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LOW GRAVITY SIMULATION BY HIGH ALTITUDE DROP TESTING

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ABSTRACT

A high altitude drop test technique for simulation of low gravity environments has been investigated. It was found that continuous low gravity test times of 24 to 26 seconds could be achieved with a maximum drag shield velocity of 820 ft/sec. Thrust applied to the drag shield opposing the drag force was required to limit the travel of the experiment package relative to the shield. Application of a constant thrust for the duration of a drop, application of a thrust increasing at a constant rate, and delayed application of a constant thrust were studied. The latter two thrust methods gave the better results (i.e., longer test times with shorter drag shield required). In some cases, 22 to 24 seconds of low gravity test time were indicated with a drag shield which allowed 15 feet of longitudinal travel of the experiment package relative to the shield.

The effects of changes in longitudinal aerodynamic stability and wind profile on the drag shield and experiment package dynamics were also studied. A wide range of values for the stability parameter was found to be acceptable. The lateral motion of the experiment package relative to the drag shield was less than one-half foot for the most severe conditions of wind and aerodynamic stability investigated.

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By

Frank Bugg

STRUCTURAL DYNAMICS SECTION
DYNAMICS ANALYSIS BRANCH
DYNAMICS AND FLIGHT MECHANICS DIVISION
AERO-ASTRODYNAMICS LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

LIST OF ILLUSTRATIONS

DEFINITION OF SYMBOLS

A dot above a coordinate is used to indicate differentiation with respect to time.

Symbol	Definition
x_s	vertical distance traveled by drag shield, ft(m) (see fig. 1)
y_s	horizontal distance traveled by drag shield, ft(m) (see fig. 1)
$x_{p/s}$	longitudinal distance traveled by experiment package relative to drag shield, ft(m) (see fig. 1)
t	time after release of drag shield, sec.
ψ	angle between drag shield centerline and vertical, degrees (see fig. 1)
α	angle between drag shield centerline and relative wind, degrees (see fig. 1)
V	velocity of horizontal wind, ft/sec (m/sec)
I	drag shield moment of inertia about its center of gravity, lbf-ft-sec^2 (N-m-sec^2)
A	maximum cross section area of drag shield, ft^2 (m^2)
$\bar{c}$	drag shield diameter, ft (m)
ρ	air density, $\frac{\text{lbf-sec}^2}{\text{ft}^4}$ (kg/m^3)
D	drag force, lbf (N) (see fig. 1)
N	normal force, lbf (N) (see fig. 1)
M	pitching moment, lbf-ft (N-m) (see fig. 1)
C_D	drag force coefficient, $\frac{D}{\frac{1}{2}\rho A \dot{x}_s^2}$
C_N	normal force coefficient, $\frac{N}{\frac{1}{2}\rho A \dot{x}_s^2}$
C_M	pitching moment coefficient, $\frac{M}{\frac{1}{2}\rho A \bar{c} \dot{x}_s^2}$

DEFINITION OF SYMBOLS (Continued)

Symbol	Definition
t_i	time at which thrust is initiated, sec
T_s	drag shield thrust, lbf (N) (see fig. 1)
T_p	experiment package thrust, lbf (N) (see fig. 1)
m_s	drag shield mass, lbm (kg)
m_p	experiment package mass, lbm (kg)
a	low gravity test acceleration, g
g	acceleration of gravity = 32.17 ft/sec^2 (9.8 m/sec^2)
$\dot{y}_{s_o}$	initial horizontal velocity of drag shield, ft/sec (m/sec)
$y_{p/s}$	lateral distance traveled by experiment package relative to drag shield, ft (m) (see fig. 1)

TECHNICAL MEMORANDUM X-53608

LOW GRAVITY SIMULATION BY HIGH ALTITUDE DROP TESTING

SUMMARY

A high altitude drop test technique for simulation of low gravity environments has been investigated. It was found that continuous low gravity test times of 24 to 26 seconds could be achieved with a maximum drag shield velocity of 820 ft/sec. Thrust applied to the drag shield opposing the drag force was required to limit the travel of the experiment package relative to the shield. Application of a constant thrust for the duration of a drop, application of a thrust increasing at a constant rate, and delayed application of a constant thrust were studied. The latter two thrust methods gave the better results (i.e., longer test times with shorter drag shield required). In some cases, 22 to 24 seconds of low gravity test time were indicated with a drag shield which allowed 15 feet of longitudinal travel of the experiment package relative to the shield.

The effects of changes in longitudinal aerodynamic stability and wind profile on the drag shield and experiment package dynamics were also studied. A wide range of values for the stability parameter was found to be acceptable. The lateral motion of the experiment package relative to the drag shield was less than one-half foot for the most severe conditions of wind and aerodynamic stability investigated.

I. INTRODUCTION

The National Aeronautics and Space Administration is engaged in a continuing research program to achieve an understanding of liquid propellant dynamics in a low gravity environment. The experimental portion of this research has been performed in the following ways:

(1) Experimenting in a low acceleration environment, by means of drop towers, aircraft flying parabolic arcs, orbital and sub-orbital rocket-launched experiments.

(2) Experimenting at one-g, choosing tank size and test liquid properties such that the ratio of body forces to adhesive forces is the same for the model at one-g as for the full scale tank at low-g.

The second method is by far the most economical way to obtain experimental data; however, because of the very small tank sizes required for scaling adhesive and body forces, viscous forces become important and the model becomes incorrect. More experimental data are needed, therefore, from a low acceleration environment for direct verification of low-g theoretical work and for definition of viscosity effects in small models to increase the value of one-g experiments.

The purpose of the present investigation is to examine by means of analog and digital computers a method of experimenting in a low acceleration environment using an experiment package inside a drag shield, as in drop tower testing, but dropped from high altitude to give more test time. A streamlined body was chosen as the drag shield shape, and the critical Mach number for this shape was taken as the maximum Mach number to be permitted during the drop. Drops were simulated on the computer with drag shield mass, drag shield thrust (thrust opposing drag) and experiment package thrust (thrust providing test acceleration) as variables. Records of drag shield and experiment package dynamics are presented as a function of time for several drops. The effects of changes in drag shield aerodynamic stability and changes in wind gradient were also investigated.

II. DISCUSSION

A. Procedure

The method of low-g testing investigated uses the techniques of drop tower testing with some additions. The drag shield with experiment package inside is lifted to the desired drop altitude by a helicopter or balloon. After release, the bomb-like drag shield (shown schematically in fig. 1) falls with the experiment free inside, and the desired test acceleration is produced by a small thrust, T_p, applied to the experiment package, as in drop tower testing. However, since the test accelerations of interest are small, the experiment package begins to move toward the forward end of the shield as the drag force increases, and a thrust, T_S, must be applied to the shield to prevent the experiment from reaching the end. A parachute system is used to recover the shield and experiment package. This study is concerned with the dynamics of the drag shield and experiment package after release and before the recovery sequence begins.

The systems of axes used are shown in figure 1 along with the positive directions assigned to the thrust vectors. The equations of motion for the drag shield and experiment package are as follows:

$$\ddot{x}_s - \frac{K_1 \dot{x}_s^2}{m_s} + g + \frac{T_s}{m_s} = 0, \quad K_1 = \frac{1}{2} \rho C_D A$$

$$\ddot{x}_p + g - \frac{T_p}{m_p} = 0$$

$$\ddot{x}_{p/s} = - \frac{K \dot{x}_s^2}{m_s} + \frac{T_s}{m_s} + \frac{T_p}{m_p} .$$

These equations, solved on the computer as shown in figure 2, were used with the following assumptions:

(1) g is constant = 32.17 ft/sec^2;

(2) ρ is constant = .00238 slug/ft^3;

(3) drag of the experiment package as it moves through the air inside the shield is negligible;

(4) C_D = constant = .03 is the drag shield drag coefficient; and

(5) A = 19.63 ft^2.

Reference 1 gives the correction for g as -.003 ft/sec^2 per 1000 feet above sea level and the air density at 10,000 feet as 74 percent of the value at sea level. Assumptions (1) and (2) are such that the shield thrust requirements in the real case would be less than those presented in this investigation. Assumption (3) is valid if the shield is partially evacuated or if the velocity of the package relative to the shield is kept very low (e.g., if 3 percent error in a is the maximum allowable for a = 10^{-3}g and the shield has not been evacuated, then $\dot{x}_{p/s}$ must be less than .92 ft/sec).

A streamlined body five feet in diameter with a maximum length-to-diameter ratio of 2.75 was chosen as the drag shield shape. The drag coefficient of this body was nearly constant and less than .03 up to a Mach number of .74 at which the drag coefficient increased rapidly (see reference 2). By assumption (4), the results are not applicable beyond M = .74 which corresponds approximately to $\dot{x}_s$ = 820 ft/sec.

B. Results

1. Drag Shield Dynamics

The effects of the drag shield mass on its free fall dynamics are shown in figure 3. The distance this streamlined body fell and the velocity attained in a given time were changed less than 10 percent by the change in shield mass from 1250 lbm to 5000 lbm. The acceleration, $\ddot{x}_s + g$, is the acceleration an accelerometer on the shield would experience as the drag force on the shield increased. An experiment package floating free inside the shield would accelerate toward the forward end of the drag shield with acceleration equal to $\ddot{x}_s + g$. The value $m_s = 5000$ lbm, chosen as a representative value, was kept constant in the remainder of the investigation. It is seen from figure 3 that the maximum low-g test time for the shield with $m_s = 5000$ lbm was 26 seconds as determined by the velocity limit of 820 ft/sec. During this time the shield fell 10,800 feet. (The 15,000-foot release altitude was chosen arbitrarily and would be changed as required to give sufficient time for deceleration of the shield by parachute.)

