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CREW ESCAPE CAPSULE RETROROCKET CONCEPT

Volume II

SELECTION OF A RETROROCKET SYSTEM

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This technical report has been reviewed and is approved for publication.

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20 ABSTRACT (Continue on reverse side if necessary and identify by block number)		
The objective of this analysis was to select a rocket design which would de- celerate a B-1 escape capsule drop test vehicle to a vertical velocity of 10 ft/sec or less at capsule impact with the terrain. The concept is based on the prediction that if the capsule is decelerated to a vertical velocity of 10 ft/sec or less at impact, the capsule occupants would not be subjected to ac- celerations which exceed the requirements of MIL-C-25969B. The results of a parametric study which considered thrust to weight ratios of 2 through 10, in (continued on next page)		

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20. combination with recovery system descent rates of 30 through 60 ft/sec, are presented. The test envelopes which could be accommodated with two different off-the-shelf rocket systems are presented. The analytical method employed in determining the test envelopes is discussed. Performance summaries for the selected rocket system are given.

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PREFACE

This report summarizes a crew escape capsule retrorocket demonstration and analytical program which was conducted by the Air Force Flight Dynamics Laboratory, Vehicle Equipment Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This report consists of two volumes:

Volume I - Demonstration Program

Volume II - Selection of a Retrorocket System

The program was conducted under Project 6065, "Aerospace Vehicle Recovery and Escape Subsystems"; Task 606501, "Aerospace Vehicle Escape;" and In-House Effort 60650120, "Crew Escape Capsule Retrorocket Concept." Mr. Marvin C. Whitney of the Recovery and Crew Station Branch, AFFDL, was the Project Engineer. Mr. James M. Peters of the Recovery and Crew Station Branch conducted the analytical program.

Volume II of this report summarizes an analytical program which led to the selection of a retrorocket system for an escape capsule retrorocket impact attenuation demonstration program.

The author is indebted to many other people who contributed to this effort, including: Mr. Richard J. Dobbek, Capt. A. M. Higgins, and Mr. Lanny A. Jines of the Recovery and Crew Station Branch.

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SECTION I
INTRODUCTION

An analysis of requirements for a retrorocket impact attenuation system for a multi-crew escape capsule has been conducted, and the allowable test envelope for a full-scale demonstration program has been defined. The characteristics of the B-1 escape capsule were used in the analysis, and the demonstration program utilizes a B-1 capsule drop test "Iron Mule," B-1 recovery system, a cluster of four (4) Thiokol rockets, and a rigid, mechanical, terrain sensing system. The objective of the program was to select a rocket design which would decelerate the capsule from the recovery parachute terminal descent velocity to a vertical velocity of 10 fps or less at capsule impact with the terrain. This concept is based on the premise that if the capsule is decelerated to a vertical velocity of 10 fps or less at time of ground impact, an inflatable impact attenuator would not be required and the occupants would not be subjected to accelerations which exceed the requirements of MIL-C-25969B.

The operating envelope of the retrorocket system was to be the same as that required of the inflatable impact bag system in terms of capsule weight range, descent rate range, temperature, terrain, winds, oscillation angle, etc.

After the capsule has reached a steady-state descent rate under the recovery parachutes, rigid mechanical probes are extended beneath the capsule. Upon probe contact with the ground, an explosive energy transfer system is actuated which in turn ignites the retrorockets located

between the parachutes and the capsule. The retrorockets provide the deceleration force necessary to reduce the capsule vertical descent rate to a tolerable level at impact.

This analysis effort was directed towards defining the rocket requirements and ground probe requirements for the capsule. The retrorockets provide a primary thrust level (thrust to weight ratio (T/W) greater than 1) followed by a sustainer thrust level ($T/W < 1$).

The program direction was later reorientated toward the utilization of an existing rocket (for demonstration purposes) which essentially changed the program approach from a design study to a performance evaluation. The performance analysis of existing rockets was directed toward defining a test envelope which could be accommodated by an existing rocket system, recognizing that only a portion of the capsule operational envelope could be covered. The effort prior to reorientation of the program was characterized by continually changing system parameters related to the B-1 capsule as more detailed knowledge of the system and its operation became known.

A change in the analysis technique, however, produced the most profound effect on establishing either a theoretical rocket design or an allowable test envelope for the demonstration. This change in the analysis technique consisted of combining a -5° ground slope with horizontal wind velocity in the direction of the down slope. This combination of parameters can add several feet to the vertical distance the capsule has to decrease after probe contact. This additional distance will require a sustainer T/W which approaches 1, resulting in prohibitively

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long sustainer burn times (thus, propellant weight is prohibitively high).

Effectively then, this particular combination of parameters precludes a rocket design of the type analyzed (two stage, fixed thrust levels) from providing acceptable impact velocities over the full operational range of the B-1 escape capsule. For the demonstration, which utilizes existing rockets, the allowable temperature range, weight range, and ground slope must all be restricted.

The original escape capsule descent and landing characteristics were selected based on existing B-1 specifications and weight status at the time of initiation of the retrorocket analysis program. These characteristics are listed below:

Weight at Impact	6921 → 7631 lbs
Vertical Descent Rate	27 → 33 fps

In addition, the escape capsule must not impact during the primary portion of the rocket burn. The following characteristics were specified for the retrorocket system:

Rocket Temperature	-65 → 160°F
Parachute Oscillation	+10°
Thrust Level Variation	±5% at any given temp.
Ground Slope	+5°
Ignition Height Error	±0.5 ft

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Horizontal Wind Velocity	34 fps (20 knots)
Maximum Allowable Vertical Impact Velocity	10 fps

In order to preclude the chance of rocket plume impingement on the capsule and/or the suspension lines, a nozzle angle of 30° was originally selected. This meant an increase in required propellant weight of approximately 15.5%. The first capsule weight change increased the weight range from 6921 → 7631 lbs to 7092 → 7802 lbs, resulting in a propellant weight increase of approximately 14%. The second capsule weight change increased the weight range from 7092 → 7802 lbs to 7186 → 8165 lbs. At the same time, analysis of additional drop test data on the B-1 recovery parachute subsystem resulted in a change of the system descent rate range from 27 → 33 fps to 23 → 33 fps. Incorporating these changes resulted in a propellant weight increase of approximately 236%.

The change in the computer analysis technique, which consisted of combining the -5° ground slope with the 34 fps ground wind in the direction of the down slope, resulted in serious questions about the design of the system. For nominal thrust levels at a given temperature, the maximum impact velocity of 10 fps or less could be met although propellant weight was approaching 200 lbs. However, when the +5% thrust variation at min weight, min descent rate, max temp was applied, the capsule impact velocity, $V_I \leq 10$ fps, could not be satisfied. The reason for this was that the sustainer T/W was very near 1 at the start of sustainer burn so that when the large amount (approximately 200 lbs) of propellant was expended, the sustainer T/W exceeded 1 and the descent

to the ground could not be accomplished. This indicated that the full operational envelope of the B-1 escape capsule could not be covered by the selected approach of level thrust primary rocket followed by level thrust sustainer rocket.

At this time, the difficulties enumerated above plus the status of resources and time available for design and development of a retrorocket system led to the decision to attempt to utilize existing rockets for the demonstration program. It was recognized, of course, that a much smaller envelope of parameters (temp, weight, ground slope) could be accommodated. A search of existing rocket motors revealed that the Thiokol TE-M-421 rocket motor was basically similar in thrust-time pattern to the one required. This rocket was subjected to an extensive performance analysis in order to determine the allowable test (demonstration) envelope.

The performance analysis indicated that a cluster of four Thiokol TE-M-421 rockets (with nozzle angle = 30°) could cover a test envelope as follows:

Weight at Impact	7625 + 7878 lbs
Vertical Descent Rate	24.7 + 31.3 fps
Rocket Temperature	40 + 110° F
Parachute Oscillation	+10°
Ground Slope	+1°
Ignition Height Error	+0.5 ft
Horizontal Wind Velocity	34 fps
Maximum Allowable Vertical Impact Velocity	11 fps

The descent rate range represents a 95% coverage of expected descent rates according to a statistical analysis of B-1 recovery system drop test data. The increase in the maximum allowable vertical impact velocity came about due to practical considerations of the demonstration program. If the 10 fps or less condition was to be met, the allowable weight and temperature ranges would be quite small. It was decided not to rigidize the test weights and test temperatures to avoid the possible 10% increase in the vertical impact velocity.

After the initial demonstration envelope was defined, information was received that the rocket thrust curves furnished by Thiokol were for the TE-M-421-3 motor, and the rockets which were to be delivered would be the TE-M-421-1 rocket. The -1 and the -3 rocket motors have slightly different thrust-time patterns. Basically, the -1 rocket motor has a higher peak primary thrust and a lower sustainer thrust than the -3 rocket motor (see Figure 1). Consequently, it became necessary to redefine the test envelope. The differences in the envelopes were that the capsule weight range changed to 7425 → 8075 lbs and the temperature range changed to 60 → 125°F. In addition, the rocket nozzle cant angle changed from 30° to 38°.

SECTION II

BACKGROUND

A parametric analysis which preceded this study considered retro-rockets in combination with several different recovery systems. The study (Ref. 1) was based on the principle that a higher steady-state nominal descent rate could be tolerated with a retrorocket deceleration system than with the current inflatable airbag impact attenuation system.

The parametric analysis indicated that a nominal descent rate of 42 fps and a retrorocket deceleration system with primary rocket $T/W = 7$, followed by a time delay, and then a sustainer rocket with $T/W = 0.63$ could provide $V_I \leq 10$ fps over the operational envelope of the B-1 capsule, with the exception that the combination of -5° ground slope condition and the horizontal wind velocity of 34 fps is not provided for in the envelope.

This follow-on analysis program was constrained by the utilization of the present B-1 parachute recovery system and by practical considerations of rocket design and development within limited resources and program time. Therefore, the theoretical design for the demonstration concentrated on a primary rocket $T/W = 5$ and no time delay between primary and sustainer. The reason for selecting a system in which the sustainer fires immediately after primary burn was that it is a less complex, more reliable system. The reason for decreasing the primary rocket thrust to weight ratio from $T/W = 7$ to $T/W = 5$ was simplicity and efficiency of rocket design.

The parametric analysis revealed that a rocket system consisting of only a primary rocket could not satisfy $V_I \leq 10$ fps. Nine primary T/Ws (2 through 10) were considered for five nominal descent rates (30 through 60 fps). Two design points representing envelope extremes were used in the analysis (see Section III, Analysis Procedure). The parametric analysis also revealed that if a time delay were provided between primary thrust and sustainer thrust, weight savings could be realized. The reason for this is that at Design Point 2 (min weight, max temperature, min descent rate) the module reaches zero velocity at some point above the terrain and then starts ascending. If the sustainer fires immediately, the capsule ascends higher before it reaches zero velocity for the second time and starts descending again. However, this concept necessitates a separate rocket system for primary and sustainer rockets, in addition to providing thrust from still another source to keep the retrorocket pack properly positioned during the time delay between primary and sustainer rocket burning. Therefore, during the early phases of the design of a rocket system for a demonstration program, the concept of primary-time delay-sustainer rocket was abandoned.

The retrorocket system that resulted from the parametric study consisted of a high thrust, short burn time primary rocket and a low thrust, long burn time sustainer rocket. As noted above, during the time delay between primary and sustainer a low rocket thrust is required to keep the rocket cluster properly positioned (see Figure 2).

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The primary rocket provided a nominal vertical T/W of 7 and a burn time of 0.23 sec. The sustainer rocket is ignited 0.5 sec (+20%) after ignition of the primary rocket and provides a nominal T/W of 0.63 for 2.20 sec. The total impulse of the retrorockets is 26, 742 lb-sec. The thrust vs. time curves at -65°F, 70°F and 160°F are shown in Figure 2.

The retrorocket system defined by the parametric analysis provides $V_I \leq 10$ fps for the following operational envelope:

Weight at Impact	6921 → 7631 lbs
Vertical Descent Rate	40 → 47 fps
Rocket Temperature	-65 → 160°F
Parachute Oscillation	+10°
Ignition Height Error	+0.5 ft

Figures 3 through 11 are performance curves based on the selected primary rocket thrust to weight ratio of $T/W = 7$, sustainer thrust to weight ratio of $T/W = 0.63$, and a nominal rate of descent of $V_0 = 42$ fps.

SECTION III

ANALYSIS PROCEDURE

The parameters which affect the design of the retrorocket system are: capsule weight, capsule descent rate under the recovery parachute, retrorocket temperature, rocket ignition height variation, ground slope, parachute oscillation angle, and ground wind velocity.

As mentioned in the background section, the previous retrorocket study (Ref. 1) considered primary rocket T/Ws of 2 through 10. Figure 12 shows that the propellant weight required decreases with increasing T/W for a given descent rate range. As T/W nears 10 the loads imposed on crew and/or structure become prohibitive. The Reference 1 study selected a primary T/W of 7 for the retrorocket design. As this analysis was to be the basis for a rocket development program with a rather compact schedule, it was decided to concentrate on the $T/W = 5$ primary rocket since it appeared to involve a more manageable development plan, although there was a small weight penalty.

The weight range was based on available B-1 capsule weight status information. The weight range includes the difference in weight between four 5th percentile crewmen and six 95th percentile crewmen. It also includes the weight with and without the drogue parachute system since in the low speed escape mode the drogue parachute is retained with the capsule.

The capsule descent rate range was at first based on the vertical velocities at which the airbag system was to be qualified. The descent rate range was later modified based on statistical evaluation of the B-1 escape capsule recovery parachute system tests.

The ignition height variation was determined from consideration of possible deviation in the length of the rigid terrain sensing probe, capsule attitude at probe/terrain contact, variation in capsule descent rate, and variation in rocket ignition time.

The rocket temperature range is the same as the required operating temperature range of the capsule escape rockets.

The maximum allowable vertical impact velocity was based on experimental data from F-111 escape capsule drop test programs (Reference 2).

The constraint that primary rocket burnout must occur prior to ground impact was based on two considerations. The first is to ensure that impact conditions are more nearly the same as in the F-111 capsule drop test program, and the second is to preclude the possibility of bounce and secondary impact.

The parachute oscillation was defined by the B-1 escape capsule specification to be a conical oscillation of up to 10° about the vertical during steady-state descent.

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Two design points representing envelope extremes are used to size a preliminary thrust-time curve and preliminary rocket ignition height. This preliminary information is then input to a two-degree-of-freedom, single body computer program for evaluation over a matrix of system parameters.

The design points are based on the following considerations. Design Point 1 determines the ignition height requirement for a specific T/W and descent rate range which determines primary burn time. Design Point 2 determines the sustainer T/W and burn time. The two design points are identified below:

Design Point 1

Max Weight

Min Temp

Max Descent Rate

Design Point 2

Min Weight

Max Temp

Min Descent Rate

The design Point 1 conditions result in the lowest actual T/W for a given nominal T/W (thrust at 70°F : average capsule weight at impact). When this minimum T/W configuration descends at the maximum descent rate, the altitude lost during primary rocket burn will be a maximum.

With the constraint that primary rocket burnout must occur before capsule impact, the primary rocket must be so designed that if it is fired at minimum ignition height rocket burnout has just occurred at impact and the descent velocity has been reduced to less than 10 fps. However, if the rocket is fired at maximum ignition height, then rocket burnout will occur above the terrain and the capsule will descend the

remaining distance to the ground either under free fall or under the action of a sustainer rocket with $T/W < 1$. In either case, the velocity at primary rocket burnout must be less than 10 fps. Initial efforts were directed towards designing a retrorocket system with a primary rocket only; however, no single rocket system (of the constant thrust level type) which was evaluated approached providing an impact velocity $V_I \leq 10$ fps for the range of weights, temperatures, and vertical velocities considered.

The equations, symbols and the sequence of calculations for sizing the primary rocket are as follows:

σ	Thrust-Temperature Coefficient (0.0011/°F)
T_C	Thrust at Minimum Temperature
T_N	Thrust at Nominal Temperature
T_H	Thrust at Maximum Temperature
TE_H	Temperature, Maximum
TE_N	Temperature, Nominal
TE_C	Temperature, Minimum
V_{01}	Initial Capsule Vertical Weight at DP1
V_{02}	Initial Capsule Vertical Weight at DP2
W_L	Capsule Weight, Minimum
W_N	Capsule Weight, Nominal
W_H	Capsule Weight, Maximum

The equations and the sequence for sizing the primary rocket are as follows:

- A nominal T/W is selected for analysis and a corresponding sustainer T/W is approximated from Figure 13.
- The low temperature thrusts are calculated by equation 1.
- A value of ignition height error $E = \pm 0.5$ ft or $2 |E| = 1.0$ ft was selected as a design goal based on previous analyses.
- V_I = maximum allowable vertical impact velocity.
- The value of the system velocity at rocket burnout, Design Point 1, V_{RB01} , is calculated from equation 2.

$$T_C = [1 + (T_{E_C} - T_{E_N})(\sigma)] T_N \quad (1)$$

$$V_{RB01} = [V_I^2 - 2g (1 - T_C/W_H) (2 |E|)]^{1/2} \quad (2)$$

The altitude lost during primary rocket burn at DP1 is calculated from equation 3.

$$SL_1 = \frac{V_{01}^2 - V_{RB01}^2}{2g(T_C/W_H - 1)} \quad (3)$$

The primary rocket burn time is determined from equation 4.

$$t_C = \frac{V_{01} - V_{RB01}}{g(T_C/W_H - 1)} \quad (4)$$

The primary rocket impulse is calculated from equation 5.

$$I = (T_C)(t_C) \quad (5)$$

At Design Point 2, the actual T/W is a maximum and descent time is a minimum so that altitude lost is considerably less (than at DP1) during primary rocket burn so that the capsule may be several feet above the terrain at primary rocket burnout.

The hot rocket thrust is determined from:

$$T_H = [1 + (T_{E_H} - T_{E_N})(\sigma)] T_N \quad (6)$$

The hot burn time is determined from:

$$t_H = I/T_H \quad (7)$$

which allows us to calculate the value of the system velocity at rocket burnout, Design Point 2:

$$V_{RB02} = V_{02} - t_H g(T_H/W_L - 1) \quad (8)$$

and the altitude lost at DP2 from:

$$SL_2 = \frac{V_{02}^2 - V_{RB02}^2}{2g(T_H/W_L - 1)} \quad (9)$$

Since $SL_2 < SL_1$, the height above the terrain will be greater than $2|E|$. The sustainer rocket T/W required to allow $V_I = 10$ fps is calculated from

$$(T_H/W_L) = 1 - \frac{V_I^2 - V_{RB02}^2}{2g(SL_1 - SL_2 + 2|E|)} \quad (10)$$

The sustainer burn time is then calculated from:

$$t_H = \frac{V_I - V_{RB02}}{g(1 - (T_H/W_L))} \quad (11)$$

The (T_H/W_L) thus obtained is converted to the T_C/W_H , and V_I is evaluated at DP1. If this value is less than the maximum allowable, the thrust time curves for -65°F , 70°F and 160°F , and the ignition heights obtained from:

$$IH_{\min} = SL_1 \quad (12)$$

and

$$IH_{\max} = SL_1 + 2|E| \quad (13)$$

are input into the single body, two-degree-of-freedom computer program (see Appendix A).

If $V_I \sim 10$ fps, the minimum ignition height is increased and impulse is added to the primary rocket in the form of additional burn time. This "new rocket" is then re-evaluated at DP2, the T/W for the sustainer recomputed, and so on until the two design points both indicate $V_I \leq 10$ fps. This computer program considers parachute drag and capsule base drag, and rocket thrust buildup and tail-off. The program output is a history of module acceleration, velocity, height above the terrain, rocket total thrust, vertical thrust and impulse.

As mentioned previously, the two design points were selected as performance envelope extremes. DP1 determines the primary rocket impulse and I_{Hmin} for a given T/W and E. DP2 sizes the sustainer rocket and since it influences allowable V_{RB01} it influences the primary rocket design during the iterative process. However, other combinations of the influencing parameters within the performance envelope could produce impact velocities of approximately 10 fps, especially when the effects of parachute drag and thrust buildup and tail-off are considered. Therefore, a large matrix of parameter combinations was evaluated within the computer program.

SECTION IV THEORETICAL ROCKETS

The first phase of this effort was directed towards establishing a rocket design suitable for the full-scale demonstration of the retro-rocket deceleration system.

