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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-4-19

RETURN-TC-LAUNCH-SITE VARIABLE RANGE-VELOCITY LINE

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

6 FEBRUARY 1976

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(NASA-CR-151011) RETURN-TC-LAUNCH-SITE VARIABLE RANGE-VELOCITY LINE (McDonnell-Douglas Technical Services) 22 p HC $3.50 CSCL 22A

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1.0 SUMMARY

This document presents the results of a study to show the effect of moving the Return-to-Launch-Site (RTLS) Range-Velocity (R-V) line closer to the landing site. Results are presented which show that a five nautical mile shift in R-V line causes the last RTLS abort to occur approximately one second earlier and that the excess range capability to Terminal-Area-Energy-Management (TAEM) interface can be dissipated without an excessive roll angle history.

2.0 INTRODUCTION

Preliminary RTLS guidance and targeting software for the Space Shuttle is documented in Reference (A). This note documents another in a series of performance verification studies planned to verify the adequacy of that software.

This study was conducted to determine the effect of moving the RTLS Main Engine Cutoff Range-Velocity (MECO R-V) target line closer to TAEM interface. The R-V line is positioned such that the Space Shuttle will have the capability to reach the maximum allowable TAEM interface range of 35 nautical miles for a three sigma (3σ) dispersed minimum range entry flight. This location then determines the last abort time for the RTLS mode boundary and the required time for an Abort Once Around (AOA). The use of this R-V line does not take advantage of the additional powered RTLS flyback range capability available for an earlier abort. It has been proposed to use an R-V line targeted to the center of the allowable TAEM range limit until the RTLS abort time increases to the value that causes the flyback trajectory throttle setting to exceed 100 percent. The targeting criteria could then be changed to the mode boundary R-V line.

3.0 DISCUSSION

This study used a three degree of freedom simulation contained on a modified Space Vehicle Dynamic Simulation (SVDS) 3.0 milestone file (Reference (B)) for a Base Reference Mission (BRM) 3A RTLS abort. The modifications to SVDS were:

a) Addition of the turnaround time prediction logic (Reference (C)).

b) Addition of the thrust termination logic (Reference (C)).

c) Interim SVDS milestone 3.1 entry aerodynamics.

The target inputs to the Powered Explicit Guidance (PEG) module were biased to the MECO minus ten seconds (MECO-10) conditions of 310,000 pounds of total weight, 230,000 feet altitude, and a 3.5 degree relative flight path angle. The biased desired flight path angle results in an angle near zero at External Tank (ET) separation. The mode boundary R-V target for MECO-10 was

$R = .069V_E - 104.1$

For thrust termination the target line for MECO was

$R = .068V_E - 165.5$

All ranges are in nautical miles measured from an aim point located at 34°34' North Geodetic Latitude and 120°28' West Longitude. The aim point is located on a 3.6 nautical mile extension of the tangent line from the space shuttle at MECO to the heading alignment circle on a 18.5° earth relative true heading (Figure 1). The extension is required to include the distance that must be flown around the