Figure 4 compares the 5000 lbm drag shield dynamics for a drop in a vacuum (no drag), a drop with drag, and drops with drag and various constant thrusts opposing drag. The drop distance for 26 seconds was approximately 1000 feet greater for the shield with the maximum thrust than for the shield with no thrust. The test time available was decreased by approximately 2.4 seconds by increasing the shield thrust from $T_s/m_s = 0$ to $T_s/m_s = 3.00$. The purpose of the drag shield thrust is to reduce the distance traveled by the experiment package relative to the shield. Since $\ddot{x}_s + g$ represents the acceleration of the package relative to the shield, when the package thrust is zero, a drag shield thrust which produced a zero value of $\ddot{x}_s + g$ throughout the drop would be ideal. To maintain $\ddot{x}_s + g = 0$ during a drop, the drag shield thrust would have to be equal to the drag force at all times. One relatively simple method of keeping $\ddot{x}_s + g$ near zero is indicated by the saw-tooth line in figure 4. A cluster of constant thrust rockets could be used and the thrust then increased in steps during the drop. Also, $\ddot{x}_s + g$ could be made to approach zero by increasing the number of steps and decreasing the step magnitude.

Drag shield drops showing the effects of shield thrusts which increase linearly with time are represented in figure 5. For the thrusts considered, the effects on drop distance and low-g test time provided are seen to be small. As expected, approximating the drag by thrusts which increased at a constant rate gave maximum values of $\ddot{x}_s + g$ much lower than were possible with any of the constant magnitude thrusts in figure 4.

2. Experiment Package Dynamics

There is more interest in experimenting in a low acceleration environment than in a zero acceleration environment; therefore, a small thrust, T_p, would be applied to the experiment package to provide the desired test acceleration. As indicated in figure 1, this thrust would accelerate the package toward the rear of the drag shield. The distance moved by the package relative to the shield is shown in figure 6 for several test accelerations. The data in this figure with $T_s = 0$ show that, for reasonable drag shield length (perhaps 25 ft), the test time available would be limited by the package travel relative to the shield and would be considerably less in most cases than the 24 to 26 seconds required for the shield to reach the limiting velocity. For the test accelerations a = .100 and a = .030 g, a negative drag shield thrust (or more drag) would be required to keep the package away from the aft end of the shield.

Figures 7 and 8 show the effects of some constant magnitude and constant rate of increase drag shield thrusts on $x_{p/s}$. Figure 9 shows the effect of constant thrusts applied to the drag shield for part of the drop time. From figure 7, it is seen that, for $T_s/m_s = .1$, .2, and .4, test times of about 22 to 23 seconds could be obtained while the experiment package moves 25 feet relative to the shield with test accelerations a = .01, .003, .001, and .0001g, respectively. For these same test accelerations, figure 8 shows that test times of 23 to 25 seconds are possible in a 25-foot shield using drag shield thrusts which increase linearly with time. Test times of 22 seconds would be available in a shield which allowed 15 feet of package travel relative to the shield for test accelerations of .003g or less (figure 8b, c, and d). The data in figure 9 were obtained by allowing the drag shield to fall for a few seconds and then applying a constant thrust for the remainder of the drop. Thrust was initiated at times, t_i, of 0 to 12.6 seconds after release of the shield. This thrust scheme gave good results for the .0001g test acceleration. Figures 9b ($t_i = 8$) and 9c ($t_i = 12.6$) show that 24-second test times can be achieved with a shield 15 feet or more in length. Therefore, the constant rate of increase and the delayed initiation thrusts (figures 8 and 9) gave better results (i.e., more test time in shorter drag shields) than the constant magnitude thrusts tried in figure 7.

3. Effect of Winds

The effect of winds on the dynamics of the drag shield was studied (the equations and constants used are shown in the appendix). The results, $y_{p/s}$, α, and ψ are presented in figures 10 and 11 as a function of drop time. Figure 12 shows the three wind profiles used. These profiles were constructed using information from reference 3.

The aerodynamic stability characteristics indicating the greatest stability, $dC_m/d\alpha = -22.9$/rad and $dC_N/d\alpha = 8.88$/rad, are values for the finned launch vehicle of reference 4 at a Mach number of .6. Values of $dC_m/d\alpha$ and $dC_N/d\alpha$ equal to one tenth and one hundredth of the maximum values were also used in the simulation, since the smaller values should be easily obtainable by proper sizing of fins and location of center of gravity in the drag shield.

Figure 10 shows that the maximum lateral distance traveled by the experiment package relative to the shield, $y_{p/s}$, was less than .5 ft for the three values of longitudinal stability parameter, $dC_m/d\alpha$, with wind C. As expected, the amplitude of the α oscillation increased with decreasing $dC_m/d\alpha$, and the frequency of the oscillation in α decreased. Changes in $dC_m/d\alpha$ had a similar effect on ψ. The experiment package would be approximately 2 feet in diameter; therefore, it could be moved laterally 1.5 feet from the center of the 5-foot diameter drag shield before touching the wall. Figure 10 indicates that the drag shield and experiment package would not touch since their relative motion laterally is less than .5 ft throughout the drop.

Figure 11 shows that there was little change in results due to wind changes at constant $dC_m/d\alpha$ and $dC_N/d\alpha$.

III. CONCLUSIONS

An investigation has been made of a high altitude drop test technique for simulation of low gravity environments. It was found that continuous low gravity test times of 24 to 26 seconds could be achieved with a maximum drag shield velocity of 820 ft/sec. Thrust applied to the drag shield opposing the drag force was required to limit the longitudinal travel of the experiment package relative to the shield. Application of a constant thrust for the duration of a drop, application of a thrust increasing at a constant rate, and delayed application of a constant thrust were studied. The latter two thrust methods gave the better results (i.e., longer test times with a shorter drag shield required.) In some cases 22 to 24 seconds of low gravity test time were indicated with a drag shield which allowed 15 feet of experiment package longitudinal travel relative to the shield.

The effects of changes in longitudinal aerodynamic stability and wind profile on the drag shield and experiment package dynamics were investigated. A wide range of values for the stability parameter was found to be acceptable. The lateral motion of the experiment package relative to the drag shield was less than .5 ft for the most severe conditions of wind and aerodynamic stability investigated.

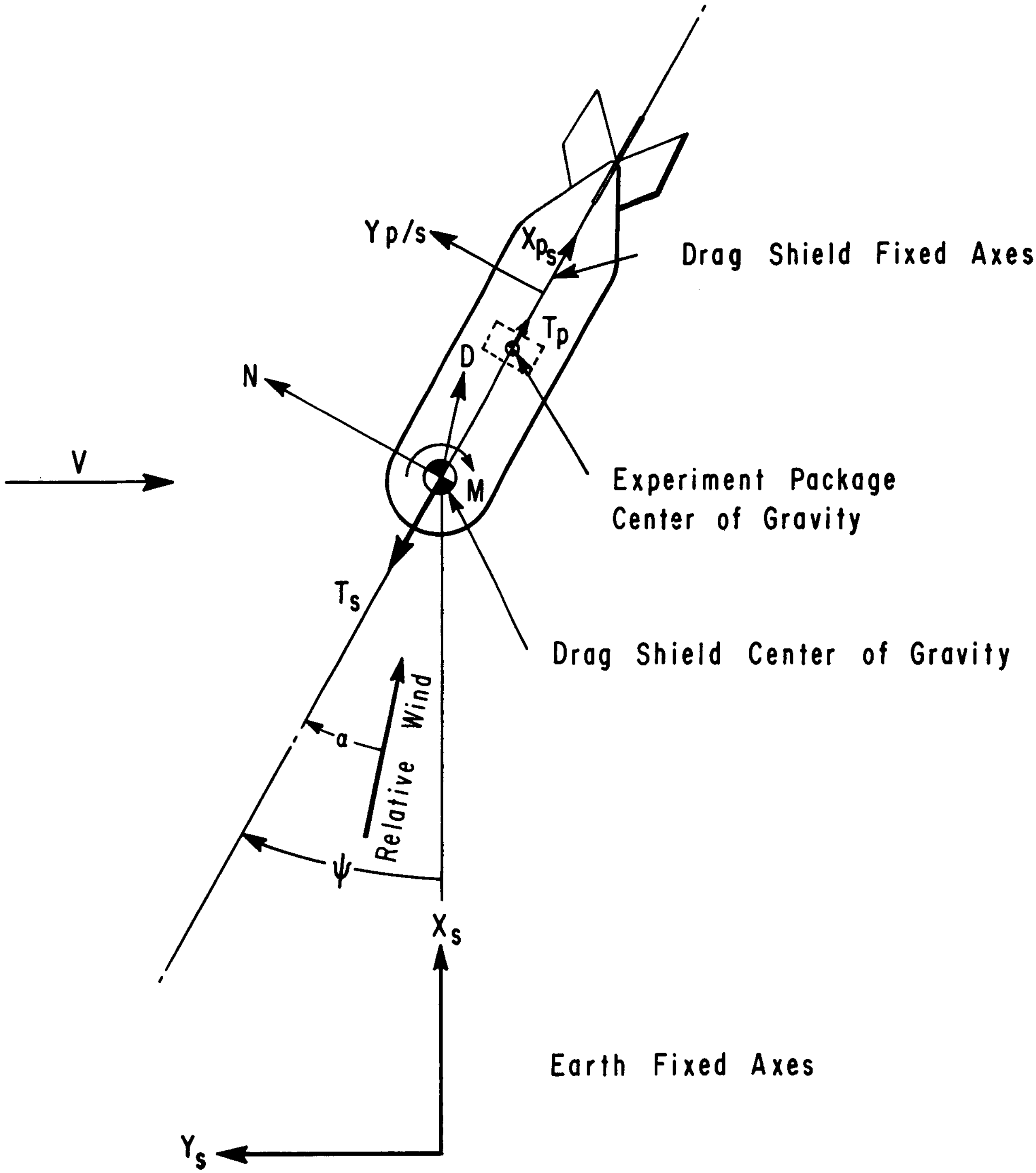

FIG. 1. AXIS SYSTEMS

(ARROWS INDICATE POSITIVE DIRECTIONS)