At that time, the analysis technique of subjecting the mathematical model to a combination of -5° ground slope and 20 knot ground wind had not evolved. Consequently, it appeared that the full operational envelope of the B-1 crew escape capsule could be accommodated with no weight penalty over the airbag system, and quite possibly with a weight savings. The previous parametric study indicated that a greater weight savings was possible because of the higher descent rate under the recovery system (therefore, a lower recovery system weight) combined with a retrorocket system with primary $T/W = 7$. As shown in Figure 12, there is a weight savings with increasing primary T/W . The higher primary T/W rocket systems, however, are extremely short burn time systems, making them less attractive from a rocket design standpoint. As this phase of the study developed, it was decided to concentrate on a rocket system with $T/W = 5$ instead of $T/W = 7$.

Figures 14 through 16 show the thrust histories for $T/W = 3, 5$, and 7 at that point in time when the capsule weight range was 7092 - 7802 lbs and the descent rate range was 27 - 33 fps. Referring to Figure 12, the system propellant weight for the $T/W = 7$ rocket is approximately 41 lbs. Analysis indicates that if a time delay were used

between the primary and sustainer rockets, the propellant weight would be 36.5 lbs. However, as mentioned previously, in spite of the weight savings it was decided not to include a time delay in the system for reasons of simplicity and reliability.

Figures 17 through 19 show the retrorocket performance at Design Points 1 and 2. It is noted that at that time the retrorocket systems shown in Figures 14 through 16 met the operational envelope requirements of the B-1 crew escape capsule.

The next change in the operational envelope for the retrorocket system was an increase in weight range from 7092 → 7802 lbs to 7186 → 8165 lbs and an increase in the descent rate range from 27 → 33 to 23 → 33 ft/sec. These changes resulted in a major weight increase in the system propellant weight (e.g., the propellant weight for the $T/W = 5$ rocket increased from 48 to 112 lbs).

When the -5° ground slope, 20 knot ground wind condition was applied, the propellant weight for the $T/W = 5$ rocket increased from 112 lbs to 190 lbs for the nominal thrust level condition. The system was now approaching weight levels which no longer made it competitive with the airbags.

When the +5% thrust level condition was applied to the $T/W = 5$ system, the T/W under the sustainer (which increases with time since W decreases) approached 1 so that in effect the capsule was almost sus-

pended above the ground until rocket burnout. An attempt was made to increase sustainer burn time but this resulted in sustainer $T/W > 1$ after a certain time so that the capsule began to ascend rather than descend.

It is recognized that the +5% thrust level, at a given temperature, would likely only occur for the rocket system if there was a single rocket (with multiple nozzles) which made up the retrorocket system. If multiple rockets (say 3 or 4) made up the retrorocket system, then the +5% thrust level at a given temperature could reasonably be neglected (since it is probable that not all rockets would be +5% thrust).

At this point in time, the program direction changed from theoretical rockets to an analysis of off-the-shelf rockets which could be employed in the demonstration. Therefore, no further work was directed towards refining the theoretical $T/W = 5$ retrorocket system.

SECTION V
PERFORMANCE ANALYSIS

1. ROCKET MOTOR TE-M-421-3

The original Thiokol rocket which was evaluated for use in the demonstration program was the TE-M-421-3 shown in Figure 20. The 90° nozzle angle shown can be modified to any angle between 0 and 90°.

Preliminary analysis showed that four of the rockets would be required and the nozzle cant angle would be approximately 30°. The nominal ignition height was 9.25 ft (8.75 min, 9.75 max). Data was provided by Thiokol for thrust vs. time at 60 and 120°F. Thrust vs. time data for intermediate temperatures at 10° increments was extrapolated from these two curves and subjected to a comprehensive computer analysis in order to determine the exact nozzle angle required for the rockets and the allowable range of test variables.

The allowable range of test parameters is as shown below for this rocket system:

Weight at Impact	7625 → 7878 lbs
Vertical Descent Rate	24.7 → 31.3 fps
Rocket Temperature	40 → 110°F
Parachute Oscillation	±10°
Ground Slope	±1°
Ignition Height Error	±0.5 ft
Horizontal Wind Velocity	34 fps
Max Allowable Vertical Impact Velocity	11 fps

During the evaluation of the TE-M-421-3 rocket, the change in analysis technique occurred (that of combining -5° ground slope with the 20 knot horizontal wind at DP2). Computer analysis indicated that the ground slope must be held to $\pm 1^\circ$ in order to cover even the limited range of test variables listed above.

2. ROCKET MOTOR TE-M-421-1

Original analyses of the Thiokol rocket were for the TE-M-421-3 rocket motor. The rocket which was actually utilized was the TE-M-421-1 rocket motor. The differences in the thrust histories of the two rockets are shown in Figure 1. After this program change, the performance analysis had to be reinstituted. The evaluation of the -1 rocket motor showed that the nozzle angle had to be changed from 30° to 38° and the nominal ignition height changed from 9.25 ft to 7.60 ft (7.1 min, 8.1 max).

Thrust time data was provided for temperatures of 60 and 125°F . Thrust histories for time intermediate temperatures (76.25, 92.5 and 108.75°F) were extrapolated from these two curves. These thrust histories are shown in Figures 21 through 25.

A summary of the results of 1000 computer runs is shown in Table I.

The -1 rocket motor enabled the test weight range to be expanded from 7675 - 7878 lbs to 7425 - 8075 lbs and changed the demonstration temperature range from $40 - 110^\circ\text{F}$ to $60 - 125^\circ\text{F}$. The performance of the -1 rocket motor at DP1 and DP2 is shown in Figures 26 through 28.

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Subsequent to the completion of the evaluation of the -1 rocket motor, Thiokol provided data from 12 motor firings at temperatures of -20, 60, and 125°F. Check runs of these thrust time histories at DP1 and DP2 indicate that the capsule impact velocities would fall within the maximum allowable for the test envelope established previously.

SECTION VI
CONCLUSIONS

1. The analysis of a retrorocket deceleration system for the B-1 escape capsule has shown that the full operational envelope of the escape capsule configuration under investigation cannot be satisfied if the maximum impact velocity is 10 fps and the rocket characteristics are level thrust primary and level thrust sustainer. An evaluation of the probability of encountering all of the envelope extremes and combinations of the extremes may show that the design approach of this study was overly conservative.
2. It appears that the operational envelope is too broad for a fixed rocket, fixed ignition height system. Therefore, either the design envelope has to be reduced statistically or physically by methods such as rocket temperature control and capsule weight range control, or the system must incorporate some form of variable thrust and/or variable ignition height retrorocket system.
3. The analysis shows that a fixed thrust level, fixed ignition height rocket system can be demonstrated for a limited portion of the operational envelope utilizing existing retrorocket systems and state-of-the-art mechanical probe systems.

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REFERENCES

1. Babish, C.A., et al, "A Parachute/Retrorocket Landing System for Aeronautical Vehicles," Unpublished Data, AFFDL/FER, 1974.
2. Peterson, R.L. and Roberts, E.O., "Experimental Investigation of the Ground Impact Characteristics of a Full-Scale Aircraft Emergency Escape Capsule System," AFFDL-TR-72-34, July 1972.

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TABLE I

SUMMARY OF IMPACT VELOCITIES - TE-M-421-1

ROCKET ANGLE: 38°

IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: -1°

HORIZ. VELOCITY: 34 FPS

START RUN #		1	26	51	76	101	126	151	176	201	226
END RUN #		25	50	75	100	125	150	175	200	225	250
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	10.41	10.71	10.69	11.00	10.38	10.68	10.03	10.32	10.37	10.66
"	29.65	10.07	10.34	10.33	10.60	10.12	10.37	9.86	10.11	10.21	10.45
"	26.35	10.09	10.27	10.41	10.57	10.34	10.50	10.27	10.42	10.62	10.77
"	24.7	10.36	10.50	10.69	10.83	10.67	10.81	10.65	10.78	10.96	11.09
7875	31.3	10.02	10.33	10.32	10.62	10.01	10.31	9.68	9.96	10.04	10.32
"	29.65	9.78	10.04	10.05	10.30	9.85	10.09	9.63	9.86	9.99	10.21
"	28.0	9.76	9.97	10.06	10.26	9.95	10.13	9.84	10.02	10.22	10.38
"	26.35	9.97	10.13	10.31	10.47	10.26	10.42	10.21	10.35	10.56	10.70
"	24.7	10.33	10.45	10.65	10.78	10.64	10.76	10.64	10.76	10.95	11.07
7675	31.3	9.65	9.95	9.93	10.24	9.66	9.95	9.36	9.63	9.73	9.99
"	29.65	9.49	9.73	9.77	10.02	9.60	9.83	9.42	9.64	9.81	10.01
"	28.0	9.58	9.78	9.91	10.09	9.83	10.00	9.75	9.90	10.14	10.29
"	26.35	9.88	10.03	10.23	10.38	10.20	10.35	10.18	10.32	10.53	10.67
"	24.7	10.31	10.43	10.61	10.74	10.62	10.75	10.66	10.77	10.96	11.07
7550	31.3	9.42	9.71	9.71	10.00	9.45	9.73	9.17	9.43	9.55	9.81
"	29.65	9.33	9.57	9.61	9.85	9.47	9.68	9.32	9.52	9.72	9.90
"	28.0	9.47	9.67	9.82	10.00	9.77	9.93	9.70	9.85	10.10	10.24
"	26.35	9.84	9.98	10.19	10.34	10.19	10.32	10.18	10.31	10.54	10.66
"	24.7	10.32	10.43	10.60	10.72	10.63	10.74	10.68	10.79	10.99	11.09
7425	31.3	9.19	9.48	9.48	9.77	9.25	9.51	9.00	9.25	9.39	9.63
"	29.65	9.16	9.40	9.48	9.70	9.36	9.56	9.23	9.41	9.65	9.83
"	28.0	9.40	9.57	9.76	9.93	9.71	9.87	9.68	9.81	10.07	10.21
"	26.35	9.82	9.95	10.16	10.30	10.17	10.30	10.19	10.31	10.54	10.66
"	24.7	10.35	10.46	10.60	10.72	10.64	10.76	10.72	10.82	11.01	11.12

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TABLE I (Continued)

ROCKET ANGLE: 38°

IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: +1°

HORIZ. VELOCITY: 34 FPS

START RUN #		251	276	301	326	351	376	401	426	451	476
END RUN #		275	300	325	350	375	400	425	450	475	500
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	9.76	10.04	10.07	10.35	9.69	9.95	9.26	9.50	9.63	9.88
"	29.65	9.27	9.47	9.54	9.76	9.24	9.45	8.92	9.09	9.27	9.43
"	28.0	9.00	9.14	9.27	9.40	9.06	9.18	8.83	8.93	9.19	9.27
"	26.35	8.97	9.04	9.25	9.30	9.13	9.17	9.00	9.00	9.37	9.36
"	24.7	9.14	9.14	9.47	9.44	9.41	9.38	9.34	9.29	9.69	9.64
7875	31.3	9.32	9.59	9.64	9.91	9.27	9.52	8.86	9.08	9.23	9.45
"	29.65	8.90	9.09	9.18	9.38	8.90	9.08	8.60	8.75	8.96	9.10
"	28.0	8.73	8.85	9.00	9.11	8.82	8.91	8.62	8.68	8.99	9.03
"	26.35	8.78	8.82	9.08	9.11	8.99	8.98	8.90	8.86	9.28	9.04
"	24.7	9.04	9.00	9.38	9.34	9.34	9.28	9.30	9.22	9.65	9.57
7675	31.3	8.89	9.14	9.20	9.46	8.85	9.08	8.45	8.66	8.83	9.04
"	29.65	8.54	8.72	8.83	9.01	8.58	8.73	8.31	8.43	8.68	8.79
"	28.0	8.46	8.55	8.75	8.83	8.60	8.65	8.44	8.47	8.84	8.84
"	26.35	8.62	8.63	8.95	8.94	8.88	8.84	8.81	8.75	9.19	9.14
"	24.7	8.95	8.89	9.31	9.25	9.29	9.21	9.28	9.17	9.63	9.53
7550	31.3	8.61	8.85	8.92	9.17	8.58	8.80	8.21	9.41	8.59	8.78
"	29.65	8.33	8.49	8.62	8.78	8.38	8.52	8.13	8.23	8.52	8.60
"	28.0	8.30	8.39	8.60	8.68	8.48	8.51	8.35	8.35	8.76	8.73
"	26.35	8.53	8.51	8.88	8.85	8.83	8.77	8.77	8.70	9.17	9.08
"	24.7	8.93	8.84	9.28	9.20	9.28	9.18	9.28	9.16	9.63	9.51
7425	31.3	8.34	8.57	8.65	8.88	8.32	8.53	7.97	8.15	8.36	8.53
"	29.65	8.12	8.27	8.41	8.56	8.20	8.31	7.97	8.04	8.38	8.42
"	28.0	8.16	8.22	8.48	8.52	8.38	8.38	8.28	8.24	8.70	8.65
"	26.35	8.45	8.42	8.82	8.77	8.79	8.72	8.75	8.65	9.15	9.05
"	24.7	8.92	8.81	9.26	9.16	9.27	9.15	9.31	9.16	9.66	9.51

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TABLE I (Continued)

ROCKET ANGLE: 38°

IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: 0°

HORIZ. VELOCITY: 34 FPS

START RUN #		501	526	551	576	601	626	651	676	701	726
END RUN #		525	550	575	600	625	650	675	700	725	750
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	10.07	10.35	10.37	10.66	10.02	10.29	9.63	9.89	9.99	10.25
	29.65	9.65	9.89	9.92	10.15	9.66	9.88	9.37	9.57	9.73	9.91
"	28.0	9.47	9.65	9.74	9.91	9.57	9.73	9.38	9.52	9.75	9.86
"	26.35	9.52	9.63	9.81	9.92	9.72	9.82	9.64	9.71	9.99	10.06
"	24.7	9.74	9.81	10.08	10.14	10.04	10.08	10.00	10.03	10.33	10.35
7875	31.3	9.67	9.94	9.96	10.24	9.62	9.89	9.25	9.50	9.62	9.86
"	29.65	9.32	9.54	9.59	9.81	9.36	9.56	9.10	9.27	9.46	9.62
"	28.0	9.23	9.39	9.51	9.66	9.36	9.49	9.22	9.32	9.59	9.68
"	26.35	9.36	9.46	9.69	9.77	9.62	9.68	9.55	9.59	9.92	9.96
"	24.7	9.67	9.71	10.01	10.06	9.99	10.02	9.97	9.99	10.31	10.32
7675	31.3	9.25	9.53	9.55	9.82	9.24	9.49	8.89	9.12	9.26	9.49
"	29.65	9.00	9.21	9.28	9.49	9.07	9.26	8.85	9.00	9.23	9.36
"	28.0	9.00	9.15	9.30	9.44	9.19	9.30	9.09	9.16	9.49	9.55
"	26.35	9.24	9.31	9.59	9.64	9.55	9.59	9.50	9.52	9.86	9.90
"	24.7	9.64	9.66	9.97	10.00	9.96	9.98	9.98	9.97	10.31	10.31
7550	31.3	9.00	9.26	9.30	9.55	8.99	9.25	8.68	8.89	9.04	9.26
"	29.65	8.51	9.01	9.10	9.29	8.91	9.07	8.71	8.84	9.09	9.23
"	28.0	8.88	9.00	9.20	9.31	9.10	9.20	9.01	9.08	9.43	9.47
"	26.35	9.18	9.23	9.54	9.59	9.50	9.54	9.48	9.50	9.85	9.87
"	24.7	9.63	9.64	9.95	9.97	9.96	9.96	10.00	9.98	10.32	10.31
7425	31.3	8.75	9.00	9.05	9.30	8.77	8.99	8.46	8.67	8.85	9.05
"	29.65	8.63	8.81	8.92	9.09	8.75	8.91	8.58	8.70	8.99	9.10
"	28.0	8.77	8.87	9.10	9.19	9.04	9.11	8.97	9.02	9.39	9.42
"	26.35	9.12	9.17	9.49	9.54	9.48	9.50	9.48	9.47	9.85	9.85
"	24.7	9.64	9.63	9.94	9.94	9.96	9.95	10.03	9.99	10.34	10.32

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TABLE I (Concluded)

ROCKET ANGLE: 38°

IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: -2°

HORIZ. VELOCITY: 34 FPS

START RUN #		751	776	801	826	851	876	901	926	951	976
END RUN #		775	800	825	850	875	900	925	950	975	1000
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	10.78	11.11	11.05	11.38	10.77	11.10	10.45	10.78	10.79	11.12
"	29.65	10.52	10.83	10.79	11.09	10.59	10.89	10.39	10.69	10.74	11.03
"	28.0	10.49	10.78	10.79	11.07	10.69	10.95	10.58	10.84	10.94	11.19
"	26.35	10.68	10.93	11.01	11.26	10.96	11.21	10.91	11.15	11.25	11.49
"	24.7	11.00	11.22	11.31	11.53	11.29	11.52	11.30	11.52	11.58	11.81
7875	31.3	10.42	10.76	10.70	11.03	10.43	10.77	10.15	10.48	10.50	10.83
"	29.65	10.26	10.56	10.53	10.84	10.37	10.67	10.20	10.49	10.57	10.85
"	28.0	10.1	10.60	10.64	10.90	10.56	10.83	10.49	10.74	10.86	11.11
"	26.35	10.59	10.84	10.93	11.18	10.91	11.15	10.88	11.12	11.22	11.45
"	24.7	10.98	11.21	11.26	11.50	11.27	11.50	11.30	11.53	11.55	11.82
7675	31.3	10.07	10.42	10.36	10.70	10.13	10.4	9.88	10.20	10.24	10.56
"	29.65	10.00	10.31	10.31	10.60	10.18	10.47	10.04	10.32	10.43	10.72
"	28.0	10.18	10.45	10.53	10.78	10.47	10.73	10.42	10.67	10.79	11.04
"	26.35	10.54	10.78	10.87	11.12	10.87	11.10	10.87	11.11	11.21	11.45
"	24.7	11.00	11.22	11.24	11.48	11.27	11.50	11.33	11.56	11.60	11.84
7550	31.3	9.87	10.21	10.15	10.48	9.95	10.27	9.72	10.04	10.10	10.41
"	29.65	9.87	10.17	10.18	10.47	10.07	10.35	9.97	10.25	10.37	10.64
"	28.0	10.10	10.38	10.47	10.73	10.42	10.69	10.39	10.65	10.76	11.02
"	26.35	10.52	10.77	10.85	11.10	10.85	11.10	10.88	11.12	11.21	11.45
"	24.7	11.02	11.25	11.24	11.47	11.29	11.52	11.36	11.59	11.63	11.86
7425	31.3	9.67	10.00	9.96	10.29	9.77	10.10	9.57	9.89	9.99	10.28
"	29.65	9.74	10.04	10.07	10.35	9.98	10.27	9.91	10.18	10.31	10.59
"	28.0	10.05	10.32	10.41	10.68	10.39	10.65	10.38	10.63	10.76	11.01
"	26.35	10.54	10.77	10.84	11.08	10.86	11.10	10.91	11.14	11.23	11.47
"	24.7	11.04	11.27	11.24	11.48	11.90	11.54				