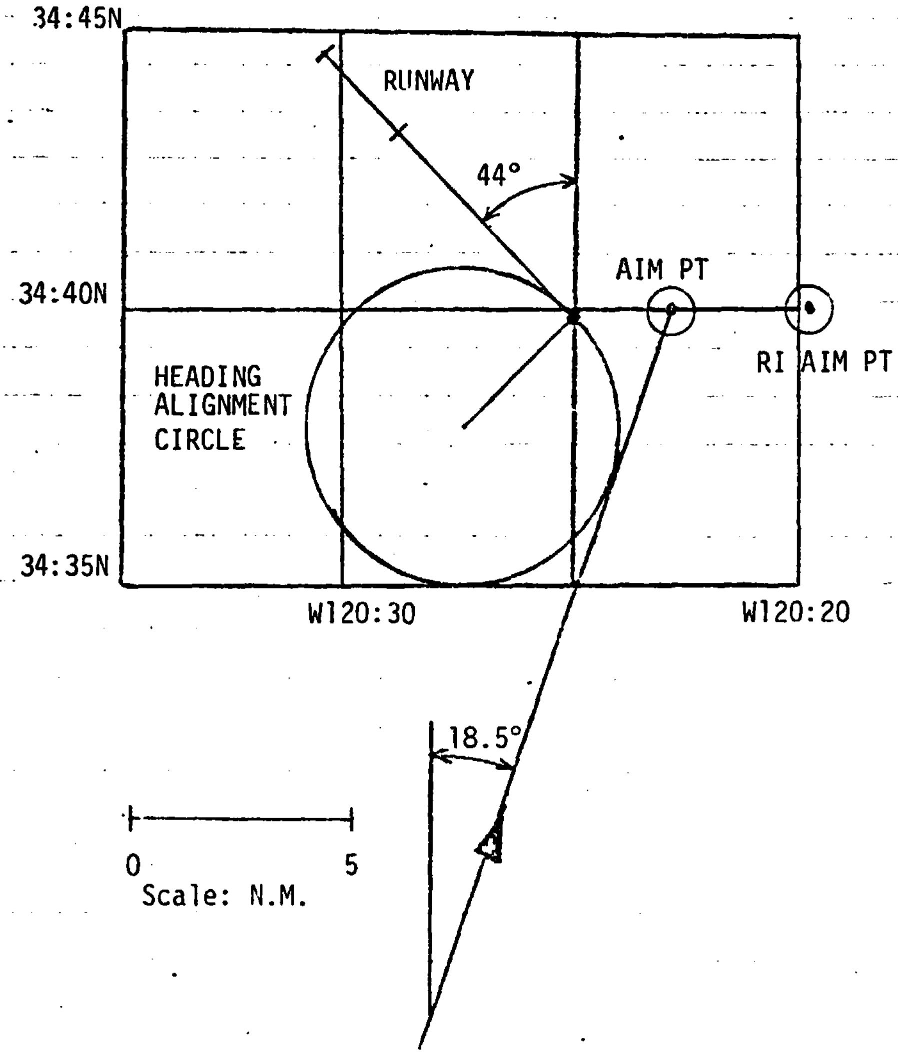


FIGURE 1 - Definition of RTLS Aim Point for Mission 3A

heading alignment circle to the runway azimuth. The BRM 3A Rockwell International (RI) aim point (Reference (D)) was used in previous studies. The aim point used in this study results in an approximate one nautical mile decrease in range from the MECO conditions used in the previous studies. The RI R-V lines were modified by one nautical mile so that the range at the start of entry would be consistent with previous simulations. The relative velocity (V_E) is in feet per second.

At MECO-10 a powered pitch down is initiated at an average rate of six degrees per second and terminates at minus four degrees angle of attack required for ET separation. A thrust termination and coast sequence ends at ET separation. The simulation continues with a ΔZ translation, RTLS load relief, and entry sequence which terminates at TAEM interface. TAEM interface is at 30 nautical miles from the aim point at a relative velocity of 1500 feet per second.

The Analytical Drag Control (ADC) entry guidance has been modified for RTLS load relief. The load relief angle of attack is 35.0 degrees and the load factor limit is 2.2. The abort conditions used in this study were 140, 230, 241, and 248 seconds from lift-off. The 140 and 230 second aborts simulate early and late aborts after Solid Rocket Booster (SRB) separation. The 241 second abort simulates the last abort at which an immediate turnaround yields an initial 100 percent flyback throttle setting. The RTLS/AOA mode boundary abort is simulated by the 248 second abort. The powered portion of the trajectories was shaped in the inertial velocity-altitude plane to be similar to the mode boundary abort as presented in Reference (E).

The modified RI R-V line was used for all cases with nominal entry aerodynamics to establish reference trajectories. A 3σ dispersed Lift over Drag (L/D) uncertainty envelope is exhibited in Figure 2 which has been reproduced from Reference (F). The L/D condition at test point seven resulted in minimum range capability. Maximum range occurred for the L/D condition at test point five. The minimum range L/D condition was used to test the applicability of the RI R-V line in the simulation used in this study.

The R-V line was moved ten nautical miles closer to the aim point for 140 and 230 second abort cases to determine the effects on turnaround time, MECO conditions, and nominal entry range. ADC guidance dissipates excess range capability of the orbiter by commanding successive reversal roll commands. The MECO conditions on the minus ten nautical mile R-V line provide the orbiter with additional excess range capability with respect to TAEM interface for nominal entry conditions. The change of nominal range capability between the two R-V lines was measured by executing the entries with zero roll angle.