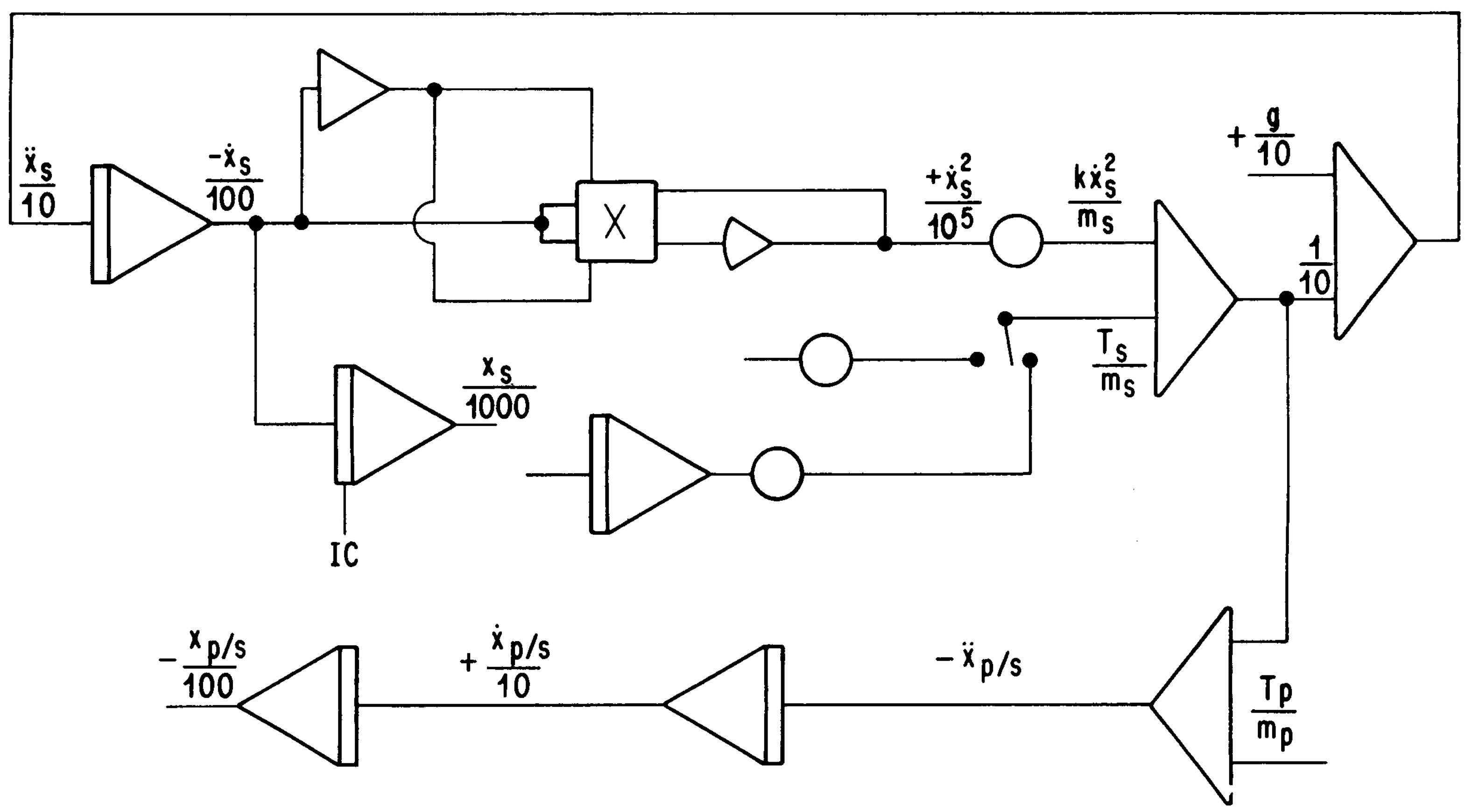

FIG. 2 ANALOG COMPUTER DIAGRAM

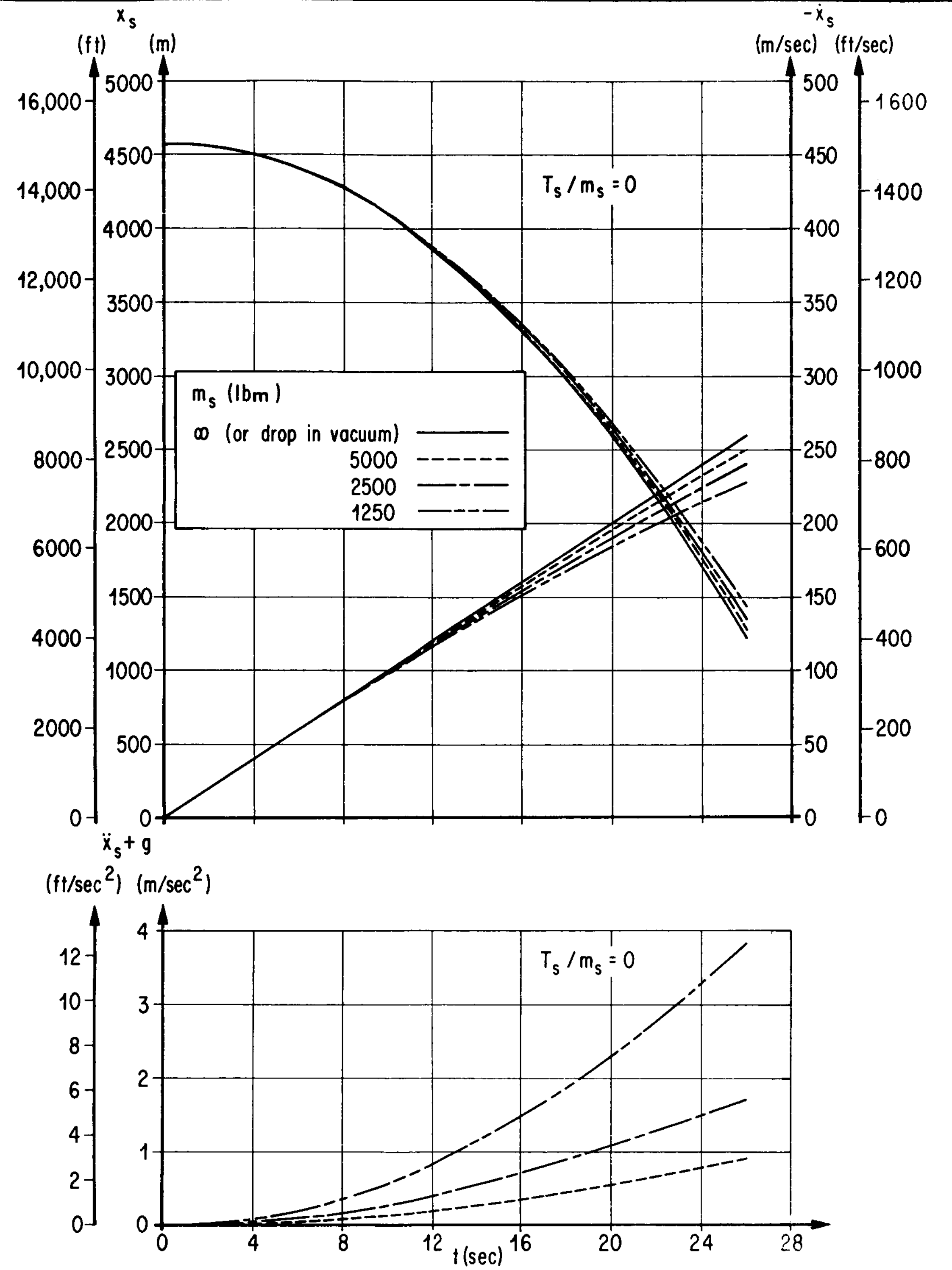

FIG. 3. DRAG SHIELD DYNAMICS
FOR SEVERAL VALUES OF SHIELD MASS WITH $T_s / m_s = 0$

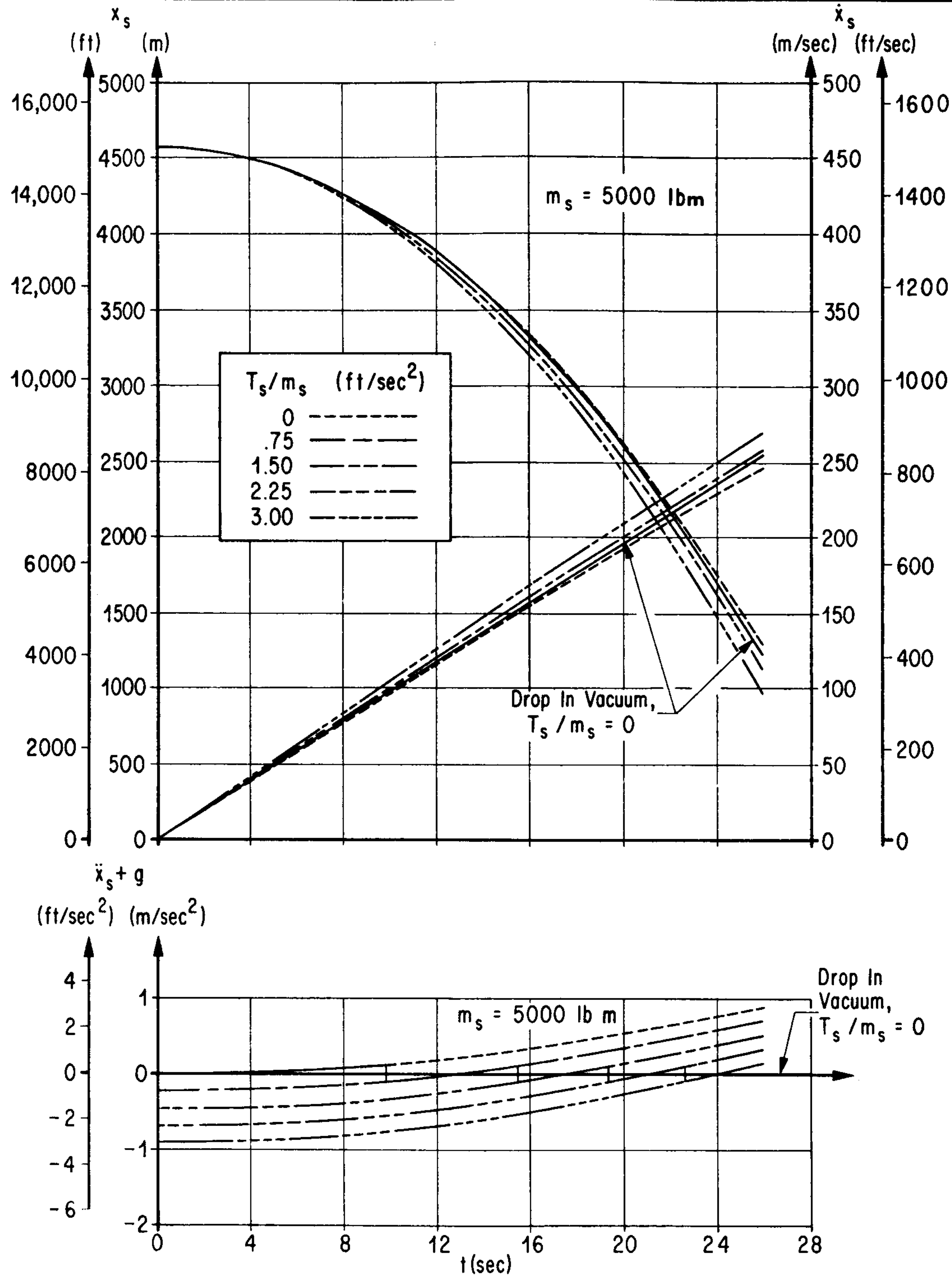

FIG. 4. DRAG SHIELD DYNAMICS