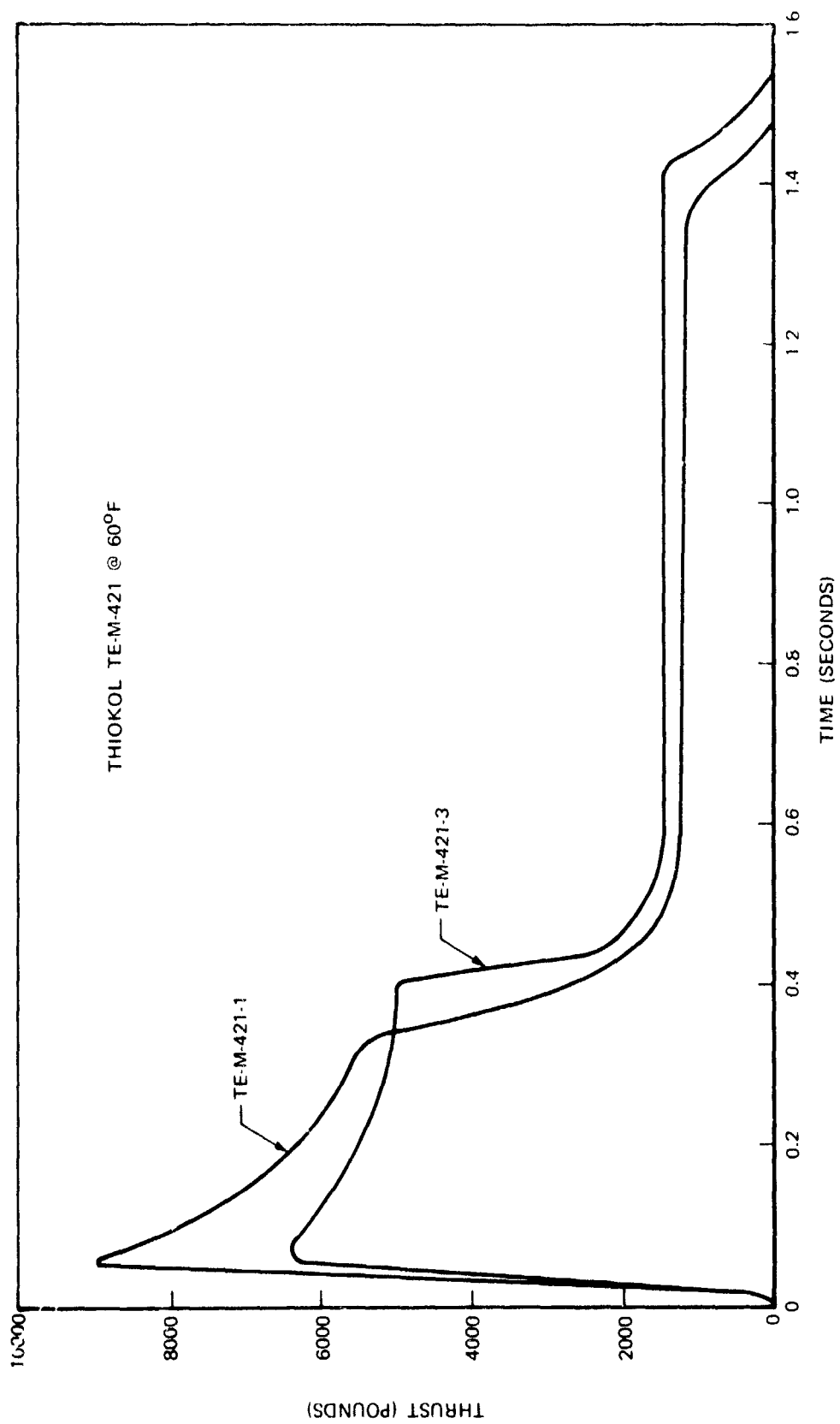


Figure 1. Thrust Versus Time for TE-M-421-1 and TE-M-421-3
at 60°F

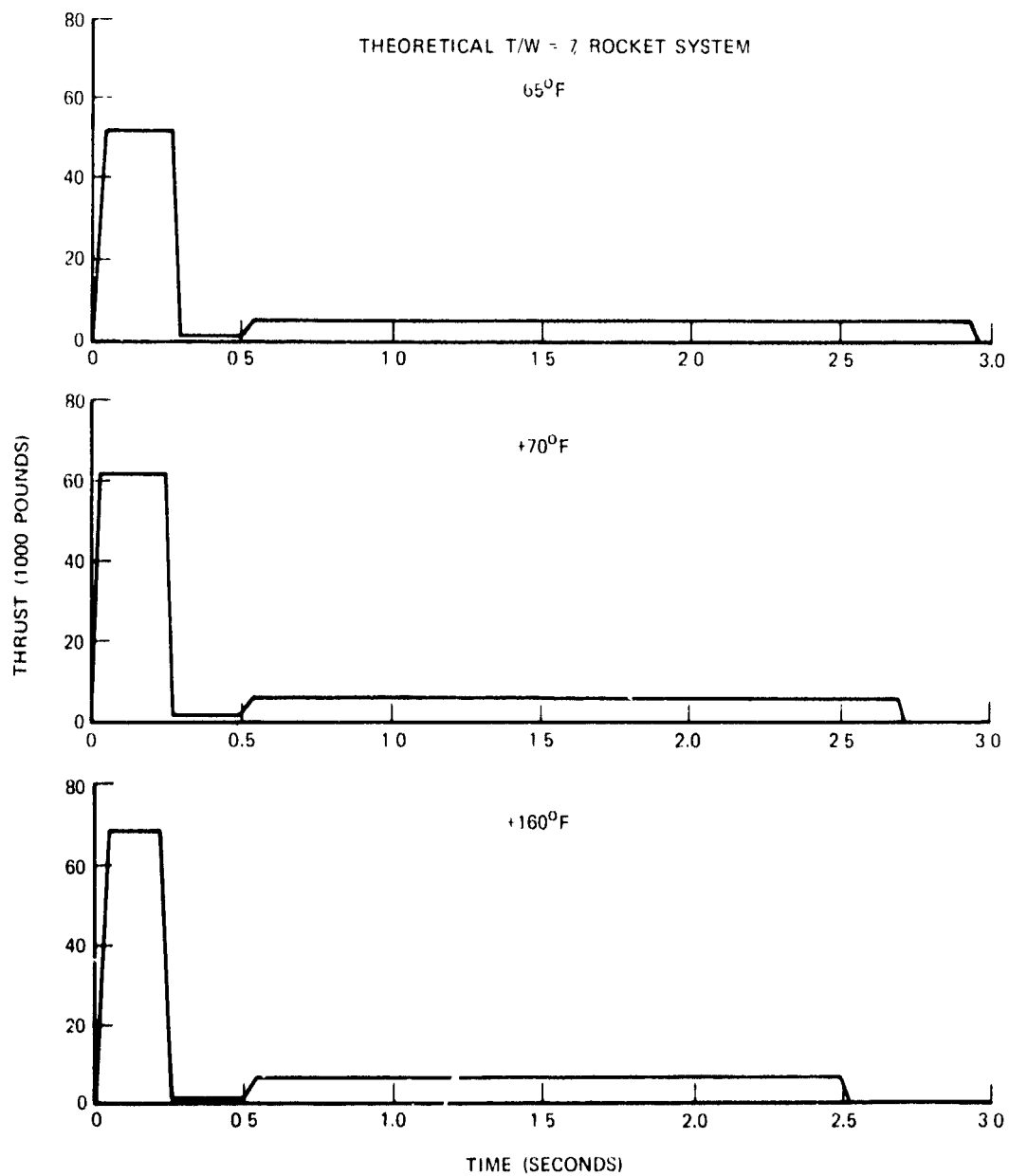


Figure 2. Thrust Versus Time for T/W = 7 Rocket at -65, 70, and 160°F

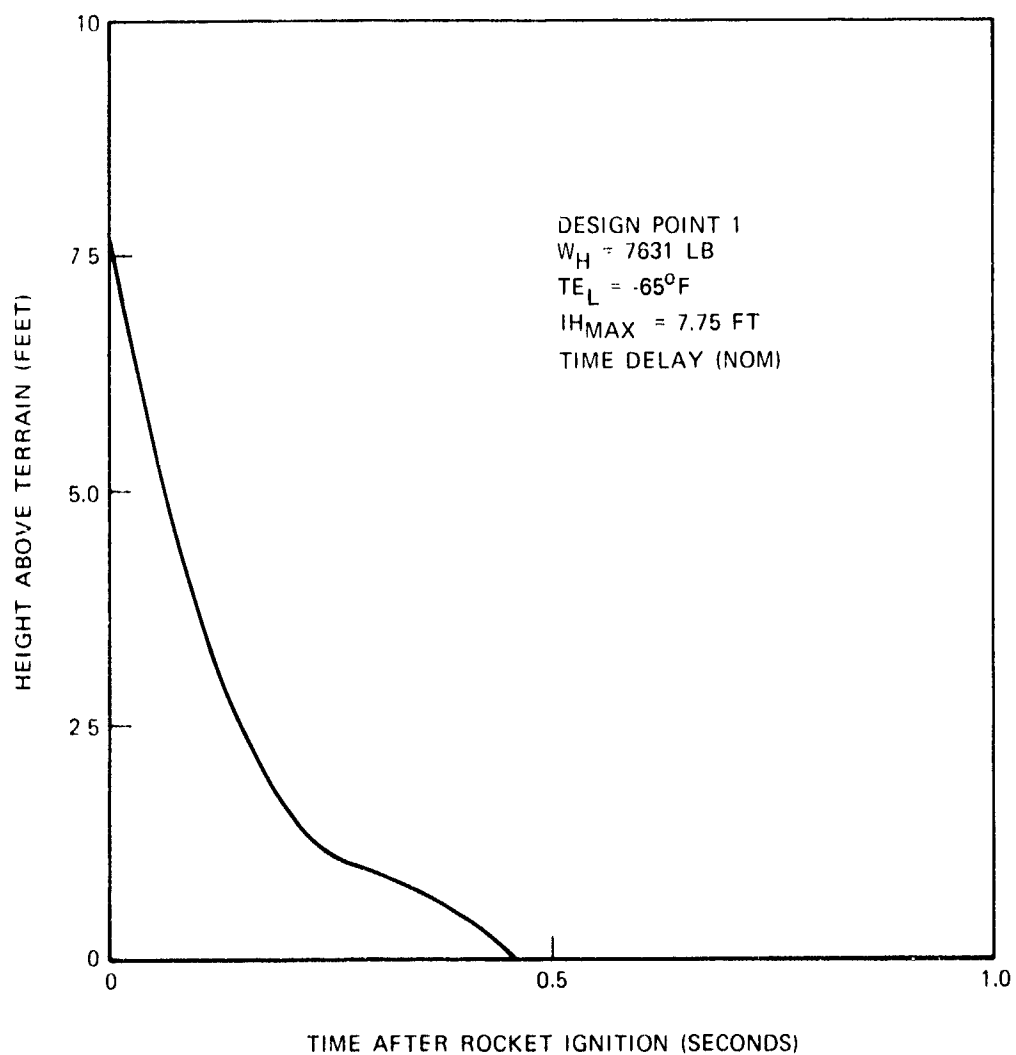


Figure 3. Height Above Terrain Versus Time After Rocket Ignition at Design Point 1

