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Flight Design System Level C Requirements

Solid Rocket Booster and External Tank Impact Prediction Processors

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SHUTTLE PROGRAM

FLIGHT DESIGN SYSTEM LEVEL C REQUIREMENTS

SOLID ROCKET BOOSTER AND EXTERNAL TANK
IMPACT PREDICTION PROCESSORS

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SYMBOLS

A	AREA OF ET DEBRIS PIECE.
AOA	ABORT ONCE AROUND
ATO	ABORT TO ORBIT
C	CAUSSIAN DISTRIBUTION SCALING CONSTANT
CR	CROSSRANGE
DOF	DEGREE OF FREEDOM
DR	DOWNRANGE
ET	EXTERNAL TANK
ETR	EASTERN TEST RANGE
FDS	FLIGHT DESIGN SYSTEM
GET	GROUND ELAPSED TIME
H	ALTITUDE OF EXTERNAL TANK
HD	GEODETIC ALTITUDE
i	ORBITAL INCLINATION
IIP	INSTANTANEOUS IMPACT POINT
L	LENGTH OF EXTERNAL TANK IMPACT CORRIDOR
LCR	LEFT CROSS RANGE
LSRB	LEFT SOLID ROCKET BOOSTER
MDB	MASTER DATA BASE
MPAD	MISSION PLANNING AND ANALYSIS DIVISION
RCR	RIGHT CROSSRANGE
RI	RANGE FLOWN BY EXTERNAL TANK
RLE	ROTATIONAL LIFTING EFFECT OF EXTERNAL TANK
RSRB	RIGHT SOLID ROCKET BOOSTER
RSS	ROOT SUM SQUARE
RTLS	RETURN TO LAUNCH SITE
SRB	SOLID ROCKET BOOSTER
SVDS	SPARE VEHICLE DYNAMIC SIMULATION
Δt_n	TIME OF NOZZLE IMPACT RELATIVE TO SOLID ROCKET BOOSTER
T	TIME
U	UNCERTAINTY
UR	UPRANGE
ΔUR_n	UPRANGE DISTANCE OF NOZZLE IMPACT POINT RELATIVE TO SOLID ROCKET BOOSTER IMPACT POINT
V	VELOCITY
W	WIDTH OF EXTERNAL TASK IMPACT CORRIDOR
WT	WEIGHT
WTR	WESTERN TEST RANGE
γ	FLIGHT PATH ANGLE
λ	LONGITUDE
μ	GAUSSIAN DISTRIBUTION MEAN
σ	GAUSSIAN DISTRIBUTION STANDARD DEVIATION
ϕ	LATITUDE
Ψ	AZIMUTH ANGLE

SUBSCRIPTS

A	AZIMUTH
AERO	AERODYNAMIC
ATM	ATMOSPHERIC

BU	BREAKUP
C	GEOCENTRIC
D	GEODETIC
DEB	EXTERNAL TANK DEBRIS
DR	DOWNRANGE
DRG	DRAG
e	EARTH RELATIVE
ET	EXTERNAL TANK
H	LIQUID HYDROGEN TANK RUPTURE
i	COUNTER INDEX
I	INERTIAL
IP	IMPACT POINT
L	LEFT SOLID ROCKET BOOSTER
LC	LEFT CROSSRANGE
LIFT	LIFT
LN	LEFT SOLID ROCKET BOOSTER NOZZLE
L/D	LEFT WITH RESPECT TO DOWNRANGE
L/R	LEFT WITH RESPECT TO RIGHT
L/U	LEFT WITH RESPECT TO UPRANGE
N	NOZZLE
o	REFERENCE POINT OR IMPACT POINT
O	LIQUID OXYGEN TANK RUPTURE
R	RIGHT SOLID ROCKET BOOSTER
RC	RIGHT CROSSRANGE
RI	GEOCENTRIC RADIUS VECTOR
RLE	ROTATIONAL LIFTING EFFECT
RN	RIGHT SOLID ROCKET BOOSTER NOZZLE
R/D	RIGHT WITH RESPECT TO DOWNRANGE
R/U	RIGHT WITH RESPECT TO UPRANGE
T	TRAJECTORY OR TOTAL
TRJ	TRAJECTORY
UR	UPRANGE
W	WIND OR WEIGHT

1.0 SUMMARY

This document describes the Level C requirements for the development of the solid rocket booster (SRB) and external tank (ET) impact prediction processors of the Flight Design System (FDS). The Level B requirements for these processors were specified in Reference 1. Sections 3 and 4 of this document specify the requirements for the two processors to compute and plot the SRB impact footprint data. Sections 5 and 6 present the requirements for the two processors which generate the ET impact footprint data for RTLS profiles. Sections 7 and 8 present the requirements for the two processors which generate the ET data for nominal, AOA, and ATO profiles. The appendixes contain the requirements for several general subprograms used by more than one of the SRB and ET processors described in the body of the report.

2.0 INTRODUCTION

2.1 PURPOSE

The Mission Planning and Analysis Division (MPAD) of Johnson Space Center (JSC) is responsible for performing the flight design for operational flights of the Space Transportation System (STS). In order to accomplish the flight design process for the high flight rates of the STS, a computerized Flight Design System (FDS) is being developed. The Level B requirements for this system are documented in Reference 1. FDS processors will be used to predict the impact areas of the solid rocket boosters (SRB) and external tank (ET). The purpose of this document is to specify the Level C requirements for the SRB and ET impact prediction FDS processors.

2.2 APPROACH

The prediction of the SRB and ET impact areas requires six separate processors. The SRB Impact Prediction Processor computes the impact areas and related trajectory data for each SRB element. Output from this processor is stored on a secure file accessible by the SRB Impact Plot Processor which generates the required plots. Similarly the ET RTLS Impact Prediction Processor and the ET RTLS Impact Plot Processor generates the ET impact footprints for return-to-launch-site (RTLS) profiles. The ET Nominal/AOA/ATO Impact Prediction Processor and the ET Nominal/AOA/ATO Impact Plot Processor generates the ET impact footprints for non-RTLS profiles.

The SRB and ET impact processors compute the size and shape of the impact footprints by tabular lookup in a stored footprint dispersion data base. The location of each footprint is determined by simulating a reference trajectory and computing the reference impact point location.

To insure consistency among all FDS users, much input required by these processors will be obtained from the FDS Master Data Base (MDB). Parameters such as launch date, time, and site, atmospheric and wind properties, and SRB and ET weights should be available in the MDB. User input at the time of execution will be minimized by using flags to select MDB inputs, and preconstructed data elements containing aerodynamic coefficients and other trajectory related parameters.

3.0 SRB IMPACT PREDICTION PROCESSOR

The purpose of the SRB Impact Prediction Processor is to compute the impact areas and the related SRB trajectory data for the two SRB's and their nozzle extensions. An overview of the processor executive is shown in Figure 3.0-1.

The locations of the SRB impact footprints are determined by simulating the nominal descent trajectories of each SRB and computing the latitude and longitude of the impact points as indicated in task 4. The location of the impact points of the nozzle extensions relative to the SRB's are correlated and stored in the processor data base. Based on the particular trajectory initial conditions, the nozzle extension impact points are computed by tabular lookup in task 3.

The downrange and crossrange dispersions of the SRB and nozzle extension impact points due to separation condition and wind uncertainties are stored in the processor data base. Tabular lookup is used in task 1 to compute the mission dependent impact dispersions which combine to form the footprints in task 2.

Output from the processor consists of a sequence of events during the SRB descent, a table of nominal impact point locations for each element, and a table listing the footprint size of each element. The data required to plot the footprints and altitude time histories of each SRB are stored on secure files which can be accessed by the SRB Impact Plot Processor. The requirements for this processor are described in Section 4.0.

The following subsections describe the detailed requirements for each task presented in the executive overview.

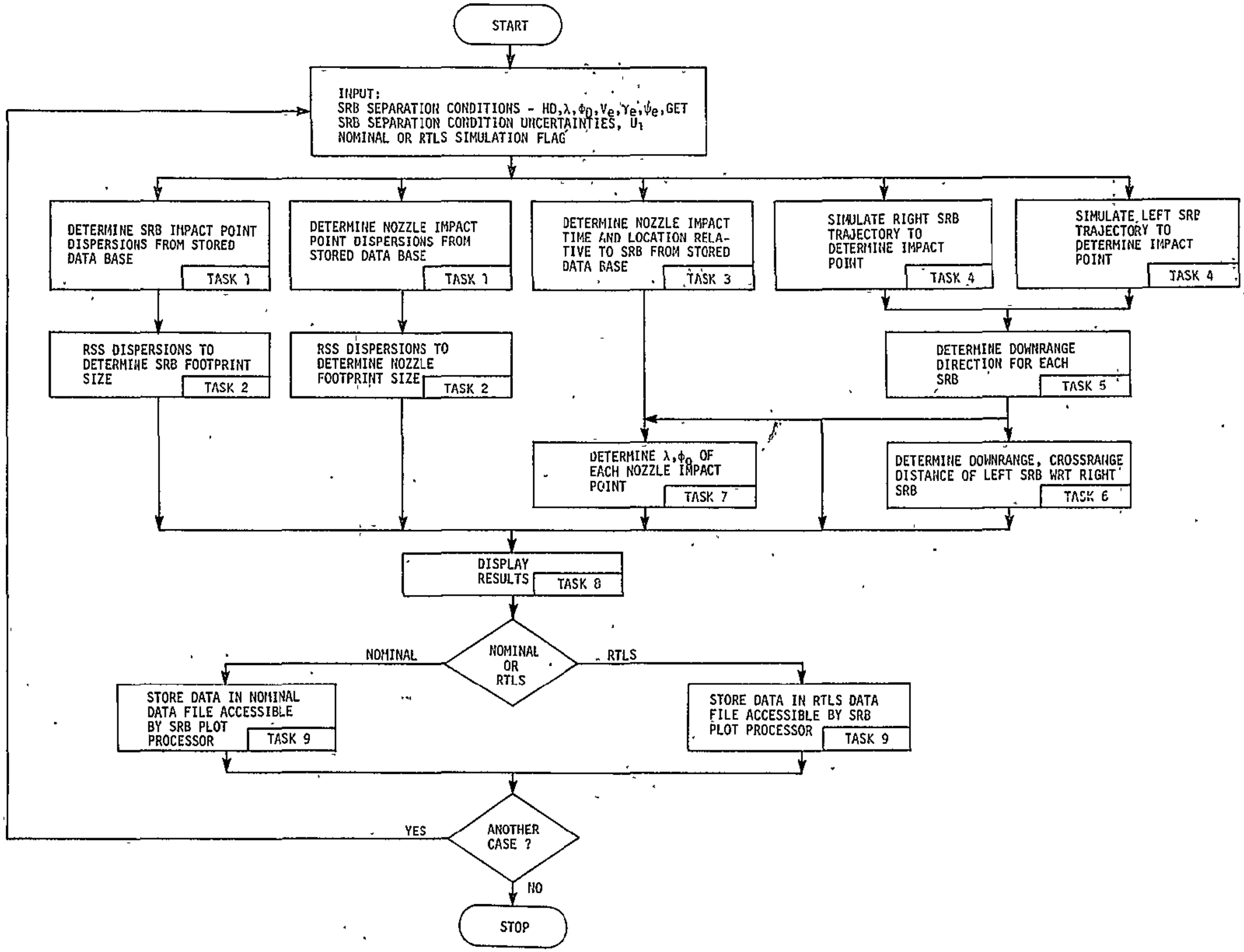


FIGURE 3.0-1 SRB IMPACT PREDICTION PROCESSOR EXECUTIVE FLOWCHART

3.1 SRB IMPACT DATA BASE

The stored data base of this processor consists of data required to determine the footprint size of the SRB and nozzle extension, location of the nozzle impact point relative to the SRB, and the time of nozzle impact relative to the SRB. Table 3.1-I presents the data required to determine the SRB impact footprint size. The uprange, downrange, and crossrange dispersions caused by separation condition uncertainties are expressed as sensitivities or partial derivatives and are constant for all trajectories. The dispersions due to winds are correlated as a function of launch azimuth, while those due to trimmed lift are constant.

The data base for the nozzle extension is presented in Table 3.1-II. The footprint dispersion parameters are the same as the SRB. The nozzle impact location and time relative to the SRB are correlated as a function of SRB separation altitude, velocity, and flight path angle.

TABLE 3.1-I SRB DATA BASE PARAMETERS

GROUP	DEPENDENT VARIABLE	INDEPENDENT VARIABLE
SRB Separation	$\frac{\partial DR}{\partial HD}, \frac{\partial DR}{\partial DR}, \frac{\partial DR}{\partial CR}, \frac{\partial DR}{\partial V_e}, \frac{\partial DR}{\partial \gamma_e}, \frac{\partial DR}{\partial \Psi_e}$	NONE
	$\frac{\partial UR}{\partial HD}, \frac{\partial UR}{\partial DR}, \frac{\partial UR}{\partial CR}, \frac{\partial UR}{\partial V_e}, \frac{\partial UR}{\partial \gamma_e}, \frac{\partial UR}{\partial \Psi_e}$	(CONSTANT)
	$\frac{\partial CR}{\partial HD}, \frac{\partial CR}{\partial DR}, \frac{\partial CR}{\partial CR}, \frac{\partial CR}{\partial V_e}, \frac{\partial CR}{\partial \gamma_e}, \frac{\partial CR}{\partial \Psi_e}$	
Lift Dispersions	DR = constant	NONE (CONSTANT)
	UR = constant	
	CR = constant	
Wind Dispersions	DR (Ψ_i)	LAUNCH AZIMUTH Ψ_i, i=1, 6
	UR (Ψ_i)	
	LCR (Ψ_i)	
	RCR (Ψ_i)	

TABLE 3.1-II - NOZZLE EXTENSION DATA BASE PARAMETERS

LOCATION AND TIME OF IMPACT RELATIVE TO SRB:

DEPENDENT VARIABLES			INDEPENDENT VARIABLES
$\frac{\partial UR}{\partial HD}$	$\frac{\partial UR}{\partial V_e}$	$\frac{\partial UR}{\partial \gamma_e}$	HD, Ve, γ_e
$\frac{\partial(\Delta t)}{\partial HD}$	$\frac{\partial(\Delta T)}{\partial V_e}$	$\frac{\partial(\Delta t)}{\partial \gamma_e}$	HD, Ve, γ_e

SIZE OF FOOTPRINT:

GROUP	DEPENDENT VARIABLE	INDEPENDENT VARIABLE
SRB Separation Condition Dispersion	$\frac{\partial DR}{\partial HD}, \frac{\partial DR}{\partial DR}, \frac{\partial DR}{\partial CR}, \frac{\partial DR}{\partial V_e}, \frac{\partial DR}{\partial \gamma_e}, \frac{\partial DR}{\partial \Psi_e}$	NONE (CONSTANT)
	$\frac{\partial UR}{\partial HD}, \frac{\partial UR}{\partial DR}, \frac{\partial UR}{\partial CR}, \frac{\partial UR}{\partial V_e}, \frac{\partial UR}{\partial \gamma_e}, \frac{\partial UR}{\partial \Psi_e}$	
	$\frac{\partial CR}{\partial HD}, \frac{\partial CR}{\partial DR}, \frac{\partial CR}{\partial CR}, \frac{\partial CR}{\partial V_e}, \frac{\partial CR}{\partial \gamma_e}, \frac{\partial CR}{\partial \Psi_e}$	
Wind Dispersions	DR (Ψ_i)	LAUNCH AZIMUTH Ψ_i, i=1,6
	UR (Ψ_i)	
	LCR (Ψ_i)	
	RCR (Ψ_i)	

NOTE: HD, Ve, γ_e, DR, CR, and Ψ_e are values of the SRB separation state vector.

3.2 IMPACT POINT DISPERSIONS - TASK 1

The impact point dispersions of the SRB's and the nozzle extensions are computed by tabular lookup and linear interpolation of the data base.

Figure 3.2-1 presents a flowchart for this task.

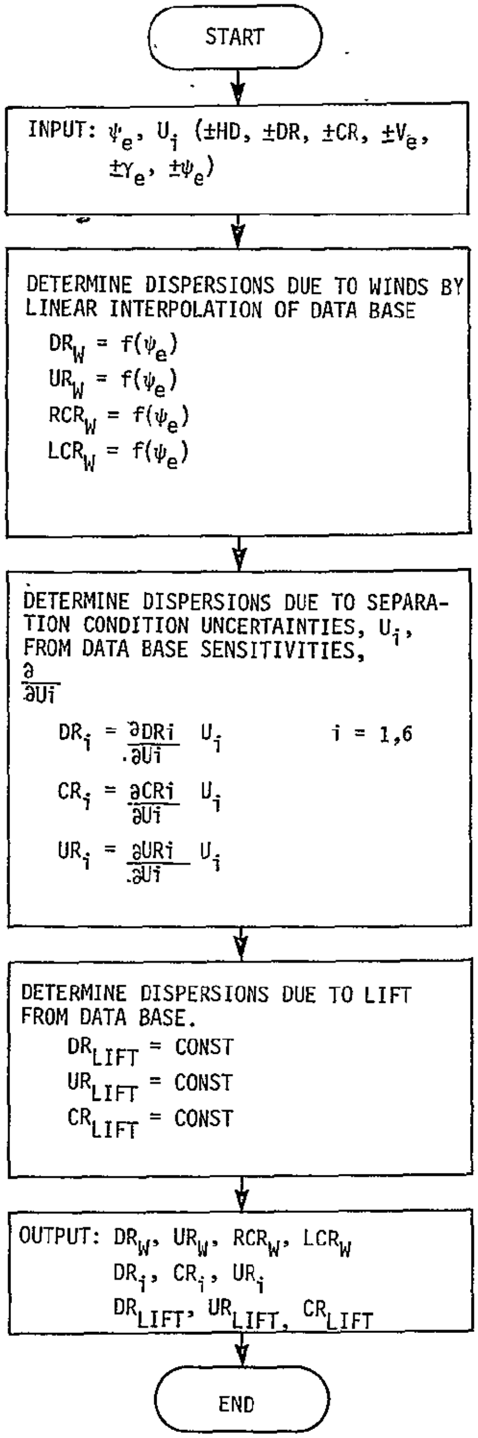


FIGURE 3.2-1 SRB IMPACT POINT DISPERSIONS FLOWCHART (TASK 1)

3.3 FOOTPRINT DIMENSIONS - TASK 2

The sizes of the footprints for the SRB and nozzle extensions are obtained by root-sum-squaring the impact point dispersions computed in task 1. Figure 3.3-1 presents a flowchart for this task.

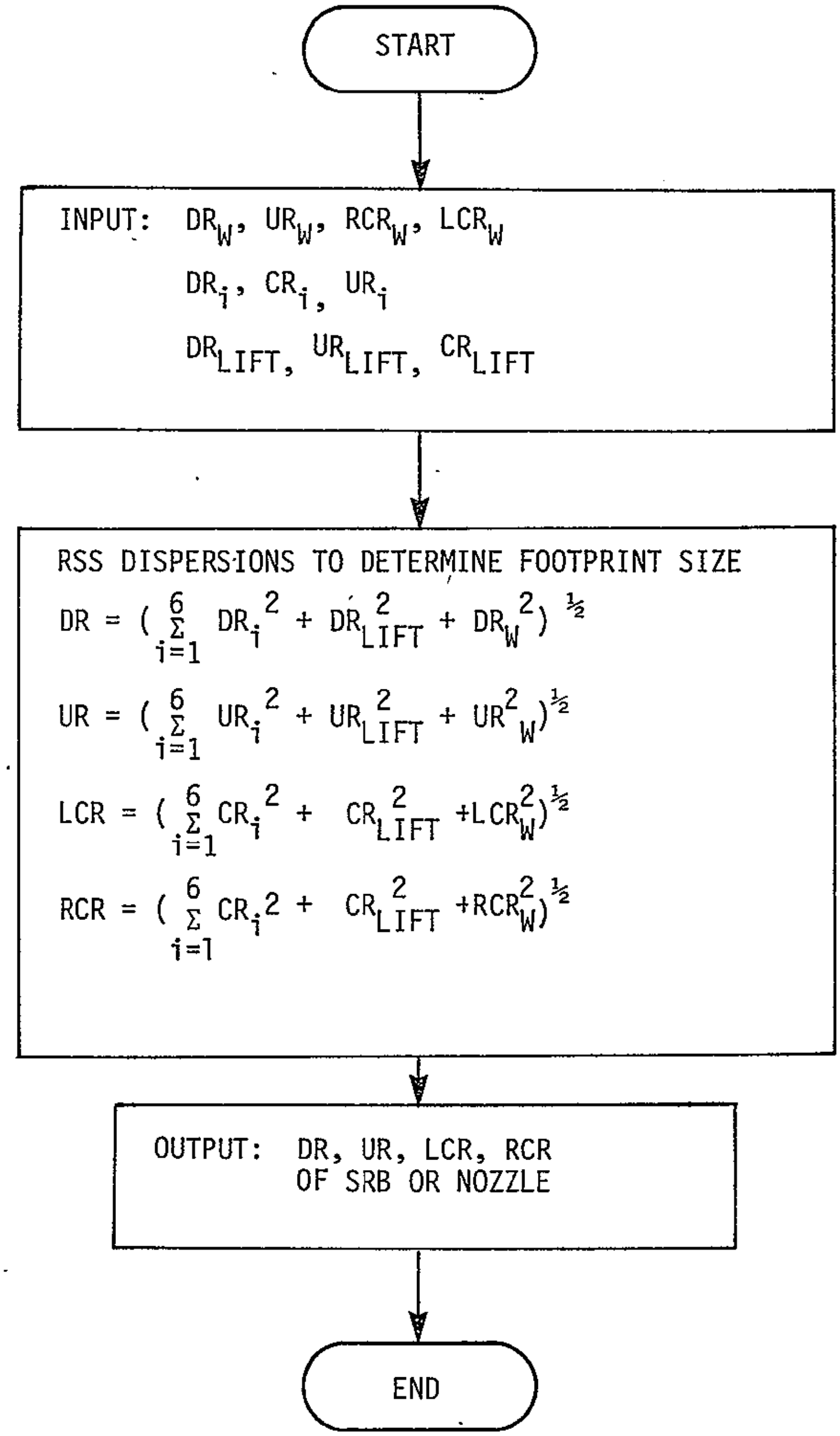


FIGURE 3.3-1 SRB FOOTPRINT DIMENSION FLOWCHART (TASK 2)

3.4 NOZZLE EXTENSION IMPACT TIME AND LOCATION - TASK 3

The time and location of the nozzle impact relative to the SRB is determined by linear interpolation of the nozzle data base. The independent variables are the altitude, velocity, and flight path angle at SRB separation. Figure 3.4-1 presents a flowchart of this task.

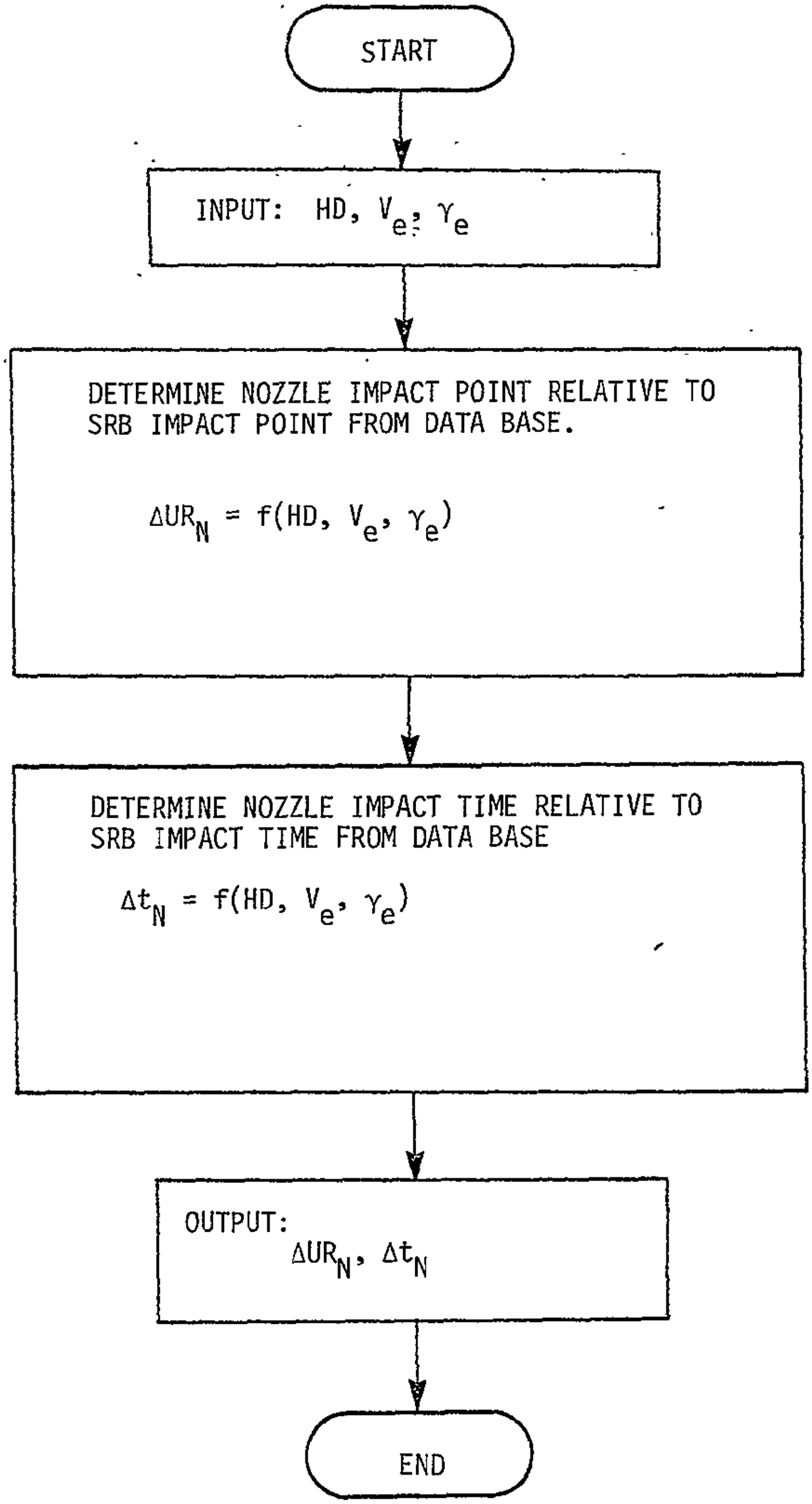


FIGURE 3.4-1 NOZZLE IMPACT TIME AND LOCATION FLOWCHART (TASK 3)

3.5 SRB DESCENT TRAJECTORY - TASK 4

The trajectory of both the left and right SRB's are simulated from SRB separation to impact. The requirements for a general 3-DOF trajectory simulation are presented in Appendix A. In order to minimize user workload at the time of execution, an input system incorporating a series of base case data elements containing data that will not change at each execution is desired. At the time of execution the data peculiar to the particular trajectory will be input. These data are the SRB separation position, velocity, ground elapsed time, and the time of nozzle jettison. Figure 3.5-1 is a flowchart of this task illustrating the input and output parameters.

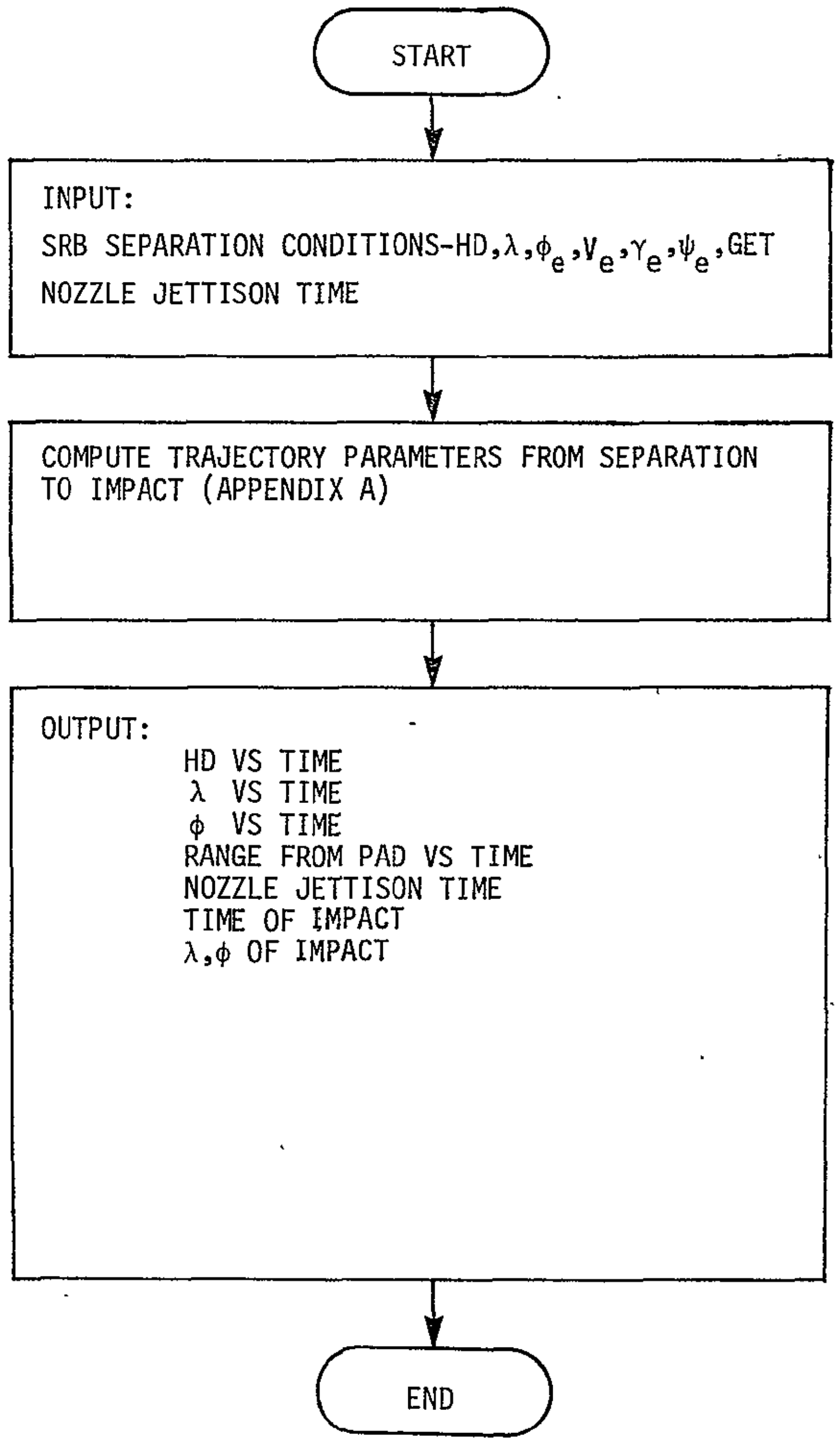
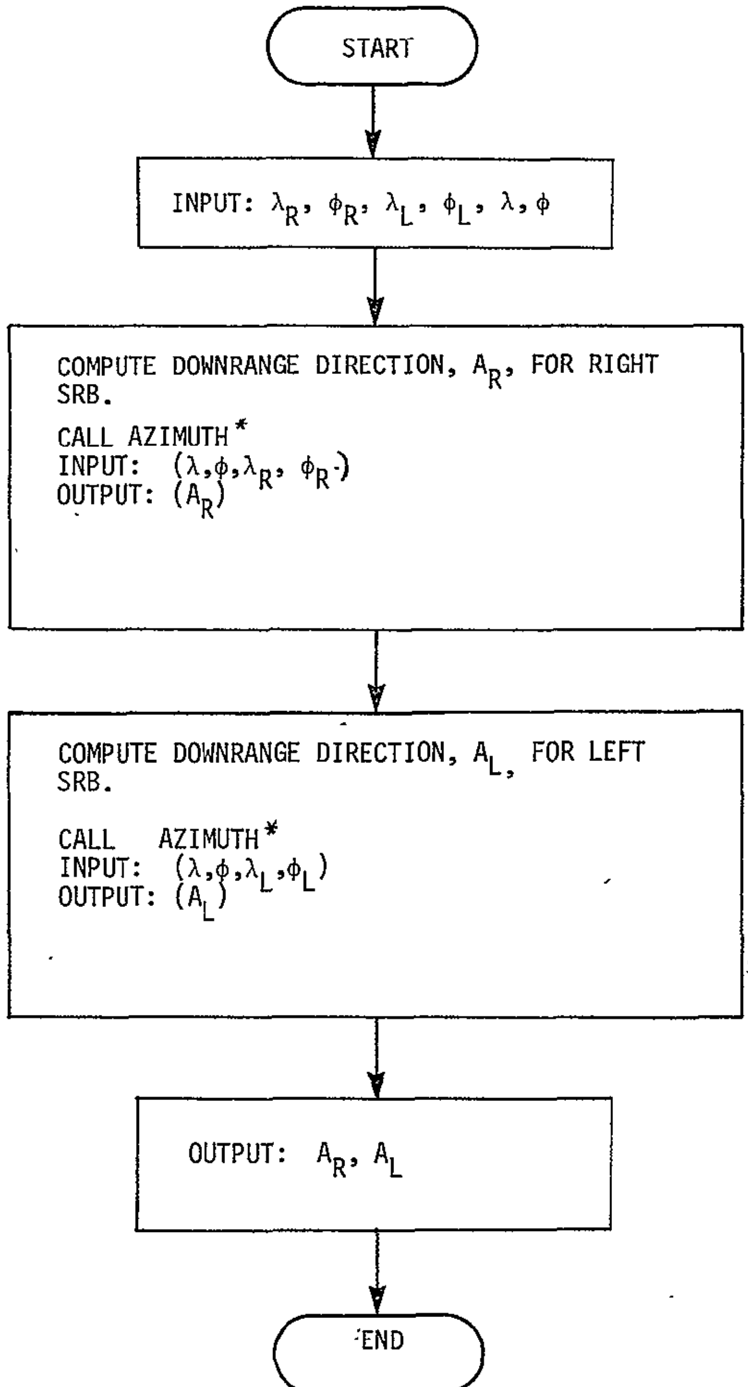


FIGURE 3.5-1 SRB DESCENT TRAJECTORY FLOWCHART (TASK 4)

3.6 SRB DOWNRANGE DIRECTION - TASK 5

The downrange direction relative to North is computed for each SRB. These angles are required to orient the impact footprints on a map and to compute relative distances between element impact points. Figure 3.6-1 presents a flowchart for this computation.