FOR SEVERAL CONSTANT VALUES OF SHIELD THRUST WITH m_s = 5000 lbm

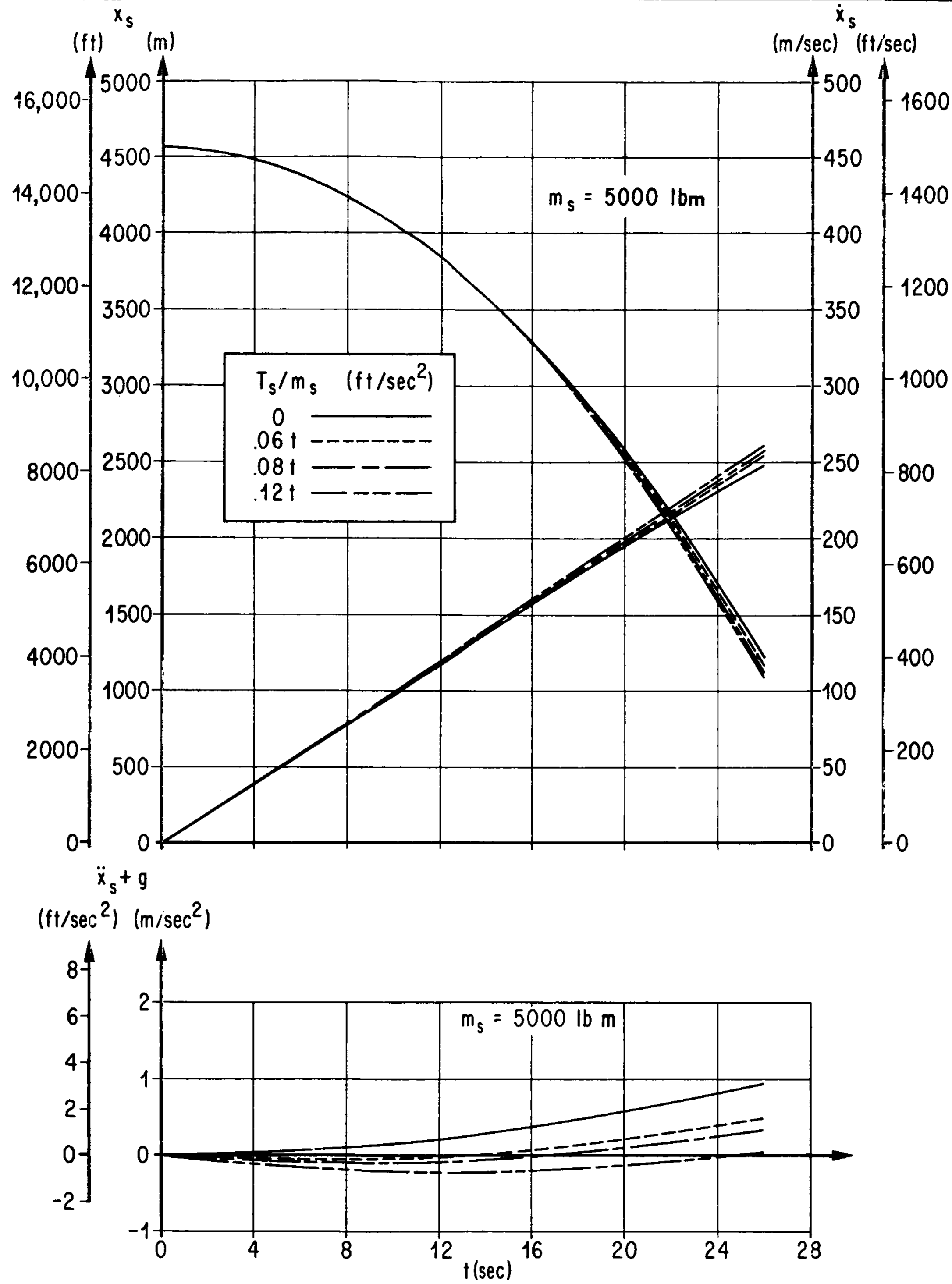

FIG. 5. DRAG SHIELD DYNAMICS
FOR SEVERAL TIME VARYING VALUES OF SHIELD THRUST WITH m_s = 5000 lbm

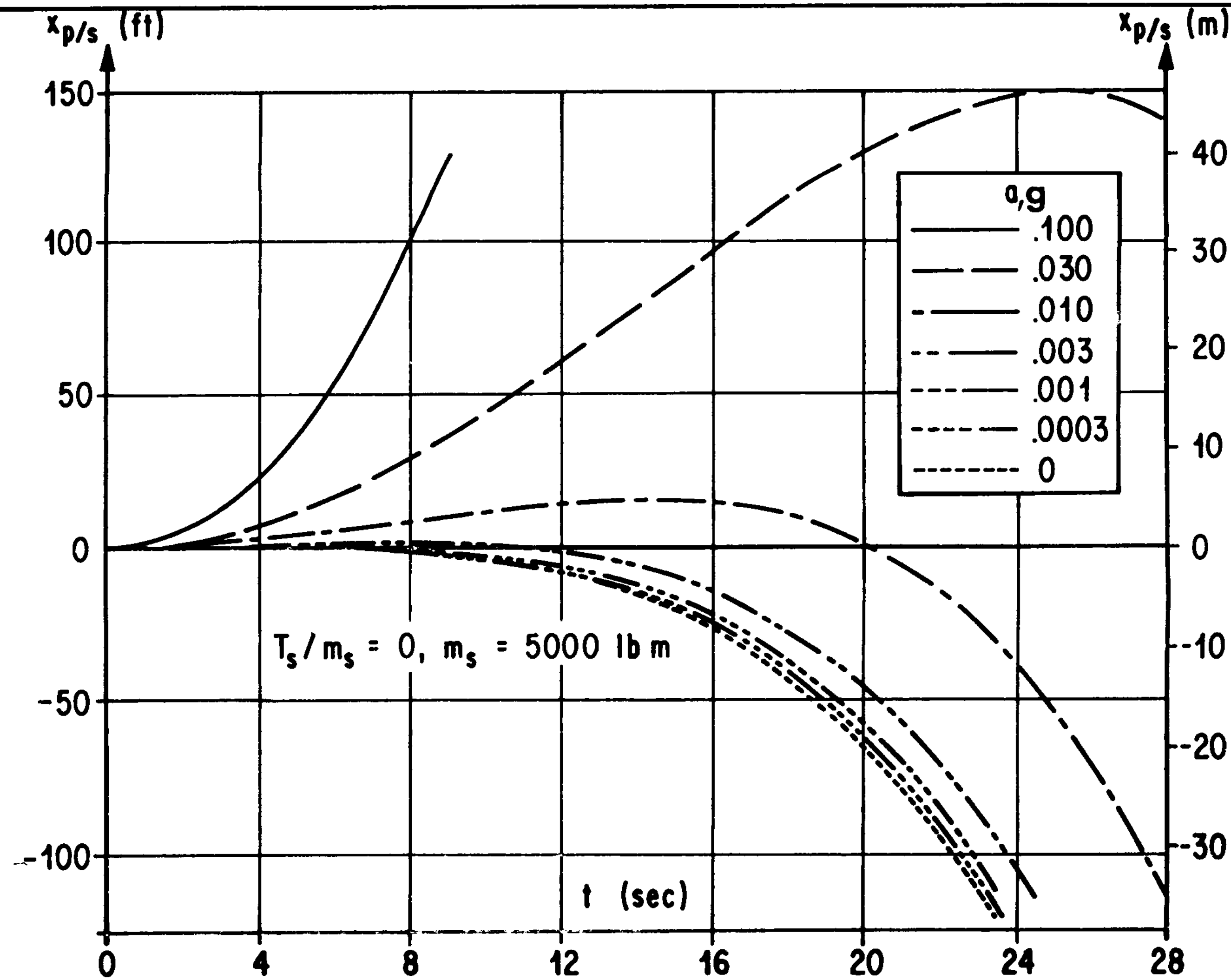