FIGURE 2

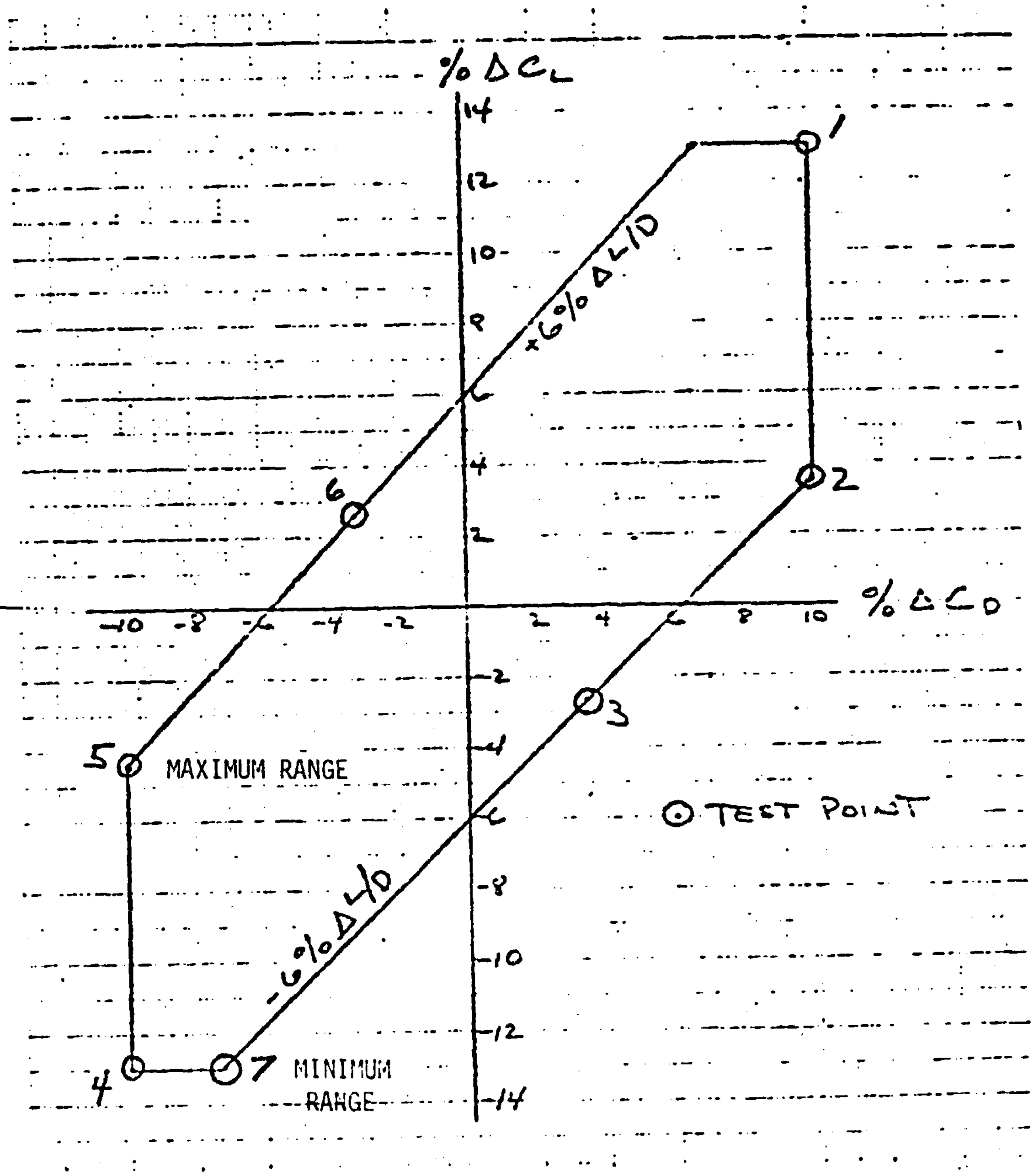


Figure 3.1-11

POSSIBLE C_L AND C_D UNCERTAINTY ENVELOPE

Repoduced from "RTLS Entry Load Relief Parameter Optimization", MDTSCO DN 1.4-4-9, 27 June 1975

The magnitude of the R-V line shift toward the aim point is constrained by the requirement that ADC guidance absorb a plus 3σ dispersed excess range capability. This constraint was tested by executing the minus ten nautical mile R-V line entry trajectories with the test point five maximum range L/D value of Figure 2.

The change in the mode boundary abort time caused by moving the R-V line was determined by executing successive aborts until an immediate turnaround yielded a 109 percent initial flyback throttle setting. The last abort for a 100 percent flyback throttle was determined in a similar manner.

4.0 RESULTS

Selected powered RTLS trajectory conditions are presented in Table I for the abort times and R-V lines used in this study. For a minus ten mile shift in the R-V line, the change in turnaround time was minus 1.8 to 1.9 seconds. The MECO arrival point moved 4.3 to 4.4 nautical miles closer to the aim point with an associated 82 to 84 feet per second increase in relative velocity. The change in MECO R-V arrival points is shown in Figure 3 for the two R-V lines.

Nominal aerodynamics provide sufficinet range capability to reach TAEM interface from both R-V lines for all of the abort cases (29.5 to 31.2 nautical miles). The range capability of the two R-V lines was determined by executing the entries with zero roll angle. The entries were terminated at the TAEM interface velocity of 1500 feet per second. The ranges from the aim point are shown in Table II. The range for the modified RI R-V line is 26.4 to 26.8 nautical miles. The range for the shifted R-V line is 14.9 to 16.3 nautical miles. This substantiates that the MECO R-V line is a line of equal opportunity. Also the ratio of the change in entry range capability per range change in R-V line is approximately one to one (10.5 to 11.5 nautical miles/10 nautical mile change in R-V line).

TABLE I

POWERED RTLS TRAJECTORY CONDITIONS FOR A VARIABLE R-V LINE

ABORT TIME SEC	MECO R-V LINE	TURNAROUND SEC	MECO CONDITIONS R-n.mi.	V_E-fps
140	(1)*	301.3	311.1	7007
140	(2)*	299.2	306.8	7091
230	(1)	248.5	293.8	6754
230	(2)	246.7	289.4	6836
239**	(2)	239	285.7	6782
241**	(1)	241	290.0	6696
246***	(2)	246	285.8	6783
248***	(1)	248	291.4	6718

* (1) $R = .068V_E - 165.5$

* (2) $R = .068V_E - 175.5$ (10 N.M. closer to aim point)

