Report 2202

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STORE SEPARATION INVESTIGATIONS BY GRID METHOD USING WIND TUNNEL DATA

by

Millard J. Bamber

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AERODYNAMICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

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SYMBOLS

A	coefficient in the interpolation formula for the squared terms
B	coefficient in the interpolation formula for the linear terms
b	reference length (store diameter)
F_L	launcher ejector force
F_X	axial force on store, positive forward
F_Y	side force on store, positive to the right
I_Y	moment of inertia of store in pitch
ℓ_s	distance of application of ejector foot ahead of CG of store
N	normal aerodynamic force on store in pounds
t	time in seconds
q	pitching velocity $\frac{d\theta}{dt}$, radians per second
$\dot{q}$	pitching acceleration $\frac{d^2\theta}{dt^2}$, radians per second-squared
V	forward speed of carrier aircraft, feet per second
W	weight of store
X	longitudinal distance (in feet) store moves — positive direction forward with respect to carrier aircraft
Y	lateral distance (in feet) store moves — positive to the right with respect to carrier aircraft
Y′	distance of Y in increments between grid points
Z	vertical distance (in feet) store moves — positive down with respect to carrier aircraft
α	angle of attack, angle between the longitudinal axis of the aircraft and the projection of the resultant wind vector on the XZ-plane, positive pitch up
β	angle of sideslip, angle between the resultant wind vector and its projection on the XZ-plane of the aircraft, positive wind vector from the right

SYMBOLS (Concluded)

γ flight-path angle (angle between the tangent to the path of the CG of the store and the horizontal), positive above the horizontal

$\dot{\gamma}$ time rate of increase of γ , radians per second

Δ increment of angle or displacement between grid points

θ attitude of the store (angle between the longitudinal reference line of the store and the horizontal); positive, nose of store up

ϕ angle of roll (angle that the aircraft has rotated about its X-axis from the position of Y-axis horizontal), positive clockwise

C_N normal force coefficient

C_A axial force coefficient

C_Y side force coefficient

C_l rolling moment coefficient

C_m pitching moment coefficient

C_n yawing moment coefficient

Subscripts

a carrier aircraft

o zero time, or zero reference points on grid

$A_{(\ )}$ term to be multiplied by $(\ )^2$

$B_{(\ )}$ term to be multiplied by ( )

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SUMMARY

A system was developed to obtain and process wind-tunnel test data on a store in the presence of an airplane, so that the data could be used by a digital computer to predict store separation characteristics following launch. A separation was computed by the grid method using these data, for comparison with a trajectory obtained by the point prediction method. These trajectories were in good agreement.

Trajectories were also analyzed to determine the effect of various separation parameters.

INTRODUCTION

A comparison of a "grid" with a "point prediction" method for obtaining aircraft store separation characteristics from wind-tunnel investigations was reported in Reference 1. It was concluded that a combination of the two methods would be superior to either alone. Because the grid method requires the accumulation and processing of a large amount of data, the prediction of separation characteristics cannot be made as the testing progresses, as is done with the point prediction method. The basic problem with the grid method is the time required to obtain and process wind tunnel data to a form that is suitable for use by an electronic computer.

This report deals with a system for processing the data, a comparison of separation characteristics obtained by the grid method with one obtained by the point prediction method, and the effects of changes in some parameters on the characteristics of the separation.

PROCEDURE FOR PROCESSING DATA

Because of variations of airflow produced by carrier aircraft on a store, combined with the six degrees of freedom of the store, a large amount of testing and data handling is required. In order to keep the amount of data required within reason, the procedure described below is used.

An example of the relations used for computing the value of a particular coefficient (C_N , for example) in this report is given in Appendix A. These relations are based on the assumption that changes in C_N with α, X, and Z are independent of each other, and at a particular value of α, X, and Z, the effects of Y, β, and ϕ are independent of each other; that is, the effects of each displacement can be represented by partial derivatives. For this investigation, it was expected that the range of the values of α, X, and Z would be large and would have a greater effect on the trajectories than would Y, β, or ϕ. To further limit the amount of data required to be accumulated, the effects of Y, β, and ϕ were obtained only at every other value of α, X, and Z of the grid.

The basic method of the grid is to use three consecutive points of one variable at a time; the other quantities are assumed constant. Because the effects of Y, β, and ϕ are measured at every other grid point, the smallest complete unit grid is 5 × 5 × 5. A grid representing the values of α, X, and Z as lengths in a cube is shown in Figure 1.

In order to organize the data, grid points are numbered starting with point 111. The number 111 indicates the most negative value of each variable. Throughout the data handling process, the values of each of the increments are kept constant. Extension of the basic 5 × 5 × 5 grid may be made by adding two increments. For example, the computer treats a 5 × 7 × 5 grid, as shown in Figure 1, as two overlapping 5 × 5 × 5 grids. Overlapping of the computations results; but the excess data are not used when computing separations.

As an example of interpolations between three consecutive points, the relationship between lateral movement Y and side-force coefficient C_Y is used. If Y' represents the distance in incremental units between the midpoint ($0\Delta Y$) and the end points ($+\Delta Y$ and $-\Delta Y$) of the interval, then

$$C_Y = A_Y(Y')^2 + B_Y(Y') + C_{0\Delta Y} \qquad [2]$$

The coefficients A_Y and B_Y are given by:

$$A_Y = \frac{C_{Y_{(+\Delta Y)}} + C_{Y_{(-\Delta Y)}}}{2} - C_{Y_{(0\Delta Y)}}$$

$$B_Y = \frac{C_{Y_{(+\Delta Y)}} - C_{Y_{(-\Delta Y)}}}{2} \qquad [3]$$

A sample of the interpolation is shown in Figure 2.

This same procedure is used for all six aerodynamic coefficients for the displacements X, Y, and Z and angles α, β, and ϕ to estimate the values of the coefficients A and B for Y, β, and ϕ at grid points like 121, 141, etc. (at which data were obtained only for the condition Y, β, and ϕ equal to 0). The effect of α, X, and Z upon the coefficients A_Y and B_Y (for example) are assumed to be linear, and are given by:

$$A_{Y_\alpha} = \frac{1}{2}\left(A_{Y_{\alpha(+\Delta\alpha)}} - A_{Y_{\alpha(-\Delta\alpha)}}\right)$$

$$B_{Y_\alpha} = \frac{1}{2}\left(B_{Y_{\alpha(+\Delta\alpha)}} - B_{Y_{\alpha(-\Delta\alpha)}}\right) \qquad [4]$$

The computer is programmed to sort and tag aerodynamic data for use in the 5 X 5 X 5 grids. The values of A and B for variations with Y, β, and ϕ are then computed using the relations of Equation [4]. These values of A and B are then interpolated at the points of the grid like points 142, 144, etc. that had data only with Y, β, and $\phi = 0$. The points used were those along lines through points like 111 → 151; 131 → 135; 115 → 151; 111 → 515; 115 → 551; etc.

