MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

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SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-4-15

# SPACE SHUTTLE THREE MAIN ENGINE RETURN TO LAUNCH SITE ABORT

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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## 1.0 SUMMARY

This document examines a Return-to-Launch-Site (RTLS) abort with three Space Shuttle Main Engines (SSME) operational. The results are trajectories and main engine cutoff (MECO) conditions that are approximately the same as a two SSME case. Requiring the three SSME solution to match the two SSME abort eliminates additional crew training and is accomplished with negligible software impact.

## 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. The three SSME RTLS abort case was executed using essentially the same procedures required for the two SSME RTLS case. The method used was to make a three SSME abort look identical to a single SSME failure by throttling back the three engines. A point is reached in throttle setting where the total thrust of all three engines is equal to the commanded thrust of two engines for a single engine failure case.

## 3.0 DISCUSSION

This study used a three degree of freedom simulation contained on a Space Vehicle Dynamic Simulation (SVDS) 2.3.11 milestone file (Reference (B)) for a Baseline Reference Mission (BRM) 3A launched from the Western Test Range (WTR).

For simplicity it is desirable to use the two SSME RTLS guidance for the three SSME RTLS abort. If the trajectories for the two cases are similar then the crew procedures will be same.

For the three SSME abort the throttle was set at 73 percent (2/3 of 109 percent) during the fuel dissipation phase. Similarly a desired throttle setting of 2/3 X 100 or 67 percent was used during the flyback. With the exception of these modifications, the two cases used identical parameters. The code for the throttle commands is presented below (Reference (C)):

$K\_CMD = .73 + .36\ (3 - N\_SSME)$

$K_1 \quad = K\_CMD - .18/N\_SSME$

where

K_CMD - fuel dissipation throttle command

$K_1$ - flyback throttle command

N_SSME- number of SSME active

The only change required to implement the three SSME is to change the value of N_SSME for the type of abort. This can be accomplished with the same flag or logic that reconfigures the autopilot at abort.

The excess Orbital Maneuvering System (OMS) and Reaction Control System (RCS) fuel was dissipated by igniting the two OMS and the four aft axial RCS engines. Subsequently a preselected quantity of OMS fuel was burned by the same RCS engines to insure complete consumption of the OMS fuel before main engine cutoff (MECO). The turnaround time is predicted assuming that the OMS and RCS engines are on until MECO. During flyback the time to go (TGO) to MECO is computed using all currently active engines.

## 4.0 RESULTS

Throttling the three SSME to the approximate thrust level of two SSME results in a successful RTLS. The conditions at MECO for three abort times are presented in Table I. Identical guidance target values were used in all cases.

The simulation included a two second interval at minimum throttle prior to shutdown. The specified 60 percent minimum throttle setting is independent of the number of active SSME. This results in a mismatch between the simulations during the thrust termination phase. The result is that the three SSME thrust termination phase is approximately 0.5 seconds shorter than that of the two SSME case because the 3 SSME case has higher acceleration during the two second minimum throttle interval. Since both simulations are targeted at approximately the same Range-Velocity (RV) point, the three SSME case must shutdown earlier to achieve the same increase in velocity as the 2 SSME case. The relative flight path angle is positive, and decreasing at approximately 0.26 degrees per second for both cases. The effect of the 0.5 second earlier shutdown is exhibited by the lower altitudes and the .15 to .20 degree higher flight path angles of the three SSME cases.

TABLE I

CONDITIONS AT RTLS MAIN ENGINE CUTOFF

| $t_{abort}$ (sec) | Number of SSME | Minimum Throttle (percent) | Relative Range (nm) | Relative Velocity (ft/sec) | Relative Flight Path Angle (deg) | Altitude (feet) |
|---|---|---|---|---|---|---|
| 140 | 2 | 60 | 308.1 | 7053 | 2.01 | 228580 |
| 140 | 3 | 60 | 307.8 | 7047 | 2.21 | 228490 |
| 140 | 3 | 40 | 307.2 | 7038 | 2.09 | 228640 |
| 180 | 2 | 60 | 301.5 | 6955 | 2.05 | 228720 |
| 180 | 3 | 60 | 301.3 | 6950 | 2.20 | 228460 |
| 180 | 3 | 40 | 300.6 | 6941 | 2.08 | 228600 |
| 220 | 2 | 60 | 293.4 | 6836 | 1.94 | 228620 |
| 220 | 3 | 60 | 293.6 | 6838 | 2.13 | 228510 |
| 220 | 3 | 40 | 293.1 | 6829 | 2.01 | 228650 |

