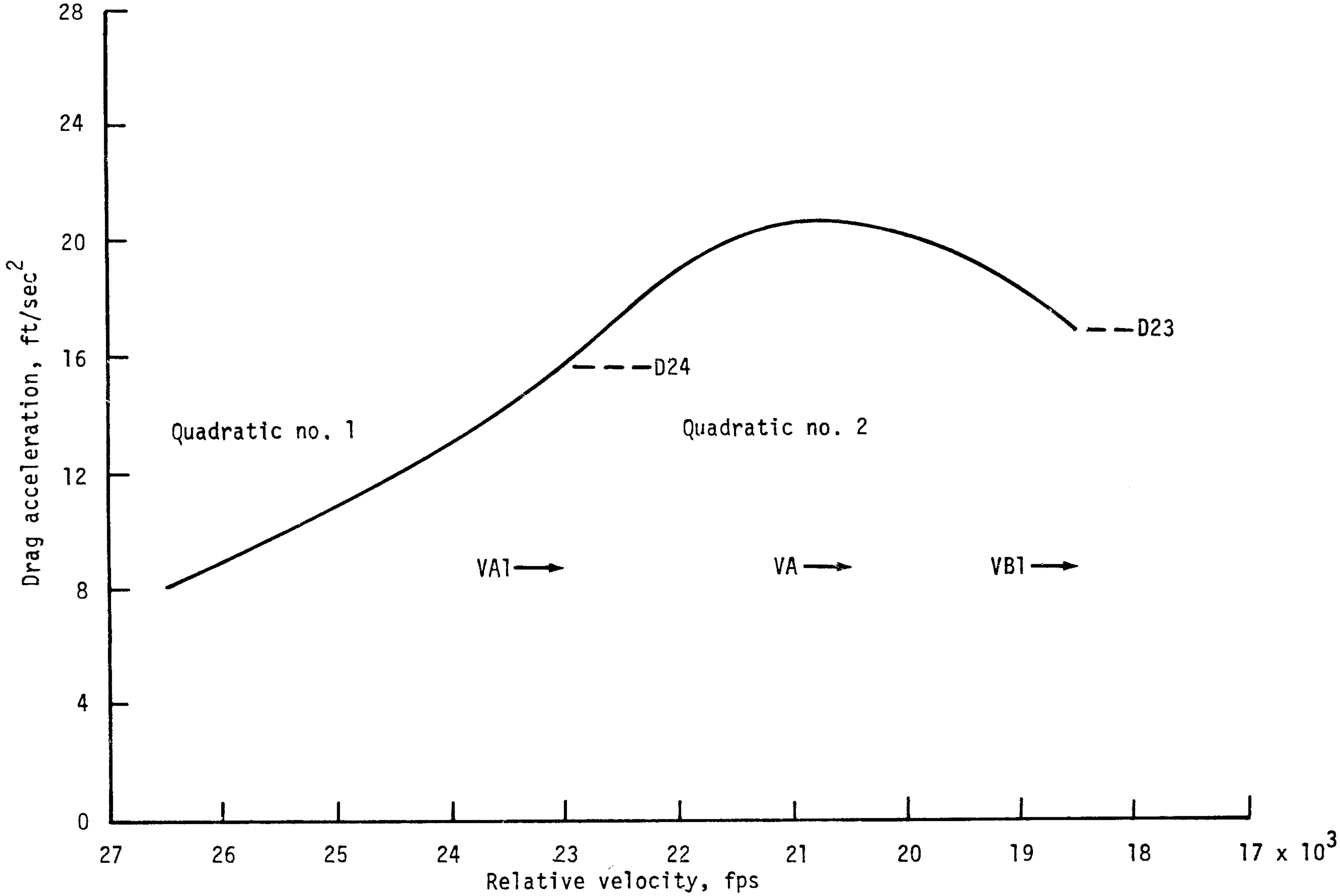


Figure 3.4.2-2.- Temperature control phase quadratic definition.

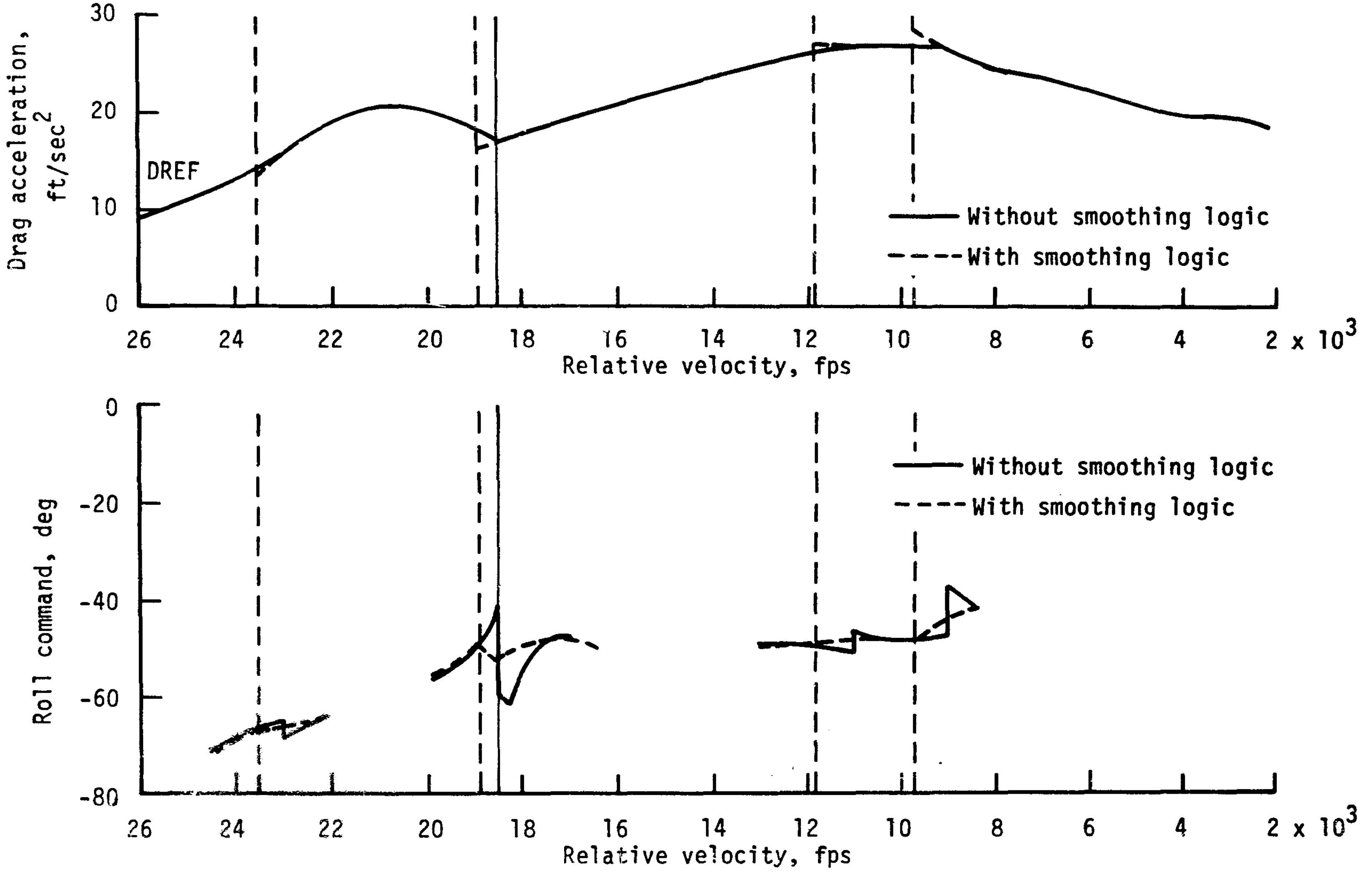


Figure 3.4.2-3.- Bank-angle smoothing logic between guidance phases.

for both phases. This transition occurs before the intersection point of the drag profiles and is accomplished using 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

$$VE < VCG + DELV$$

and

$$DREFP > DREFP4$$

where $DREFP4 = T2 + GS3\,(RDTREF + 2\,HS\,T2/VE)$ 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

$$VE < VTRAN + DELV$$

and

$$VCG < VTRAN$$

and

$$DREFP > DREFP5$$

where $DREFP5 = DF + (EFF - EEF4)\,C1 + GS4\,(RDTREF - RDTRFT)$ 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

DREFP > DREFP5

where DREFP5 = DREFP5 in the equilibrium glide phase and is computed in EGCOMN.

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 EGCOMN function is called.

d. The phase transition logic for the preentry phase (ISLECT = 1) and the first alternate 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 with EGEXEC at any time. The output commands are then computed by calling EGALPCMD (angle-of-attack command) and the sequence EGGNSLCT, EGLODVCMD, and EGROLCMD (bank-angle command). If ISLECT = 1, EGGNSLCT and EGLODVCMD 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

$$\mathrm{RDTRF} = -\mathrm{HS} \quad \frac{2D}{VE} + \frac{\dot{D}}{D} + \frac{\dot{cd}}{cd}$$

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.

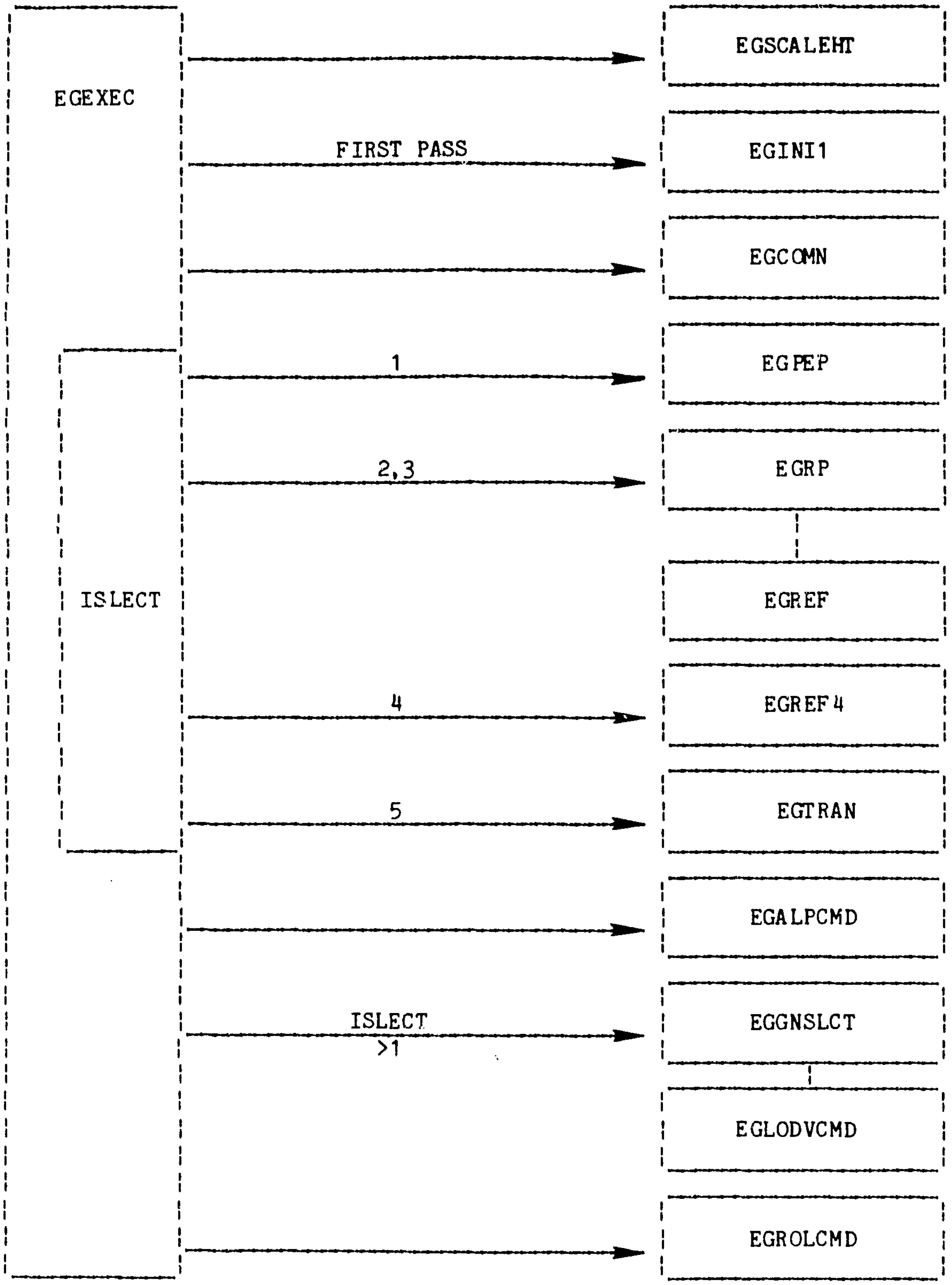


Figure 3.4.2-4.- Entry guidance sequence.

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 ILOAD 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 MM304ϕ by the flight controller. Also, the angle-of-attack command issued in EGALPCMD should be overridden by MM304α. The preentry phase (ISLECT = 1) is terminated by EGEXEC at a sensed total acceleration level equal to ASTART (currently 5.66 ft/sec^2).

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 and 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 VCG, the computed intersection

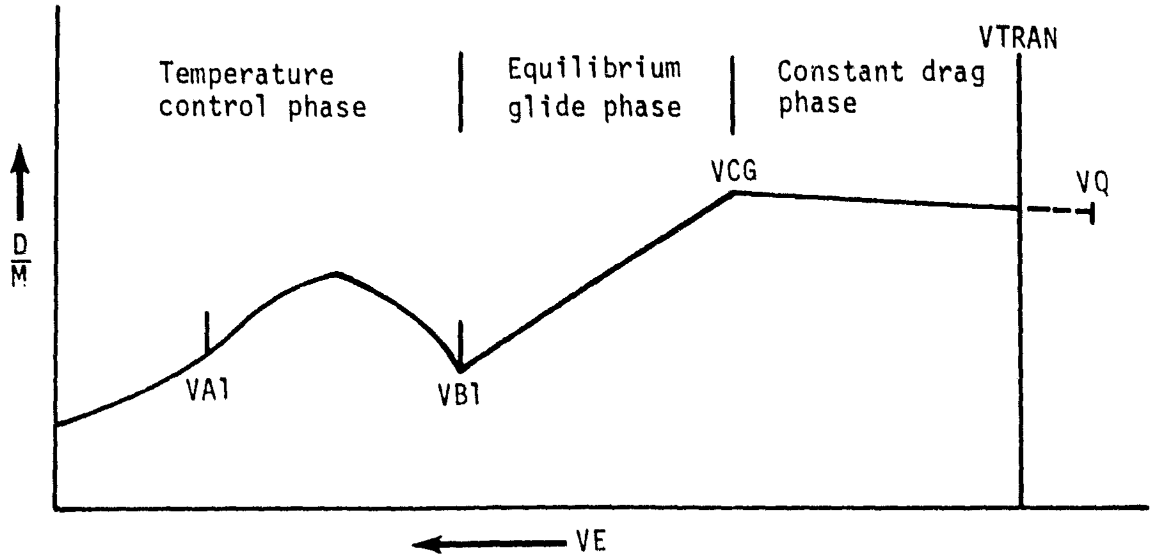


Figure 3.4.7-1.- Drag-velocity segments used in range predictions.

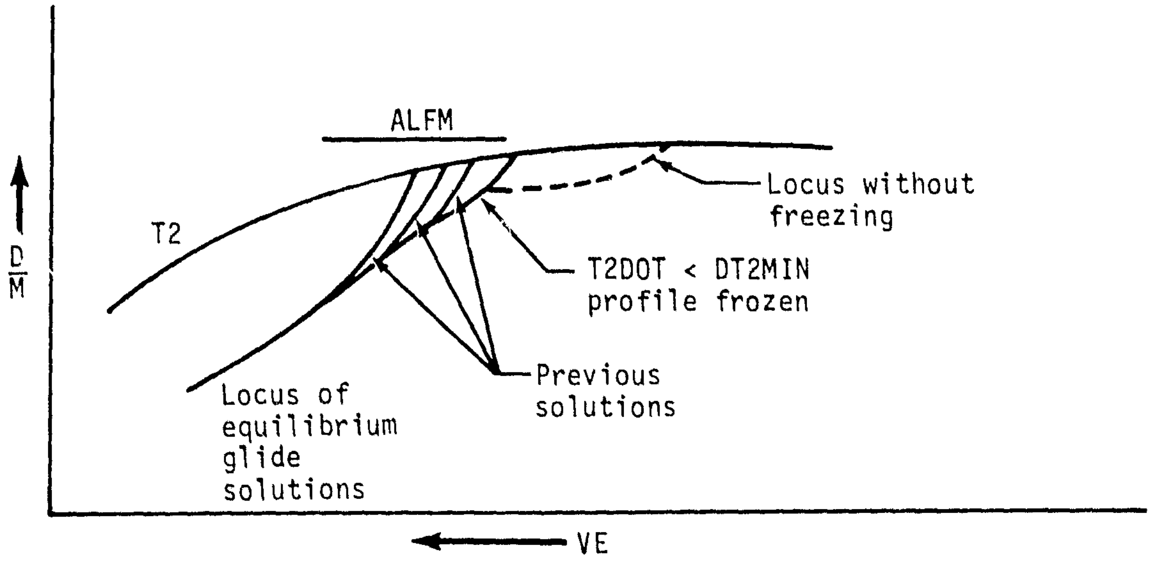


Figure 3.4.7-2.- Freezing of equilibrium glide profile.

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 $VE > VB1 \quad VB = VB1$

If $VE \leq VB1 \quad VB = VE$

In the equilibrium glide phase, as the drag profile approaches the desired constant drag level, the focus 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 junction 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, as 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 (EGGNSLCT)

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

a. Compute the L/D reference parameter (ALDREF).

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

c. Compute the vertical L/D command from the controller equation

$$\mathrm{LODX} = \mathrm{ALDREF} + \mathrm{C16}\ (\mathrm{DRAG} - \mathrm{DREFP}) + \mathrm{C17}\ (\mathrm{RDTRF} + \mathrm{DLRDOT} - \mathrm{RDOT})$$

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

e. 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

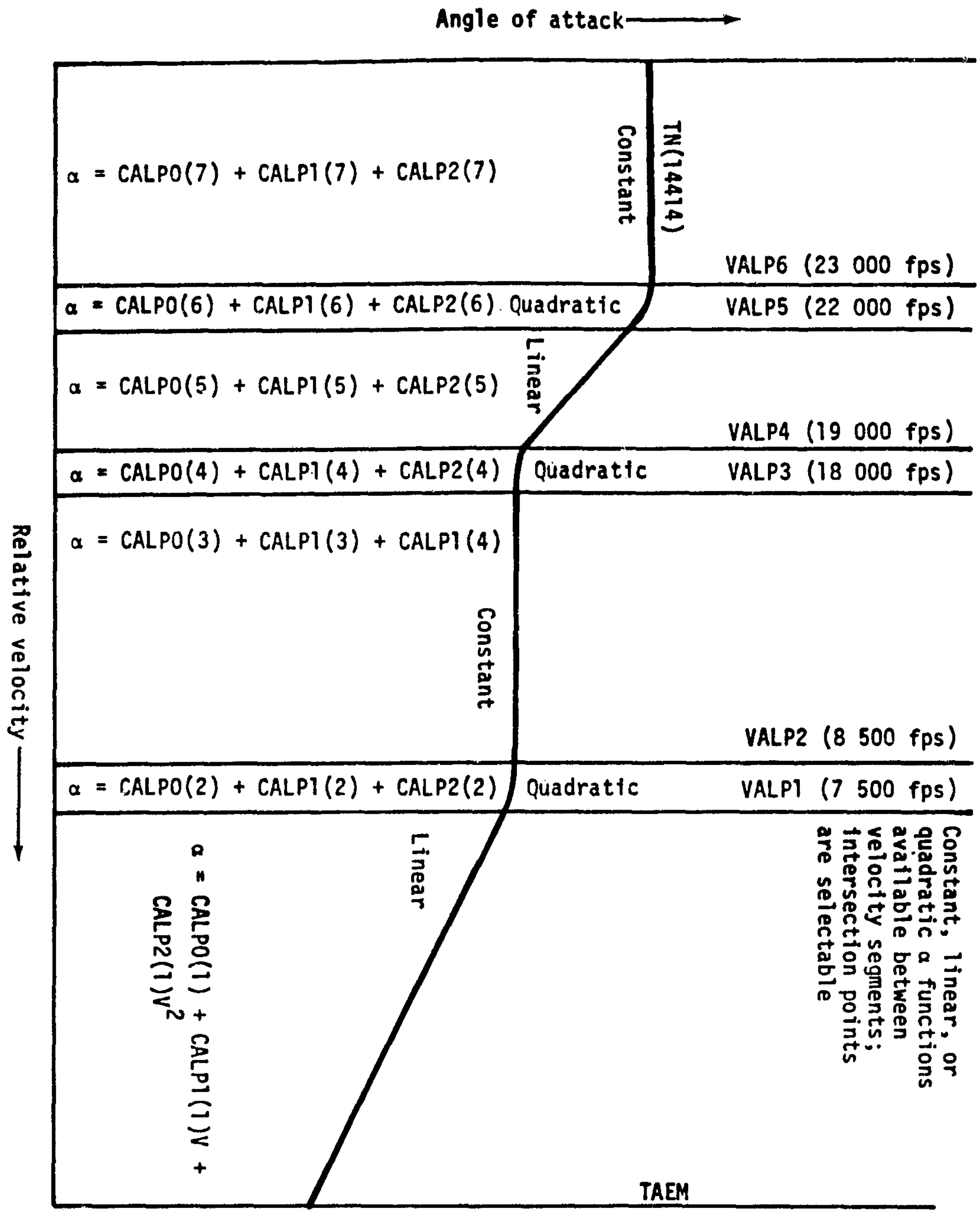


Figure 3.4.11-1.- Angle-of-attack selection capability.

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 three-degree-of-freedom autopilot is required to execute the bank-angle 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 (β) is always assumed to be zero.

The entry guidance generates a bank-angle 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 sec), 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 four-pass Runge-Kutta integrator, PHSPLN is called on the first and third pass by means of the pass counter (ICTTRN). 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.

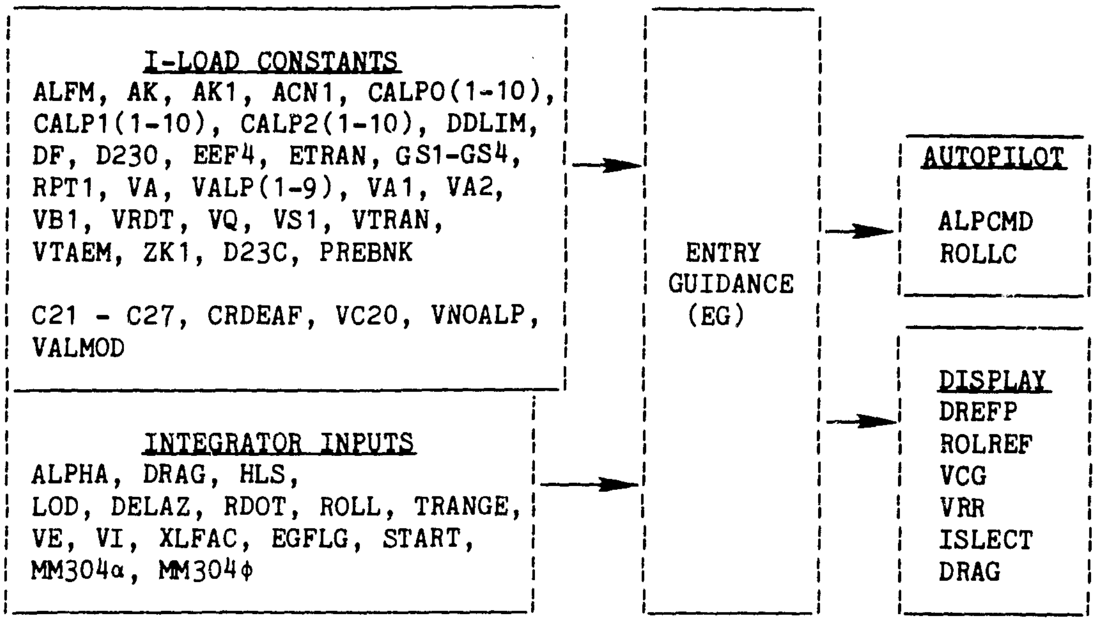


Figure 3.4.15-1.- Entry guidance external data flow summary.