Using these values of A and B and the measured data with Y, β, and $\phi = 0$, all of the values of the A's and B's in relation [4] were computed.

This information is stored on tapes ready for the trajectory program. The relations for obtaining aerodynamic coefficients at specific values of displacement and attitude are given in Appendix A.

Some plotting and fairing of data had to be done by hand in order to extrapolate for the displacements in Z and α that were not obtainable because of mechanical interference between the store or the store support system and the carrier aircraft or its support system. Because a value of β of -5° could not be attained by the store support system and also because the bomb was stored on the center line of the airplane, the values of the coefficients from the $+\Delta\beta$ data tests were used for $-\Delta\beta$.

PROCEDURES FOR DETERMINING SEPARATION CHARACTERISTICS

The separation characteristics can be determined by the use of wind-tunnel-test data and suitable equations of motion for the airplane and store. This is accomplished by predicting the attitude and relative position of the airplane and store at successive, small increments of time. At each increment of time aerodynamic data are obtained and used to predict the characteristics for the next increment of time. This process is started at the instant of store release and is continued as long as desired. Most of the relations used for computing the trajectory are given in Reference 2.

The difference between the grid and point prediction methods of obtaining trajectories is the manner in which the aerodynamic data are obtained. For the grid method, the values are interpolated from the grid data at each cycle (time increment) through the computations for the particular store position and attitude and used for the next cycle. For the point prediction method, the values of the aerodynamic data are obtained from direct wind tunnel measurement for the particular conditions computed. The wind tunnel data are used to estimate values for new conditions at the start of every cycle by using the rate of change of the coefficients measured in free air. In this way, the interruptions in computations for wind tunnel testing can be kept to a tolerable amount.

DATA ACQUISITION

Data used in this report were obtained for models of an airplane and of a store tested in the TMB 7- by 10-Foot Transonic Wind Tunnel. Figure 3 is a photograph showing models of an airplane and a store mounted in the tunnel on separate sting balance support systems. The store support system has six degrees of freedom. The store (bomb) could be positioned at any point along a trajectory from the carry position to regions where it can be assumed that the interference effects of the airplane are negligible.

An ALWAC III-E digital computer was used for the reduction and compilation of test data and for the prediction of the separation characteristics.

The models were tested for the conditions given in Table 1. The grid consisted of seven values of α, five values of X, and seven values of Z. There should be 245 test points with Y, β, and $\phi = 0$. For values of $\pm Y$, $+\beta$ and $\pm\phi$ not zero, there should be 240 points. A total of 541 test points were taken, which included 53 check points. These data are on file with Aerodynamics Laboratory, and are available upon request. The actual testing time was about 16 hours. Computer time to reduce the data to the form used for the separation computations would be about 20 hours. This includes the time required for the necessary extrapolation of the data into the small and negative Z values. It does not include the time to examine test data for irregularities. The computer time for each separation averaged about one and one-half hours. The time required to obtain a separation by the point prediction method has never been less than two hours.

ACCURACY

The accuracy of the separation characteristics as predicted from wind tunnel data is dependent upon the test data and how well it represents full-scale conditions, upon the stability derivatives, and upon the degree of refinement of the mathematical relations used. Because the difference in airspeeds between bomb and airplane in actual flight for the conditions of this investigation was nil, it caused no error. Because the different flight paths of the store and aircraft during separation cannot be duplicated in the wind tunnel, either the geometric angle between the carrier and store or the angle of attack must be different. This difference is equal to the difference in flight-path angles. (The bomb was positioned for the correct angle of attack.)

PRESENTATION OF DATA

Separation characteristics obtained by the point prediction method and by the grid method are given in Figure 4. For the variables given in Table 2, the values of θ, γ, and Z obtained at times 0.050, 0.100, and 0.150 second are given in Figures 5 through 9. The "additional" values of the parameters were changed only one at a time; all others were "standard."

Figure 10 presents the values of ΔZ, α, θ, and γ plotted against time for the condition of launcher force applied 0.125 foot aft of the CG.

For all of the data given no reference is made to Y, β, ϕ, or X because they are too small to be of consequence.

DISCUSSION

The separation characteristics obtained by the grid and the point prediction methods appear to be well within reasonable limits. (See Figure 4.) The values of the coefficients C_N and C_m obtained by the two methods are generally within ±0.05. This seemingly large difference is not surprising because the probable balance accuracy is ±0.05. Also, for the grid data, the contributions of α, X, and Z were considered to be independent of each other and, in addition, nearly all of these data had to be obtained by extrapolation to the values of Z required.

The variations of θ, α, and Z at fixed intervals of time are believed to give a good indication of the effects of different bomb and launcher characteristics. (See Figures 5 through 9.) For this particular "standard" trajectory, changing the damping in pitching, $\frac{\partial C_m}{\partial\left(\frac{qb}{2V}\right)}$ from 0 to -1.5 had no effect. In fact, using zero for all aerodynamic coefficients changed the trajectory very little (see Figure 5). It follows that the comparatively small changes in aerodynamic coefficients produced by the interference of the airplane or the bomb would produce very small changes in the separation characteristics. The characteristics obtained, therefore, are very nearly those that could have been predicted purely from the weight, mass, and moment of inertia of the bomb and the ejector force of the launcher. It is unfortunate that the store was so insensitive to aerodynamic forces in comparison with the launcher force and the weight and mass of the store. Also, because the store was mounted symmetrically with respect to the airplane, all lateral forces and moments were too small to have any meaningful effect on the trajectories.

The force of the launcher acting at 0.5 foot behind the center of gravity ("standard" condition) gave the bomb such a large pitching-up moment that in most cases the angle of pitch soon became greater than the test data available. See Figure 8.

With the launcher force applied 0.125 foot behind the center of gravity, the computations could be continued until the bomb had dropped to the limit of the grid used, 12 feet. See Figure 10.