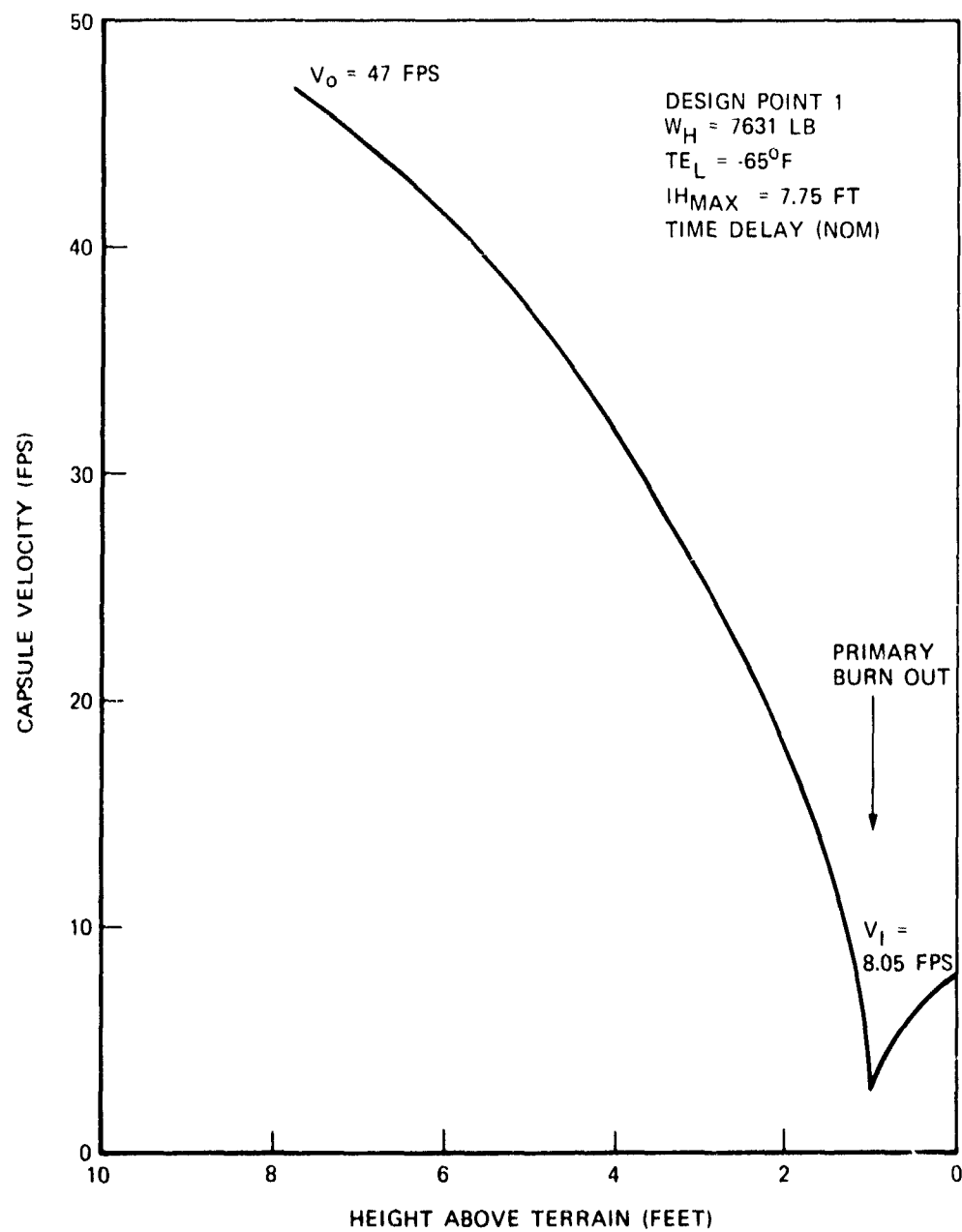


Figure 4. Capsule Velocity Versus Height Above Terrain at Design Point 1

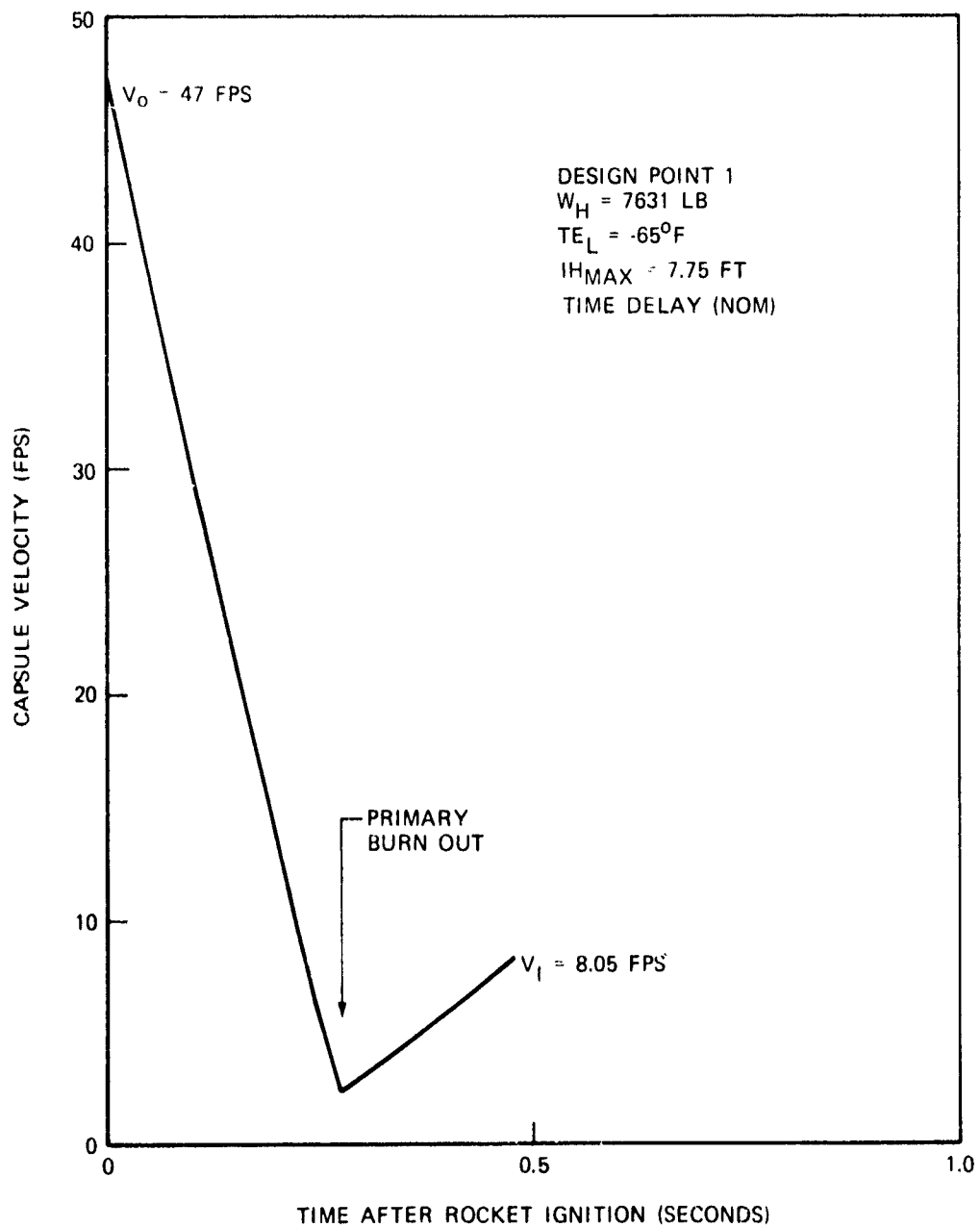


Figure 5. Capsule Velocity Versus Time After Rocket Ignition at Design Point 1

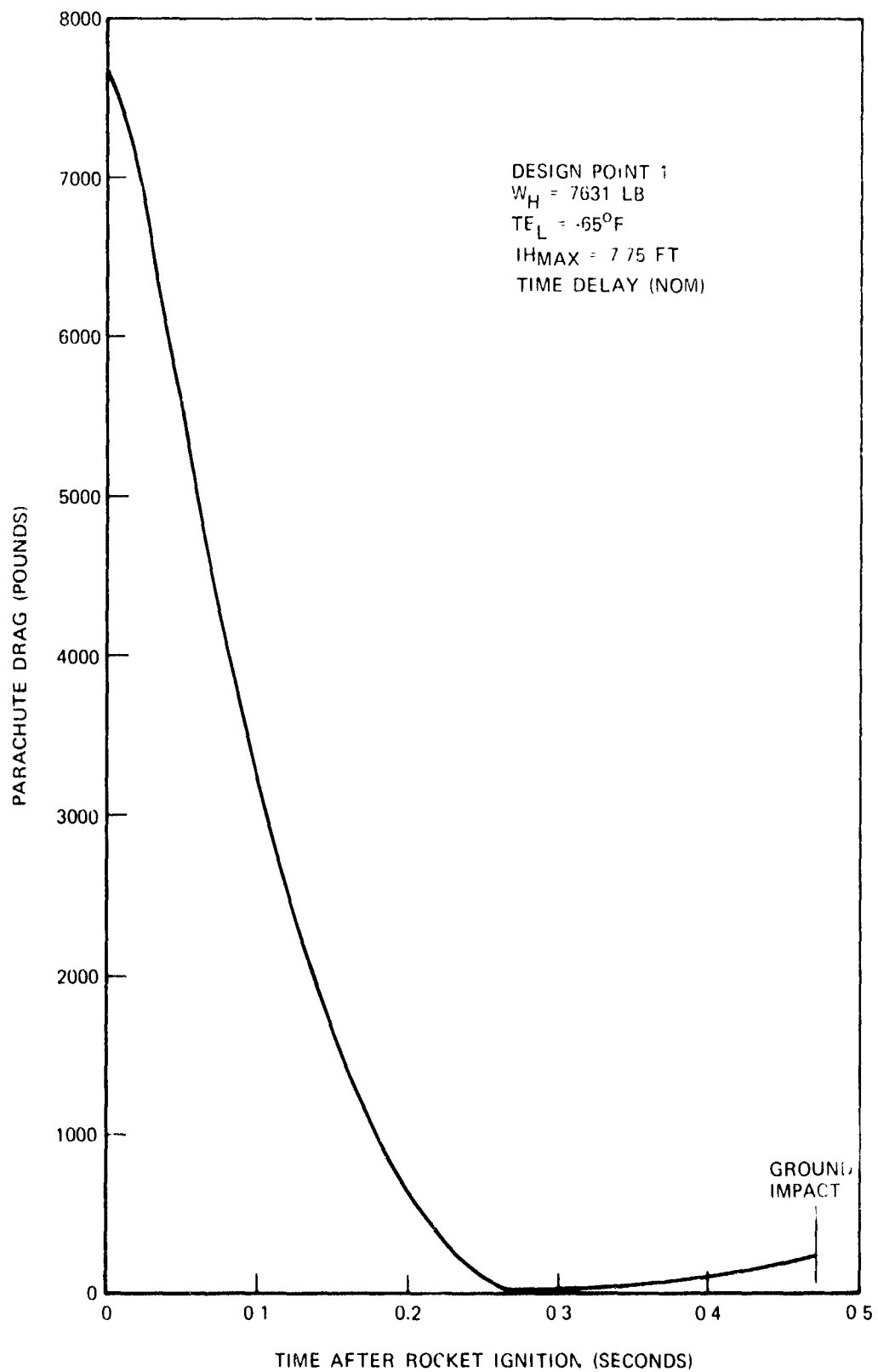


Figure 6. Parachute Drag Versus Time After Rocket Ignition at Design Point 1

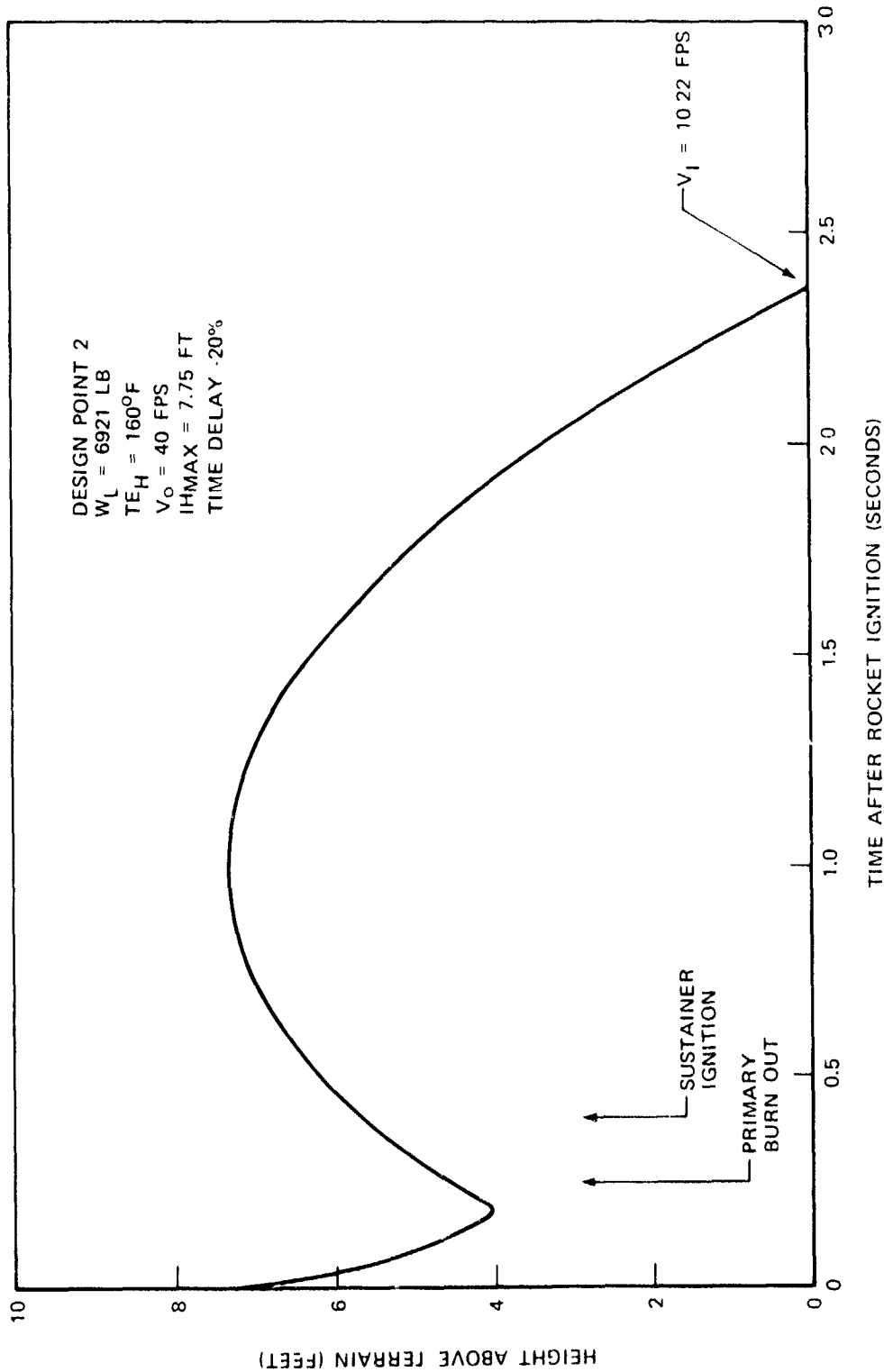


Figure 7. Height Above Terrain Versus Time After Rocket Ignition at Design Point 2