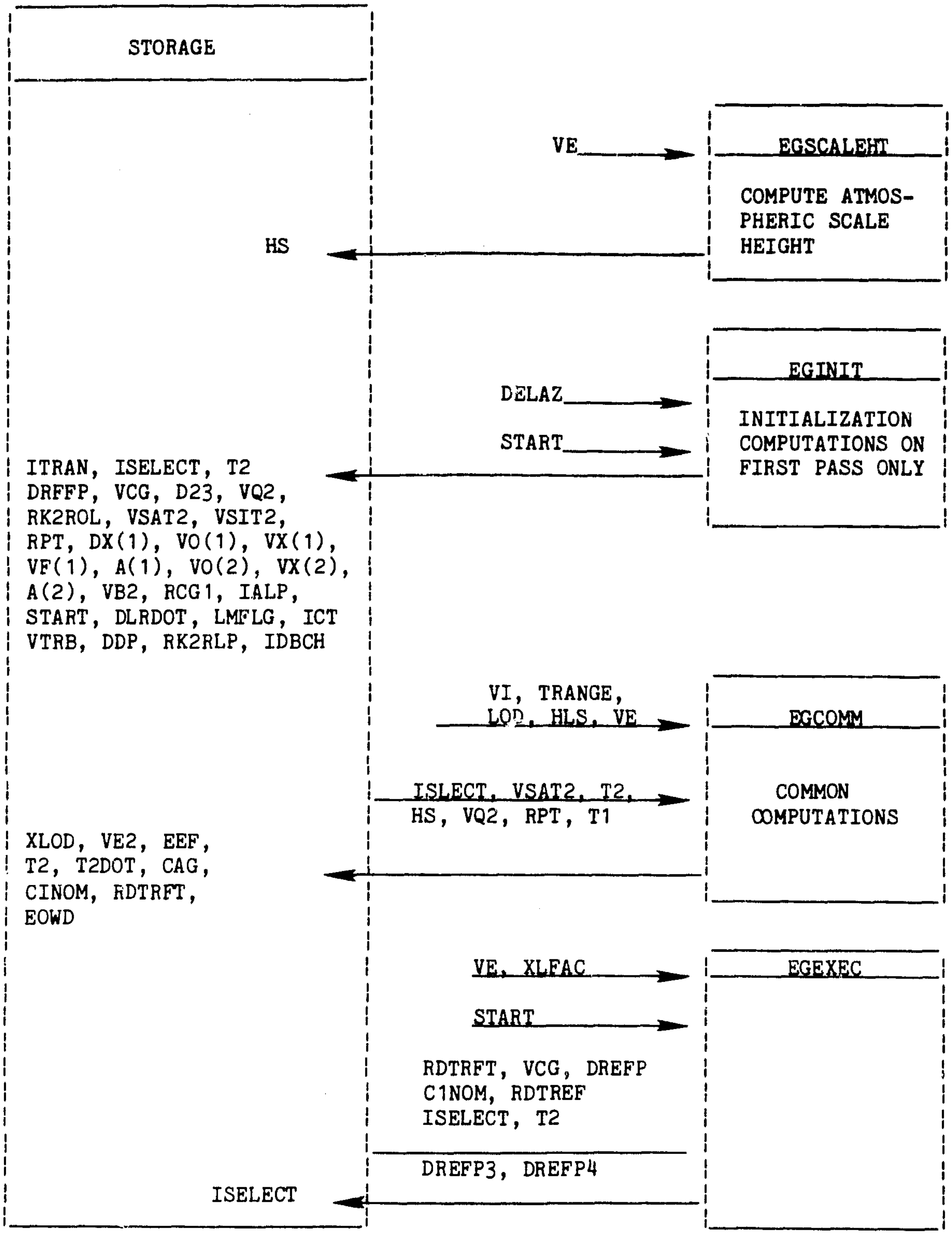


Figure 3.4.15-2.- Entry guidance internal data flow.

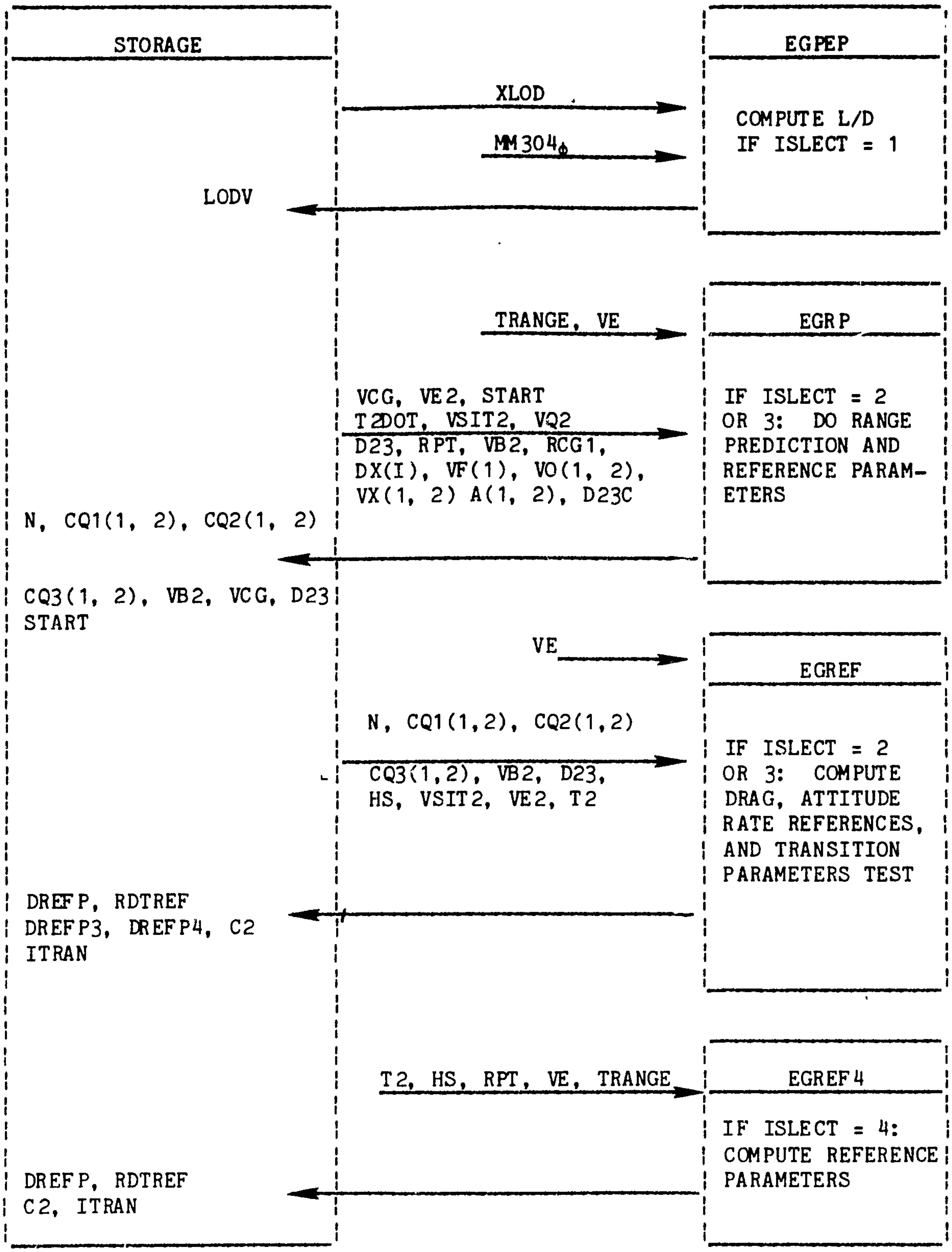


Figure 3.4.15-2.- Continued.

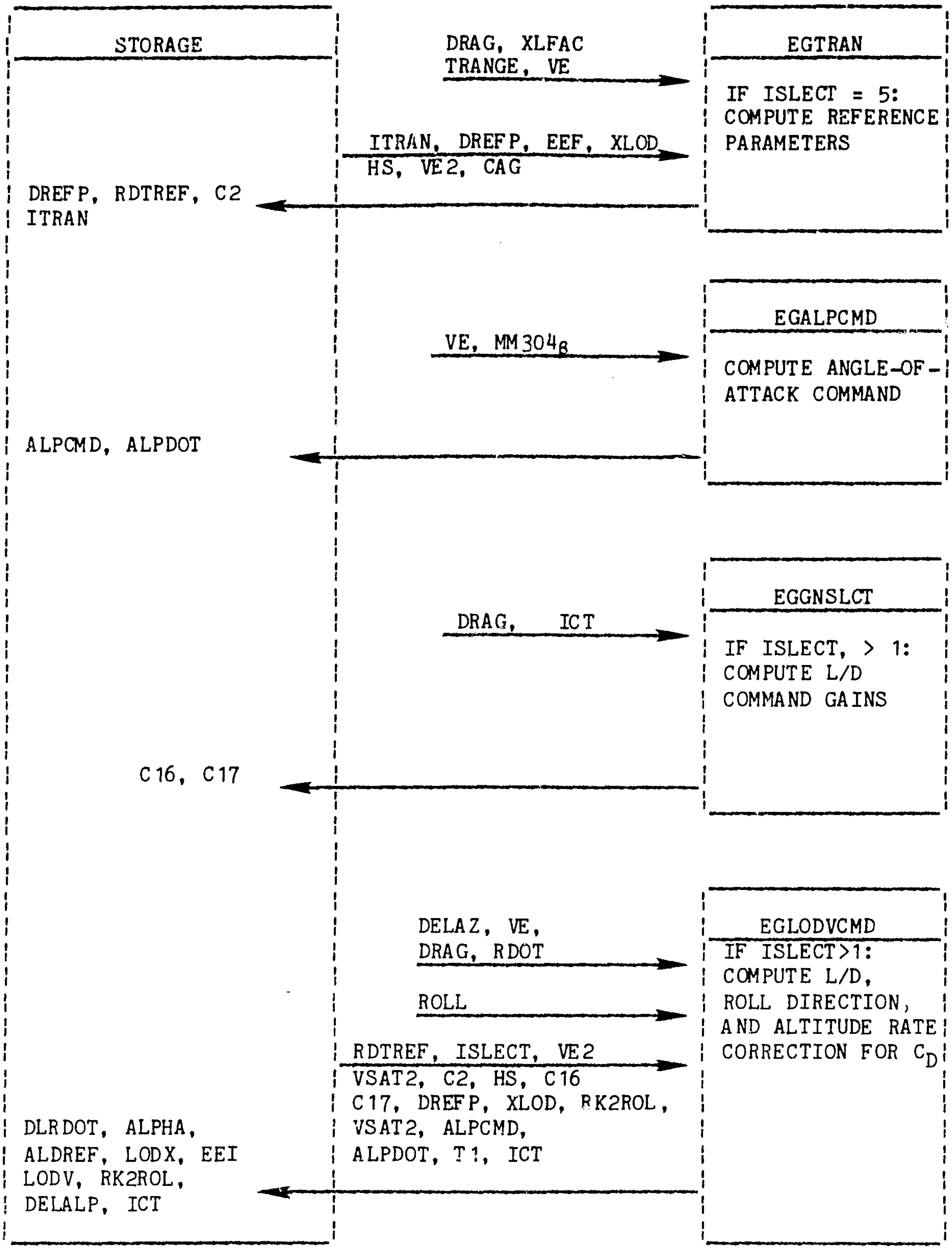


Figure 3.4.15-2.- Continued.

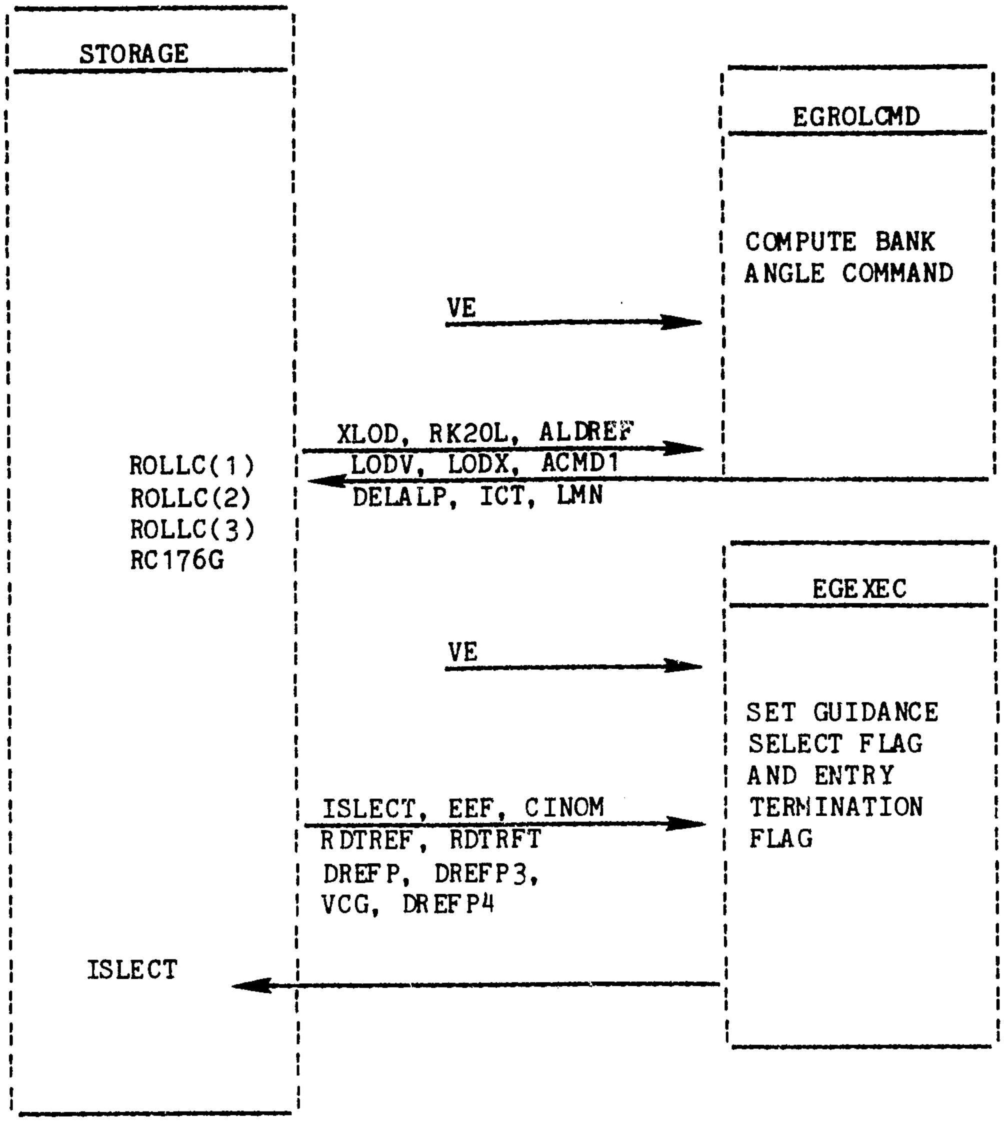


Figure 3.4.15-2.- Concluded.

3.5.3 Autopilot Phase Plane (PHSPLN)

The PHSPLN routine is a simplified phase plane that is used to generate the Orbiter bank-angle and angle-of-attack attitude. The routine PHSPLN has two entry points (ROLPLN and PCHPLN), which update the bank-angle and angle-of-attack attitudes, respectively. The phase plane logic uses an acceleration level (RA or PA), a maximum rate (RRM or PRM), an attitude deadband (RADB or PADB), and a bank-angle 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 Δt, 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 alinement circle. This is accomplished by determining the tangent point on the heading alinement circle of a vector from the vehicle to the alinement circle. 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 alinement circle 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 alinement circle, 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 alinement tangent point. The targeting will nominally select the nearest heading alinement circle on the same side of the runway centerline as the Shuttle position. The option to force the selection of the left-hand heading alinement circle independent of Shuttle position is exercised by setting the HAC select flag (MEP=1) by MED input. 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:

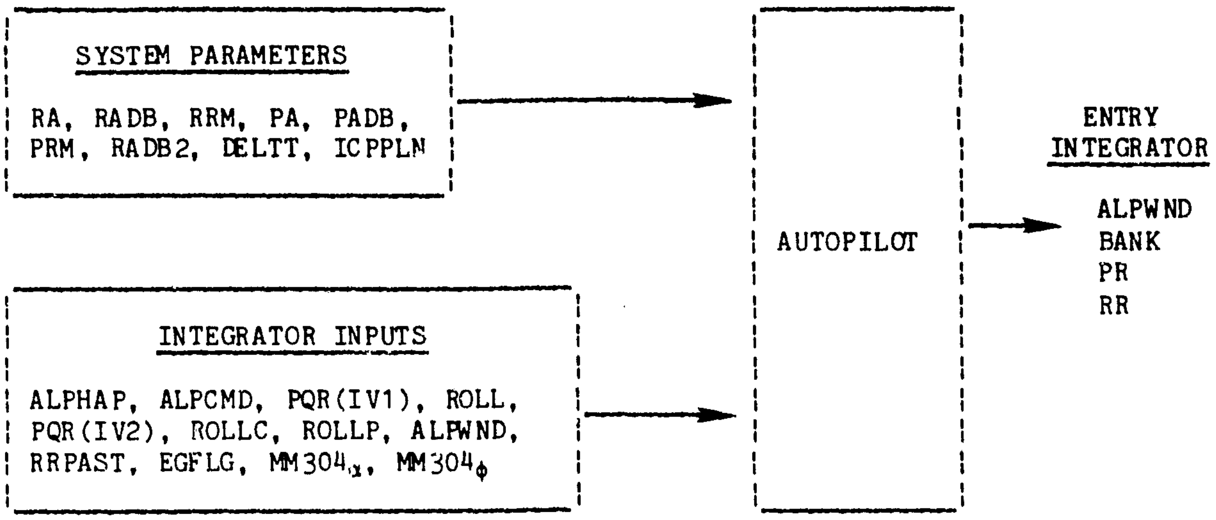


Figure 3.5.4-1.- Autopilot external data flow.

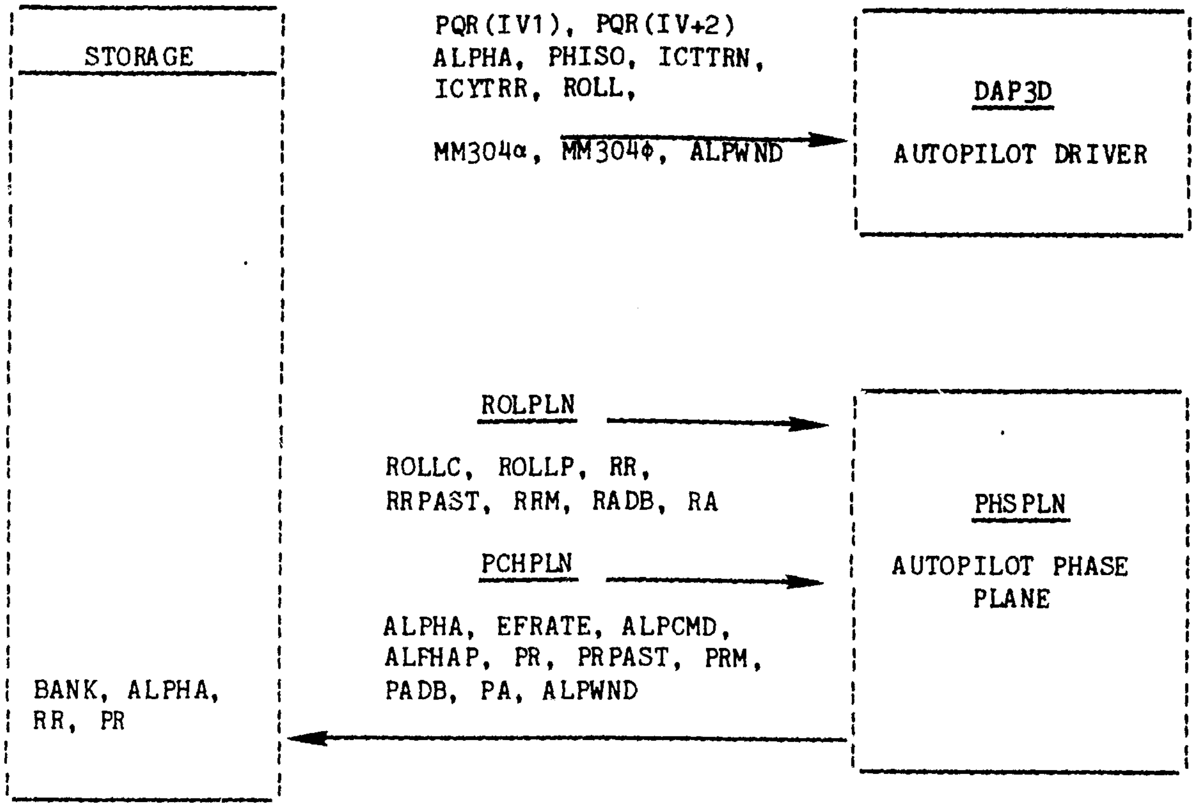


Figure 3.5.4-2.- Autopilot internal data flow.

3.6.1 EGRT-EXEC, Targeting Executive Logic

This routine calculates the Earth-fixed to runway transformation matrix for the primary and secondary runway (if performing midpoint targeting), sets the entry guidance redesignation and midpoint targeting flags, averages range and azimuth error for midpoint targeting, and calls the following subfunctions:

3.6.2 EGRT-CHACRC, Center of Heading, Alinement Circle - Runway Coordinates

This routine computes the position of the center of the heading alinement circle in runway coordinates.

3.6.3 EGRT-CHACRC, Center of Heading, Alinement Circle in Earth-fixed Coordinates

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

3.6.4 EGRT-BV, Bearing of the Vehicle

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

3.6.5 EGRT-BVCHAC, Bearing to Center of the Alinement Circle

This function computes the heading of the vehicle to the center of the heading alinement circle.

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 circle.

3.6.7 EGRT-DWP1, Distance to WPI

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

3.6.8 EGRT-DVNEP, Range-to-Threshold Point

This function computes the heading to the tangency point on the heading alinement circle, the distance around the alinement circle, and the final range to runway threshold point. This function also saves the range to the primary runway in the case of midpoint targeting.

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 circle. It also saves the azimuth error to the primary runway in the case of midpoint targeting.

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, Revision 1. JSC IN 74-FM-25, 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.

APPENDIX A

ENTRY GUIDANCE FLOW CHARTS

APPENDIX A

ENTRY GUIDANCE FLOW CHARTS

The following flow charts define the entry guidance formulations.

Function	Figure	Number of Flow Charts
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
EGREF4	A-8	1
EGTRAN	A-9	2
EGALPCMD	A-10	1
EGGNSLCT	A-11	1
EGLODVCMD	A-12	2
EGROLCMD	A-13	1

PAGE A-2 INTENTIONALLY BLANK

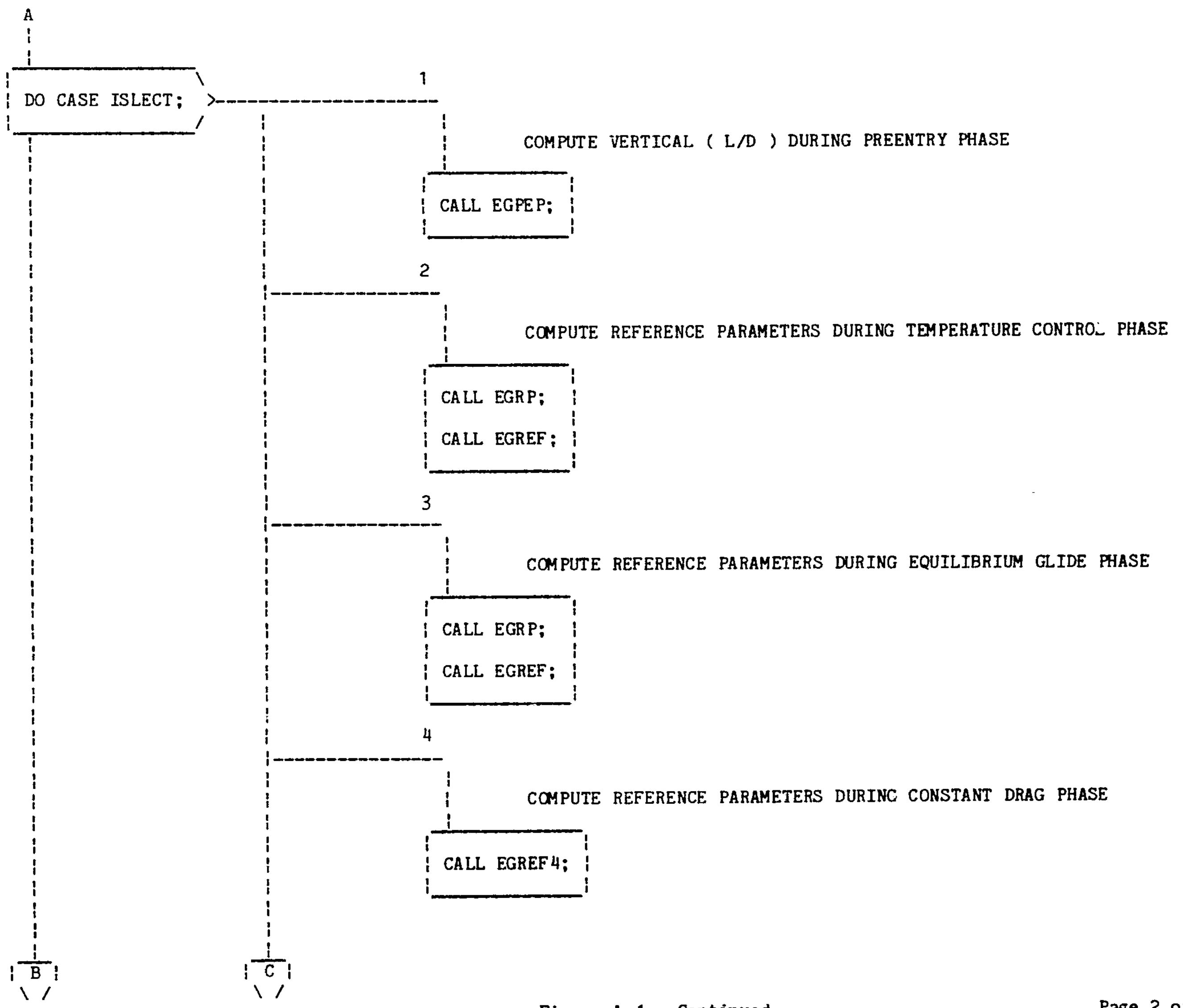


Figure A-1.- Continued.

