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**STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE U. S. NAVY 1,000  
POUND LOW - DRAG BOMB AT TRANSONIC SPEEDS**

**FC  
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5 APRIL 1957



**U. S. NAVAL ORDNANCE LABORATORY  
WHITE OAX, MARYLAND**

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Aeroballistic Research Report 345

STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE  
U. S. NAVY 1,000 POUND LOW-DRAG BOMB AT  
TRANSONIC SPEEDS

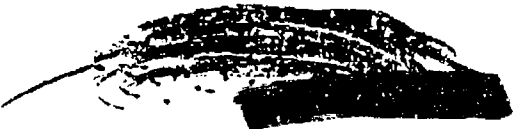
Prepared by:

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ABSTRACT: The Magnus and static stability characteristics of a 0.214-scale model of the U. S. Navy 1,000 pound Low-Drag Bomb have been obtained from transonic wind-tunnel tests at angles of attack up to 22 degrees and for various free-stream Reynolds numbers. The variation in static aerodynamic coefficients due to roll orientation of the bomb through the range 0 - 180 degrees and drag effects due to the addition of external mounting lugs were also investigated. The tests were conducted by NOL in the Cornell Aeronautical Laboratory 4 x 3 foot transonic test facility.

The results of the test indicate that the Magnus characteristics of the bomb are linear with rotational speed and non-linear with angle of attack. Variation in the free-stream Reynolds number is seen to affect the measured Magnus characteristics appreciably at all Mach numbers and angles of attack. It is further shown that significant changes in the pitch, yaw, and roll moments may be expected to accompany variations in the roll orientation of the bomb.

U. S. NAVAL ORDNANCE LABORATORY  
WHITE OAK, MARYLAND



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This report presents the Magnus and static stability characteristics of a 0.214-scale model of the U. S. Navy 1,000 pound Low-Drag Bomb at transonic speeds. The data were obtained in the 4 x 3 foot transonic test facility at the Cornell Aeronautical Laboratory in Buffalo, New York under task number 803-767/73003/01. Special instrumentation required to spin the model and measure dynamic forces and moments was furnished by the Naval Ordnance Laboratory.

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Captain, USN  
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By direction

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STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE  
U. S. NAVY 1,000 POUND LOW-DRAG BOMB AT  
TRANSONIC SPEEDS

INTRODUCTION

1. The Low-Drag Bomb family stems from an external-store design originally developed by the Douglas Aircraft Company. The bombs of the series are geometrically similar in shape but vary in weight from 250 pounds (Mk 79) to 2,000 pounds (Mk 82). For the purpose of the investigation reported herein, the 1,000 pound bomb, Mk 81, has been chosen as the representative bomb to which all test parameters have been referred.
2. During initial field evaluation and development of the Low-Drag Bomb, it was observed that on occasion the bomb would develop large pitching and yawing motions during the course of its trajectory. Subsequently it was conjectured that the cause of this somewhat erratic motion stemmed from the combined effects of the rolling motion, the pitch and yaw frequency, and the resulting yaw and Magnus moments which arise due to the roll and pitch characteristics of the bomb (reference a). In order to obtain experimental data that would help to explain such erratic missile motion as was observed, the Bureau of Ordnance directed the Naval Ordnance Laboratory to investigate the aerodynamic characteristics of the bomb.
3. As part of the subsequent Low-Drag Bomb program, NOL has conducted tests in recent months to determine the Magnus and static stability characteristics of the bomb at low-subsonic speeds ( $V \leq 250$  feet per second), reference (b). More recently, NOL has tested the bomb in the Cornell Aeronautical Laboratory test facilities to determine the transonic aerodynamics of the configuration at angles of attack up to 22 degrees and Mach numbers from 0.60 to 1.25.
4. Using a 0.214-scale model of the bomb, six-component static data and Magnus force and moment characteristics were measured at spin rates scaled from the 1,000 pound bomb. The Magnus data were obtained at free-stream Reynolds numbers of  $2 \times 10^6$ ,  $4 \times 10^6$ , and  $6 \times 10^6$ , based on model total length. Static coefficients were obtained only at a free-stream Reynolds number of  $4 \times 10^6$ . The figures showing static stability coefficients are presented in graphical form only for representative Mach numbers; however, a complete listing of the static coefficients for all test Mach numbers are tabulated in Appendix I.

Symbols

- A      maximum body cross-sectional area (sq. ft.)
- C<sub>A</sub>    axial force coefficient
- C<sub>N</sub>    normal force coefficient =  $N/qA$

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Symbols (Cont'd)

|                   |                                                                                                                                                           |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| $C_Y$             | side force coefficient = $Y/qA$                                                                                                                           |
| $C_l$             | rolling moment coefficient = $M_l / qAd$                                                                                                                  |
| $C_{M_{c.g.}}$    | pitching moment coefficient referred to the center of gravity = $M_{c.g.} / qAd$                                                                          |
| $C_{\psi_{c.g.}}$ | yawing moment coefficient referred to the center of gravity = $M_{\psi_{c.g.}} / qAd$                                                                     |
| $C_{Y_p}$         | Magnus force coefficient (side force coefficient due to spin) = $\frac{\partial Y}{\partial p} \cdot \frac{1}{qA} \cdot \frac{2V}{d}$                     |
| $C_{\psi_p}$      | Magnus moment coefficient (yawing moment coefficient due to spin) = $\frac{\partial M_{\psi_{c.g.}}}{\partial p} \cdot \frac{1}{qA} \cdot \frac{2V}{d^2}$ |
| $C_{N_\alpha}$    | slope of normal force coefficient through $\alpha = 0$ degrees                                                                                            |
| $C_{m_\alpha}$    | slope of pitching moment coefficient through $\alpha = 0$ degrees                                                                                         |
| $d$               | maximum body diameter (ft.) = 1 (one) caliber                                                                                                             |
| $l$               | body length (ft.)                                                                                                                                         |
| $M_l$             | rolling moment (ft.-lbs.)                                                                                                                                 |
| $M_{c.g.}$        | pitching moment referred to the center of gravity (ft.-lbs.)                                                                                              |
| $M_{\psi_{c.g.}}$ | yawing moment referred to the center of gravity (ft.-lbs.)                                                                                                |
| $D$               | drag force (lbs.)                                                                                                                                         |
| $N$               | normal force (lbs.)                                                                                                                                       |
| $Y$               | side force (lbs.)                                                                                                                                         |
| $p$               | body rotational speed (radians/sec) - positive when model is rotating clockwise as viewed from the base                                                   |
| $q$               | dynamic pressure (lbs./sq.ft.)                                                                                                                            |
| $Re$              | Reynolds number = $\frac{\rho V l}{\mu}$                                                                                                                  |
| $V$               | free-stream velocity (ft./sec.)                                                                                                                           |
| $\mu$             | absolute coefficient of viscosity of air (lbs.-sec./ft.sq.)                                                                                               |
| $\rho$            | air density (slugs/cu.ft.)                                                                                                                                |