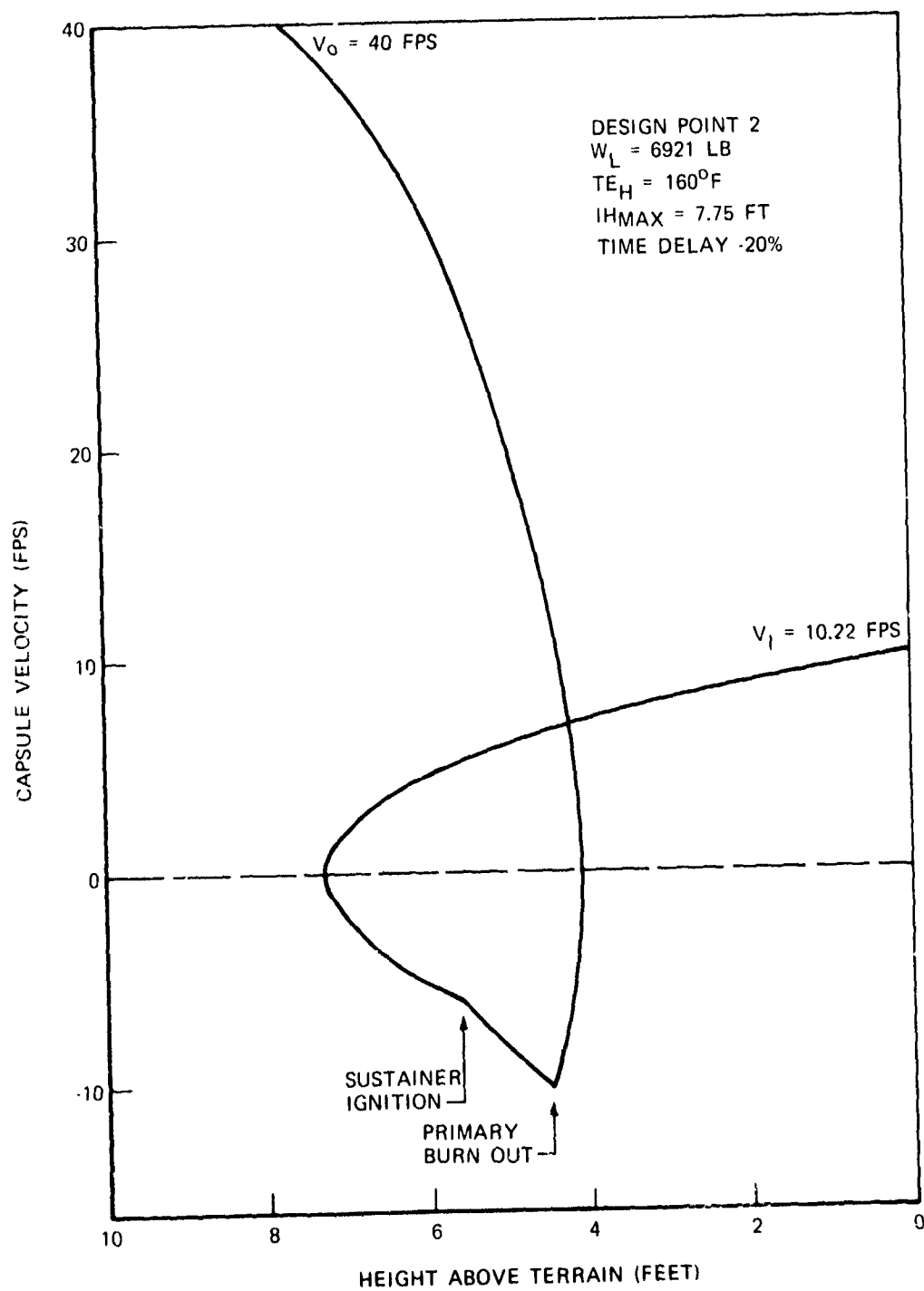


Figure 8. Capsule Velocity Versus Height Above Terrain at Design Point 2

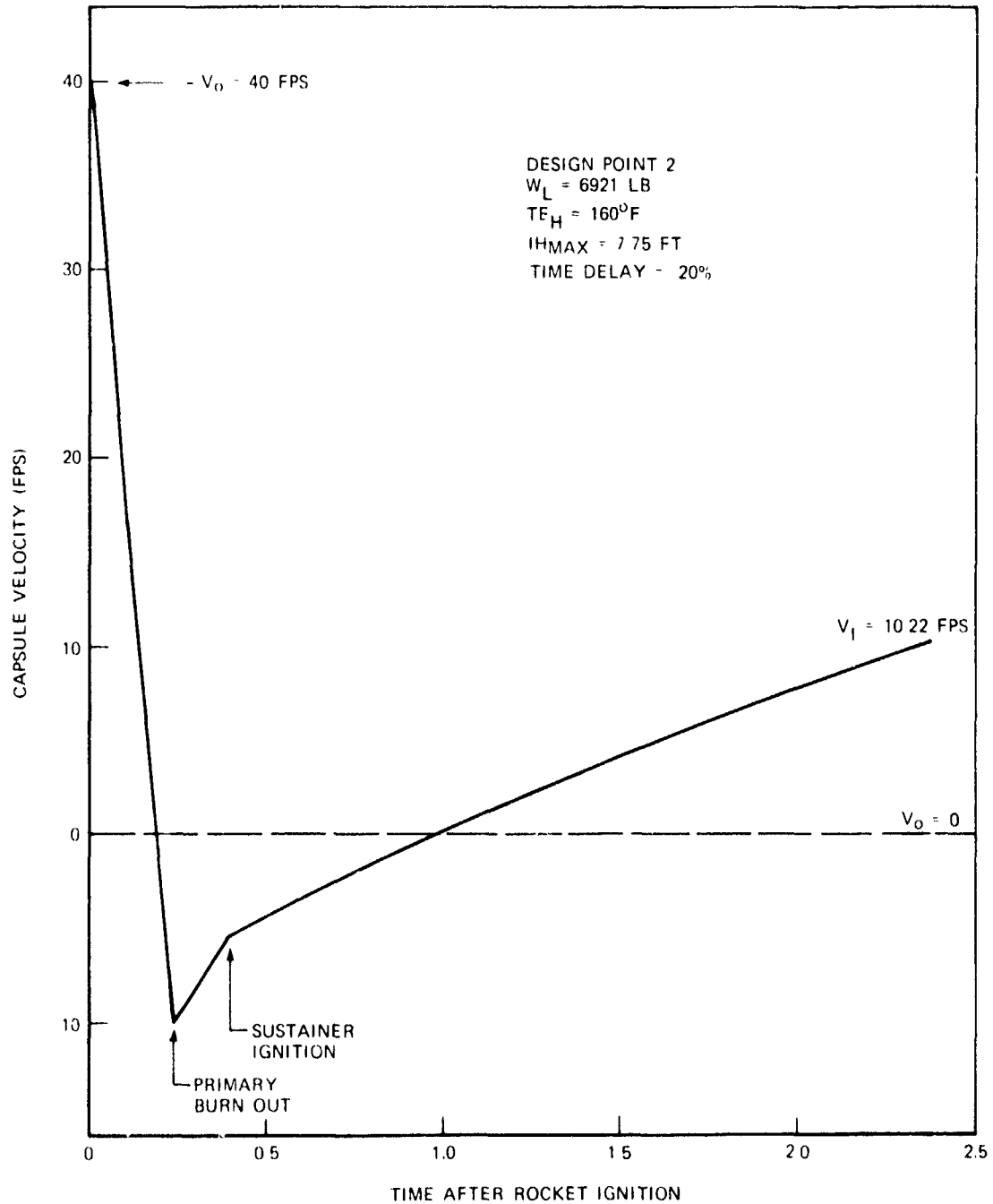


Figure 9. Capsule Velocity Versus Time After Rocket Ignition at Design Point 2

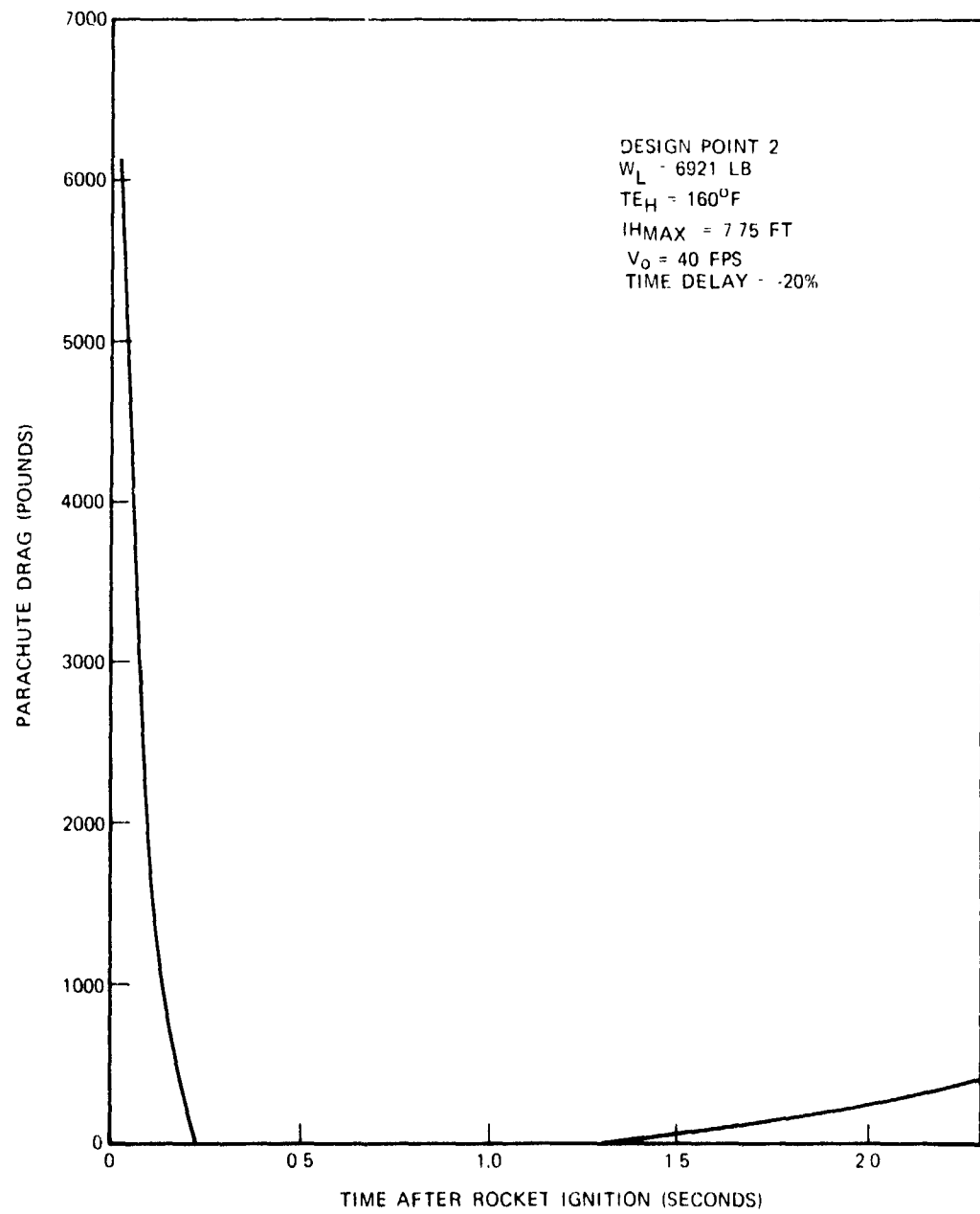


Figure 10. Parachute Drag Versus Time After Rocket Ignition at Design Point 2

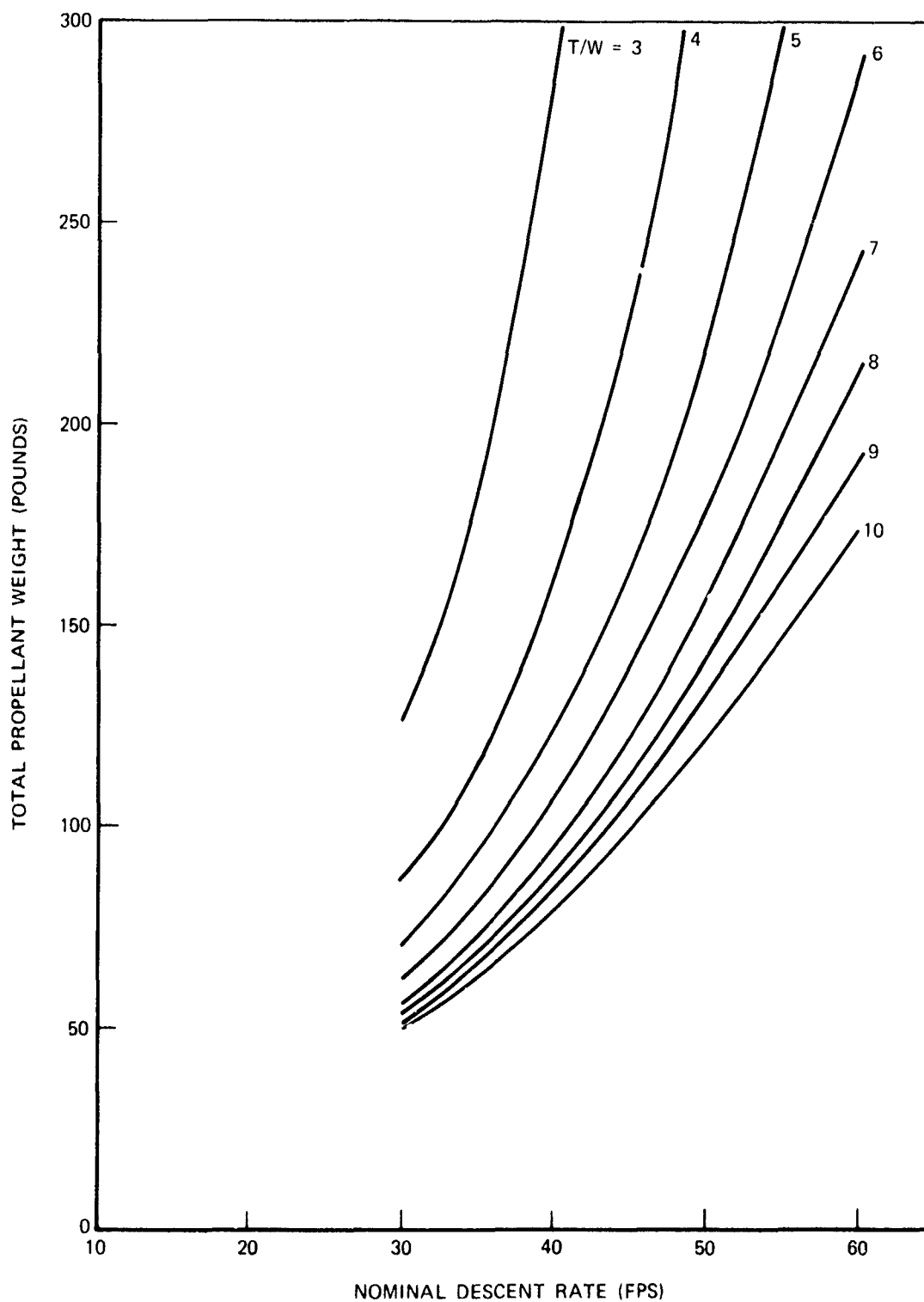


Figure 11. Total Propellant Weight as a Function of Descent Rate and Primary T/W

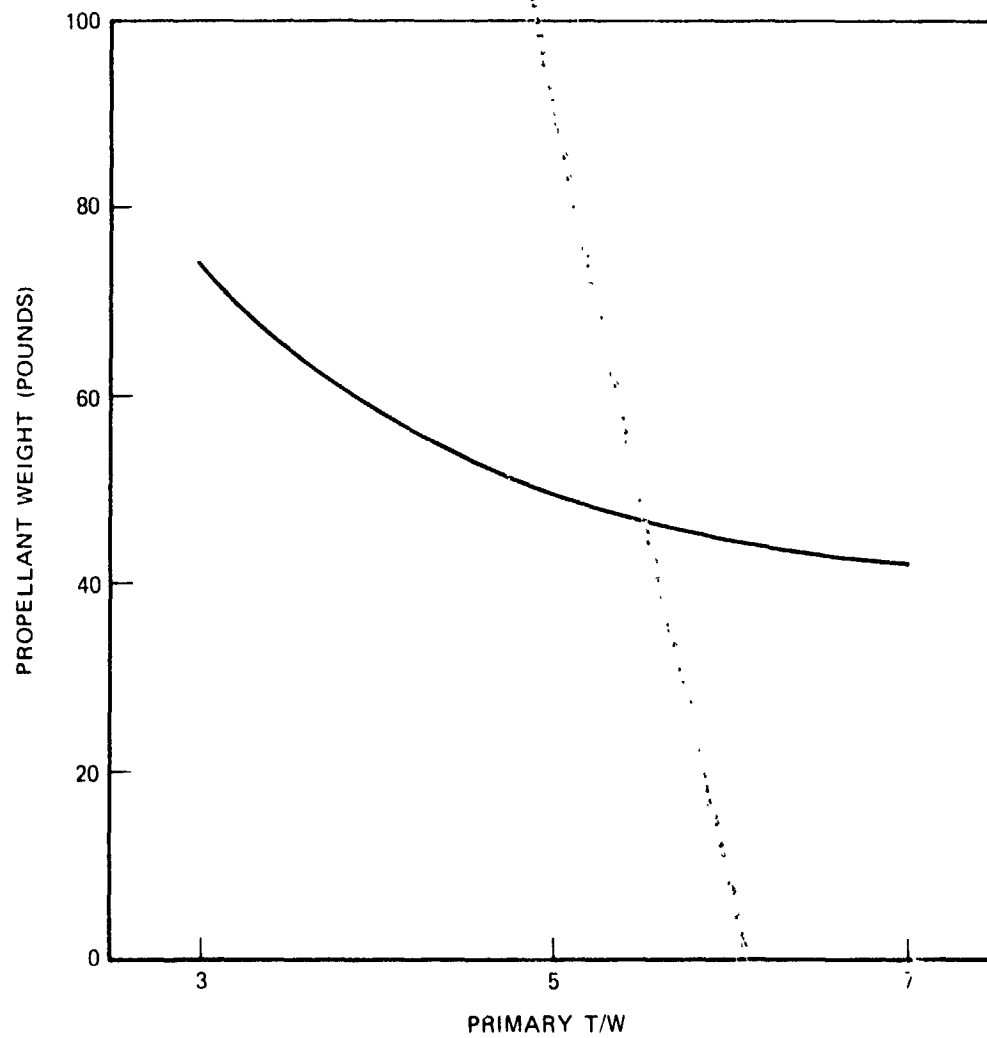


Figure 12. Total Propellant Weight (No Time Delay) as a Function of Primary T/W

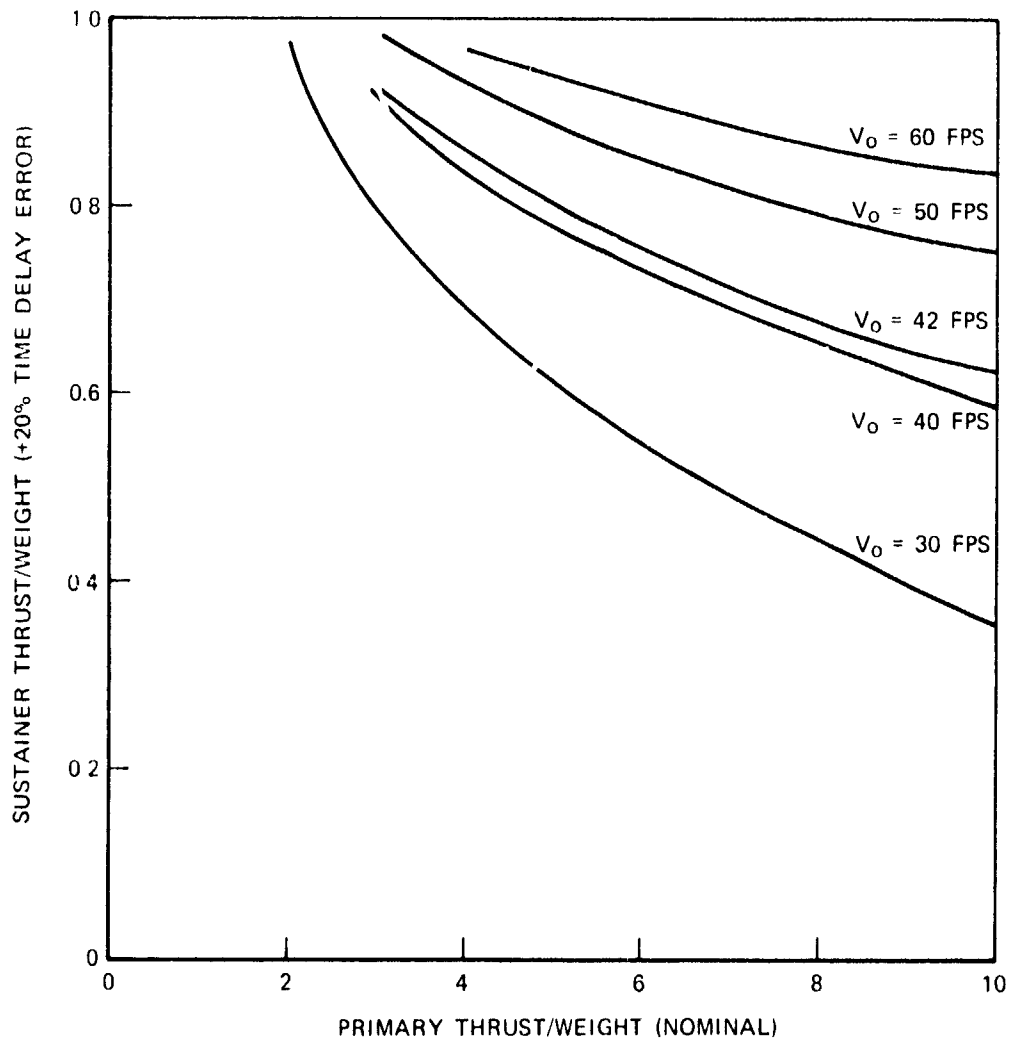


Figure 13. Sustainer T/W (20% Time Delay Error) as a Function of Primary T/W and Descent Rate