Page 2 of 4

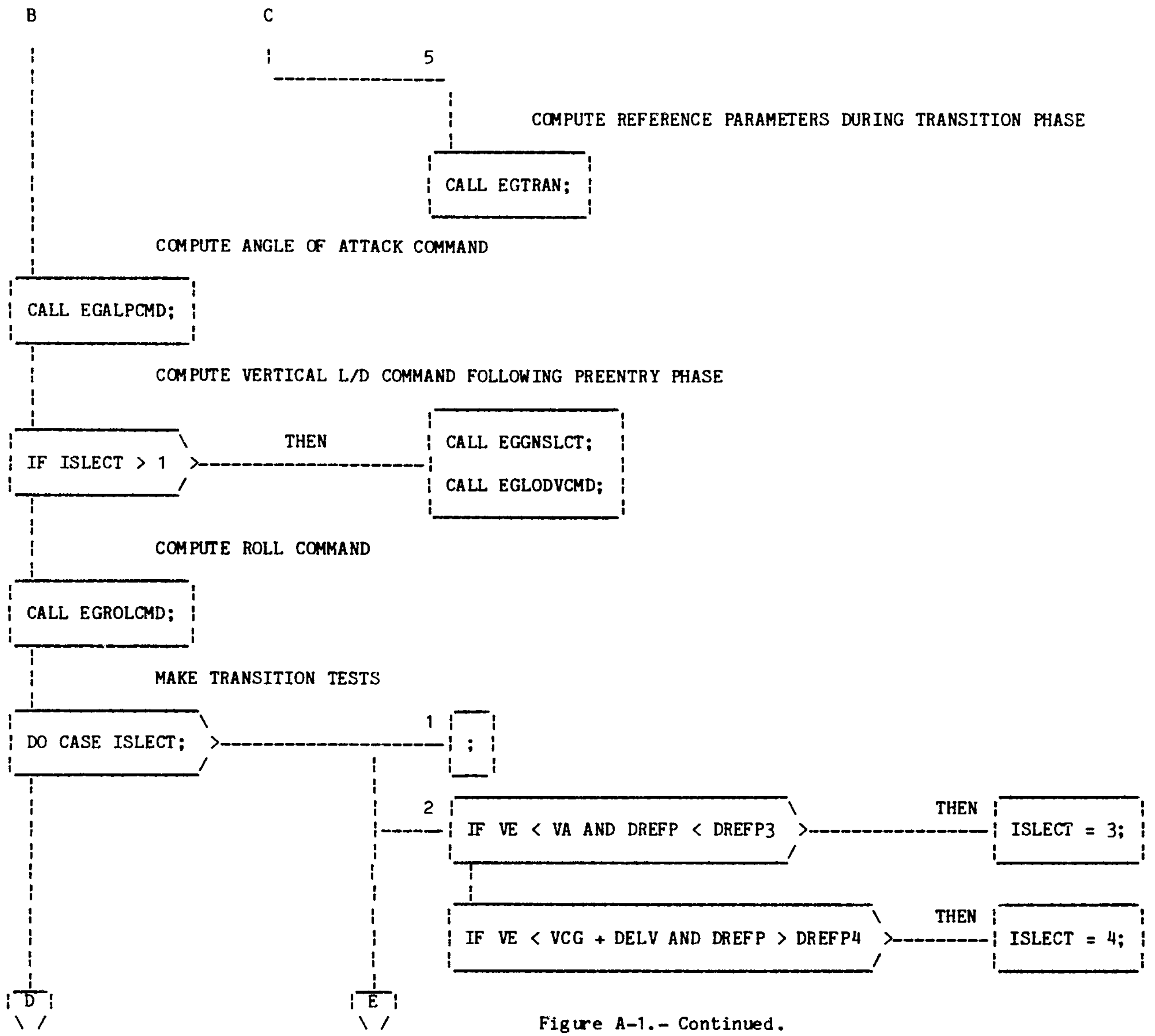
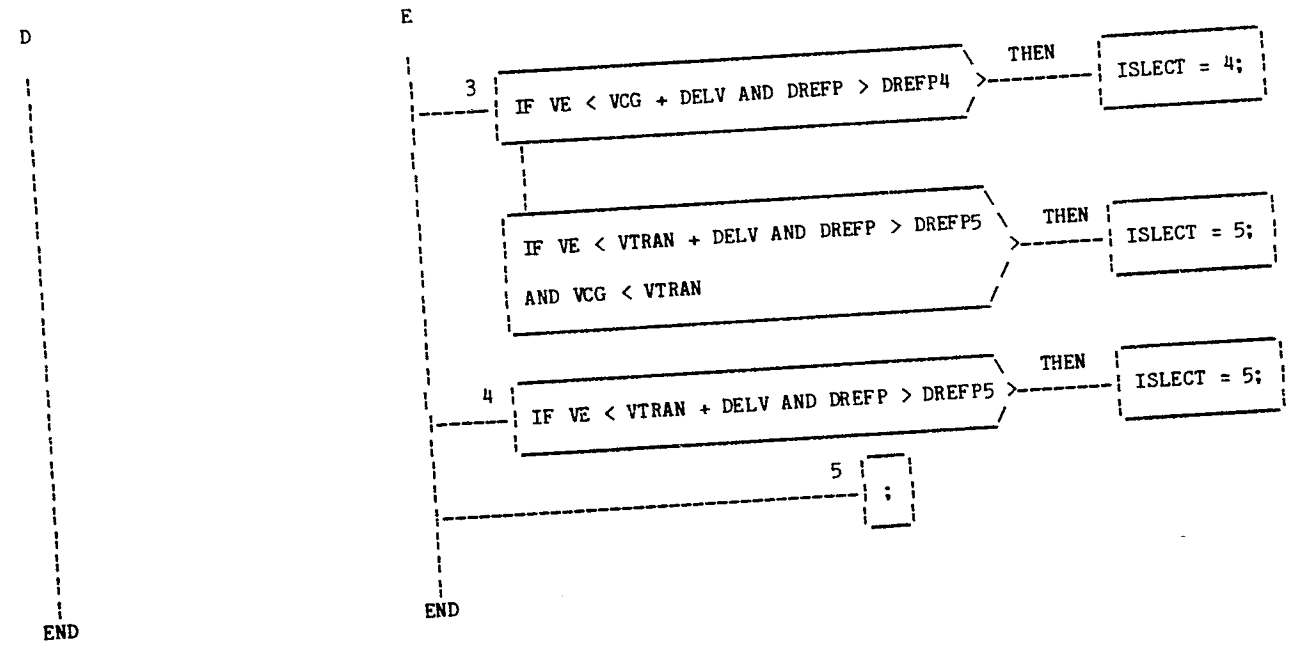


Figure A-1.- Continued.



Page 4 of 4

Figure A-1.- Concluded.

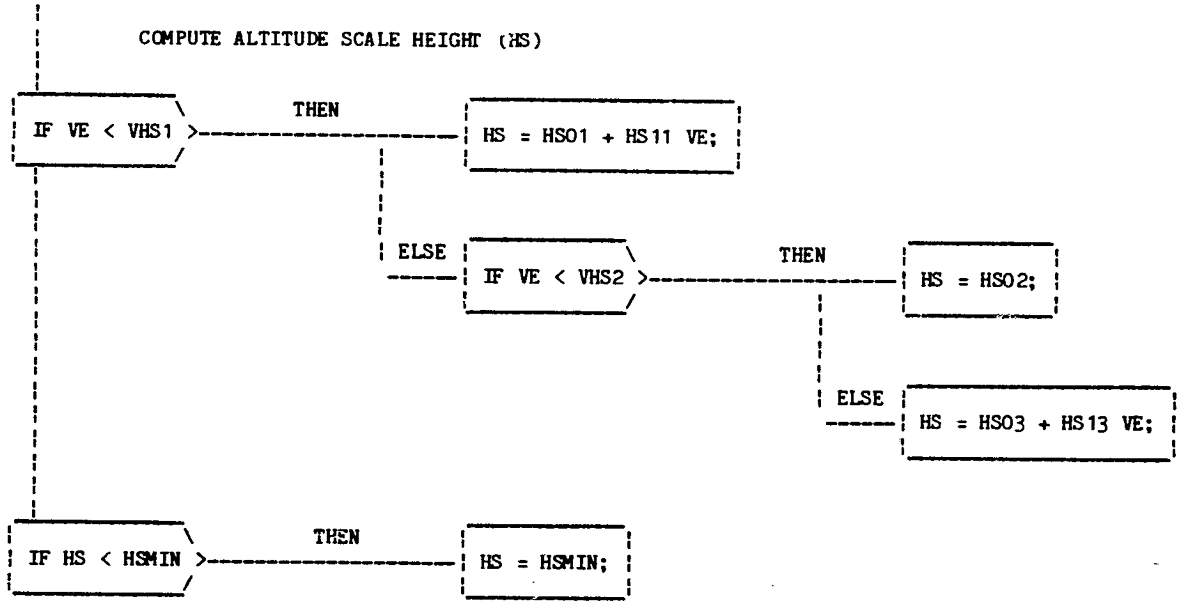


Figure A-2.- EGSCALHT, scale height.

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);

DLRDOT = 0.;

LMFLG = 0;

VTRB = 60000.;

DDP = 0.;

RK2RLP = RK2ROL;
```

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;

DX1 = 1.;
```

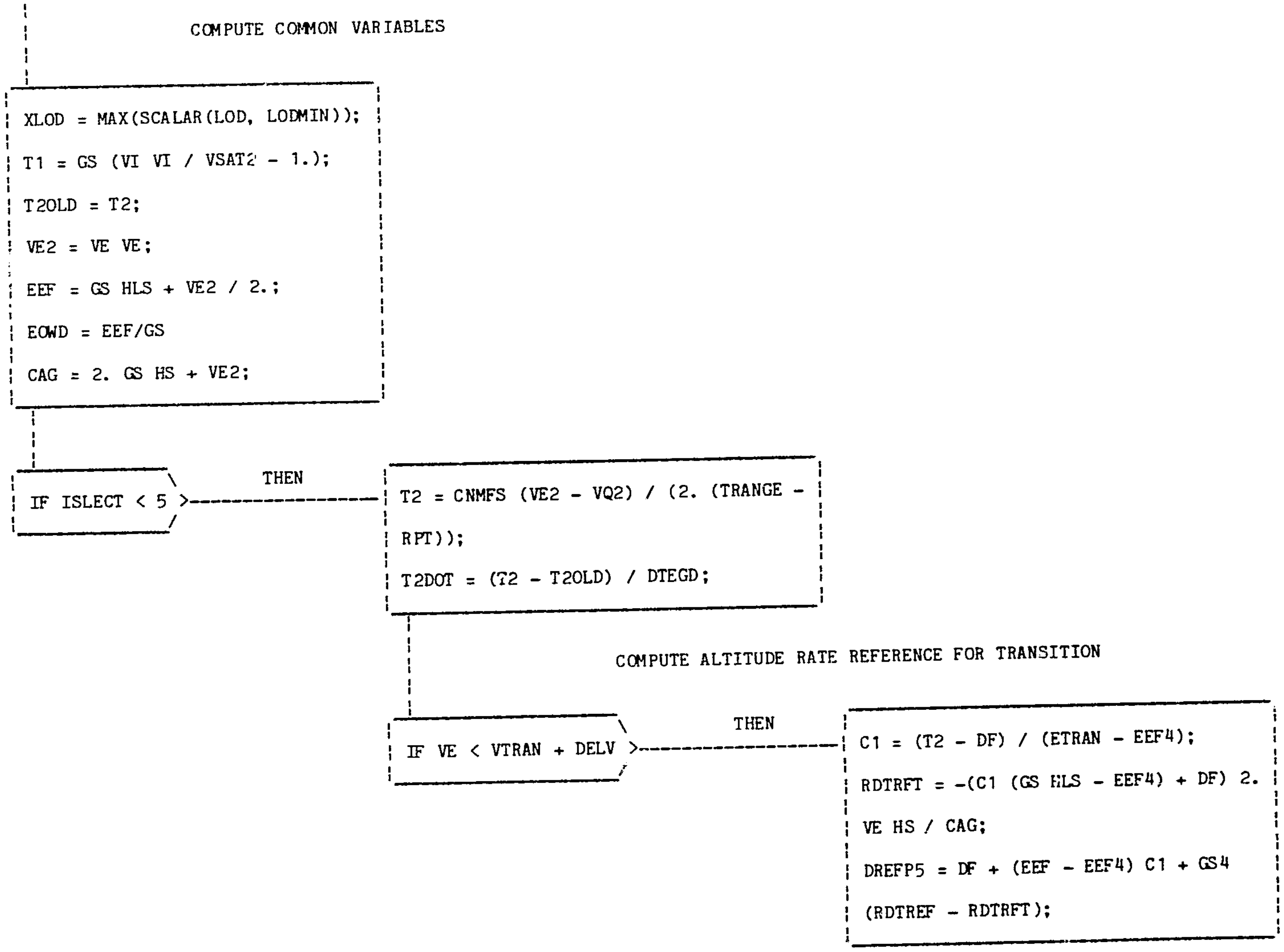
A

Figure A-3.- EGINIT, initialization.

Page 1 of 2

```
A

$VO_1$ = VB1;
$VX_1$ = VA;
$VF_1$ = VA1;
$A_1$ = AK;
$VO_2$ = VA1;
$VX_2$ = VA2;
$A_2$ = AK1;
$VB_2$ = VB1 VB1;

        COMPUTE COMPONENT OF CONSTANT DRAG PHASE RANGE, PCG

RCG1 = CNMFS (VSIT2 - VQ2) / (2. ALFM);

IALP = NALP;
START = 1;
```

Figure A-3.- Concluded. Page 2 of 2



```
COMPUTE COMMON VARIABLES
XLOD = MAX(SCALAR(LOD, LODMIN));
T1 = GS (VI VI / VSAT2 - 1.);
T2OLD = T2;
VE2 = VE VE;
EEF = GS HLS + VE2 / 2.;
EOWD = EEF/GS
CAG = 2. GS HS + VE2;
IF ISLECT < 5
    THEN
        T2 = CNMFS (VE2 - VQ2) / (2. (TRANGE -
        RPT));
        T2DOT = (T2 - T2OLD) / DTEGD;
        COMPUTE ALTITUDE RATE REFERENCE FOR TRANSITION
        IF VE < VTRAN + DELV
            THEN
                C1 = (T2 - DF) / (ETRAN - EEF4);
                RDTRFT = -(C1 (GS HLS - EEF4) + DF) 2.
                VE HS / CAG;
                DREFP5 = DF + (EEF - EEF4) C1 + GS4
                (RDTREF - RDTRFT);
```

Figure A-4.- EGCOMN, common.

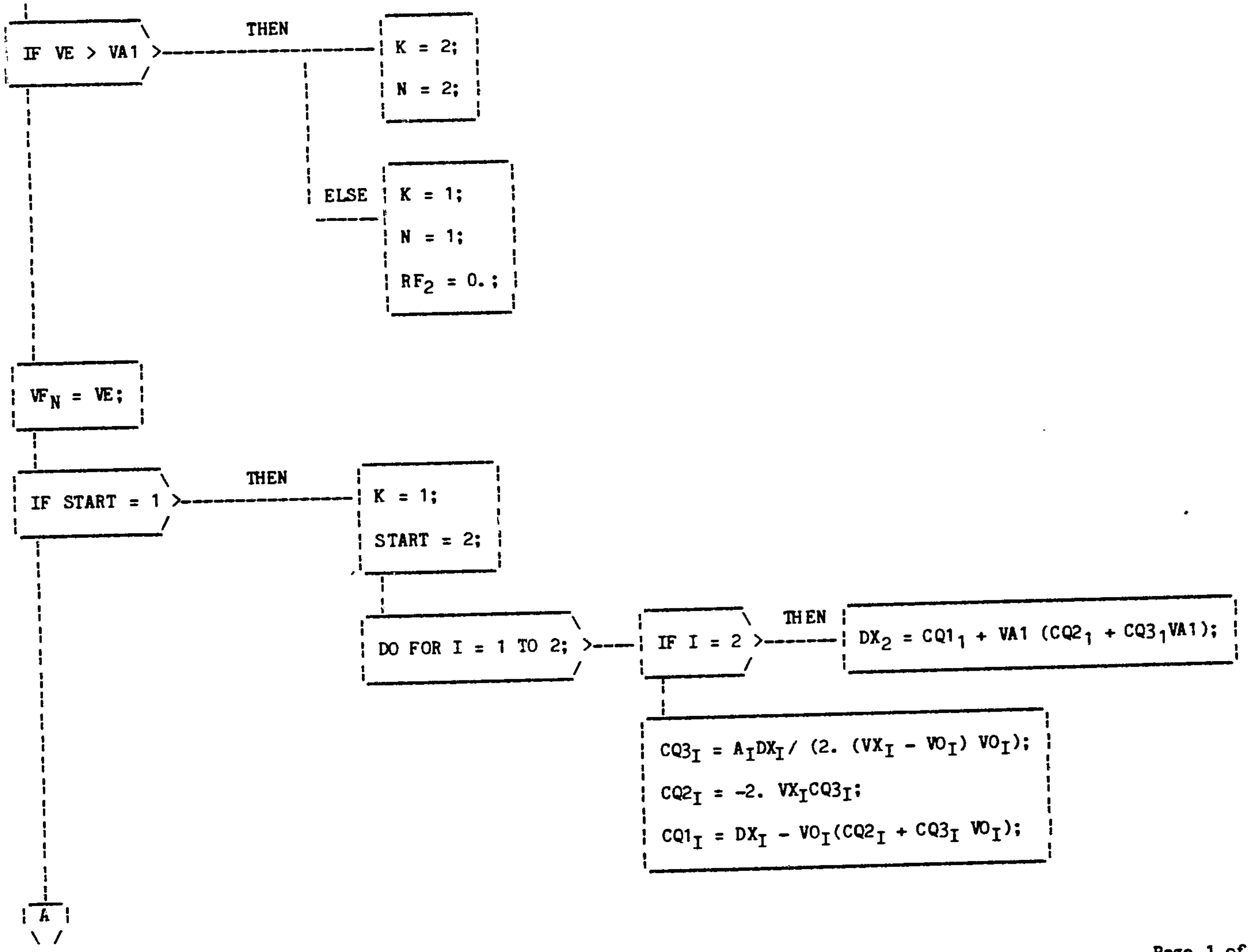
Page 1 of 1

COMPUTE VERTICAL L/D DURING PREENTRY PHASE

```
LODX  XLOD COS (MM3040 / 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 > VA1
    THEN
        K = 2;
        N = 2;
    ELSE
        K = 1;
        N = 1;
        $RF_2$ = 0.;
$VF_N$ = VE;
IF START = 1
    THEN
        K = 1;
        START = 2;
        DO FOR I = 1 TO 2;
            IF I = 2
                THEN
                    $DX_2 = CQ1_1 + VA1 (CQ2_1 + CQ3_1 VA1)$;
            $CQ3_I = A_I DX_I / (2. (VX_I - VO_I) VO_I)$;
            $CQ2_I = -2. VX_I CQ3_I$;
            $CQ1_I = DX_I - VO_I (CQ2_I + CQ3_I VO_I)$;
A
```

Figure A-6.- EGRP, range prediction.

Page 1 of 4

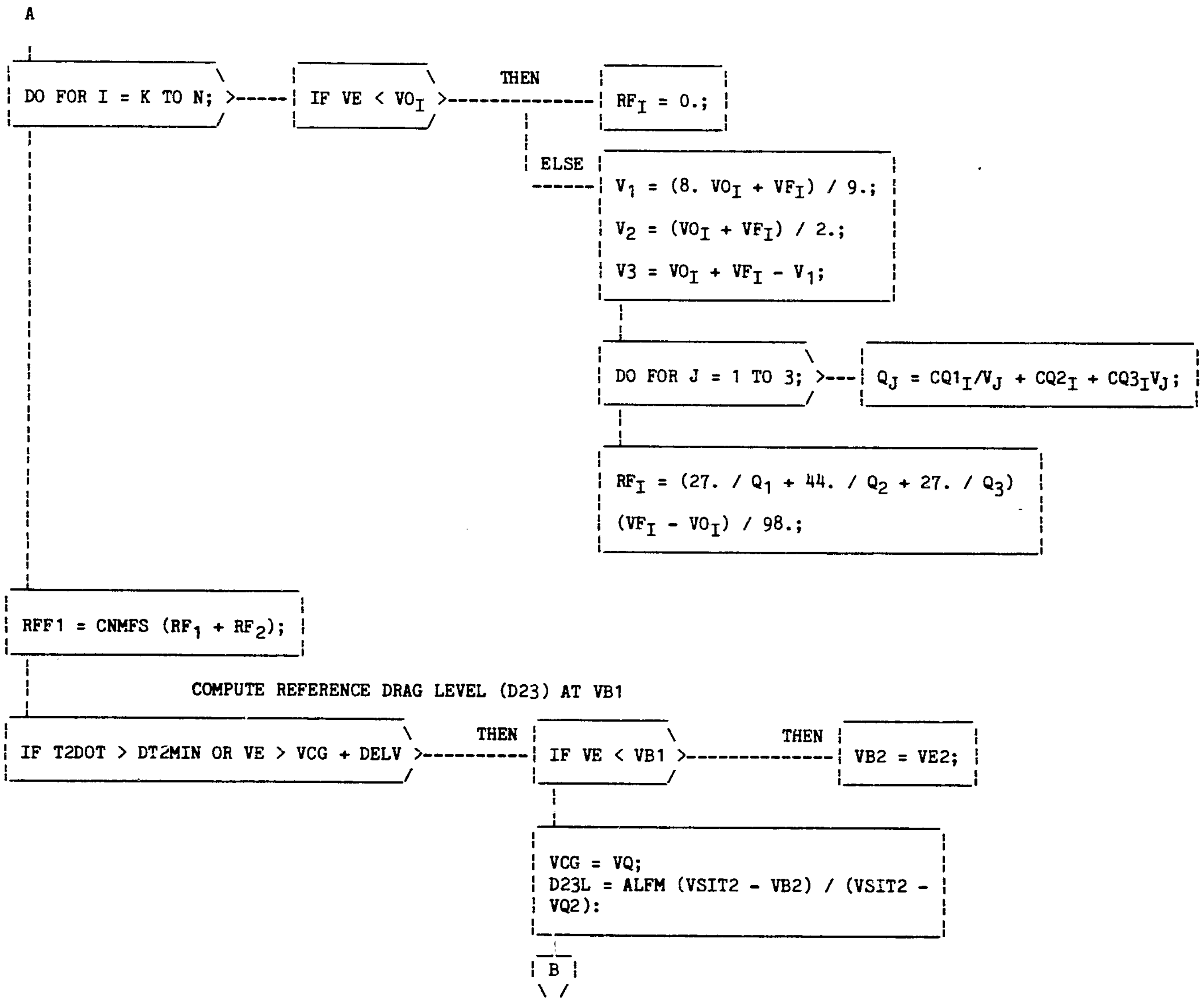
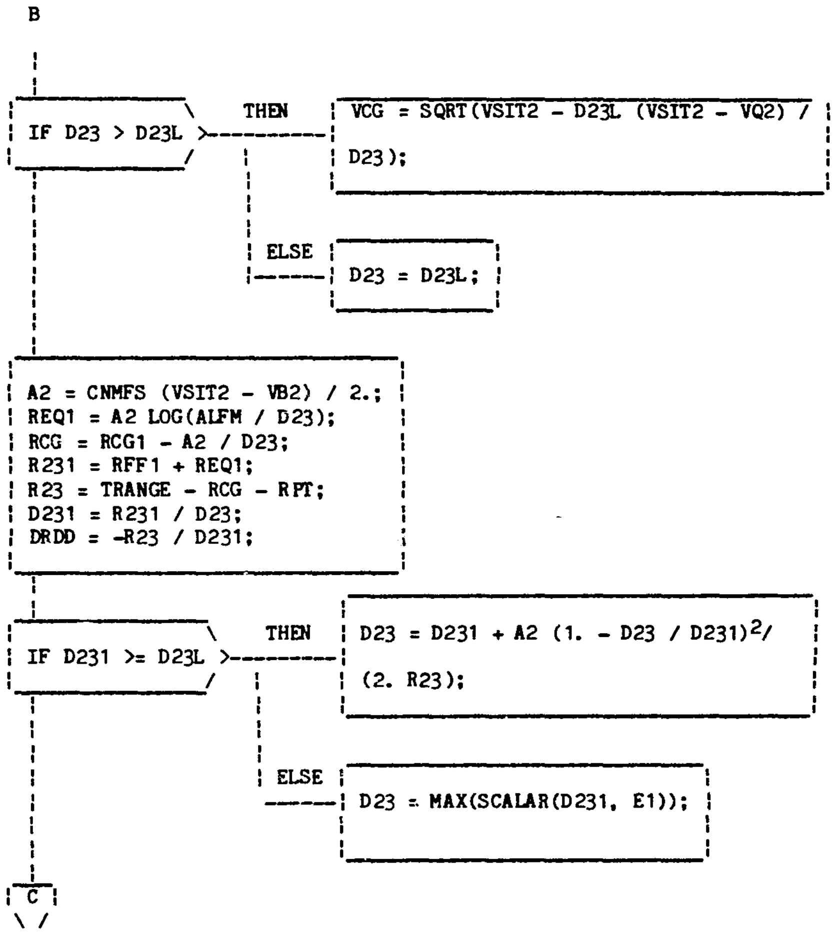


Figure A-6.- Continued.

80FM23



```
B

IF D23 > D23L
    THEN  VCG = SQRT(VSIT2 - D23L (VSIT2 - VQ2) /
          D23);
    ELSE  D23 = D23L;

A2 = CNMFS (VSIT2 - VB2) / 2.;
REQ1 = A2 LOG(ALFM / D23);
RCG = RCG1 - A2 / D23;
R231 = RFF1 + REQ1;
R23 = TRANGE - RCG - RPT;
D231 = R231 / D23;
DRDD = -R23 / D231;

IF D231 >= D23L
    THEN  D23 = D231 + A2 (1. - D23 / D231)²/
          (2. R23);
    ELSE  D23 = MAX(SCALAR(D231, E1));

C
```

Figure A-6.- Continued.

Page 3 of 4

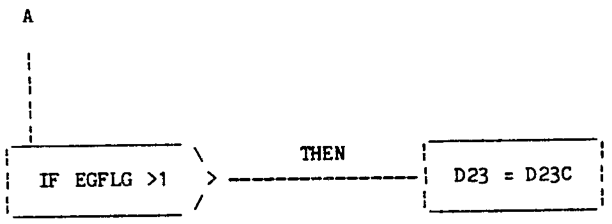


Figure A-6.- Concluded.