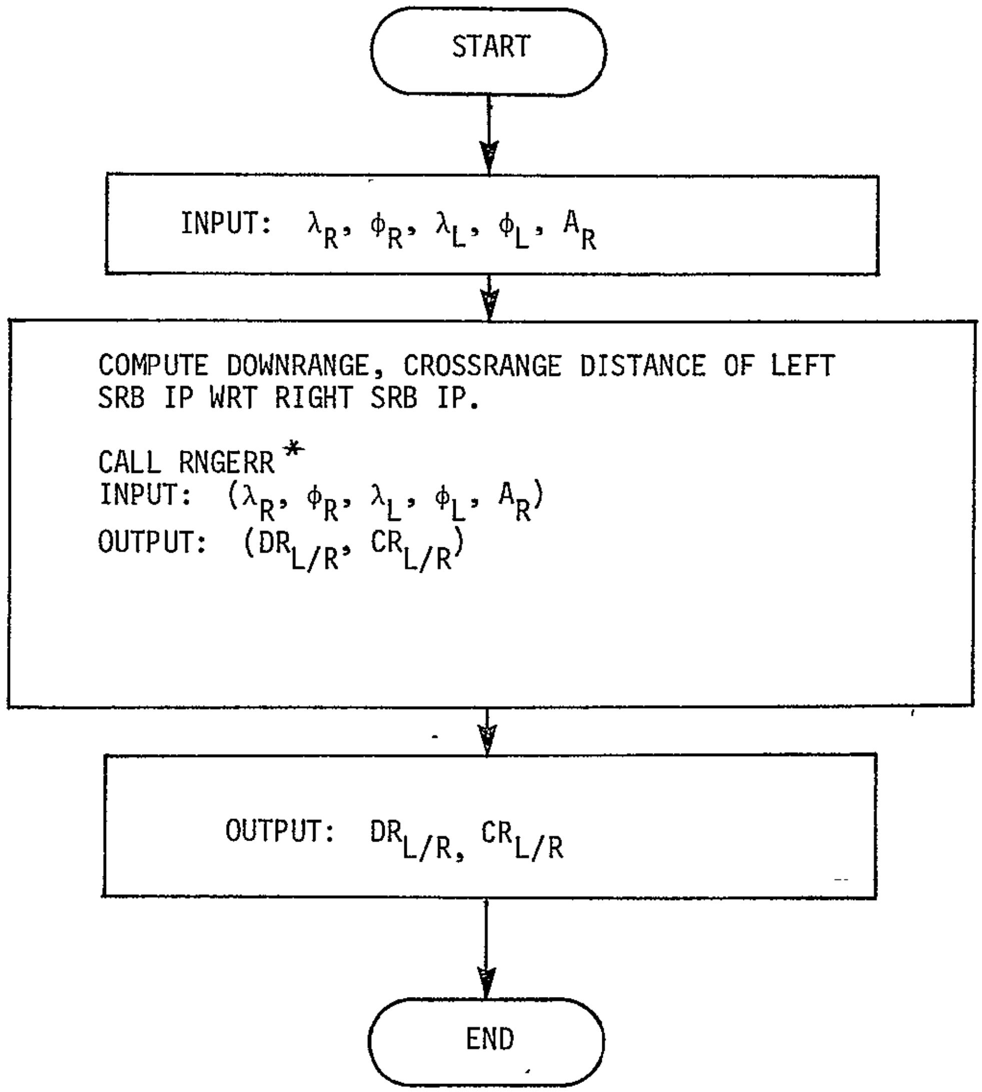


*APPENDIX C

FIGURE 3.6-1 SRB DOWNRANGE DIRECTION FLOWCHART (TASK 5)

3.7 IMPACT POINT RELATIVE DISTANCE - TASK 6

The relative downrange and crossrange of the left SRB with respect to the right SRB is computed as illustrated in Figure 3.7-1.

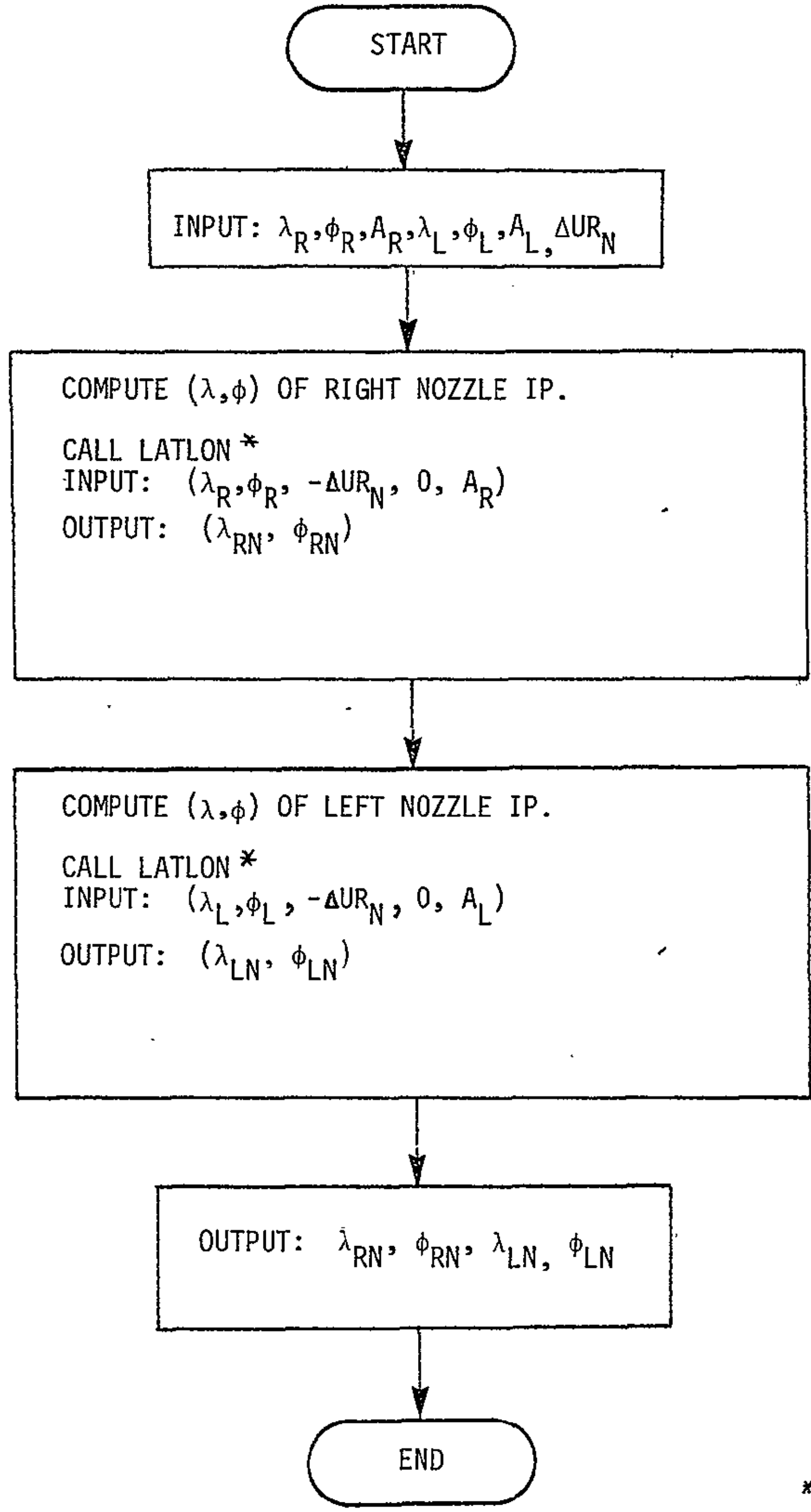


*APPENDIX D

FIGURE 3.7-1 SRB IMPACT POINT RELATIVE DISTANCE FLOWCHART (TASK 6)

3.8 NOZZLE IMPACT POINT LOCATION - TASK 7

The latitude and longitude of each nozzle is computed from the SRB impact latitude and longitude and the relative position of the nozzle with respect to the SRB as shown in Figure 3.8-1.



*APPENDIX E

FIGURE 3.8-1 NOZZLE IMPACT POINT LOCATION FLOWCHART (TASK 7)

3.9 OUTPUT DISPLAYS - TASK 8

Tabular output from the SRB Impact Prediction Processor will consist of terminal screen displays and hardcopy print of document quality. Tables 3.9-I through 3.9-III are examples of the data and format to be output. Tables 3.9-I is a list of the SRB separation conditions. Table 3.9-II is a list of the sequence of events during the SRB descent trajectory. Table 3.9-III is a list of the element impact point parameters and the footprint dimensions of each element.

TABLE 3.9-I EXAMPLE SRB SEPARATION CONDITIONS TABLE

GET =	124.64	sec.
HD =	165063.85	ft.
λ =	-80.271208	deg.
ϕ_D =	28.814192	deg.
V_e =	4026.8563	fps.
γ_e =	38.818961	deg.
Ψ_e =	55.335925	deg.
RI =	21074612.	ft.
ϕ_c =	28.653253	deg.
V_I =	4999.4456	fps.
γ_I =	30.325536	deg.
Ψ_I =	65.574246	deg.

TABLE 3.9-II

EXAMPLE SRB SEQUENCE OF EVENTS TABLE

	TIME (SEC)	ALTITUDE (FT.)
SRB SEPARATION (LIFTOFF + 124.64 sec)	0.0	155064.
NOZZLE JETTISON	82.4	269558.
NOSE CAP JETTISON	238.1	17000.
FRUSTUM JETTISON	261.1	7000.
SRB IMPACT	309.9	0.
NOZZLE EXTENSION IMPACT	363.0	0.

TABLE 3.9-III EXAMPLE SRB IMPACT SUMMRY TABLE

IMPACT POINT:

ELEMENT	GEODETIC LATITUDE (deg.)	LONGITUDE (deg.)	RANGE FROM PAD (n.mi.)	DR (n.mi)	CR (n.mi.)	GROUND ELAPSED TIME (sec.)
Right SRB	29.790	-78.615	126.2	---	---	434.5
Left SRB	29.783	-78.610	126.2	0.0**	0.5**	434.7
Right Nozzle	29.741	-78.703	120.8	-5.4*	0.0*	487.6
Left Nozzle	29.734	-78.698	120.8	-5.4*	0.0*	487.6

FOOTPRINT DIMENSIONS:

ELEMENT	UPRANGE (n.mi.)	DOWNRANGE (n.mi.)	LEFT CROSSRANGE (n.mi.)	RIGHT CROSSRANGE (n.mi.)
SRB	4.04	4.37	1.72	1.68
NOZZLE	2.62	5.32	1.17	0.95

*DR, CR are Downrange and Crossrange relative to respective SRB.
**DR, CR are Downrange and Crossrange relative to the right SRB.

3.10 STORED PLOT DATA - TASK 9

All data required by the SRB Impact Plot Processor is stored in secure catalogued files. Based on an input flag, the required data will be stored in a nominal data file or an RTLS data file. Table 3.10-I lists the parameters which are stored in the files and used by the plot processor.

TABLE 3.10-I SRB STORED PLOT DATA

PARAMETER	DESCRIPTION
DR, UR, LCR, RCR	FOOTPRINT SIZE FOR EACH SRB AND NOZZLE.
λ, ϕ_D	IMPACT POINTS FOR EACH SRB AND NOZZLE.
A_R, A_L	DOWNRANGE DIRECTION OF EACH SRB.
H_D vs. TIME λ vs. TIME ϕ_d vs TIME RANGE vs. TIME	TRAJECTORY PARAMETERS FOR EACH SRB.
ΔUR NOZZLE $DR_{L/R}$, $CR_{L/R}$	RELATIVE DISTANCES OF IMPACT POINTS.

4.0 SRB IMPACT PLOT PROCESSOR

The purpose of the SRB Impact Plot Processor is to plot the SRB impact data generated by the SRB Impact Prediction Processor. Footprints of both SRB's and nozzle extensions and the altitude time histories of the SRB's are plotted. The data required by the processor is stored on either a nominal or RTLS data file. The plot processor accesses the data and constructs the desired plots. Figures 4.0-1 through 4.0-4 present examples of the plots to be generated. An overview of the processor executive is presented in Figure 4.0-5. The following subsections describe the detailed requirements for each task presented in the executive flowchart.

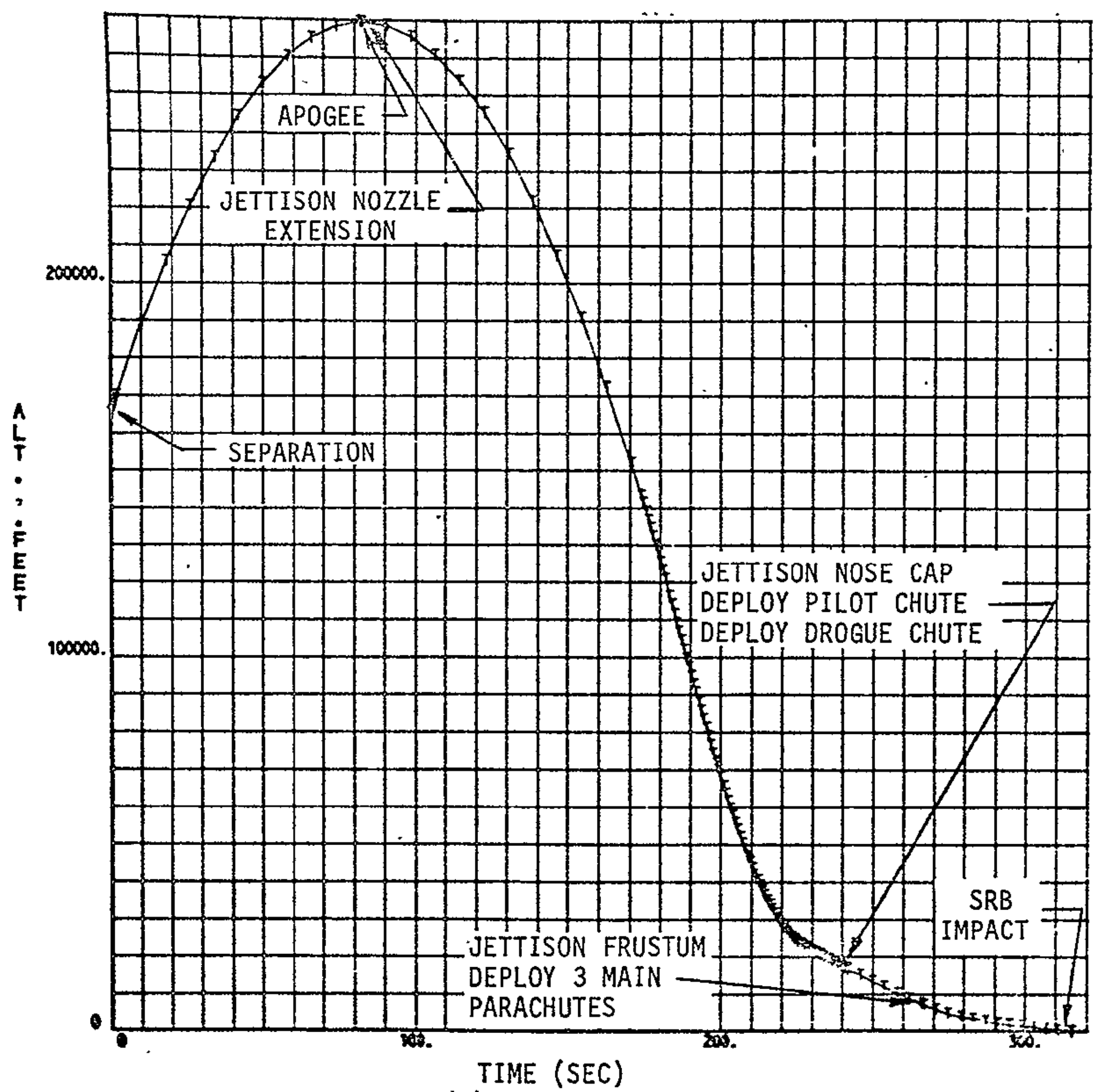


FIGURE 4.0-1

EXAMPLE SRB ALTITUDE TIME HISTORY PLOT

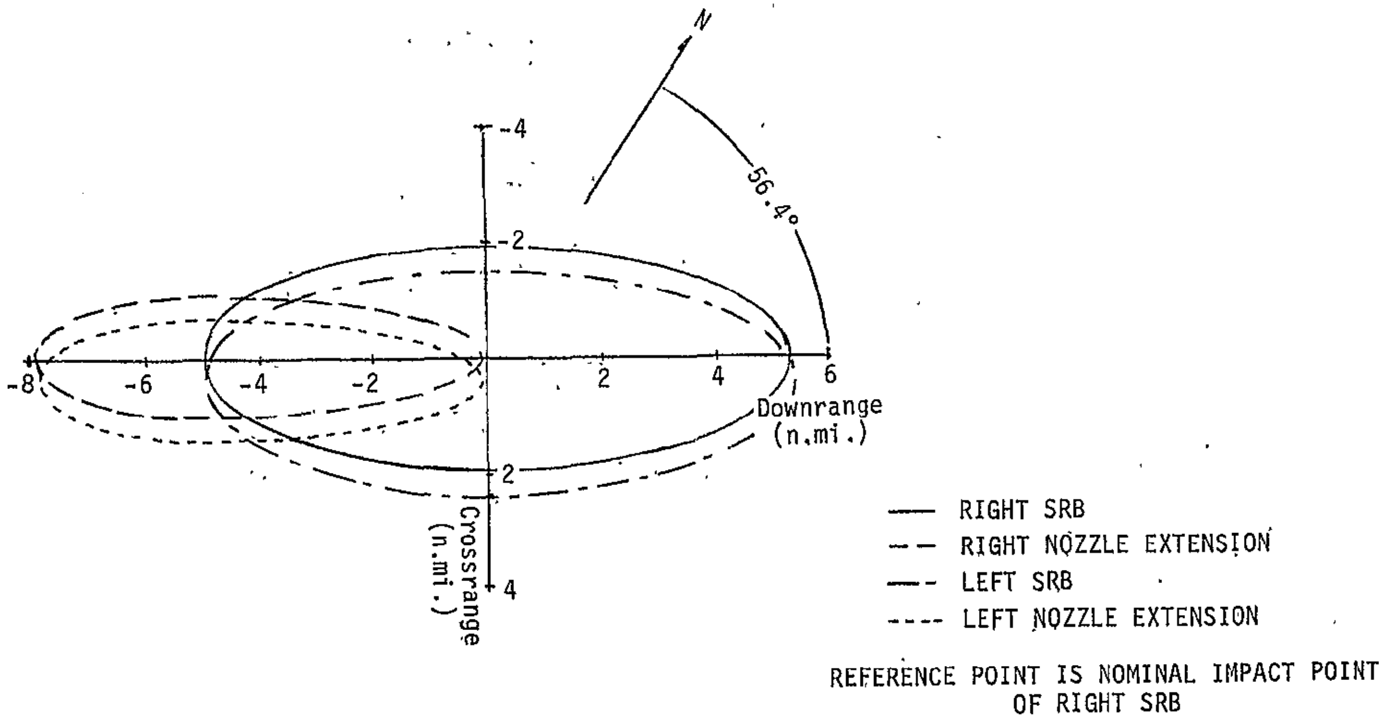


FIGURE 4.0-2 EXAMPLE SRB, NOZZLE FOOTPRINT PLOT

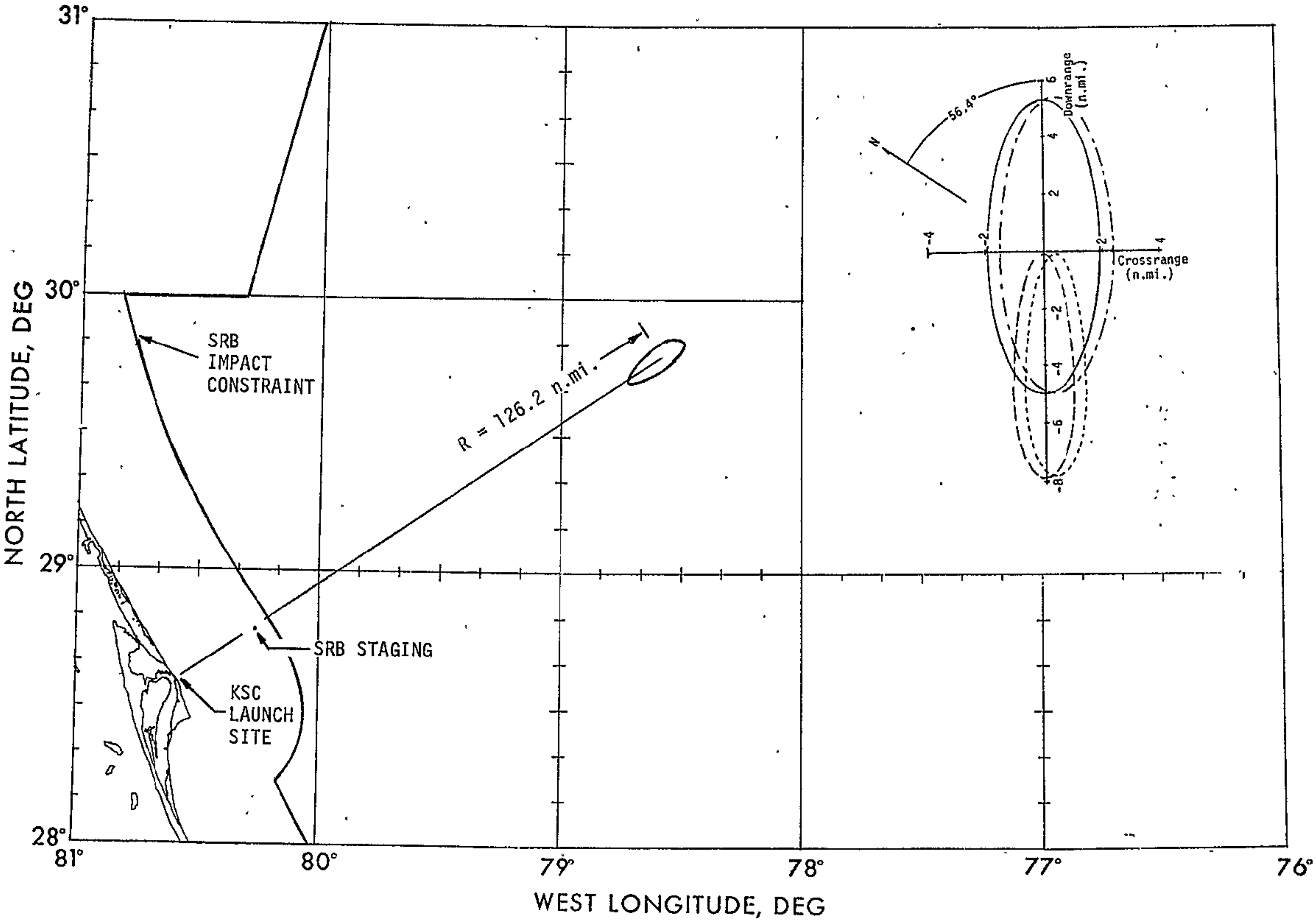


FIGURE 4.0-3 EXAMPLE SRB COMPOSITE FOOTPRINT PLOT

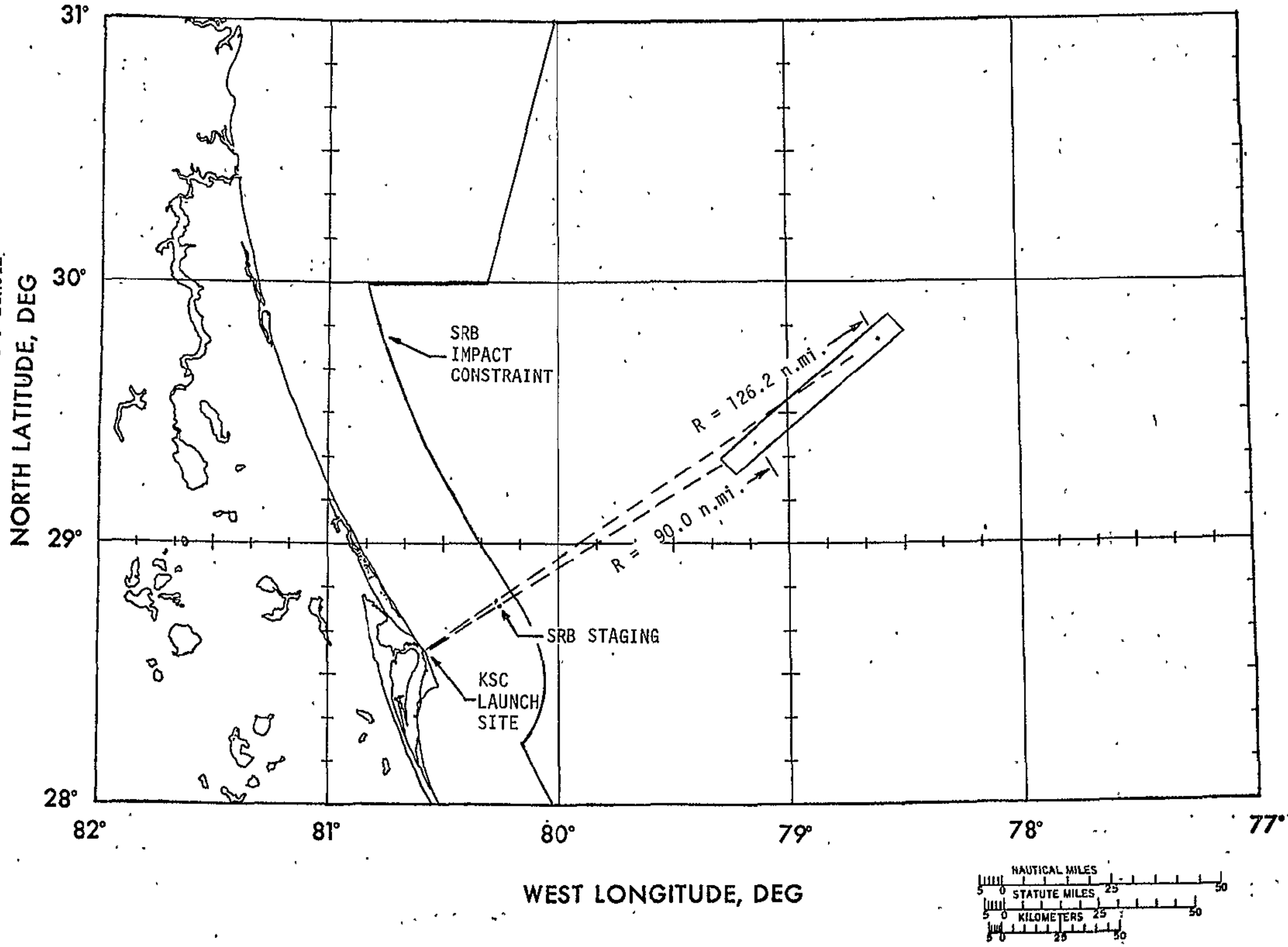


FIGURE 4.0-4 EXAMPLE SRB IMPACT CORRIDOR PLOT

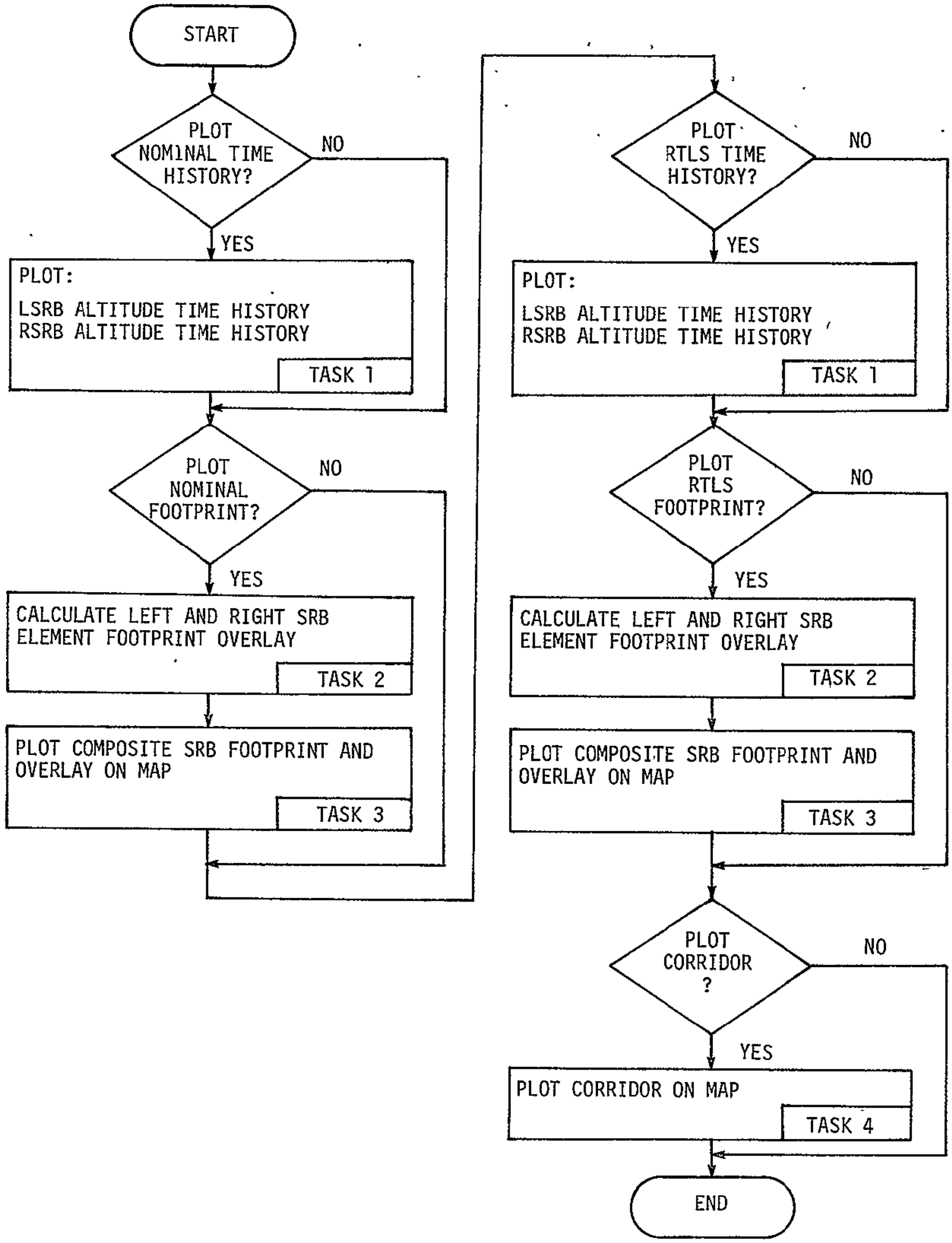


FIGURE 4.0-5 SRB IMPACT PLOT PROCESSOR EXECUTIVE FLOWCHART

4.1 SRB ALTITUDE TIME HISTORY PLOT - TASK 1

Figure 4.1-1 presents a flowchart for plotting the SRB altitude time histories. The format of the plot is presented in Figure 4.0-1. SRB separation, nozzle jettison, nose cap jettison, main chute deployment, and impact are labeled on the plot.