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Symbols (Cont'd)

- $\alpha$       angle of attack (degrees)
- $\psi$       angle of yaw (degrees)
- $\phi$       model roll angle - positive when model is rolled clockwise as viewed from the base

Test Apparatus and Procedure

5. The tests were conducted using the Cornell Aeronautical Laboratory 4 x 3 foot transonic cart. The cart is essentially a separate test section which can be placed in the normal 10 x 12 foot wind-tunnel test section. Speeds up to about Mach number 1.25 can be obtained. Normal angle of attack range is limited to approximately  $\pm 15$  degrees. However, for angles above 15 degrees, a "dog-leg" sting adapter may be used to extend the angle of attack range in one direction. Further information on the Cornell test facility may be found in reference (c).
6. The pertinent dimensions of the bomb configuration and the details of the mounting lugs are shown in Figure 2. In order to test at angles above 20 degrees, the model length was limited to approximately 24 inches and the maximum body diameter to 3 inches. Model spin was provided by a 7 H.P. 24,000 RPM, variable frequency, water-cooled motor mounted on the forward end of a strain-gaged balance beam. The motor was internally geared to the model by a 4.2:1 reduction gear. Strain-gage leads, motor wires, and water tubes were coupled to their respective power sources by running the leads through a hollow center core in the sting. Model spin was measured by a tachometer mounted in the rear of the motor section. From the tachometer signal, the spin rate was recorded in revolutions per minute on a Berkeley EPUT counter.
7. Magnus forces and moments acting on the model were measured by means of a four-component strain-gage balance designed and manufactured by the Naval Ordnance Laboratory. Since it was desirable to obtain the variation, if any, of the stability coefficients between a "minimum" spin rate (i.e., a spin rate just sufficient to "average" the normal forces and pitching moments due to static roll orientation--approximately 30 RPM) and the maximum test spin rate of 2,000 RPM, the balance was also designed to measure normal forces and pitching moments. Both the Magnus and "static" stability characteristics were obtained up to 22 degrees angle of attack in increments of four degrees. Test procedure for the Magnus measurements was to set the model at the desired angle of attack and slowly advance the model spin to the maximum rate. The output signals of the strain-gages measuring Magnus forces and moments were suitably amplified and supplied to the pen drive on a two-channel, Leeds and Northrup, Speed-O-Max recorder. By modifying the conventional time drive of the recorder chart to include a servo-motor

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driven by the model tachometer signal, it was possible to position the chart as a function of the model rotational speed and thus obtain a "trace" or record of the Magnus moment and pitching moment about each of the gage sections as a function of model spin rate for each angle of attack. However, due to the inability of the recorder chart to follow a tachometer signal corresponding to approximately 50 revolutions per minute or less, it was necessary to extrapolate the moment "traces" to zero rotational speed in order to obtain an initial slope through zero.

8. Six-component static measurements on the bomb were obtained using the CAL B-112 balance (reference d). Free-stream Reynolds number based on total model length was kept constant at  $4 \times 10^6$  throughout the static measurements. Six-component data were obtained only to 22 degrees angle of attack for selected model roll positions from 0 degrees to 180 degrees.

Data Reduction

9. Within the experimental error, the Magnus moment "traces" obtained on the recorder charts were found to be linear with model rotational speed. It was sufficient, therefore, in determining coefficients, to use only the difference in the gage Magnus moment between the extrapolated zero RPM value and 2000 RPM. From this value, the Magnus coefficients,  $C_{Yp}$  and  $C_{Wp}$ , were converted to non-dimensional form by the relations

$$C_{Yp} = \frac{\partial Y}{\partial p} \cdot \frac{2V}{d} \cdot \frac{1}{qA}$$
$$C_{Wp} = \frac{\partial M_{x.c.g.}}{\partial p} \cdot \frac{2V}{d^2} \cdot \frac{1}{qA}$$

Normal force, pitching moment, side force, yawing moment, roll moment, and drag were reduced to the conventional coefficient forms as shown in the section under Symbols.

Precision of Data

10. The precision of the Magnus data obtained during the test is somewhat poorer than would be desirable. Since it was necessary that the Magnus balance measure relatively small forces and moments (Magnus forces in the order of 10 percent to 20 percent of the expected normal forces), as a consequence it was also sensitive to any random model oscillations or free-stream disturbances. From previous experience, it was expected that the recorder traces would show that the model was experiencing a somewhat erratic, high frequency small amplitude oscillation. Oscillations of this type are not surprising in view of the flexible balance used and the

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relatively high rotational speeds attained during the test. Past experience in similar tests has indicated that severe buffetting of the model will often occur at angles of attack above 10 to 15 degrees, depending on the spin rate and general configuration of the model. As a consequence, the "Magnus traces" consisted of "bands" whose limits were the maximum and minimum peaks of the high-frequency model oscillations. The value of the Magnus moment at any spin rate was then assumed to be the displacement of a point, on a mean line through the fluctuations, relative to any indicated moment due to static side forces which might arise at zero spin rate. Taking into account the model oscillations, plus the uncertainties involved in determining the test parameters, physical measurements and reader error, the probable error in the Magnus coefficients at various angles of attack has been estimated to have the following values:

| $\alpha$ = angle of attack | $C_{Yp}$   | $C_{Yp}$   |
|----------------------------|------------|------------|
| 4°                         | $\pm 0.32$ | $\pm 0.24$ |
| 12°                        | $\pm 0.45$ | $\pm 0.49$ |
| 22°                        | $\pm 1.00$ | $\pm 1.03$ |

11. In view of the fairly large uncertainties in the Magnus data and plus the relatively small angle of attack correction indicated by a deflection load calibration, it was thought unnecessary to correct the Magnus data for pitch deflection loads at angle of attack. All the Magnus data shown in this report therefore are presented for indicated angles of attack only.

12. Uncertainties in the static data have been estimated from repeated measurements to be as follows:

|             |             |
|-------------|-------------|
| $C_N$       | $\pm .0046$ |
| $C_{mc.g.}$ | $\pm .0099$ |
| $C_Y$       | $\pm .0033$ |
| $C_{yc.g.}$ | $\pm .0045$ |
| $C_L$       | $\pm .0061$ |
| $C_A$       | $\pm .0035$ |

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Discussion of Results

13. With the advent in recent years of reliable dynamic test techniques, it has become of increasing value to include measurements of the Magnus forces and moments in wind-tunnel development tests of spinning, fin-stabilized configurations. Unstable flights of Weapon A and the 6-inch Test Vehicle (references e and f) together with subsequent calculations and dynamic wind-tunnel measurements, have borne out the necessity for Magnus measurements and their inclusion in the method of predicting the stability performance of any spinning, fin-stabilized configuration. Accordingly, developmental wind-tunnel tests of the Low-Drag Bomb have included measurements of the Magnus forces and moments acting on the bomb, at spin rates and angles of attack comparable to those which might be expected in free-flight tests.