Page 4 of 4

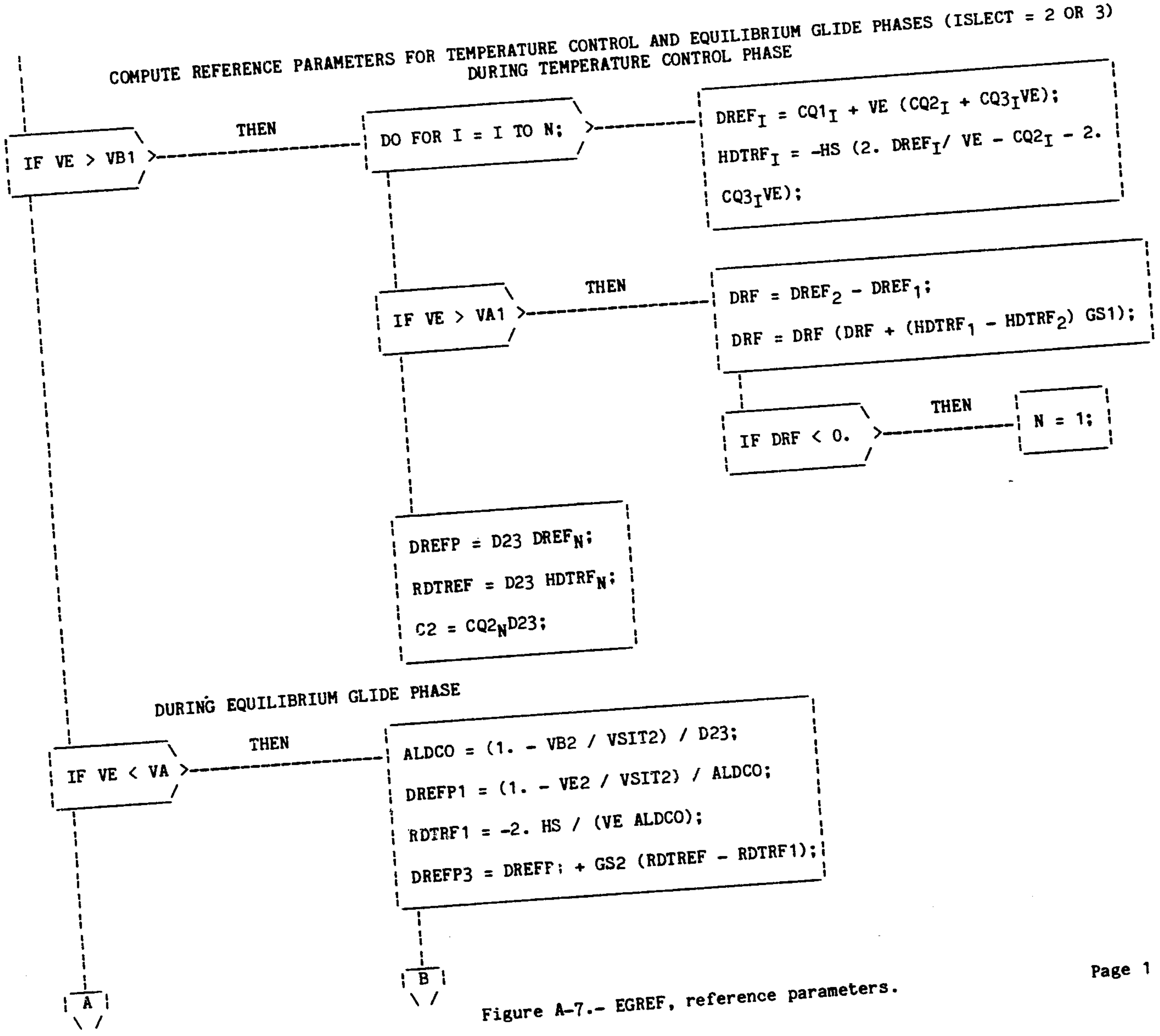
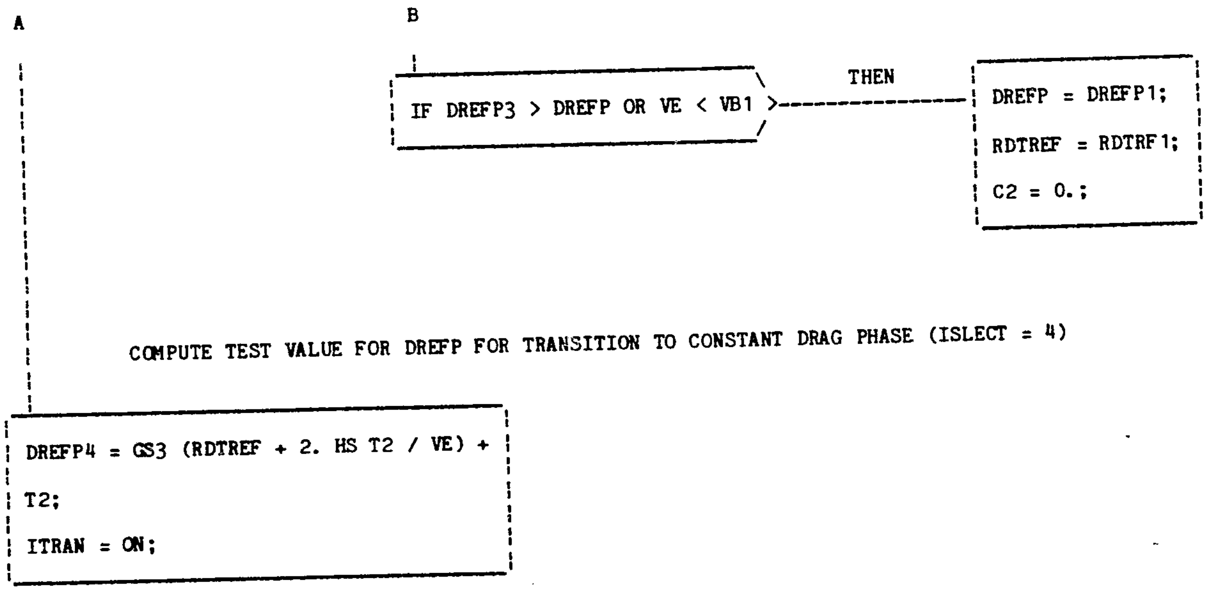


Figure A-7.- EGREF, reference parameters.

Page 1 of 2



```
IF DREFP3 > DREFP OR VE < VB1 > THEN
    DREFP = DREFP1;
    RDTREF = RDTRF1;
    C2 = 0.;

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

DREFP4 = GS3 (RDTREF + 2. HS T2 / VE) +
T2;
ITRAN = ON;
```

Figure A-7.- Concluded.

Page 2 of 2

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.- EGREF4, constant drag phase.

```
  |
  |      COMPUTE REFERENCE PARAMETERS DURING TRANSITION PHASE
  |
 _______________________            __________________
|                       \    THEN  | DREFP = ALFM;    |
| IF ITRAN = OFF         >---------|                  |
|                       /          | ITRAN = ON;      |
|_______________________/          |__________________|
  |
  |
  |
 ___________________________
|                           |
| DREFPT = DREFP - DF;      |
|___________________________|
  |
  |
 _____________________________           ________________________________
|                             \   THEN  |                                |
| IF ABS(DREFPT) < E1          >--------| DREFP = DF + E1 SIGN(DREFPT);  |
|                             /         |________________________________|
|_____________________________/
  |
  |
 ___________________________            _______________
|                           \   THEN   |               |
| IF DREFP < E1              >---------| 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 |
 \ /
```

Figure A-9.- EGTRAN, transition phase. Page 1 of 2

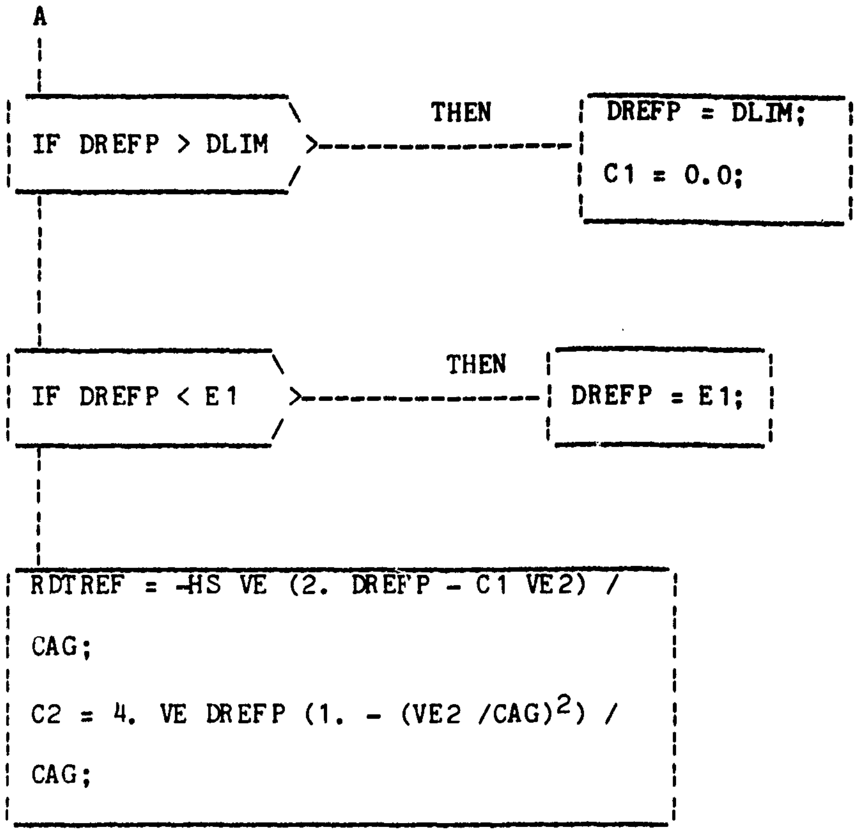


Figure A-9.- Concluded.

Page 2 of 2

COMPUTE ANGLE OF ATTACK COMMAND

```
DO WHILE VE < $VALP_{IALP}$ AND IALP > 0;
    IALP = IALP - 1;
J = IALP + 1;
ALPCMD = $CALPO_J + VE (CALP1_J + CALP2_J VE)$;
IF ISLECT = 1
    THEN
        ALPCMD = MM 304α
ALPDOT = (ALPCMD - ACMD1)/DTEGD
ACMD1 = ALPCMD
```

Figure A-10.- EGALPCMD, angle-of-attack command. Page 1 of 1

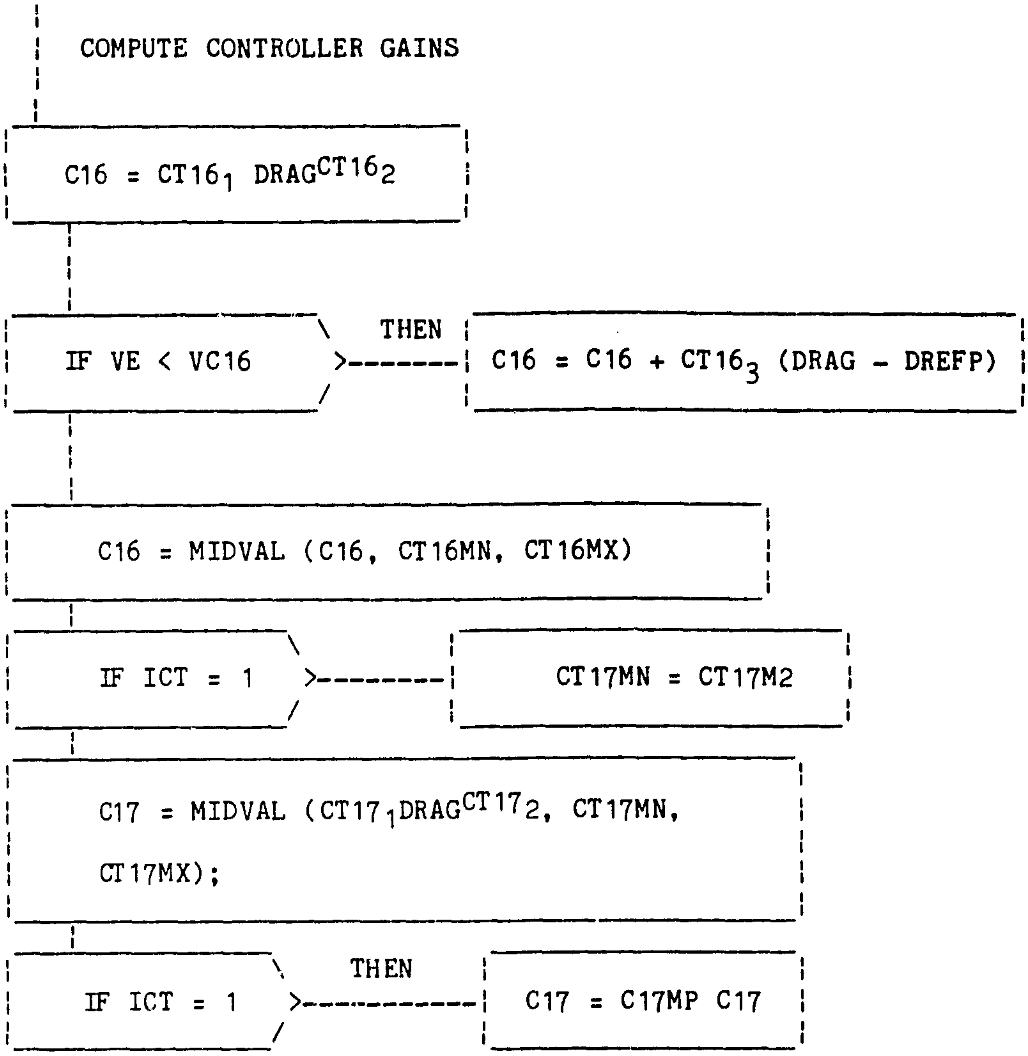
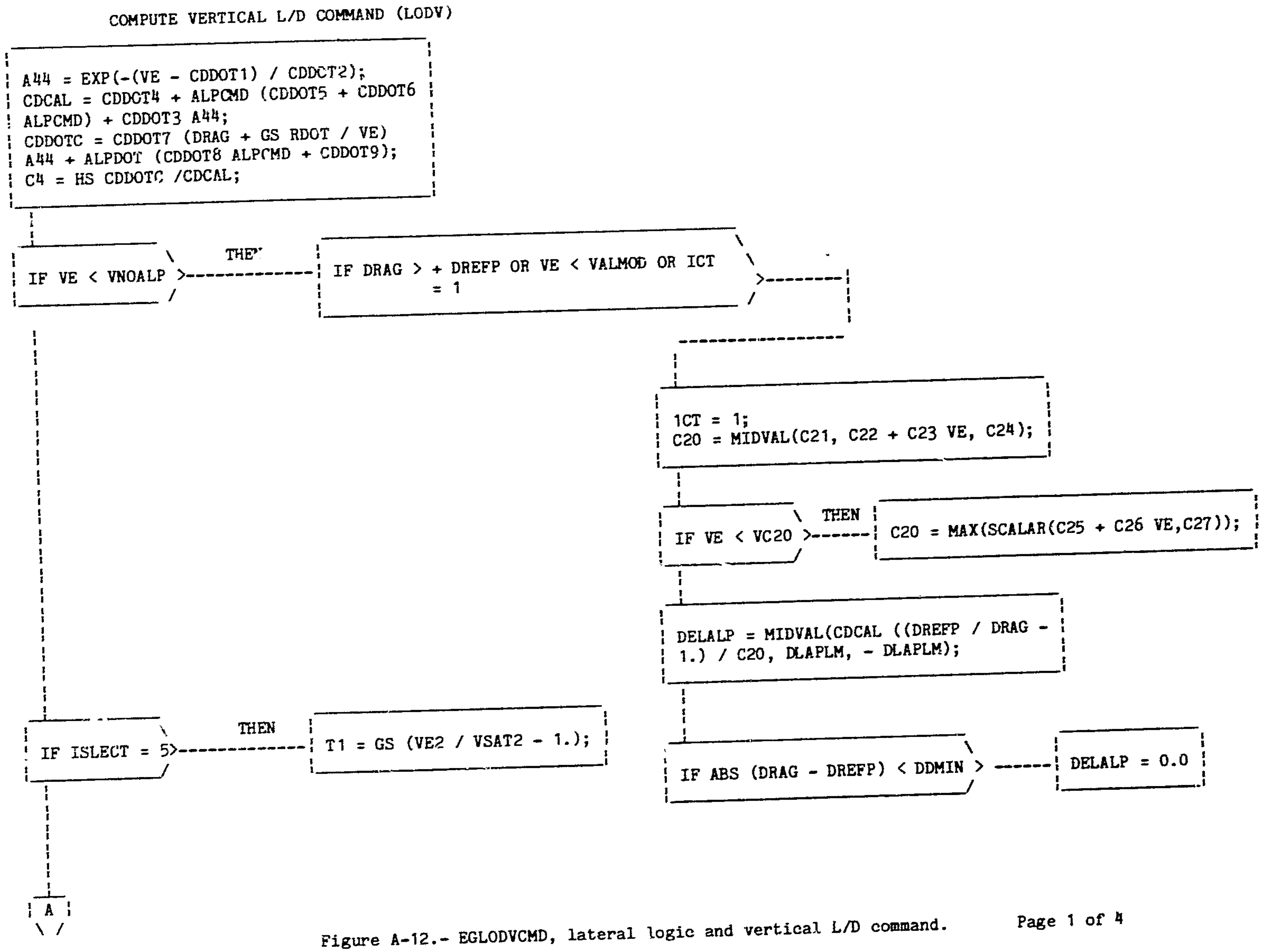
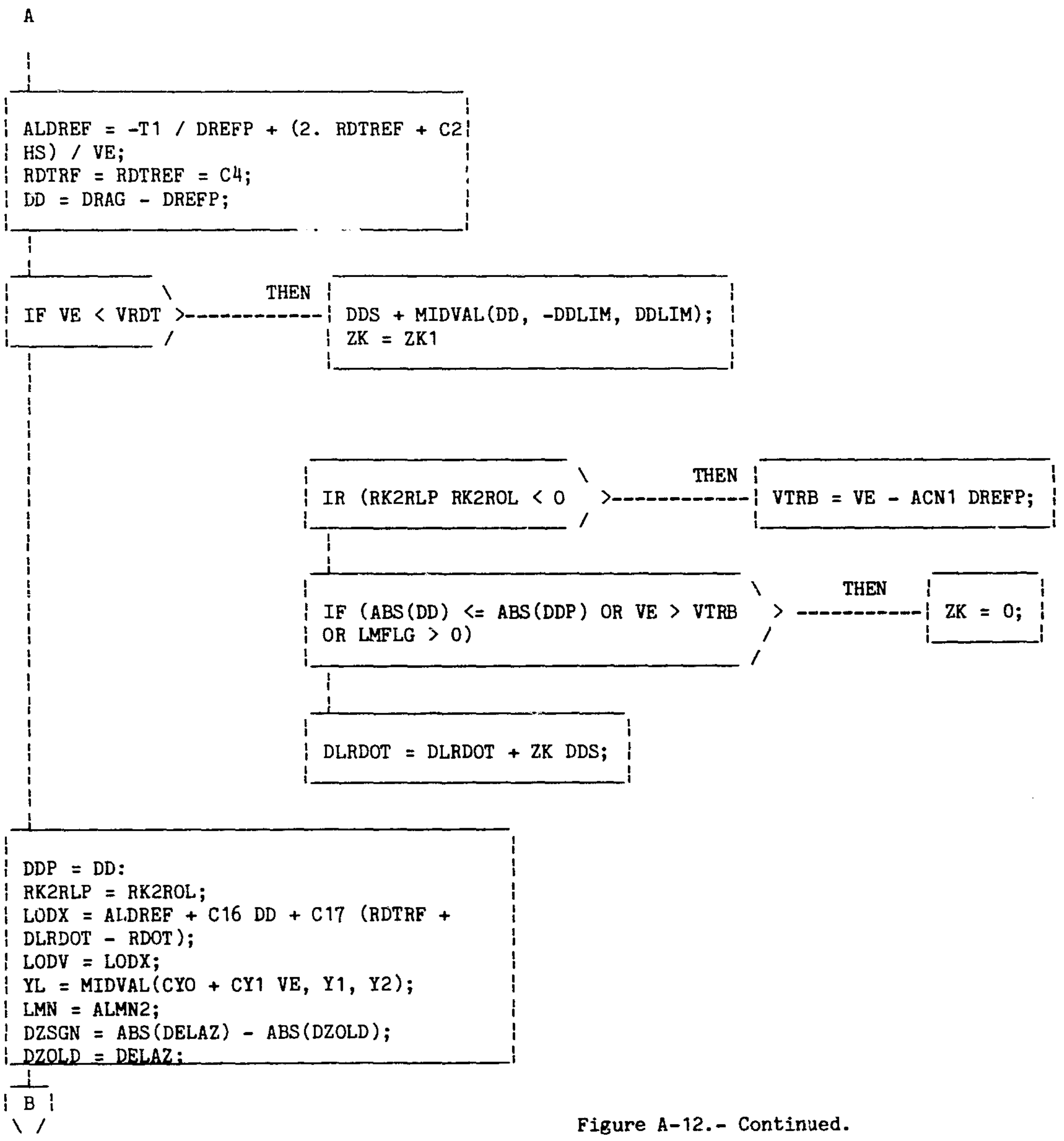


Figure A-11.- EGGNSLCT, gain select. Page 1 of 1



```
COMPUTE VERTICAL L/D COMMAND (LODV)

A44 = EXP(-(VE - CDDOT1) / CDDCT2);
CDCAL = CDDCT4 + ALPCMD (CDDOT5 + CDDOT6
ALPCMD) + CDDOT3 A44;
CDDOTC = CDDOT7 (DRAG + GS RDOT / VE)
A44 + ALPDOT (CDDOT8 ALPCMD + CDDOT9);
C4 = HS CDDOTC /CDCAL;
IF VE < VNOALP THEN
    IF DRAG > + DREFP OR VE < VALMOD OR ICT = 1
        1CT = 1;
        C20 = MIDVAL(C21, C22 + C23 VE, C24);
        IF VE < VC20 THEN
            C20 = MAX(SCALAR(C25 + C26 VE,C27));
        DELALP = MIDVAL(CDCAL ((DREFP / DRAG - 1.) / C20, DLAPLM, - DLAPLM);
        IF ABS (DRAG - DREFP) < DDMIN
            DELALP = 0.0
IF ISLECT = 5 THEN
    T1 = GS (VE2 / VSAT2 - 1.);
A
```

Figure A-12.- EGLODVCMD, lateral logic and vertical L/D command. Page 1 of 4



```
ALDREF = -T1 / DREFP + (2. RDTREF + C2
HS) / VE;
RDTRF = RDTREF = C4;
DD = DRAG - DREFP;

IF VE < VRDT
    THEN
    DDS + MIDVAL(DD, -DDLIM, DDLIM);
    ZK = ZK1

    IR (RK2RLP RK2ROL < 0
        THEN
        VTRB = VE - ACN1 DREFP;
    IF (ABS(DD) <= ABS(DDP) OR VE > VTRB
    OR LMFLG > 0)
        THEN
        ZK = 0;
    DLRDOT = DLRDOT + ZK DDS;

DDP = DD:
RK2RLP = RK2ROL;
LODX = ALDREF + C16 DD + C17 (RDTRF +
DLRDOT - RDOT);
LODV = LODX;
YL = MIDVAL(CYO + CY1 VE, Y1, Y2);
LMN = ALMN2;
DZSGN = ABS(DELAZ) - ABS(DZOLD);
DZOLD = DELAZ;
```

Figure A-12.- Continued.

Page 2 of 4

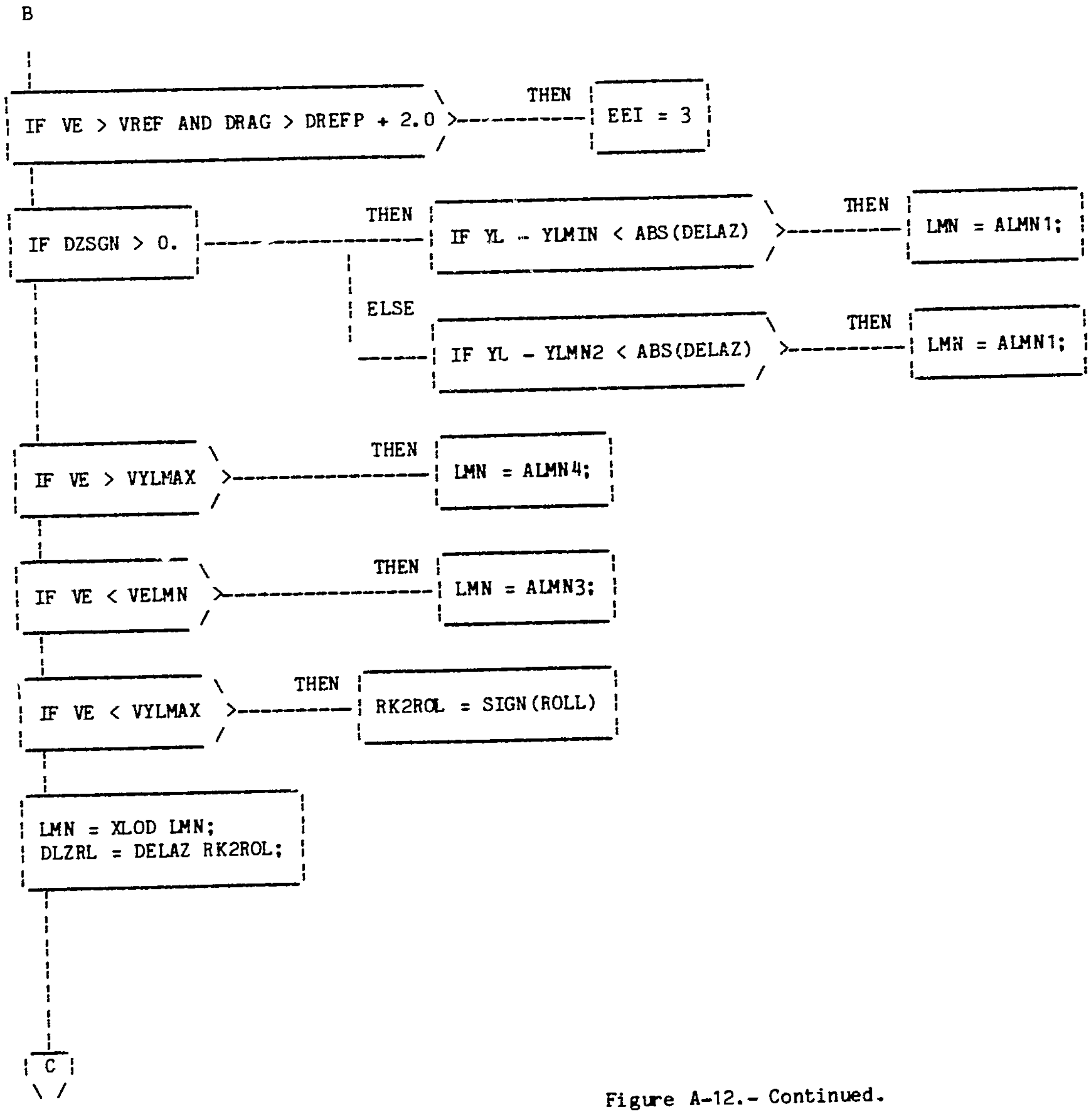


Figure A-12.- Continued.