FIG. 6. EFFECT OF TEST ACCELERATION ON DISTANCE TRAVELED BY PACKAGE RELATIVE TO SHIELD

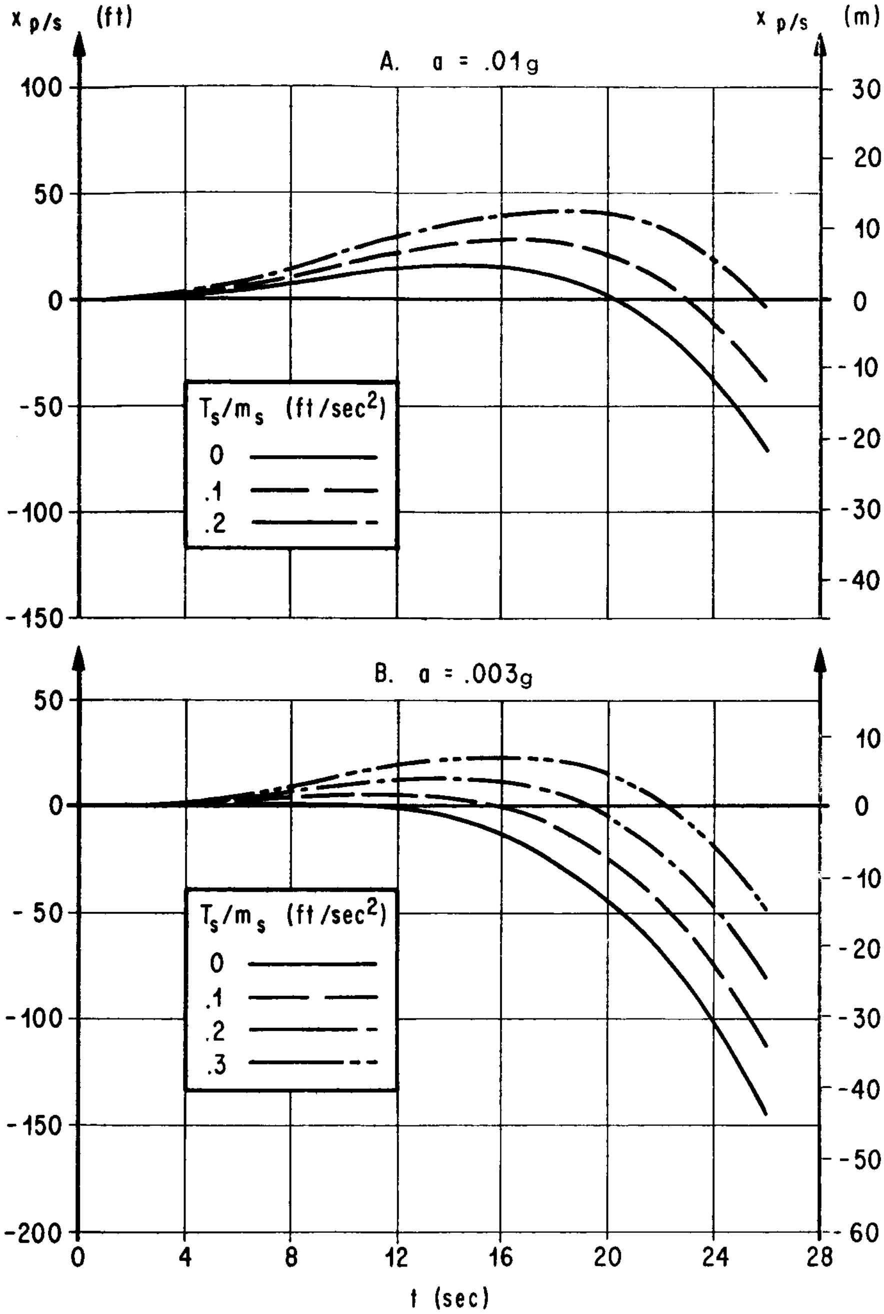

FIG. 7. EFFECT OF CONSTANT SHIELD THRUST ON DISTANCE TRAVELED BY PACKAGE RELATIVE TO SHIELD WITH m_s = 5000 lbm

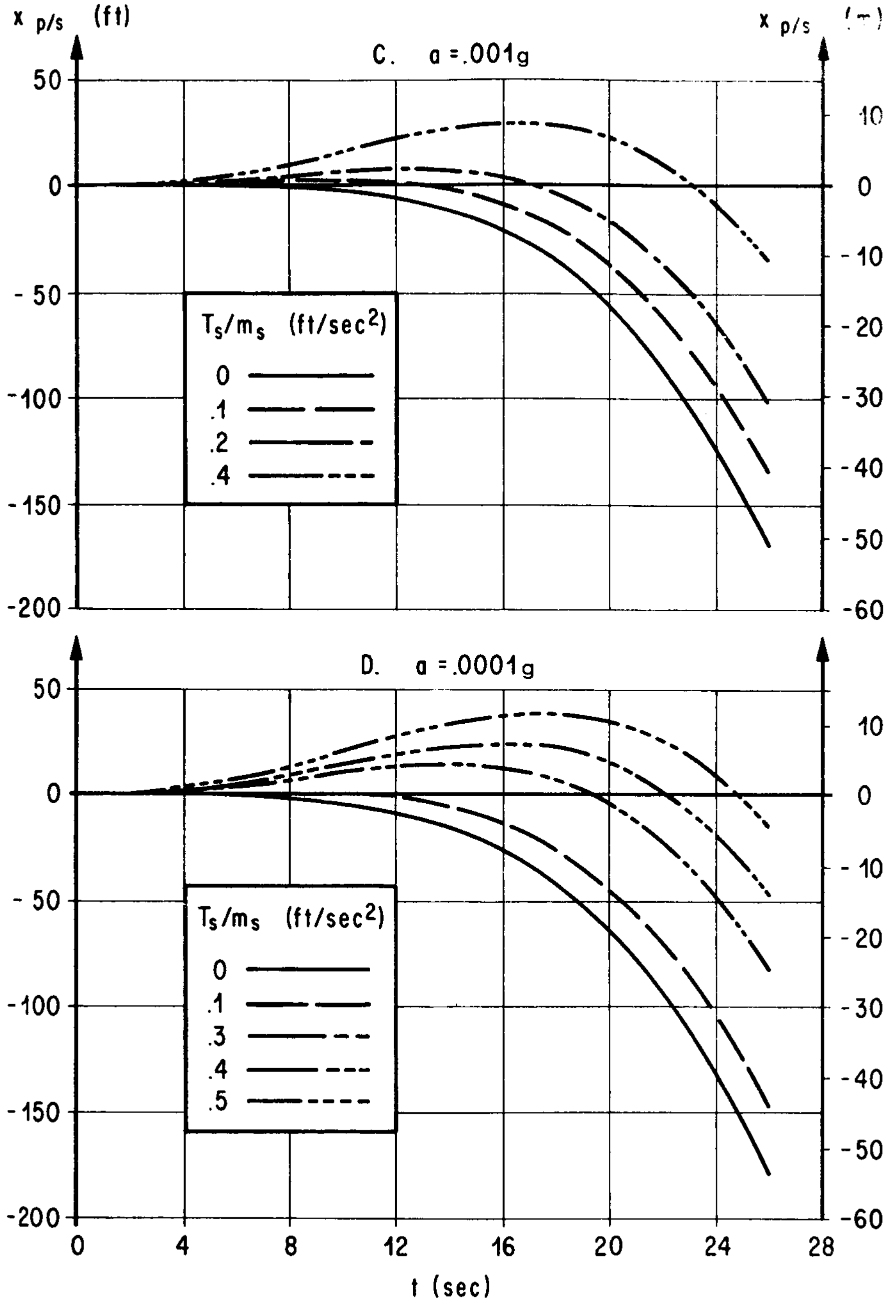

FIG. 7. (continued)