14. Figures 3 through 11 present the Magnus force and moment coefficients of the bomb as a function of angle of attack for various Reynolds numbers and Mach numbers. The free-stream Reynolds number was held constant at  $2 \times 10^6$  and  $4 \times 10^6$  (based on total model length) for two separate Mach number runs from  $M = 0.80$  to  $M = 1.25$ , and at  $5 \times 10^6$  for a third Mach number run ranging only from  $M = 0.60$  to  $M = 0.95$ .

15. Examination of Figures 3 through 10 shows that the variation of the Magnus coefficients is, in general, non-linear with increasing angle of attack. This is markedly so for the Magnus coefficients at free-stream Reynolds numbers of  $2 \times 10^6$ . At this Reynolds number, the Magnus moment varies from negative values at  $M = 1.25$  at all angles of attack, to positive values at a Mach number of  $M = 1.00$  and below. The change in moment is due to oppositely directed Magnus forces rather than to movement of the center of pressure. At the higher free-stream Reynolds numbers of  $4 \times 10^6$  and  $5 \times 10^6$  the Magnus moment is positive throughout the respective range of test Mach numbers. An explanation for the "reversed" Magnus forces is not readily available. However, it has recently been observed by some experimenters (reference g) that at low subsonic speeds it is possible to generate either positive or negative Magnus forces, for example on a spinning cylinder in cross-flow, by varying the local Reynolds number around the periphery of the cylinder in such a way as to cause asymmetrical boundary-layer transition and/or separation. In this manner, the pressure distribution around the cylinder is such that the Magnus forces may act in either direction depending on the magnitude of the local Reynolds number and consequent boundary-layer separation position. It is conceivable then that the combination of the local cross-flow Reynolds number, model surface condition, and possible shock-boundary layer interaction along the model surface may set up conditions favorable to "reversed" Magnus forces such as those measured during the test. From Figures 3 through 10 it can be seen that the variation in the Magnus coefficients with Reynolds number is wide-spread. This is especially true for the higher

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angles of attack. In general, it is thought that much of the suspected Reynolds number effect believed to be present in the Magnus coefficients has been obliterated by the somewhat large experimental error in the "raw" Magnus data. The small magnitude of the Magnus forces and moments together with the relatively large normal forces and pitching moments experienced by the bomb impede, to a certain extent, compatible simultaneous measurements of these forces and moments using the type of balance system necessitated by the test parameters.

16. Figure 11 indicates that the Magnus force and moment characteristics of the bomb are highly non-linear with increasing Mach number, especially in the region of  $M = 1.0$  and above. It is to be noted that Figure 11 shows the Magnus force and moment coefficient only at a spin rate of 2000 RPM and for a free-stream Reynolds number of  $4 \times 10^6$ . However, since the Magnus data at any given angle of attack is linear with model spin rate, the data shown in Figure 11 are representative of the variation of the Magnus characteristics with Mach number for all spin rates, at least up to 2000 RPM. Note that the magnitude of the maximum Magnus moment (at  $M = 0.60$ ) is only 15 percent of the maximum pitching moment of the bomb at 22 degrees angle of attack.

17. A previous investigation of the bomb at a Reynolds number of  $6.3 \times 10^6$  and a Mach number of  $M = 0.22$  (reference b) indicates that little change in the Magnus characteristics might be expected between  $M = 0.50$  and  $M = 0.22$ .

18. Figures 12 through 19 show the normal force and pitching moment characteristics of the bomb for various roll orientations from 0 to 180 degrees. The zero degree roll position is taken to be the position of the model when the mounting lugs (Figure 2) lie in the pitch plane of the model and the fins are displaced 45 degrees from that plane. Figures 12 through 19 also show the variation of the normal force center of pressure with angle of attack for various roll positions. It is evident from examination of these data that the bomb is statically stable throughout the test Mach number range. To be noted is the expected large variation in pitching moment and normal force that occurs as the model is rolled 45 degrees from the zero roll position. In general, at 22 degrees angle of attack an average increase of 75 percent in the pitching moment coefficient occurs for a roll displacement of 45 degrees from the zero roll position at Mach numbers of  $M = 0.60$  through  $M = 1.25$ . Similar increases in the normal force coefficients amount to approximately 10 percent at  $M = 1.25$  to about 25 percent at  $M = 0.60$ . The center of pressure travel due to angle of attack increase is relatively small, varying less than one-half caliber at most Mach numbers.

19. Figure 20 indicates that the variation of the normal-force and pitching-moment coefficients with Mach number is generally slight for Mach numbers below approximately  $M = 1.0$ . An appreciable variation is noted, however, at

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angles of attack above 16 degrees where a somewhat precipitate drop in the pitching-moment coefficient occurs as the Mach number is increased beyond  $M = 1.0$ . The decrease is due, however, to a forward travel in the center of pressure rather than a loss in lift.

20. Figure 21 shows a comparison of the normal-force and pitching-moment coefficient slopes,  $C_{N_L}$  and  $C_{m_L}$ , respectively, from wind-tunnel and free-flight measurements (reference g). The cross-hatched band depicts the maximum and minimum limits of the slopes due to static model roll positions of  $\phi = 45^\circ$  and  $\phi = 0^\circ$  respectively. As indicated on the plot, the broken curves illustrate the variation of the slopes as determined from free-flight measurements in the NOL Pressurized Ballistics Range and from wind-tunnel measurements made with the model spinning at the maximum rate of 2000 RPM. Data from these tests are considered to be somewhat less reliable than the static or free-flight data since considerable scatter was present in the coefficients at low angles of attack. These latter measurements were, of course, subject to the same disturbances as previously cited for the Magnus measurements and because of this are plotted only for a qualitative comparison with the static and free-flight slopes. As can be noted from Figure 21, the normal-force coefficient slopes from the static and free-flight data agree quite well except at the higher Mach numbers above approximately  $M = 1.05$ . The moment slopes are not in as good agreement, the free-flight data indicating less "stability" at Mach numbers in the range  $0.9 \leq M \leq 1.1$  and somewhat higher "stability" in the immediate range around  $M = 1.0$  than is indicated by the wind-tunnel data.