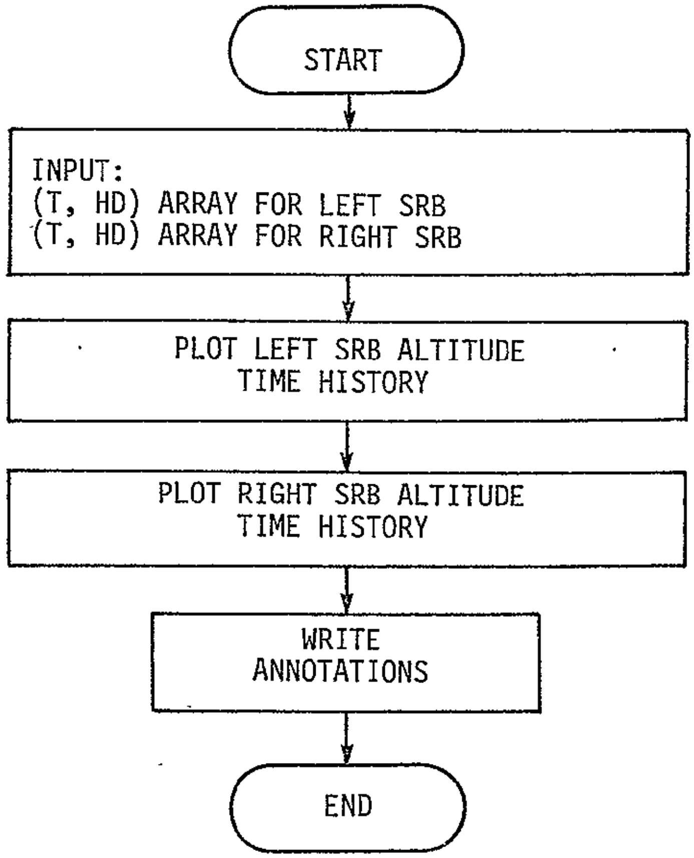
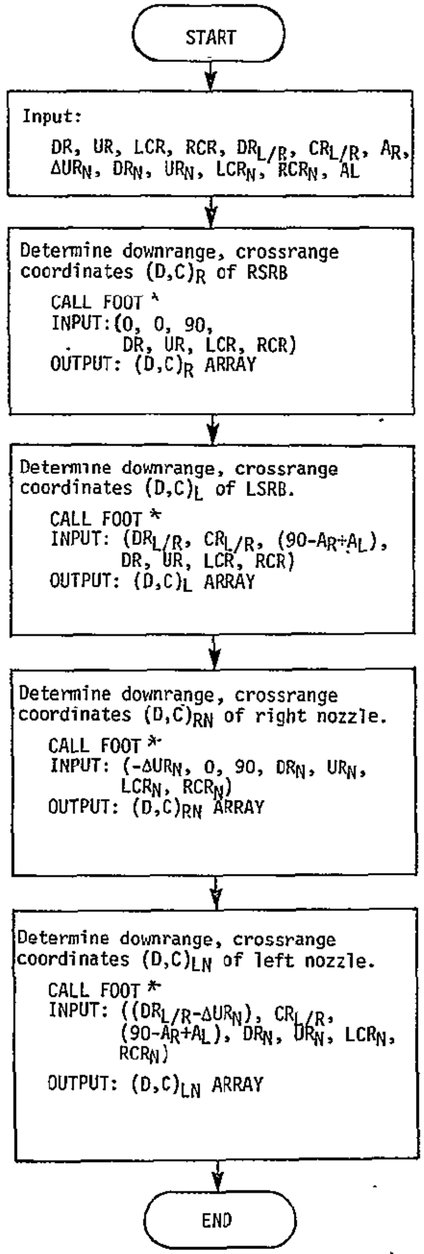


FIGURE 4.1-1 SRB ALTITUDE TIME HISTORY FLOWCHART (TASK 1)

4.2 SRB, NOZZLE EXTENSION FOOTPRINT PLOT - TASK 2

The footprints of the left and right SRB's and nozzle extensions are plotted on the same downrange, crossrange grid as illustrated in Figure 4.0-2. A flowchart of this task is presented in Figure 4.2-1.

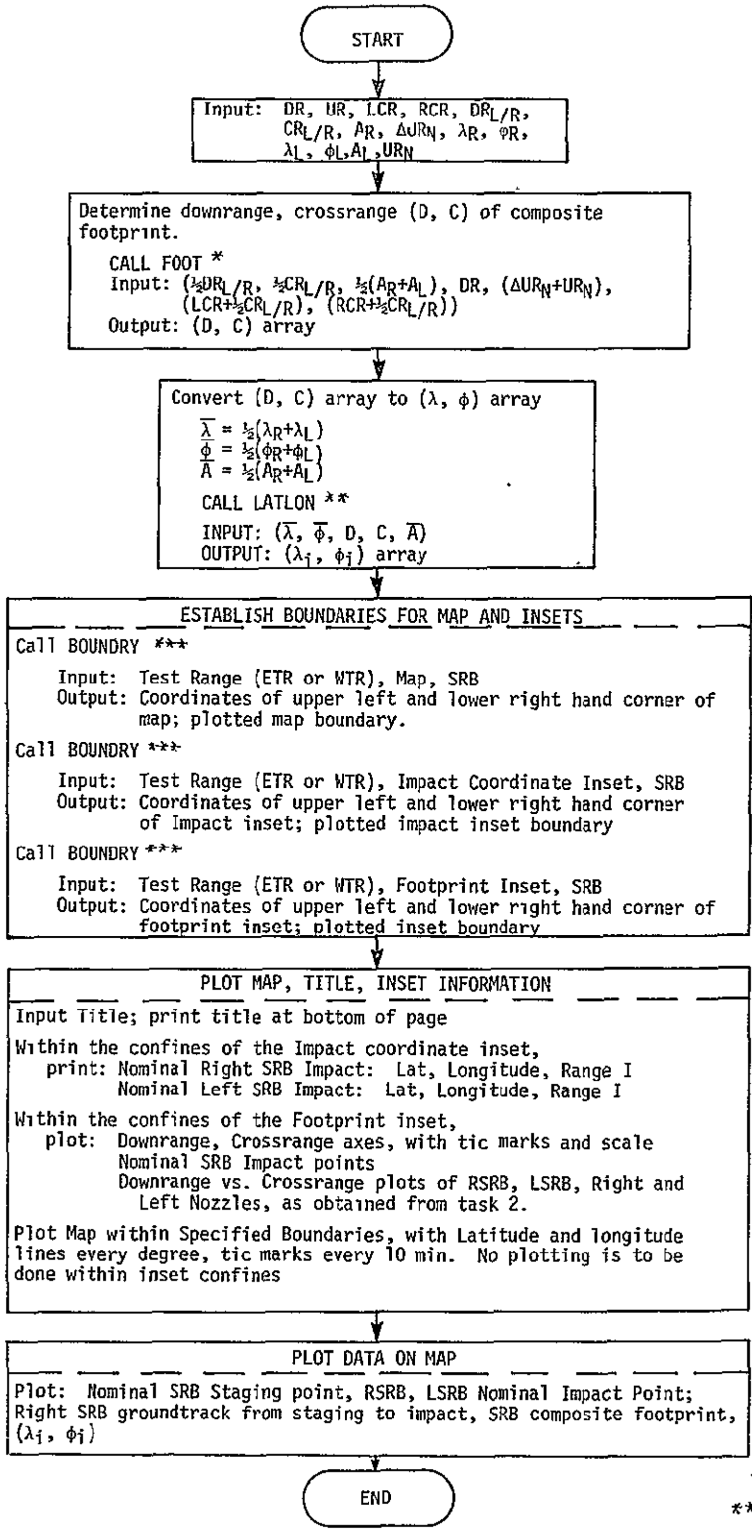


*APPENDIX B

FIGURE 4.2-1 SRB, NOZZLE FOOTPRINT PLOT FLOWCHART (TASK 2)

4.3 SRB COMPOSITE FOOTPRINT PLOT - TASK 3

The composite footprint of all SRB elements is plotted on a map as illustrated in Figure 4.0-3. The plot will contain the footprint, the right SRB groundtrack, landmasses, and appropriate annotations. A flowchart of this task is presented in Figure 4.3-1.

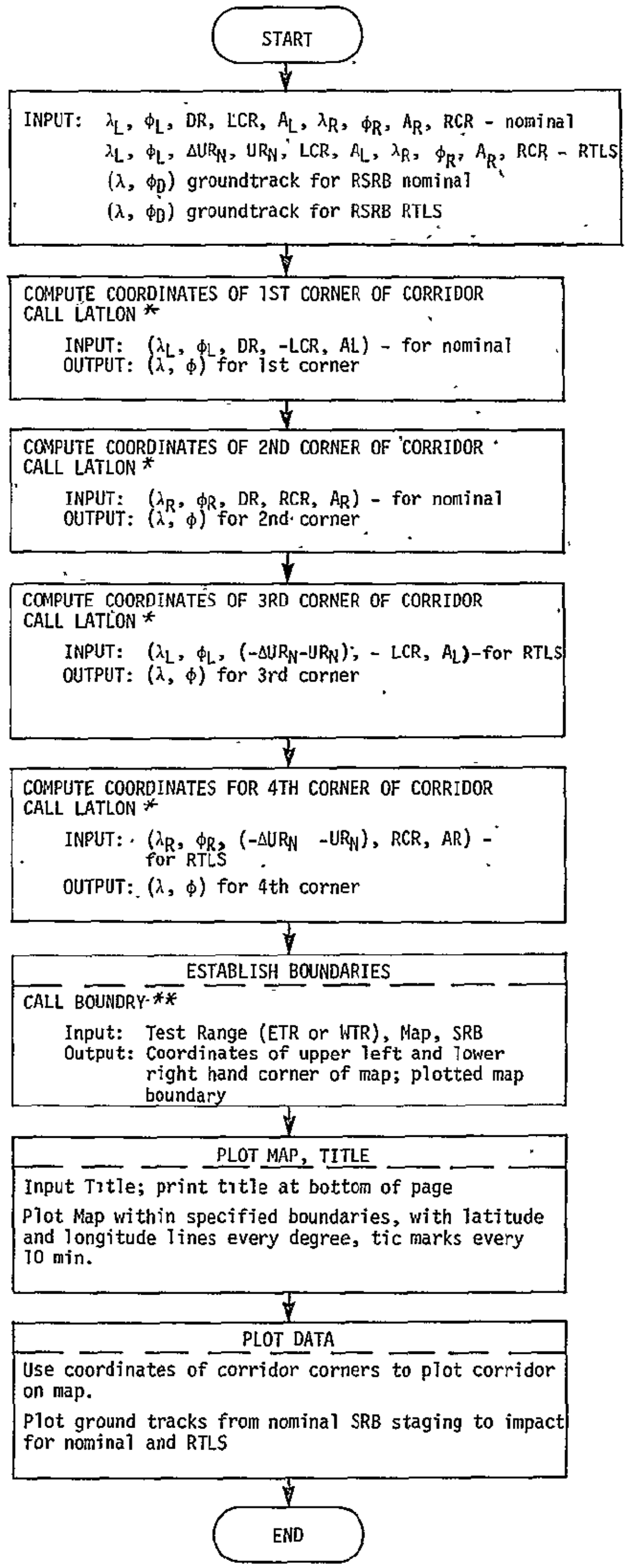


*APPENDIX B
**APPENDIX E
***APPENDIX F

FIGURE 4.3-1 SRB COMPOSITE FOOTPRINT PLOT FLOWCHART (TASK 3)

4.4 SRB IMPACT CORRIDOR PLOT - TASK 4

The SRB impact corridor is a rectangle containing the nominal and RTLS SRB footprints. Figure 4.4-1 presents the equations which define the latitude, longitude coordinates of the four corners of the rectangle. Figure 4.0-4 presents the desired plot format with the corridor, groundtracks, landmasses, and annotations.



*APPENDIX E
**APPENDIX F

FIGURE 4.4-1 SRB IMPACT CORRIDOR PLOT FLOWCHART (TASK 4)

5.0 ET RTLS IMPACT PREDICTION PROCESSOR

The purpose of the ET RTLS Impact Prediction Processor is to compute the impact area of the ET for RTLS abort profiles. Output of the processor consists of the size and shape of the ET impact footprint and the location of the four footprints which form the extremes of the impact corridor for all RTLS trajectories. Figure 5.0-1 is an overview of the processor executive.

The processor is constructed such that several sets of ET separation conditions, representing the scope of RTLS trajectories, are input. The instantaneous impact point (IIP) of each case is computed and the four cases which result in the largest downrange, uprange, left, and right crossrange are identified (task 1 & 2). The descent trajectories of these four cases are simulated to determine the actual impact point locations as shown in task 3.

The downrange, crossrange impact point dispersions due to separation condition, environmental, and aerodynamic uncertainties are stored in the processor data base. Tabular lookup is used in task 6 to determine the mission dependent dispersions which are combined to form the footprint in task 7. The impact corridor is computed using the footprint size and the four extreme impact point locations.

Output from the processor consists of tables of separation conditons and impact points of the four extreme trajectories, and the size and shape of the impact footprint and corridor. The data required to plot the footprint and the impact corridor and groundtracks are stored on secure files. The plots are generated by the ET RTLS Plot Processor described in Section 6.0.

The following subsections describe the requirements for each task presented in the executive flowchart.

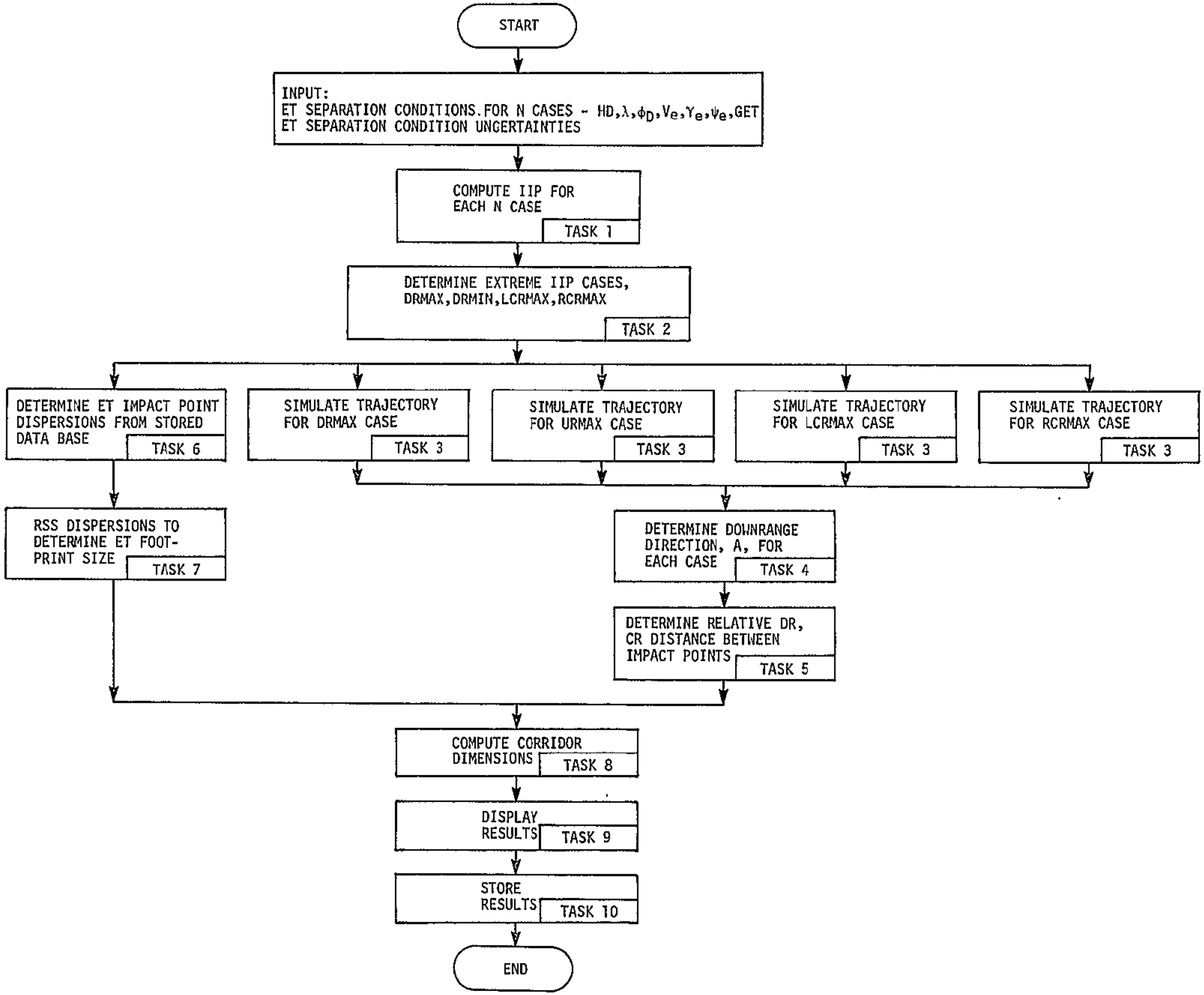


FIGURE 5.0-1 ET RTLS IMPACT PREDICTION PROCESSOR EXECUTIVE FLOWCHART

5.1 ET RTLS IMPACT DATA BASE

The stored data base of this processor consists of data from which the impact point dispersions are computed. Table 5.1-I presents the parameters comprising the data base. The uprange, downrange, and crossrange dispersions caused by separation condition uncertainties are expressed as sensitivities and are constant for all trajectories. The dispersions due to winds are correlated as a function of launch azimuth. The dispersions caused by atmospheric density and aerodynamic uncertainties are constant.

TABLE 5.1-I ET RTLS DATA BASE PARAMETERS

GROUP	DEPENDENT VARIABLE	INDEPENDENT VARIABLE
Separation Condition Dispersions	$\frac{\partial DR}{\partial HD}, \frac{\partial DR}{\partial DR}, \frac{\partial DR}{\partial CR}, \frac{\partial DR}{\partial V_e}, \frac{\partial DR}{\partial \gamma_e}, \frac{\partial DR}{\partial \Psi_e}$	NONE (CONSTANT)
	$\frac{\partial UR}{\partial HD}, \frac{\partial UR}{\partial DR}, \frac{\partial UR}{\partial CR}, \frac{\partial UR}{\partial V_e}, \frac{\partial UR}{\partial \gamma_e}, \frac{\partial UR}{\partial \Psi_e}$	
	$\frac{\partial CR}{\partial HD}, \frac{\partial CR}{\partial DR}, \frac{\partial CR}{\partial CR}, \frac{\partial CR}{\partial V_e}, \frac{\partial CR}{\partial \gamma_e}, \frac{\partial CR}{\partial \Psi_e}$	
Atmospheric Dispersions	DR = CONSTANT UR = CONSTANT CR = CONSTANT	NONE (CONSTANT)
Aerodynamic Dispersions	DR = CONSTANT UR = CONSTANT CR = CONSTANT	NONE (CONSTANT)
Wind Dispersions	DR (Ψ_i) UR (Ψ_i) LCR (Ψ_i) RCR (Ψ_i)	LAUNCH AZIMUTH Ψ_i, i = 1,6

5.2 INSTANTANEOUS IMPACT POINT COMPUTATION - TASK 1

Figure 5.2-1 presents a flowchart for this task. The instantaneous impact points (IIP) for each set of input ET separation conditions are computed using logic similar to SVDS subroutine IMPACT (Reference 2). The output from this task is the latitude, longitude coordinates of the IIP for each case.

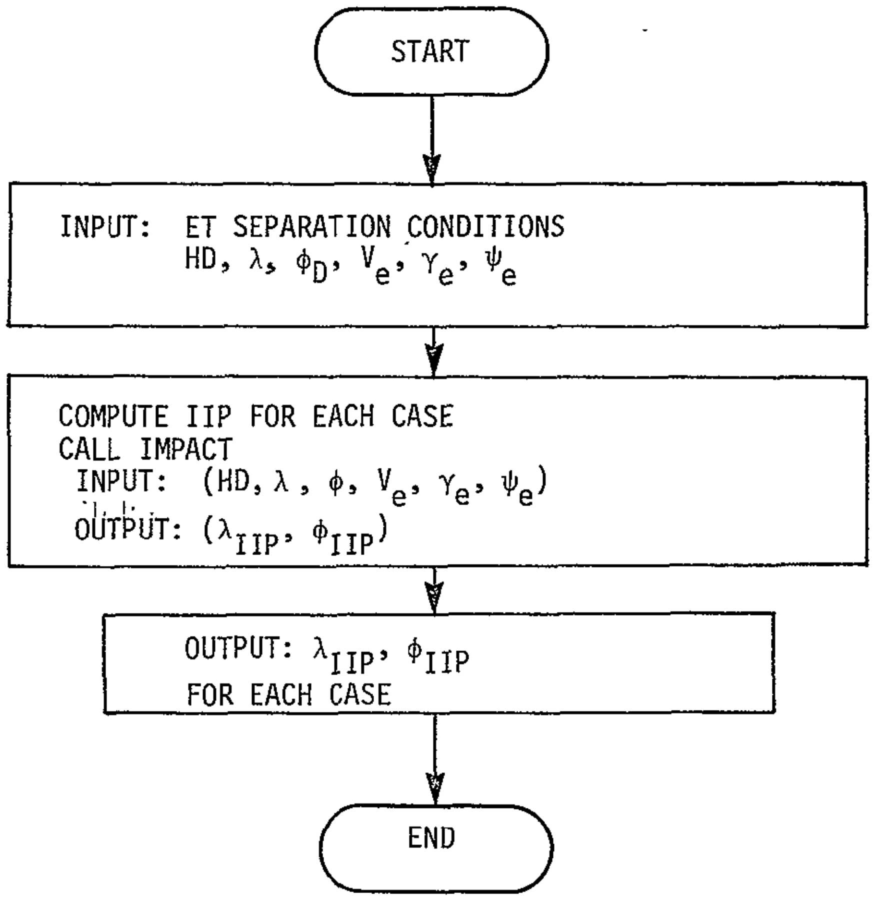


FIGURE 5.2-1 INSTANTANEOUS IMPACT POINT FLOWCHART (TASK 1)

5.3 EXTREME INSTANTANEOUS IMPACT POINT CASES - TASK 2

A flowchart for this task is presented in Figure 5.3-1. The relative distance between the IIP for each case is computed. The four cases which result in the largest uprange, downrange, left and right crossrange are identified and output.

START

INPUT: SEPARATION POSITION OF EACH CASE, (λ_i, ϕ_i)
IIP OF EACH CASE $(\lambda_{IIPi}, \phi_{IIPi})$

COMPUTE DOWNRANGE DIRECTION Ai of each case.
CALL AZIMUTH *
INPUT: $(\lambda_i, \phi_i, \lambda_{IPPi}, \phi_{IIPi})$ OUTPUT: Ai

COMPUTE REFERENCE DIRECTION AND IMPACT POINT

$$\overline{A} = (\sum_{i=1}^{N} Ai)/N \qquad \overline{\phi} = (\sum_{i=1}^{N} \phi_{IPPi})/N$$

$$\overline{\lambda} = (\sum_{i=1}^{N} \lambda_{IIPi})/N$$

COMPUTE DOWNRANGE, CROSSRANGE DISTANCE FROM REFERENCE POINT TO EACH IIP
CALL RNGERR **
INPUT: $\overline{\lambda}, \overline{\phi}, \lambda_{IIPi}, \phi_{IIPi}, \overline{A}$
OUTPUT: DR_i, CR_i

DETERMINE WHICH CASES RESULT IN MAXIMUM AND MINIMUM DOWNRANGE AND CROSSRANGE

OUTPUT: IDENTIFICATION OF DRMAX, DRMIN, LCRMAX, RCRMAX CASES

END

*APPENDIX C

**APPENDIX D

FIGURE 5.3-1 EXTREME INSTANTANEOUS IMPACT POINT CASES FLOWCHART (TASK 2)

5.4 ET RTLS DESCENT TRAJECTORY - TASK 3

The trajectories of each of the four extreme IIP cases are simulated from ET separation to impact. The requirements for a general 3-DOF trajectory simulation are presented in Appendix A. General data such as ET weight, atmospheric model flag, and wind data will be obtained from the Master Data Base. Aerodynamic coefficients will be input from a preconstructed data file. At the time of execution the only input data required are the ET separation conditions. Figure 5.4-1 presents a flowchart for this task illustrating the input and output parameters.

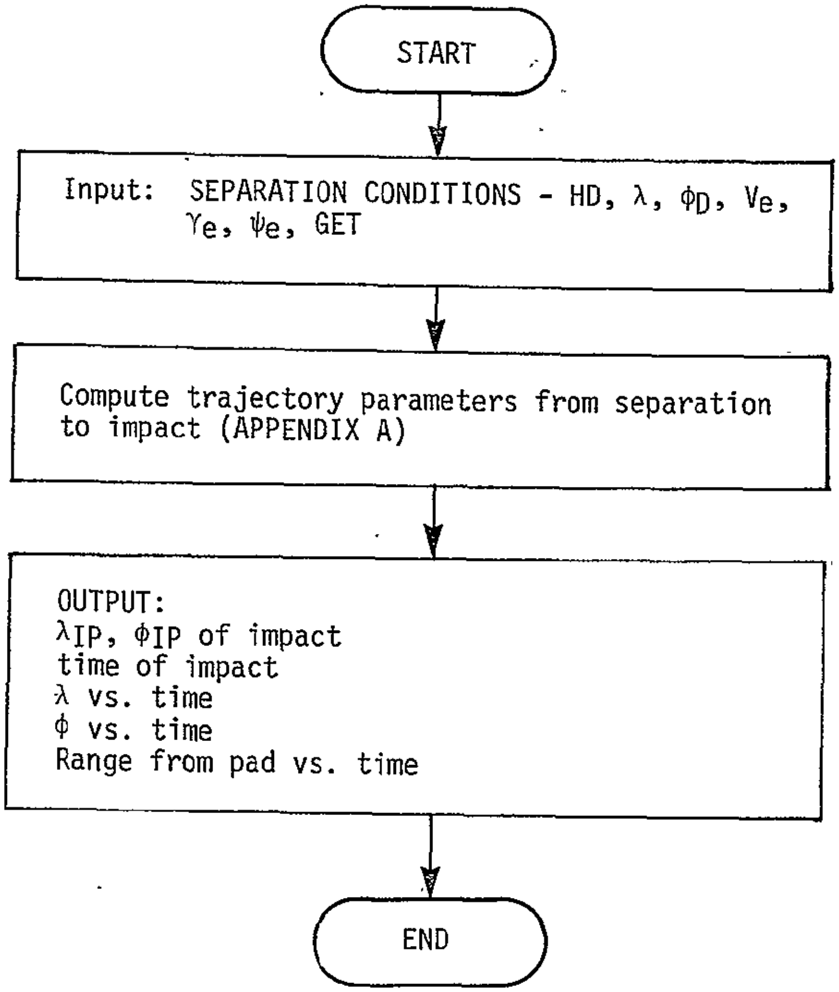
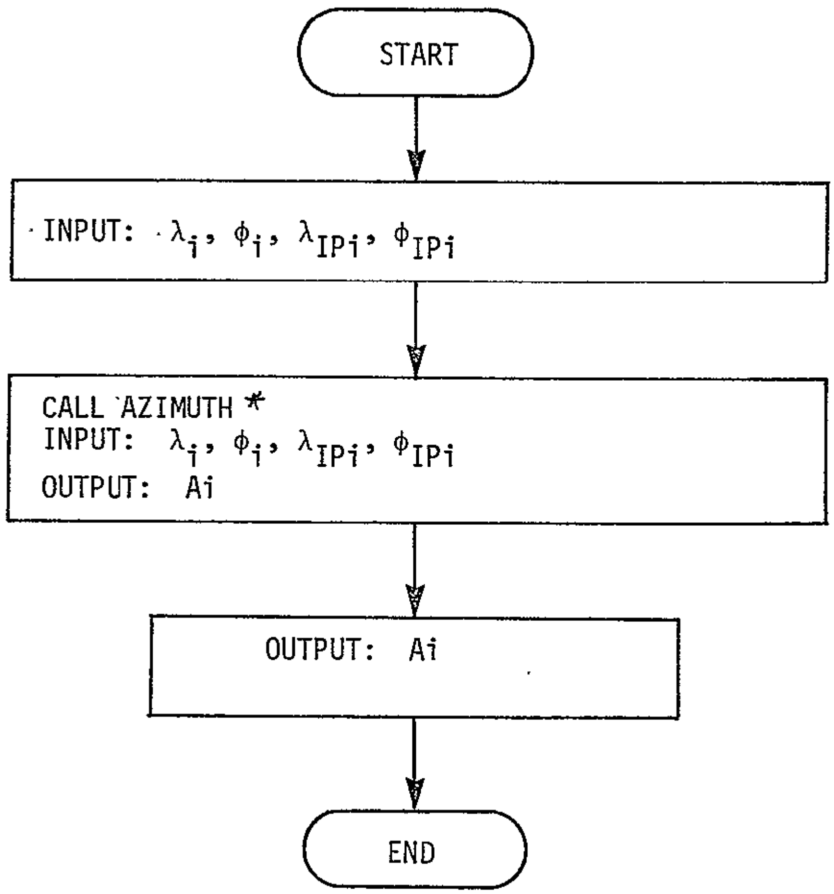


FIGURE 5.4-1 ET RTLS DESCENT TRAJECTORY FLOWCHART (TASK 3)

5.5 ET RTLS DOWNRANGE DIRECTION - TASK 4

The downrange direction of each of the four extreme IIP cases are computed in order to compute the relative distances between impact points, and to orient the footprints on a map. Figure 5.5-1 presents a flowchart for this computation.

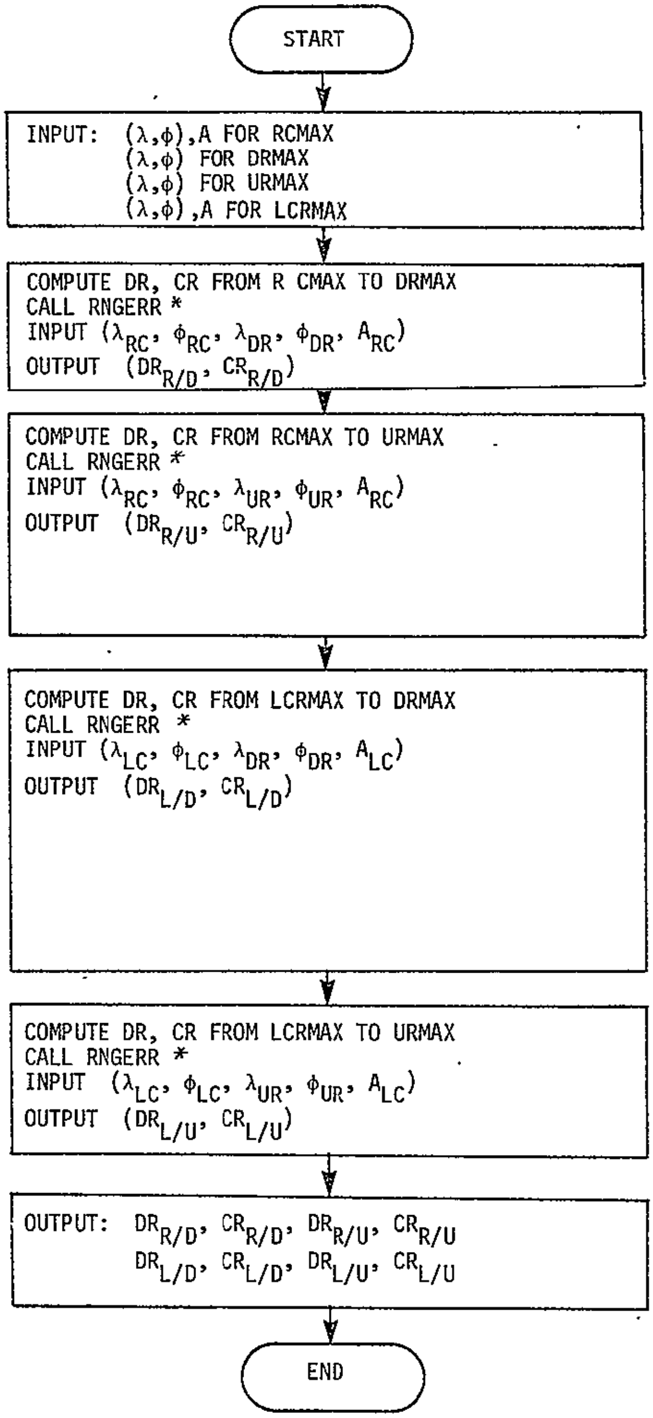


*APPENDIX C

FIGURE 5.5-1 ET RTLS DOWNRANGE DIRECTION FLOWCHART (TASK 4)

5.6 IMPACT POINT RELATIVE DISTANCE - TASK 5

The relative downrange, crossrange distances between the impact points of the four extreme IIP cases are required to compute the size of the impact corridor. Figure 5.6-1 presents a flowchart for this task.