** Last at 100% flyback throttle

*** Last at 109% flyback throttle

FIGURE 3

ARRIVAL CONDITIONS FOR VARIABLE MECO AND MECO-10 R-V LINES

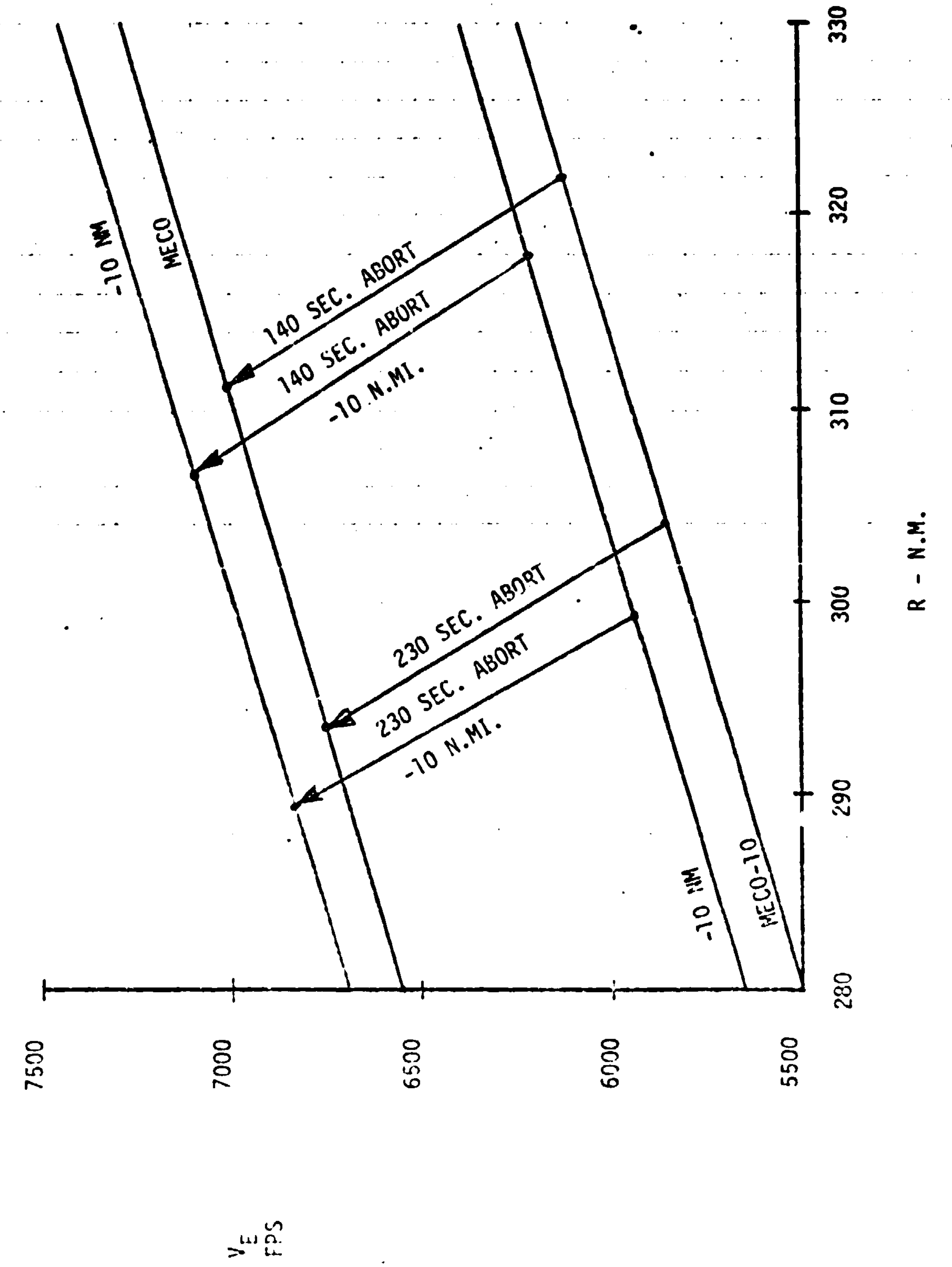


TABLE II

TAEM INTERFACE RANGE FOR VARIABLE R-V LINES USING NOMINAL AND 3σ DISPERSED L/D

RTLS ABORT TIME - SEC	MECO R-V LINE	ENTRY CONDITIONS	RANGE AT TAEM - N.M.
140	(1)	Nominal	30.1
140	(1)	Nominal - Zero Roll	25.4
140	(1)	- 3σ L/D	39.4
140	(2)	Nominal	29.5
140	(2)	Nominal - Zero Roll	14.9
140	(2)	- 3σ L/D	32.4
140	(2)	- 3σ L/D - Zero Roll	28.8
140	(2)	+ 3σ L/D	28.5
140	(2)	+ 3σ L/D - Zero Roll	9.0
230	(1)	Nominal	30.8
230	(1)	Nominal - Zero Roll	26.3
230	(1)	- 3σ L/D	39.5
230	(2)	Nominal	29.8
230	(2)	Nominal - Zero Roll	16.3
230	(2)	- 3σ L/D	33.3
230	(2)	- 3σ L/D - Zero Roll	29.3
230	(2)	+ 3σ L/D	28.3
230	(2)	+ 3σ L/D - Zero Roll	7.0
239	(2)	Nominal	29.7
241	(1)	Nominal	31.2
246	(2)	Nominal	29.7
248	(1)	Nominal	30.6

(1) $R = .068V_E - 165.5$

(2) $R = .068V_E - 175.5$ (10 N.M. closer to aim point)

The RI R-V line does not provide enough range capability for the simulation used in this study. As shown in Table II, the 3σ minimum range L/D entries terminated at 39.4 to 39.5 nautical miles. This is 4.4 to 4.5 miles short of the maximum TAEM range of 35 nautical miles. This indicates that the R-V line must be moved approximately five nautical miles closer to the aim point for the simulation used in this study. Another five mile shift is required to target the R-V line to the nominal TAEM interface range of 30 nautical miles.

