CR151010

MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-4-7

RETURN-TO-LAUNCH-SITE THREE DEGREE OF FREEDOM ANALYSIS, CONSTANT INERTIAL ATTITUDE DURING THE FUEL DISSIPATION PHASE

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

17 OCTOBER 1975

This Design Note is Submitted to NASA Under Task Order No. D0303, Task Assignment 1.4-4-D in Fulfillment of Contract NAS 9-13970.

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1.0 SUMMARY

This document presents the results of a study to show the effect of selecting a constant inertial attitude during the fuel dissipation phase of a Return-to-Launch-Site (RTLS) abort. Results are presented which show that the selection of the constant inertial attitude will affect the arrival point on the Range-Velocity (R-V) target line. An alternate selection of the inertial attitude will provide control over the trajectory shape.

2.0 INTRODUCTION

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

After a main engine shutdown and crew selection of the RTLS mode, a fuel dissipation phase subsequent to solid rocket booster (SRB) staging is required. The duration of this phase is greatest for early aborts and decreases to zero near the mode boundary. A constant inertial attitude during this phase will affect the trajectory and the point of arrival on the R-V line. The purpose of this note is to parametrically examine the amount of R-V line and trajectory control available.

One goal of the trajectory control is to make the flyback trajectories neighboring. This may be important from the monitoring and/or reversion to manual back-up flight.

3.0 DISCUSSION

This study was conducted to determine the changes in the arrival points on the main engine cutoff (MECO) R-V line and in the fly-back trajectories caused by changes in the constant inertial attitude. After a space shuttle main engine (SSME) failure and an RTLS command, the space shuttle is rotated to a predetermined attitude and continues downrange to dissipate fuel at this constant inertial attitude. The abort times used in this study were 140, 180, and 220 seconds from launch. The range of thrust directions or body attitudes (which are coincident in the 3 degree of freedom simulation) was 40 to 60 degrees measured from a plane normal to the local geodetic vertical at time of launch (Figure 1). This reference plane is fixed for the entire RTLS simulation. The rotation to the desired attitude is done in the pitch plane or about the body axis through the orbiter wings.

This study used a three degree of freedom simulation contained on a modified Space Vehicle Dynamic Simulation (SVDS) 2.3.11 milestone file (Reference (B)) for a mission 3A RTLS abort launched from the Western Test Range. The modifications to SVDS were:

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

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

The inputs to PEG were biased to the Main Engine Cutoff minus ten seconds (MECO-10) target conditions, total weight of 310,000 pounds,