21. In reference to Figures 22 through 25, it is usually assumed that a cruciform finned projectile pitched at an arbitrary angle of attack will experience no side force or yawing moment as long as the fins are in a symmetrical position relative to the pitch plane. If the projectile is rolled about the longitudinal axis until the fins are no longer symmetrical relative to the pitch plane, a side force and yawing moment will appear which are dependent on the roll angle  $\phi$ , and the magnitude of the angle of attack,  $\alpha$ . Reference (a), in discussing the action of the yawing moment in connection with the phenomenon of so-called "catastrophic yaw," suggests that for certain special cases the yawing moment may combine with the Magnus moment and thus give rise to the occasionally-observed large pitching and yawing motions of spinning, fin-stabilized missiles.

22. Figures 22 through 25 show the variation of the side force and yawing moment coefficients with model roll angle for various angles of attack. As is evident from these data, the coefficients are roughly proportional to  $\sin 4\phi$  at any arbitrary angle of attack. It is to be noted that the indicated test points on these plots have been adjusted by an amount equal to the displacement of the side force or yawing moment coefficient from the zero coefficient value at zero angle of attack for each roll position. The "uncorrected" values of the side force and yawing moment coefficients are tabulated in the Appendix. The small "trim" angles in the data at zero angle of attack were assumed to arise from misalignments of the model along the tunnel centerline and not from aerodynamic causes.

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23. As previously mentioned, reference (a) suggests that for certain cases (viz., "lunar motion" or "resonance") the yawing and Magnus moments acting on a finned missile may combine when the missile is rolled at an angle such that the moments are of the same sign. It may be seen from Figures 22 through 25 that these "critical" angle ranges for the bomb apparently occur in the vicinity of  $55^\circ \leq \phi \leq 85^\circ$ , and  $135^\circ \leq \phi \leq 180^\circ$ . Note that the magnitude of the yawing moment is considerably less for  $55^\circ \leq \phi \leq 85^\circ$ . In this range, the mounting lugs are located in the lee-side of the model and skewed relative to the pitch plane at angles of attack. Thus, it is possible that the lugs may influence the body-shed vortices in such a manner as to introduce an interference effect which would be felt by the fins with a resultant variation in the magnitude of the yawing moment in this roll angle range.

24. In general, the yawing moment is little affected by Mach number at angles of attack of 16 degrees and below. At higher angles, however, and, in particular at model roll angles where the peak, positive yawing moments occur, the variation of the yaw moment with Mach number is somewhat erratic and inconclusive.

25. Static rolling moment coefficients are shown in Figures 26 through 29 as a function of model angle of attack and roll orientation. As may be noted from these plots, the rolling moment coefficient is also roughly dependent on  $\sin \phi$ , at least for angles of attack of 16 degrees and above. The relatively constant moment experienced by the model at angles of attack of 12 degrees and below indicate that little or no induced roll effects are present at these angles.

26. The variation of the roll moment coefficient with Mach number appears to be negligible at 12 degrees angle of attack and below. At the higher angles, however, if the peak positive and negative moments are considered, the maximum moments show somewhat different characteristics. In general, it is seen that for roll angles of  $\phi$  equal to approximately 22.5 and 112.5 degrees, the tendency of the maximum roll coefficient is to decrease with increasing Mach number from  $M = 0.60$  to  $M = 1.25$ . For roll angles of  $\phi = 67.5$  degrees and 157.5 degrees, the roll coefficient generally increases (i.e., a larger negative moment in this case) except for a small region between  $M = 0.90$  to  $M = 1.0$ . Here, the rolling moment coefficient decreases quite rapidly, appearing almost as a discontinuity for certain angles of attack, but increasing once again beyond  $M = 1.0$ .

27. Figure 30 shows the variation of the spin parameter,  $pd/2V$ , as a function of angle of attack for various Mach numbers. For these tests, it was desired to obtain some idea of the equilibrium spin rate of the bomb with increasing angle of attack. By removing the motor and gearing structure the model was free to rotate, presumably somewhere near the equilibrium spin rate. Since it was not possible to determine the bearing friction in the model, Figure 30 shows only a qualitative representation of the spin history. From these data it appears that the model spin reaches a

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maximum at some angle of attack around 18 - 20 degrees for the lower Mach numbers. Above  $M = 0.95$ , however, a peak is reached at somewhat lower angles. Note the fairly rapid drop in spin rate that occurs around  $M = 1.25$ .

28. Previous low-speed investigations on the Low-Drag Bomb (NOL unpublished data) have indicated that a similar "speed-up" in roll rate occurs when the bomb is subjected to angles of attack above approximately 30 degrees. Results of these tests show that the spin rate can approach values as high as four times the zero angle of attack roll rate, depending on the angle of attack. Tests are presently being carried out in the Smoke Tunnel at the University of Notre Dame in an effort to determine and subsequently control the aerodynamic mechanism governing the roll speed-up phenomenon.

29. Figure 31 presents the zero-lift drag coefficient of the bomb with and without mounting lugs attached to the bomb. For comparison, the total zero-lift drag coefficient of the bomb determined from firings of a 0.056-scale model with lugs in the NOL Pressurized Ballistics Range is also shown (reference g). It should be noted that the wind-tunnel coefficients have been adjusted to zero base drag. Accordingly, the solid curves in Figure 31 are representative of only the wave drag plus skin friction drag of the model. It may be noted from these curves that the drag coefficient shows the characteristic transonic drag rise at approximately  $M = 1.05$  to 1.10. The increase in drag due to mounting lugs is fairly consistent throughout the Mach number range, averaging approximately 0.025 in terms of the coefficient value.

Summary

30. In summary, the results presented in this report show that the Magnus force and moment coefficients of the bomb are linearly dependent on the bomb rotational speed. It is seen that the Magnus force and moment are also dependent on the free-stream Reynolds number in some cases being of opposite sign due to reversed Magnus forces experienced at the lower Reynolds numbers. In addition, the Magnus coefficients are seen to be generally non-linear with angle of attack and of relatively small magnitude compared to the static normal force and pitching moment coefficients.

31. The results also show the bomb to be statically stable at all angles of attack. It is seen that static normal forces and pitching moments vary appreciably with fin-roll orientation. A roll displacement of 45 degrees from the zero roll position can increase the pitching moment by approximately 75 percent and the normal force up to 25 percent. Static side forces and moments, and static rolling moments, were also found to be non-linear with increasing angle of attack. Variation of these coefficients with model roll angle is roughly proportional to  $\sin 4\phi$  for angles of attack above approximately 12 degrees. In addition, it is seen that the drag rise due

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to mounting lugs is fairly small over the test Mach number range, averaging only 0.025 in terms of the coefficient value.