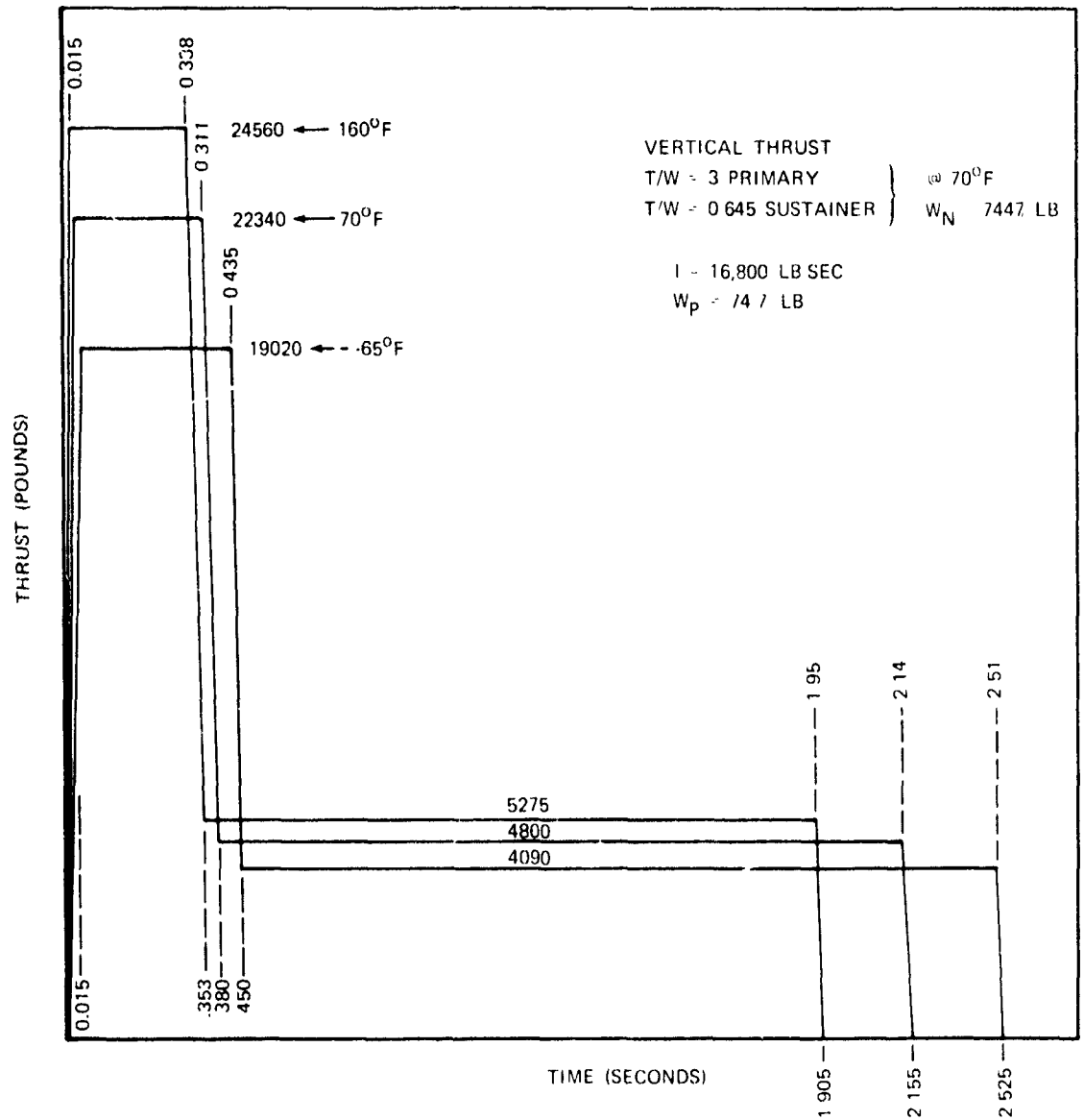


Figure 14. Thrust Versus Time for $T/W = 3$

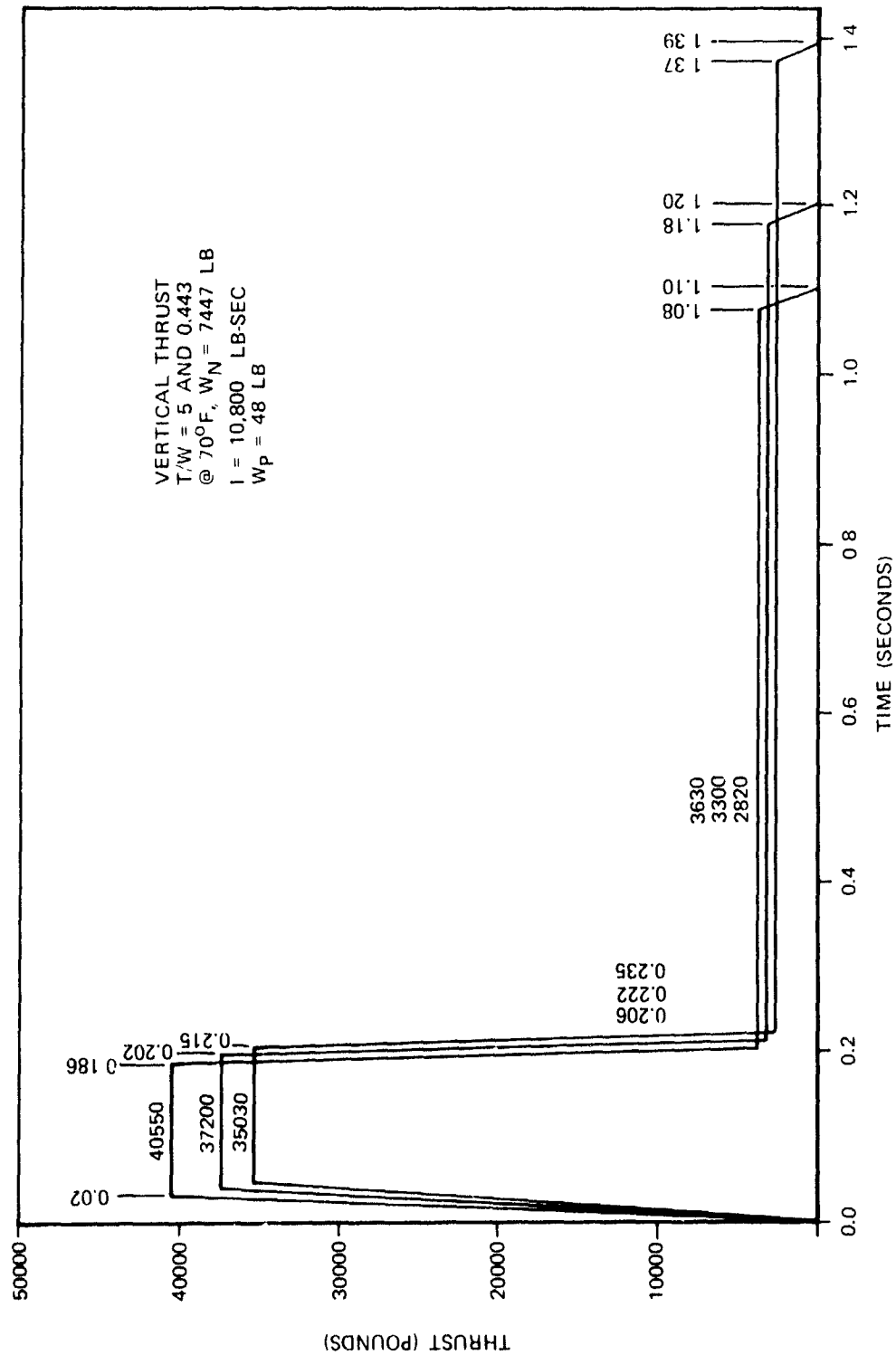


Figure 15. Thrust Versus Time for T/W = 5

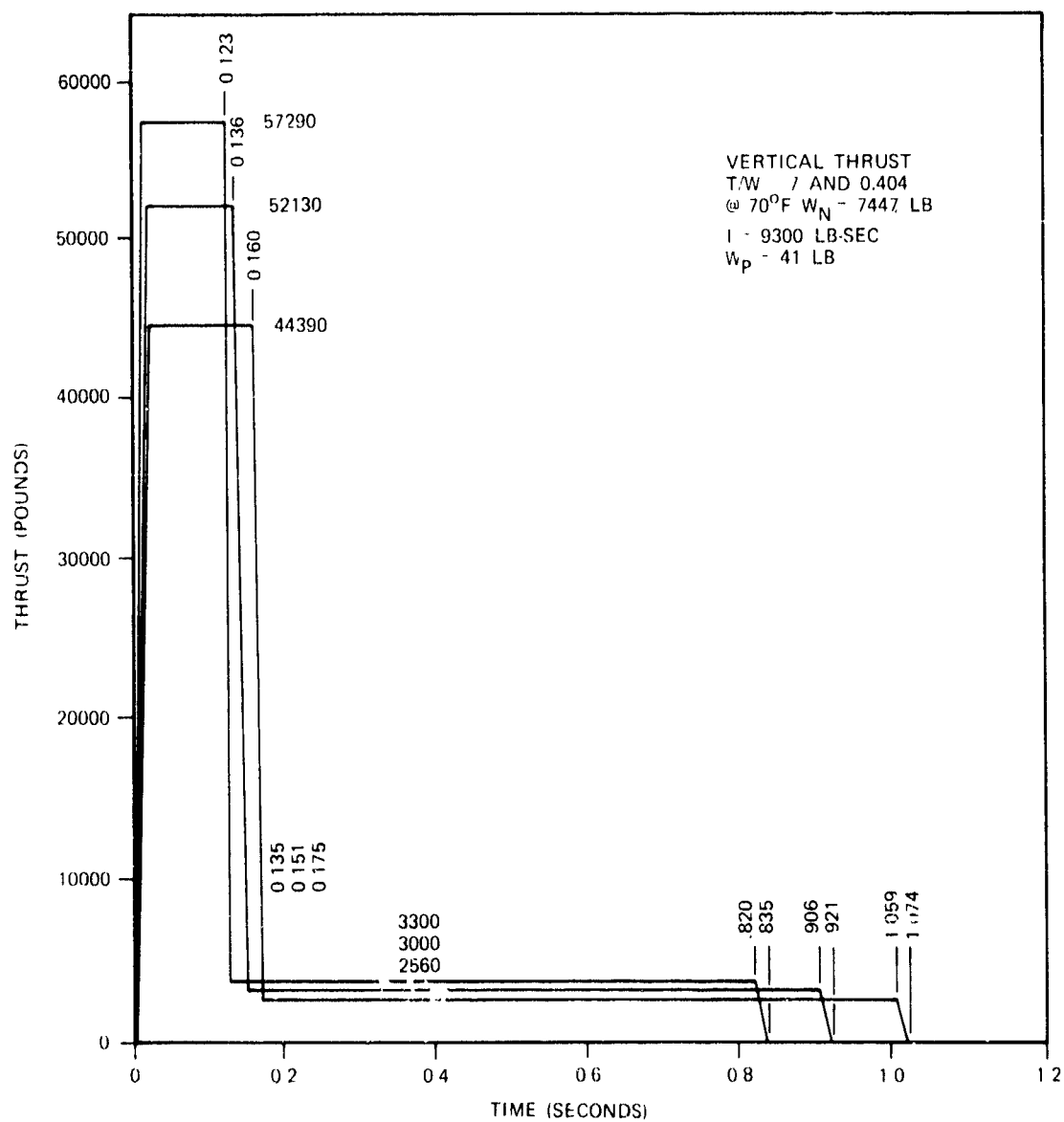


Figure 16. Thrust Versus Time for T/W = 7

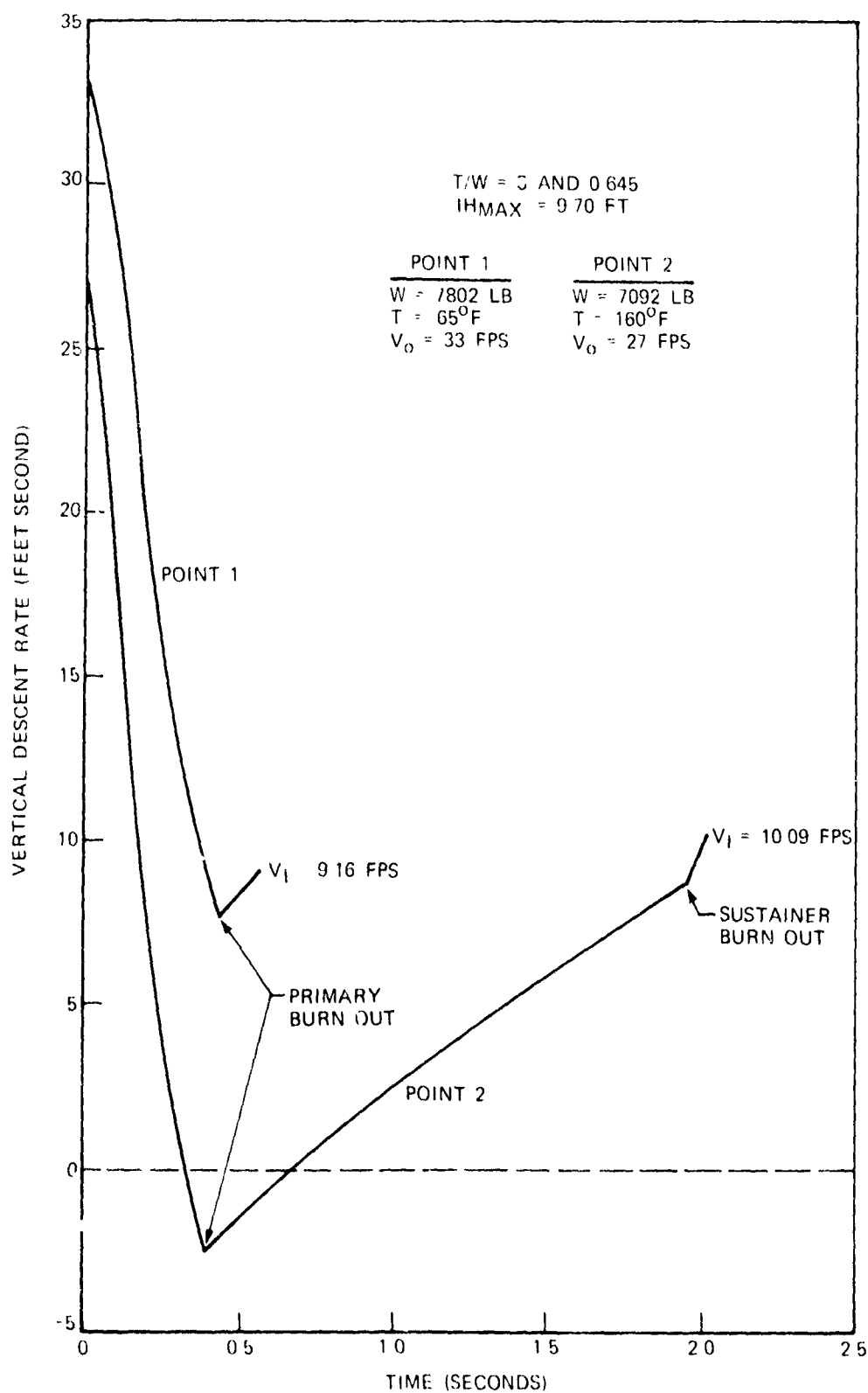


Figure 17. Capsule Velocity Versus Time at Design Points 1 and 2
for $T/W = 3$

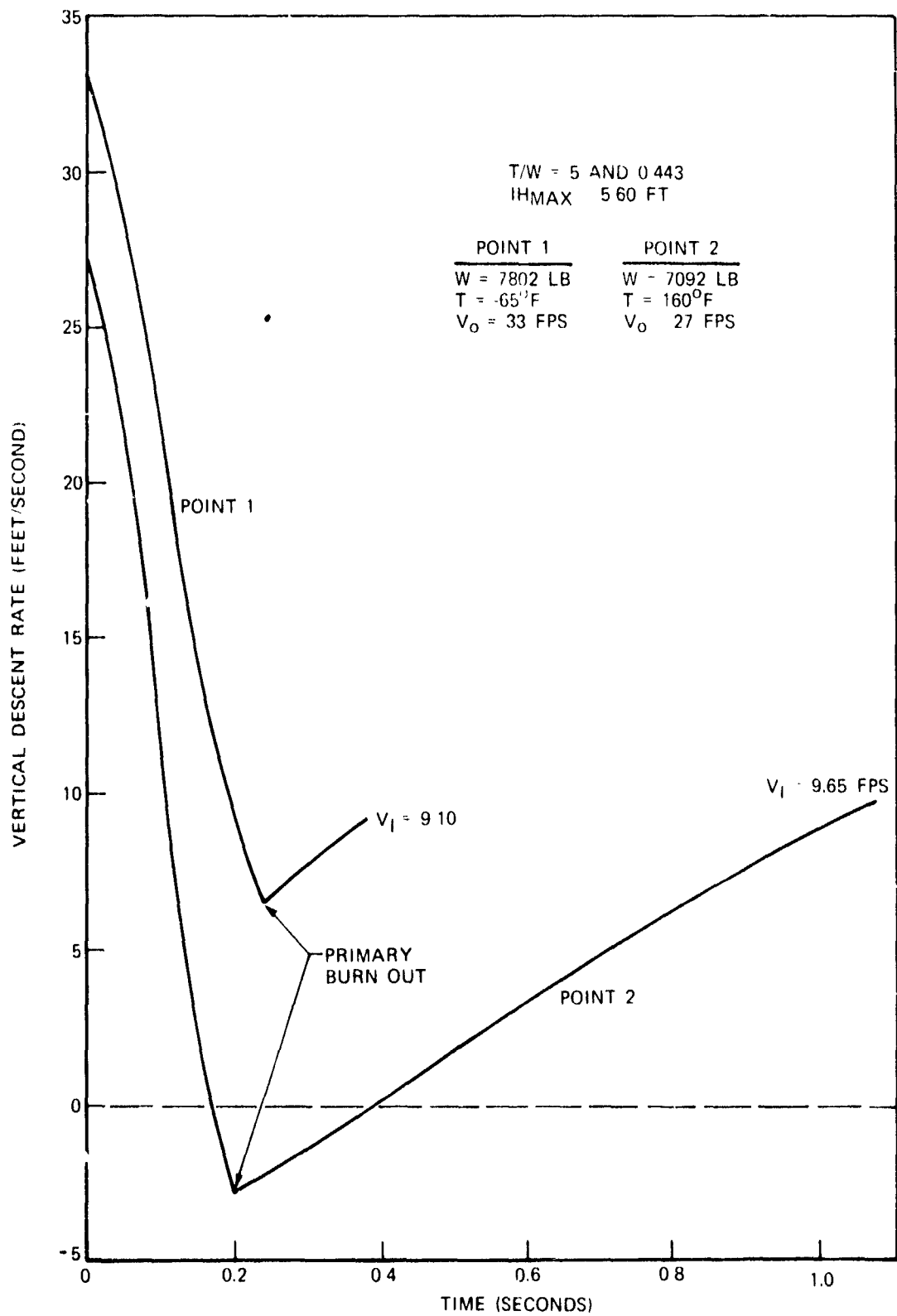


Figure 18. Capsule Velocity Versus Time at Design Points 1 and 2
for T/W = 5

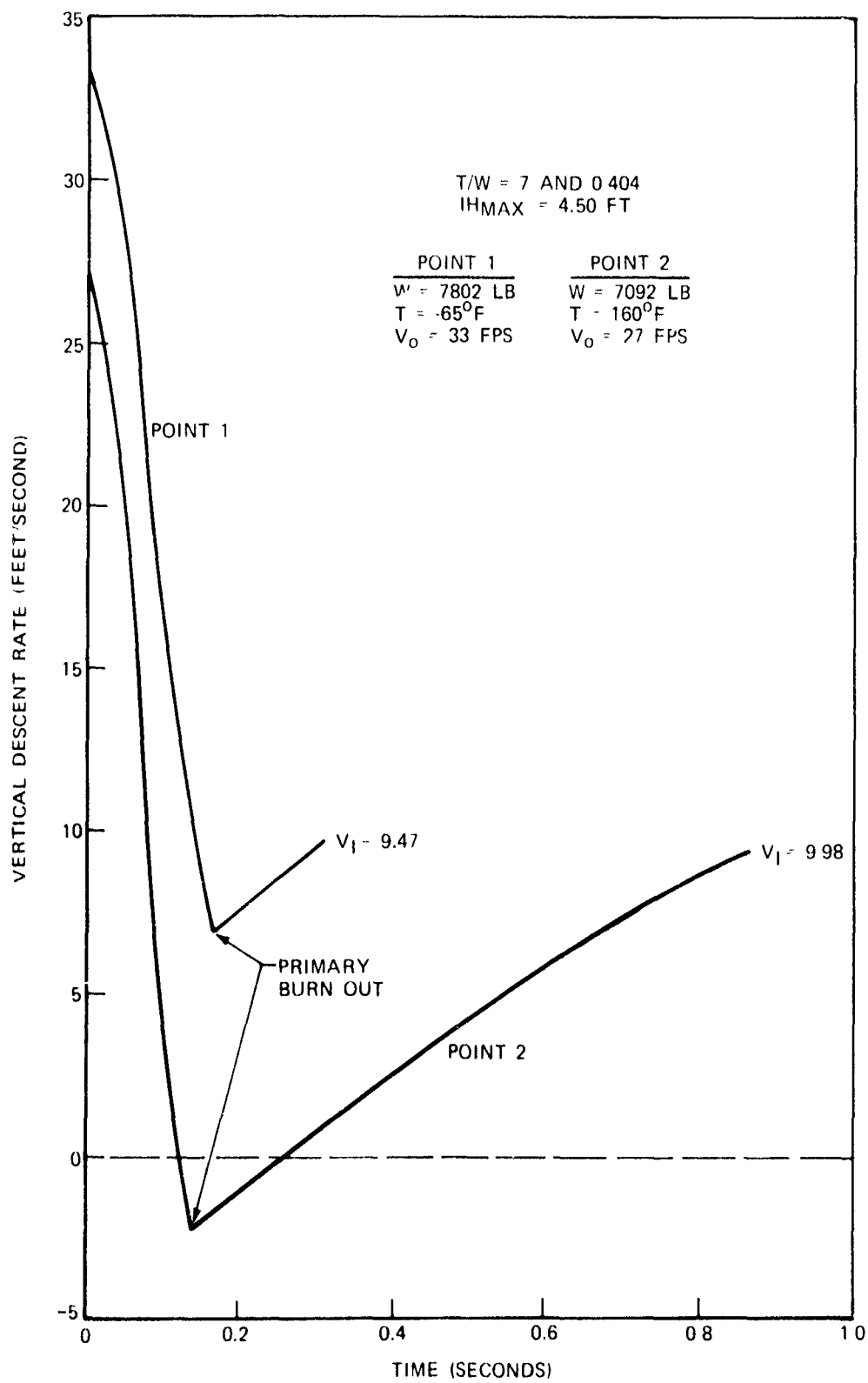
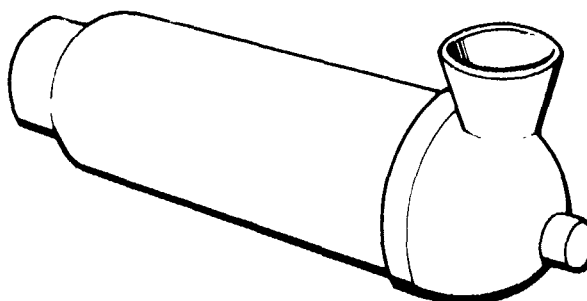


Figure 19. Capsule Velocity Versus Time at Design Points 1 and 2
for T/W = 7



The TE-M-421-3 is a feasibility test motor for soft landing space capsules. Two motors are used to slow the capsule just prior to impact. The motors have nozzles that provide thrust in a direction 90 degrees to the case center line. The motor is designed to operate reliably after exposure to space environment.

MOTOR PERFORMANCE*

WEIGHTS, lbm

	Boost	Sustain		
Burn Time/Act Time (t_b/t_d), sec	0.418	0.960/1.428	Total Loaded	26.00
Ignition Delay Time (t_{di}), sec	-	0.035	Propellant	15.31
Burn Time Avg. Ch. Pr. ($\bar{P}_b$), psia	1,990	600	Case Assembly	4.83
Action Time Avg. Ch. Pr. ($\bar{P}_a$), psia	-	N/App	Nozzle Assembly	3.80
Maximum Cham. Press. (P_{max}), psia	-	2,400	Igniter Assembly	0.75
Total Impulse (I_T), lbf-sec	-	3,670	Internal Insulation	0.87
Burn Time Impulse (I_b), lbf-sec	2,210	1,430	External Insulation	0
Motor Spec. Imp. (I_{mo}), lbf-sec/lbm	-	141	Liner	0.25
Prop. Spec. Imp. (I_{sp}), lbf-sec/lbm	-	239	Miscellaneous	0.19
Burn Time Average Thrust ($\bar{F}_b$), lbf	5,300	1,490	Total Inert	10.65
Action Time Average Thrust ($\bar{F}_a$), lbf	-	N/App	Burnout	10.4
Maximum Thrust (F_{max}), lbf	-	6,500	Propellant Mass Fraction	0.589
Measured Thrust Coefficient (C_F)	1.46	1.36		
Theoretical Thrust Coefficient (C_F^0)	1.61	1.51		
Discharge Coefficient (C_d)	0.91	0.904		