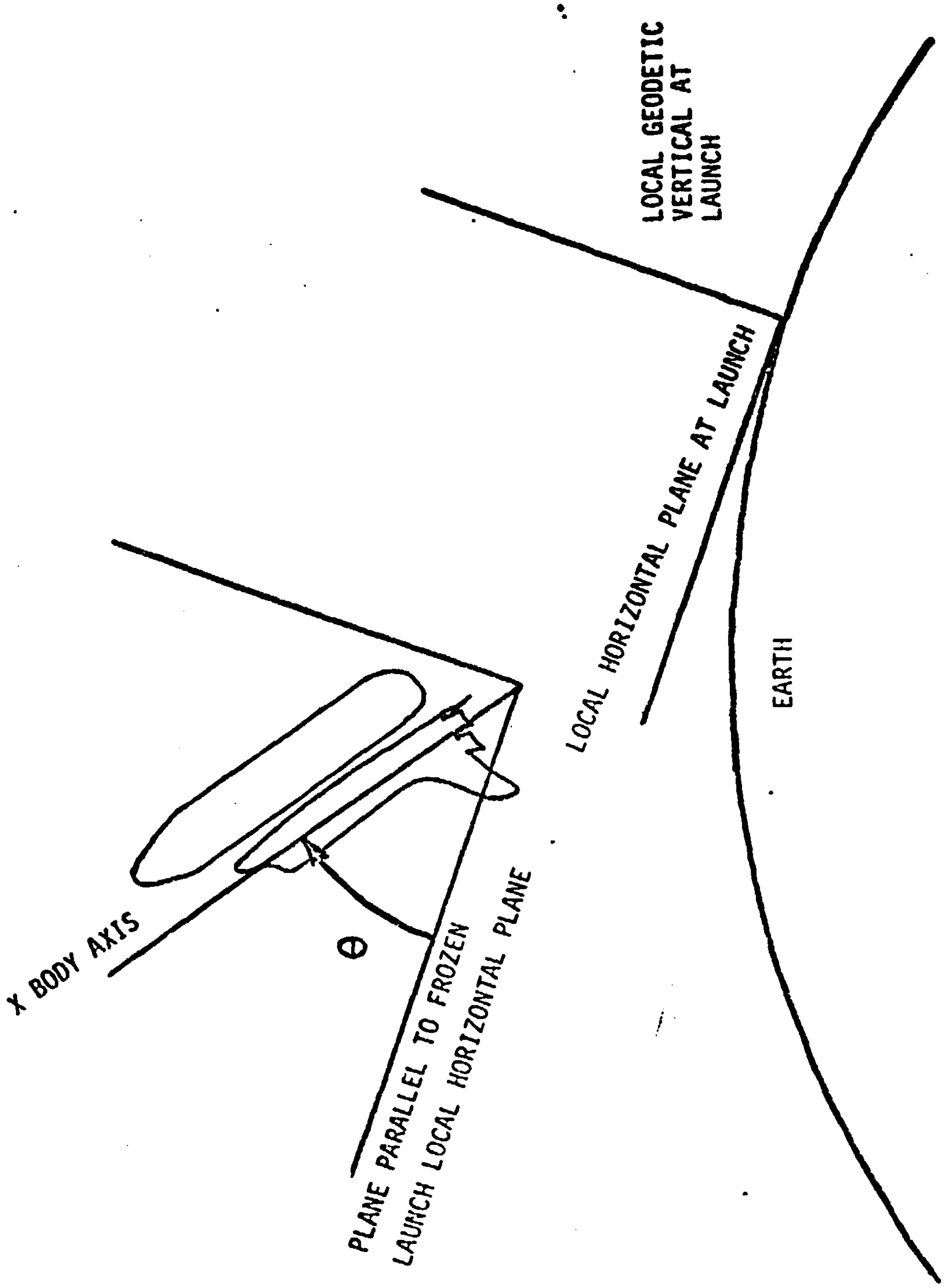


Figure 1 - Definition of Inertial Attitude Angle

230,000 feet altitude, and a 4 degree earth relative flight path angle. The biased desired flight path angle at the MECO-10 R-V target line results in an angle near zero at external tank separation. The Rockwell International (RI) R-V target line for MECO-10 was used:

$R = .069V_R - 110.1$

For thrust termination the target was the RI MECO R-V line:

$R = .068V_R - 171.5$

All ranges are from the landing site at the Western Test Range in nautical miles.

4.0 RESULTS

Typical thrust direction histories for aborts occurring at 140 and 220 seconds are shown in Figures (2) and (3). The variation in termination conditions at external tank separation is shown below:

altitude	229,126 to 230,763 feet
flight path angle	.15 to .75 degrees
dynamic pressure	3.94 to 4.63 p.s.f.

More precise targeting and prediction of powered pitch down effects on MECO conditions could reduce the variation but would not be meaningful at this stage in the performance testing.

An examination of the numerical results presented in Tables I to III and Figures (2) and (3) provides the following general observations. The time of abort has a definite effect upon the arrival point on the R-V line (i.e. the earlier the abort the higher the terminal velocity). A thrust direction of 60 degrees tends to loft the trajectory such that the space shuttle achieves altitudes in excess of 400,000 feet with an associated lower velocity.

The turnaround time shown in the abort time tables are the times at the end of the downrange fuel dissipation phase. The choice of down-range gimbal angle causes a difference of up to 43.5 seconds in the turnaround time with the nose low case turning earlier. Essentially, at turnaround time the lofted trajectory has a higher altitude, lower velocity, greater range, and less fuel remaining than the 40 degree