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TABLE I  
Test Conditions

| Run | Mach No. | Dynamic Pressure<br>(lbs/ft <sup>2</sup> ) $\pm$ 1 psf | Reynolds No.<br>(Re x 10 <sup>-6</sup> ) | Measure-<br>ment           | Roll Angle<br>( $\phi$ -Degrees) |
|-----|----------|--------------------------------------------------------|------------------------------------------|----------------------------|----------------------------------|
| 1   | 1.25     | 213                                                    | 2                                        | Magnus                     |                                  |
| 2   | 1.20     | 205                                                    | 2                                        | Magnus                     |                                  |
| 3   | 1.10     | 197                                                    | 2                                        | Magnus                     |                                  |
| 4   | 1.00     | 187                                                    | 2                                        | Magnus                     |                                  |
| 5   | 0.95     | 180                                                    | 2                                        | Magnus                     |                                  |
| 6   | 0.90     | 177                                                    | 2                                        | Magnus                     |                                  |
| 7   | 0.80     | 162                                                    | 2                                        | Magnus                     |                                  |
| 8   | 1.25     | 427                                                    | 4                                        | Magnus                     |                                  |
| 9   | 1.00     | 374                                                    | 4                                        | Magnus                     |                                  |
| 10  | 1.20     | 411                                                    | 4                                        | Magnus                     |                                  |
| 11  | 1.10     | 394                                                    | 4                                        | Magnus                     |                                  |
| 12  | 0.95     | 359                                                    | 4                                        | Magnus                     |                                  |
| 13  | 0.90     | 348                                                    | 4                                        | Magnus                     |                                  |
| 14  | 0.80     | 317                                                    | 4                                        | Magnus                     |                                  |
| 15  | 0.95     | 539                                                    | 6                                        | Magnus                     |                                  |
| 16  | 0.90     | 514                                                    | 6                                        | Magnus                     |                                  |
| 17  | 0.80     | 477                                                    | 6                                        | Magnus                     |                                  |
| 18  | 0.60     | 384                                                    | 6                                        | Magnus                     |                                  |
| 19  | 0.60     | 384                                                    | 6                                        | Magnus                     |                                  |
| 47  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 0°                               |
| 48  | 1.20     | 411                                                    | 4                                        | 6-compo-<br>nent<br>static | 0°                               |
| 49  | 1.10     | 394                                                    | 4                                        | 6-compo-<br>nent<br>static | 0°                               |
| 50  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 0°                               |
| 51  | 0.95     | 359                                                    | 4                                        | 6-compo-<br>nent<br>static | 0°                               |
| 52  | 0.90     | 348                                                    | 2                                        | 6-compo-<br>nent<br>static | 0°                               |
| 53  | 0.80     | 317                                                    | 4                                        | 6-compo-<br>nent<br>static | 0°                               |

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TABLE I (Cont'd)

| Run | Mach No. | Dynamic Pressure<br>(lbs/ft <sup>2</sup> ) $\pm$ 1 psf | Reynolds No.<br>(Re x 10 <sup>-6</sup> ) | Measure-<br>ment           | Roll Angle<br>( $\beta$ -Degrees) |
|-----|----------|--------------------------------------------------------|------------------------------------------|----------------------------|-----------------------------------|
| 54  | 0.60     | 251                                                    | 4                                        | 6-compo-<br>nent<br>static | 0°                                |
| 55  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 11.25°                            |
| 56  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 11.25°                            |
| 57  | 0.90     | 348                                                    | 4                                        | 6-compo-<br>nent<br>static | 11.25°                            |
| 58  | 0.60     | 251                                                    | 4                                        | 6-compo-<br>nent<br>static | 11.25°                            |
| 59  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 22.50°                            |
| 60  | 1.10     | 394                                                    | 4                                        | 6-compo-<br>nent<br>static | 22.50°                            |
| 61  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 22.50°                            |
| 62  | 0.90     | 348                                                    | 4                                        | 6-compo-<br>nent<br>static | 22.50°                            |
| 63  | 0.60     | 251                                                    | 4                                        | 6-compo-<br>nent<br>static | 22.50°                            |
| 64  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 33.75°                            |
| 65  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 33.75°                            |
| 66  | 0.90     | 348                                                    | 4                                        | 6-compo-<br>nent<br>static | 33.75°                            |
| 67  | 0.60     | 251                                                    | 4                                        | 6-compo-<br>nent<br>static | 33.75°                            |
| 68  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 45.00°                            |

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TABLE I (Cont'd)

| Run | Mach No. | Dynamic Pressure<br>(lbs/ft <sup>2</sup> ) $\pm$ 1 psf | Reynolds No.<br>(Re x 10 <sup>-6</sup> ) | Measure-<br>ment           | Roll Angle<br>( $\phi$ Degrees) |
|-----|----------|--------------------------------------------------------|------------------------------------------|----------------------------|---------------------------------|
| 69  | 1.10     | 394                                                    | 4                                        | 6-compo-<br>nent<br>static | 45.00°                          |
| 70  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 45.00°                          |
| 71  | 0.90     | 348                                                    | 4                                        | 6-compo-<br>nent<br>static | 45.00°                          |
| 72  | 0.60     | 251                                                    | 4                                        | 6-compo-<br>nent<br>static | 45.00°                          |
| 73  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 67.50°                          |
| 74  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 67.50°                          |
| 75  | 0.90     | 348                                                    | 4                                        | 6-compo-<br>nent<br>static | 67.50°                          |
| 76  | 0.60     | 251                                                    | 4                                        | 6-compo-<br>nent<br>static | 67.50°                          |
| 77  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 90.00°                          |
| 78  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 90.00°                          |
| 79  | 0.90     | 348                                                    | 4                                        | 6-compo-<br>nent<br>static | 90.00°                          |
| 80  | 0.60     | 251                                                    | 4                                        | 6-compo-<br>nent<br>static | 90.00°                          |
| 81  | 1.25     | 427                                                    | 4                                        | 6-compo-<br>nent<br>static | 112.50°                         |
| 82  | 1.00     | 374                                                    | 4                                        | 6-compo-<br>nent<br>static | 112.50°                         |
| 83  | 0.90     | 348                                                    | 4                                        | 6-compo-<br>nent<br>static | 112.50°                         |