The outstanding advantage of the "point prediction" method is that it will give a trajectory in a short time. The outstanding advantages of the "grid" method are:

1. It is not necessary to coordinate wind-tunnel operation with the computer.

2. One set of grid data can be used to investigate a number of store and launcher characteristics.

3. Grid data are suitable for study of the flow field about the airplane.

The time required to obtain trajectories as given here means little because now an SDS 930 computer will be used. This will reduce the computation time and will be to the advantage of both methods. The new computer will not reduce the time spent in coordinating the tunnel and computer, nor will it help with the time to obtain data for the grid.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
March 1966

APPENDIX A

RELATION FOR COMPUTING THE VALUE OF C_N AS USED IN THIS REPORT

$$
\begin{aligned}
C_N = C_{N_o} &+ \left[A_{N_\alpha}\alpha' + B_{N_\alpha}\right]\alpha' + \left[A_{N_X}X' + B_{N_X}\right]X' \\
&+ \left[A_{N_Z}Z' + B_{N_Z}\right]Z' \\
&+ \left[A_{N_\phi} + A_{N_{\phi_\alpha}}\alpha' + A_{N_{\phi_X}}X' + A_{N_{\phi_Z}}Z'\right](\phi')^2 \\
&+ \left[B_{N_\phi} + B_{N_{\phi_\alpha}}\alpha' + B_{N_{\phi_X}}X' + B_{N_{\phi_Z}}Z'\right]\phi' \\
&+ \left[A_{N_\beta} + A_{N_{\beta_\alpha}}\alpha' + A_{N_{\beta_X}}X' + A_{N_{\beta_Z}}Z'\right](\beta')^2 \\
&+ \left[B_{N_\beta} + B_{N_{\beta_\alpha}}\alpha' + B_{N_{\beta_X}}X' + B_{N_{\beta_Z}}Z'\right]\beta' \\
&+ \left[A_{N_Y} + A_{N_{Y_\alpha}}\alpha' + A_{N_{Y_X}}X' + A_{N_{Y_Z}}Z'\right](Y')^2 \\
&+ \left[B_{N_Y} + B_{N_{Y_\alpha}}\alpha' + B_{N_{Y_X}}X' + B_{N_{Y_Z}}Z'\right]Y'
\end{aligned}
$$

Prime (′) denotes the displacement from the grid test point in grid increments, Δ's.

REFERENCES

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2. Nichols, James H., Jr. A Method for Computing Trajectories of Store Launched From Aircraft. Wash., Nov 1964. 29 p. incl. illus. (David Taylor Model Basin. Rpt. 1878. Aero Rpt. 1079) (AD 612,515)

Table 1

Full-Scale Conditions Assumed for Store Separation Tests

[Mach number, 0.824; altitude, 37,500 feet.]

Airplane	
Angle of attack α_a, degrees	5.40
Bomb	
Distance from stored position, feet	
X	-2.50, -1.25, 0, 1.25, 2.50
Y	-0.83, 0, 0.83
Z	0.83*, 2.50*, 4.17, 5.83, 7.50, 9.17, 10.83
Angle, degrees	
α	-10.44, -6.96, -3.48, 0, 3.48, 6.96, 10.44
β	0, 5.0
ϕ	-10, 0, 10

Length of ejector stroke: 0.533 foot

*Because of mechanical interference between store and carrier aircraft, these values could not be tested under all configurations.

Table 2

Variables Assumed for Store Separation

Variable	Standard	Additional Values
Angle of attack α_{store} , degrees	4.39	2.39 and 6.39
Weight, pounds	2133	1633 and 2633
Ejection force, pounds	17,300	12,300 and 23,300
Point force is applied on bomb (aft of CG), feet	0.500	-0.125, -0.312, -1.000
X , in feet	0	0.60
I_Y , slug-ft^2	380	280, 480
$\frac{\partial C_m}{\partial\left(\frac{qb}{2V}\right)}$	-0.375	0, -1.500