It should be noted that the minimum throttle interval may not be required for RTLS and then no mismatch will exist. The minimum throttle 2/3 SSME mismatch was removed from the simulation by using 40 percent as the setting for the three SSME shutdown. This throttle setting is equivalent to 60 percent used in the two SSME cases. The MECO conditions for these runs compare favorably to those of the two SSME cases. The maximum difference between flight path angles was reduced from .20 to .08 degrees. A one degree change in the RTLS entry flight path angle yields approximately a five nautical mile change in range (Reference (D)). The flight path angle differences shown in Table I would have a minimal effect upon the RTLS entry range.

The trajectories are presented in Figures 1 to 3 for the inertial velocity-altitude plane. The trajectories are very similar. The differences are due to the requirement that SSME throttle settings be implemented in one percent increments. For instance, a change from 100% to 99% for the two SSME case would not be matched in the three SSME case since for three SSME it would amount to only 2/3%. The SSME throttle histories (Figures 4 to 6) show typical response.

The software impact is negligible, consisting of an increase in core storage of three constants and an increase in computation time due to five additional arithmetic operations.

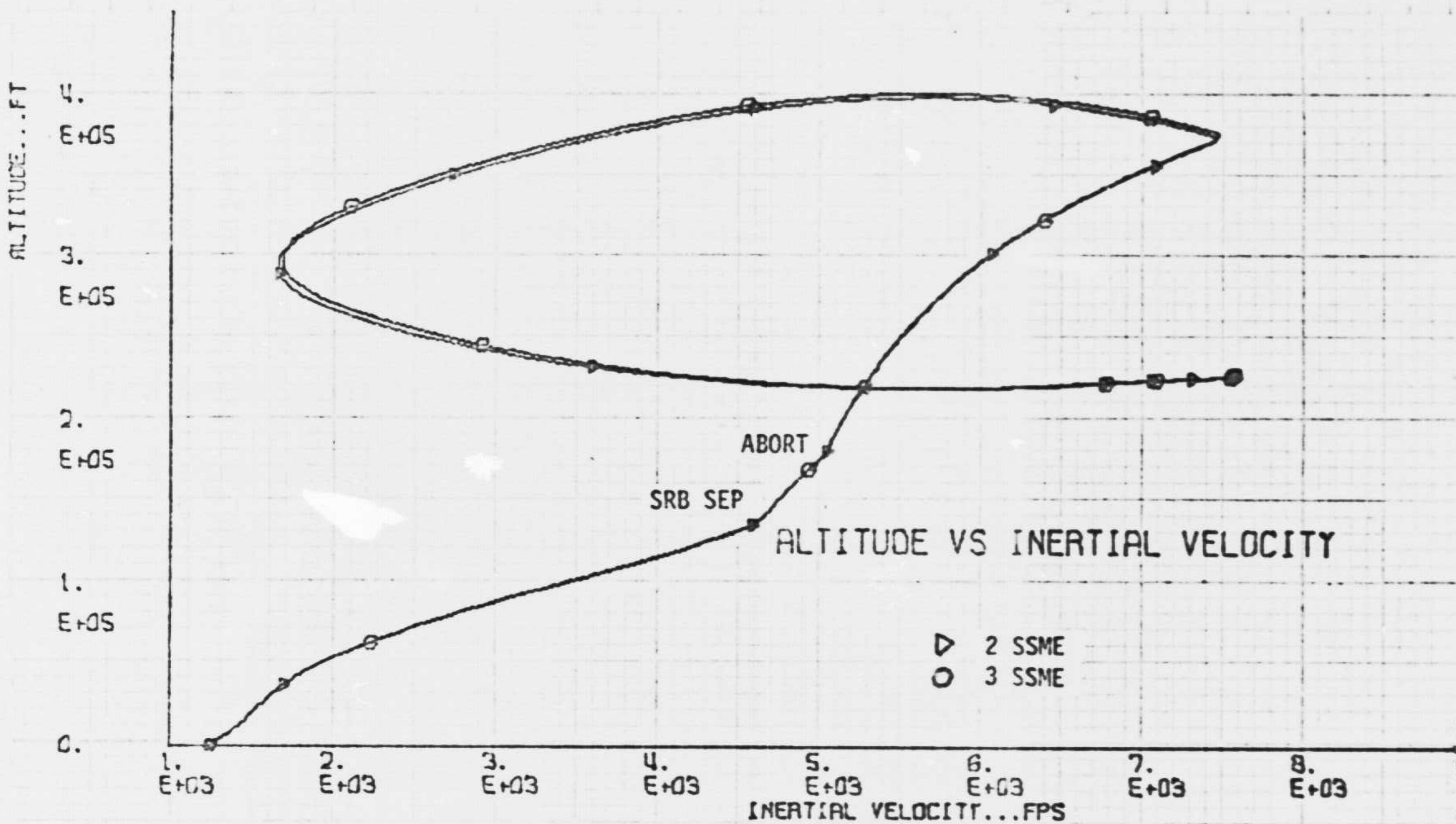


Figure 1 - Altitude vs Inertial Velocity for 140 Second Abort, 3 and 2 SSME

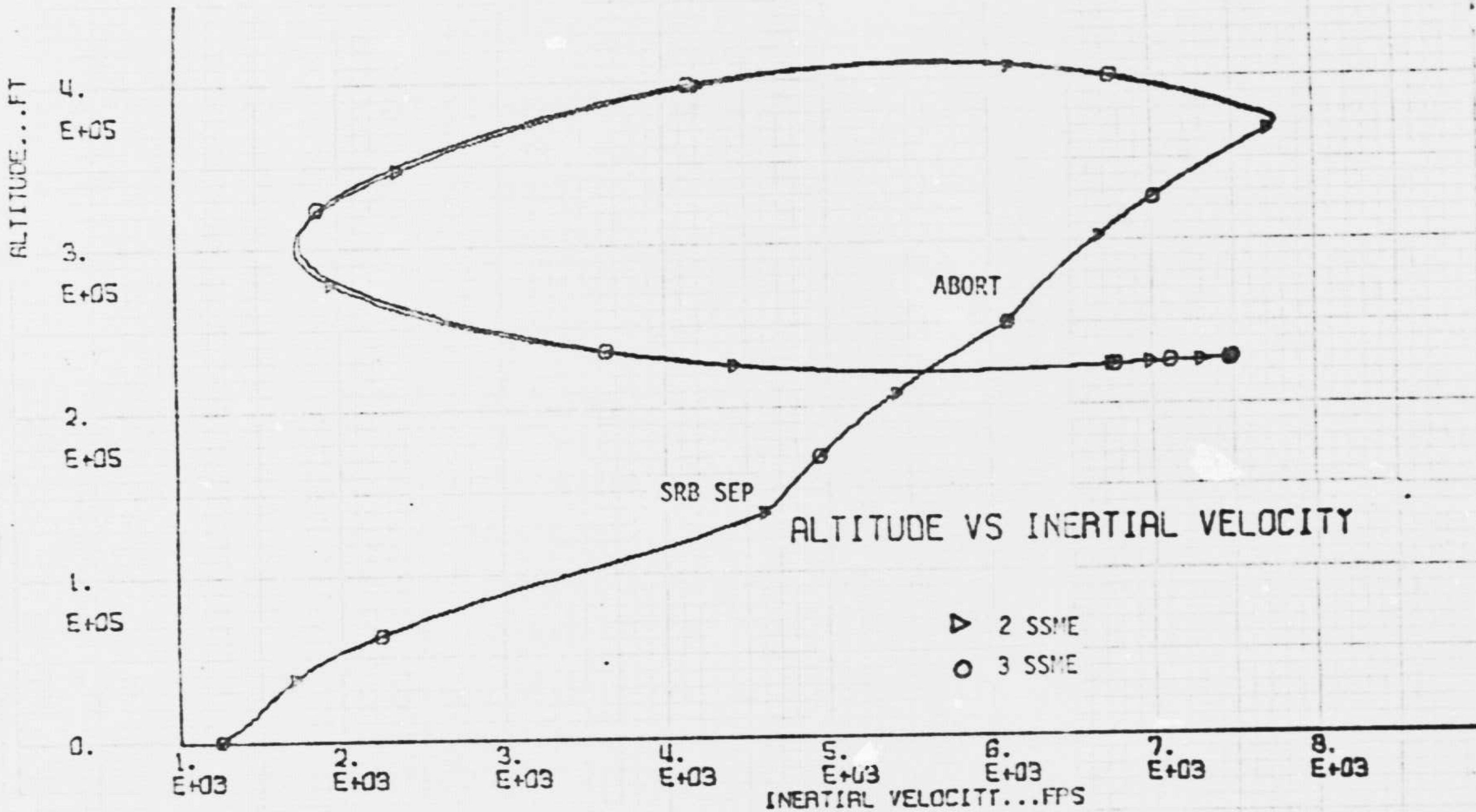


Figure 2 - Altitude vs Inertial Velocity for 180 Second Abort, 3 and 2 SSME

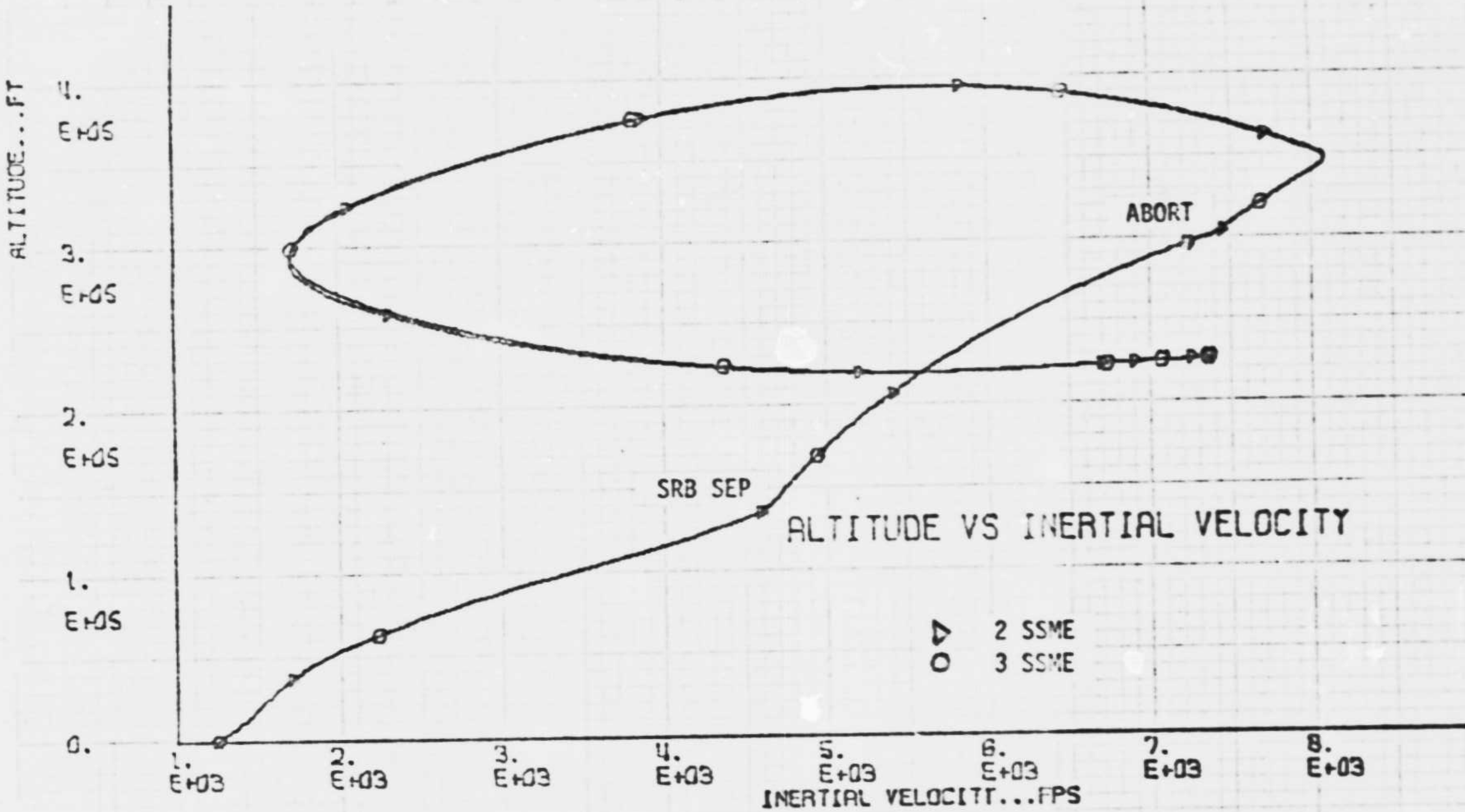


Figure 3 - Altitude vs Inertial Velocity for 220 Second Abort, 3 and 2 SSME

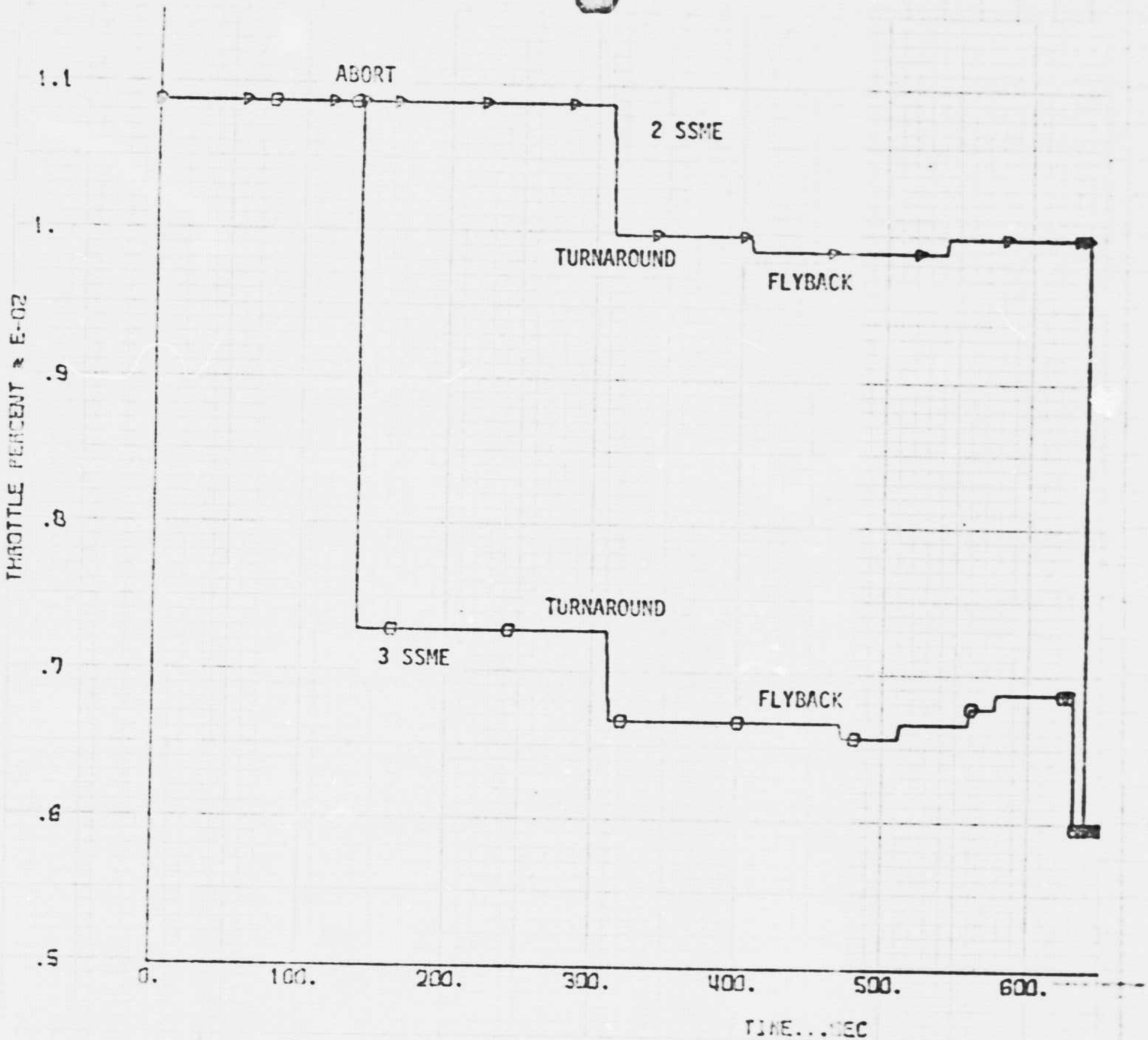


Figure 4 - Engine Throttle vs time for
140 Second Abort, 3 and 2 SSME