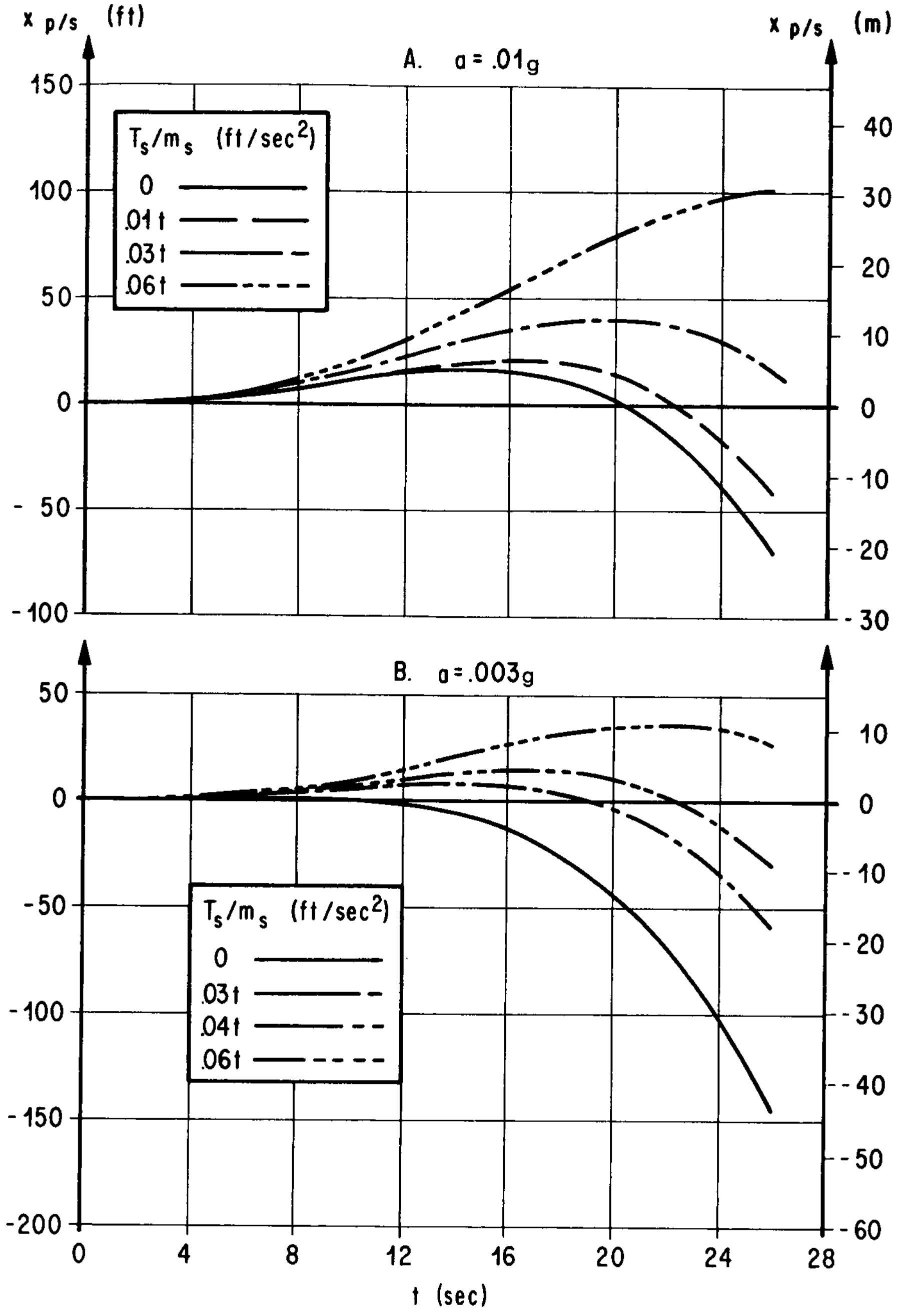

FIG. 8. EFFECT OF TIME-VARYING SHIELD THRUST ON DISTANCE TRAVELED BY PACKAGE RELATIVE TO SHIELD WITH m_s = 5000 lbm

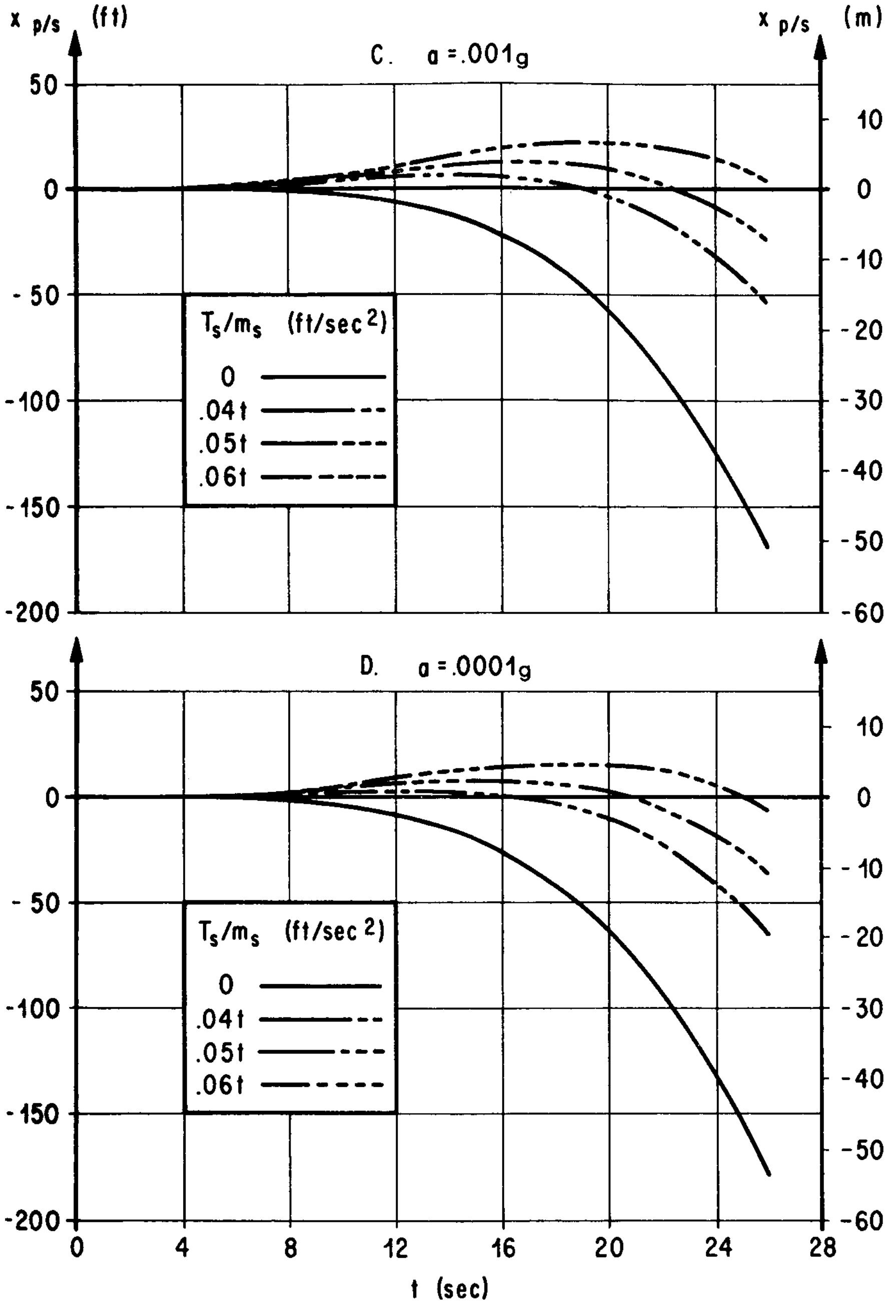

FIG. 8. (continued)