*APPENDIX D

FIGURE 5.6-1 ET IMPACT POINT RELATIVE DISTANCE FLOWCHART (TASK 5)

5.7 IMPACT POINT DISPERSIONS - TASK 6

The impact point dispersions are computed by tabular lookup and linear interpolation of the data base. Figure 5.7-1 presents a flowchart for this task.

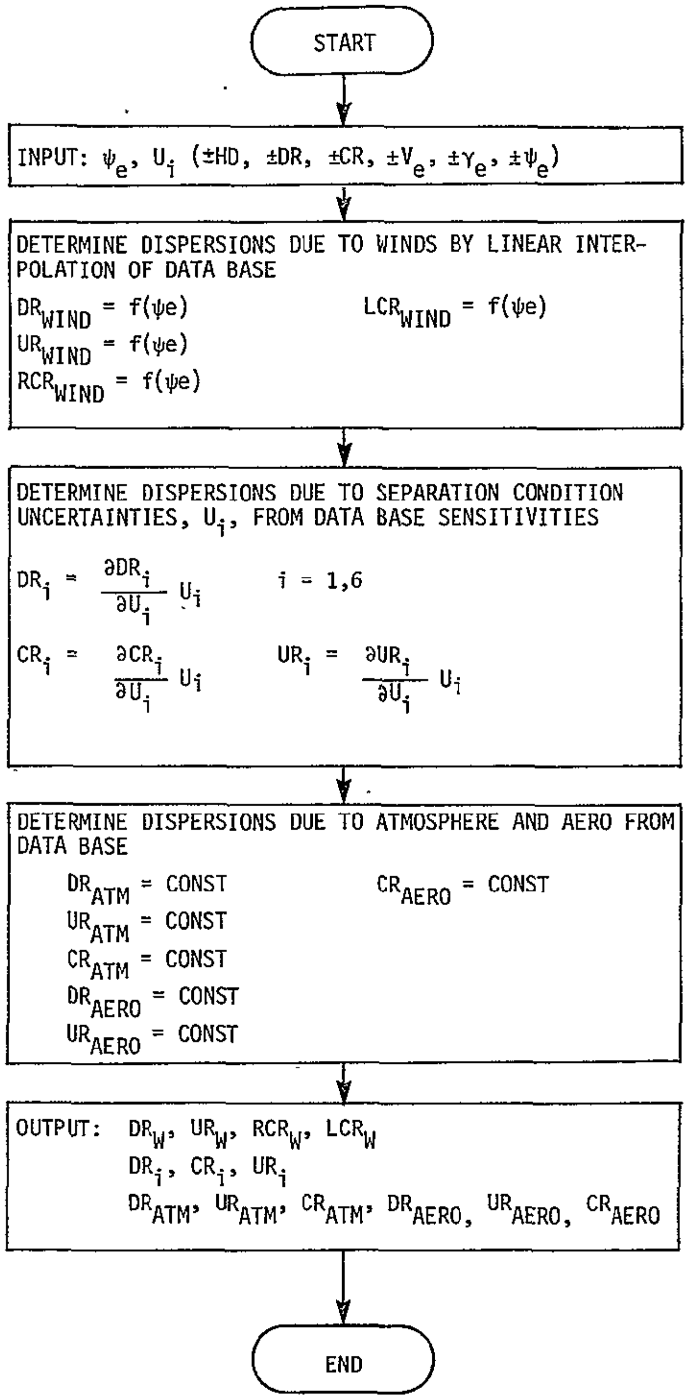


FIGURE 5.7-1 ET IMPACT POINT DISPERSIONS FLOWCHART (TASK 6)

5.8 FOOTPRINT DIMENSIONS - TASK 7

The dimensions of the ET impact footprint are computed by root-sum-squaring the impact dispersions from task 6. Figure 5.8-1 presents a flowchart for this task.

START

INPUT: DR_W, UR_W, RCR_W, LCR_W,
DR_i, CR_i, UR_i,
DR_{AERO}, UR_{AERO}, CR_{AERO},
DR_{ATM}, UR_{ATM}, CR_{ATM}

RSS DISPERSIONS TO DETERMINE FOOTPRINT SIZE

$$DR = \left(\sum_{i=1}^{6} DR_i^2 + DR_W^2 + DR_{AERO}^2 + DR_{ATM}^2\right)^{1/2}$$

$$UR = \left(\sum_{i=1}^{6} UR_i^2 + UR_W^2 + UR_{AERO}^2 + UR_{ATM}^2\right)^{1/2}$$

$$LCR = \left(\sum_{i=1}^{6} CR_i^2 + LCR_W^2 + CR_{AERO}^2 + CR_{ATM}^2\right)^{1/2}$$

$$RCR = \left(\sum_{i=1}^{6} CR_i^2 + RCR_W^2 + CR_{AERO}^2 + CR_{ATM}^2\right)^{1/2}$$

OUTPUT: DR, UR, LCR, RCR

END

FIGURE 5.8-1 ET RTLS FOOTPRINT DIMENSIONS FLOWCHART (TASK 7)

5.9 IMPACT CORRIDOR DIMENSIONS - TASK 8

The ET impact corridor is the area which contains all the RTLS impact footprints for the particular mission. The size of the corridor is computed from the relative distance between the extreme impact points and the footprint size as shown in Figure 5.9-1.

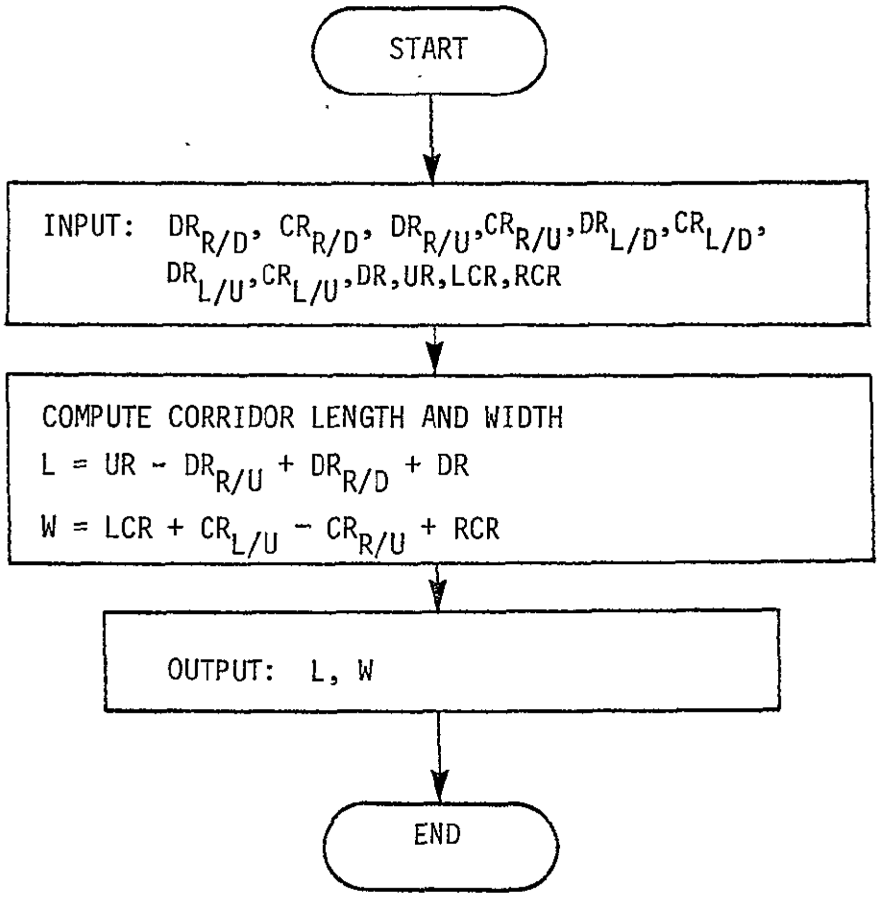


FIGURE 5.9-1 ET IMPACT CORRIDOR DIMENSIONS FLOWCHART (TASK 8)

5.10 OUTPUT DISPLAYS - TASK 9

Tabular output from the ET RTLS Impact Prediction Processor consists of terminal screen displays and hardcopy print of document quality. Tables 5.10-I and 5.10-II are examples of the data and format to be output. Table 5.10-I is a list of ET separation conditions for the four extreme IIP cases. Table 5.10-II is an impact summary table listing the impact point locations and the size of the footprint and corridor.

TABLE 5.10-I EXAMPLE ET RTLS SEPARATION CONDITIONS TABLE

	MAX UPRANGE IMPACT POINT	MAX DOWNRANGE IMPACT POINT	MAX LEFT CROSSRANGE IMPACT POINT	MAX RIGHT CROSSRANGE IMPACT POINT
GET (sec)	796.040	800.322	799.865	782.935
Altitude (ft)	231518.8	228627.3	231332.8	230542.3
Longitude (deg)	-76.973	-77.136	-77.007	-76.009
Geodetic Latitude (deg)	30.678	30.358	30.836	30.756
Relative Velocity (fps)	6633.057	6445.577	6636.169	6526.115
Relative Flightpath Angle (deg)	-.221	-1.407	.425	.956
Relative Azimuth (deg)	-118.5	-116.122	-120.901	-117.895
Radius Vector (ft)	21139109	21136560	21138754	21137760
Geocentric Latitude (deg)	30.511	30.192	30.669	30.536
Inertial Velocity (fps)	6633.057	5282.541	5540.553	5875.667
Inertial Flightpath Angle (deg)	-.267	-1.717	.509	1.003
Inertial Azimuth (deg)	-125.146	-122.500	-127.961	-124.895

TABLE 5.10-II EXAMPLE ET RTLS IMPACT SUMMARY TABLE

CASE	GEODETIC LATITUDE (DEG)	LONGITUDE (DEG)	RANGE FROM PAD (N.MI.)	DCR* (N.MI.)	CR* (N.MI.)	GET (SEC)
MAX UPRANGE	29.807	-78.615	128.503	-	-	905.63
MAX DOWNRANGE	29.670	-78.773	114.650	32.053	.925	924.83
MAX LEFT CROSSRANGE	29.75	-78.635	124.785	10.534	2.36	915.48
MAX RIGHT CROSSRANGE	29.859	-78.650	126.504	15.243	1.09	910.54

	UR (N.MI.)	DR (N.MI.)	LCR (N.MI.)	RCR (N.MI.)
FOOTPRINT DIMENSION	11.36	14.36	3.70	2.50

	LENGTH (N.MI.)	WIDTH (N.MI.)
CORRIDOR DIMENSION	50.49	15.60

*DR, CR are downrange and crossrange distances from the maximum uprange impact point.

5.11 STORED PLOT DATA - TASK 10

All data required by the ET RTLS Plot Processor is stored in a secure catalogued file. Table 5.11-I lists the parameters which are stored in the file and used by the plot processor.

TABLE 5.11-I ET RTLS STORED PLOT DATA

PARAMETER	DESCRIPTION
DR, UR, LCR, RCR	ET IMPACT FOOTPRINT SIZE
$(\lambda_{LCR}, \phi_{LCR})$, $(\lambda_{RCR}, \phi_{RCR})$	IMPACT LOCATION OF EXTREME CROSSRANGE CASES
A_{LCR}, A_{RCR}	DOWNRANGE DIRECTION OF EXTREME CROSSRANGE CASES
λ vs. TIME ϕ vs. TIME RANGE vs. TIME	TRAJECTORY PARAMETERS OF FOUR EXTREME CASES
$DR_{R/D}$, $CR_{R/D}$, $DR_{R/U}$, $CR_{R/U}$ $DR_{L/D}$, $CR_{L/D}$, $DR_{L/U}$, $CR_{L/U}$	RELATIVE DISTANCES BETWEEN EXTREME IMPACT POINTS

6.0 ET RTLS PLOT PROCESSOR

The purpose of the ET RTLS Plot Processor is to construct the ET impact footprint and corridor plots for RTLS profiles. The data required by the processor is generated by the ET RTLS Impact Prediction Processor described in Section 5.0, and stored on a file. The plot processor accesses the data and constructs the desired plots as illustrated in the flowchart of Figure 6.0-1. Figures 6.0-2 and 6.0-3 are examples of the plots to be generated. The quality of the plots will be sufficient for inclusion in documents. The following subsections describe the requirements for the two tasks presented in the executive flowchart.

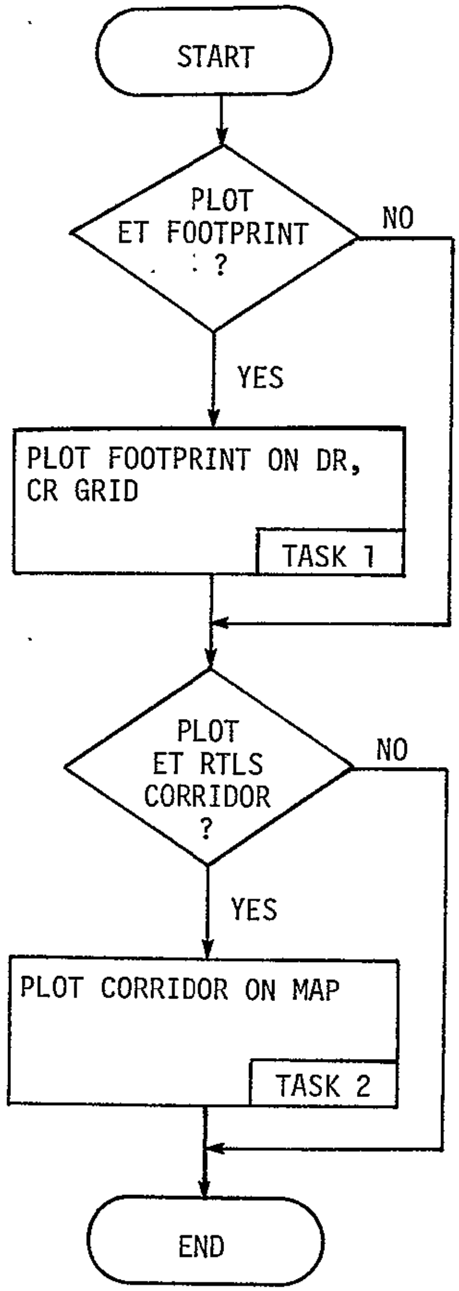
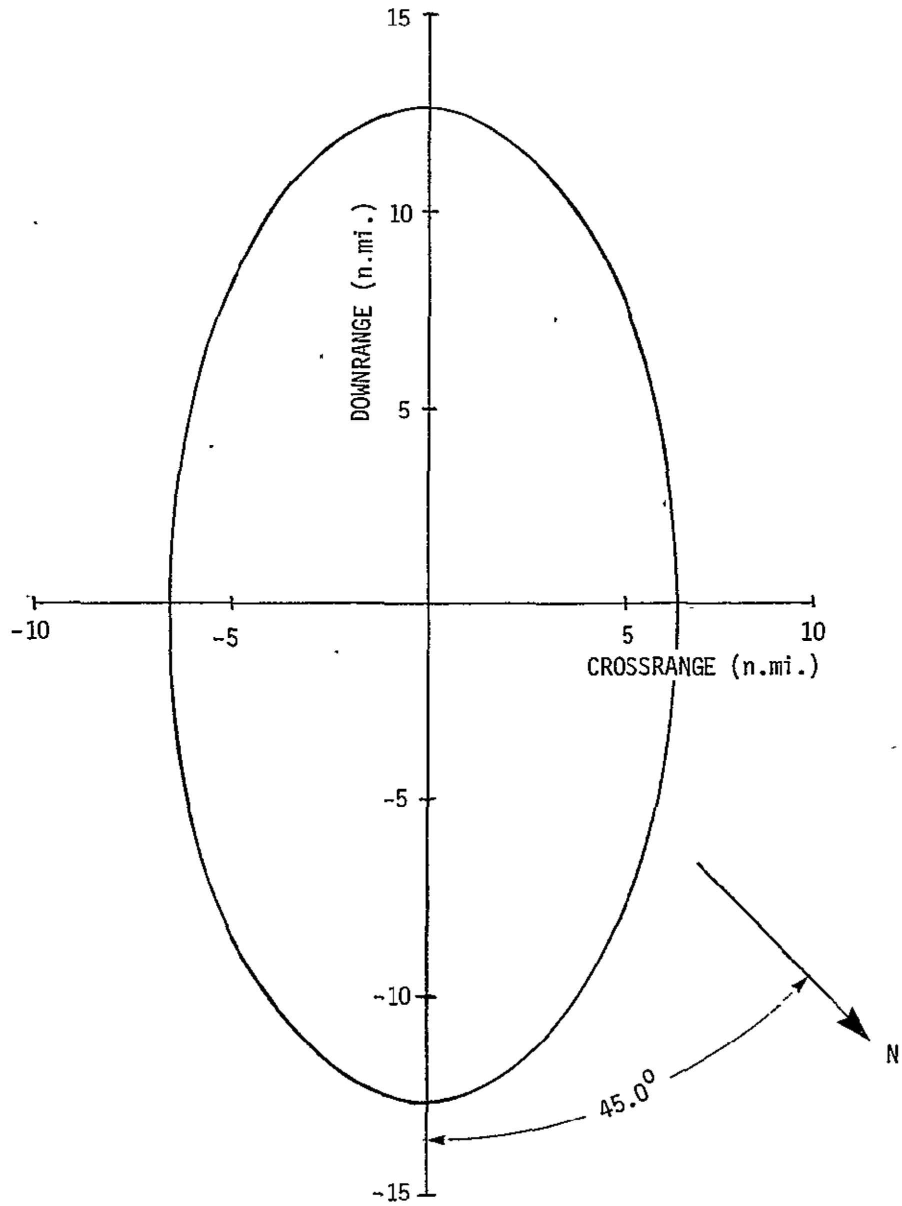
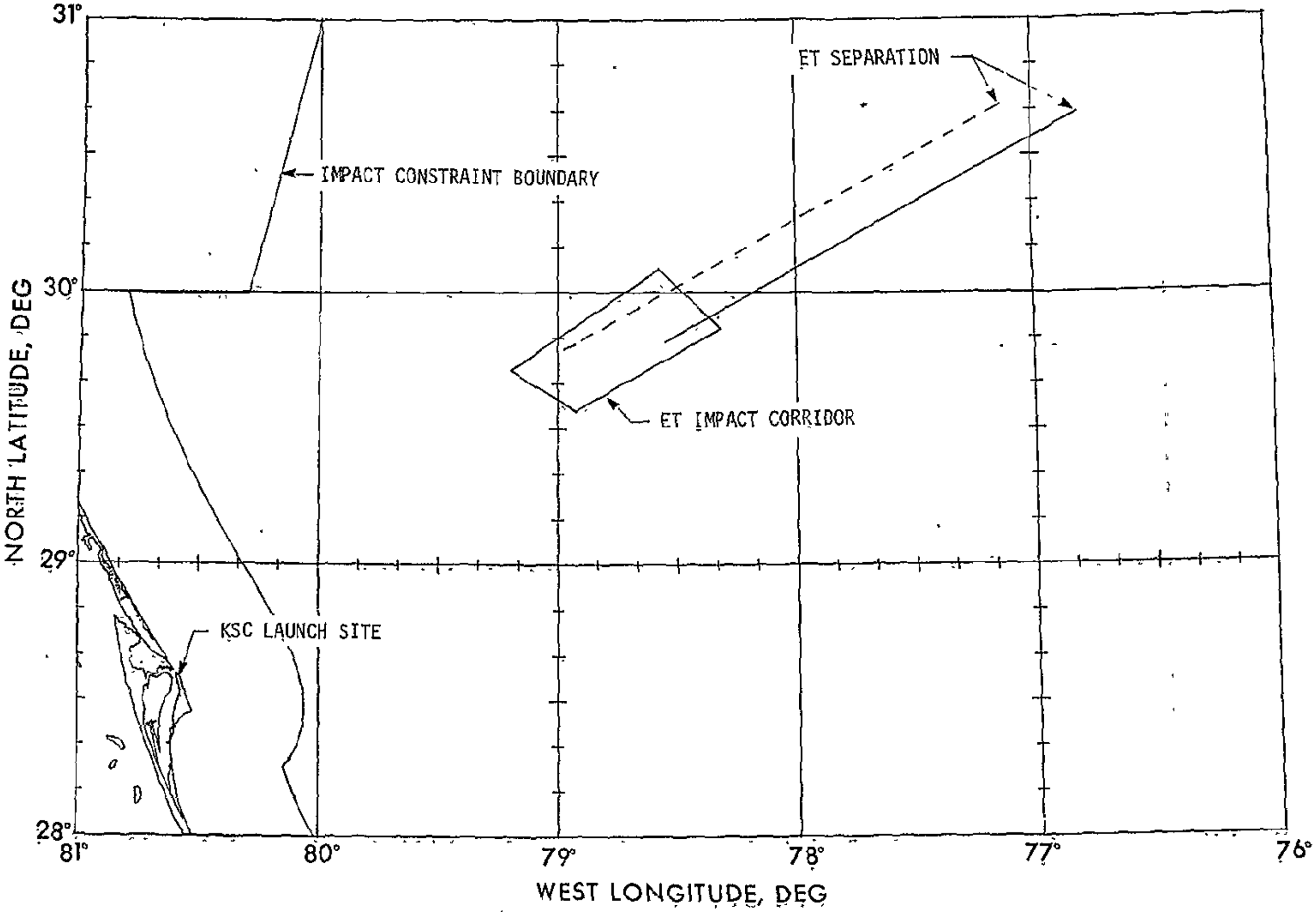


FIGURE 6.0-1 ET RTLS PLOT PROCESSOR EXECUTIVE FLOWCHART



STS-1 ET RTLS IMPACT FOOTPRINT

FIGURE 6.0-2 EXAMPLE ET RTLS IMPACT FOOTPRINT PLOT

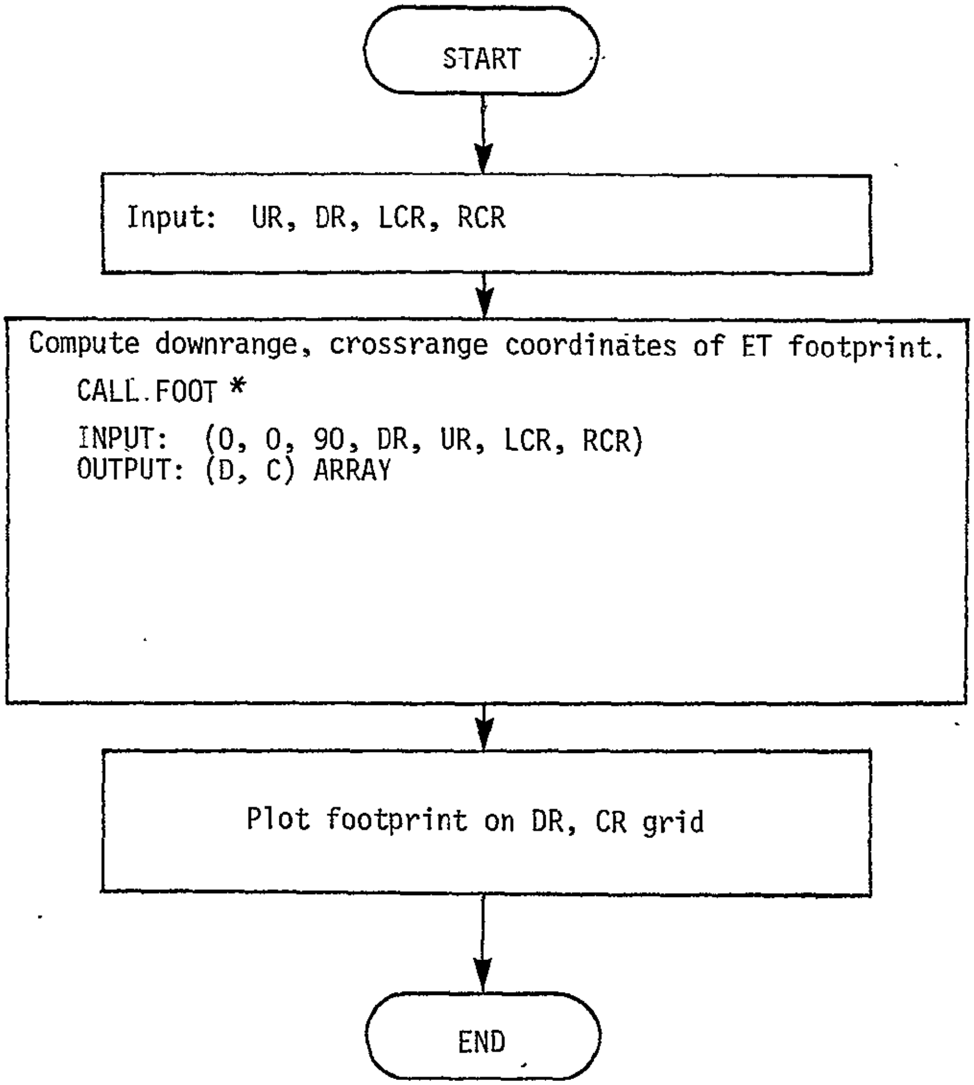


STS-1 RTLS ET IMPACT CORRIDOR

FIGURE 6.0-3 EXAMPLE ET RTLS IMPACT CORRIDOR PLOT

6.1 ET RTLS FOOTPRINT PLOT - TASK 1

The impact footprint of the ET is plotted on a downrange, crossrange grid as illustrated in Figure 6.0-2. A flowchart of this task is presented in Figure 6.1-1.

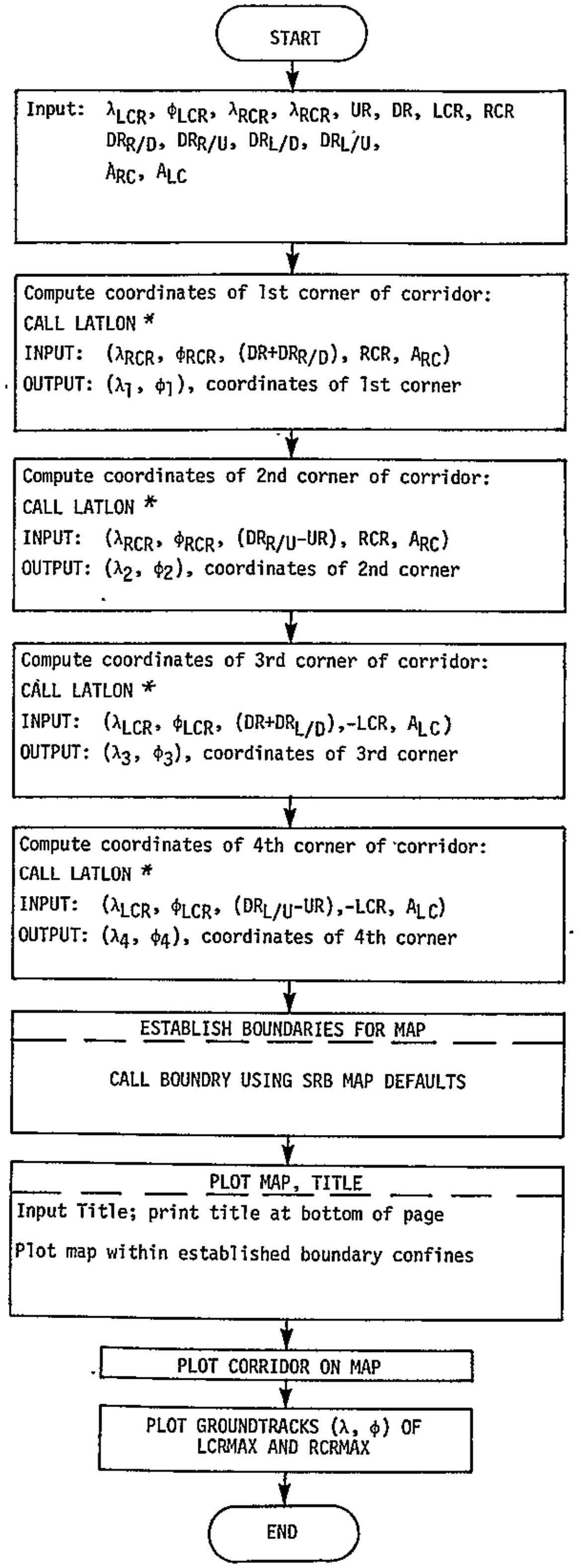


*APPENDIX B

FIGURE 6.1-1 ET RTLS IMPACT FOOTPRINT PLOT FLOWCHART (TASK 1)

6.2 ET RTLS IMPACT CORRIDOR - TASK 2

The ET impact corridor is the area containing all the ET impact footprints for a particular mission. Figure 6.2-1 presents a flowchart for computing the latitude, longitude coordinates of the four corners of the corridor. Figure 6.0-3 presents the desired plot format with the corridor, groundtracks, landmasses, and annotations.



*APPENDIX E

FIGURE 6.2-1 ET RTLS IMPACT CORRIDOR PLOT FLOWCHART (TASK 2)

7.0 ET NOMINAL/AOA/ATO IMPACT PREDICTION PROCESSOR

The purpose of the ET Nominal/AOA/ATO Impact Prediction Processor is to compute the ET impact footprints and related ET disposal trajectory data for nominal, Abort-to-Orbit (ATO), and Abort-Once-Around (AOA) profiles. An overview of the processor executive is presented in Figure 7.0-1.

The downrange, crossrange dimensions of the impact footprint are determined in tasks 1 through 11. The impact point dispersions due to the rotational lifting effect (RLE), trajectory uncertainties, and debris scatter after ET breakup, are obtained by tabular lookup in the processor data base (tasks 2 - 5). These dispersions are then statistically combined in tasks 6 through 11 to define the total footprint dimensions.

The location of the ET footprint is obtained by simulating the ET descent trajectory and computing the latitude and longitude of the impact point as identified in task 14.

Output from the processor consists of tabular and stored data as shown in tasks 15-16. The tabular data lists the impact dispersions and footprint size and location. The stored data consists of the ET groundtrack and footprint dimensions which are stored on a secure file accessible to the ET Plot Processor. The ET Plot Processor uses this data to construct the ET footprint plot on a map.

The following subsections describe the detailed requirements for each task presented in the executive overview.

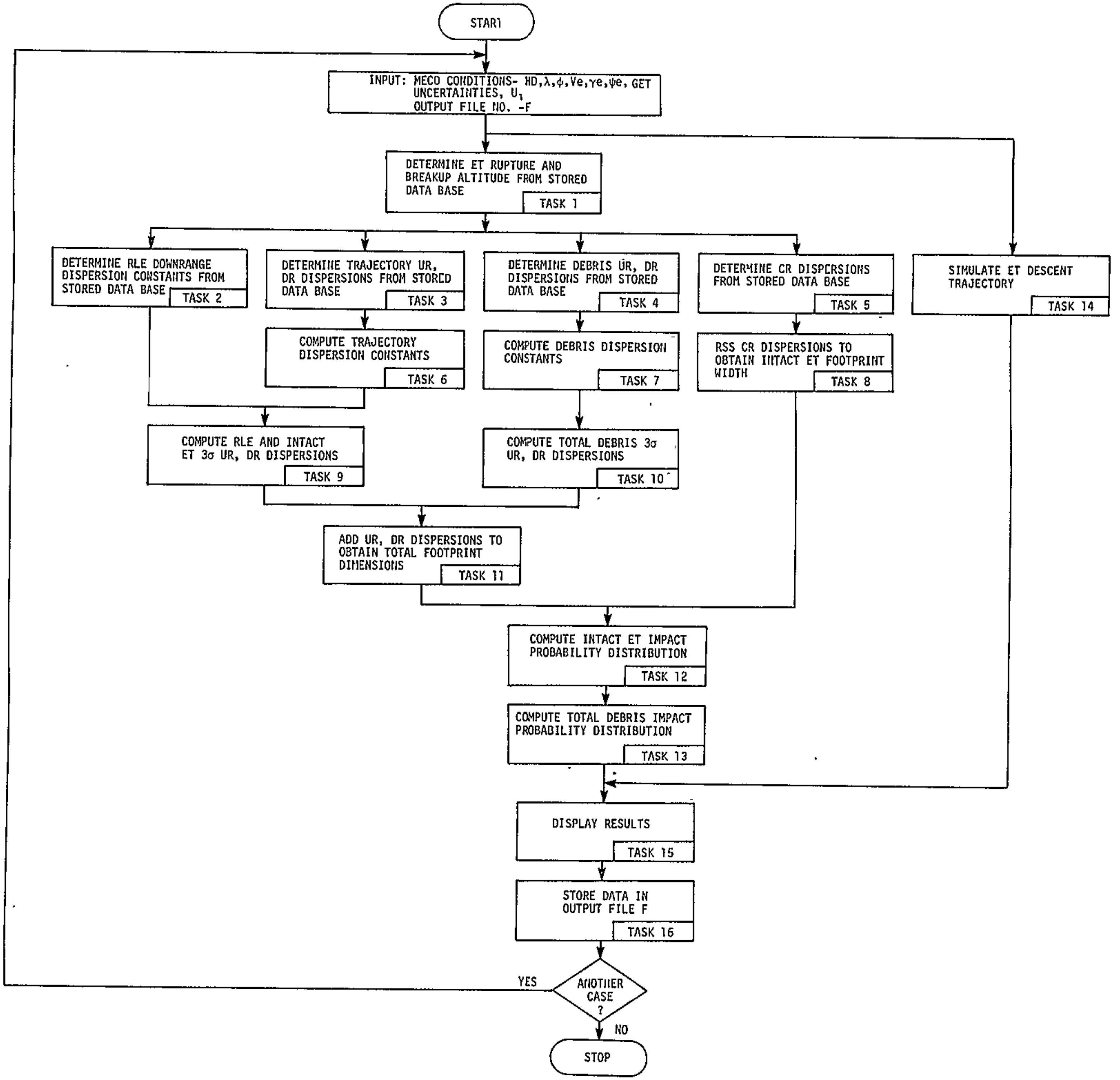


FIGURE 7.0-1 ET NOMINAL/AOA/ATO IMPACT PREDICTION PROCESSOR EXECUTIVE

7.1 ET NOMINAL/AOA/ATO IMPACT DATA BASE

The stored data base of this processor consists of the data required to determine the ET footprint size by tabular lookup. Table 7.1-I presents the parameters comprising the data base. The altitudes of liquid hydrogen tank rupture, liquid oxygen tank rupture, and breakup are stored as a function of ET weight and orbital inclination. The uprange, downrange, and crossrange dispersions caused by MECO condition uncertainties are expressed as sensitivities and stored as a function of MECO altitude, ET weight, and launch site. The dispersions caused by the rotational lifting effect are expressed as constants of a composite curve consisting of three Gaussian distributions, and are stored as a function of MECO altitude, ET weight, breakup altitude, and launch site. The uprange, downrange, and crossrange dispersions of each piece of debris are stored as a function of breakup altitude.