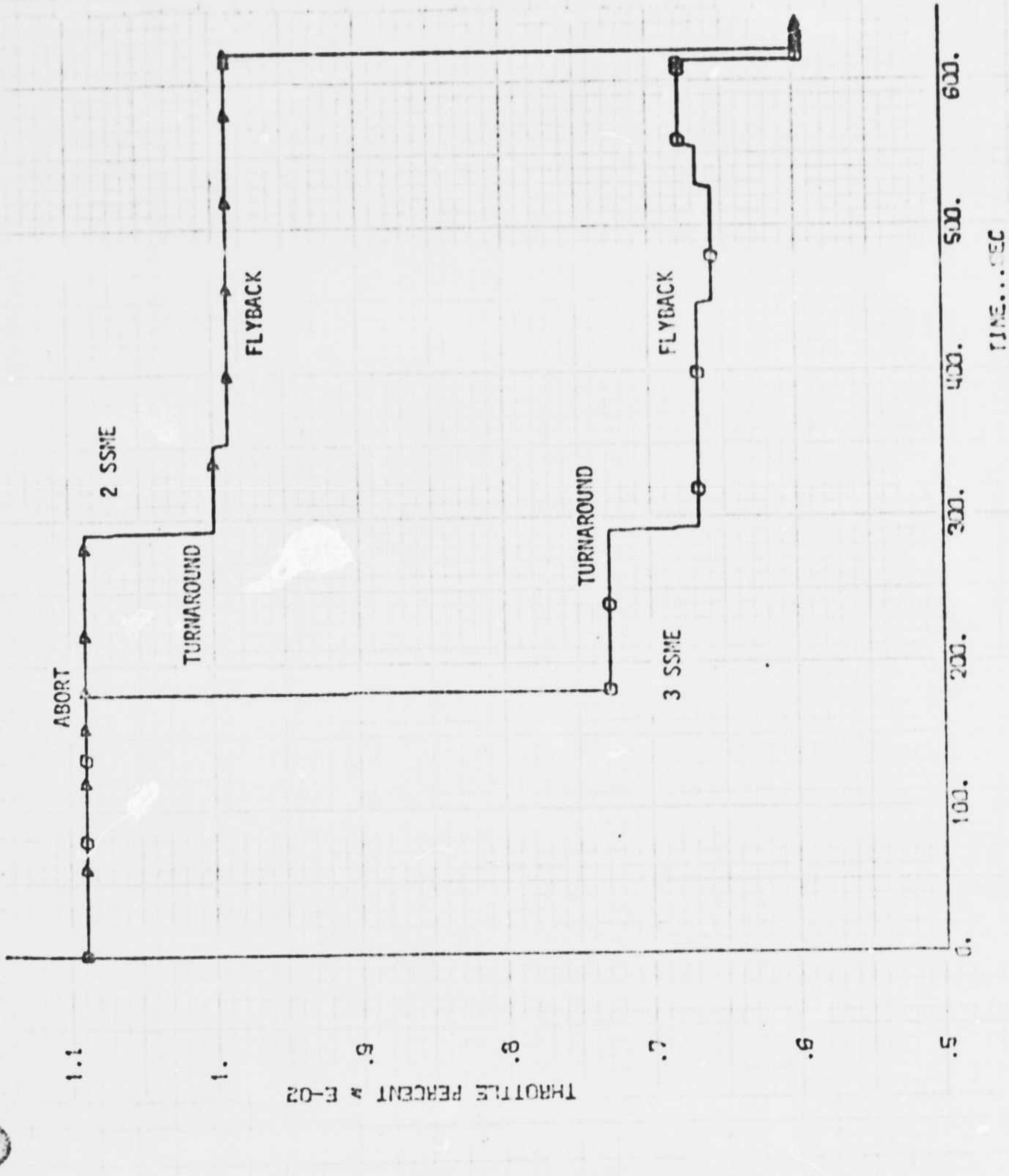


Figure 5 - Engine Throttle vs time for
180 Second Abort, 3 and 2 SSME

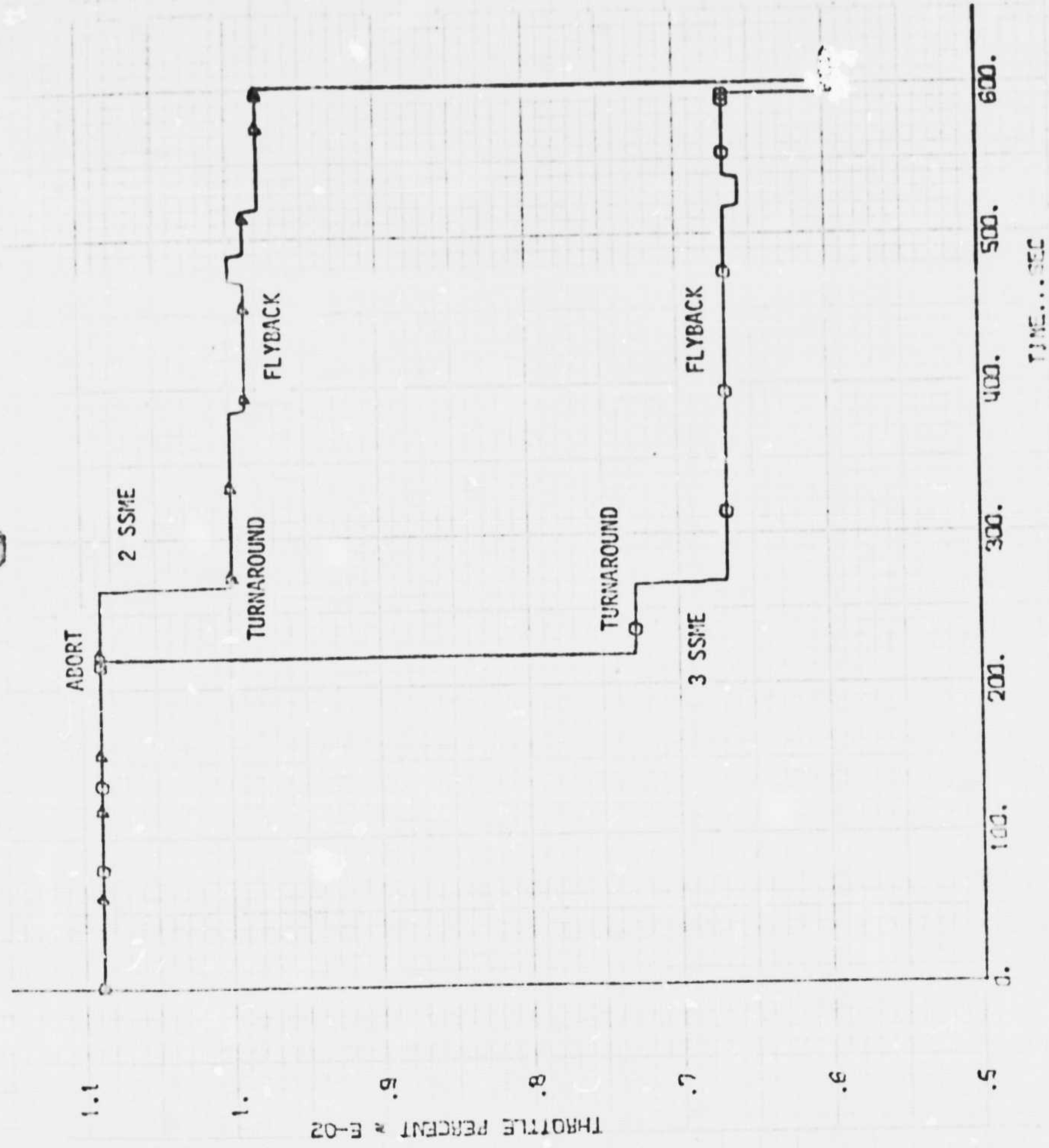


Figure 6 - Engine Throttle vs time for 220 Second Abort, 3 and 2 SSME

## 5.0 CONCLUSIONS

A three SSME RTLS abort can be accomplished by throttling the three engines in a manner to make the thrust approximately the same as the two SSME case. Minimum additional software is required to support this case since it consists of only

a) an increase of core storage for three constants

b) an increase of computational time due to five additional arithmetic operations.

## 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 Dynamic Simulation (SVDS) Program Revision 2, JSC Internal Note No. 73-FM-67 November 14, 1974.

(C) CSDL C-4356 "Space Shuttle Powered Flight Guidance Detailed Flow Diagrams" Revision 1, September 1975.

(D) MDTSCO WBS 1.4 unpublished data.