Page 3 of 4

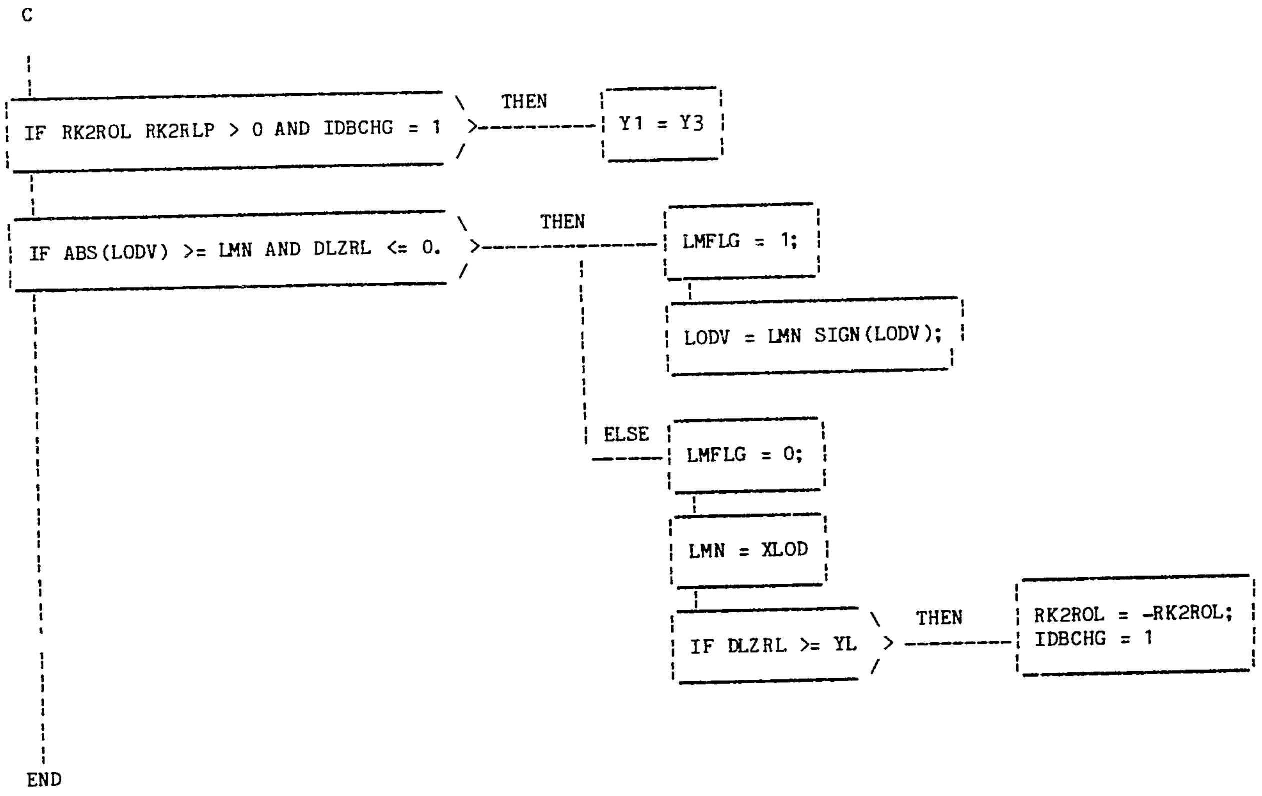
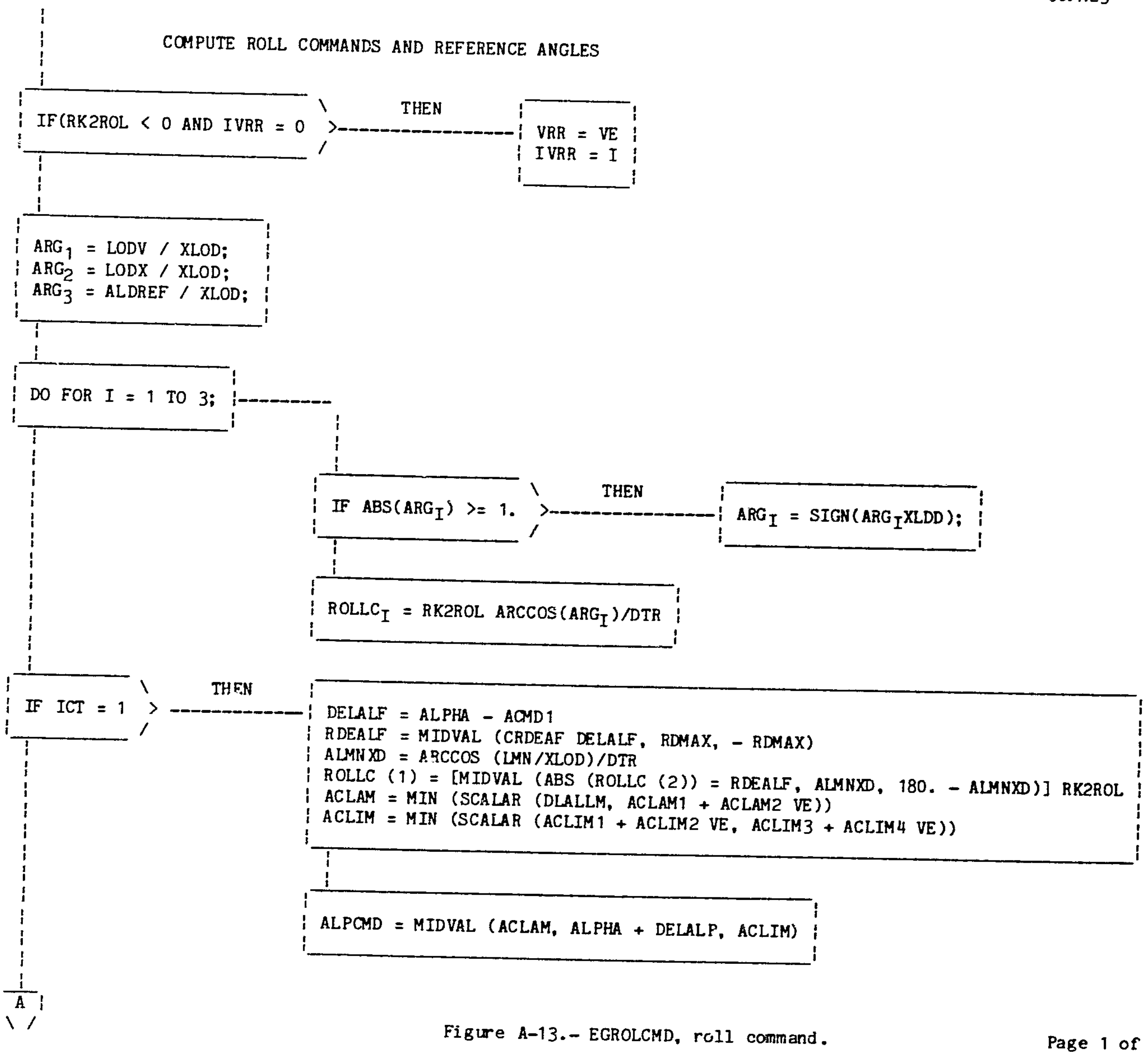


Figure A-12.- Concluded.

Page 4 of 4



```
COMPUTE ROLL COMMANDS AND REFERENCE ANGLES

IF(RK2ROL < 0 AND IVRR = 0
    THEN
        VRR = VE
        IVRR = I
$ARG_1$ = LODV / XLOD;
$ARG_2$ = LODX / XLOD;
$ARG_3$ = ALDREF / XLOD;
DO FOR I = 1 TO 3;
    IF ABS($ARG_I$) >= 1.
        THEN
            $ARG_I$ = SIGN($ARG_I$XLDD);
    $ROLLC_I$ = RK2ROL ARCCOS($ARG_I$)/DTR
IF ICT = 1
    THEN
        DELALF = ALPHA - ACMD1
        RDEALF = MIDVAL (CRDEAF DELALF, RDMAX, - RDMAX)
        ALMNXD = ARCCOS (LMN/XLOD)/DTR
        ROLLC (1) = [MIDVAL (ABS (ROLLC (2)) = RDEALF, ALMNXD, 180. - ALMNXD)] RK2ROL
        ACLAM = MIN (SCALAR (DLALLM, ACLAM1 + ACLAM2 VE))
        ACLIM = MIN (SCALAR (ACLIM1 + ACLIM2 VE, ACLIM3 + ACLIM4 VE))
        ALPCMD = MIDVAL (ACLAM, ALPHA + DELALP, ACLIM)
A
```

Figure A-13.- EGROLCMD, roll command.

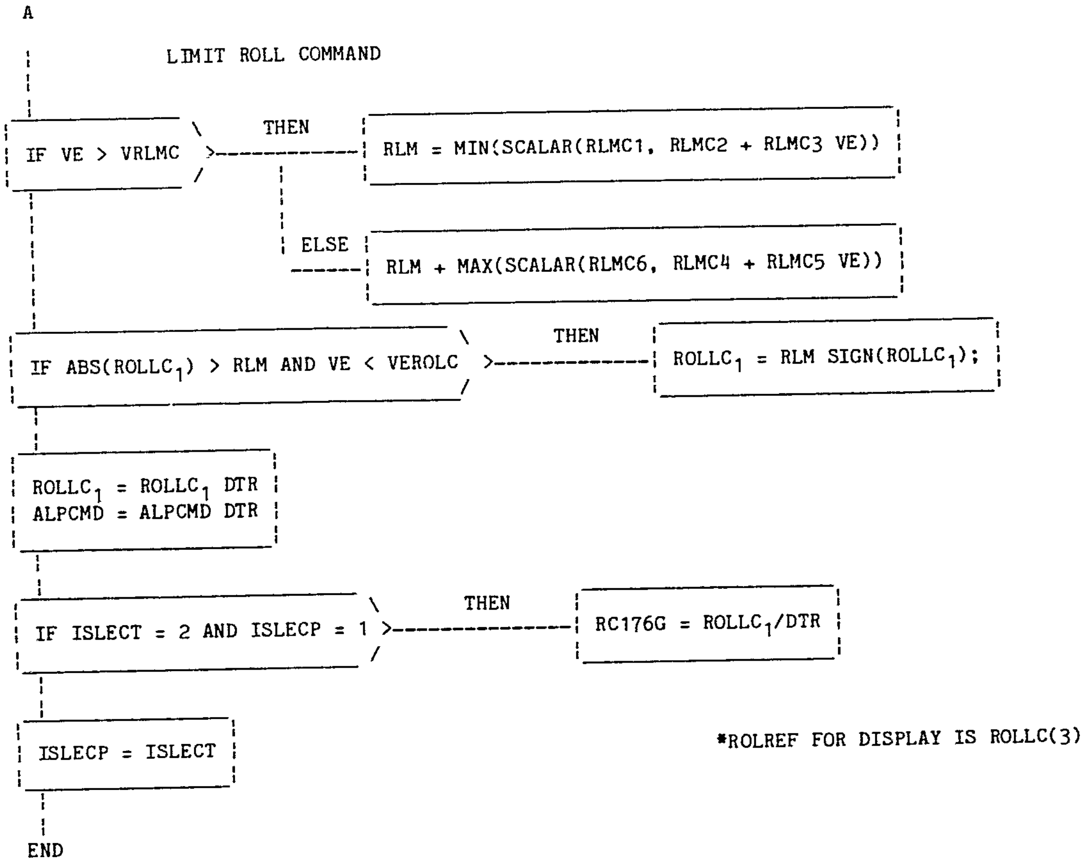


Figure A-13.- Concluded.

Page 2 of 2

APPENDIX B

ENTRY AUTOPILOT FLOW CHARTS

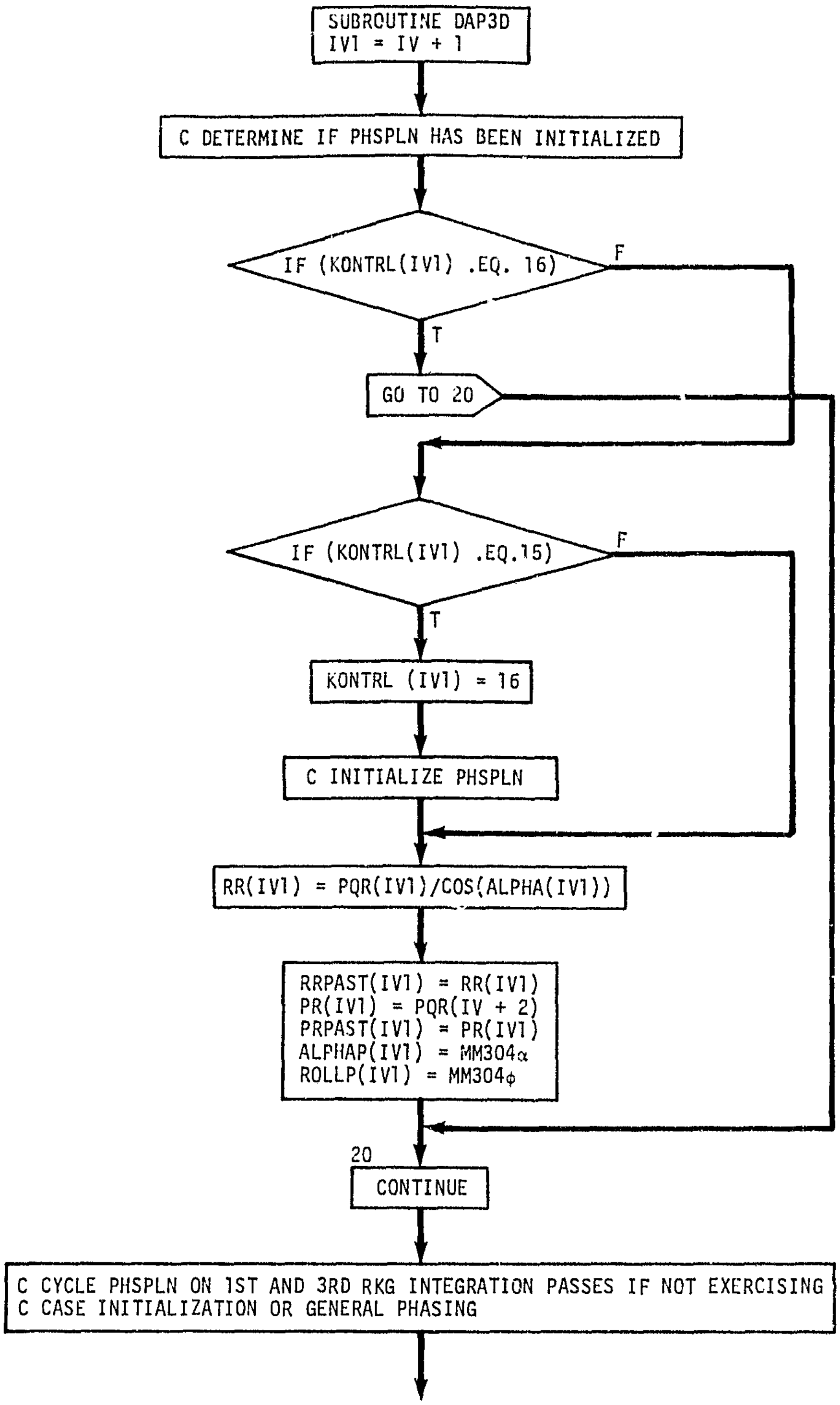
APPENDIX B

ENTRY AUTOPILOT FLOW CHARTS

The following flow charts define the entry autopilot formulations.

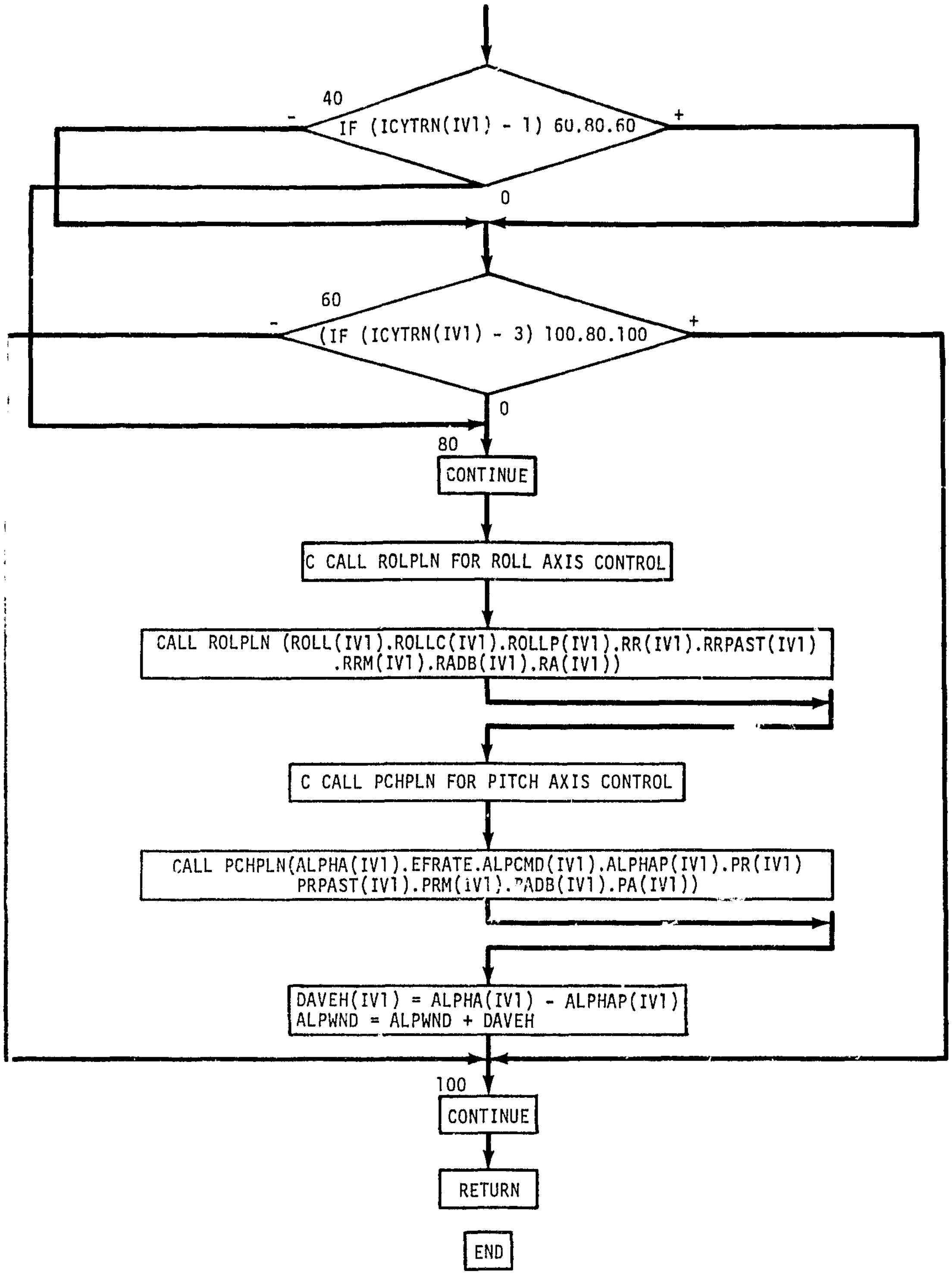
Function	Figure	Number of flow charts
DAP3D	B-1	2
PHSPLN	B-2	10

PAGE B-2 INTENTIONALLY BLANK



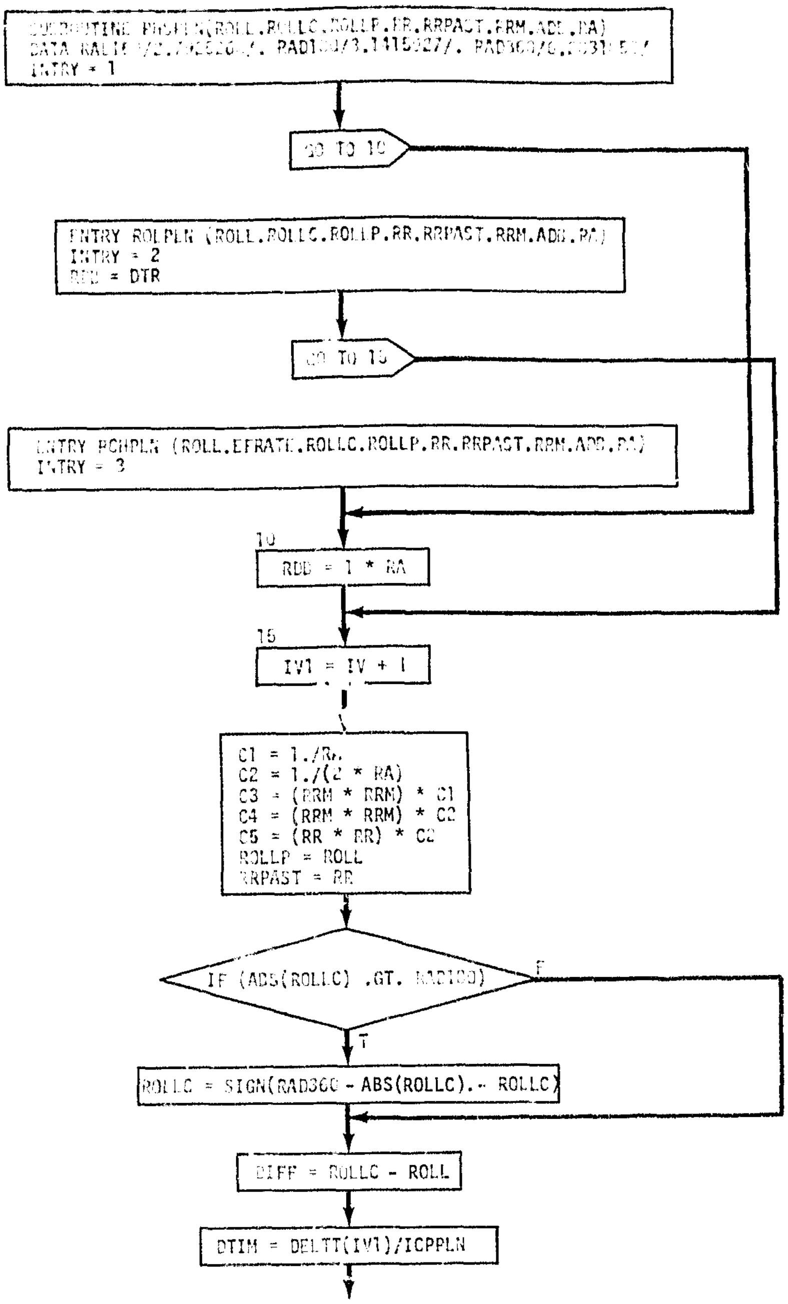
Page 1 of 2

Figure B-1.- DAP3D.