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TABLE I (Cont'd)

| Run | Mach No. | Dynamic Pressure<br>(lbs/ft <sup>2</sup> ) + 1 psf | Reynolds No.<br>(Re x 10 <sup>-6</sup> ) | Measure-<br>ment           | Roll Angle<br>( $\phi$ -Degrees) |
|-----|----------|----------------------------------------------------|------------------------------------------|----------------------------|----------------------------------|
| 84  | 0.60     | 251                                                | 4                                        | 6-compo-<br>nent<br>static | 112.50°                          |
| 85  | 1.25     | 427                                                | 4                                        | 6-compo-<br>nent<br>static | 135.00°                          |
| 86  | 1.00     | 374                                                | 4                                        | 6-compo-<br>nent<br>static | 135.00°                          |
| 87  | 0.90     | 348                                                | 4                                        | 6-compo-<br>nent<br>static | 135.00°                          |
| 88  | 0.60     | 251                                                | 4                                        | 6-compo-<br>nent<br>static | 135.00°                          |
| 89  | 1.25     | 427                                                | 4                                        | 6-compo-<br>nent<br>static | 157.00°                          |
| 90  | 1.00     | 374                                                | 4                                        | 6-compo-<br>nent<br>static | 157.00°                          |
| 91  | 0.90     | 348                                                | 4                                        | 6-compo-<br>nent<br>static | 157.00°                          |
| 92  | 0.60     | 251                                                | 4                                        | 6-compo-<br>nent<br>static | 157.00°                          |
| 93  | 1.25     | 427                                                | 4                                        | 6-compo-<br>nent<br>static | 180.00°                          |
| 94  | 1.20     | 411                                                | 4                                        | 6-compo-<br>nent<br>static | 180.00°                          |
| 95  | 1.10     | 394                                                | 4                                        | 6-compo-<br>nent<br>static | 180.00°                          |
| 96  | 1.00     | 374                                                | 4                                        | 6-compo-<br>nent<br>static | 180.00°                          |
| 97  | 0.90     | 348                                                | 4                                        | 6-compo-<br>nent<br>static | 180.00°                          |
| 98  | 0.60     | 251                                                | 4                                        | 6-compo-<br>nent<br>static | 180.00°                          |

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Appendix

The Appendix lists the static coefficients obtained at a Reynolds number of  $4 \times 10^6$  for various roll angles from 0 degrees to 180 degrees. Column nomenclature is listed at the top of the columns as shown on the first page of the tabulated data.

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| Run | Point<br>No. | Mach<br>No. | $\alpha$ | $\phi$ | $\psi$ | CH      | CM <sub>C.E.</sub> | CY      | C <sub>C.E.</sub> | C <sub>A</sub> | C <sub>A</sub> |
|-----|--------------|-------------|----------|--------|--------|---------|--------------------|---------|-------------------|----------------|----------------|
| 47  | 02           | 1.25        | 8.14     | .00    | .00    | .60354  | 1.81387-           | .02734- | .07574            | .04369         | .27456         |
| 47  | 03           | 1.25        | 12.25    | .00    | .00    | 1.07834 | 1.19477-           | .04037- | .03026            | .04472         | .28425         |
| 47  | 04           | 1.25        | 16.39    | .00    | .01    | 1.52250 | 1.59950-           | .04579- | .00094            | .03465         | .29170         |
| 47  | 05           | 1.25        | 20.68    | .00    | .00    | 2.32987 | 1.59963-           | .06009- | .15029            | .00331-        | .29278         |
| 47  | 07           | 1.25        | .00      | .00    | .00    | .02056  | .02085-            | .01929- | .06090            | .01743         | .25136         |
| 48  | 02           | 1.20        | .01      | .00    | .01    | .03397  | 1.0555-            | .00742  | .07030-           | .02342         | .24904         |
| 48  | 03           | 1.20        | 3.11     | .00    | .02    | .72659  | 1.07658-           | .00034- | .07701-           | .03737         | .26879         |
| 48  | 04           | 1.20        | 12.23    | .00    | .02    | 1.13796 | 1.54206-           | .00233- | .09486-           | .03896         | .28107         |
| 48  | 05           | 1.20        | 15.34    | .00    | .03    | 1.58612 | 1.79824-           | .00206- | .10314-           | .02858         | .28617         |
| 48  | 06           | 1.20        | 20.60    | .00    | .02    | 2.26000 | 1.92074-           | .00446- | .05873-           | .00563         | .28071         |
| 48  | 07           | 1.20        | 22.77    | .00    | .01    | 2.75101 | 2.00915-           | .10395- | .25956            | .01363         | .28133         |
| 48  | 08           | 1.20        | .00      | .00    | .01    | .03259  | 1.0414-            | .01478  | .07309-           | .01828         | .25259         |
| 49  | 02           | 1.10        | .01      | .00    | .00    | .00429- | .09970             | .00209  | .01170            | .03090         | .24802         |
| 49  | 03           | 1.10        | 8.12     | .00    | .00    | .62339  | .60739-            | .01058  | .02828-           | .03864         | .25259         |
| 49  | 04           | 1.10        | 12.24    | .00    | .00    | 1.05648 | 1.18273-           | .00732  | .02651-           | .04017         | .26049         |
| 49  | 06           | 1.10        | 16.35    | .00    | .01    | 1.48099 | 1.47355-           | .00206  | .06737-           | .03809         | .26387         |
| 49  | 07           | 1.10        | 20.51    | .00    | .02    | 1.98009 | 1.49025-           | .01811  | .12007-           | .01689         | .27750         |
| 49  | 08           | 1.10        | 22.69    | .00    | .02    | 2.47003 | 1.65413-           | .05263  | .20240-           | .00152-        | .27876         |
| 49  | 09           | 1.10        | .01      | .00    | .00    | .00469- | .09357             | .00395  | .01271            | .01977         | .24942         |
| 50  | 01           | 1.00        | .00      | .00    | .00    | .00423  | .00368-            | .00235  | .00378            | .01654         | .11712         |
| 50  | 02           | 1.00        | 8.10     | .00    | .00    | .56539  | .70969-            | .00219- | .00913-           | .02347         | .11781         |
| 50  | 03           | 1.00        | 12.18    | .00    | .01    | .99120  | 1.27680-           | .00048  | .03493-           | .02796         | .12152         |
| 50  | 04           | 1.00        | 16.27    | .00    | .00    | 1.42301 | 1.77137-           | .00760- | .00616-           | .01388         | .10484         |
| 50  | 05           | 1.00        | 20.39    | .00    | .01    | 1.95471 | 2.19375-           | .00489- | .01980-           | .00960         | .09057         |
| 50  | 06           | 1.00        | 22.49    | .00    | .02    | 2.20121 | 2.13564-           | .00368  | .11055-           | .00016         | .07943         |
| 50  | 07           | 1.00        | .01      | .00    | .03    | .00471- | .00802             | .00233  | .00643            | .01243         | .11724         |