Figure 2

Thrust Direction

140 Sec. Abort

50 Deg.

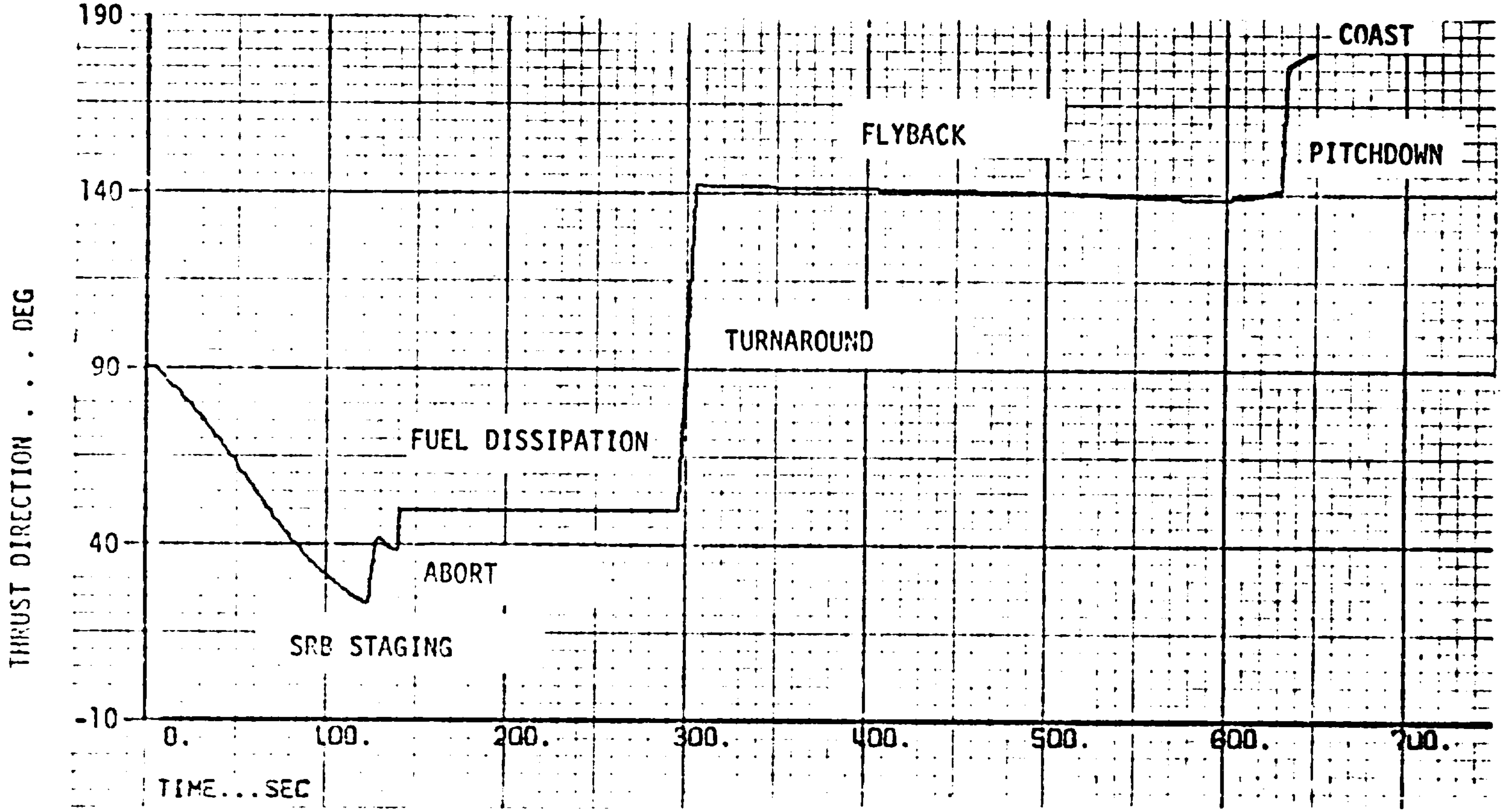


Figure 3

Thrust Direction

220 Sec. Abort

40 Deg.

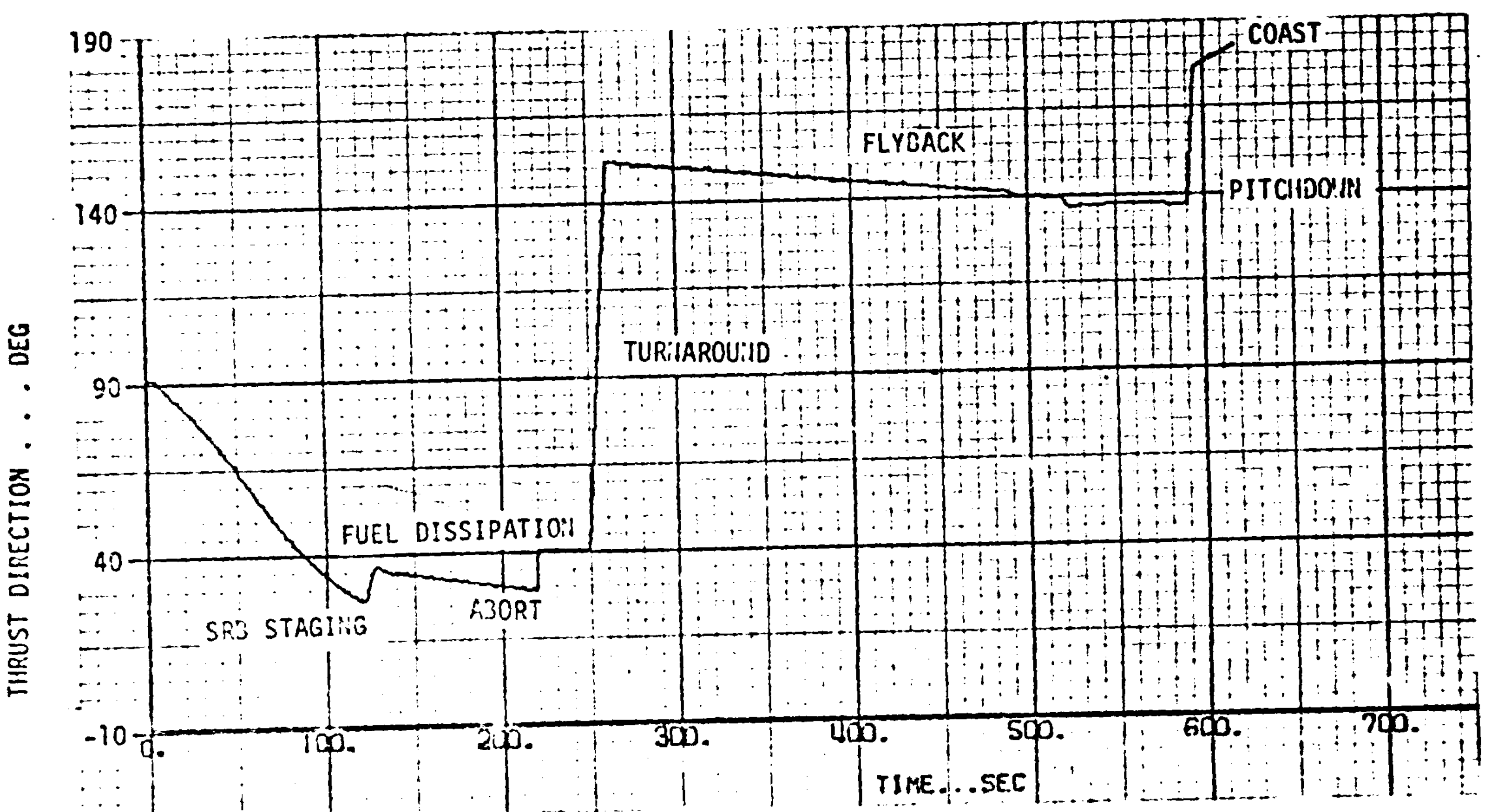


TABLE I

Conditions at Selected Trajectory Study Points

Constant Inertial Thrust Direction

140 Second Abort

CONDITION	THRUST DIRECTIONS 60°	50°	40°
Turnaround			
Time - sec	321.7	301.1	278.2
Relative Velocity - fps	7453.3	7744.2	7757.0
Range - n.m.	229.24	213.40	190.76
Altitude - feet	440305	372271	325082
MECO - 10			
Weight - lbs	309871	309854	309839
Altitude - feet	224756	224442	224262
Flight Path Angle - deg	3.939	3.973	4.004
MECO			
Range - n.m.	293.78	308.15	315.63
Relative Velocity - fps	6839.4	7052.8	7161.5
Time - sec	646.7	641.3	639.1