*60°F, Sea Level

TEMPERATURE LIMITS

Operation	20°F to +180°F
Storage	20°F to +180°F

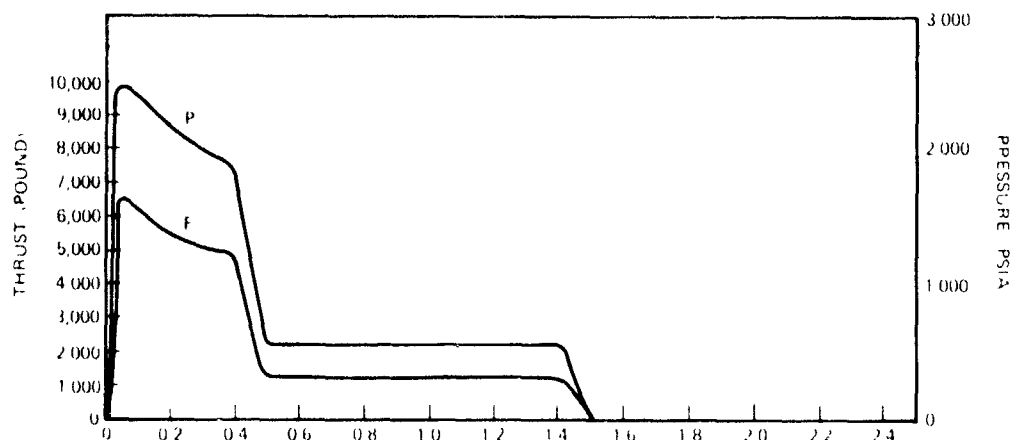


Figure 20. TE-M-421-3 Rocket Characteristics

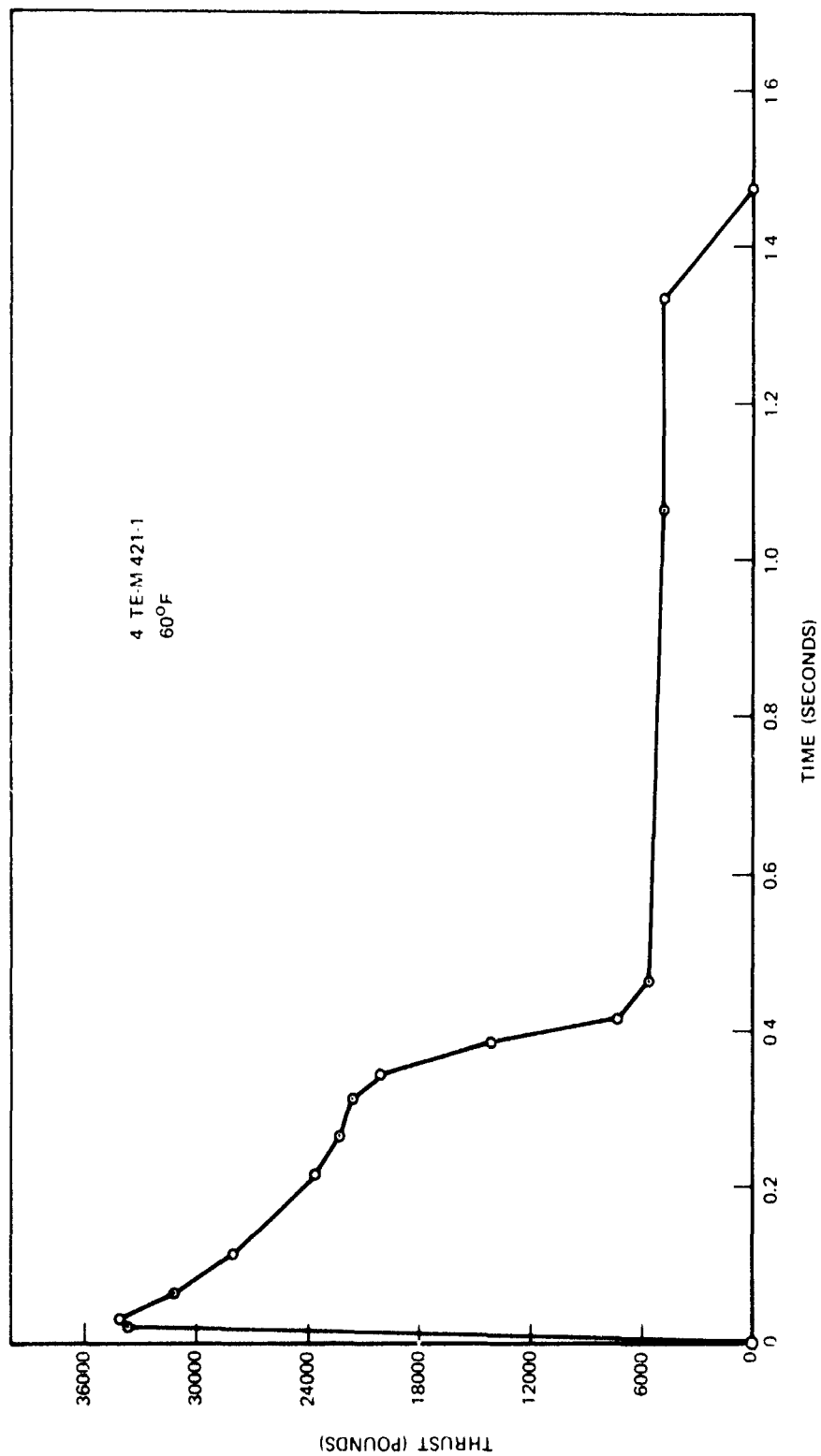


Figure 21. Thrust Versus Time for TE-M-421-1 at 60°F

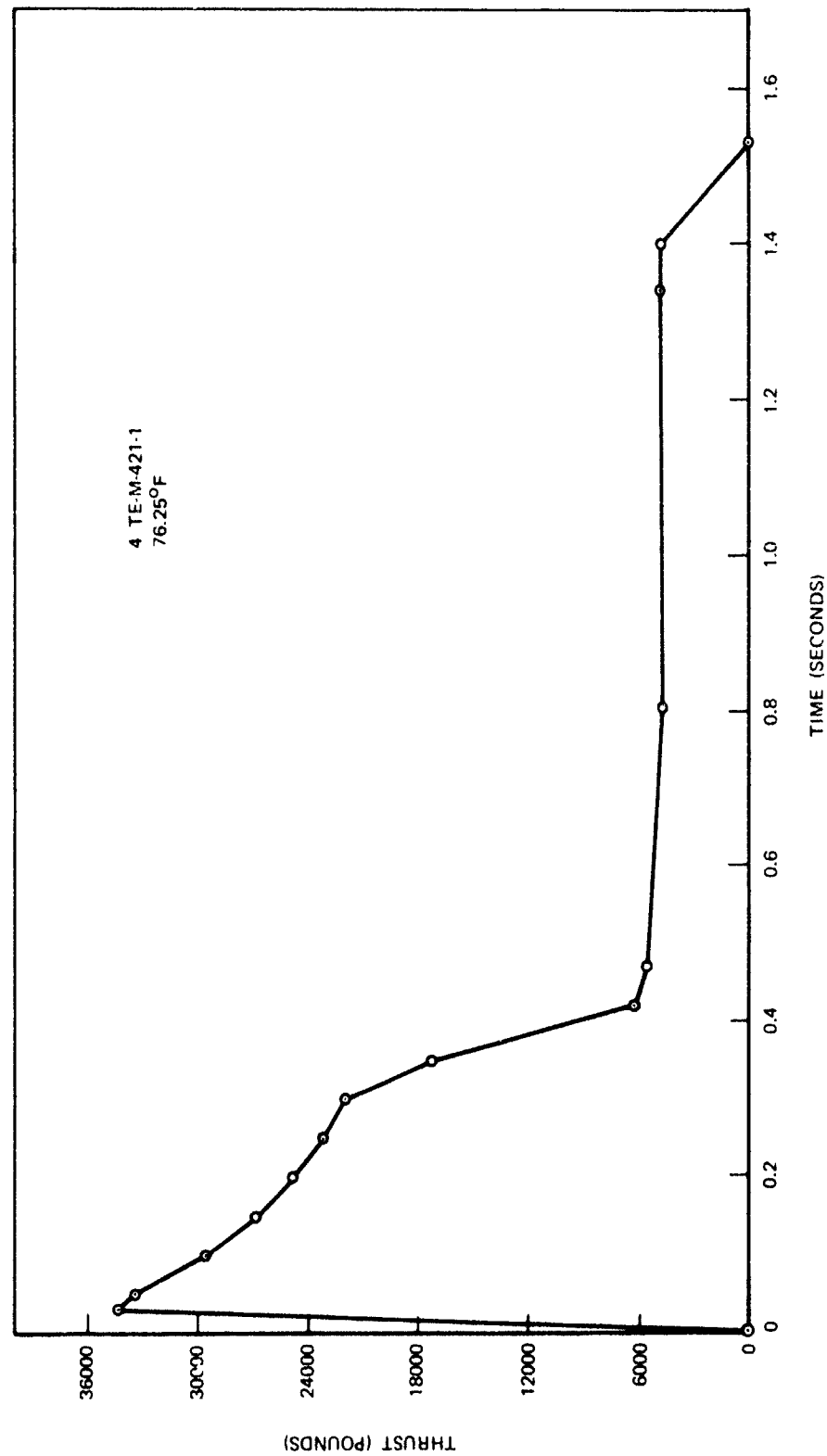


Figure 22. Thrust Versus Time for TE-M-421-1 at 76.25°F

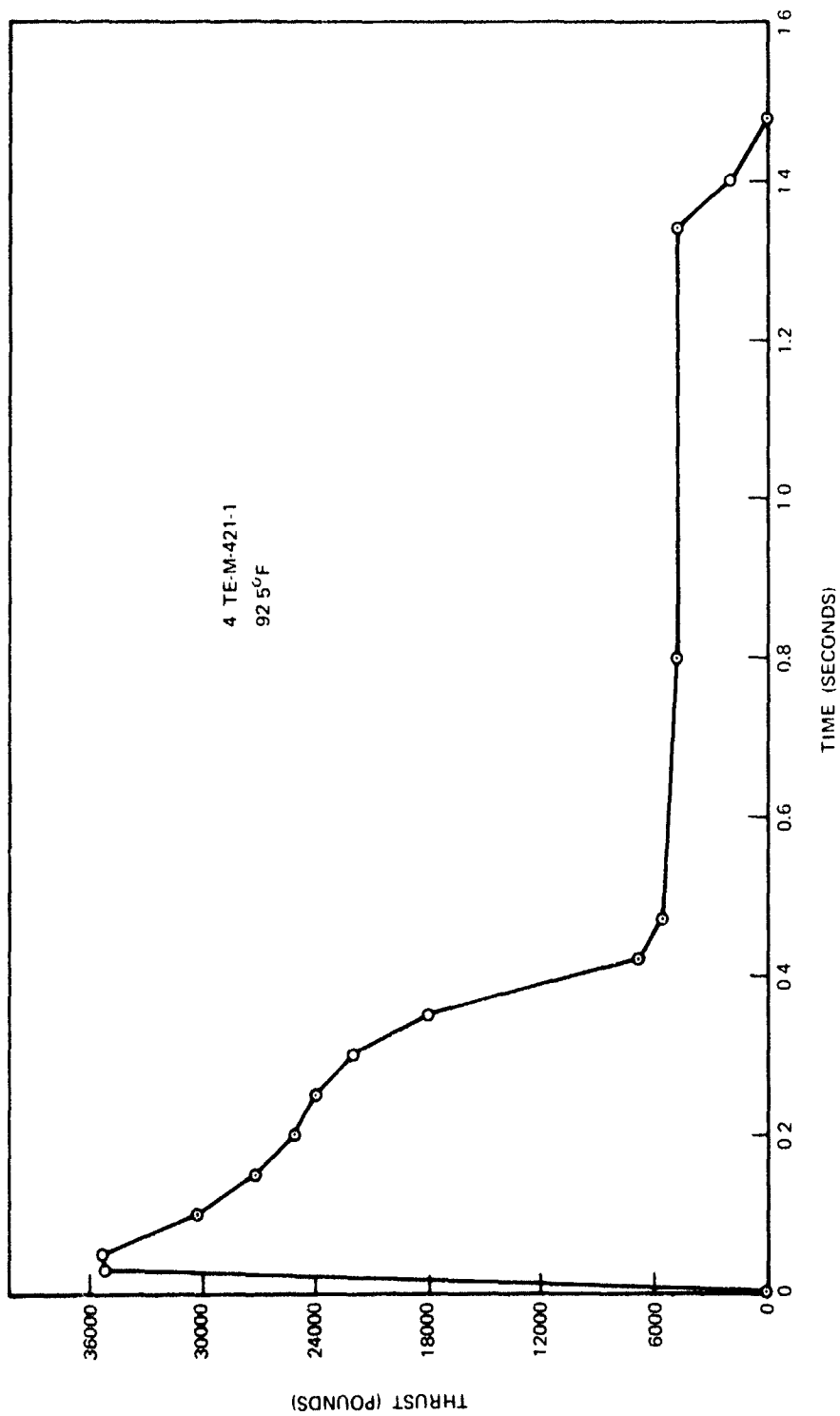


Figure 23. Thrust Versus Time for TE-M-421-1 at 92.5°F

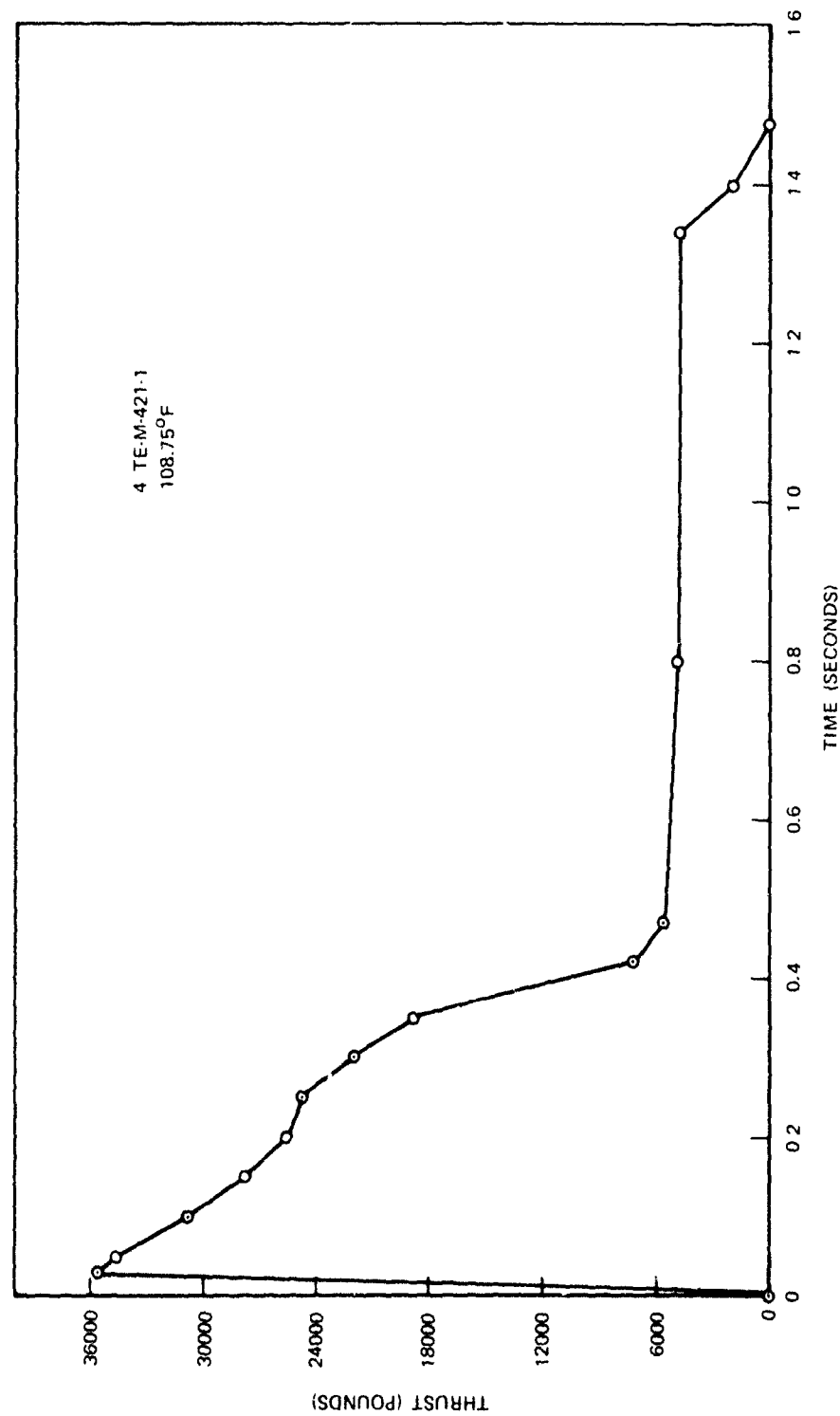


Figure 24. Thrust Versus Time for TE-M-421-1 at 108.75°F

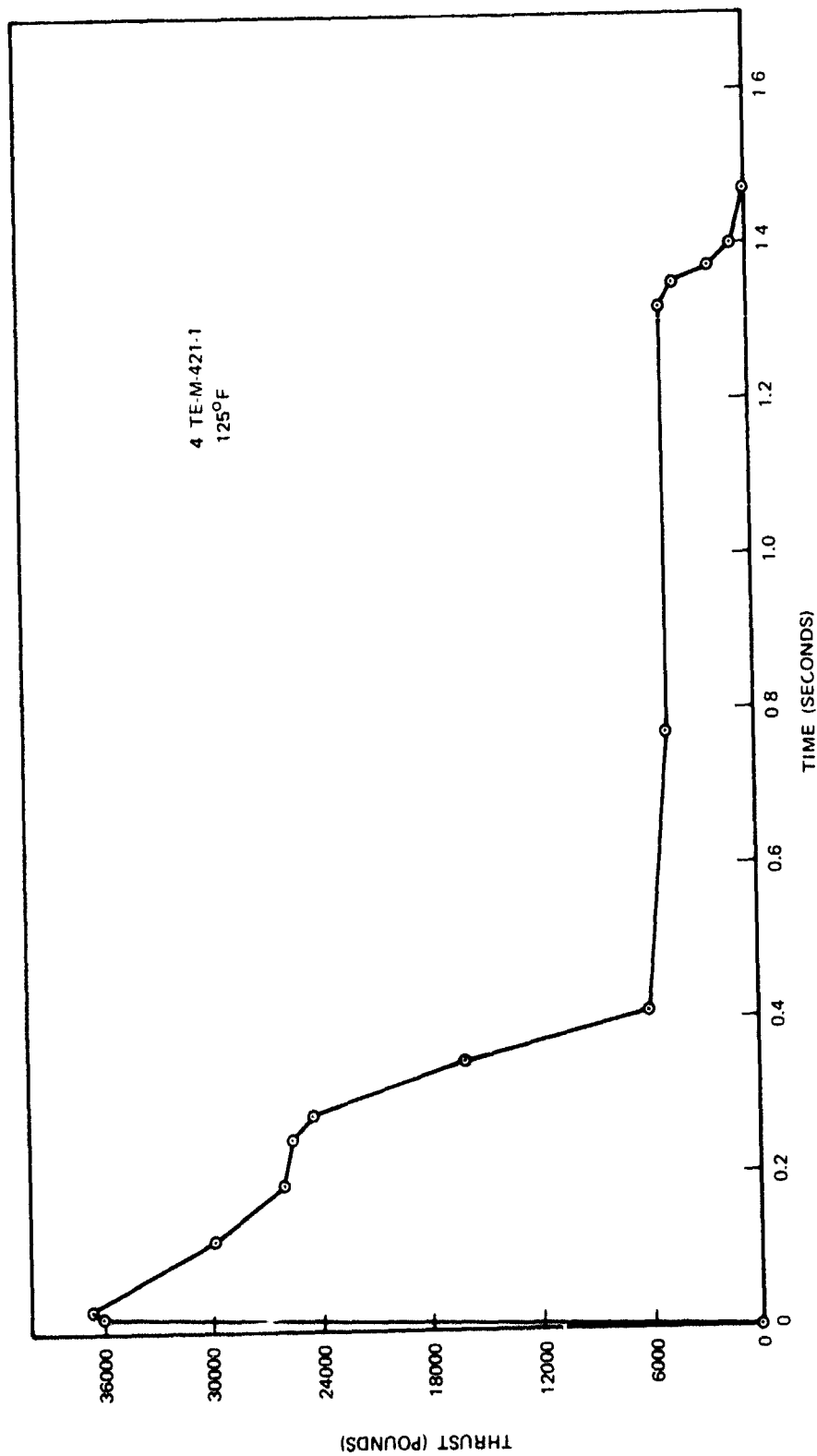


Figure 25. Thrust Versus Time for TE-M-421-1 at 125°F

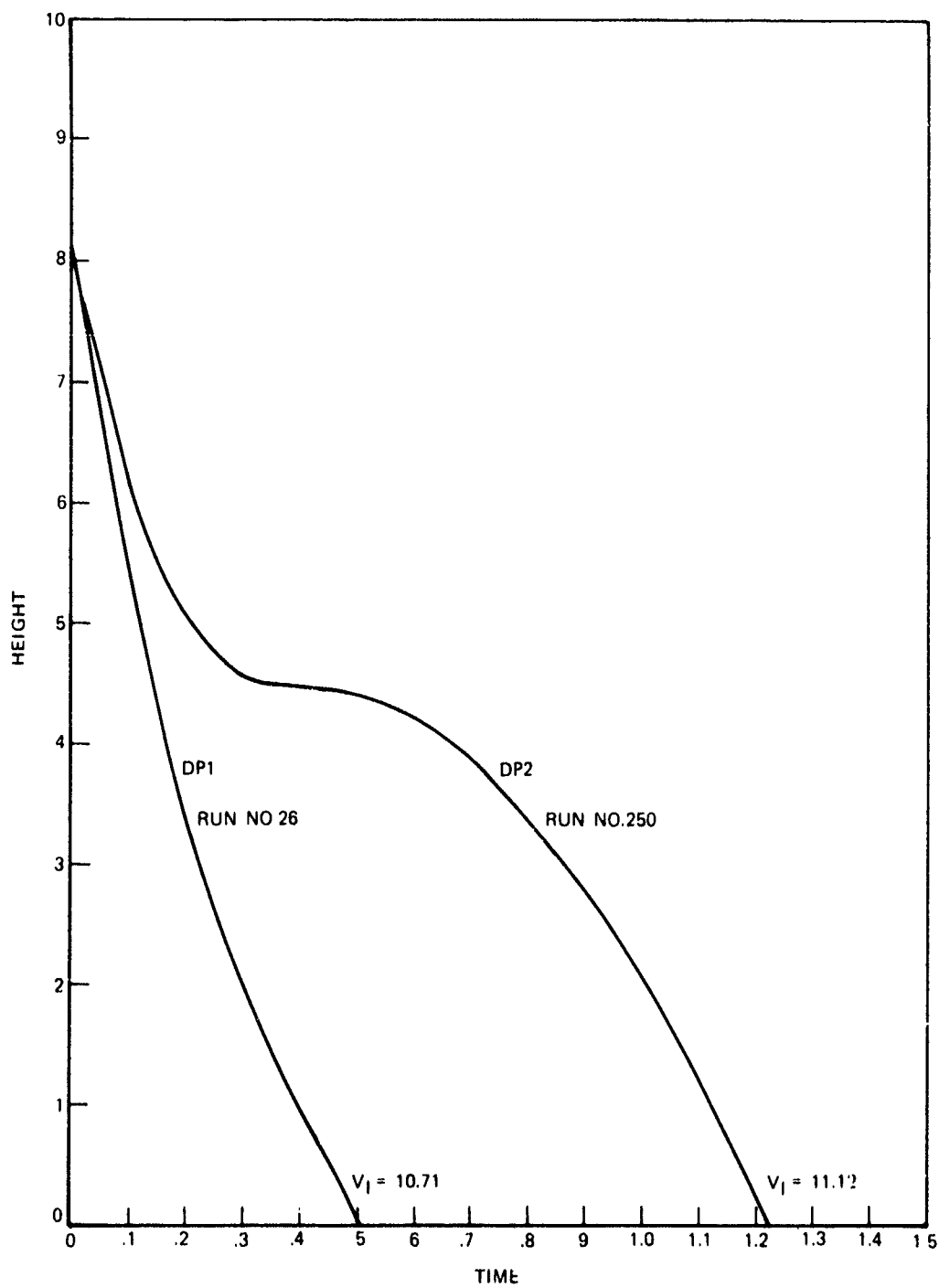


Figure 26. Capsule Height Versus Time, TE-M-421-1,
Ground Slope = -1° , $V_H = 34$ fps

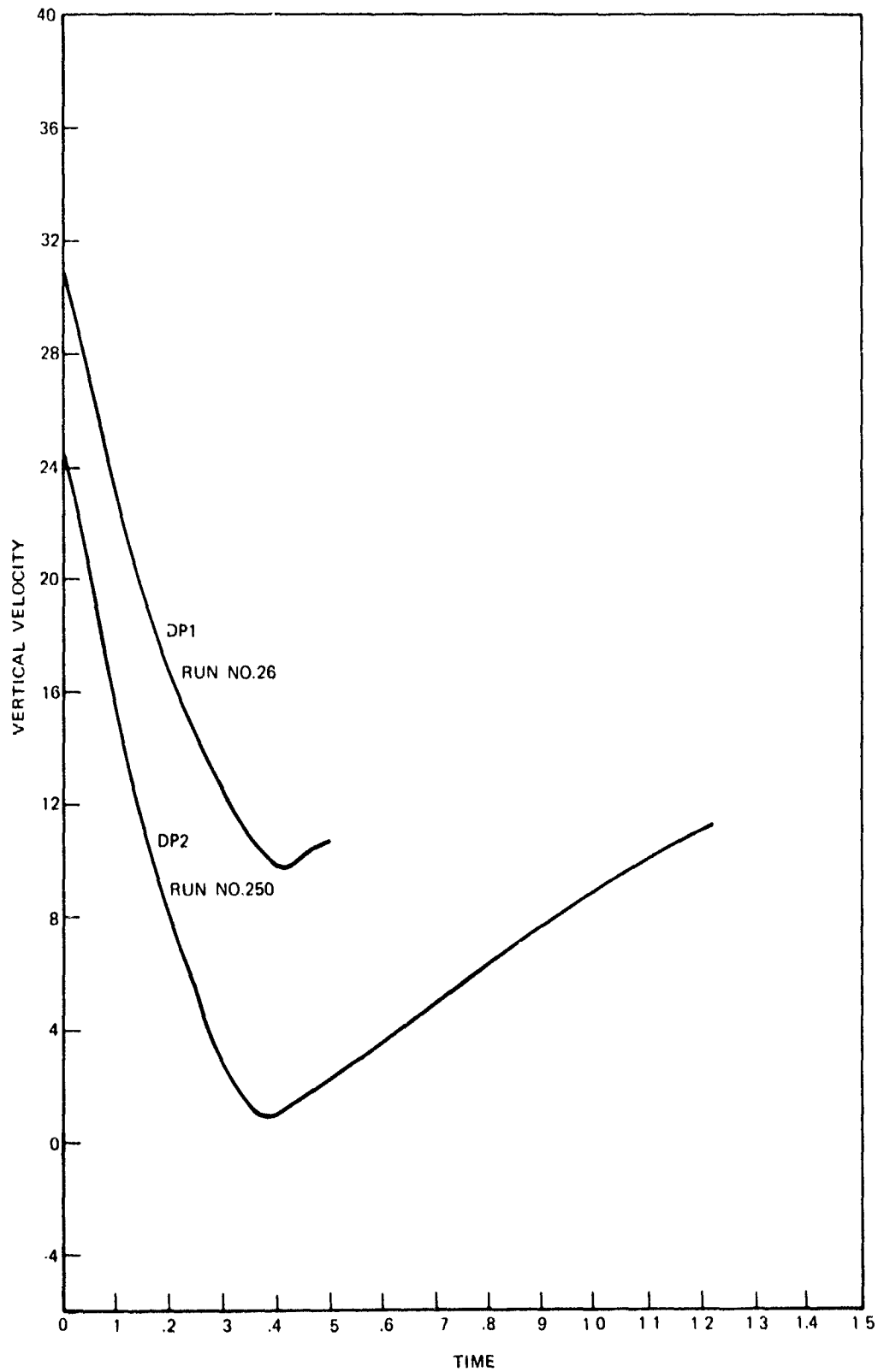


Figure 27. Capsule Velocity Versus Time, TE-M-421-1,
Ground Slope = -1° , $V_H = 34$ fps