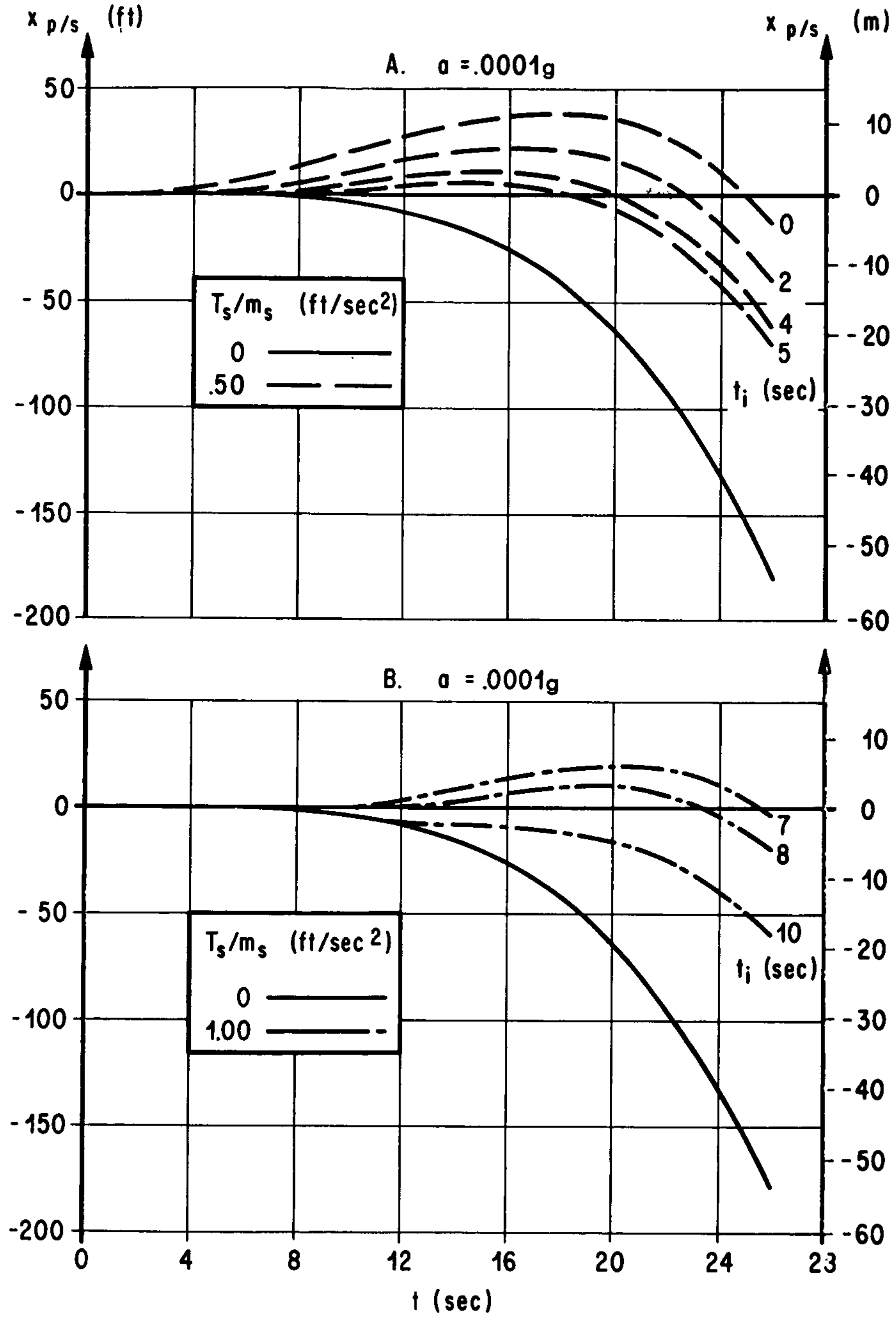

FIG. 9. EFFECT OF DELAYED INITIATION OF CONSTANT SHIELD THRUST WITH m_s = 5000 lbm

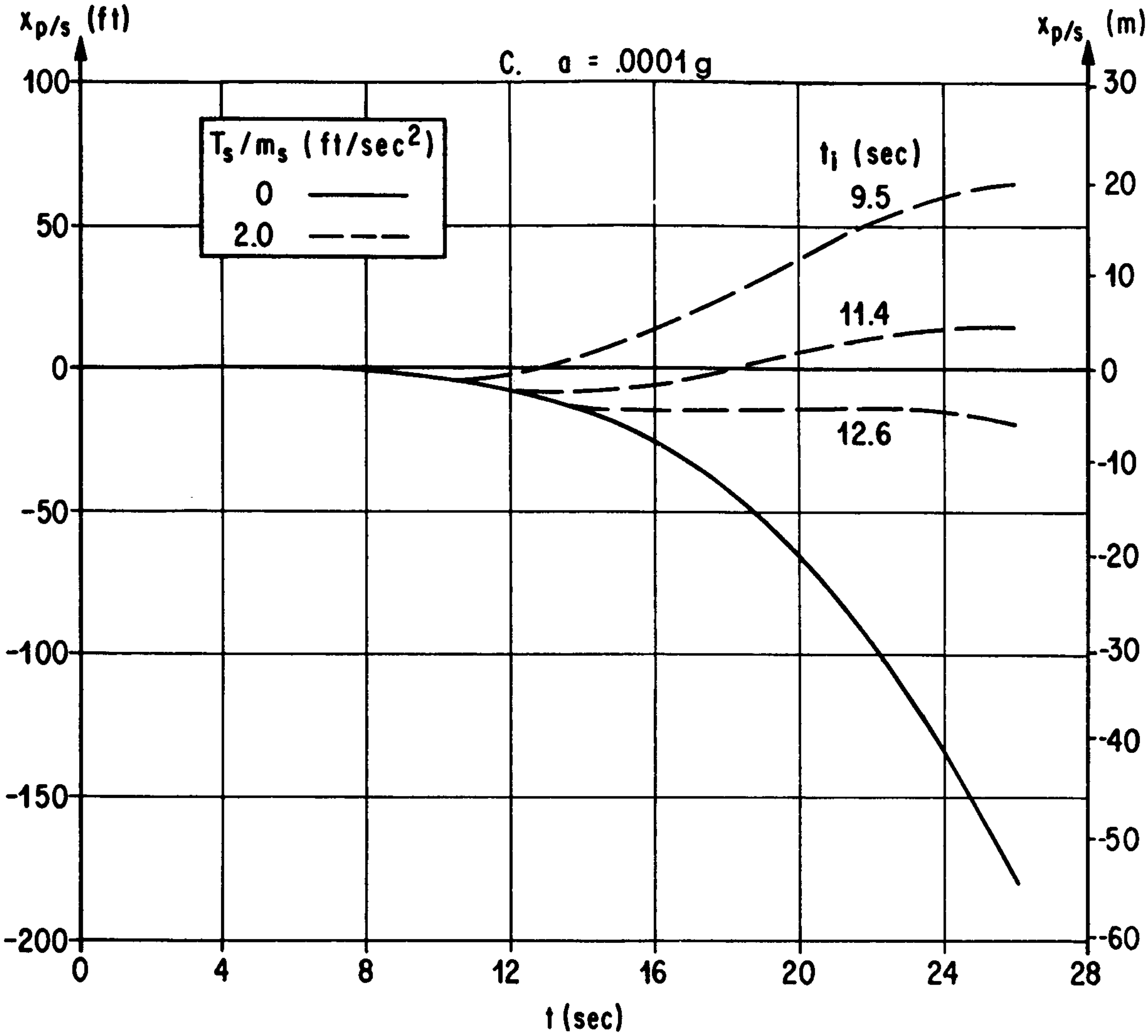

FIG. 9 (continued)