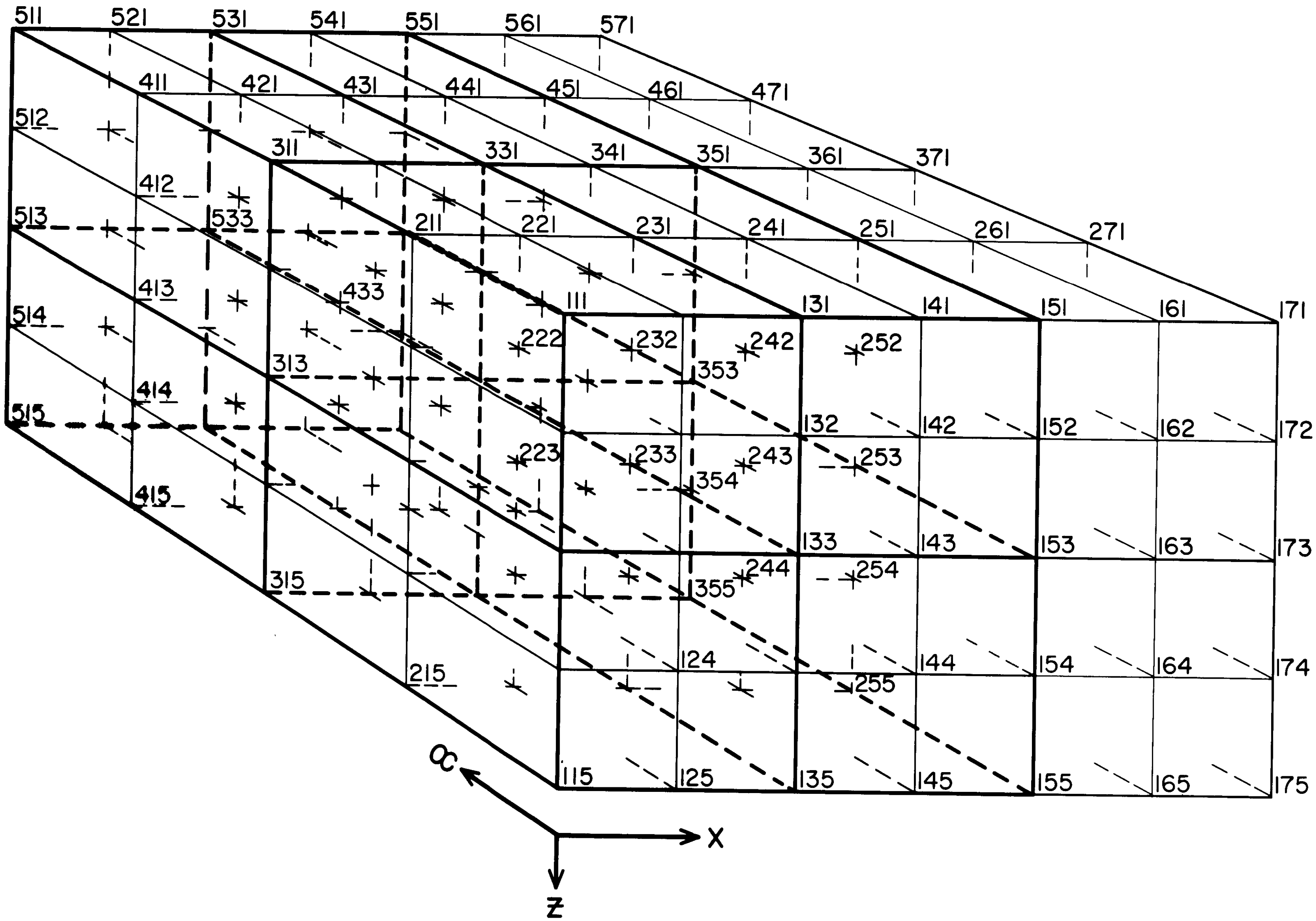
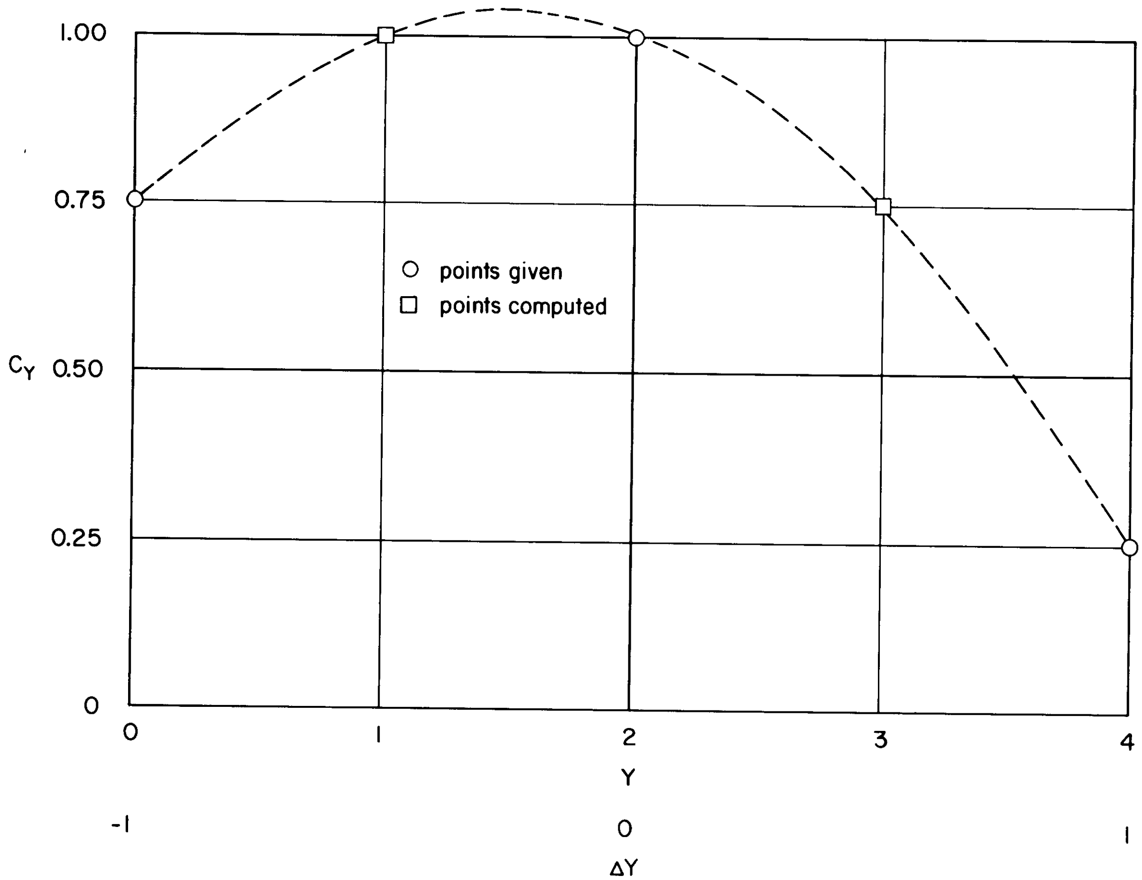


Figure 1 - Store Reference Point Positions and Numbering for a 5x7x5 Grid



$\Delta Y = 2$

$A_Y = \frac{1}{2}(0.25 + 0.75) - 1.0 = -0.50$

$B_Y = \frac{1}{2}(0.25 - 0.75) \qquad = -0.25$

when $Y = 3$ then $Y' = \frac{3-2}{2} = \frac{1}{2}$

and $C_Y = -0.5\left(\frac{1}{2}\right)^2 + (-0.25)\frac{1}{2} + 1 = 0.75$

when $Y = 1$ then $Y' = \frac{1-2}{2} = -\frac{1}{2}$

and $C_Y = -0.5\left(-\frac{1}{2}\right)^2 + (-0.25)\left(-\frac{1}{2}\right) + 1 = 1.00$