Entry trajectories were executed from the shifted R-V line using the maximum and minimum entry range L/D conditions. The minimum range L/D simulations terminated at 32.4 to 33.3 nautical miles. The maximum range L/D simulations terminated at 28.3 to 28.5 nautical miles when ADC ranging was used. The zero roll angle terminal ranges for these cases are 7.0 to 9.0 nautical miles. ADC guidance must dissipate the excess range capability that results from the 3σ maximum range L/D. The entry roll history for the 140 second abort case that used the shifted R-V line and nominal aerodynamics is shown in Figure 4. The roll history for the 3σ maximum range L/D is shown in Figure 5. The roll histories with the same entry conditions are displayed in Figures 6 and 7 for the 230 second abort case.

As shown in Figures 5 and 7, the excess range capability was absorbed without excessive roll saturation. After load relief terminates, ADC commands a ranging roll at the limit of 70 degrees for a

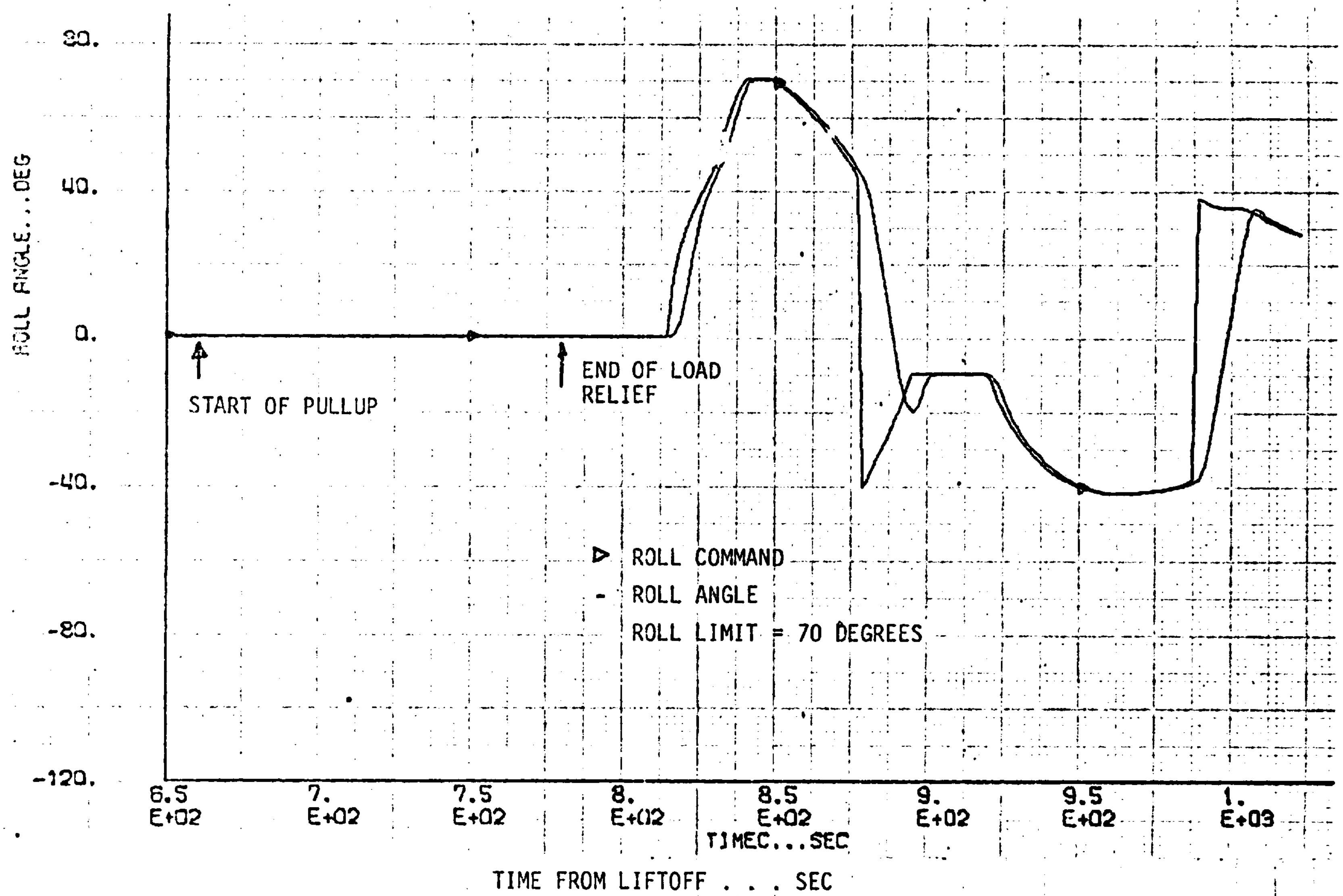
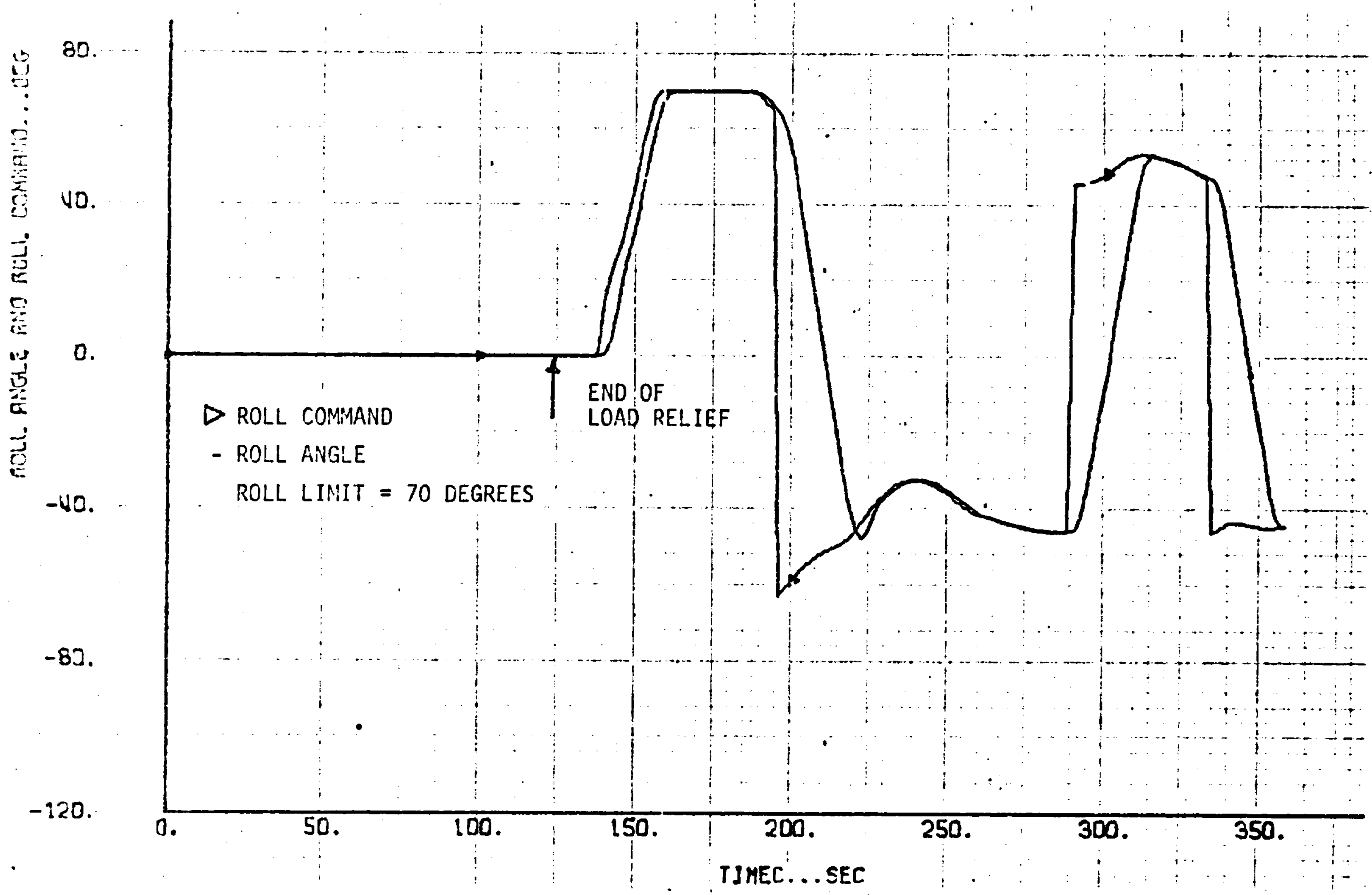