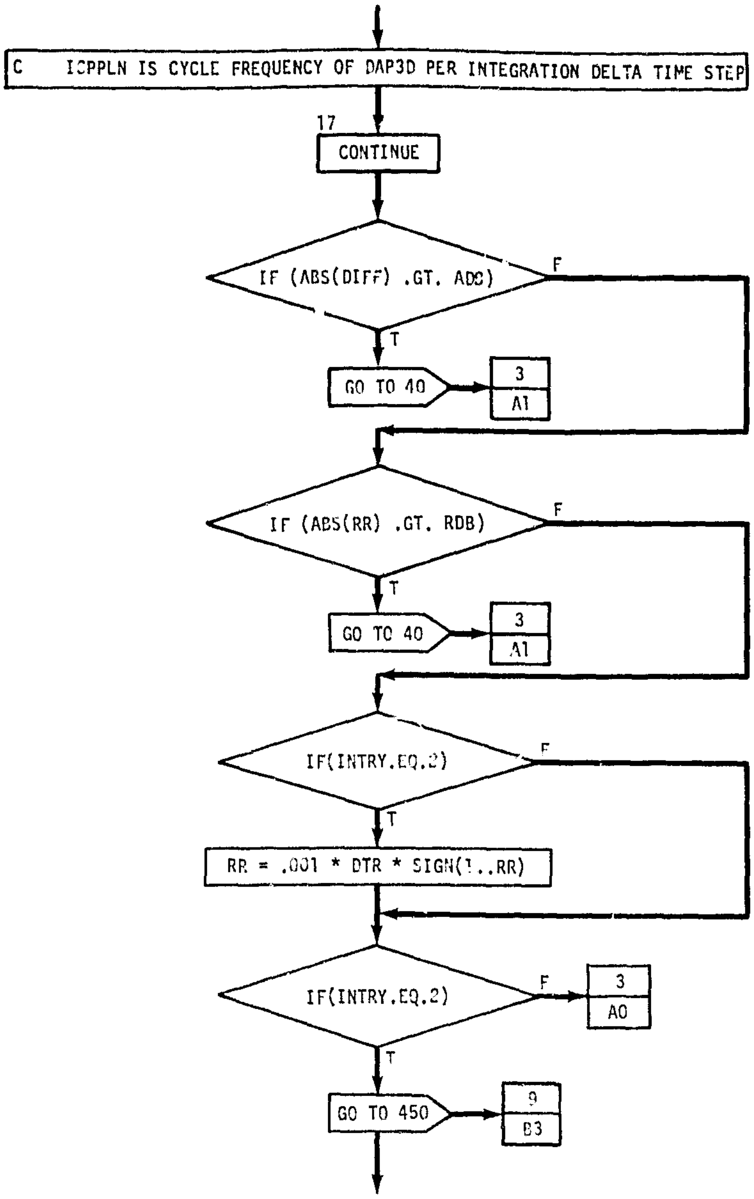
Page 2 of 2

Figure B-1.- Concluded.



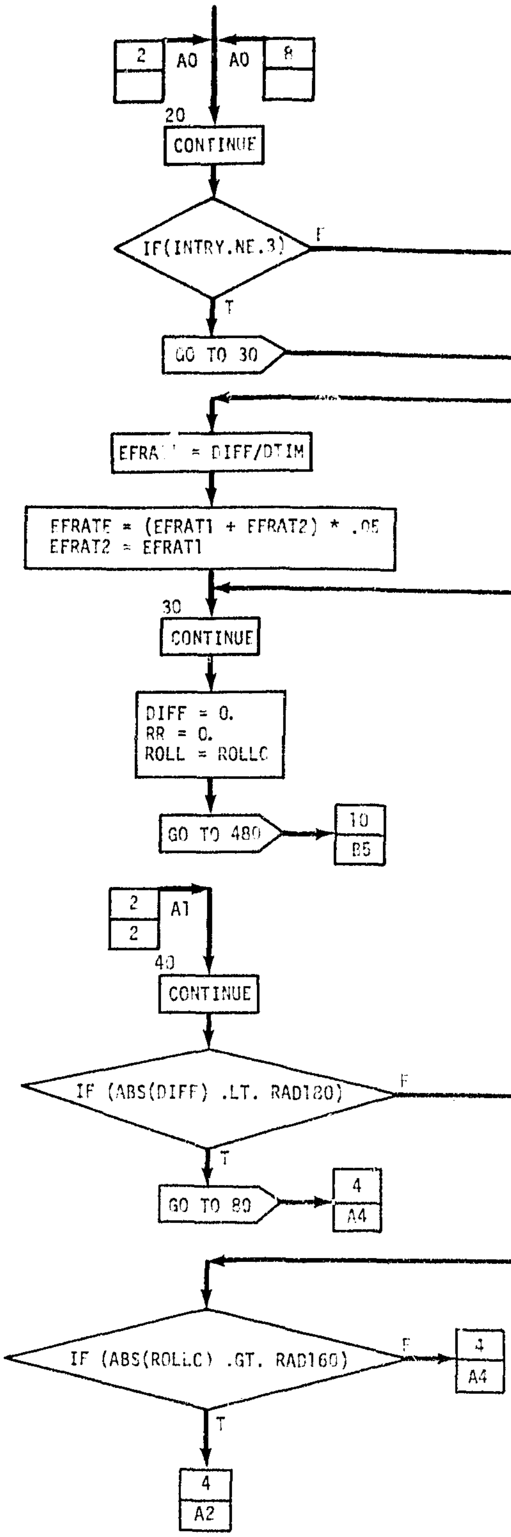
Page 1 of 1

Figure B-2.- PHSPLN.



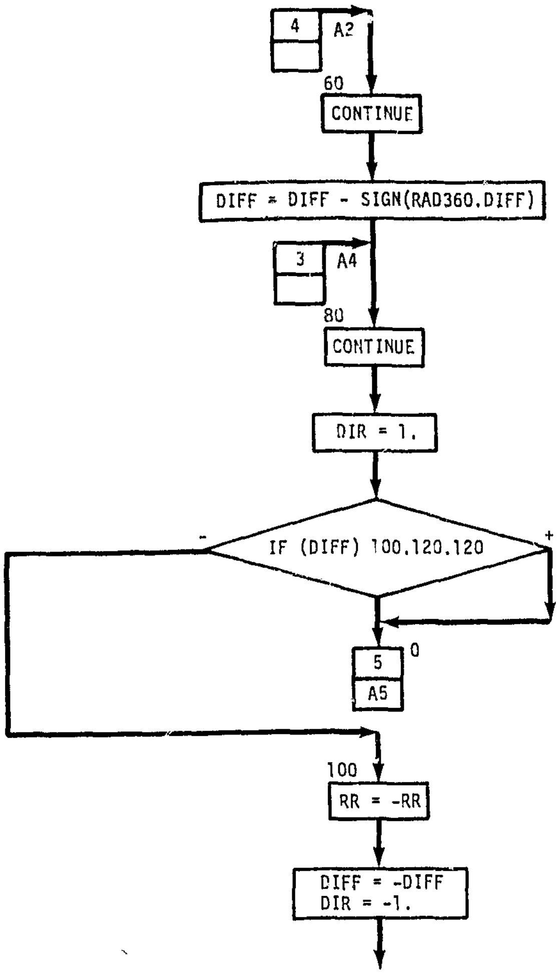
Page 2 of 10

Figure B-2.- Continued.



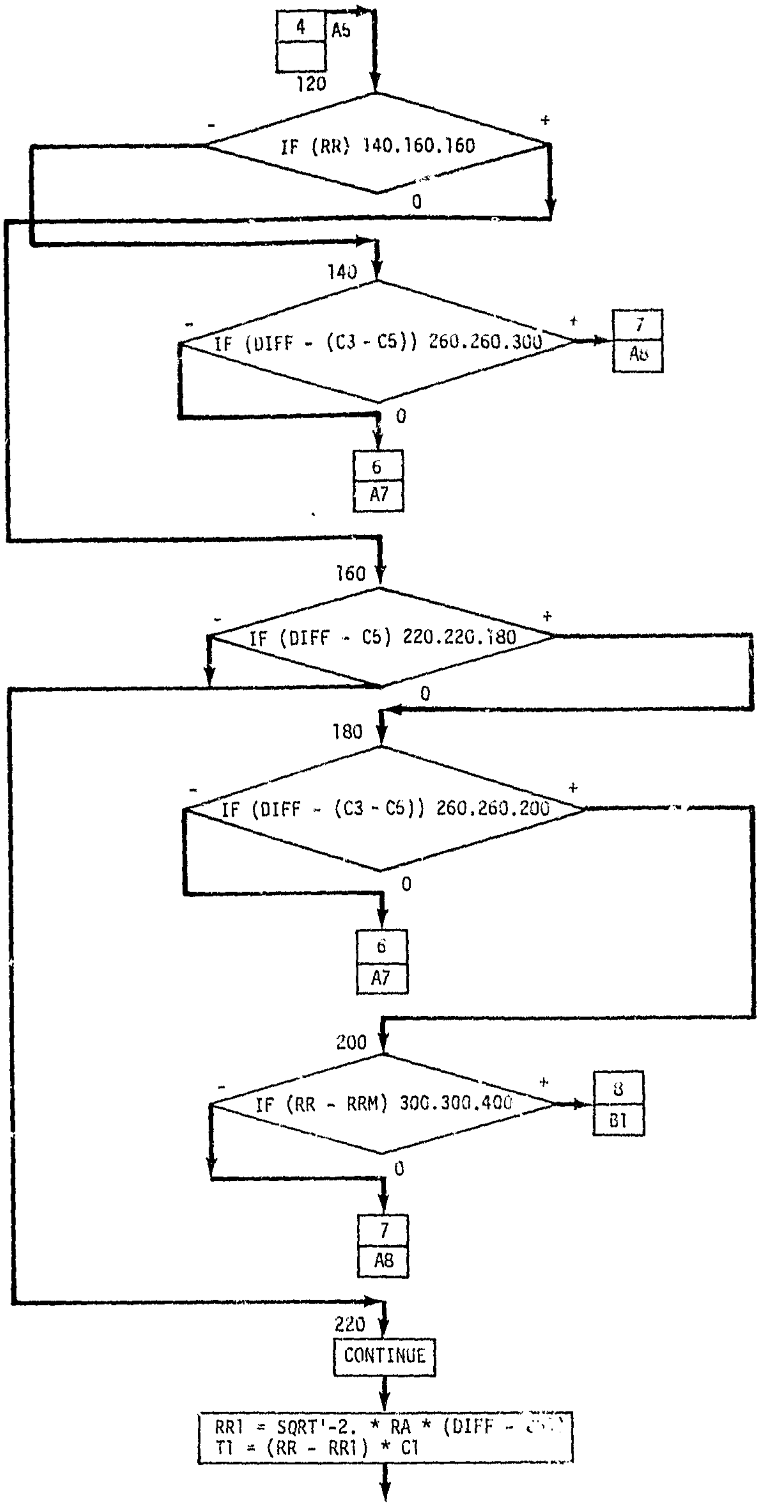
Page 3 of 10

Figure B-2.- Continued.



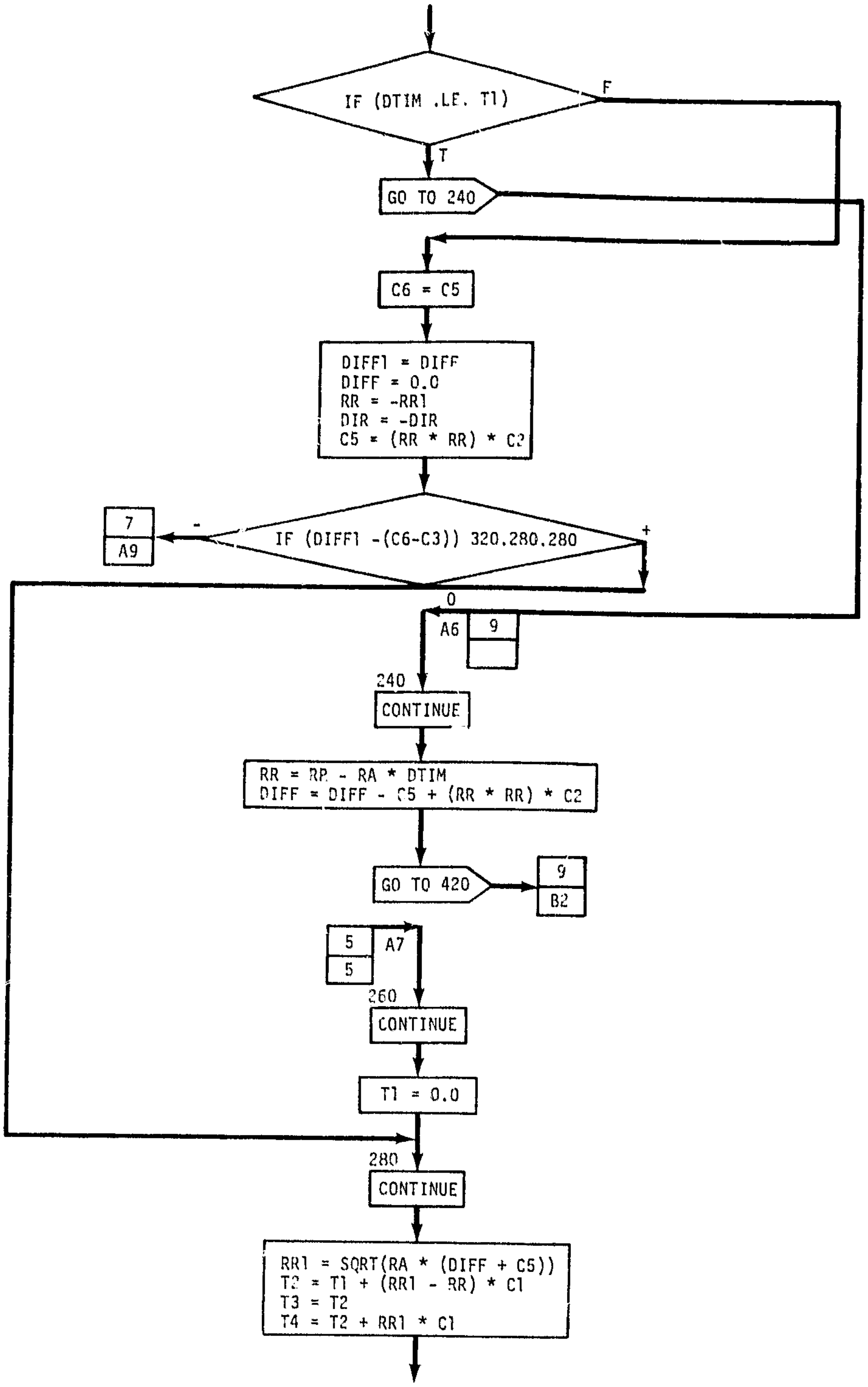
Page 4 of 10

Figure B-2.- Continued.



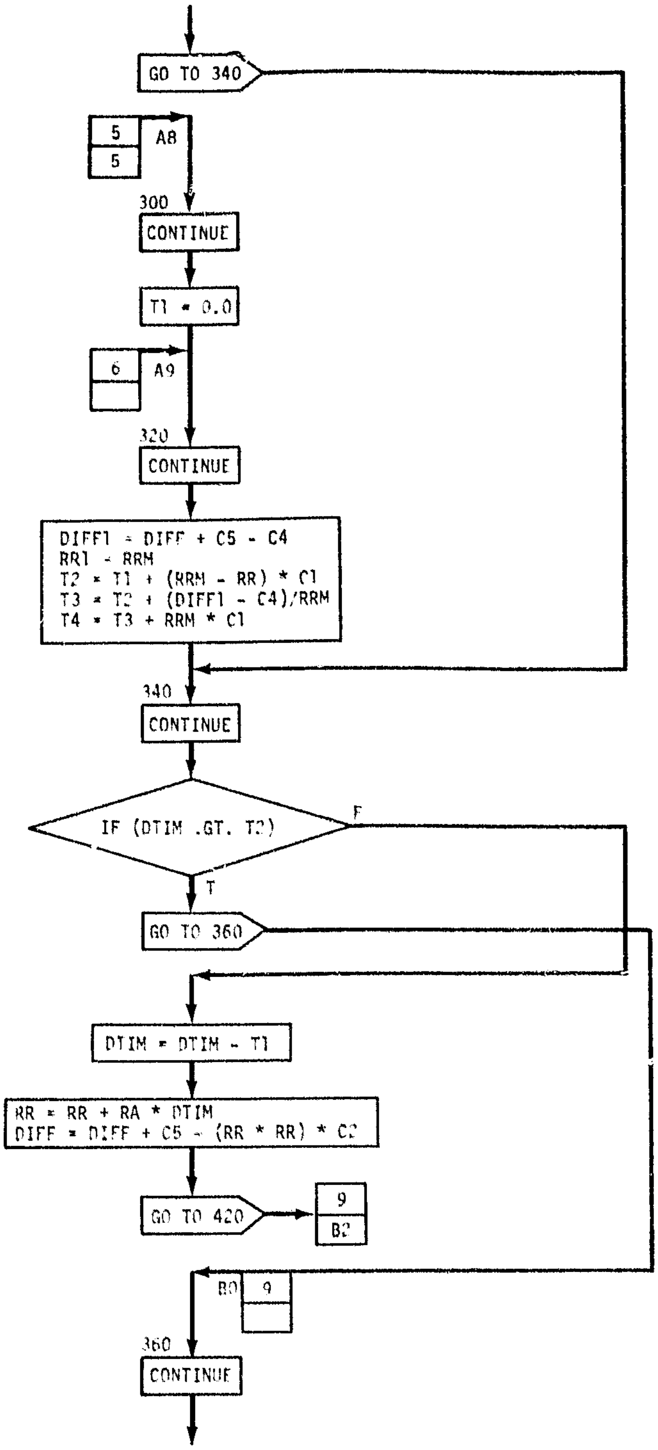
Page 5 of 10

Figure B-2.- Continued.



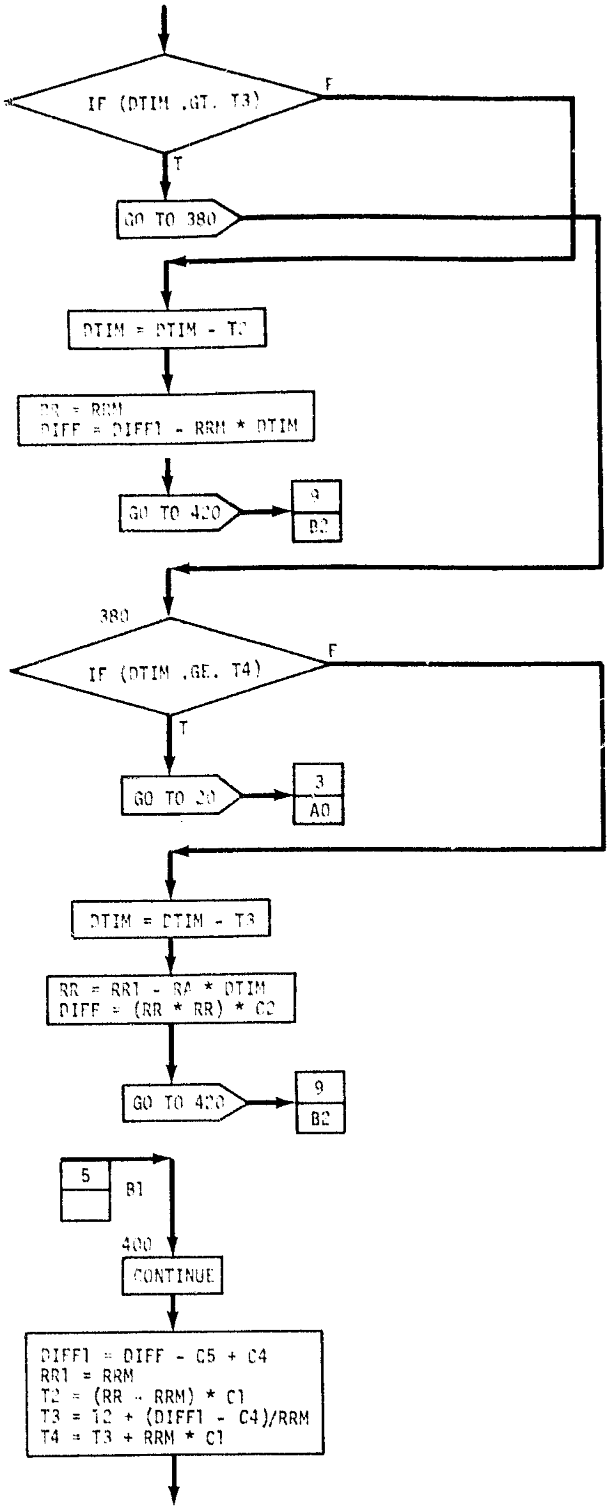
Page 6 of 10

Figure B-2.- Continued.



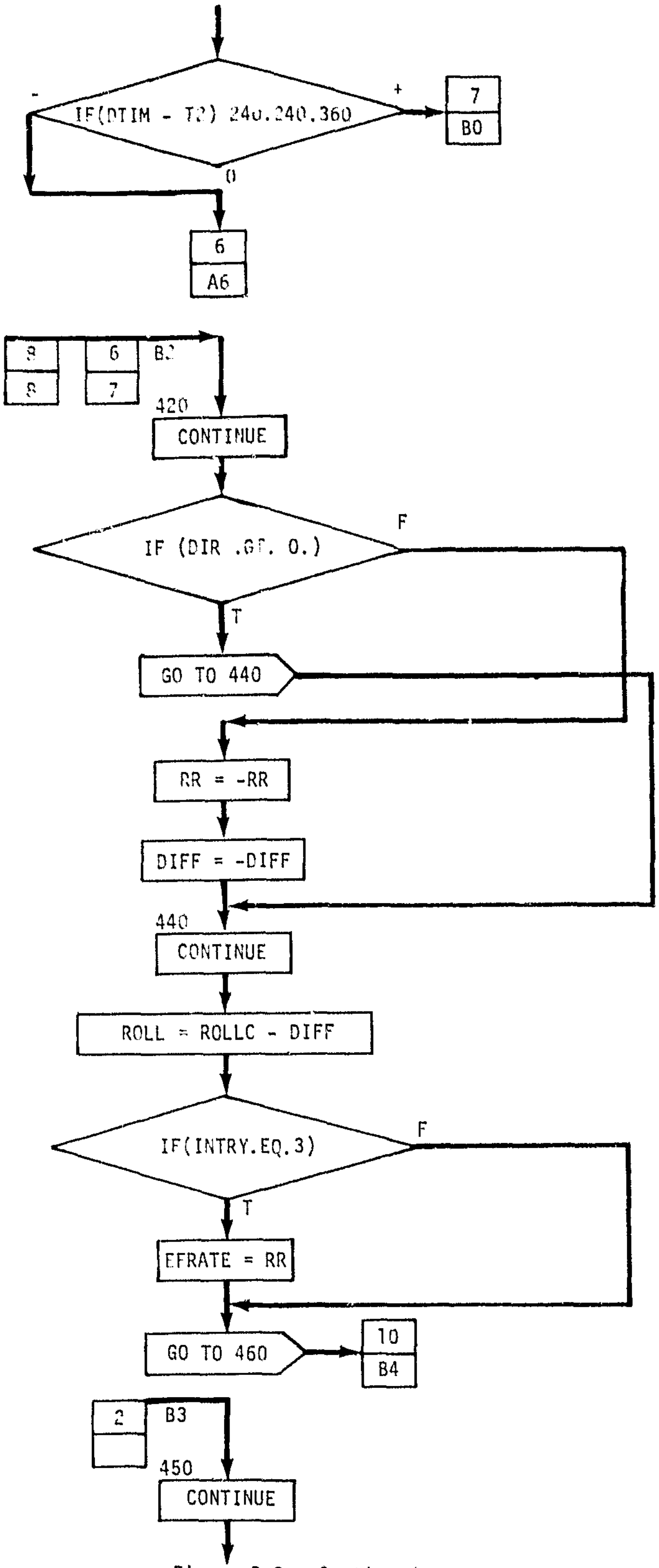
Page 2 of 10

Figure B-2.- Continued.



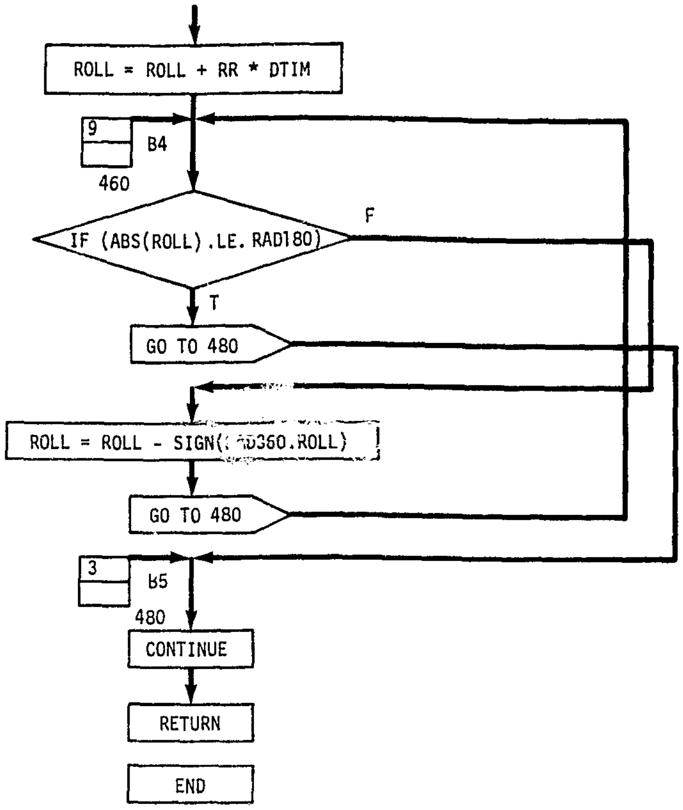
Page 9 of 10

Figure B-2.- Continued.



Page 9 of 10

Figure B-2.- Continued.



Page 10 of 10

Figure B-2.- Concluded.