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|    |    |      |       |    |     |    |         |          |        |        |       |       |
|----|----|------|-------|----|-----|----|---------|----------|--------|--------|-------|-------|
| 51 | 02 | 0.95 | 01-   | 00 | 00  | 00 | 00755-  | 02263    | 00809- | 01452  | 03540 | 09181 |
| 51 | 03 | 0.95 | 8.09  | 00 | 01- | 00 | 57249   | 70417-   | 01245- | 00028  | 04982 | 09283 |
| 51 | 04 | 0.95 | 12.16 | 00 | 01- | 00 | 94572   | 1.24442- | 02005- | 01165  | 04497 | 09092 |
| 51 | 05 | 0.95 | 16.23 | 00 | 00  | 00 | 1.36297 | 1.72336- | 02808- | 05467  | 04217 | 08380 |
| 51 | 06 | 0.95 | 20.35 | 00 | 02- | 00 | 1.82334 | 2.04945- | 00049- | 09917- | 01488 | 06543 |
| 51 | 07 | 0.95 | 22.44 | 00 | 03- | 00 | 2.05614 | 2.09627- | 02859  | 22941- | 01512 | 05949 |
| 51 | 08 | 0.95 | 00    | 00 | 00  | 00 | 01225-  | 02594    | 00589- | 01293  | 03532 | 09300 |
| 52 | 01 | 0.90 | 01-   | 00 | 00  | 00 | 00806-  | 01748    | 00620- | 01241  | 03330 | 08783 |
| 52 | 02 | 0.90 | 0.09  | 00 | 01- | 00 | 55597   | 59879-   | 01063- | 00362- | 04527 | 08789 |
| 52 | 03 | 0.90 | 12.14 | 00 | 01- | 00 | 92016   | 1.24320- | 01828- | 01029  | 04341 | 08788 |
| 52 | 04 | 0.90 | 16.22 | 00 | 00  | 00 | 1.34256 | 1.72016- | 03122- | 04755  | 04057 | 08036 |
| 52 | 05 | 0.90 | 20.32 | 00 | 02- | 00 | 1.75937 | 2.00935- | 00385- | 07811- | 02170 | 06511 |
| 52 | 06 | 0.90 | 22.39 | 00 | 03- | 00 | 1.97465 | 2.05553- | 00919  | 15033- | 01235 | 05897 |
| 52 | 08 | 0.90 | 00    | 00 | 00  | 00 | 00835-  | 01792    | 00402- | 00894  | 03015 | 08857 |
| 53 | 02 | 0.80 | 01-   | 00 | 00  | 00 | 01444-  | 03001    | 00443- | 00975  | 02864 | 08441 |
| 53 | 03 | 0.80 | 8.07  | 00 | 03- | 00 | 55107   | 70024-   | 00653- | 00765- | 04170 | 08518 |
| 53 | 04 | 0.80 | 12.14 | 00 | 01- | 00 | 91644   | 1.22972- | 00762- | 01628- | 04330 | 08676 |
| 53 | 05 | 0.80 | 15.18 | 00 | 00  | 00 | 1.29538 | 1.70136- | 03265- | 04777  | 07435 | 07703 |
| 53 | 06 | 0.80 | 20.27 | 00 | 01- | 00 | 1.69471 | 2.00830- | 01922- | 00028  | 02324 | 06602 |
| 53 | 07 | 0.80 | 22.34 | 00 | 01- | 00 | 1.88117 | 2.07935- | 01380- | 04078- | 02345 | 06343 |
| 54 | 02 | 0.60 | 01-   | 00 | 00  | 00 | 01173-  | 03341    | 00884- | 01474  | 03056 | 07940 |
| 54 | 03 | 0.60 | 8.06  | 00 | 00  | 00 | 53778   | 69309-   | 02912- | 05729  | 04725 | 08189 |
| 54 | 04 | 0.60 | 12.09 | 00 | 00  | 00 | 88546   | 1.22072- | 02095- | 01527  | 04479 | 08092 |
| 54 | 05 | 0.60 | 16.13 | 00 | 00  | 00 | 1.26595 | 1.75410- | 02222- | 01971  | 03714 | 07206 |
| 54 | 06 | 0.60 | 20.18 | 00 | 01- | 00 | 1.63035 | 2.12582- | 01829- | 00328- | 02079 | 05659 |
| 54 | 07 | 0.60 | 22.23 | 00 | 01- | 00 | 1.03477 | 2.29046- | 01652- | 00895- | 02108 | 06257 |
| 54 | 08 | 0.60 | 00    | 00 | 00  | 00 | 01070-  | 02418    | 01165- | 00094  | 03484 | 07781 |

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|        |      |       |       |      |         |          |         |         |        |        |
|--------|------|-------|-------|------|---------|----------|---------|---------|--------|--------|
| 108 02 | 1.20 | .00   | 22.50 | .01- | .04484  | .11801-  | .01880  | .09198- | .02929 | .21077 |
| 108 03 | 1.20 | 8.12  | 22.50 | .03- | .72166  | 1.17986- | .04988  | .24910- | .03663 | .23577 |
| 108 04 | 1.20 | 12.20 | 22.50 | .07- | 1.18251 | 1.72041- | .11045  | .56740- | .04274 | .25367 |
| 108 05 | 1.20 | 16.33 | 22.50 | .10- | 1.64234 | 2.01881- | .18322  | .85874- | .06811 | .26429 |
| 108 06 | 1.20 | 20.39 | 22.50 | .13- | 2.40239 | 2.35281- | .23068  | .09123- | .09568 | .26742 |
| 108 07 | 1.20 | 23.13 | 22.50 | .11- | 4.17021 | 3.36710- | .12902  | .77099- | .10394 | .26400 |
| 108 08 | 1.20 | .00   | 22.50 | .01- | .05300  | .12377-  | .01485  | .08876- | .02420 | .21576 |
| 109 09 | 1.10 | .00   | 22.50 | .00  | .333    | .07861   | .00978  | .00435- | .02554 | .21942 |
| 109 10 | 1.10 | 8.12  | 22.50 | .01- | .66683  | .80364-  | .04938  | .17547- | .02680 | .22685 |
| 109 11 | 1.10 | 12.21 | 22.50 | .05- | 1.09016 | 1.37641- | .12579  | .52697- | .02434 | .23267 |
| 109 12 | 1.10 | 16.32 | 22.50 | .10- | 1.55155 | 1.75118- | .21251  | .94352- | .04670 | .24392 |
| 109 13 | 1.10 | 20.52 | 22.50 | .13- | 2.09549 | 1.88745- | .26749  | .17492- | .06991 | .25756 |
| 109 14 | 1.10 | 22.68 | 22.50 | .13- | 2.64949 | 2.22785- | .27654  | .22616- | .06943 | .25777 |
| 109 15 | 1.10 | .00   | 22.50 | .00  | .00332  | .07855   | .00974  | .00431- | .02076 | .21973 |
| 110 02 | 0.60 | .01-  | 22.50 | .00  | .00349- | .01062   | .01492- | .01924  | .03803 | .05662 |
| 110 03 | 0.60 | 8.04  | 22.50 | .01- | .55229  | .77324-  | .01638  | .12905- | .05134 | .06131 |
| 110 04 | 0.60 | 12.08 | 22.50 | .03- | .92455  | 1.40046- | .07888  | .38274- | .04595 | .06371 |
| 110 05 | 0.60 | 16.11 | 22.50 | .06- | 1.33513 | 2.04471- | .17418  | .81322- | .06265 | .06001 |
| 110 06 | 0.60 | 20.16 | 22.50 | .08- | 1.73938 | 2.49460- | .24176  | .12493- | .11320 | .05492 |
| 110 07 | 0.60 | .22   | 22.50 | .09- | 1.93083 | 2.68695- | .26176  | .21315- | .13152 | .05209 |
| 110 08 | 0.60 | .01-  | 22.50 | .00  | .01152- | .02551   | .00561- | .00828  | .04216 | .05534 |