TABLE 7.1-I ET NOMINAL/AOA/ATO DATA BASE PARAMETERS

PARAMETER	DEPENDENT VARIABLE	INDEPENDENT VARIABLE
ROTATIONAL LIFTING EFFECT CONSTANTS	C_1, C_2, C_3 μ_1, μ_2, μ_3 $\sigma_1, \sigma_2, \sigma_3$	ETR OR WTR MECO ALTITUDE ET WEIGHT BREAKUP ALTITUDE
ROTATIONAL LIFTING EFFECT CROSSRANGE DISPERSION	CR_{RLE}	
MECO CONDITION UNCERTAINTY	$\frac{\partial DR}{\partial HD}, \frac{\partial DR}{\partial V_e}, \frac{\partial DR}{\partial \gamma_e}, \frac{\partial DR}{\partial W}$ $\frac{\partial DR}{\partial HD}, \frac{\partial DR}{\partial V_e}, \frac{\partial DR}{\partial \gamma_e}, \frac{\partial DR}{\partial W}$	ETR OR WTR MECO ALTITUDE ET WEIGHT
ET DRAG	$\Delta UR_{DRG}, \Delta DR_{DRG}$	
ATMOSPHERE	$\Delta DR_{ATM}, \Delta UR_{ATM}$	
TRAJECTORY CROSSRANGE	CR_{TRJ}	
DEBRIS DISPERSIONS	$UR_{DEB}, DR_{DEB}, CR_{DEB}$	BREAKUP ALTITUDE
LH_2 RUPTURE ALTITUDE	H_H	
LO_2 RUPTURE ALTITUDE	H_O	ET WEIGHT ORBIT INCLINATION
BREAKUP ALTITUDE	H_{BU}	

7.2 RUPTURE AND BREAKUP ALTITUDES - TASK 1

The liquid hydrogen tank rupture altitude, liquid oxygen tank rupture altitude, and the breakup altitude are determined by linear interpolation of the data base. Figure 7.2-1 presents a flowchart for this task.

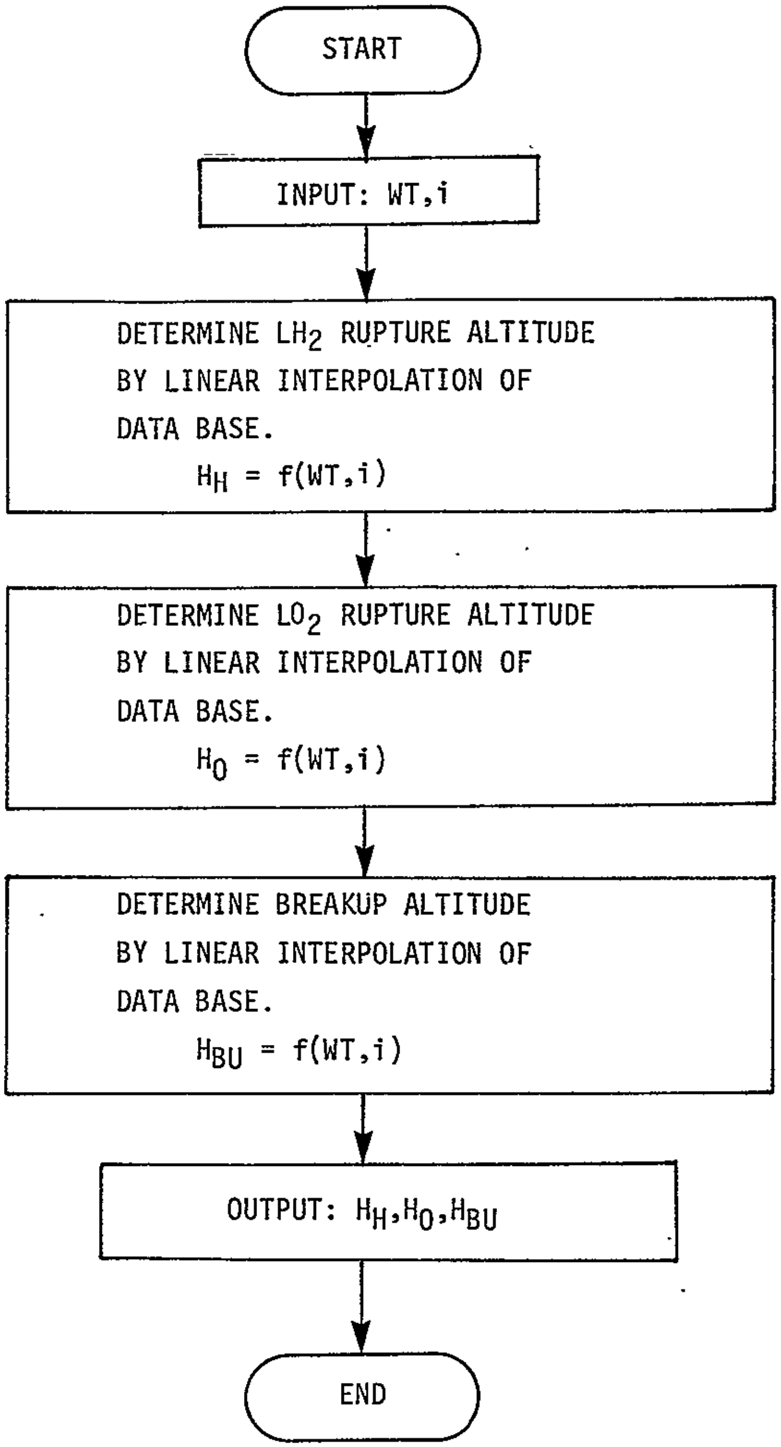


FIGURE 7.2-1 RUPTURE AND BREAKUP ALTITUDE FLOWCHART (TASK 1)

7.3 ROTATIONAL LIFTING EFFECT DISPERSION CONSTANTS - TASK 2

The distribution of impact point dispersions due to the rotational lifting effect (RLE) are represented by the sum of three Gaussian curves. The coefficients defining these curves are correlated and stored in the data base. Linear interpolation is used to compute the coefficients as shown in the flowchart of Figure 7.3-1.

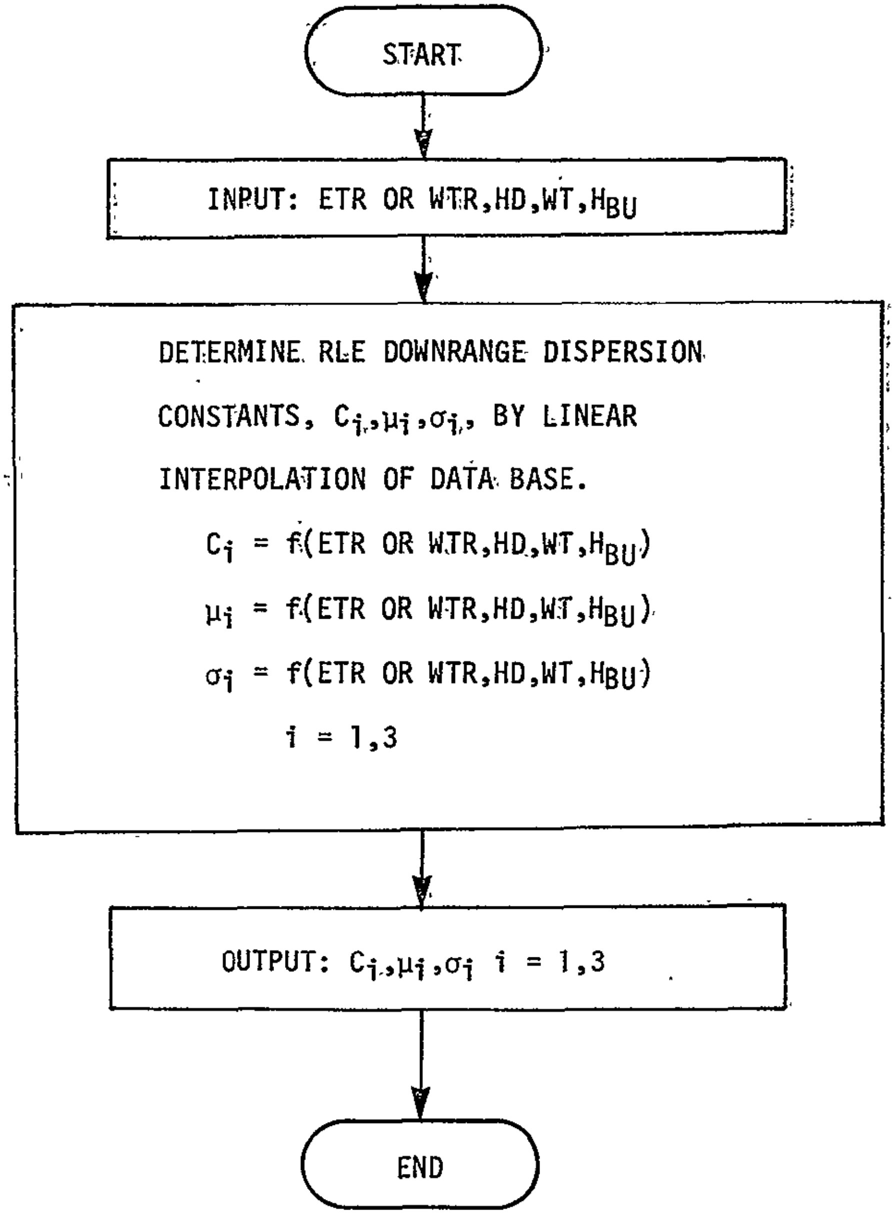


FIGURE 7.3-1 RLE DISPERSION CONSTANTS FLOWCHART (TASK 2)

7.4 TRAJECTORY DISPERSIONS - TASK 3

The uprange, downrange impact point dispersions due to MECO condition uncertainties, drag uncertainties, and atmospheric uncertainties are obtained by linear interpolation of the data base. Figure 7.4-1 presents a flowchart for this task.

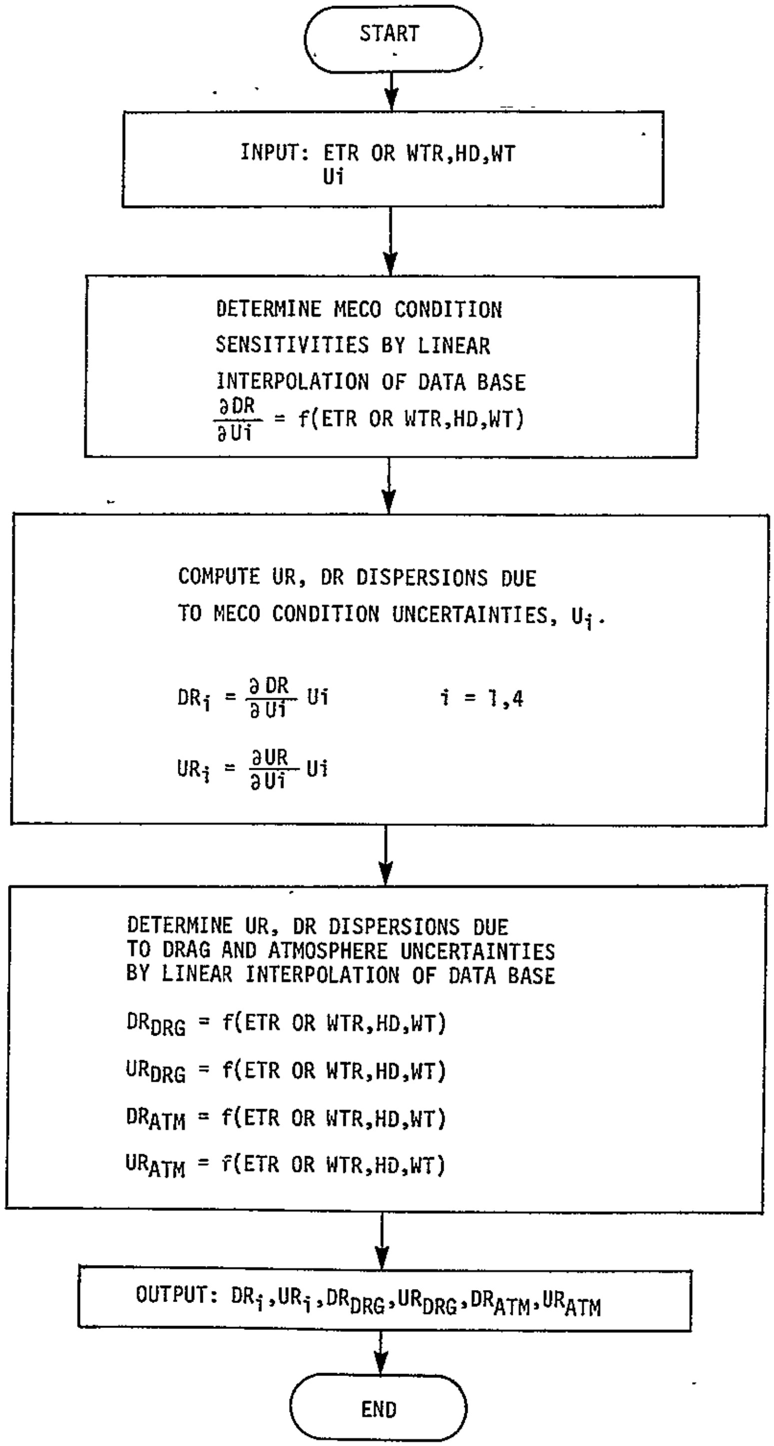


FIGURE 7.4-1 TRAJECTORY DISPERSION FLOWCHART (TASK 3)

7.5 DEBRIS IMPACT DISPERSIONS - TASK 4

The uprange, downrange impact point dispersions of each of the twenty-one pieces of debris are obtained by linear interpolation of the data base. Figure 7.5-1 presents a flowchart for this task.

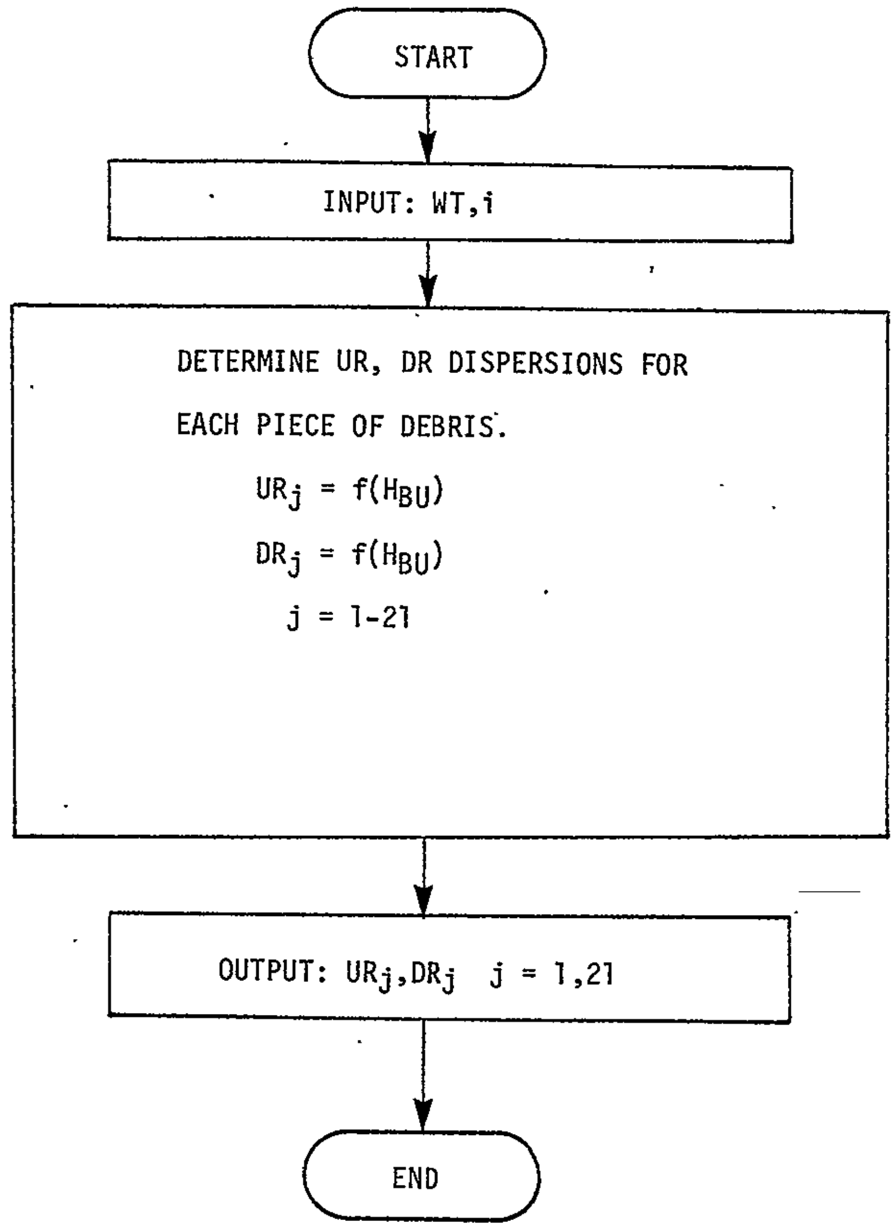


FIGURE 7.5-1 DEBRIS IMPACT DISPERSION FLOWCHART (TASK 4)

7.6 CROSSRANGE IMPACT POINT DISPERSIONS - TASK 5

The crossrange impact point dispersions due to the rotational lifting effect, trajectory uncertainties, and debris scatter are obtained by linear interpolation of the data base. Figure 7.6-1 presents a flowchart for this task.

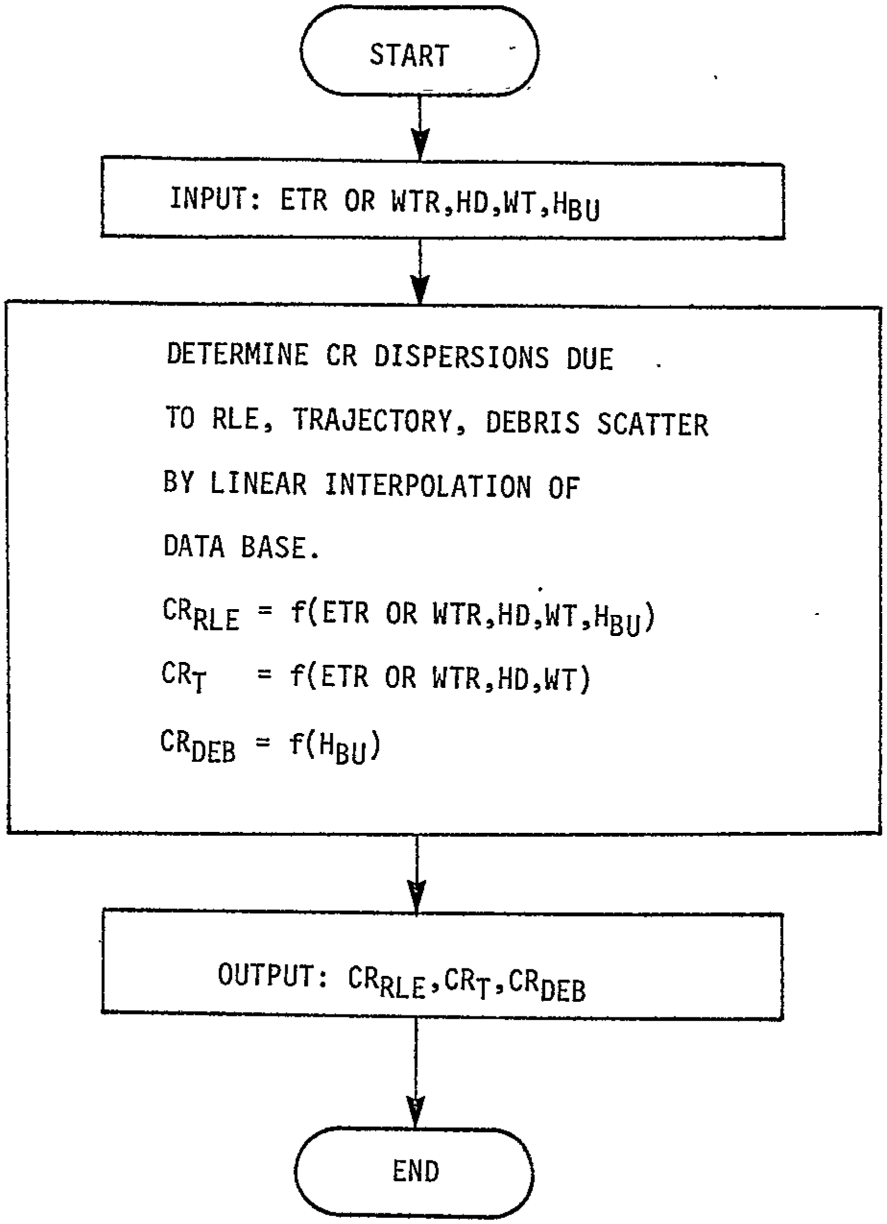


FIGURE 7.6-1 . CROSSRANGE IMPACT PRINT DISPERSIONS FLOWCHART (TASK 5)

7.7 TRAJECTORY DISPERSION CONSTANTS - TASK 6

The uprange, downrange dispersions caused by each trajectory uncertainty are root-sum-squared to obtain the $+3\sigma$ and -3σ trajectory dispersions. The constants of the Gaussian distribution reflecting these 3σ dispersions are obtained as illustrated in the flowchart of Figure 7.7-1.

START

INPUT: $DR_i, UR_i, DR_{DRG}, UR_{DRG}, DR_{ATM}, UR_{ATM}$

COMPUTE 3σ RSS TRAJECTORY UR AND DR

$$UR_T = \left(\sum_{i=1}^{4} UR_i^2 + UR_{DRG}^2 + UR_{ATM}^2 \right)^{1/2}$$

$$DR_T = \left(\sum_{i=1}^{4} DR_i^2 + DR_{DRG}^2 + DR_{ATM}^2 \right)^{1/2}$$

COMPUTE GAUSSIAN DISTRIBUTION CONSTANTS.

$C_T = 1.0$

$\mu_T = (DR_T - UR_T)/2.0$

$\sigma_T = (DR_T + UR_T)/6.0$

OUTPUT: $UR_T, DR_T, C_T, \mu_T, \sigma_T$

END

FIGURE 7.7-1 TRAJECTORY DISPERSION CONSTANTS FLOWCHART (TASK 6)

7.8 DEBRIS DISPERSION CONSTANTS - TASK 7

The impact points of each piece of debris are assumed to be normally distributed between the uprange and downrange 3σ impact points. The constants of the Gaussian distributions for each of the twenty-one debris pieces are computed as shown in the flowchart of Figure 7.8-1.

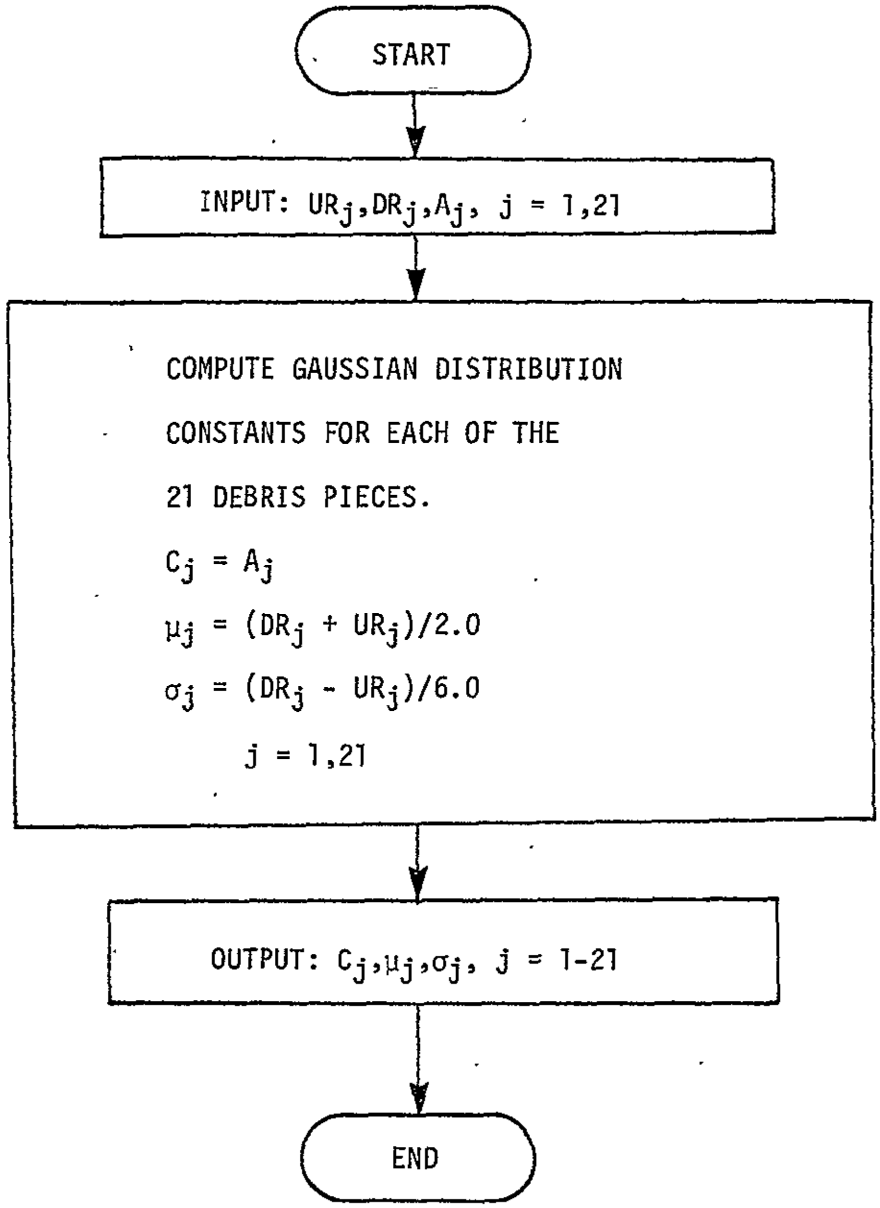


FIGURE 7.8-1 DEBRIS DISPERSION CONSTANTS FLOWCHART (TASK 7)

7.9 INTACT ET FOOTPRINT WIDTH - TASK 8

The width of the intact ET footprint is computed by root-sum-squaring the 3σ crossrange dispersions caused by the trajectory uncertainties and rotational lifting effect. Figure 7.9-1 presents a flowchart of this task.

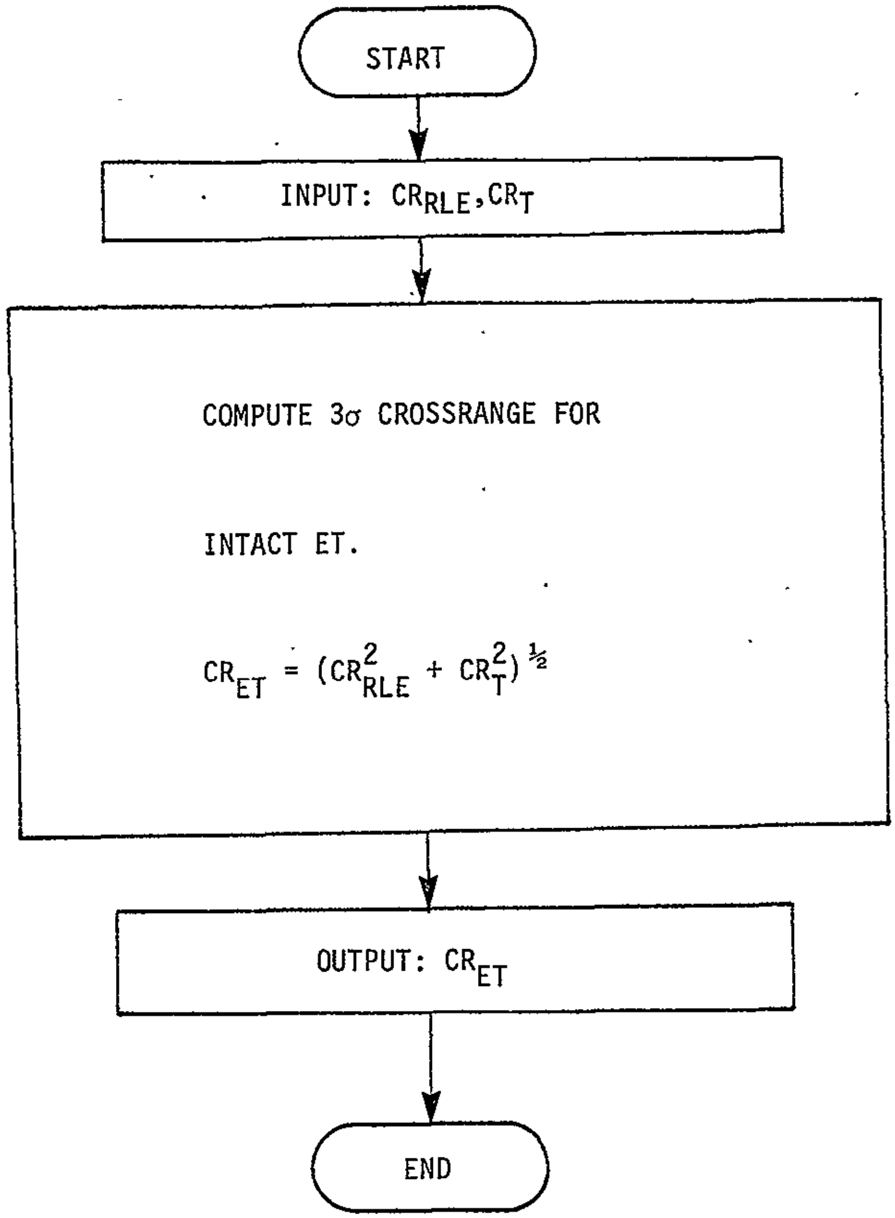


FIGURE 7.9-1   INTACT ET FOOTPRINT WIDTH FLOWCHART (TASK 8)

7.10 INTACT ET FOOTPRINT LENGTH - TASK 9

The impact distributions representing the trajectory and rotational lifting effect dispersions are combined to form the impact dispersion distribution for the intact ET. This distribution is integrated through a call to subroutine SIGMA and the 3σ uprange and downrange are computed. Similarly, the distribution for the rotational lifting effect is integrated to obtain the 3σ uprange and downrange distances. Figure 7.10-1 through Figure 7.10-3 are flowcharts for this task.