TABLE II

Conditions at Selected Trajectory Study Points

Constant Inertial Thrust Direction

180 Second Abort

CONDITION	THRUST DIRECTIONS 60°	50°	40°
Turnaround			
Time - sec	292.6	279.3	267.0
Relative Velocity - fps	7847.6	8032.9	8088.6
Range - n.m.	212.70	199.52	186.03
MECO - 10			
Weight - lbs	309755	309853	309864
Altitude - feet	224530	224564	224481
Flight Path Angle - deg	3.935	3.975	3.994
MECO			
Range - n.m.	293.84	301.50	305.96
Relative Velocity - fps	6841.0	6954.6	7027.7
Time - sec	626.6	622.7	620.1

TABLE III

Conditions at Selected Trajectory Study Points

Constant Inertial Thrust Direction

220 Second Abort

CONDITION	THRUST DIRECTION		
	60°	50°	40°
Turnaround			
Time - sec	260.8	255.4	250.9
Relative Velocity - fps	8304.4	8360.8	8379.7
Range - n.m.	182.97	176.14	170.50
Altitude - feet	353264	345255	338085
MECO - 10			
Weight - lbs	309746	309816	309877
Altitude - feet	224578	224613	224691
Flight Path Angle - deg	3.968	3.977	4.000
MECO			
Range - n.m.	291.71	293.37	295.30
Relative Velocity - fps	6809.4	6835.7	6864.1
Time - sec	605.1	603.1	600.8

trajectory. The lofted trajectory overtakes the lower trajectory and terminates lower on the R-V line.

Figure (4) is a carpet plot which shows a summary of the effect of inertial attitude during the fuel dissipation phase and abort time on range to launch site at MECO. Since all cases terminated at the R-V line, the relative velocity associated with the range is available from the MECO R-V expression presented above. The velocity spread at the R-V line, for the inertial attitudes considered, range from 322 ft/sec for the earliest aborts to 55 ft/sec for a 220 sec. abort. The spread would continue to decrease until 235-240 second abort when control over the point of arrival on the R-V line would no longer be available. This abort time is, of course, not the latest available but represents the latest for flyback at 100 percent throttle. The RTLS/Abort Once Around (AOA) boundary is at approximately 255 seconds for flyback at 109 percent throttle.

One of the reasons for control over the velocity at the R-V line is to achieve more benign entry conditions. That is, a higher velocity results in higher dynamic pressures which tend to alleviate entry load relief problems in that the angle of attack need not be reduced so much for g limiting and thus the excursion into the less desirable