Figure 2 - Example of Interpolation

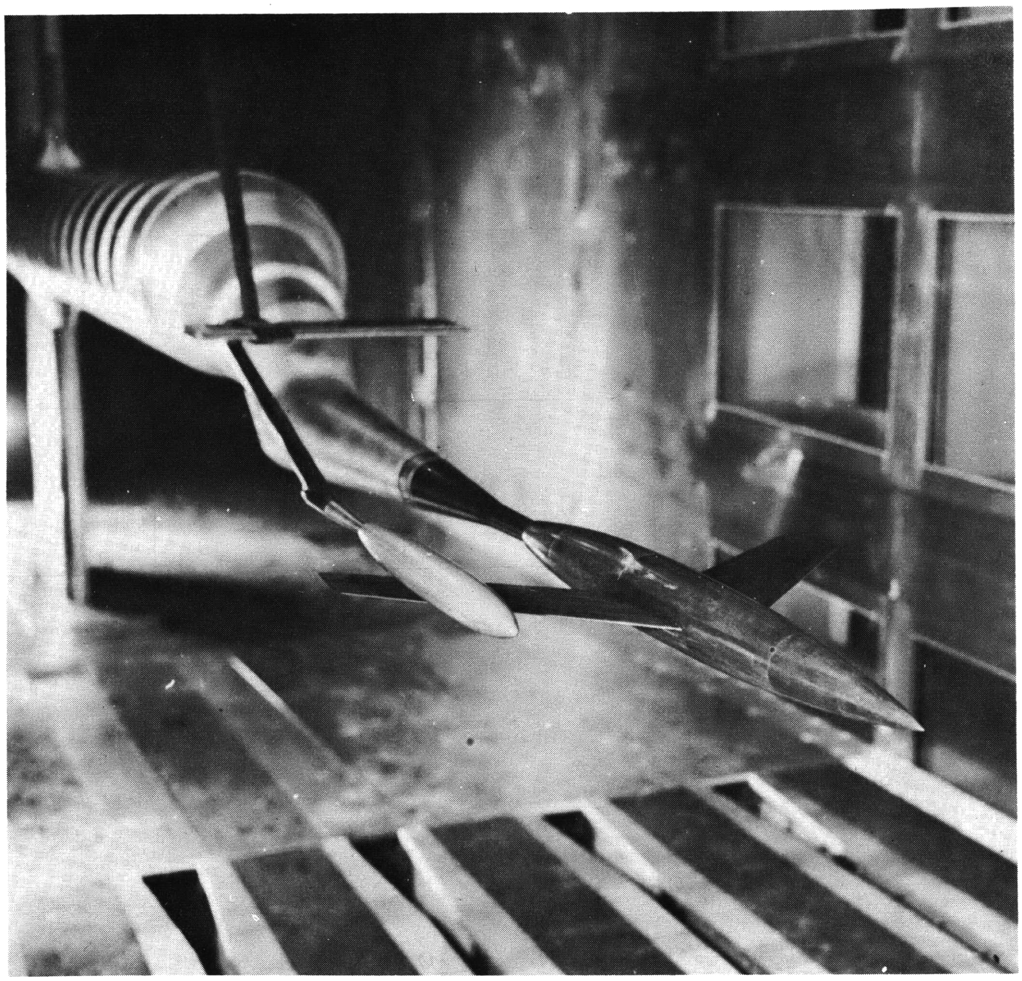


Figure 3 - Photograph of Models of an Airplane and a Bomb (Store) Mounted in the Transonic Wind Tunnel for Separation Testing