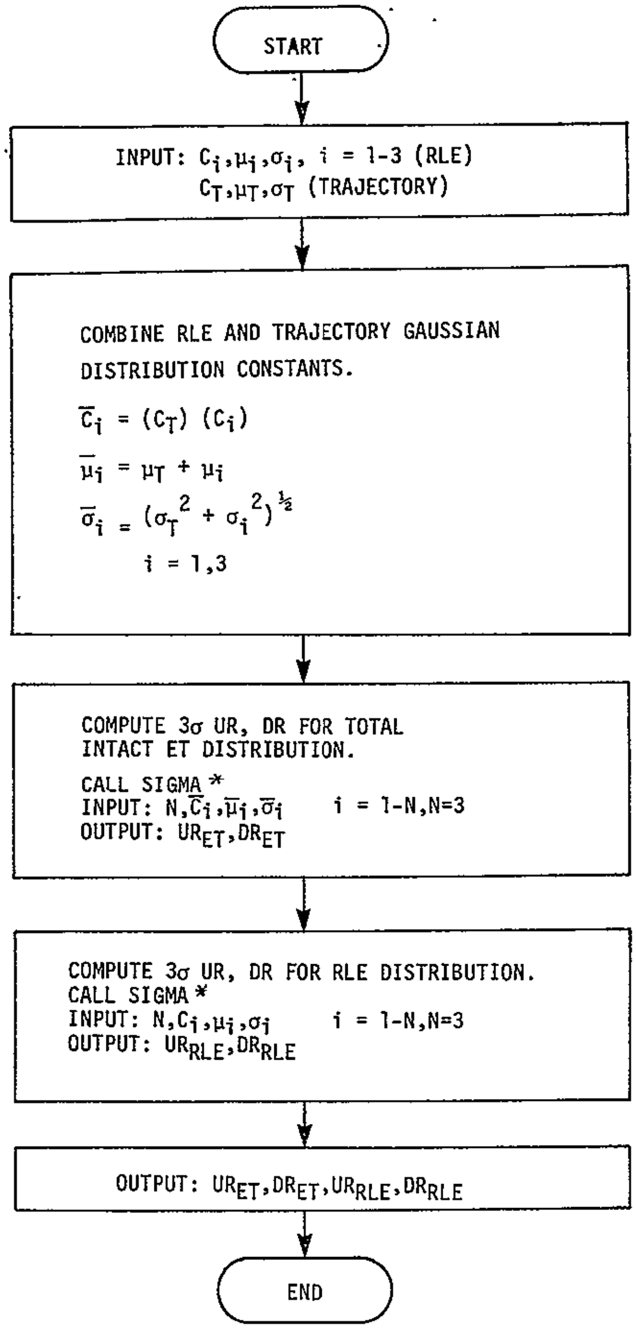


*Figure 7.10-2

FIGURE 7.10-1 INTACT ET FOOTPRINT LENGTH FLOWCHART (TASK 9)

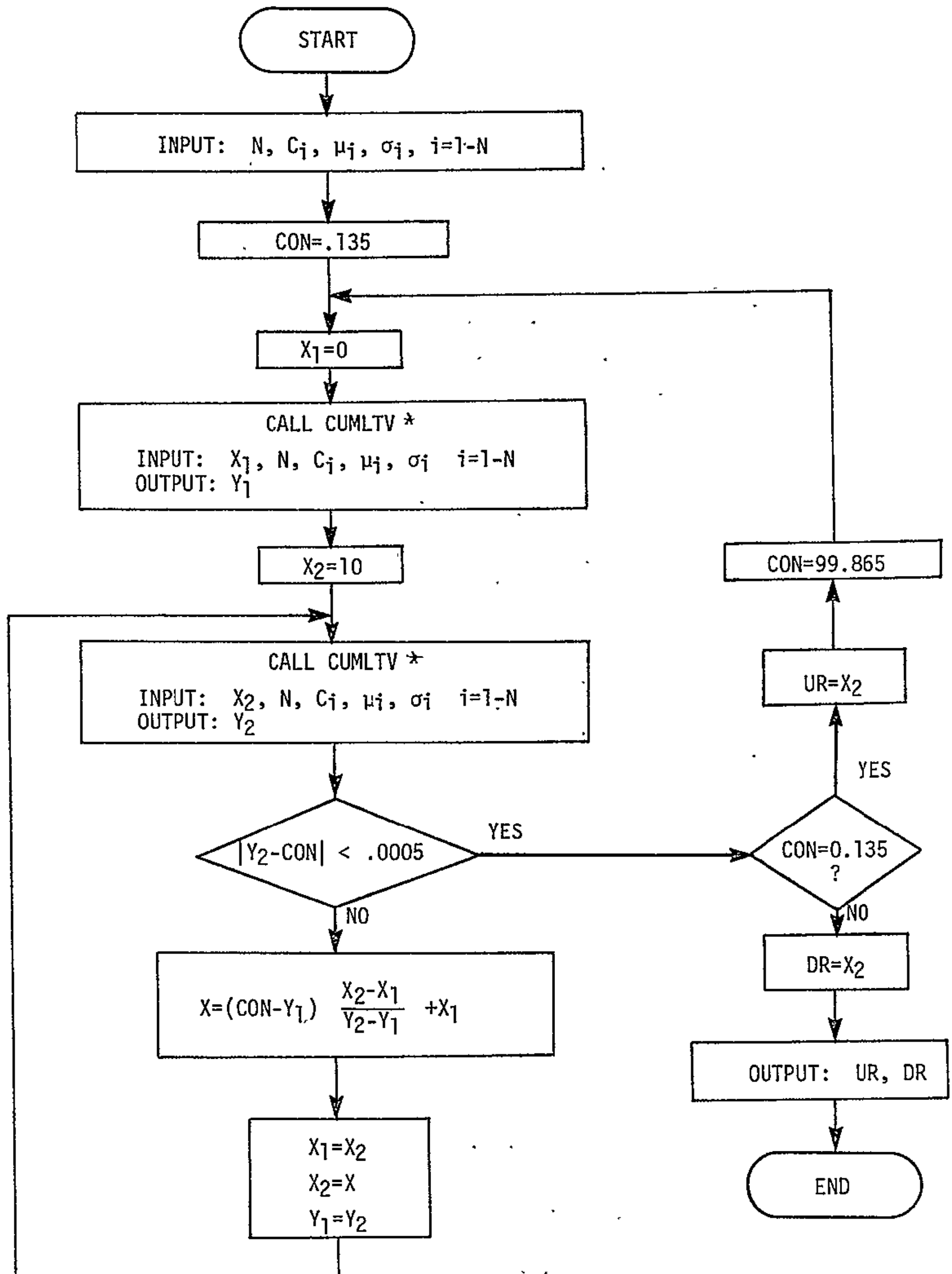
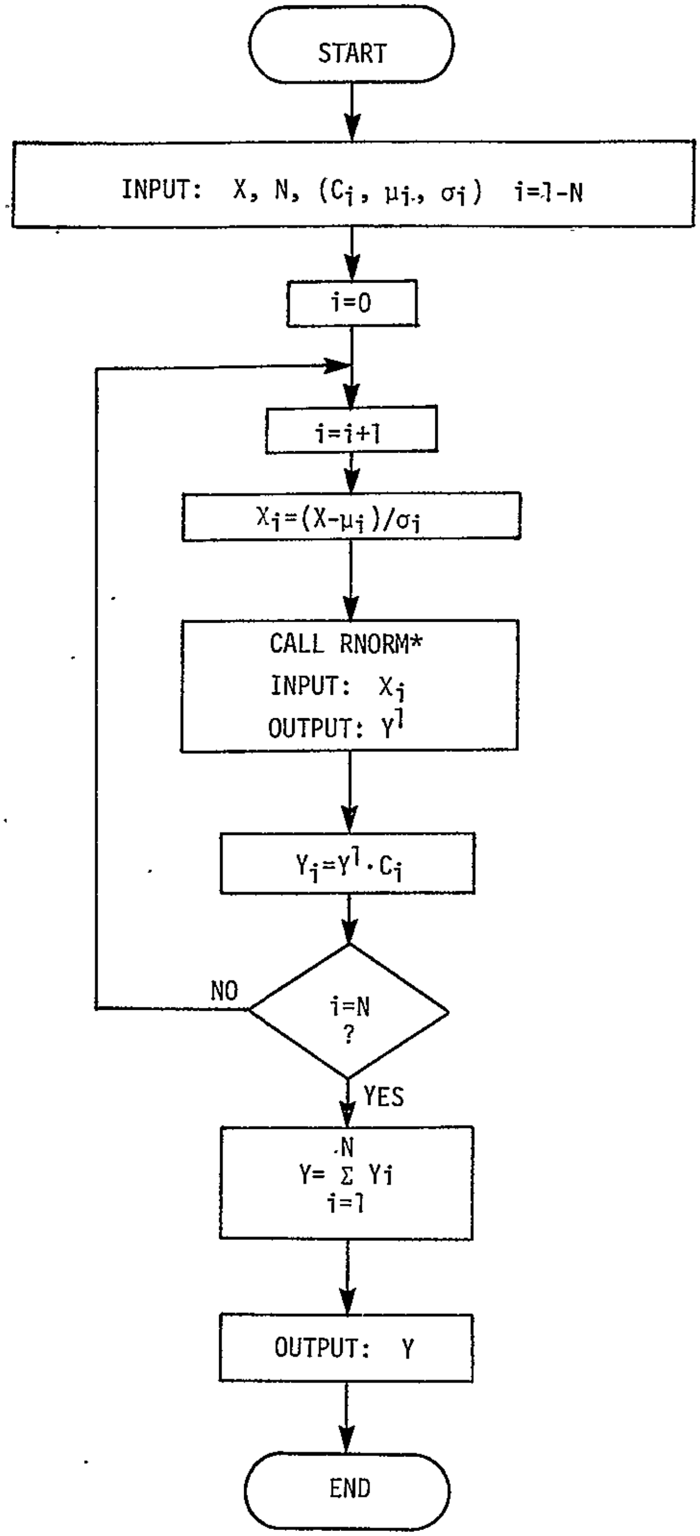


*Figure 7.10-3

FIGURE 7.10-2 FLOWCHART OF SUBROUTINE SIGMA



*See Reference 3
Page 12-1.

FIGURE 7.10-3 FLOWCHART OF SUBROUTINE CUMLTV

7.11 TOTAL DEBRIS DISPERSIONS - TASK 10

The impact distributions for each of the twenty-one debris pieces are summed to obtain the total debris impact distribution. This is integrated to obtain the $\pm$ 3σ debris impact dispersions. A flowchart of this task is presented in Figure 7.11-1.

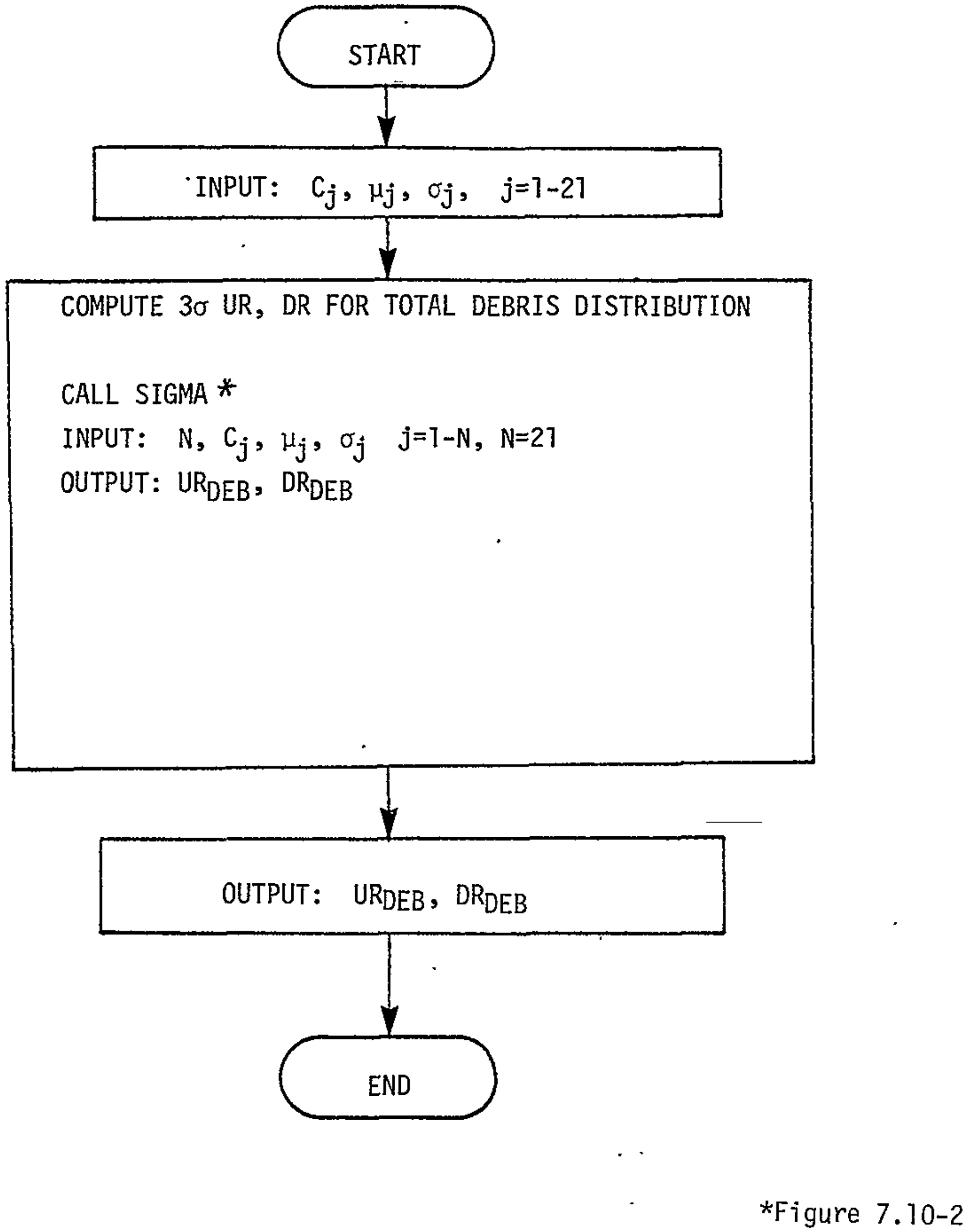


FIGURE 7.11-1 TOTAL DEBRIS DISPERSIONS FLOWCHART (TASK 10)

7.12 TOTAL FOOTPRINT DIMENSIONS - TASK 11

The dimensions of the total ET footprint are computed by adding the debris dispersions to the intact ET dispersions. Figure 7.12-1 presents a flowchart for this task.

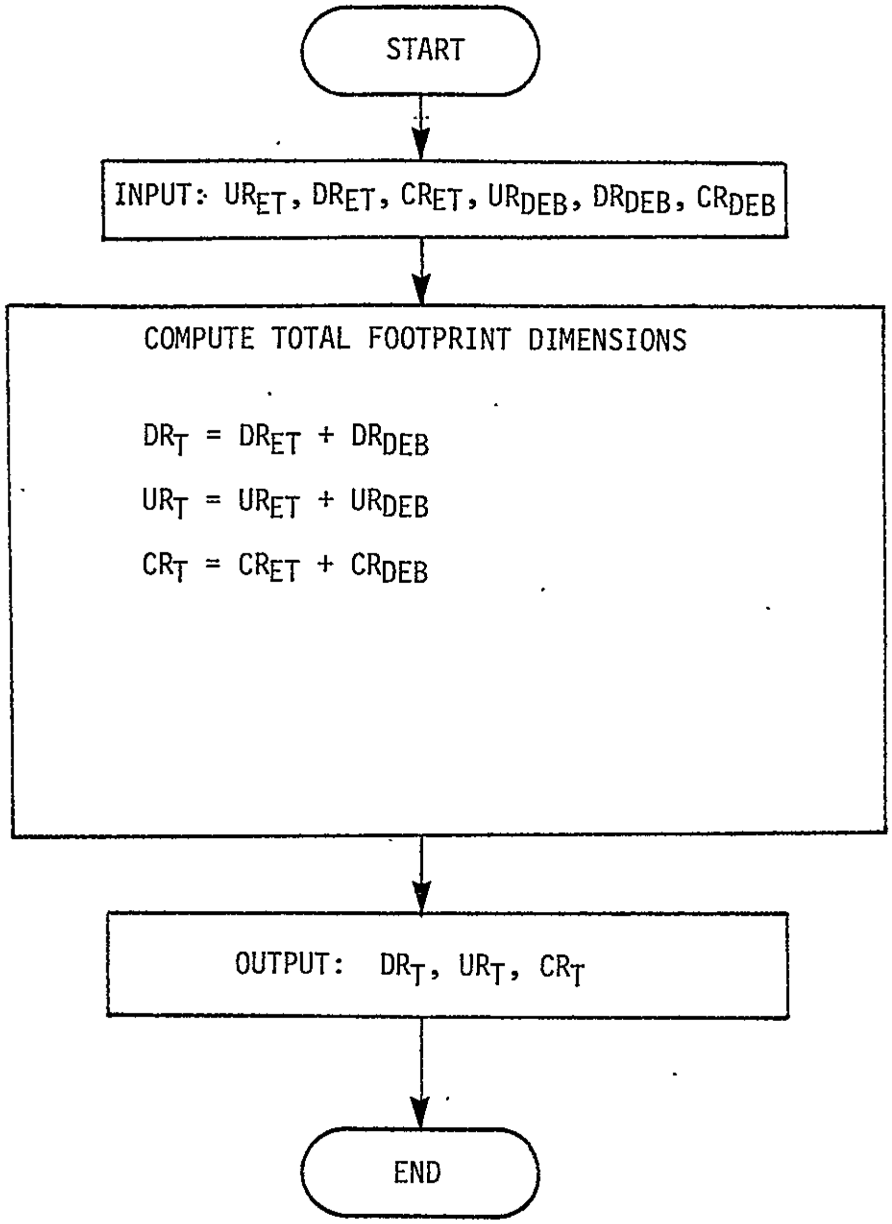


FIGURE 7.12-1 TOTAL FOOTPRINT DIMENSIONS FLOWCHART (TASK 11)

7.13 INTACT ET IMPACT DISTRIBUTION - TASK 12

The impact probability distribution of the intact ET is computed from the uprange footprint limit to the downrange limit. A flowchart for this task is presented in Figures 7.13-1 through 7.13-3.

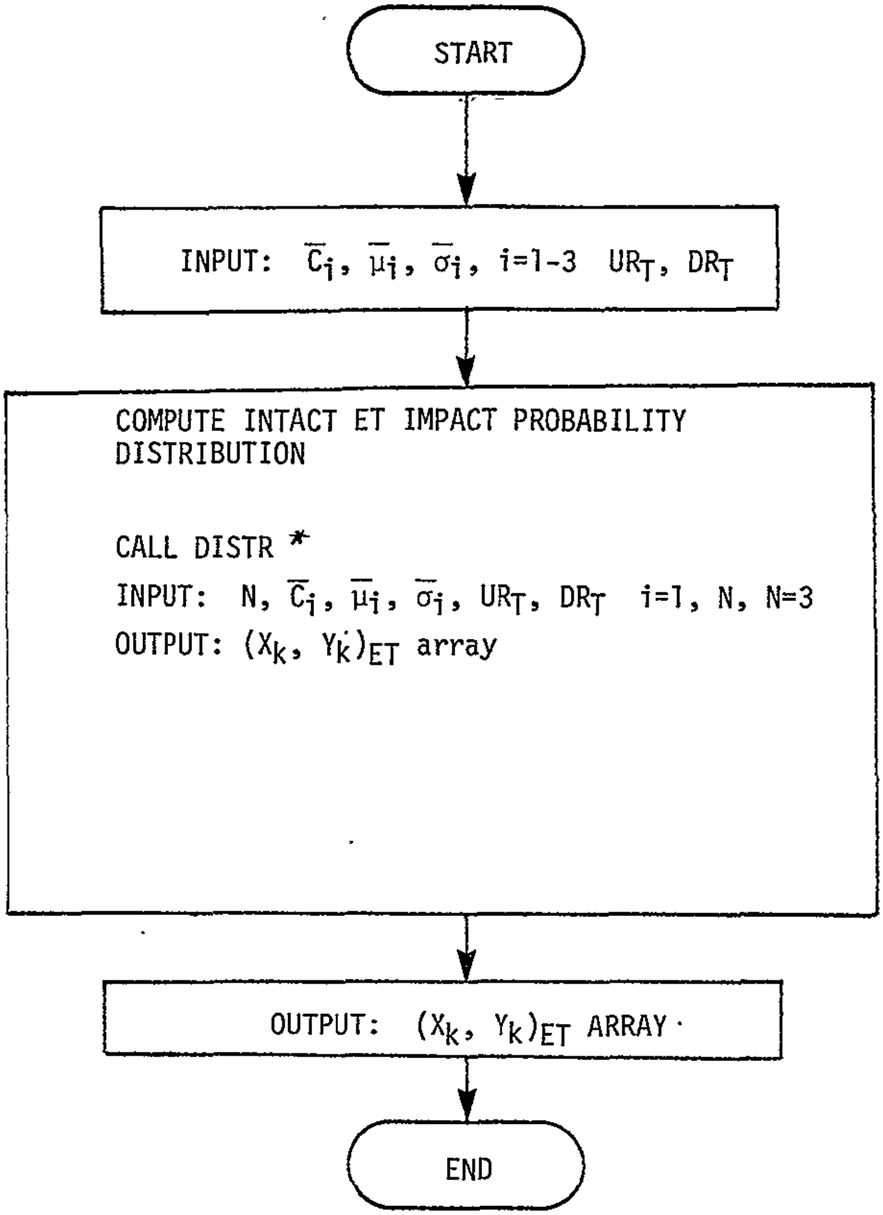


*Figure 7.13-2

FIGURE 7.13-1 ET IMPACT DISTRIBUTION FLOWCHART (TASK 12)

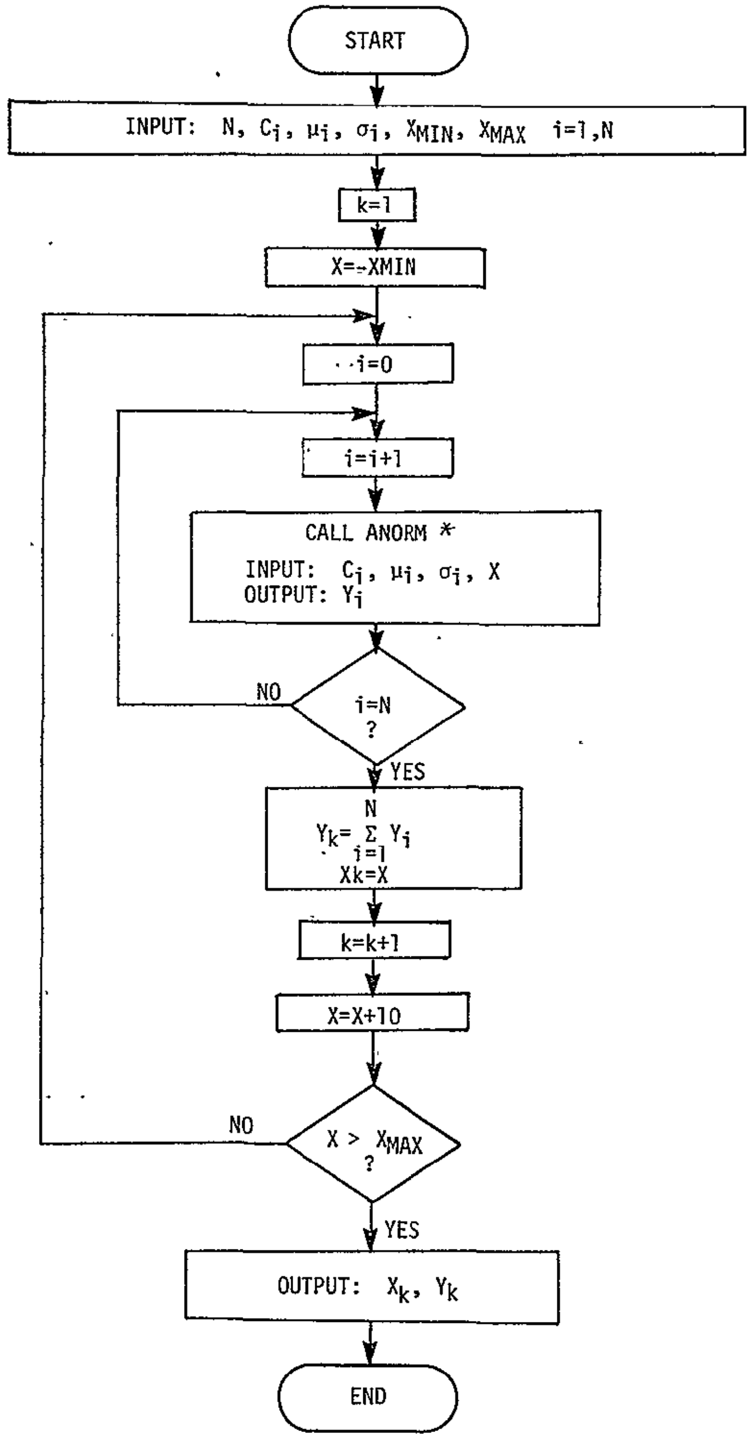


*Figure 7.13-3

FIGURE 7.13-2 FLOWCHART OF SUBROUTINE DISTR

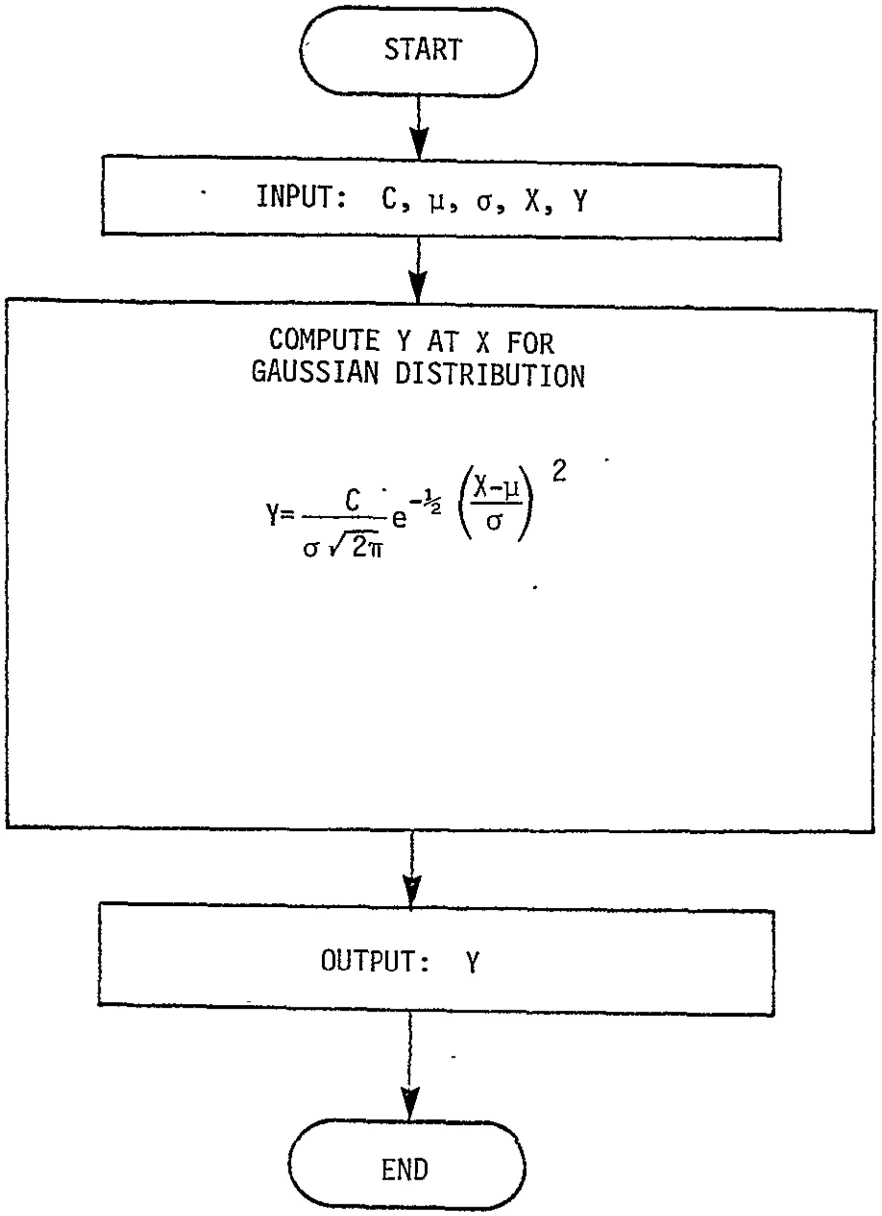


FIGURE 7.13-3 FLOWCHART OF SUBROUTINE ANORM

7.14 DEBRIS IMPACT DISTRIBUTION - TASK 13

The impact probability distribution for all the debris pieces is computed from the 3σ uprange limit to the 3σ downrange limit of the debris scatter. A flowchart of this task is presented in Figure 7.14-1.

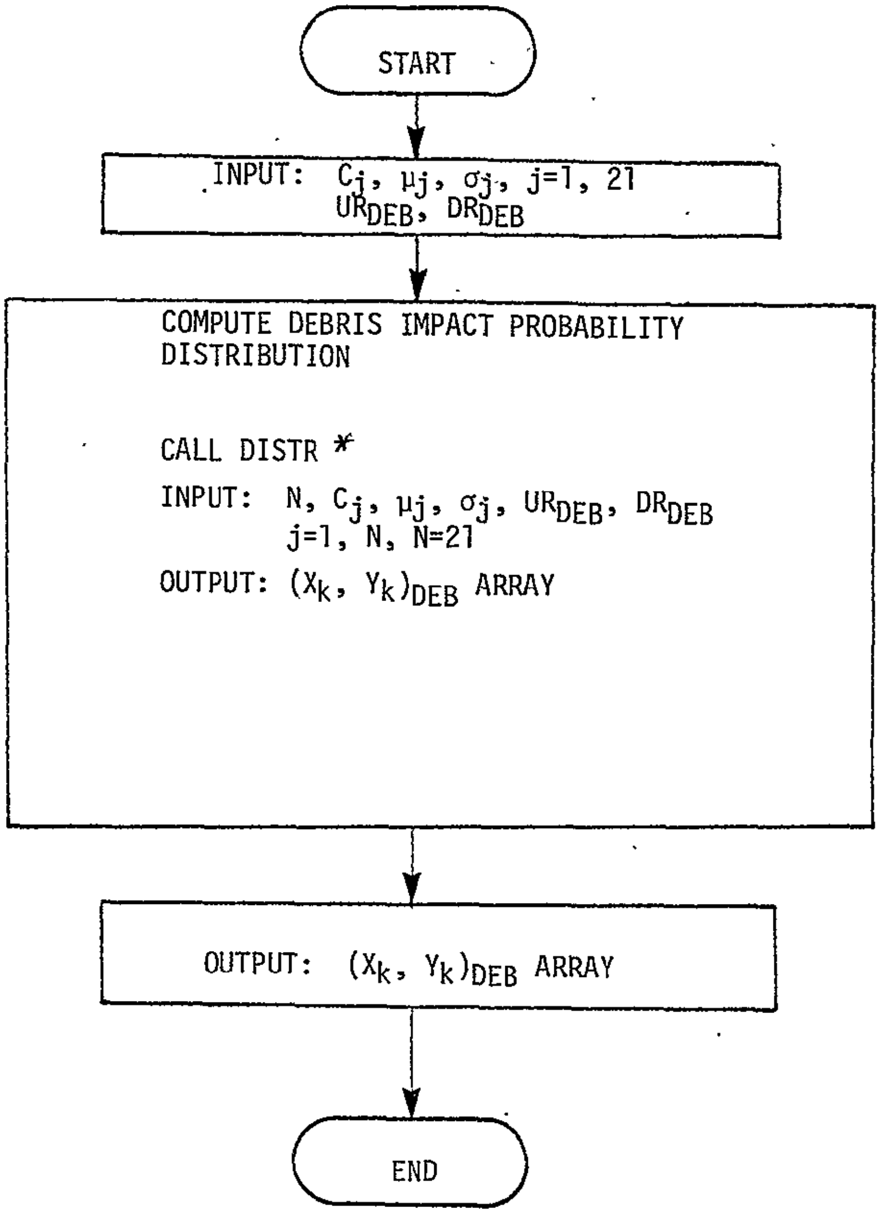


*Figure 7.13-2

FIGURE 7.14-1 DEBRIS IMPACT DISTRIBUTION FLOWCHART (TASK 13)

7.15 ET DESCENT TRAJECTORY - TASK 14

The ET descent trajectory is simulated from MECO to an input termination value of either longitude or geodetic latitude. Output from this task is latitude, longitude, and range versus time, and impact time and location. The requirements for a general 3-DOF trajectory program are presented in Appendix A. Figure 7.15-1 presents a flowchart for this task illustrating the input and output parameters.