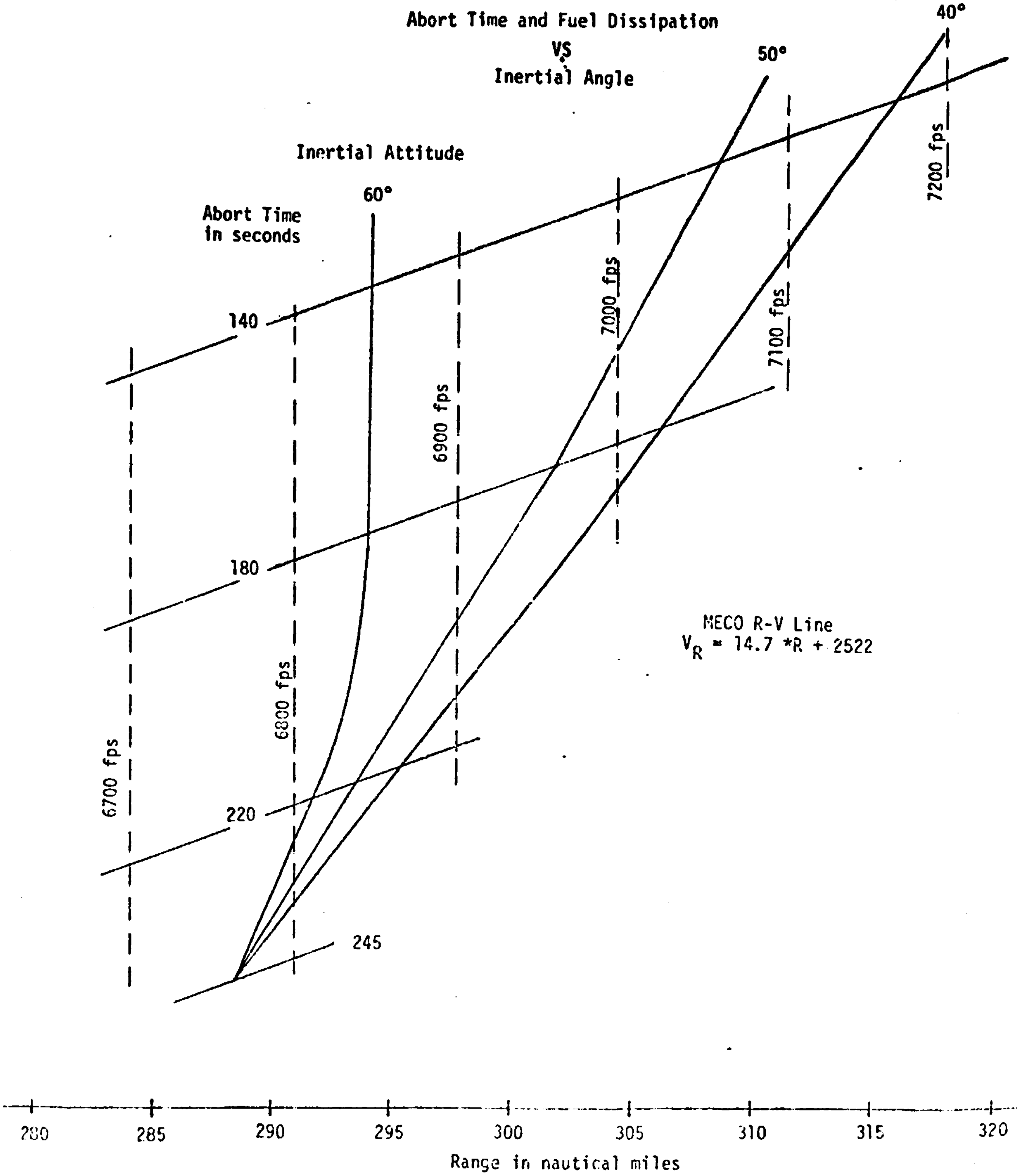
FIGURE 4

MECO R-V Arrival Points

Abort Time and Fuel Dissipation

VS

Inertial Angle



stability area is limited. However, the velocity spread available only results in a maximum of 9% change in dynamic pressures at separation. A 5000 ft decrease in altitude on the other hand results in a 25% increase. It would appear, subject to further investigation, that altitude variations for dynamic pressure control would be a more profitable approach. Another use for the velocity control would be to arrive at a "point" on the R-V line for all abort times thus making the entry basically the same for each mission and reducing crew training requirements for the entry phase. Referring again to Figure (4) it can be seen that there is no one range (and therefore velocity) that is common to all abort times although the range of entry conditions could certainly be narrowed.

Range control is more significant with 21.9 NM available at the earliest aborts, 4.6 miles at 220 sec. abort and, again, falling to zero at approximately 235-240 second aborts. Range control is not felt to be significant in the sense that each R-V point represents a point of equal opportunity for successful return. It is thought that a better approach would be to translate the target R-V line towards the launch site when the abort time is earlier than 235-240 seconds and, by definition excess fuel remains. This results in a "pad" or arrival nearer the center of the Terminal Area Energy Management (TAEM) footprint. Targeting to the center of the footprint has not been shown to cause excessive roll reversals.

It is apparent that, at this point, no good case exists for controlling the arrival location on the R-V line. Control can be exercised over the flyback trajectories, i.e. making them neighboring, within the linear range of the fuel dissipation phase inertial attitudes. Figure (5) illustrates what has recently been achieved by proper selection on the inertial attitude (Reference (D)). Note that a merging of the flyback trajectories does not make the MECO conditions the same. For the cases shown in Figure (5) the range variation is from 289.5 to 311.7 NM.