APPENDIX C

TARGETING FLOW CHARTS

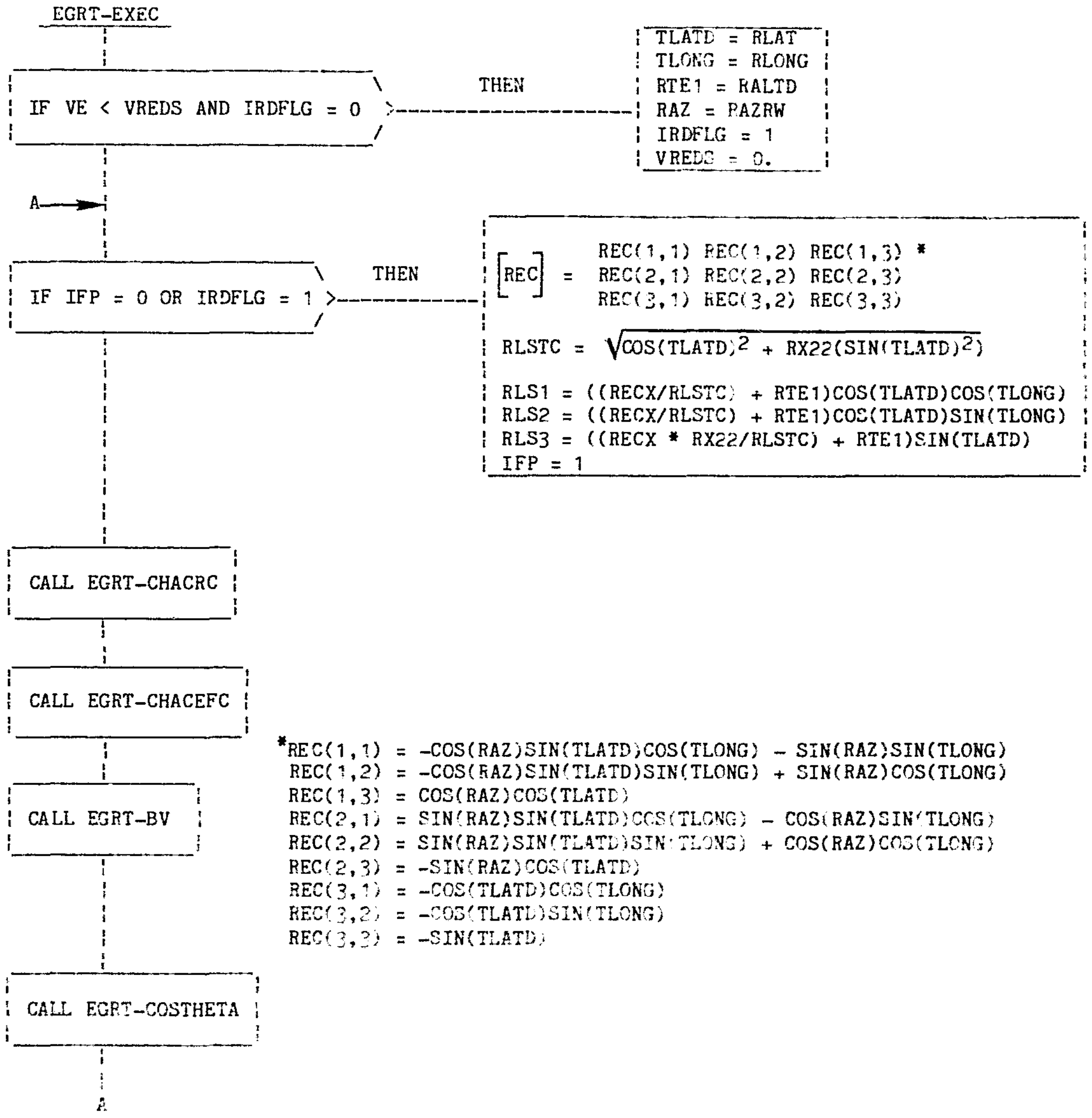
APPENDIX C

TARGETING FLOW CHARTS

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

Function	Figure	Number of flow charts
EGRT-EXEC	C-1	1
EGRT-CHACRC	C-2	1
EGRT-CHACEFC	C-3	1
EGRT-BV	C-4	1
EGRT-BVCHAC	C-5	1
EGRT-COSTHETA	C-6	1
EGRT-DWP1	C-7	1
EGRT-DVNEP	C-8	1
EGRT-DELAZ	C-9	1

PAGE C-2 INTENTIONALLY BLANK



```
*REC(1,1) = -COS(RAZ)SIN(TLATD)COS(TLONG) - SIN(RAZ)SIN(TLONG)
 REC(1,2) = -COS(RAZ)SIN(TLATD)SIN(TLONG) + SIN(RAZ)COS(TLONG)
 REC(1,3) = COS(RAZ)COS(TLATD)
 REC(2,1) = SIN(RAZ)SIN(TLATD)COS(TLONG) - COS(RAZ)SIN(TLONG)
 REC(2,2) = SIN(RAZ)SIN(TLATD)SIN(TLONG) + COS(RAZ)COS(TLONG)
 REC(2,3) = -SIN(RAZ)COS(TLATD)
 REC(3,1) = -COS(TLATD)COS(TLONG)
 REC(3,2) = -COS(TLATD)SIN(TLONG)
 REC(3,3) = -SIN(TLATD)
```

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

Page 1 of 2

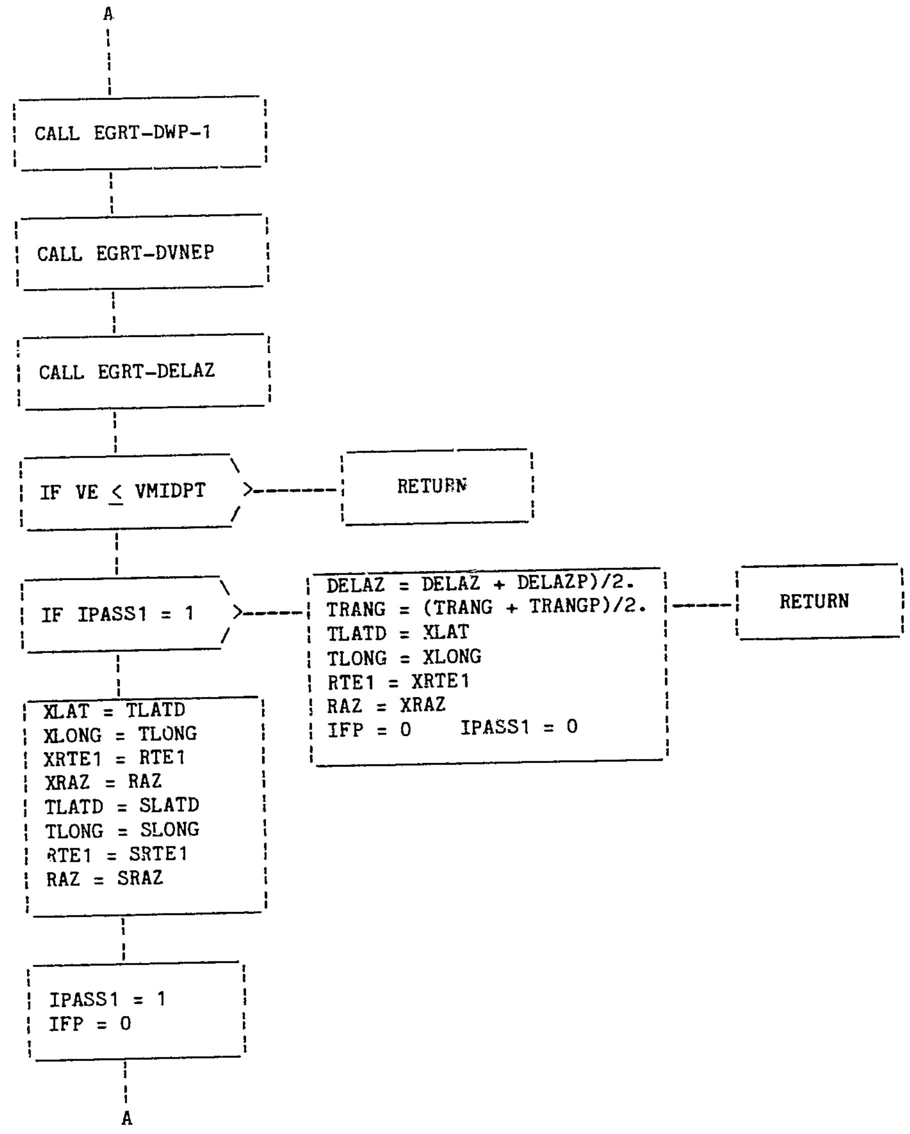


Figure C-1.- Concluded.

Page 2 of 2

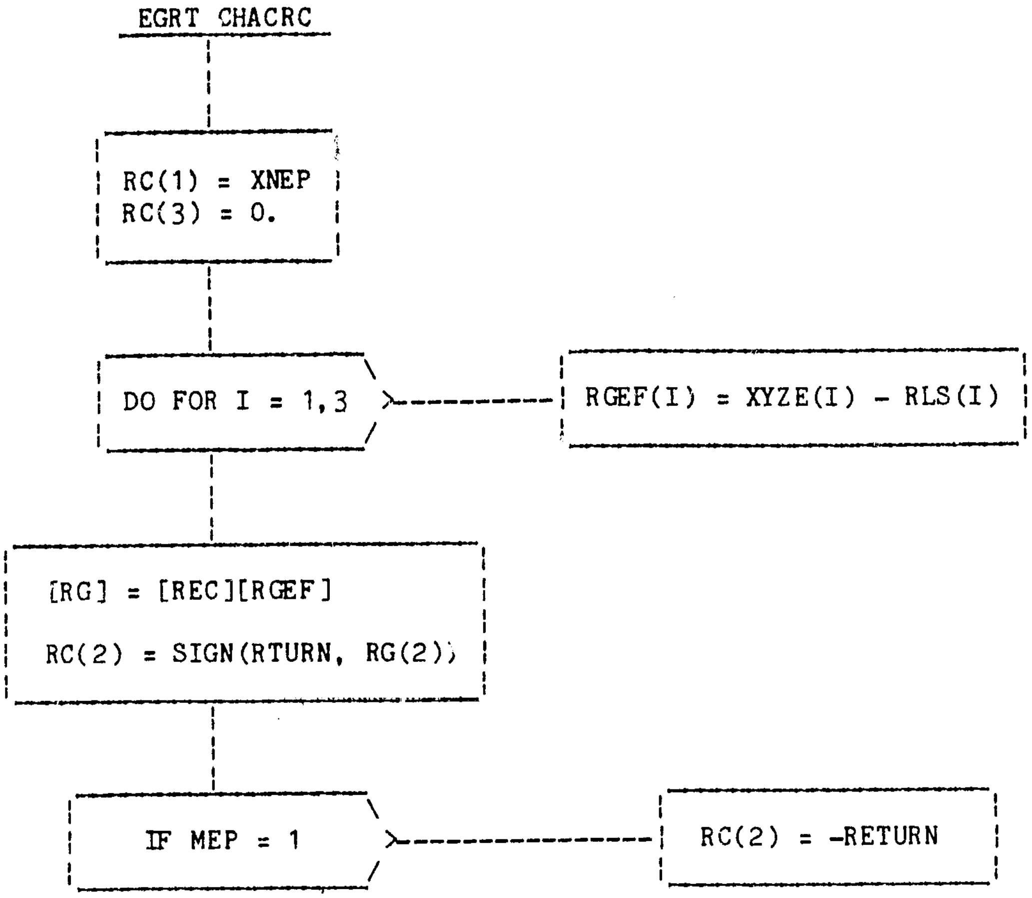
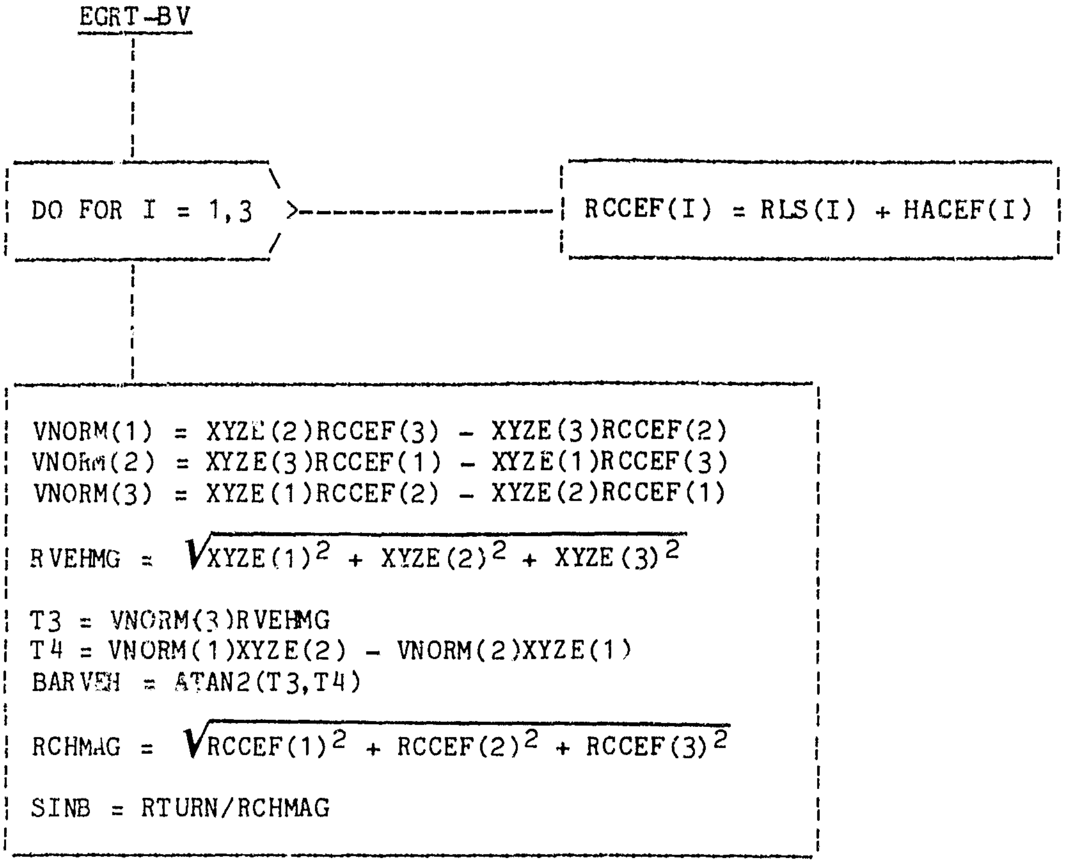


Figure C-2.- EGRT-CHACRC, center heading alinement circle - runway coordinate system.

EGRT-CHACEFC

$$[HACEF] = [REC]^{-1}[RC]$$

Figure C-3.- EGRT-CHACEFC, center heading alinement circle - Earth-fixed cooredinates.



```
EGRT-BV
  DO FOR I = 1,3
      RCCEF(I) = RLS(I) + HACEF(I)
  VNORM(1) = XYZE(2)RCCEF(3) - XYZE(3)RCCEF(2)
  VNORM(2) = XYZE(3)RCCEF(1) - XYZE(1)RCCEF(3)
  VNORM(3) = XYZE(1)RCCEF(2) - XYZE(2)RCCEF(1)
  RVEHMG = $\sqrt{XYZE(1)^2 + XYZE(2)^2 + XYZE(3)^2}$
  T3 = VNORM(3)RVEHMG
  T4 = VNORM(1)XYZE(2) - VNORM(2)XYZE(1)
  BARVEH = ATAN2(T3,T4)
  RCHMAG = $\sqrt{RCCEF(1)^2 + RCCEF(2)^2 + RCCEF(3)^2}$
  SINB = RTURN/RCHMAG
```

Figure C-4.- EGRT-BV, bearing of vehicle.

```
EGRT-BVCHAC

T5 = VNORM(3)RCHMAG
T6 = RCCEF(2)VNORM(1) - VNORM(2)RCCEF(1)
BARCC = ATAN2(T5,T6)
```

Figure C-5.- EGRT-BVCHAC, bearing to center of alinement circle.

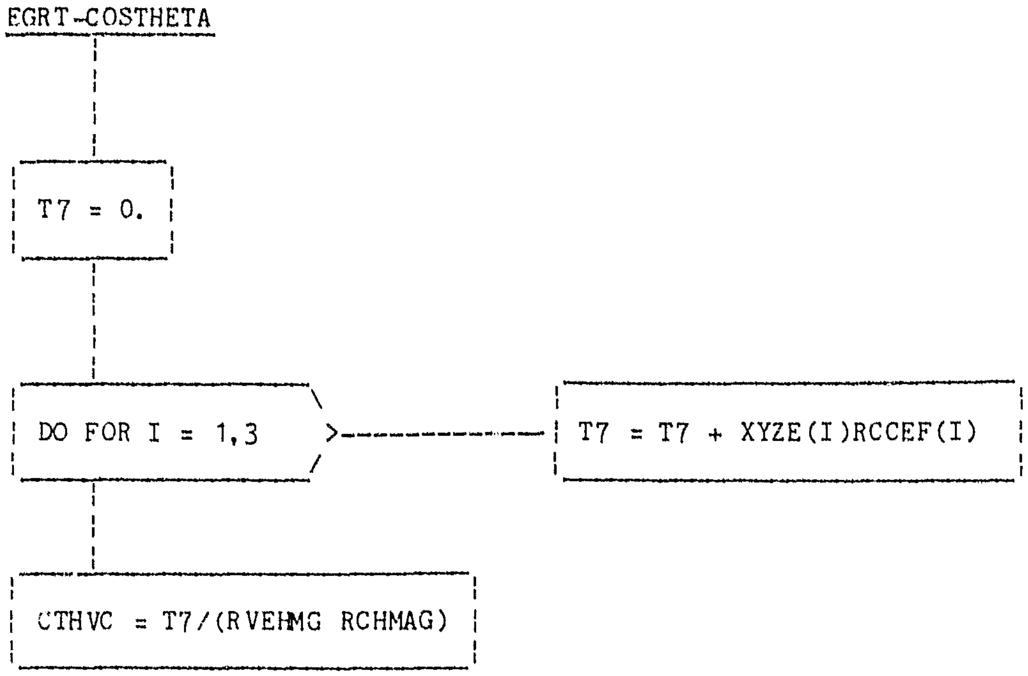
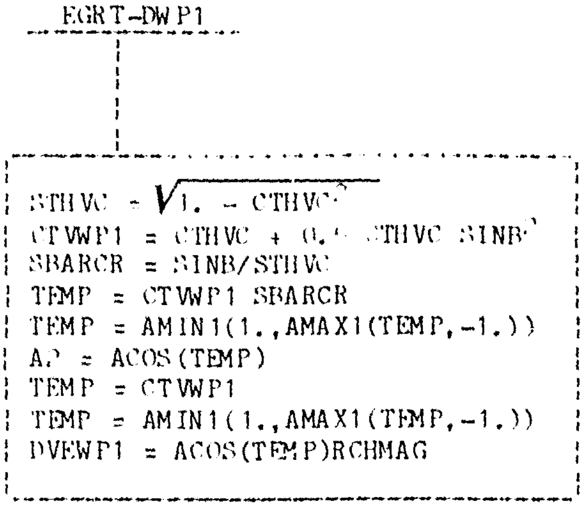


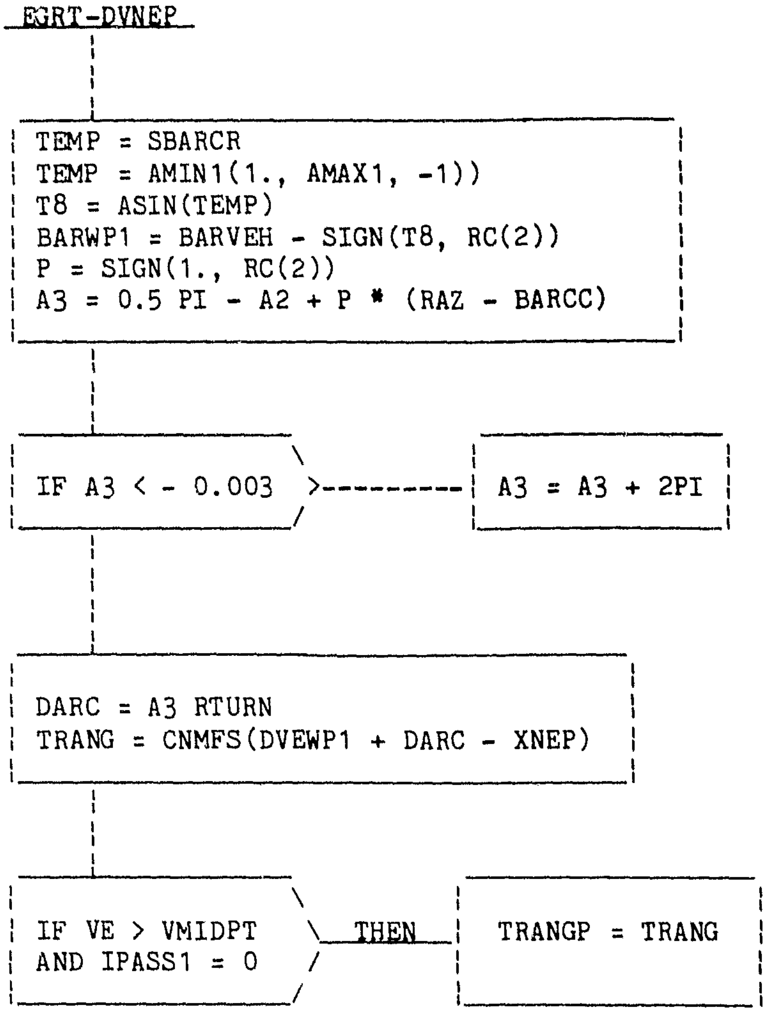
Figure C-6.- EGRT-COSTHETA, great circle arc.



EGRT-DWP1

```
STHVC = $\sqrt{1. - CTHVC^2}$
CTWP1 = CTHVC + 0.5 STHVC $SINB^2$
SBARCR = SINB/STHVC
TEMP = CTWP1 SBARCR
TEMP = AMIN1(1.,AMAX1(TEMP,-1.))
AP = ACOS(TEMP)
TEMP = CTWP1
TEMP = AMIN1(1.,AMAX1(TEMP,-1.))
DVEWP1 = ACOS(TEMP)RCHMAG
```

Figure C-7.- EGRT-DWP1, distance to WP1.



```
EGRT-DVNEP

TEMP = SBARCR
TEMP = AMIN1(1., AMAX1, -1))
T8 = ASIN(TEMP)
BARWP1 = BARVEH - SIGN(T8, RC(2))
P = SIGN(1., RC(2))
A3 = 0.5 PI - A2 + P * (RAZ - BARCC)

IF A3 < - 0.003  >---------- A3 = A3 + 2PI

DARC = A3 RTURN
TRANG = CNMFS(DVEWP1 + DARC - XNEP)

IF VE > VMIDPT
AND IPASS1 = 0   \ THEN   TRANGP = TRANG
```

Figure C-8.- EGRT-DVNEP, range-to-threshold point.

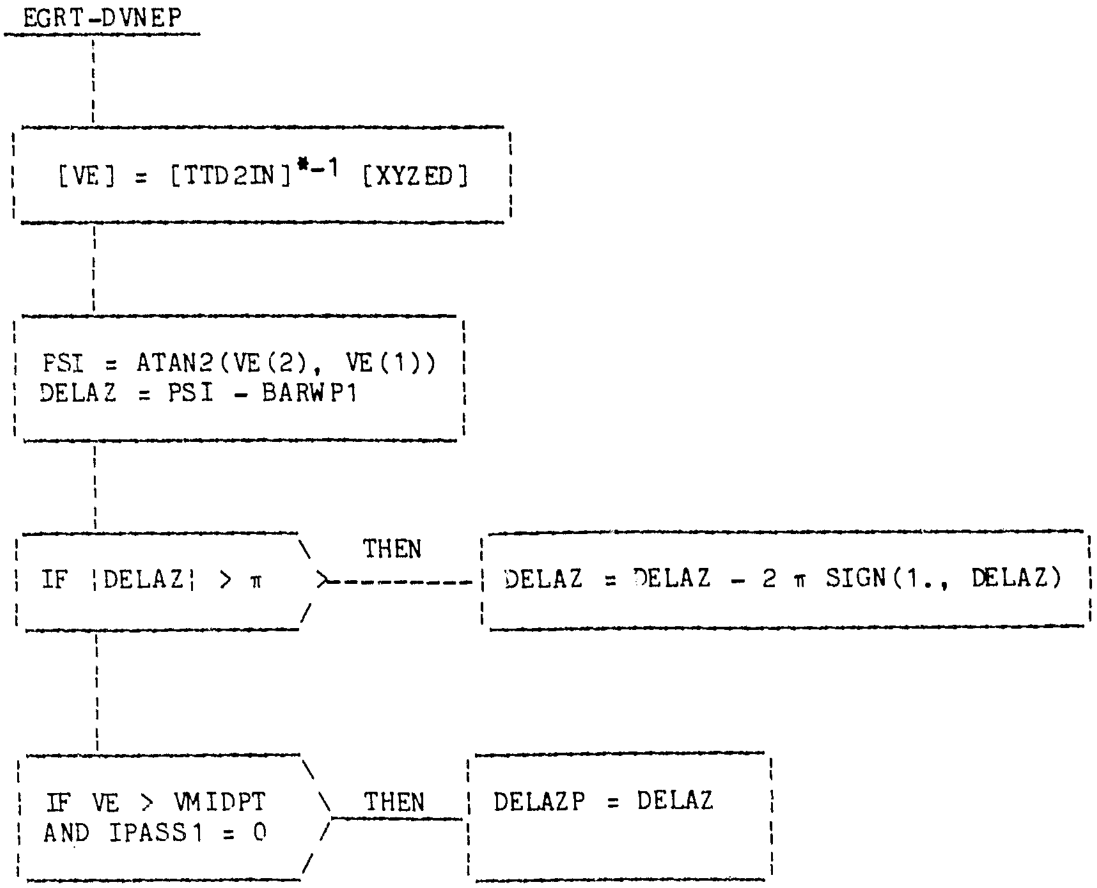


Figure C-9.- EGRT-DELAZ, azimuth error.

APPENDIX D

IBM AUTOPILOT FLOW CHARTS

APPENDIX D

IBM AUTOPILOT FLOW CHARTS

The flow charts presented in this appendix represent 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.

PAGE D-2 INTENTIONALLY BLANK

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 DEAD BAND
RADB2 - ETG SPECIAL BANK DEAD BAND
PADB - ANGLE-OF-ATTACK DEAD BAND
RAD160 - 160° 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.