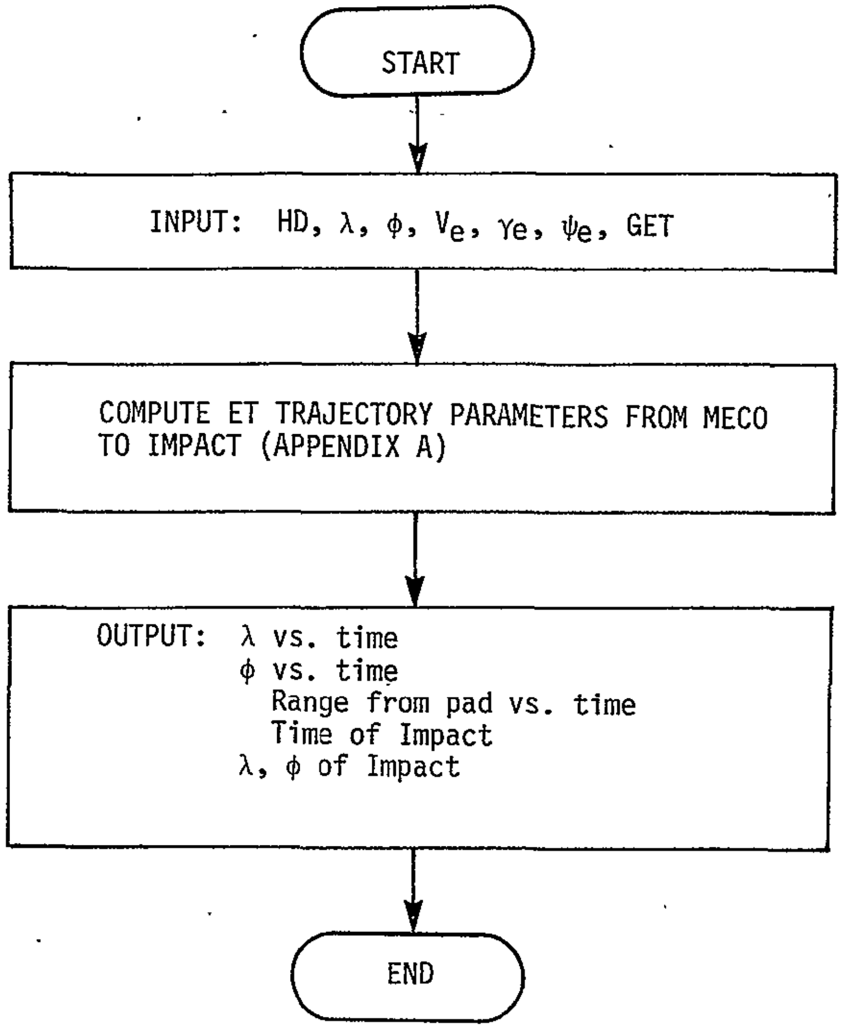


FIGURE 7.15-1 ET DESCENT TRAJECTORY FLOWCHART (TASK 14)

7.16 OUTPUT DISPLAYS - TASK 15

Tabular output from the ET Impact Prediction Processor will consist of terminal screen displays and hardcopy print of document quality. Table 7.16-I presents the data and format to be output.

TABLE 7.16-I EXAMPLE ET IMPACT SUMMARY TABLE

TABLE 3-XI.- MISSION-OFT-1 AOA EXTERNAL TANK DISPERSION

SSME Cutoff Conditions:
- Flight Path Angle: 0.488 degree
- Velocity: 25 688 fps
- Inclination: 38 degrees
- Altitude: 60 n.mi.
- Lat: 35.0 degrees N
- Long: 62.9 degrees W
- Range: 983 n.mi.
- ET Wt: 89 261 lbs

Breakup Altitude = 193,000 ft.
LH_2 Rupture Altitude = 343,000 ft.
LO_2 Rupture Altitude u= 260000 ft.

Impact Point:
- Lat: 31.6 degrees S
- Long: 95.9 degrees E
- Surface Range from Pad: 10 632 n.mi.

Error Source	3σ Error	Downrange n.mi.	Uprange n.mi.	Crossrange n.mi.
Separation Altitude	±1926 ft	110	110	2
Separation Velocity	±11.06 fps	663	589	14
Separation Flight Path Angle	±0.022 degree	70	78	1
Rotational Lifting Effect	10-50 deg/sec tumble rate	317	308	3
Drag	±Tolerances	92	144	2
Atmosphere	3σ Dense 3σ Thin	175	278	4
Weight	±10 000 lb	68	79	1
Trajectory Dispersion	3σ RSS	750	751	15
Debris Scatter		113	124	15
Total Dispersion		863	875	30

7.17 STORED PLOT DATA - TASK 16

All data required by the ET Nominal/AOA/ATO Plot Processor is stored in a secure catalogued file selected by the user. Table 7.17-I lists the parameters which are stored in the files and used by the plot processor.

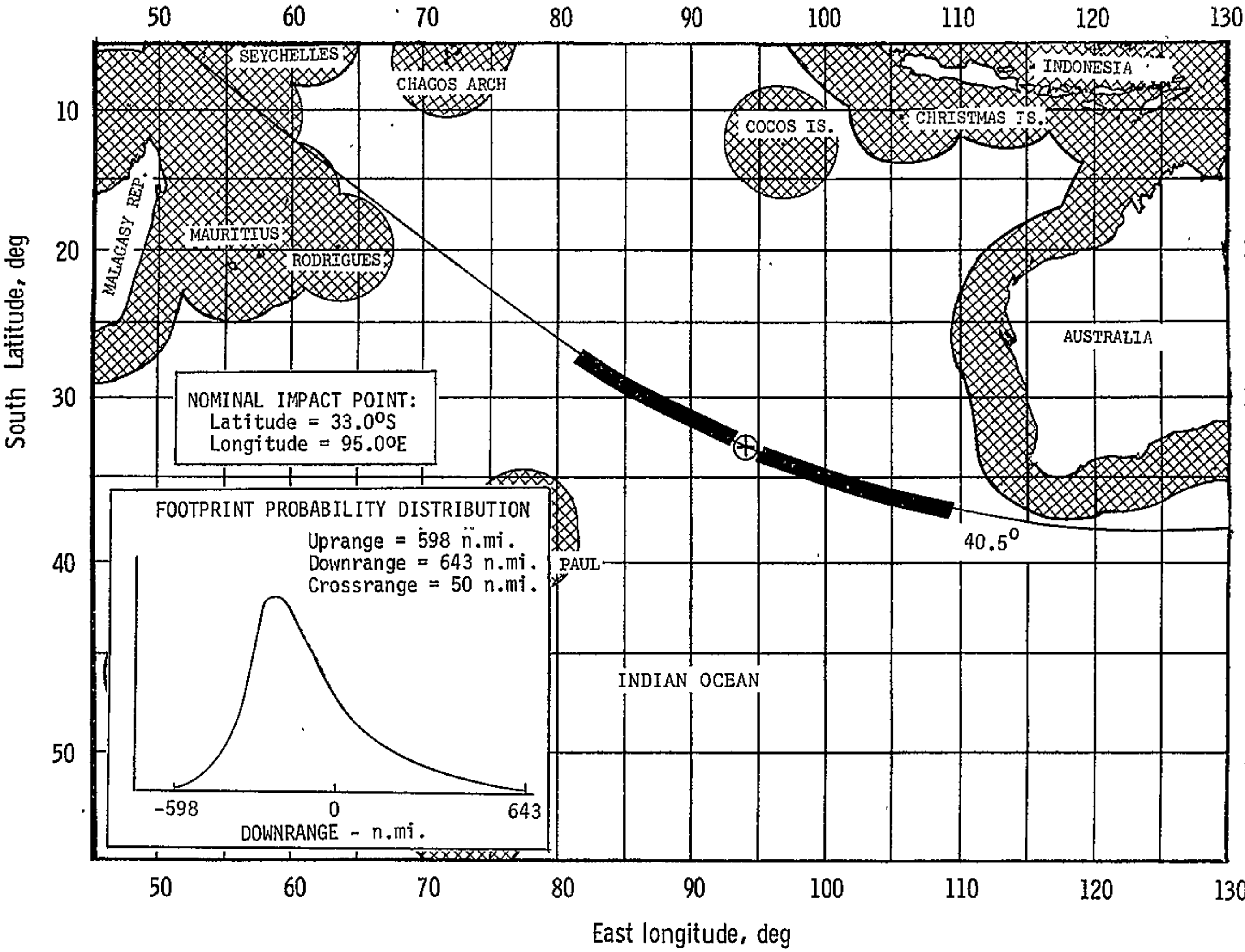
TABLE 7.17-I ET STORED PLOT DATA

PARAMETER	
λ, ϕ, Range, vs. time	Time history of ET trajectory.
λ, ϕ, Range, Time	Coordinates and time of ET impact.
DR_T, UR_T, CR_T	Total footprint dimensions (Task 11)
$(X_R, Y_R)_{ET}$ array	Intact ET impact probability distributions (Task 12)
$(X_R, Y_R)_{DEB}$ array	Debris impact probability distribution (Task 13)

8.0 ET NOMINAL/AOA/ATO PLOT PROCESSOR

The ET Nominal/AOA/ATO Plot Processor is designed to use data generated by the ET Nominal/AOA/ATO Impact Processor to produce ET impact footprints for nominal, AOA, and ATO missions. The processor will have the capability to plot single or multiple footprints on high resolution maps. Single trajectory maps will also have an inset describing the nominal impact point and an optional inset displaying the ET footprint probability distribution. Sample output required for a single trajectory map appears in Figure 8.0-1.

The processor consists of four major logical units which 1) specify and plot map boundaries; 2) specify and plot inset boundaries and inset data; 3) Plot map and print title and; 4) plot the groundtrack, footprint, impact point and inclination. Additional logic controls branching for multiple groundtracks, a user option to change map format, the production of hard copy and the production of new maps as shown in Figure 8.0-2. Functional descriptions of the major units appear in the following subparagraphs.



STS-1 NOMINAL ET IMPACT FOOTPRINT

FIGURE 8.0-1 EXAMPLE ET IMPACT FOOTPRINT PLOT

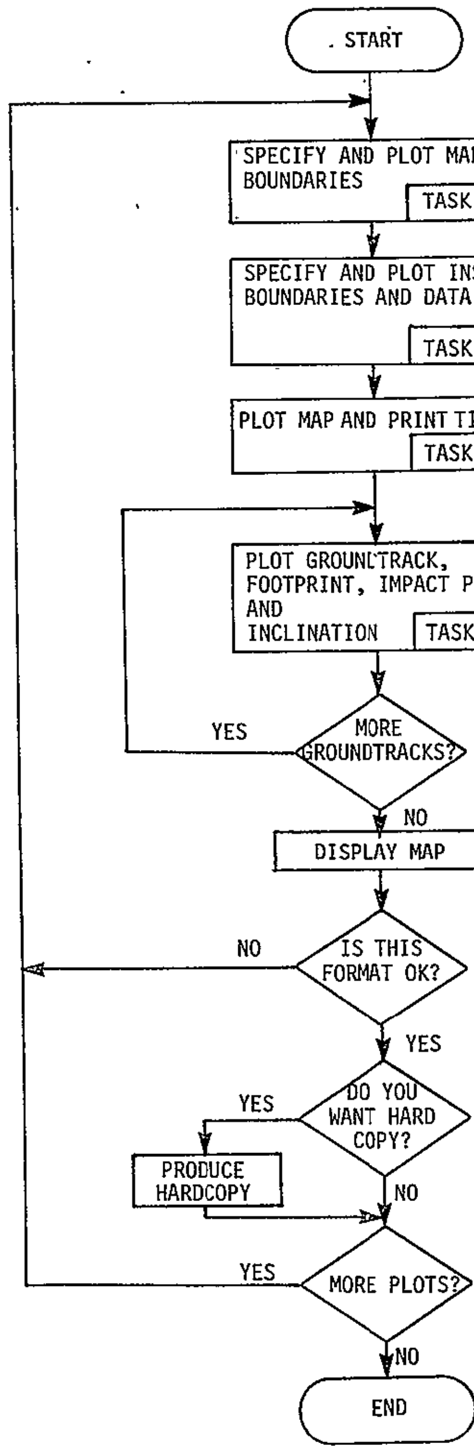
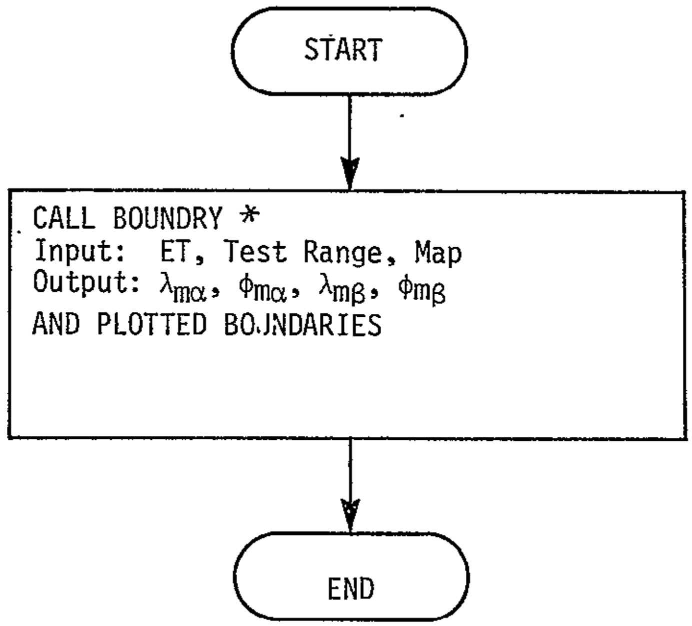


FIGURE 8.0-2 ET NOMINAL/AOA/ATO IMPACT PLOT PROCESSOR EXECUTIVE FLOWCHART

8.1 SPECIFY AND PLOT MAP BOUNDARIES - TASK 1

The capability is required to produce a rectangular map containing any region of the world, the boundaries being specified by the latitude and longitude of the upper left and lower right corners of the map. Further, it is desired that separate default parameters be supplied to specify boundaries for Eastern Test Range (ETR) and Western Test Range (WTR) launches. Subroutine BOUNDRY (Appendix F) will establish and plot these limits, accepting user defined boundaries or referencing a lookup table for default values. Figure 8.1-1 presents a flowchart for this task.



*APPENDIX F

FIGURE 8.1-1 MAP BOUNDARIES FLOWCHART (TASK 1)

8.2 SPECIFY AND PLOT INSET BOUNDARIES AND DATA - TASK 2

Maps containing multiple trajectories will have no insets. Single trajectory maps will contain an inset specifying the latitude and longitude of the impact point. The user may also specify an inset containing the ET footprint probability distribution. Printed in this inset will be the values of the footprint uprange, downrange, crossrange and a graph of the probability distribution, with scale. Using subroutine BOUNDRY, the user shall have the capability to specify the inset location by specifying the latitude and longitude of the upper left and lower right hand corners of the inset. Default values will be supplied for ETR or WTR launches by referencing a lookup table. Should the inset size or location be changed by user specified values of the corners, inset information within the inset shall retain the same relative dimensions. Figure 8.2-1 presents a flowchart for this task.

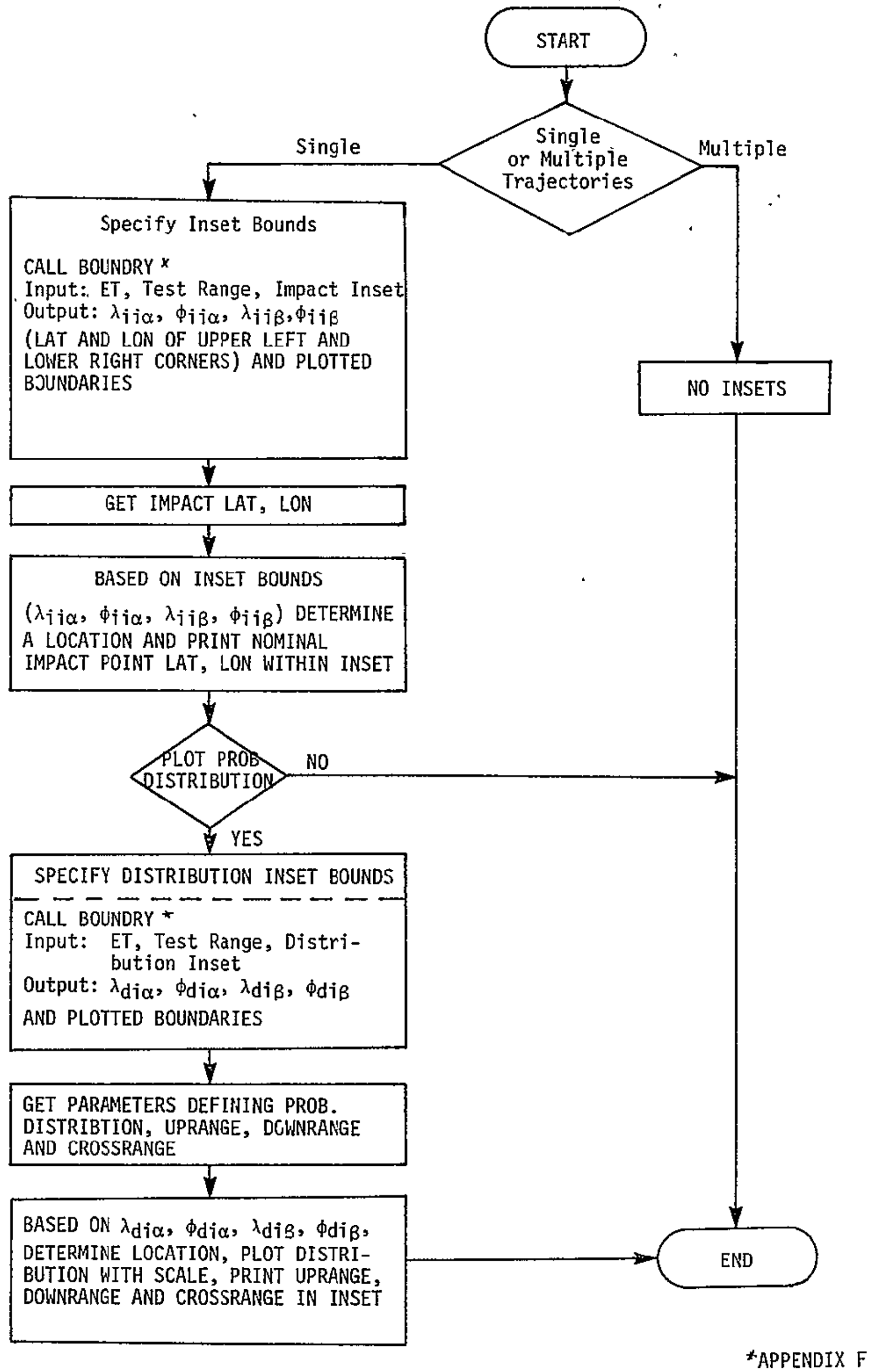


FIGURE 8.2-1 INSET BOUNDARIES FLOWCHART (TASK 2)

8.3 PLOT MAP AND TITLE - TASK 3

A map of the region of the world lying within the limits specified by BOUNDRY is to be plotted on the console CRT as shown in Figure 8.3-1. Nothing is to be printed within the boundaries of an inset. The map itself shall be of high resolution and contain: (see Figure 8.0-1).

- O Landmasses with labels
- O Limit lines of 200 n.mi. around landmasses
- O Water body labels
- O Latitude and longitude grid lines every 5^{o} and labels every 10^{o}.

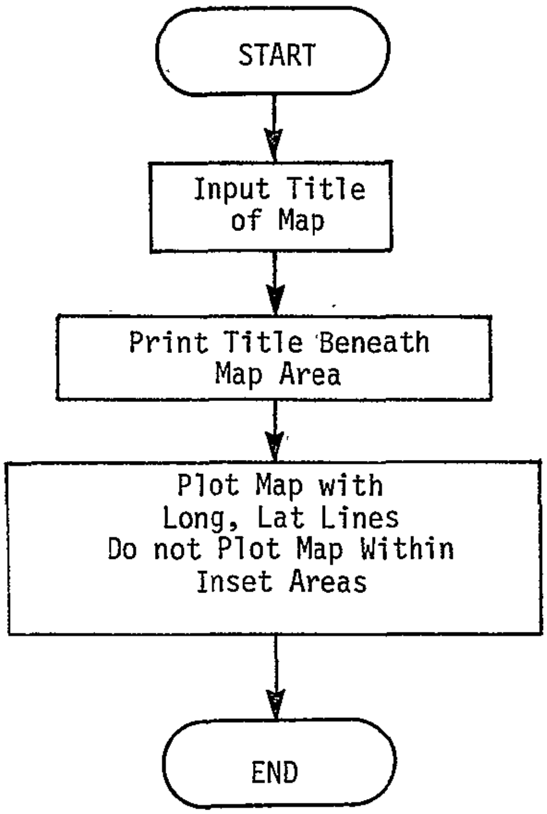
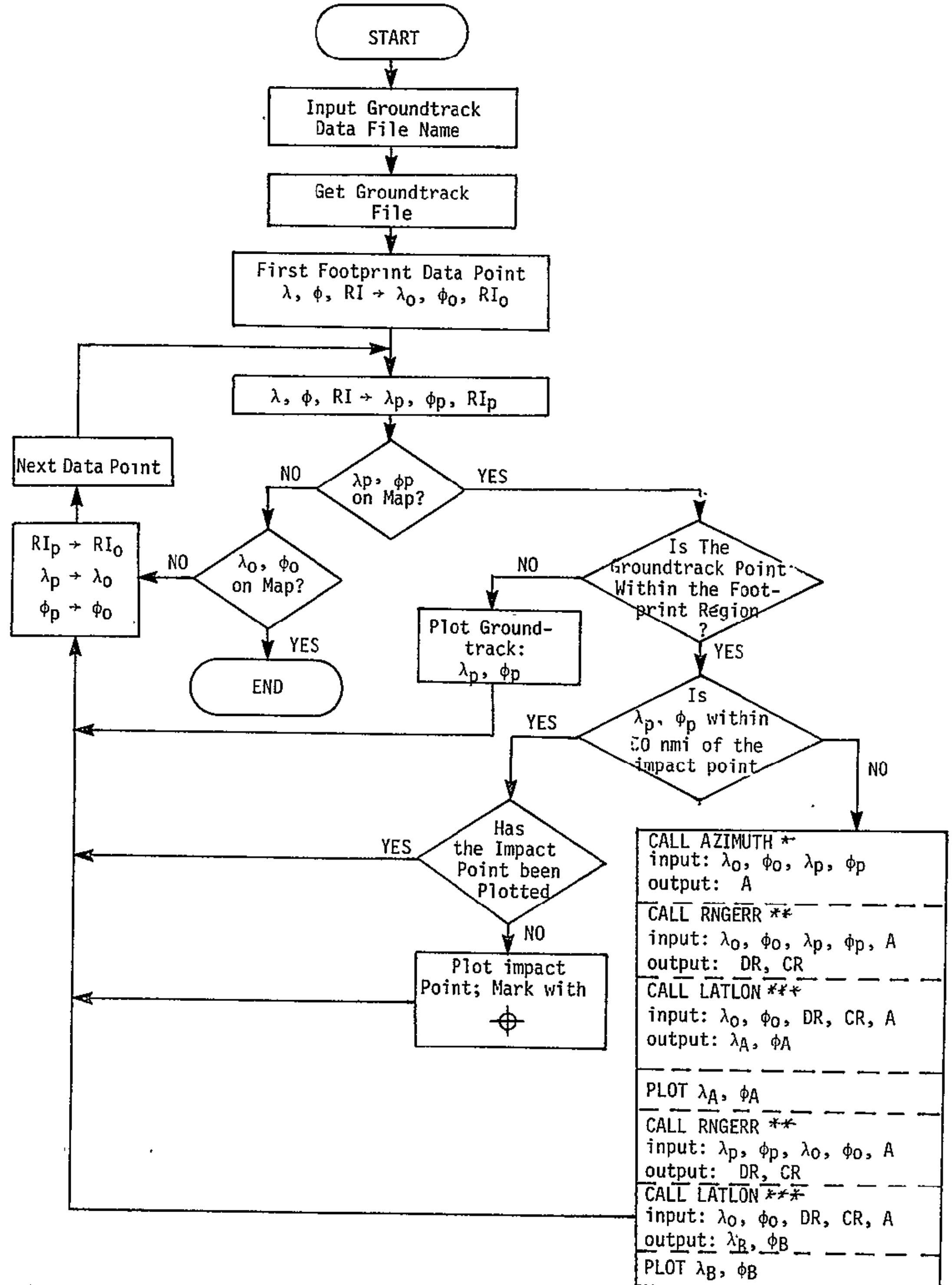


FIGURE 8.3-1 MAP PLOTTING FLOWCHART (TASK 3)

8.4 PLOT GROUNDTRACK, FOOTPRINT, IMPACT POINT AND INCLINATION - TASK 4

A line representing the ET groundtrack is to be plotted on the map, extending to the map boundaries. Within the region of the footprint, the width of this line is to be representative of the crossrange of the footprint. Subroutine AZIMUTH (Appendix C) approximates the azimuth at a point on the groundtrack, utilizing the latitude and longitude of the current and previous groundtrack data points. Subroutine RNGERR (Appendix D) uses the azimuth to calculate crossranges, which are converted to points on the map using subroutine LATLON (Appendix E). Within the footprint region the plot line should connect the crossrange points from data point to data point in a zig-zag fashion, so as to give the appearance of a broadened line.

Within a range of 50 miles of the impact point, no footprint or groundtrack is to be plotted, so that the impact point can be clearly denoted with a cross and concentric circle. The footprint will then continue as a broad line until the downrange limit, where the inclination of the groundtrack shall be printed. The groundtrack should then extend to the map boundary. Figure 8.4-1 presents a flowchart of this task.



*APPENDIX C
**APPENDIX D
***APPENDIX E

FIGURE 8.4-1 FOOTPRINT PLOT FLOWCHART (TASK 4)

9.0 REFERENCES

1. JSC IN 76-FM-50, "Flight Design System-2 (FDS-2) User's Requirements", Vol. I-V, September 1978.

2. JSC IN 76-FM-26, "Space Vehicle Dynamics Simulation (SVDS) Program: Users Guide", Vol. II, Rev. 2, October 1977.

3. UNIVAC UP-7502, "UNIVAC Large Scale Systems Stat Pack", Revision 1, 1972.

APPENDIX A

THREE DEGREE OF FREEDOM TRAJECTORY SIMULATION

APPENDIX A

THREE DEGREE OF FREEDOM TRAJECTORY SIMULATION

A.1 DESCRIPTION

This processor will perform a three degree of freedom, translation only, trajectory analysis from separation to impact for a Solid Rocket Booster (SRB) or an External Tank (ET). Its purpose is to calculate trajectory data required by the various plot processors to plot groundtracks and impact points. An overview of the executive is illustrated in Figure A-1. The executive is divided into six tasks, each of which is explained in Figures A-2 through A-4 and Section A.2 through A.7. All references to SVDS subroutines and models refer to the Space Vehicle Dynamic Simulation, milestone 3.13. A brief description of the processor flow follows. Data defining the type of trajectory to be simulated is input in task 1. The data applicable to the first phase is used to initialize flags and variables in task 2 prior to beginning the integration cycle. Tests for case and phase termination are performed in task 3. If the present phase is terminated, control is transferred to task 2. If the last phase is terminated, the trajectory simulation ends. User specified data is output in task 4. Task 5 computes vehicle accelerations, integrates them to obtain velocity and position, then converts all of these to the required output units. All forces acting on the vehicle are computed and summed in task 6. Control then returns to task 3. The following subsections describe the detailed requirements for each task.

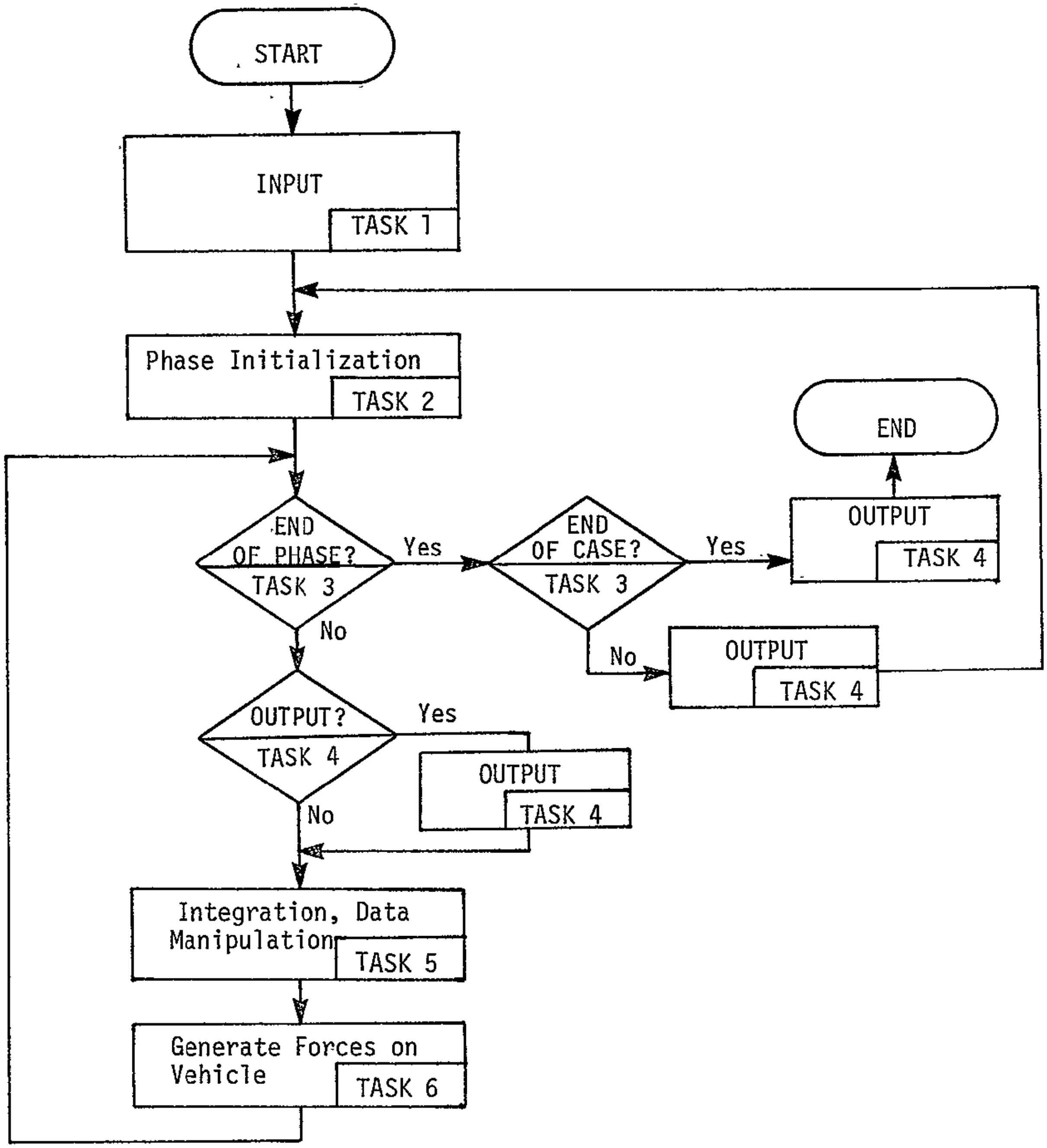


FIGURE A-1 FLOWCHART OF 3-DOF TRAJECTORY PROGRAM

A.2 INPUT - TASK 1

The input data required for the execution of the trajectory program is listed in Table A-I. Much of the input required will be available in the FDS Master Data Base. Use will also be made of preconstructed data elements containing aerodynamic coefficients, thrust tables, and similar data which does not change for a particular vehicle. Initialization of the position and velocity will be by inputting either inertial (OPTION 1) or earth relative (OPTION 2) parameters.