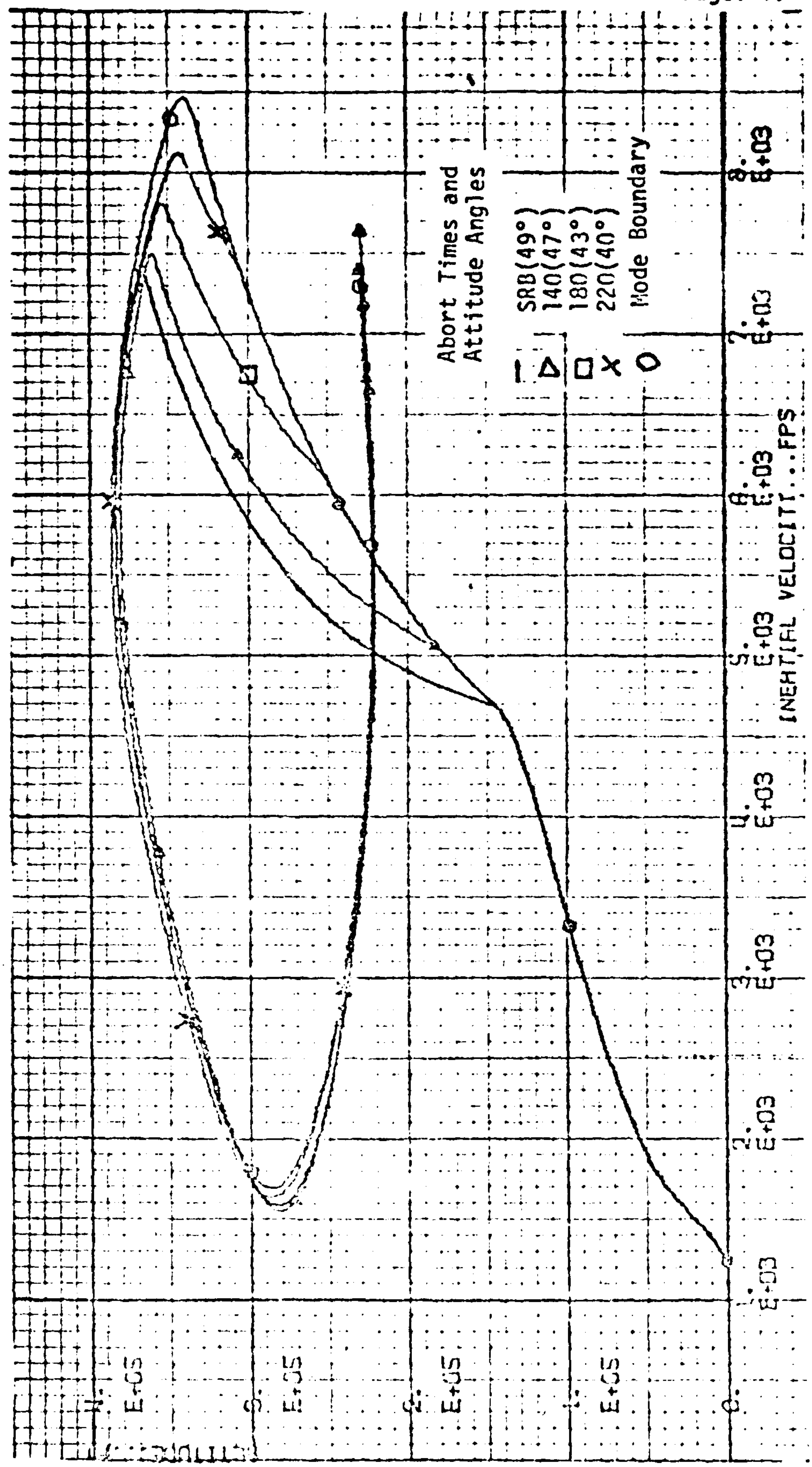


Figure 5 - Trajectory Shaping Altitude vs Inertial Velocity for Varying Attitude Angles and Abort Time

Nominal Trajectories

5.0 CONCLUSIONS

The following conclusions can be made concerning the use of a constant inertial attitude during the RTLS fuel dissipation phase:

1. The value of the constant inertial attitude can be chosen either to influence the point of arrival on the R-V line or to shape the flyback trajectory. Neighboring flyback trajectories appear significant from the monitoring and reversion to manual backup aspects.
2. In either case, the control over the parameter variation is greatest for early aborts and decreases to zero at the RTLS/AOA boundary.
3. Control over the range to landing site and/or dynamic pressure at external tank separation, if desirable to produce more benign entry conditions, can be more effectively achieved by varying target conditions (translating the R-V line and changing altitude respectively) than by using the R-V line arrival point control available. This leaves the inertial attitude selection free for merging the flyback trajectories.

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