PSD-320,552

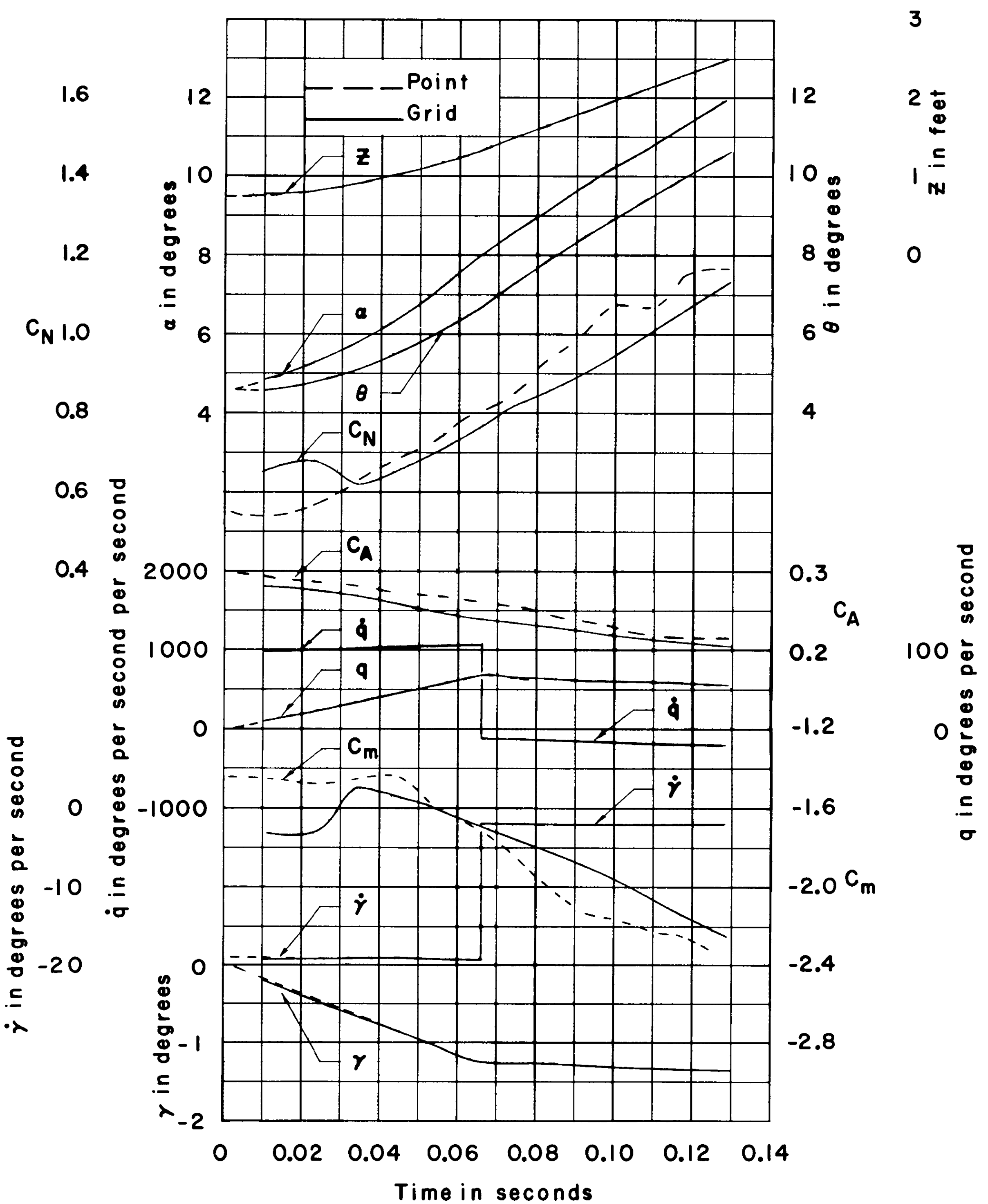


Figure 4 - Characteristics of Trajectories by Point Prediction and Grid Methods

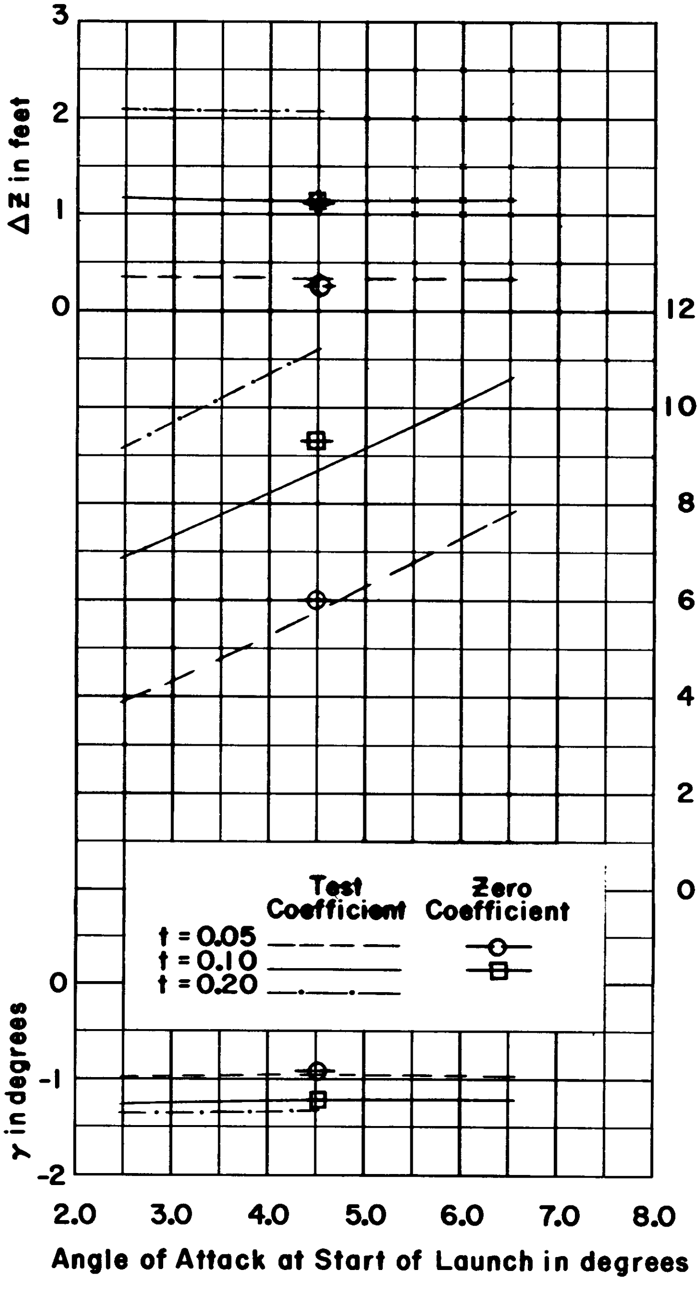


Figure 5 - Effect of Angle of Attack of Bomb in Carry Position and of Making Aerodynamic Coefficients Zero