FIGURE 4 - Roll Commanded and Roll Angle for 140 Second Abort, R-V Line Shifted 10 N.MI., and Nominal Aerodynamics



TIME FROM START OF PULLUP . . . SEC

FIGURE 5 - Roll Angle for 140 Second Abort, R-V Line Shifted 10 N.Mi., and 3σ Maximum Range Aerodynamics

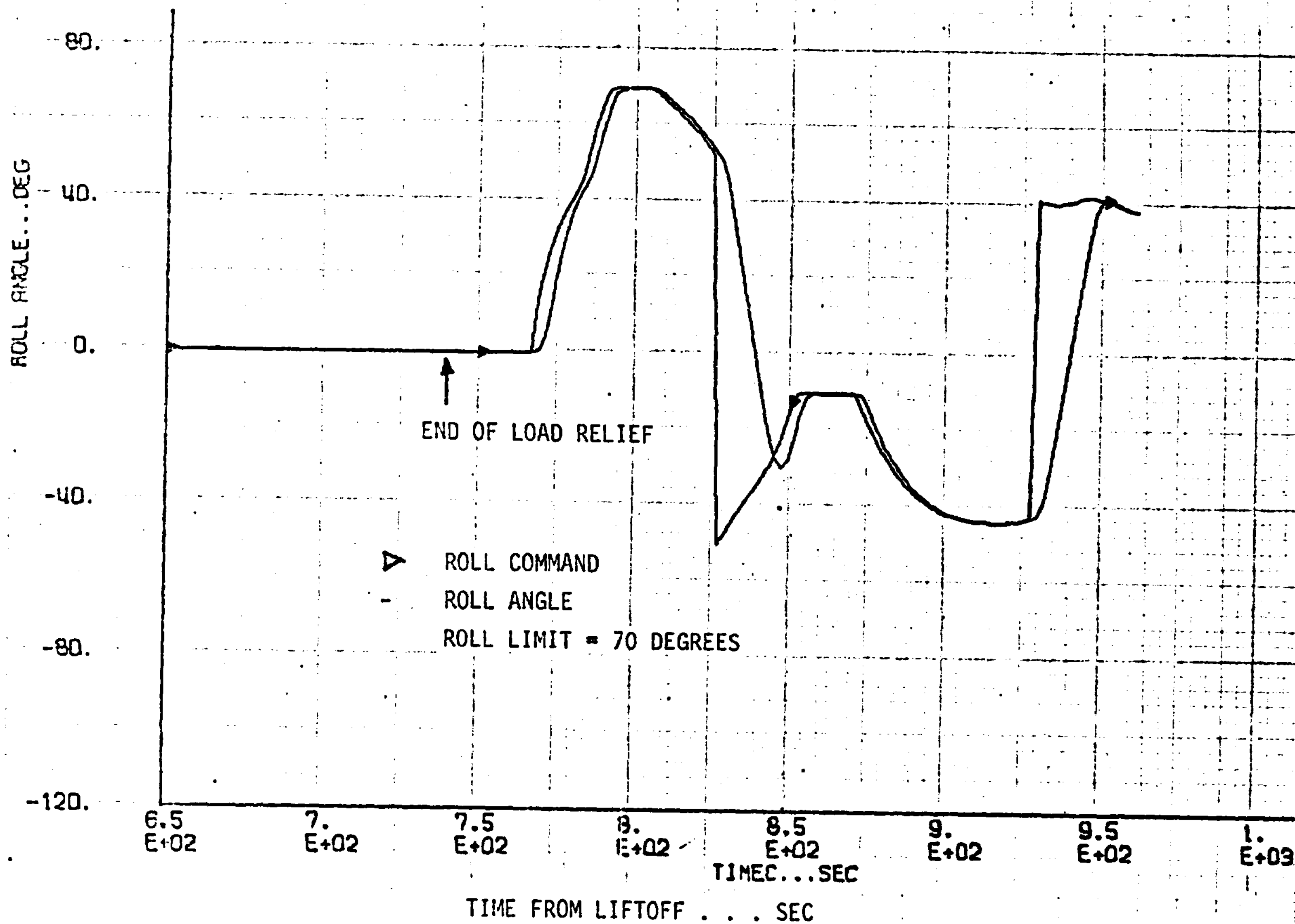
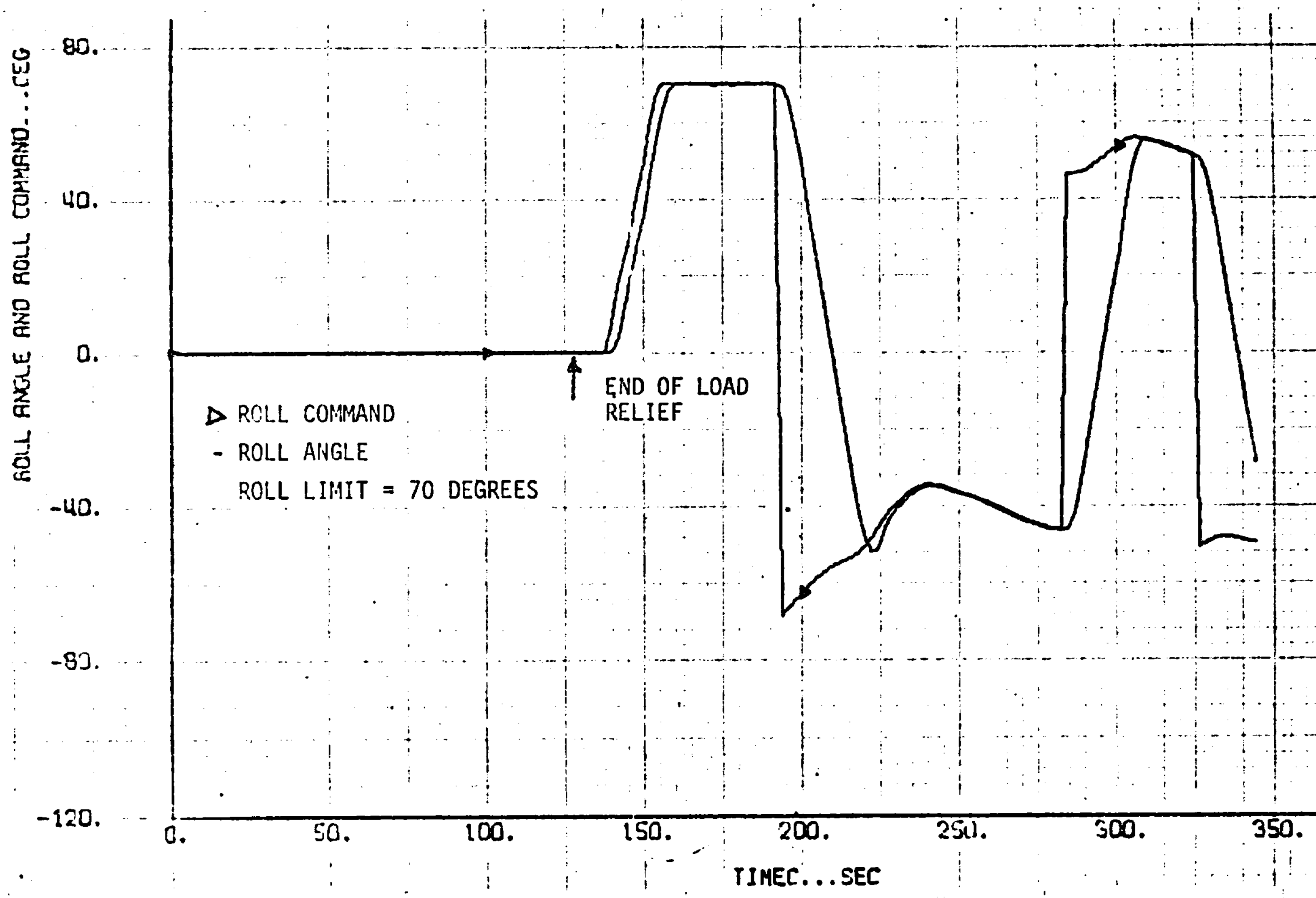