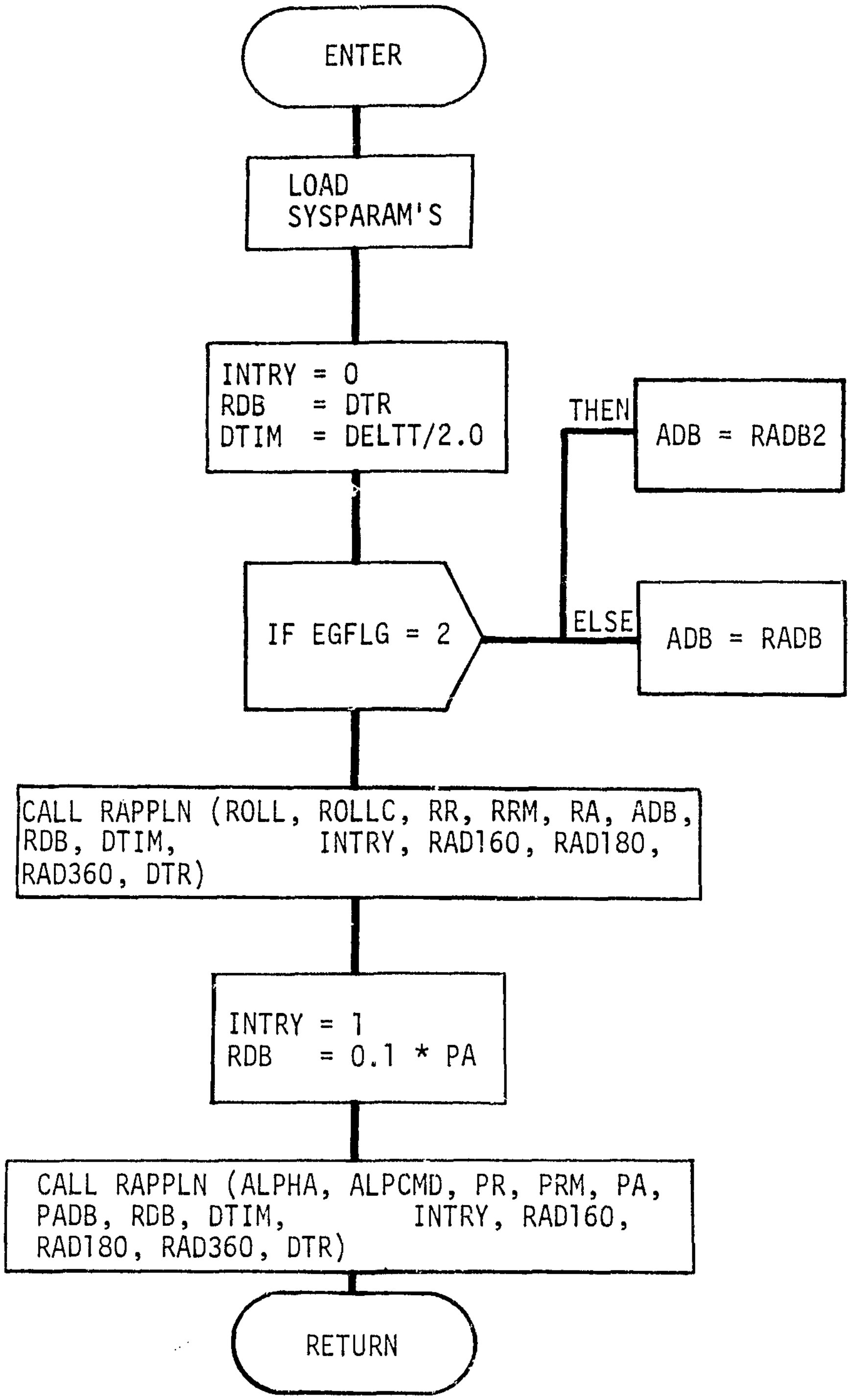


Figure D-1.- Continued.

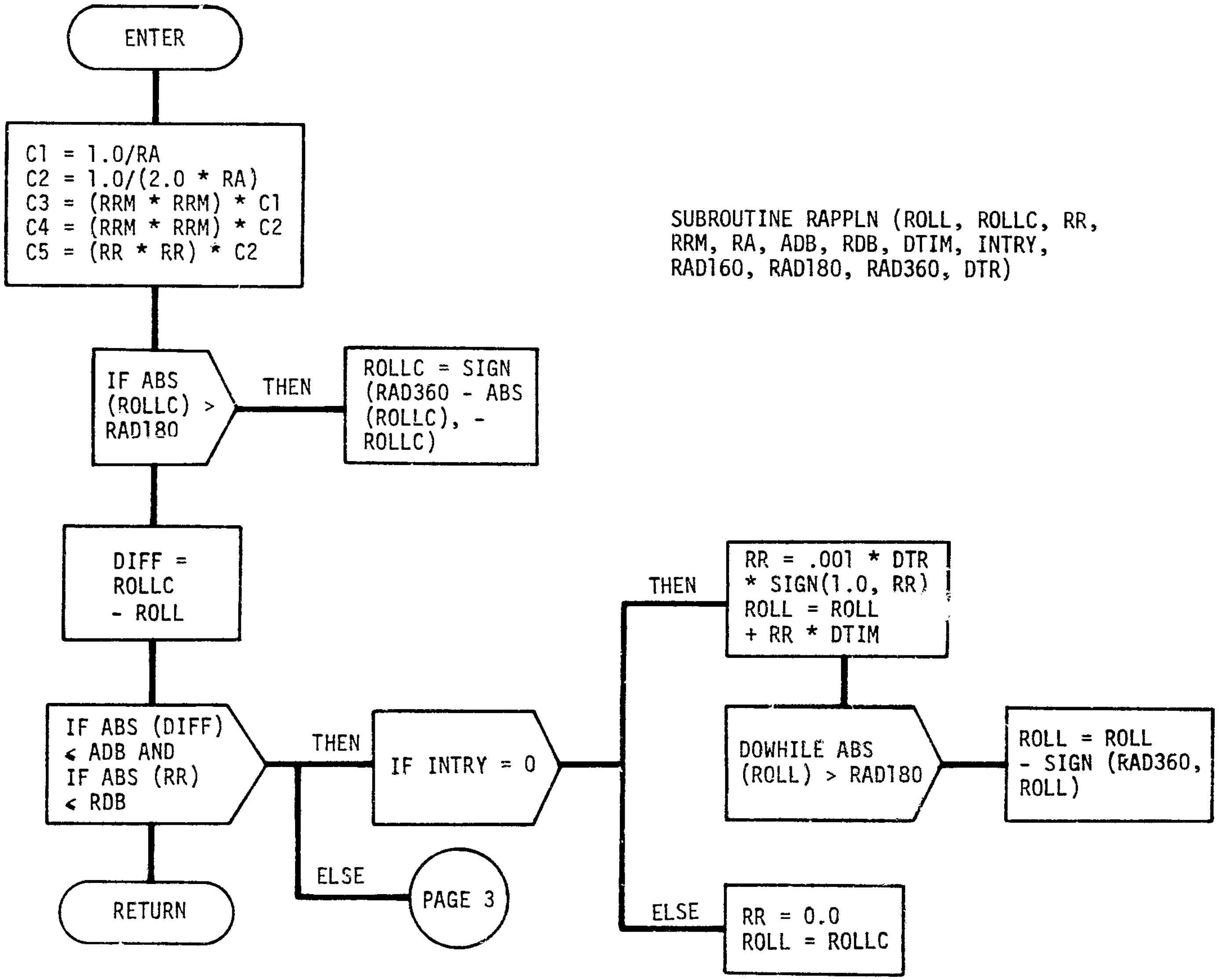


Figure D-1.- Continued.

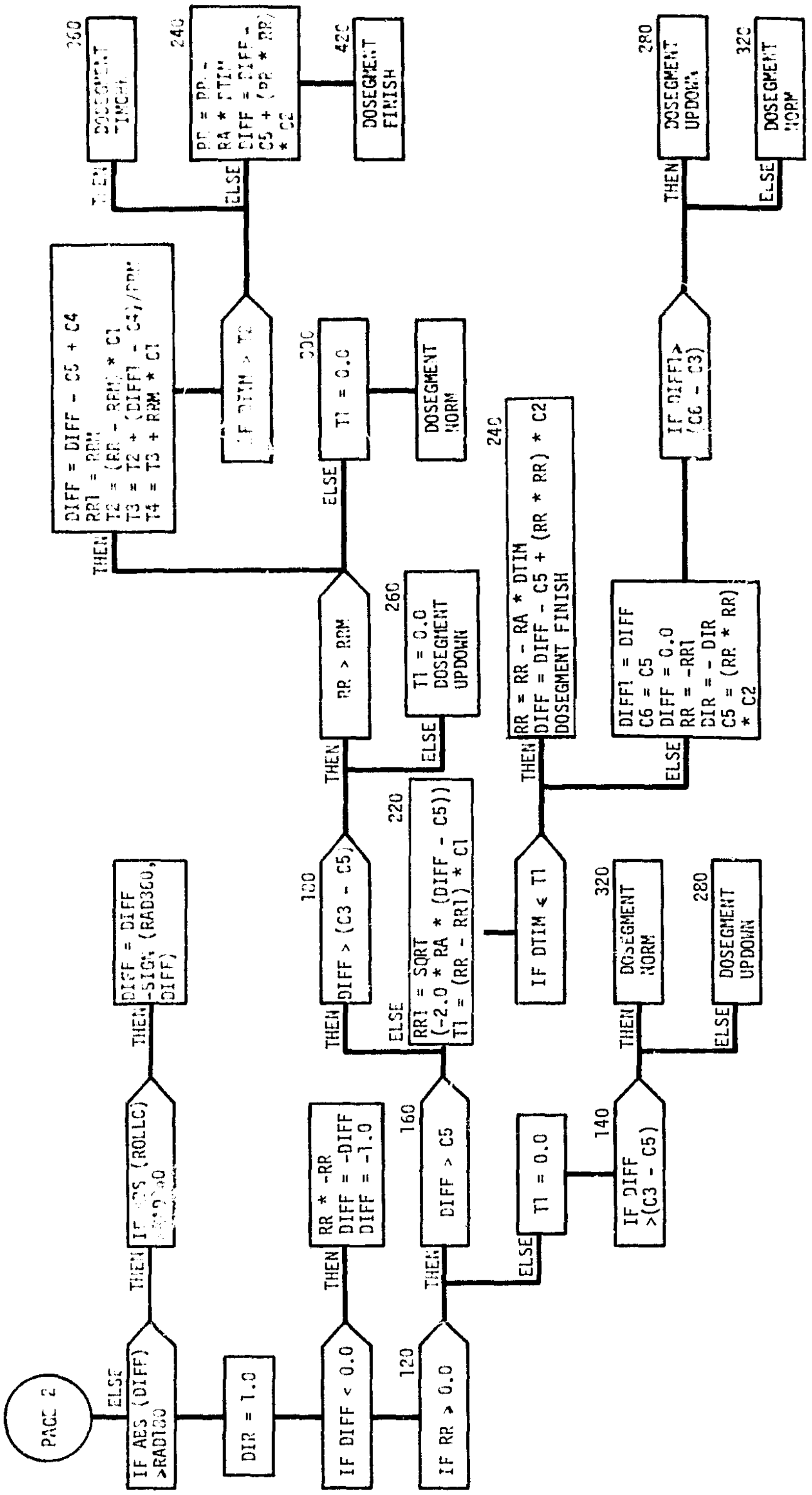
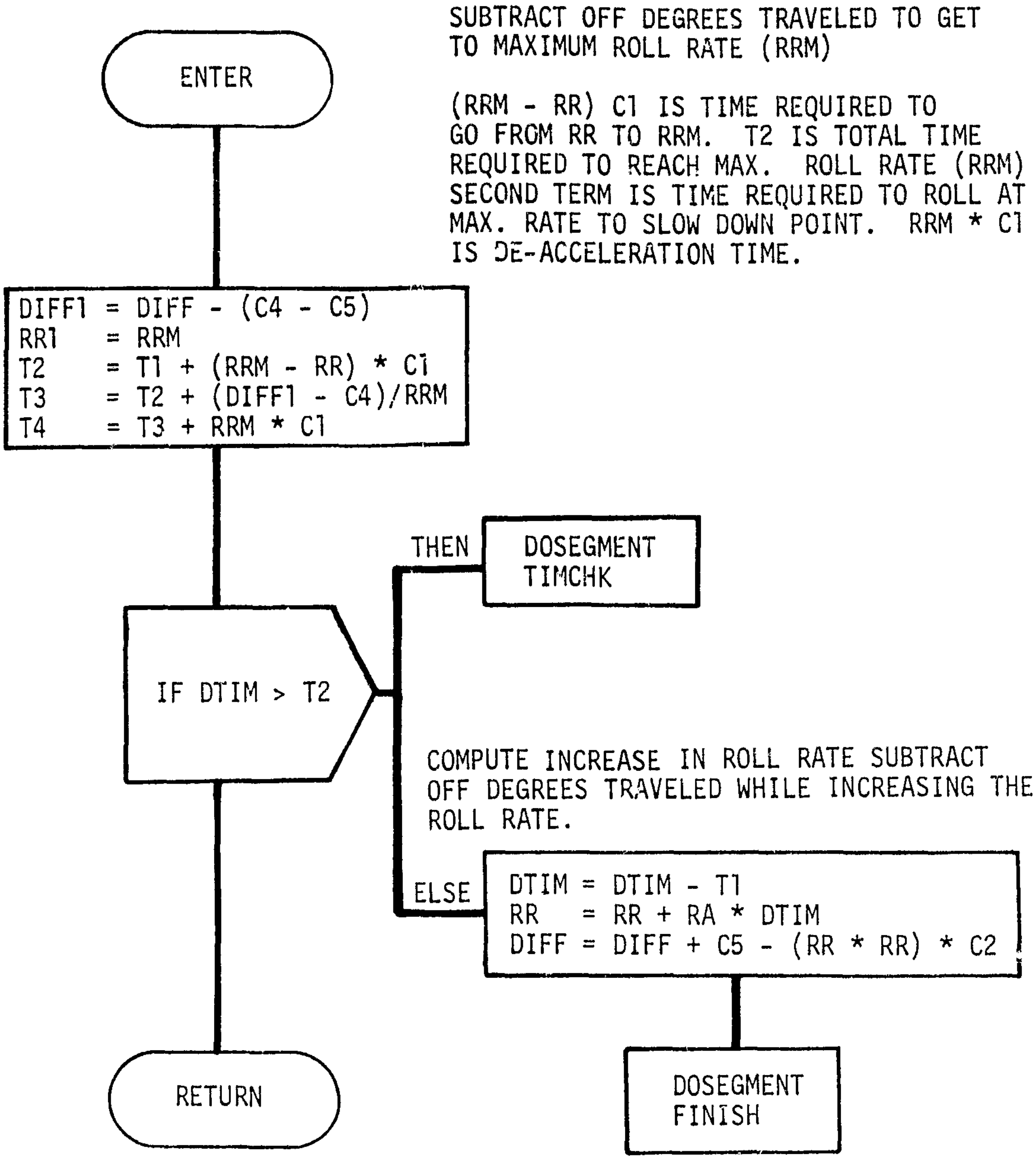


Figure D-1.- Continued.



SUBTRACT OFF DEGREES TRAVELED TO GET TO MAXIMUM ROLL RATE (RRM)

(RRM - RR) C1 IS TIME REQUIRED TO GO FROM RR TO RRM. T2 IS TOTAL TIME REQUIRED TO REACH MAX. ROLL RATE (RRM) SECOND TERM IS TIME REQUIRED TO ROLL AT MAX. RATE TO SLOW DOWN POINT. RRM * C1 IS DE-ACCELERATION TIME.

COMPUTE INCREASE IN ROLL RATE SUBTRACT OFF DEGREES TRAVELED WHILE INCREASING THE ROLL RATE.

SEGMENT NORM

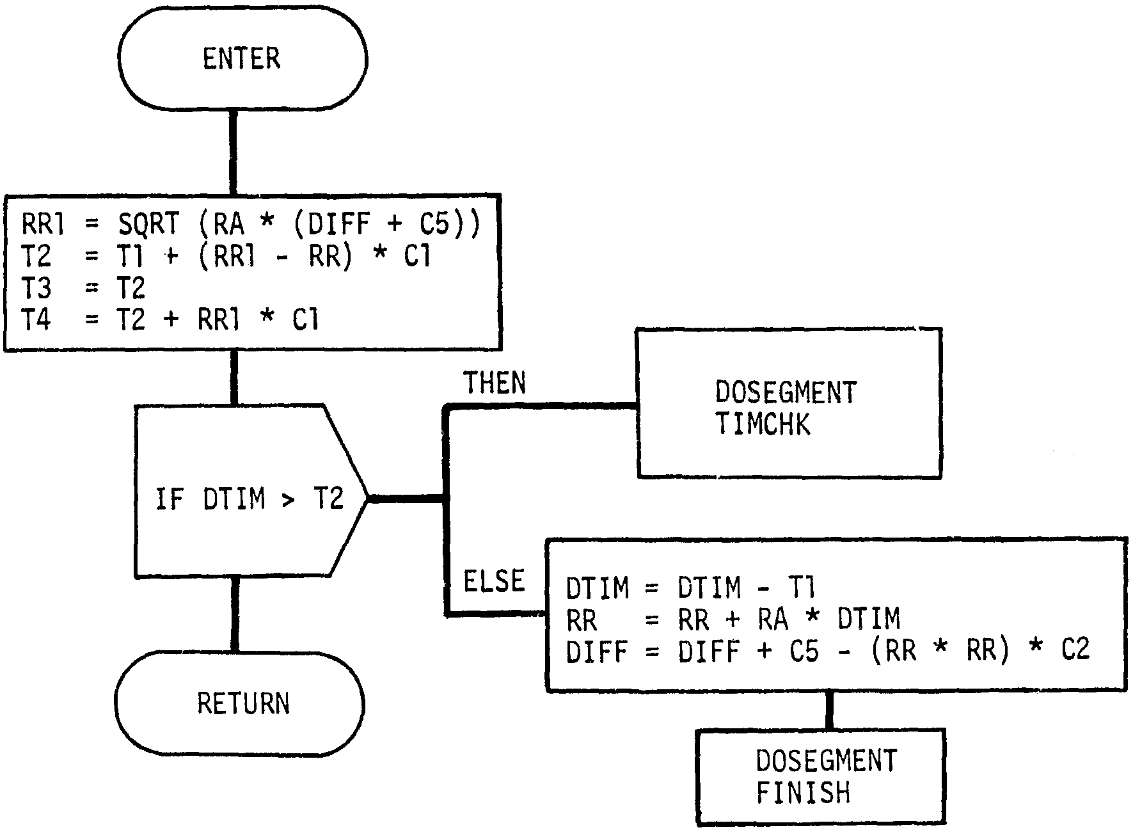
Figure D-1.- Continued.

THIS SEGMENT IS USED FOR TWO PURPOSES.

1. MOST COMMON USE IS WHEN DIFF IS SHORTER THAN DISTANCE TO SPEED ROLLING TO MAX (RRM) PLUS SLOWDOWN DEGREES (C4). HERE RR1 IS MAX VELOCITY REACHED AT START OF SLOWDOWN.
2. A SECOND USE IS WHEN INITIAL ROLL RATE IS AWAY FROM ROLLC. HERE RR1 IS MAX ROLL RATE REACHED COMING BACK TO ROLLC AFTER STOPPING.

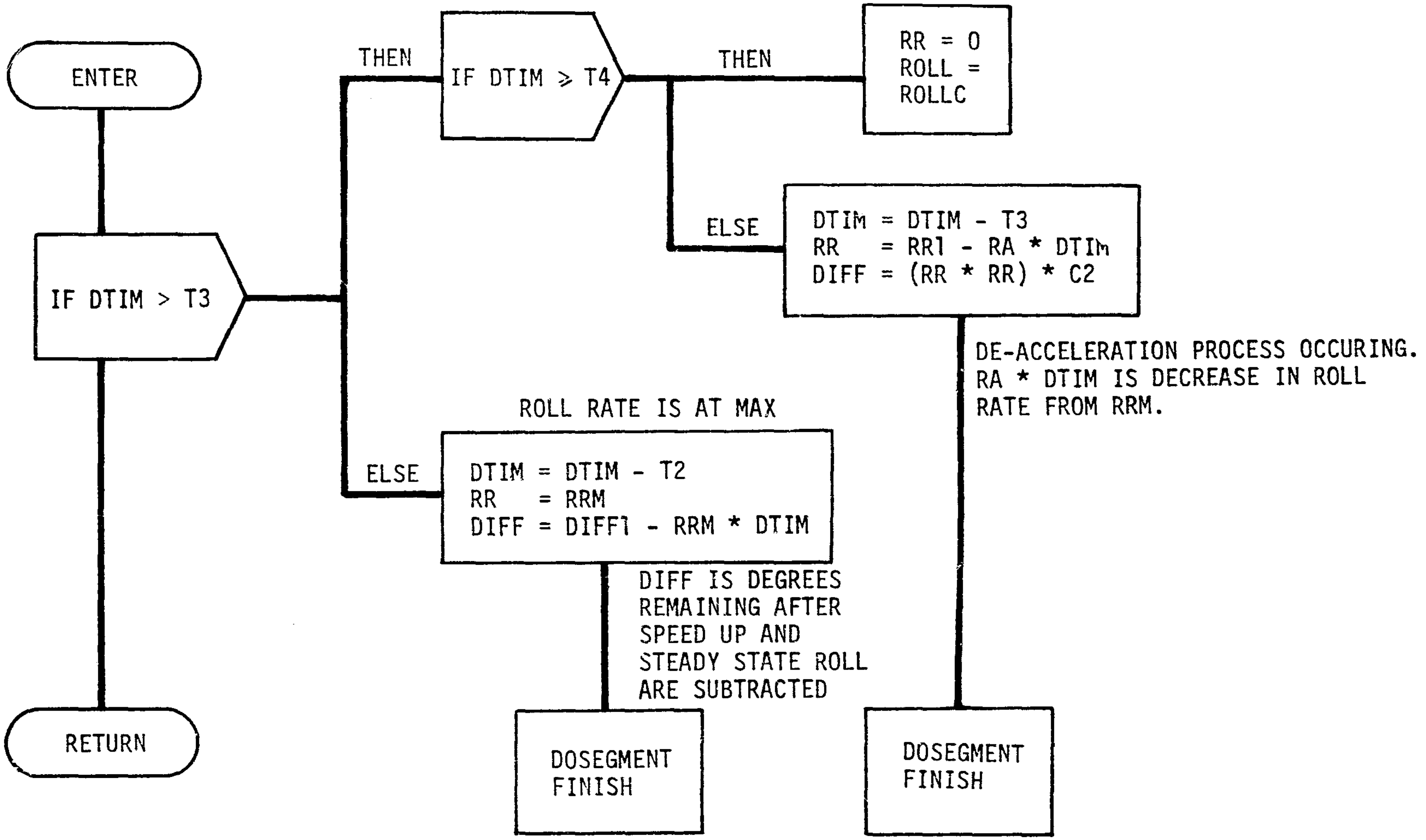
T2 IS THE TIME AT RR1

T4 IS TOTAL TIME TO REDUCE DIFF TO ZERO.



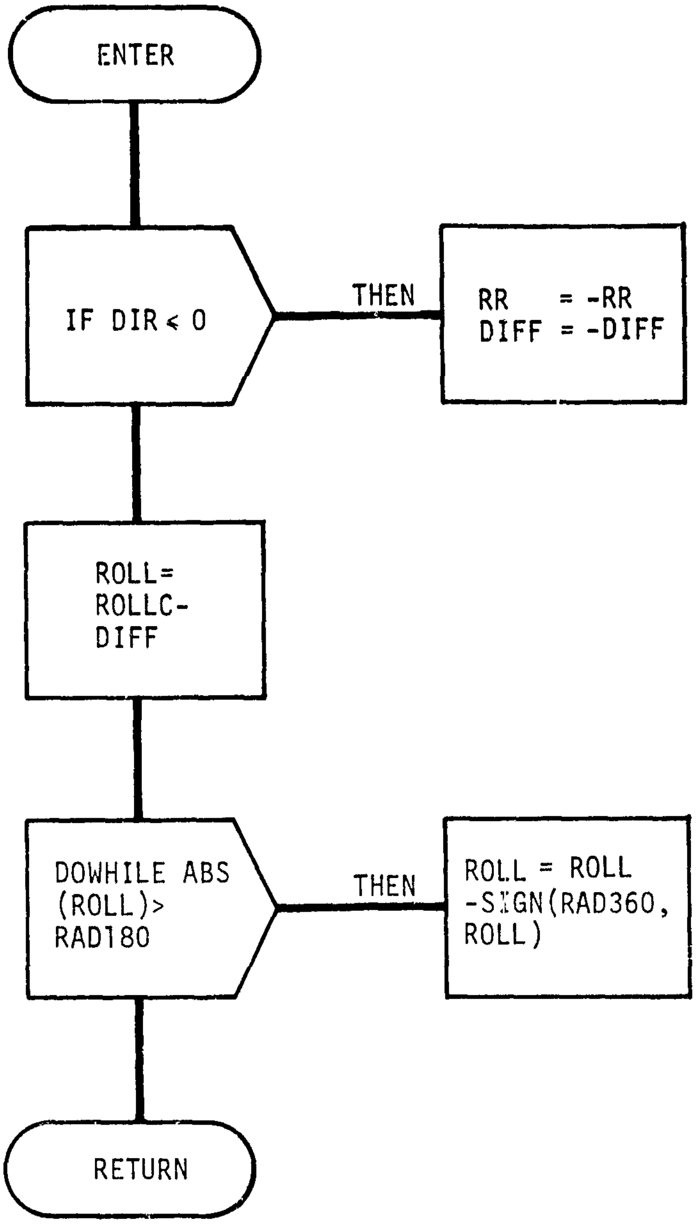
SEGMENT UPDOWN

Figure D-1.- Continued.



SEGMENT TIMCHK

Figure D-1.- Continued.



SEGMENT FINISH

Figure D-1.- Concluded.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980 671-100/2054