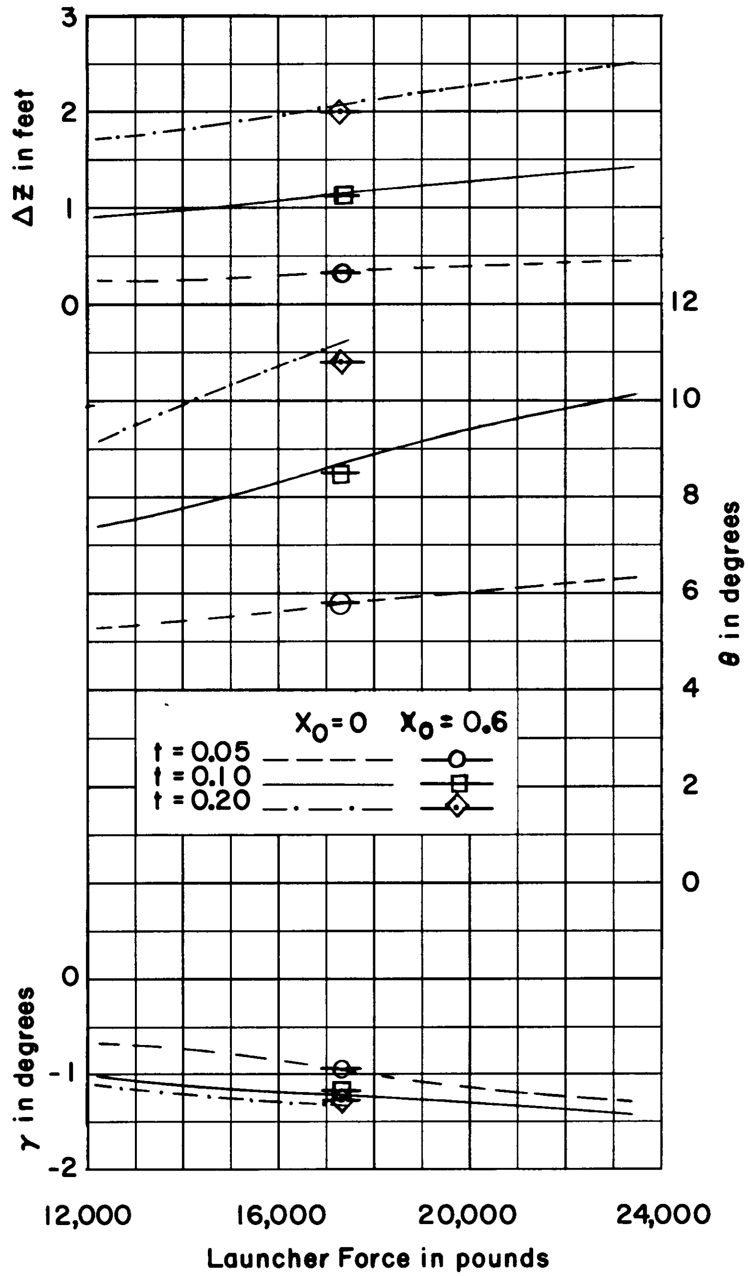


Figure 6 - Effect of Launcher Force and of forward Carry Position

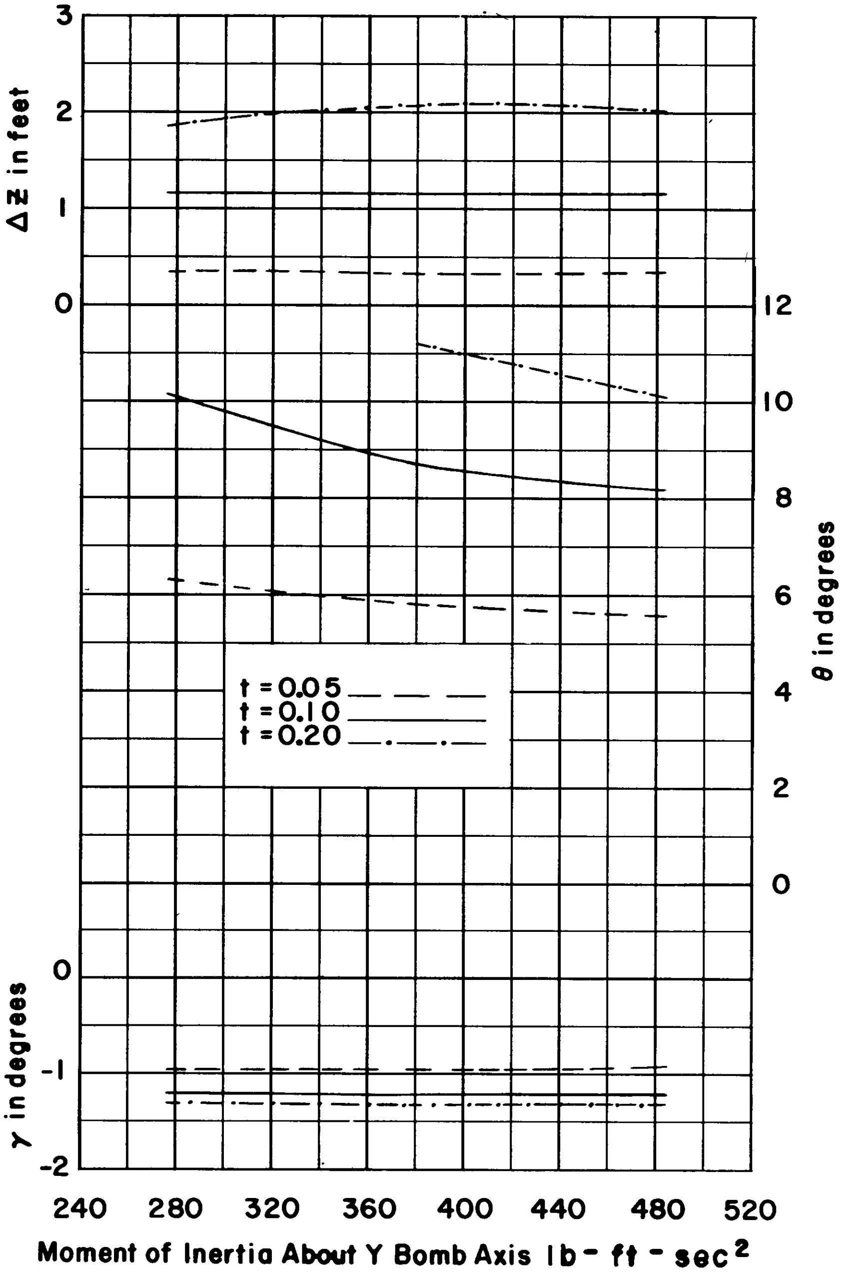


Figure 7 - Effect of Moment of Inertia of Bomb

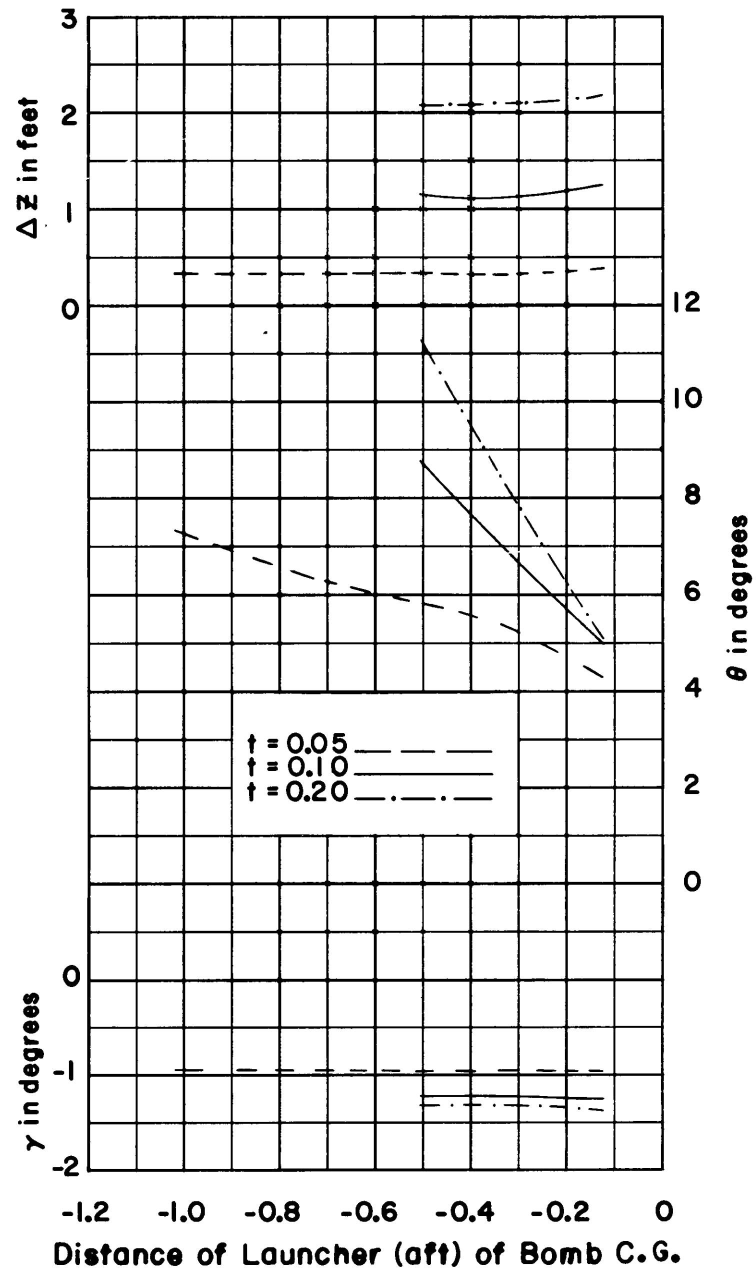


Figure 8 - Effect of Launcher Foot Location

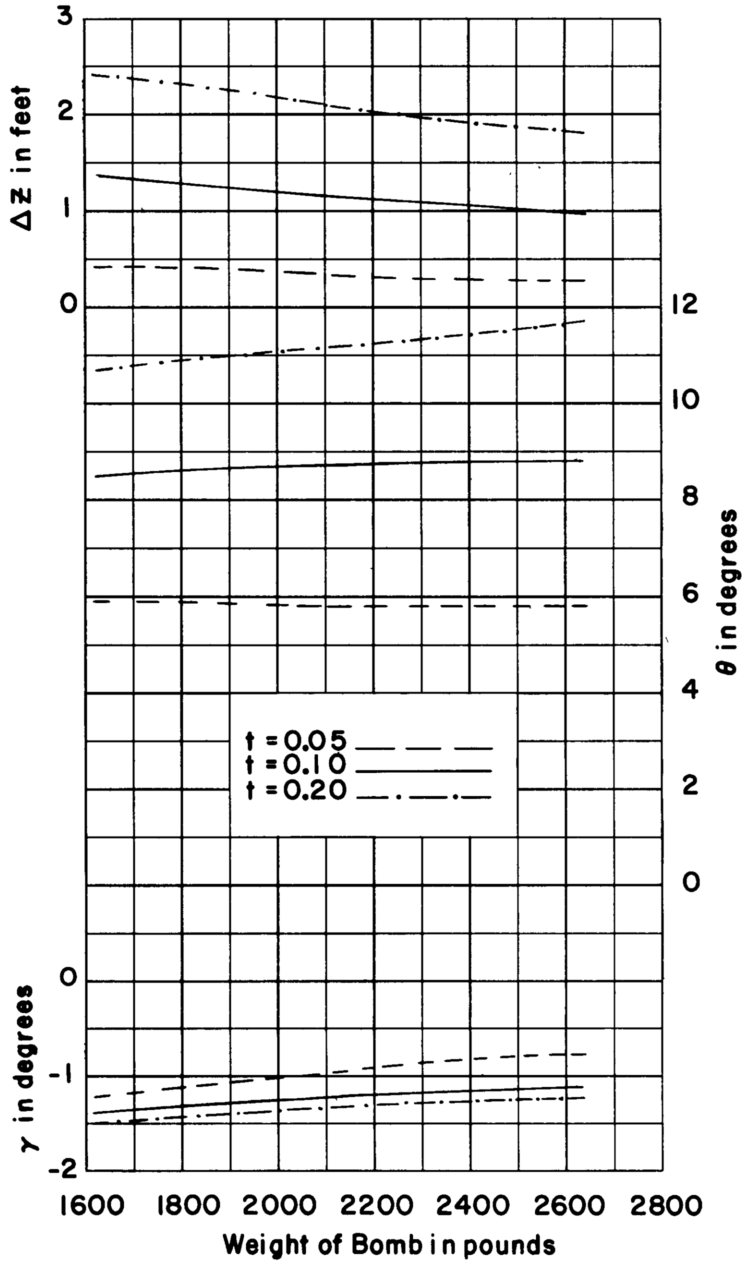


Figure 9 - Effect of Weight of Bomb

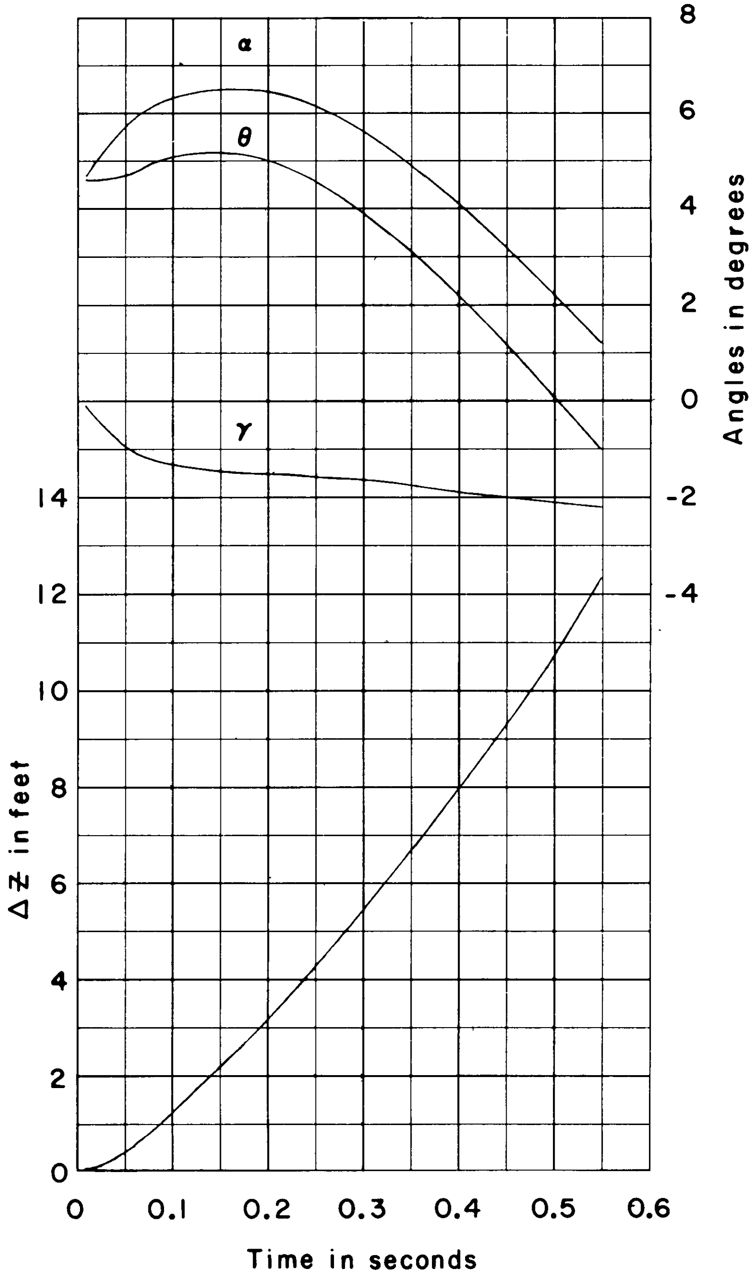


Figure 10 - Separation Characteristics with Launcher Foot 0.125 Foot Aft of Bomb C.G.

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13. ABSTRACT

A system was developed to obtain and process wind-tunnel test data on a store in the presence of an airplane, so that the data could be used by a digital computer to predict store separation characteristics following launch. A separation was computed by the grid method using these data, for comparison with a trajectory obtained by the point prediction method. These trajectories were in good agreement.

Trajectories were also analyzed to determine the effect of various separation parameters.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Grid Method (Computerized)						
Moment of Inertia						
Weight						
Launcher Force						
Launcher Location						
Stored Attitude						

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David Taylor Model Basin. Report 2202
STORE SEPARATION INVESTIGATIONS BY GRID METHOD USING WIND TUNNEL DATA, by Millard J. Bamber. Wash. Apr 1966. iv,25 p. incl. illus. 2 refs. (Aerodynamics Laboratory. Aero Rpt. 1107. Aero Problem 645-166)

A system was developed to obtain and process wind-tunnel test data on a store in the presence of an airplane, so that the data could be used by a digital computer to predict store separation characteristics following launch. A separation was computed by the grid method using these data, for comparison with a trajectory obtained by the point prediction method. These trajectories were in good agreement. Trajectories were also analyzed to determine the effect of various separation parameters.

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