FIGURE 6 - Roll Command and Roll Angle for 230 Second Abort, R-V Line Shifted 10 N.MI., and Nominal Aerodynamics



TIME FROM START OF PULLUP . . . SEC

FIGURE 7 - Roll Angle for 230 Second Abort, R-V Line Shifted 10 N. MI., and 3σ Maximum Range Aerodynamics

duration of approximately 25 seconds. As the roll angle command is decreasing the azimuth error build up causes a roll reversal. The magnitude of the roll command continues to decrease after the reversal as shown in Figures 4 to 7. In the nominal simulations the roll command decreases to the minimum magnitude of ten degrees Approximately twenty seconds later the roll command magnitude is increased due to the requirements of ADC guidance. In the maximum range L/D simulations the roll command magnitude starts the same increase prior to reaching the minimum angle. The roll histories of Figures 5 and 7 represent a dissipation of 19.5 to 21.3 nautical miles of excess range capability.

As stated earlier the modified RI R-V line did not provide an entry capability to reach TAEM interface with minimum range L/D for the simulation used in this study. The R-V line was moved ten nautical miles to satisfy the minimum range requirement and to move the TAEM target from 35 to 30 nautical miles. The overall effect was an approximate two second decrease in the last RTLS abort time (248 to 246 seconds shown in Table I). This indicates that a five nautical shift of the R-V line would change the last RTLS abort time by approximately one second. A R-V line targeted to 30 nautical miles could be selected for those missions which contain a RTLS/AOA mode boundary overlap that could absorb the loss of approximately one second. The software necessary to change the R-V line targeting criteria during flight consists of a logic test and two additional storage locations for the A(1) constants of the MECO-10 and MECO lines where:

$$V_E = A(1) + A(2)R$$

To eliminate this additional software the R-V line targeted to 35 nautical miles could be selected for RTLS critical missions.

5.0 CONCLUSIONS

The following conclusions can be made concerning a shifted R-V line:

1. The zero roll angle TAEM arrival range decreases approximately one nautical mile per nautical mile MECO R-V line shift towards the aim point.
2. The MECO R-V line is a line that provides equal capability to reach a specified range at TAEM interface.
3. The ADC guidance can dissipate the excess range capability resulting from a five mile R-V line shift towards the aim point and a three sigma maximum range L/D dispersion.
4. An R-V line targeted to the TAEM interface range of 30 nautical miles can be selected for missions which contain a RTLS/AOA mode boundary overlap by giving up approximately one second of RTLS abort capability.
5. An R-V line targeted to the limit TAEM interface range of 35 nautical miles should be selected for missions which do not have a RTLS/AOA mode boundary overlap.

6.0 REFERENCES

(A) FM41 (75-32), Return-to-Launch-Site (RTLS) Preliminary Combined Guidance and Targeting Formulation Presented to the Powered Flight Working Group (April 2-3, 1975), April 28, 1975.

(B) User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program Revision 2, JSC Internal Note No. 73-FM-67 November 14, 1974.

(C) "Powered Flight Guidance Ascent Supervisor", John P. Higgins, December 18, 1974.

(D) Rockwell International (RI) Internal Letter SAS/NR&I-75-063 "Targeting Criteria for the Powered Phase of Mission 3A RTLS Aborts", April 1, 1975.

(E) MDTSCO Design Note No. 1.4-4-14, "Return-to-Launch-Site Trajectory Shaping", October 17, 1975.

(F) MDTSCO Design Note No. 1.4-4-9, "RTLS Entry Load Relief Parameter Optimization", June 27 1975.