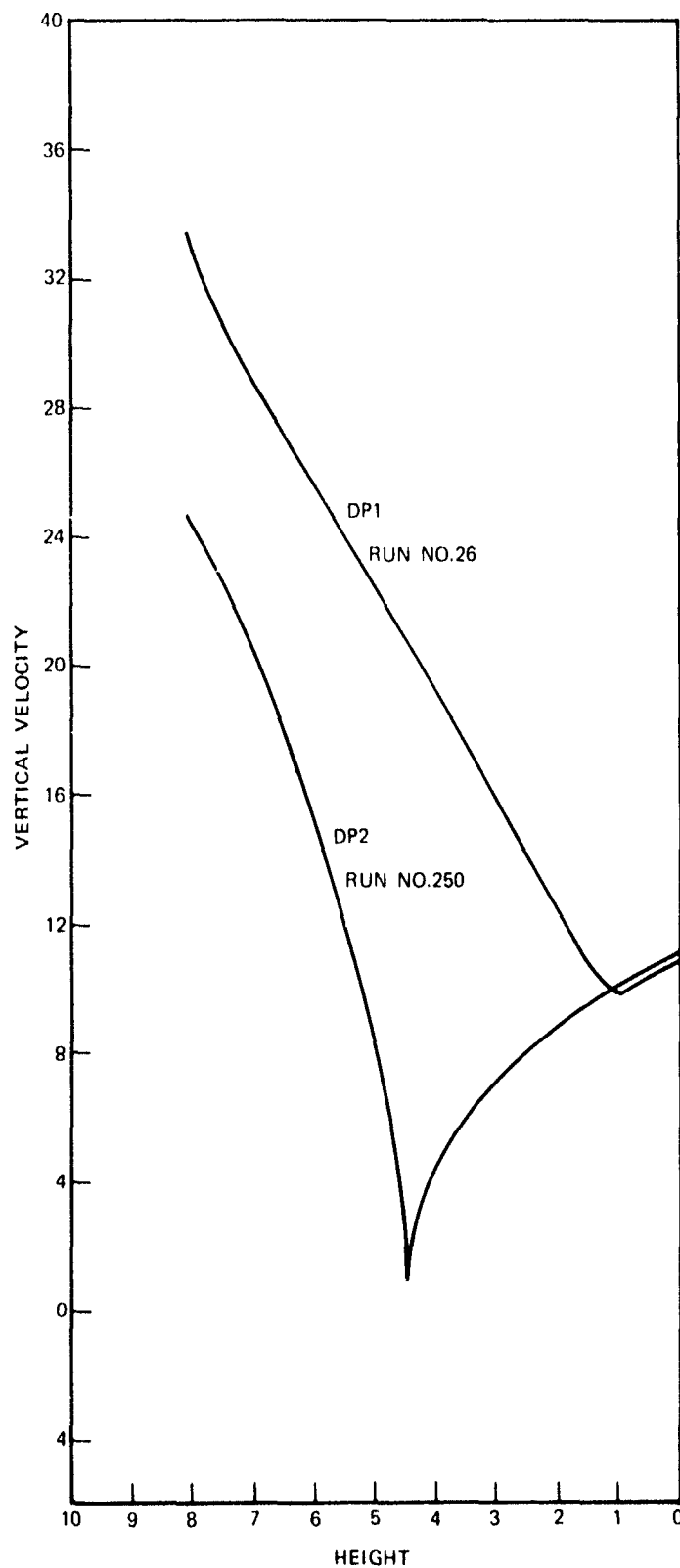


Figure 28. Capsule Velocity Versus Height, TE-M-421-1,
Ground Slope = -1° , $V_H = 34$ fps

APPENDIX A
DROPPER COMPUTER PROGRAM
INPUT ARRAY AND PROGRAM LISTING

INPUT DATA ARRAY FOR SYSTEM PERFORMANCE COMPUTER PROGRAM

D(7)	Weight of Capsule System	(lbs)
D(8)	Altitude of Terrain	(ft)
D(9)	Parachute Diameter	(ft)
D(10)	Parachute Drag Coefficient	
D(11)	Module Reference Area	(ft ²)
D(12)	Module Drag Coefficient	
D(13)	Initial Altitude	(ft)
D(14)	Altitude of Retrorocket Ignition	(ft)
D(16)	Rocket Thrust Angle	(deg)
D(17)	Rocket Temperature	(°F)
D(18)	Rocket Thrust Factor	
D(19)	Parachute Drag Factor	
D(23)	Initial Vertical Velocity	(ft/sec)
D(24)	Time of Retrorocket Ignition	(sec)
D(25)	DELTA Time for Computations	(sec)
D(26)	Printing Interval for Output	(sec)
D(27)	Specific Impulse of Rocket	(lb-sec/lb)
D(28)	Thrust Angle	(deg)
D(29)	Initial Horizontal Velocity	(ft/sec)
D(30)	Oscillation Angle	(deg)
D(31)	Ground Slope	(deg)

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SOURCE LISTING

```

C DECK TO COMPUTE RETROCKET LANDINGS.....10/04/72
PROGRAM DROPPER (INPUT,OUTPUT,TAPES=INPUT,TAPES=OUTPUT)
DIMENSION P(50),D(50),BNTIME(15,3),THRUST(15,3),BNTIM(15,3)
COMMON /RCT/ TIM(15,21),THR(15,21),TIC(14,21),CAT(14,21)
1  FORMAT(1H),(F10.3,9F11.2,F11.1)
2  FORMAT(1H,16HGROUND) IMPACT.....)
3  FORMAT(1H,20HINPJT ARRAY.... RUY ,IS///,(6F14.4))
6  FORMAT(2(1H/),7X,4TIME,6X,6HHEIGHT,3X,9HSINK RATE,4X,7HACC-G'S,
.4X,6THRUST,4X,7HVTHRUST,4X,7HCHTLLOAD,4X,8HRIMPULSE,4X,5HRANGE,5X,
.84VELOCITY,4X,64ENERGY)
7  FORMAT(6F12.6)
8  FORMAT (/140,10HOUTPUT.....)
9  FORMAT (140,20HPROPELLANT WEIGHT - ,F8.2,5H LBS.)
101 FORMAT(1H,(F10.3,9F11.2,F11.1))
103 FORMAT (4(1H0/)50X,20H*** END OF JOB ****)
104 FORMAT (A1)
EQUIVALENCE (D(7), WGT ),(D(8), ALTG ),(D(9), D ),(D(10), COORDROP0150
. ),(D(11), JAREA),(D(12), GDB ),(D(13), ALTO ),(D(14), RKTALT),(DROP0160
.D(15), KCTT ),(D(16), RKTANG),(D(17), TEMP ),(D(18),FFRR),(D(19),DROP0170
.FFCC),(D(23),VEL0),(D(24),RKTIM),(D(25),DELIIM),(D(26),RNTH)
. ,(D(27),SIMP),(D(28),SKEW),(D(29),VELH0),(D(30),ALPHA)
. ,(D(31),GSLP)
EQUIVALENCE (P(1),TIME),(P(2),HGT),(P(3),VEL),(P(4),GB),(P(5),THROKOP0200
.USD),(P(7),PDRA),(P(8),RIMP),(P(9),VTHRST),(P(9),DISTH),
.(P(10),VELH),(P(11),ENERGY)
EQUIVALENCE (TIM(1,19), BNTIME(1,1)),(THR(1,19),THRUST(1,1))
REAL NZLANJ
NAMELIST /NEWSET/ D,RCNTR,BNTIME,THRUST
DATA ENDOJB /1H/, RCNTR /-0.0/
READ(5,7) D
READ(5,NEWSET)
+ CONTINUE
DROP0000
DROP0005
DROP0010
DROP0020
DROP0030
DROP0040
DROP0050
DROP0060
DROP0070
DROP0080
DROP0090
DROP0100
DROP0110
DROP0120
DROP0130
DROP0140
DROP0150
DROP0160
DROP0170
DROP0180
DROP0190
DROP0195
DROP0200
DROP0210
DROP0220
DROP0230
DROP0240
DROP0250
DROP0260
DROP0270
DROP0280
DROP0290

```

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SOURCE LISTING CONTINUED

```

IF(KCNR) 95,95,96
  RCNTR = 1.0
  CONTINUE
  IRUN = KCNR
  WRITE(6,3) IRUN,0
  WRITE(6,4)
  WRITE(6,5)
  NPRT = 1
  NDAG = 1
  NOJT=11
  NFIRST = 1
  DO 11 I=1,NDUT
    P(I)=0.0
    NTH = RNT4
    IFIRST=1
    IROCK = 1
    INT=J
    SALPHA = SIN(ALPHA*0.017453292)
    CALPHA = COS(ALPHA*0.017453292)
    ACCH = 0.0
    VELH = VE-40
    DISTH = 0.0
    PVELH = 0.0
    PJISTH = J.0
    ACC=0.0
    VEL = VELD
    TIME=0.0
    DIST=0.0
    PVEL = 0.0
    PJIST = 0.0
    PAREA=3.14159*(JO**2)*.25
    HGTQ=ALTO-ALTG
  
```

DROP0300
 DROP0310
 DROP0320
 DROP0330
 DROP0340
 DROP0350
 DROP0360
 DROP0370
 DROP0380
 DROP0390
 DROP0400
 DROP0410
 DROP0420
 DROP0430
 DROP0440
 DROP0450
 DROP0460
 DROP0470
 DROP0480
 DROP0490
 DROP0500
 DROP0510
 DROP0520
 DROP0530
 DROP0540
 DROP0550
 DROP0560
 DROP0570
 DROP0580
 DROP0590
 DROP0600
 DROP0610

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SOURCE LISTING CONTINUED

FRUCK = 0.0	DROP0620
THRUST = 0.0	DROP0630
VTXST = 0.0	DROP0640
NZLAN = SKEW*0.017453292	DROP0650
RIMP=0.0	DROP0660
PAGT = 0.0	DROP0670
DPWGT = 0.0	DROP0680
PRWGT = WGT	DROP0690
PRIMP=RIMP	DROP0700
WGT = HGT	DROP0710
HGTG = 0.0	DROP0715
ALT = ALT	DROP0720
CALL ATMOS(ALT,DEGR,SIGMA,RHO,THETA,DELTA,VSONIC,AMU,K)	DROP0730
QJE=RHO*(VEL**2)*.5	DROP0740
PORAJ = 200*QJE*PAREA	DROP0750
ENERGY = WGT*((VEL**2/64.348)+HGT)	DROP0760
WRITE(6,1)(P(I),I=1,NOJT)	DROP0770
	DROP0780
RUNGE KUTTA	DROP0790
5 INT=INT+1	DROP0800
	DROP0810
B=ACC*DELTIM	DROP0820
A = ACCH*DELTIM	DROP0830
C = VALH*DELTIM	DROP0840
F = VEL*DELTIM	DROP0850
G=FRUCK*DELTIM	DROP0860
GO TO(10,20,30,40),INT	DROP0870
10 B1=B	DROP0880
F1 = F	DROP0890
A1 = A	DROP0900
C1 = C	DROP0910
G1=G	DROP0920

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SOURCE LISTING CONTINUED

B=3/2.	DROP0930
F = F/2.	DROP0940
A = A/2.	DROP0950
C = C/2.	DROP0960
G=G/2.	DROP0970
PDIST=DIST	DROP0980
PVEL=VEL	DROP0990
PDIST = DIST	DROP1000
PVEL = VEL	DROP1010
PRIMP=IMP	DROP1020
GO TO 50	DROP1030
20 32=J	DROP1040
F2 = F	DROP1050
A2 = A	DROP1060
C2 = C	DROP1070
A = A/2.	DROP1080
C = C/2.	DROP1090
G2=G	DROP1100
B=B/2.	DROP1110
F = F/2.	DROP1120
G=G/2.	DROP1130
GO TO 50	DROP1140
30 33=B	DROP1150
F3 = F	DROP1160
A3 = A	DROP1170
C3 = C	DROP1180
G3=G	DROP1190
GO TO 50	DROP1200
40 34=B	DROP1210
A4 = A	DROP1220
C4 = C	DROP1230
F4 = F	DROP1240

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SOURCE LISTING CONTINUED

G4=G	DROP1250
B=(B1+2.*(B2+B3)+B4)/6.	DROP1260
A = (A1+2.*(A2+A3)+A4)/6.	DROP1270
C = (C1+2.*(C2+C3)+C4)/6.	DROP1280
F = (F1+2.*(F2+F3)+F4)/6.	DROP1290
G=(G1+2.*(G2+G3)+G4)/6.	DROP1300
50 VEL=PVEL+3	DROP1310
DIST = PDIST + F	DROP1320
VFLH = PVELH + A	DROP1330
DISTH = PDISTH + C	DROP1340
RIMP=PRIMP+5	DROP1350
GO TO(60,70,60,70),INT	DROP1360
50 TIME=TIME+DELTIM/2.	DROP1370
70 CONTINUE	DROP1380
ALT=ALT0+DIST	DROP1390
C	DROP1400
GET ATMOSPHERE DATA	DROP1410
C	DROP1420
CALL ATMOS(ALT,DEGR,SIGMA,RHO,THETA,DELTA,VSONIC,AMU,K)	DROP1430
C	DROP1440
CALCULATE DRAG FORCES	DROP1450
C	DROP1460
QJE=RHO*(VEL**2)*.5	DROP1470
50 TO (300,301),NDRAG	DROP1480
300 PDRAQ = DDQ*QJE*PAREA	DROP1490
301 CONTINUE	DROP1500
C	DROP1510
BDRAG=CJLQ*QJE*BAREA	DROP1520
C	DROP1530
CALCULATE BODY MASS	DROP1540
C	DROP1550
AMASS=WGT/32.174	DROP1560

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SOURCE LISTING CONTINUED

```

C      GO GET ROCKET FTRUST      DROP1570
C      DROP1580
C      DROP1590
C      HGTG = DISTH*TAN(GSLP*0.017453292)  DROP1595
C      HST = HGT) + UIST - HGTG      DROP1600
C      ENERGY = HST*((VEL**2/64.348)+HST)  DROP1610
C      GO TO (31,51), FROCK      DROP1620
C      DROP1630
C      DROP1640
C      DROP1650
C      DROP1660
C      DROP1670
C      DROP1680
C      DROP1690
C      DROP1700
C      DROP1710
C      DROP1720
C      DROP1730
C      DROP1740
C      DROP1750
C      DROP1760
C      DROP1770
C      DROP1780
C      DROP1790
C      DROP1800
C      DROP1810
C      DROP1820
C      DROP1830
C      DROP1840
C      DROP1850
C      DROP1860
C      DROP1870

```

```

C      GO GET ROCKET FTRUST
C      HGTG = DISTH*TAN(GSLP*0.017453292)
C      HST = HGT) + UIST - HGTG
C      ENERGY = HST*((VEL**2/64.348)+HST)
C      GO TO (31,51), FROCK
C      51 HST1 = -HST
C      IF(HST1-RKTALE) 41,41,51
C      41 HST1 = -0.0
C      FROCK = 2
C      51 CONTINUE
C      GO TO(80,30,80,30),INT
C      80 CALL ROCK (TIME,HGT1,RKT1,TEMP,RKTANG,RKTIM,RKTALE,FROCK,IFIRST)
C      FROCK=FROCK*FFR
C      90 VTRFC = FROCK*COS (NZLANG)
C      VTRST = VTRFC
C      THRUS)=FRJCK
C      GO TO (91,93), NFIRST
C      91 IF(FROCK.EQ.0.0) 50 TO 93
C      PDRAQ=PDRAQ*FFC
C      WRITE (6,101) (P(I),I=1,NOUT)
C      NFIRST = 2
C      93 CONTINUE
C      CALCULATE NET FORCE
C      IF(VEL) 201,201,200
C      PDRAQ = 0.0
C      203 IF(TIME.GT.0.1.AND.PDRAQ.EQ.0.0) NDRAQ = 2

```

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SOURCE LISTING CONTINUED

```

201 CONTINUE
   IF (ABS(HGT).LE.RK(TALT)) PORAG = PORAG*FFCC
   IF (TIME.GE.RK(TIM.AN).RK(TALT.LT.U.) PORAG = PORAG*F=CC
   FNET = PORAG+30RAG+VRTFC-WGT
   FVNET = BDRAG - WGT + CALPHA * (PORAG + VRTFC)
   FVNET = CALPHA * (PORAG + VRTFC)
   ACC = FVNET/AMASS
   ACCH = FVNET/AMASS
   G3V = ACC/32.174
   G3H = ACC/32.174
   ACCT = FNET/AMASS
   G4 = ACCT/32.174
   GO TO(5,5,5,100),INT
C
C      OUTPUT
C
100 INT=0
   IF(SPIMP) 203,203,202
202 OPWGT = G/SPIMP
   PWGT = PWGT + OPWGT
   WGT = WGT - OPWGT
203 CONTINUE
   IF(NPRT-NFH) 110,111,111
111 CONTINUE
   WRITE(6,101)(P(I),I=1,NOUT)
   NPRT = 1
   GO TO 112
110 NPRT = NPRT + 1
112 CONTINUE
   IF(HSI)121,5,5
120 WRITE(6,2)
   WRITE(6,101)(P(I),I=1,NOUT)
DROP1880
DROP1890
DROP1900
DROP1910
DROP1920
DROP1930
DROP1940
DROP1950
DROP1960
DROP1970
DROP1980
DROP1990
DROP2000
DROP2010
DROP2020
DROP2030
DROP2040
DROP2050
DROP2060
DROP2070
DROP2080
DROP2090
DROP2100
DROP2110
DROP2120
DROP2130
DROP2140
DROP2150
DROP2160
DROP2170
DROP2180
DROP2190

```

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SOURCE LISTING CONTINUED

```

IF(SPIMP.51.0.0) WRITE (6,9) PM3T
W3T = PM3T
READ (5,134) FULAST
IF(FULAST.E1.ENGJOB) GO TO 102
BACKSPACE 5
RCNTR = RCNTR + 1.0
READ (5,NEWSET)
GO TO 4
102 WRITE (6,103)
STOP
END
DROP2200
DROP2210
DROP2220
DROP2230
DROP2240
DROP2260
DROP2250
DROP2270
DROP2280
DROP2290
DROP2300

```

LIST OF SYMBOLS

DP1	Design Point 1
DP2	Design Point 2
E	Ignition Height Error
I	Rocket Impulse
IHmin	Minimum Ignition Height
IHmax	Maximum Ignition Height
SL1	Altitude Lost at DP1
SL2	Altitude Lost at DP2
σ	Thrust-Temperature Coefficient (0.0011/°F)
t	Time
t_C	Rocket Burn Time at Minimum Temperature
t_N	Rocket Burn Time at Nominal Temperature
t_H	Rocket Burn Time at Maximum Temperature
T	Thrust
T/W	Thrust to Weight Ratio
T_C	Thrust at Minimum Temperature
T_N	Thrust at Nominal Temperature
T_H	Thrust at Maximum Temperature
TE_H	Temperature, Max
TE_N	Temperature, Nom
TE_C	Temperature, Min
V	Velocity
V0	Initial Capsule Vertical Velocity
V01	Initial Capsule Vertical Velocity at DP1
V02	Initial Capsule Vertical Velocity at DP2

LIST OF SYMBOLS (Concluded)

V_I	Vertical Velocity at Impact
V_H	Horizontal Velocity
V_{RB01}	Vertical Velocity at Rocket Burn-Out, DP1
V_{RB02}	Vertical Velocity at Rocket Burn-Out, DP2
W_L	Capsule Weight, Minimum
W_N	Capsule Weight, Nominal
W_H	Capsule Weight, Maximum
W_P	Propellant Weight