TABLE A-I - INPUT DATA REQUIRED FOR 3-DOF TRAJECTORY SIMULATION

Velocity Initialization Option 1	
VI	Magnitude of vehicle inertial velocity vector.
GAMI	Inertial flightpath angle.
PSII	Inertial azimuth.
Velocity Initialization Option 2	
VE	Magnitude of vehicle earth relative velocity vector.
GAME	Earth relative flightpath angle.
PSIE	Earth relative azimuth.
Position Initialization Option 1	
FLAMB	Longitude of subvehicle point, measured positive east of Greenwich.
PHIC	Geocentric latitude of subvehicle point, positive north of equator.
RI	Magnitude of the vehicle inertial radius vector.
Position Initialization Option 2	
FLAMB	Longitude of the subvehicle point, measured positive east of Greenwich.
PHID	Geodetic latitude of subvehicle point, positive north of equator.
HD	Geodetic altitude of the vehicle.
GET	Ground elapsed time from launch to start of trajectory simulation.
DELTT	Integration step size.
ISTAN	Atmospheric model selection flag.
Phase & Case Termination Input	Input necessary to terminate a phase within a specified tolerance of a specified value of vehicle altitude, earth relative flightpath angle, dynamic pressure, latitude, longitude or phase time.
Aerodynamic Coefficient Tables	Drag coefficient as a function of any combination of Mach number, altitude, or phase time.
WT	Vehicle weight.
Engine Thrust Tables	Thrust magnitude and direction in the Trajetory Axis Coordinate System as a function of phase time.
Launch Pad Coordinates	Geodetic latitude and longitude of launch site.
Wind Properties Table	Table of wind speed and direction versus altitude.

A.3 PHASE INITIALIZATION - TASK 2

The flowchart for phase initialization is shown in Figure A-2. Initialization of vehicle position and velocity involves calculating ECI components of position and velocity for use in the integrator as well as the values associated with the unused input option.

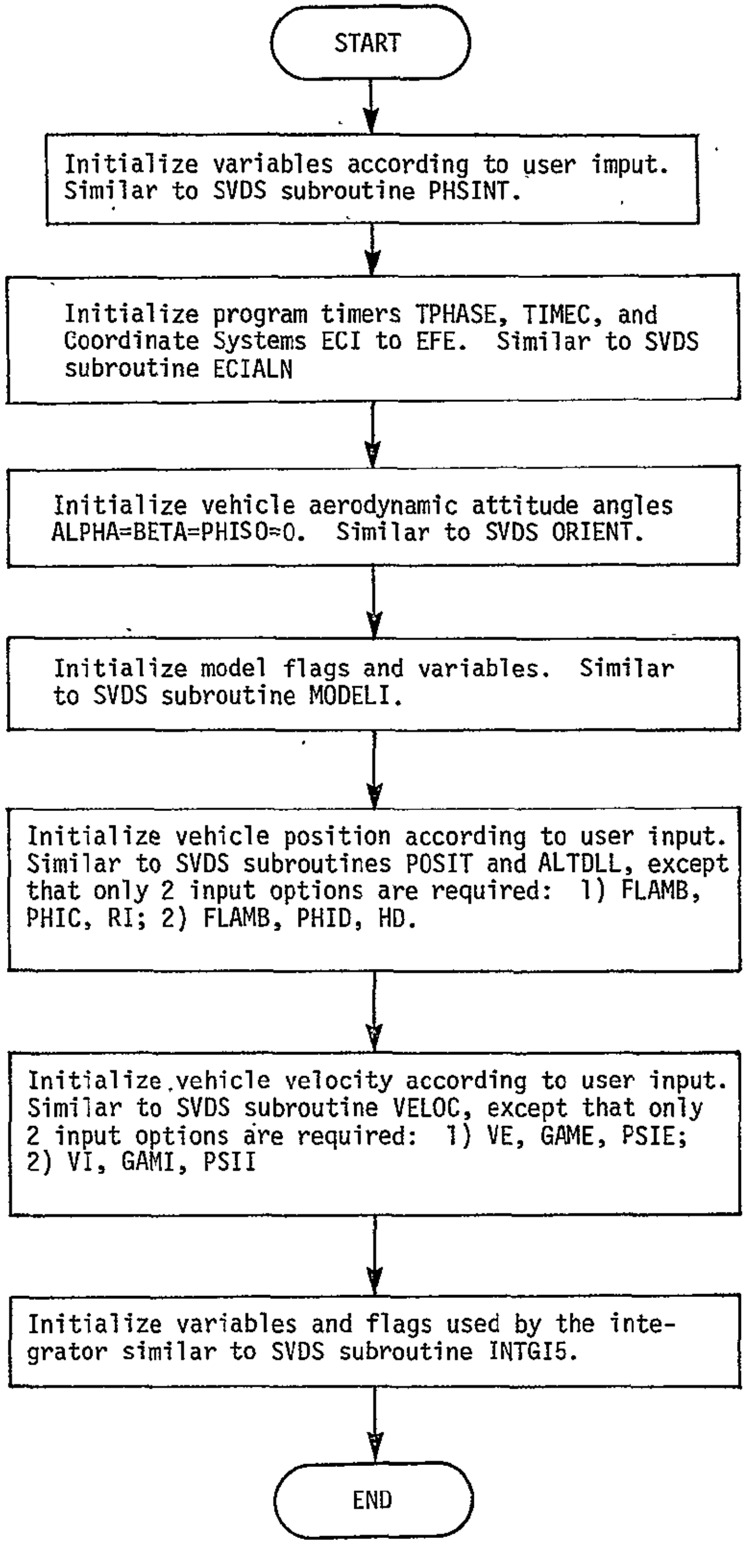


FIGURE A-2 PHASE INITIALIZATION FLOWCHART (TASK 2)

A.4 CASE AND PHASE TERMINATION - TASK 3

The program must have the ability to phase (interrupt the program, reinitialize certain variables, then continue the program). This capability is modeled as a reduced version of SVDS subroutines PHSEXC and TERMIN. Phasing should be user selected on specified values of: 1) vehicle geodetic altitude, 2) vehicle earth relative flightpath angle, 3) vehicle dynamic pressure, 4) vehicle geodetic latitude, 5) vehicle longitude, or 6) elapsed time since beginning the present phase.

A.5 OUTPUT PROCESSING - TASK 4

Output processing for this program consists of computing the values of specified variables and storing them in common locations accessible by the rest of the ET/SRB Disposal FDS processors. Output is required on case termination, phase termination, and user specified output frequency. Output will consist of ground elapsed time since launch, vehicle range from launch pad, vehicle longitude, vehicle geodetic latitude, and vehicle geodetic altitude.

A.6 INTEGRATION AND DATA MANIPULATION - TASK 5

The flowchart for integration and data manipulation is shown in Figure A-3. The last step of this flowchart involves computing earth relative and inertial values for velocity magnitude, azimuth, and flightpath angle from ECI velocity components. Longitude, geocentric and geodetic latitudes, inertial radius vector and geodetic altitude are computed from ECI position components.

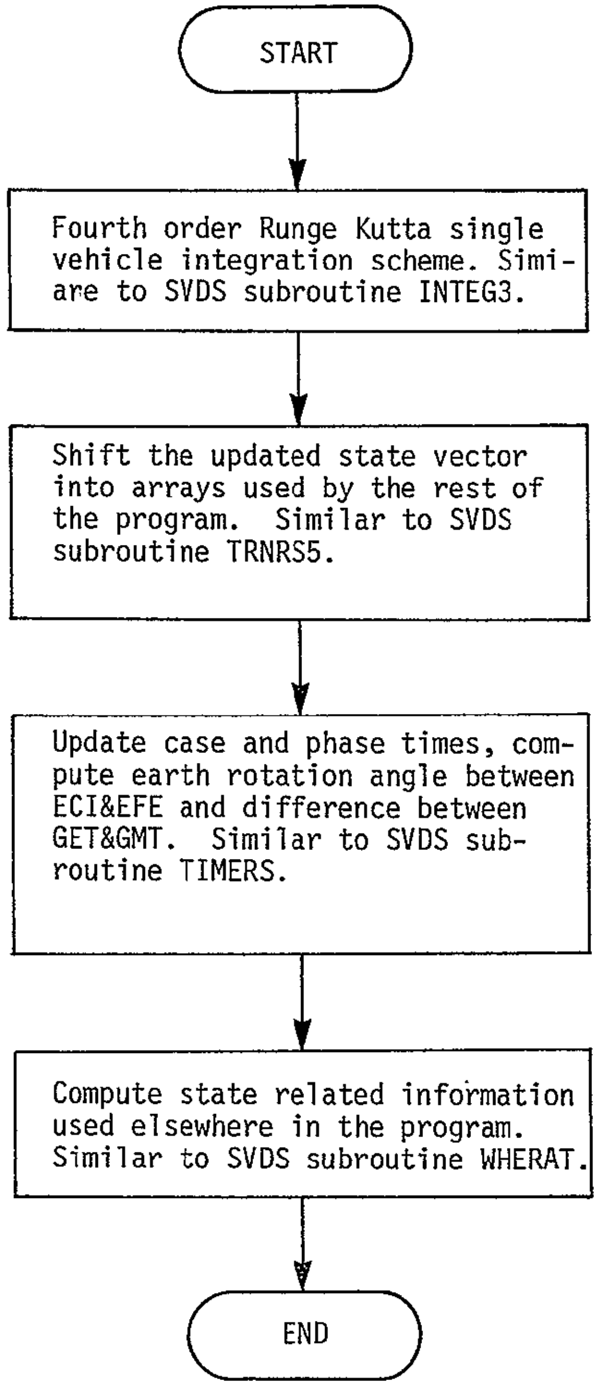


FIGURE A-3 INTEGRATION FLOWCHART (TASK 5)

A.7 COMPUTE FORCES ACTING ON THE VEHICLE - TASK 6

Figure A-4 shows the flowchart for computing forces acting on the vehicle. The atmosphere models will compute atmospheric pressure, temperature, density, and speed of sound from vehicle geodetic altitude. Three models will be required: 1) 1962 standard layered atmosphere (SVDS Model ATMOS), 2) 1963 Patrick AFB spline fit atmosphere (SVDS model ATMSPL), 3) 1971 Vandenberg AFB reference atmosphere (SVDS VRA 71). The wind model will compute wind velocity and azimuth from vehicle geodetic altitude by interpolation of wind data contained in the FDS Master Data Base. Some trajectories will not use the winds model. Aerodynamic attitude angles will be generated from vehicle earth relative velocity and wind velocity. Atmospheric drag is the only aerodynamic force to be computed. Mach number and dynamic pressure are computed from the output of the atmosphere and wind models and the vehicle earth relative velocity. Drag coefficients are interpolated from a user supplied table using any combination of vehicle Mach number, geodetic altitude, and elapsed time since the beginning the present phase as independent variables. Drag is calculated from dynamic pressure, drag coefficient and vehicle reference area, then rotated through the aerodynamic attitude angles to account for wind effects. Gravitational Forces on the vehicle due to the Earth are computed using the second (J2), third (J3), and fourth (J4) zonal harmonics, the second sectorial (S22, C22) harmonic, the vehicle radius vector and longitude. The engine model will interpolate three components of thrust in the trajectory axis coordinate system with respect to elapsed time since beginning the present phase. Some trajectories will not use this model.

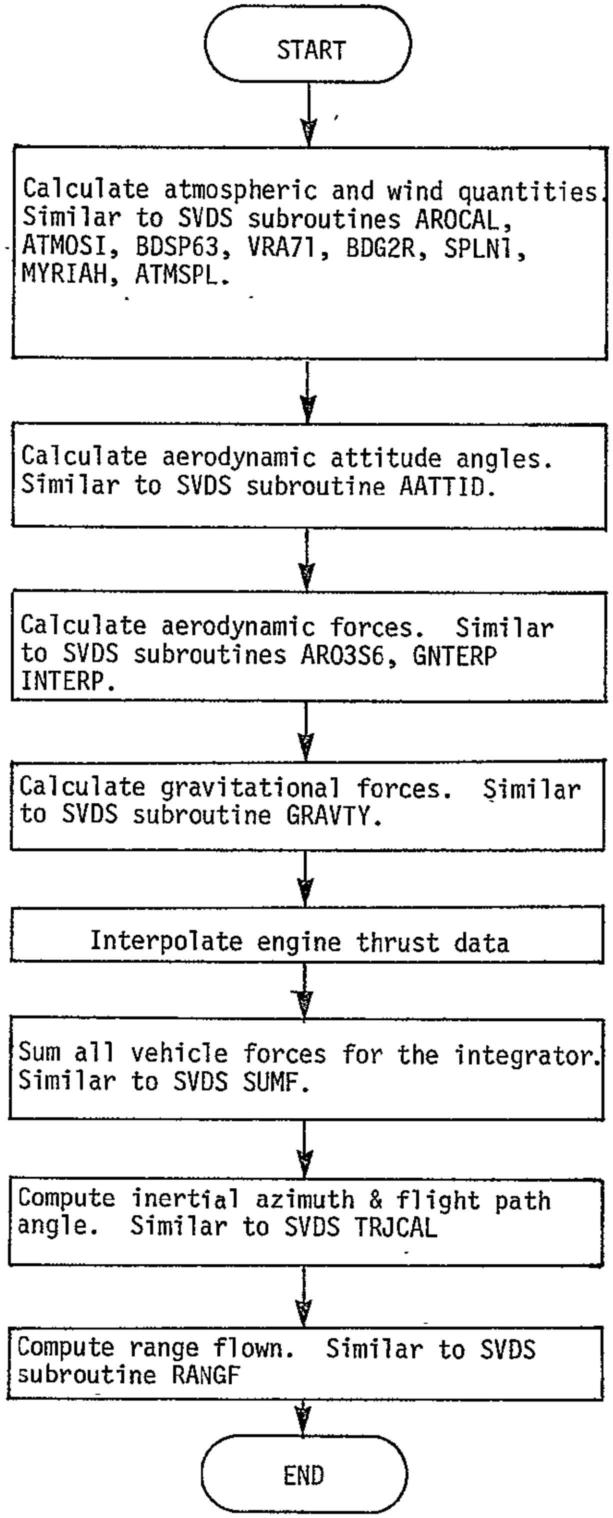


FIGURE A-4 VEHICLE FORCES FLOWCHART (TASK 6)

APPENDIX B

SUBROUTINE FOOT

APPENDIX B

SUBROUTINE FOOT

B.1 DESCRIPTION

Subroutine FOOT computes a set of points defining an impact footprint, using planar trigonometric relations. The footprint is modeled as a non-symetric ellipse consisting of four ellipse segments, each spanning an angle of 90 degrees. This is done by changing the major axis (either the RSS downrange dispersion or the RSS uprange dispersion) and the minor axis (either the RSS right or left crossrange dispersions) of the ellipse according to the quadrant under consideration.

B.2 CALLING ARGUMENTS

Seven inputs are required to execute the subroutine as shown in the flowchart in Figure B-1. The variables X_0 and Y_0 denote the downrange and right crossrange distance respectively (in nautical miles) between the vehicles nominal impact point and the reference point. The variable A denotes the azimuth of the downrange direction for the current vehicle. The variables DR, UR, LCR, RCR are the downrange, uprange, left crossrange, and right crossrange RSS dispersions, respectively. The output is a two dimensional array containing the points defining the ellipse relative to the reference point.

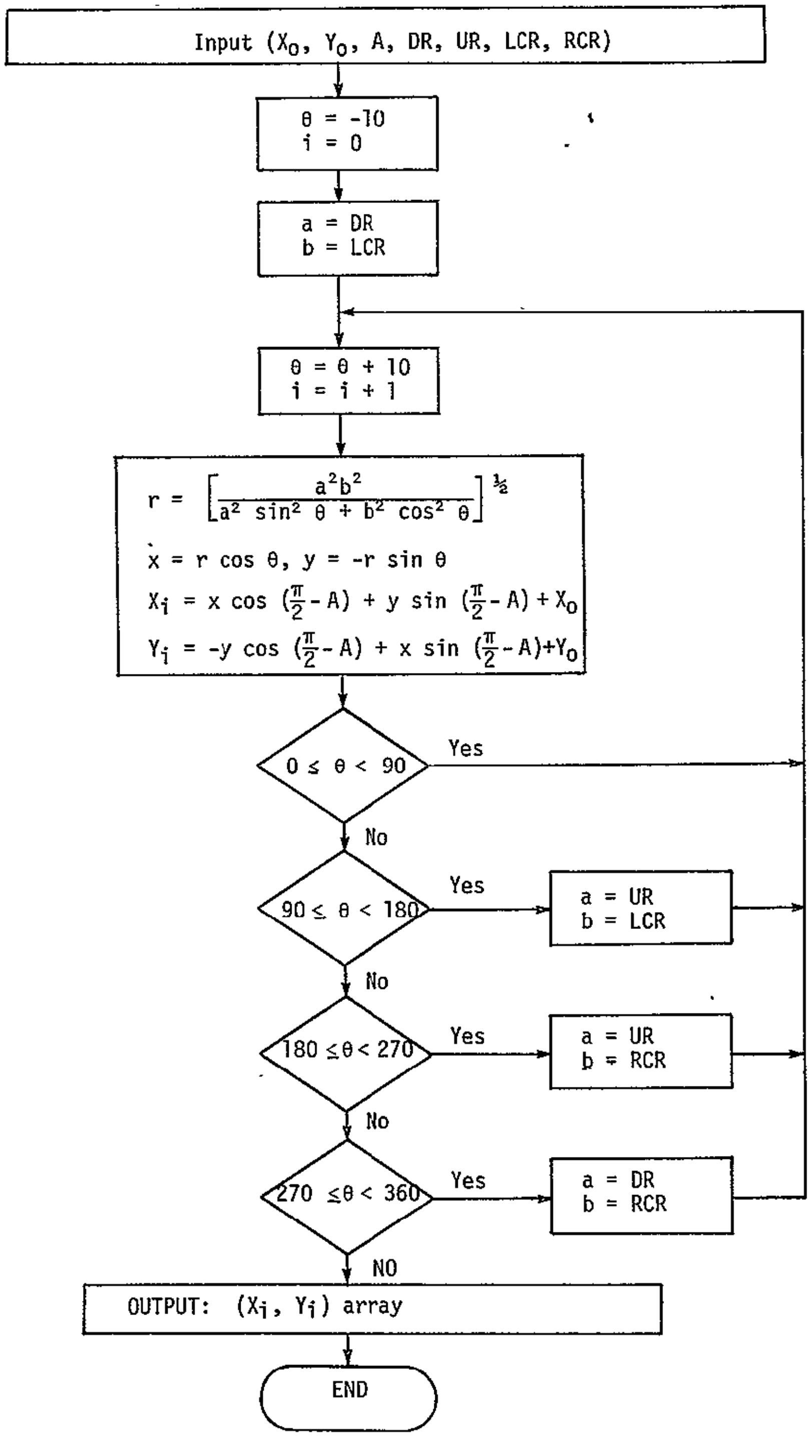


FIGURE B-1 FLOWCHART FOR SUBROUTINE FOOT

APPENDIX C

SUBROUTINE AZIMUTH

APPENDIX C

SUBROUTINE AZIMUTH

C.1 DESCRIPTION

Subroutine AZIMUTH computes the azimuth of the groundtrack from one point (pt.O) to another (pt.p) using spherical trigonometric relations. The flowchart is shown in Figure C-1.

C.2 Calling Arguments

AZIMUTH is called with five arguments:

(λo,ϕo)-the longitude and latitude of point O
(λp,ϕp)-the longitude and latitude of pointP
A -the output azimuth angle

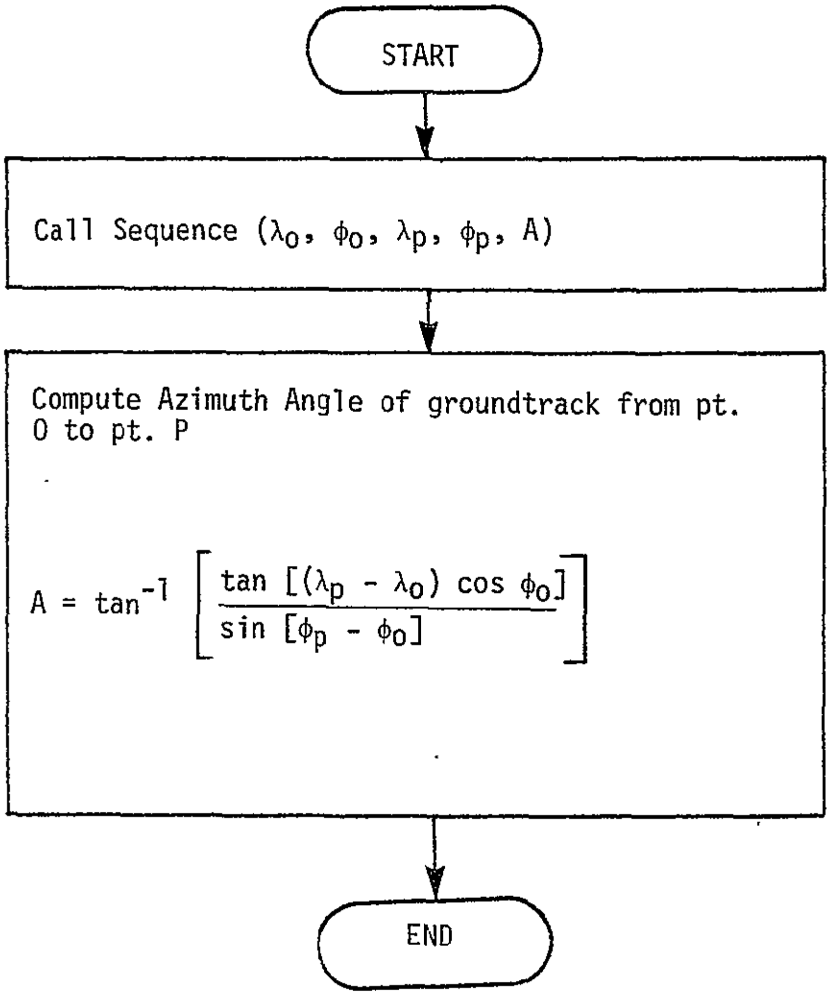


FIGURE C-1 FLOWCHART FOR SUBROUTINE AZIMUTH

APPENDIX D

SUBROUTINE RNGERR

APPENDIX D

SUBROUTINE RNGERR

D.1 DESCRIPTION

Subroutine RNGERR computes the downrange and right crossrange distance in nautical miles from one point (pt.O) to another point (pt.p) using spherical trigonometric relations. The flowchart is shown in Figure D-1.

D.2 CALLING ARGUMENTS

RNGERR is called with seven arguments:

($\lambda o, \phi o$) - the longitude and latitude of the reference point
($\lambda p, \phi p$) - the longitude and latitude of the point of interest
A - the azimuth of the reference downrange direction
(DR,CR) - the output downrange and crossrange distances

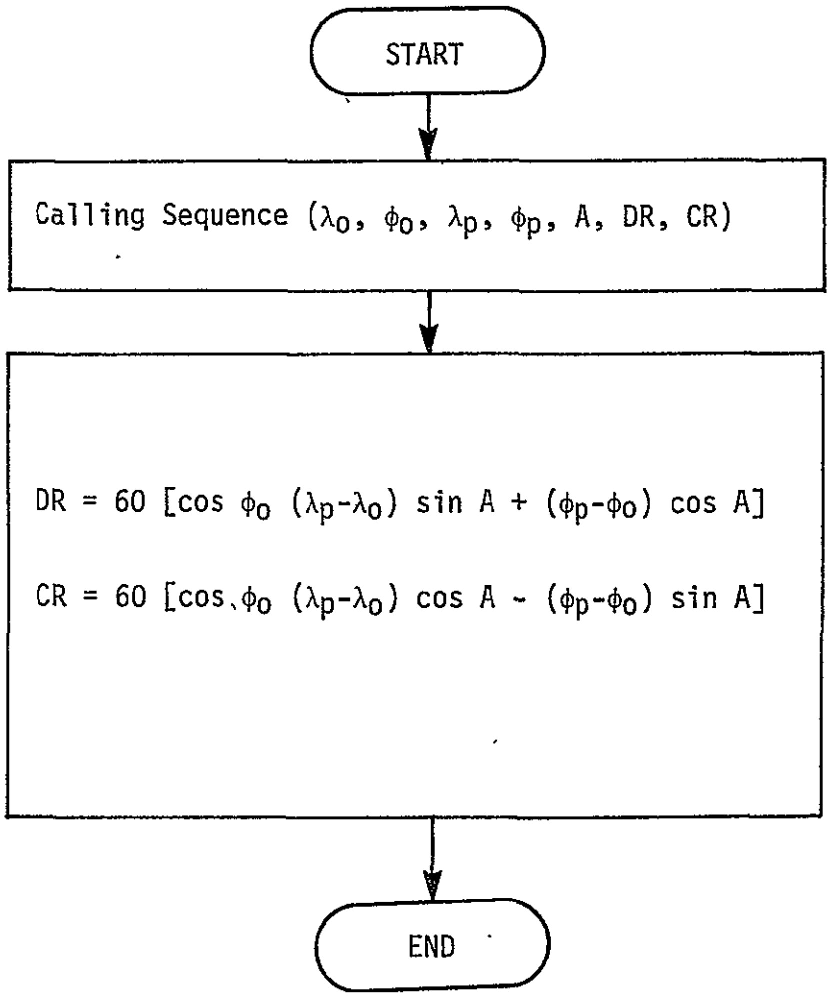


FIGURE D-1 FLOWCHART FOR SUBROUTINE RNGERR

APPENDIX E

SUBROUTINE LATLON

APPENDIX E

SUBROUTINE LATLON

E.1 DESCRIPTION

Subroutine LATLON computes the latitude and longitude of a point, (pt. p), using spherical trigonometric relations given its position relative to a reference point (pt.0). The flowchart is shown in Figure E-1.

E.2 CALLING ARGUMENTS

Seven calling arguments are required for subroutine LATLON:

(λo, ϕo) - the longitude and latitude of the reference point
(DR,CR) - the downrange and crossrange distances to the point of interest
A - the azimuth of the reference downrange direction
(λp, ϕp) - the output longitude and latitude of the point of interest

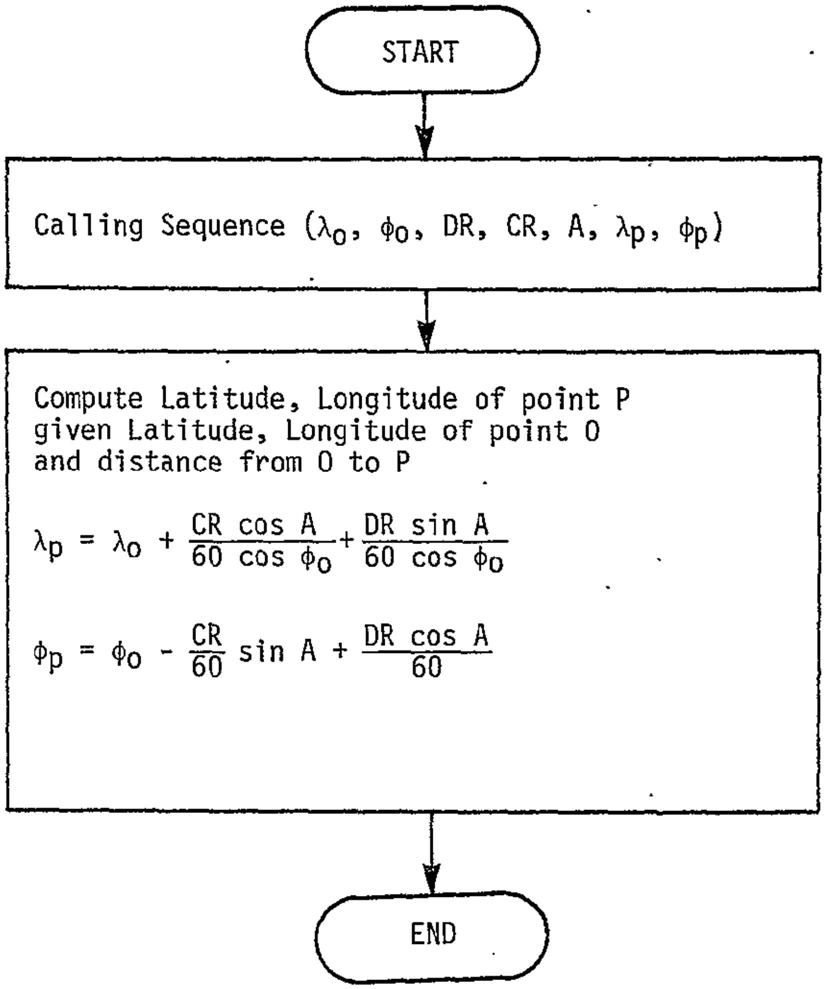


FIGURE E-1 FLOWCHART FOR SUBROUTINE LATLON

APPENDIX F

SUBROUTINE BOUNDRY

APPENDIX F

SUBROUTINE BOUNDRY

F.1 DESCRIPTION

The purpose of this subroutine is to establish and plot boundaries for the ET and SRB plot processors. The upper left and lower right hand corner coordinates for maps and map insets are stored in lookup tables for reference by the subroutine, although the user may override these by specifying new values. Figure F-1 presents a flowchart for this subroutine.

F.2 CALLING ARGUMENTS

Subroutine inputs identify the boundaries to be established; input A indicates ET or SRB boundaries, while B indicates an Eastern Test Range (ETR) or Western Test Range (WTR) launch. Input C indicates which boundaries are to be returned, either map boundaries or those of a particular inset. These values are returned to the calling program and a rectangle with these coordinates as the upper left and lower right corner is plotted on the CRT.

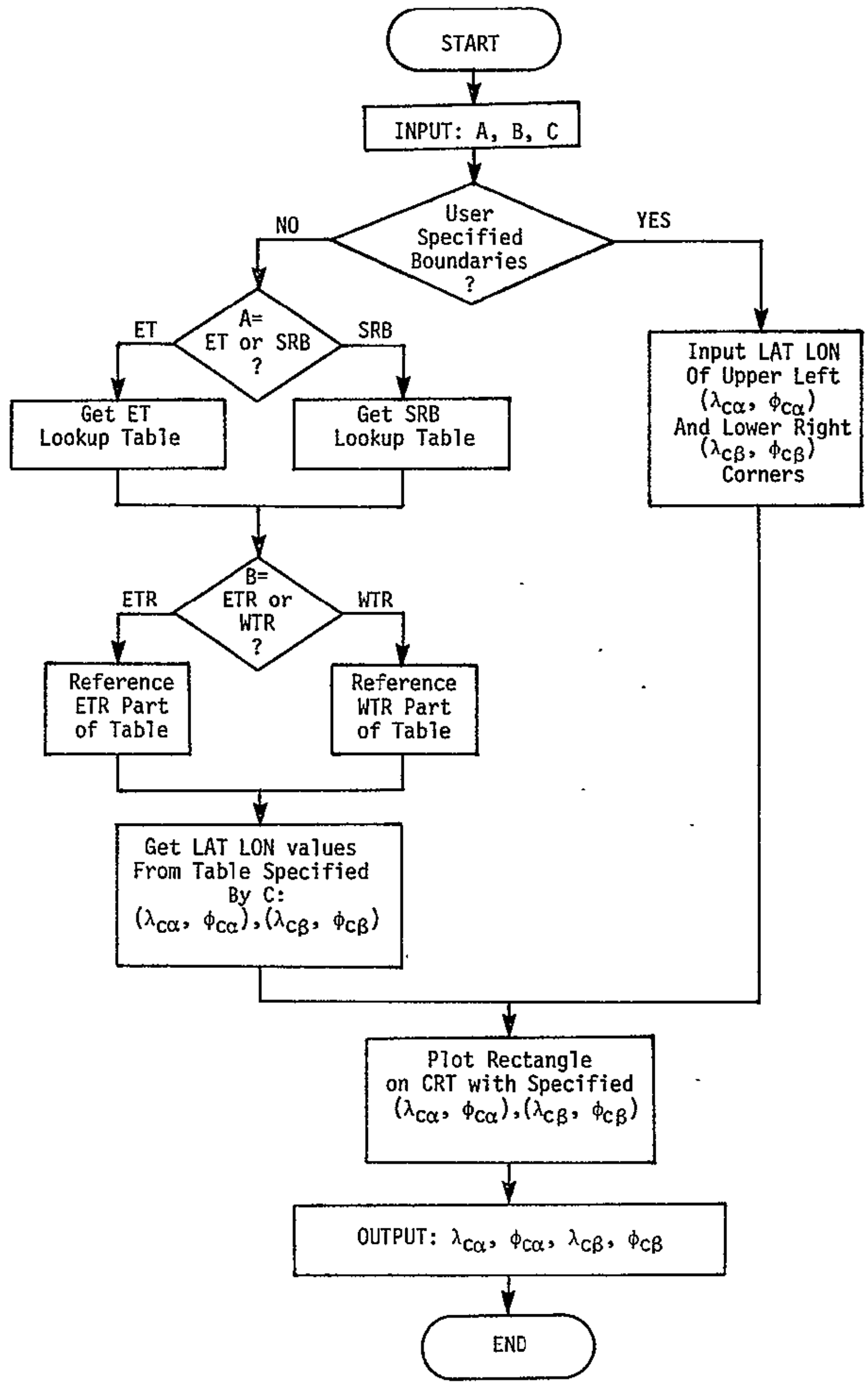


FIGURE F-1 FLOWCHART FOR SUBROUTINE BOUNDRY

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