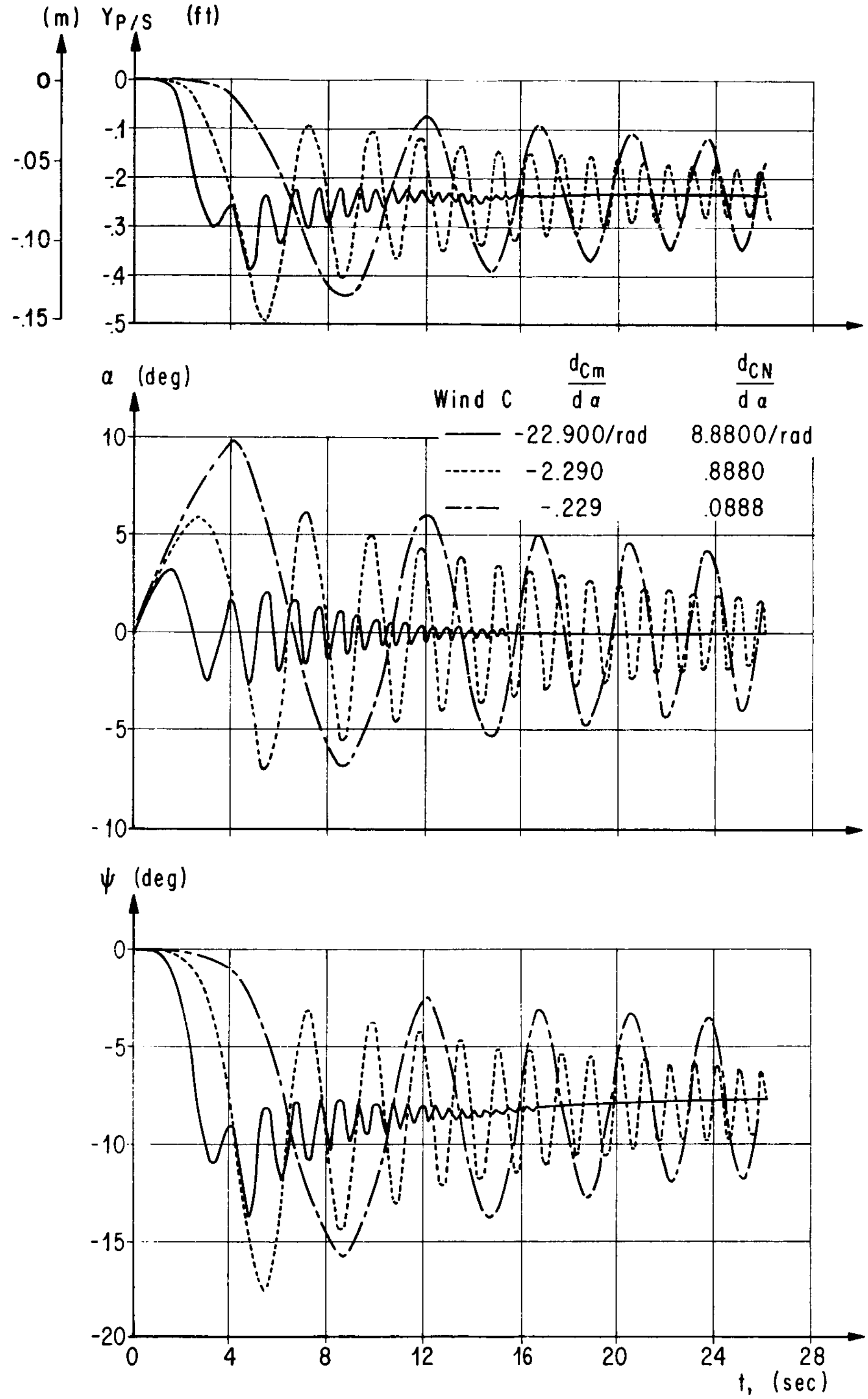

FIG. 10. EFFECT OF LONGITUDINAL AERODYNAMIC STABILITY ON DRAG SHIELD DYNAMICS

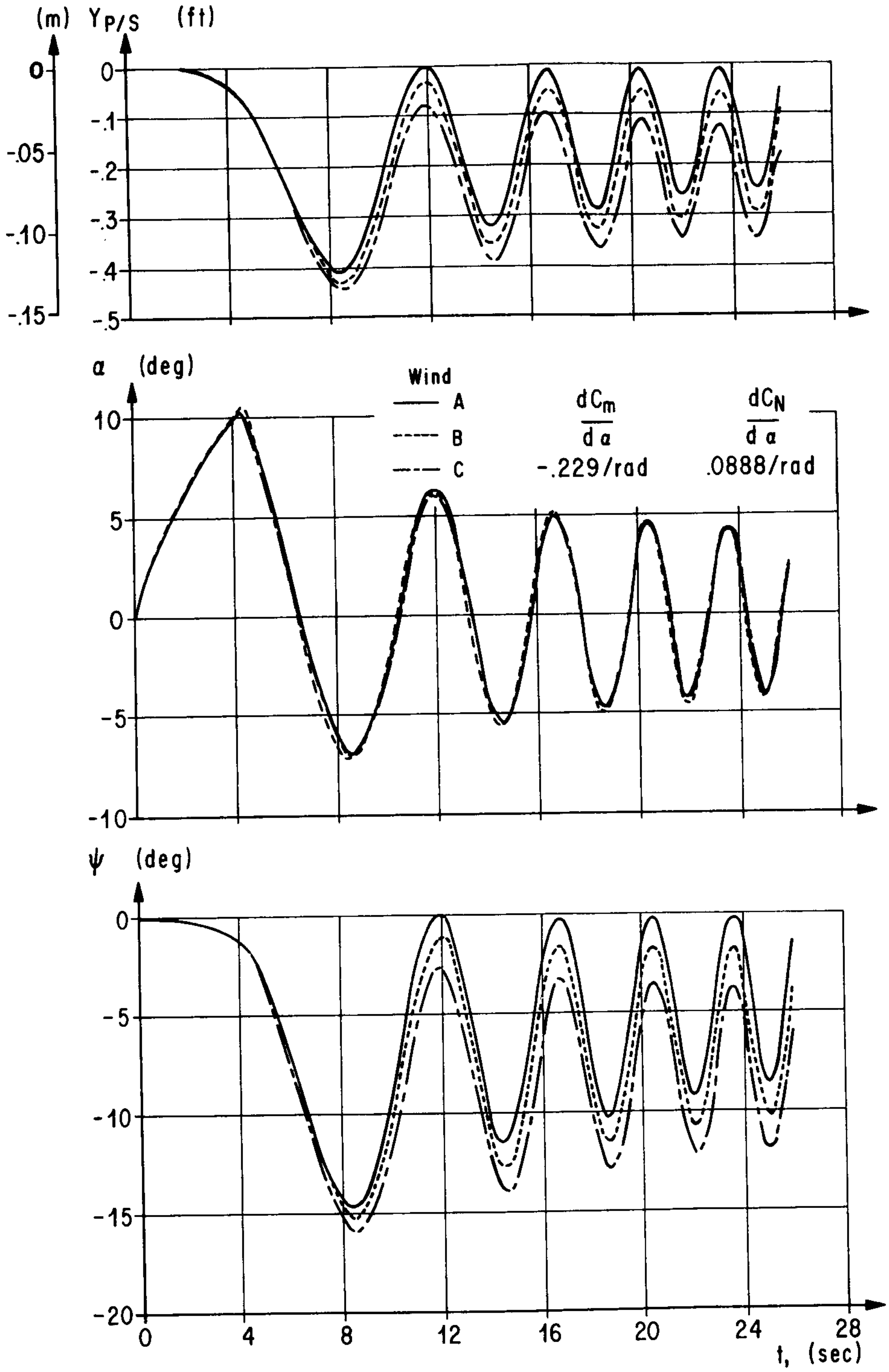

FIG. 11. EFFECT OF WIND PROFILE ON DRAG SHIELD DYNAMICS

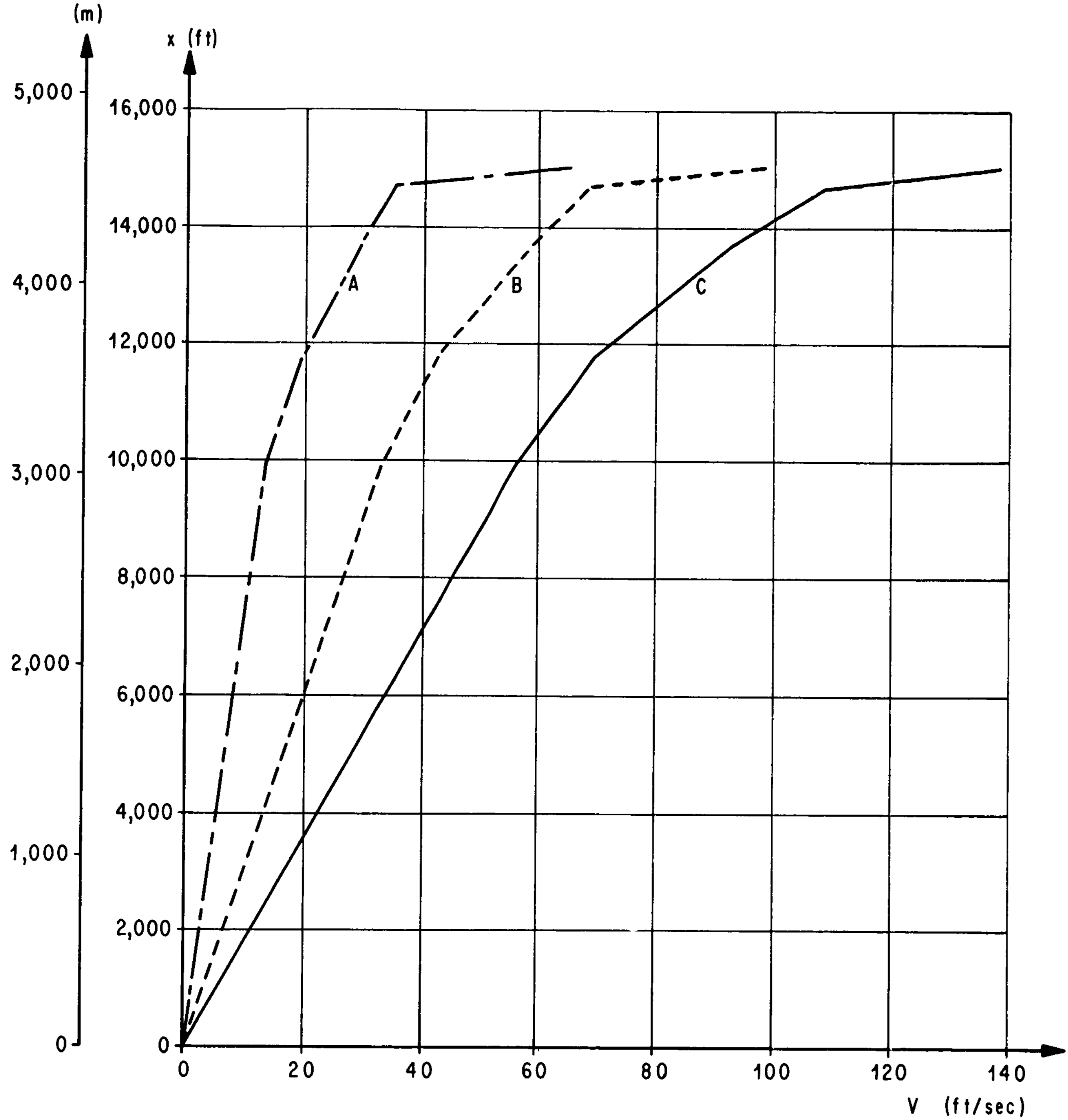

FIG. 12. SYNTHETIC WIND PROFILES

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APPENDIX

Effect of Winds

The effect of wind on the dynamics of the falling drag shield was studied using wind data from reference 3. The normal force coefficients and pitching moment coefficients of the finned launch vehicle in reference 4 were taken as typical values and were reduced in magnitude to represent values which should be obtainable with the drag shield. Drops were simulated using the following equations with the assumption that ψ and α were small angles.

$$\alpha = \psi - \tan^{-1}\left(\frac{V + \dot{y}_s}{-\dot{x}_s}\right)$$

$$I\,\ddot{\psi} - K_2\,\dot{x}_s^2\,\alpha = 0$$

$$m_s\ddot{y}_s - K_3\,\dot{x}_s^2\,\alpha = 0$$

$$m_s\ddot{x}_s - K_1\,\dot{x}_s^2 + m_s g = 0,$$

$$y_{p/s} = \dot{y}_{s_o} t - y_s$$

where

$$K_2 = \frac{1}{2}\,\rho\,A\,\bar{c}\,\frac{dC_m}{d\alpha}$$

$$K_3 = \frac{1}{2}\,\rho\,A\,\frac{dC_N}{d\alpha}$$

$$K_1 = \frac{1}{2}\,\rho\,A\,C_D.$$

The constants used were

$$I = 3229 \text{ lb-sec}^2\text{-ft}$$

$$m_s = 155\ \frac{\text{lbf-sec}^2}{\text{ft}}$$

$$g = 32.17 \quad ft/sec^2$$

$$\rho = .00238 \ lbf\text{-}sec^2/ft^4$$

$$A = 19.63 \ ft^2$$

$$\bar{c} = 5 \ ft.$$

The initial conditions for the simulated drops were

$$x_s = 15,000 \ ft$$

$$\dot{x}_s = 0$$

$$\dot{y}_{s_o} = -V.$$

The values of $dC_m/d\alpha$, $dC_N/d\alpha$, and V used are shown on figures 10, 11, and 12.

REFERENCES

1. Marks, Mechanical Engineers Handbook, Sixth Edition, McGraw-Hill Book Company, Inc., New York, 1958.

2. Hoerner, Fluid-Dynamic Drag, published by the author, New Jersey, 1958.

3. Daniels, Scoggins and Smith, "Terrestrial Environment (Climatic) Criteria Guidelines for Use in Space Vehicle Development, 1966 Revision," NASA TM X-53328, 1966, MSFC, Huntsville, Alabama.

4. Kelly and Keynton, "Transonic Wind Tunnel Investigation of the Static Aerodynamic Characteristics of Several Configurations of the Blue Scout Launch Vehicle," NASA TN D-1958, September 1963.

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By Frank Bugg

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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