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|    |    |      |       |       |      |         |          |         |         |        |        |
|----|----|------|-------|-------|------|---------|----------|---------|---------|--------|--------|
| 55 | 02 | 1.25 | .00   | 11.25 | .00  | .01260  | .00012-  | .01935- | .06354  | .02468 | .24736 |
| 55 | 03 | 1.25 | 5.15  | 11.25 | .00  | .69434  | .83715-  | .90824  | .02443- | .02614 | .27657 |
| 55 | 04 | 1.25 | 12.25 | 11.25 | .02- | 1.11186 | 1.26066- | .06440  | .23846- | .02037 | .28682 |
| 55 | 05 | 1.25 | 16.39 | 11.25 | .05- | 1.56535 | 1.46989- | .08299  | .40047- | .03677 | .29360 |
| 55 | 06 | 1.25 | 22.17 | 11.25 | .03- | 2.12255 | 1.85341- | .15432  | .66792- | .04326 | .30042 |
| 55 | 07 | 1.25 | 25.66 | 11.25 | .07- | 2.32355 | 1.69555- | .16246  | .66269- | .02630 | .30311 |
| 55 | 08 | 1.25 | .00   | 11.25 | .00  | .02036  | .02073-  | .01917- | .06046  | .01499 | .25336 |
| 55 | 09 | 1.25 | .00   | 11.25 | .00  | .00862- | .02300   | .00044  | .00221  | .03226 | .10284 |
| 55 | 10 | 1.00 | .00   | 11.25 | .00  | .55765  | .67783-  | .03455  | .09223- | .02610 | .10803 |
| 55 | 11 | 1.00 | 8.10  | 11.25 | .00  | .97520  | 1.27955- | .08947  | .30932- | .01935 | .10794 |
| 55 | 12 | 1.00 | 12.17 | 11.25 | .02- | 1.44119 | 1.84551- | .13770  | .53621- | .03838 | .10440 |
| 55 | 13 | 1.00 | 16.26 | 11.25 | .05- | 1.51014 | 2.21276- | .15561  | .52342- | .06452 | .10228 |
| 55 | 14 | 1.00 | 20.38 | 11.25 | .04- | 2.29501 | 2.25581- | .16121  | .52303- | .08697 | .09693 |
| 55 | 15 | 1.00 | 22.49 | 11.25 | .03- | .57526  | .66653-  | .04030  | .10566- | .02039 | .11653 |
| 55 | 16 | 1.00 | 5.10  | 11.25 | .00  | .01707- | .03455   | .00034  | .09271  | .02568 | .11455 |
| 55 | 17 | 1.00 | .01-  | 11.25 | .00  | .56908  | .73198-  | .03550  | .10015- | .02377 | .09539 |
| 55 | 18 | 0.90 | 8.08  | 11.25 | .00  | .94582  | 1.29871- | .07995  | .27407- | .01626 | .09356 |
| 55 | 19 | 0.90 | 12.14 | 11.25 | .02- | 1.36859 | 1.63124- | .14985  | .55695- | .01611 | .08913 |
| 55 | 20 | 0.90 | 16.21 | 11.25 | .04- | 1.78590 | 2.10256- | .13982  | .43890- | .06212 | .08678 |
| 55 | 21 | 0.90 | 20.32 | 11.25 | .02- | 2.01422 | 2.22655- | .14539  | .44395- | .07129 | .08189 |
| 55 | 22 | 0.90 | 24.39 | 11.25 | .02- | .00511- | .00960   | .00478  | .00051- | .02114 | .09621 |
| 55 | 23 | 0.90 | .01   | 11.25 | .00  | .02544- | .05245   | .00256- | .00610  | .03912 | .07812 |
| 55 | 24 | 0.60 | .01-  | 11.25 | .00  | .53925  | .70133-  | .02276  | .05352- | .04753 | .08068 |
| 55 | 25 | 0.60 | 8.05  | 11.25 | .00  | .89326  | 1.28255- | .06369  | .24275- | .03700 | .08164 |
| 55 | 26 | 0.60 | 12.09 | 11.25 | .01- | 1.26150 | 1.53195- | .11692  | .48566- | .04371 | .07292 |
| 55 | 27 | 0.60 | 16.13 | 11.25 | .03- | 1.64596 | 2.22757- | .18623  | .75093- | .06774 | .06824 |
| 55 | 28 | 0.60 | 20.16 | 11.25 | .05- | 1.83404 | 2.35013- | .21168  | .79655- | .07701 | .06803 |
| 55 | 29 | 0.60 | 22.22 | 11.25 | .04- | .04381- | .05091   | .01169- | .01609  | .04768 | .07937 |
| 55 | 30 | 0.60 | .01-  | 11.25 | .00  | .00     | .00      | .00     | .00     | .00    | .00    |

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|    |    |      |       |       |      |         |          |         |         |        |        |
|----|----|------|-------|-------|------|---------|----------|---------|---------|--------|--------|
| 57 | 02 | 1.25 | .00   | 22.50 | .00  | .01869  | .02047-  | .03023- | .07634  | .02752 | .24872 |
| 58 | 03 | 1.25 | 8.14  | 22.50 | .00  | .70085  | .86843-  | .05108  | .12743- | .01601 | .27474 |
| 59 | 04 | 1.25 | 12.24 | 22.50 | .04- | 1.12465 | 1.39911- | .11597  | .43048- | .02142 | .28525 |
| 60 | 05 | 1.25 | 16.37 | 22.50 | .09- | 1.56920 | 1.64605- | .16849  | .74504- | .04371 | .29183 |
| 61 | 06 | 1.25 | 20.66 | 22.50 | .12- | 2.39952 | 2.02273- | .16047  | .91606- | .07211 | .30079 |
| 62 | 07 | 1.25 | 22.82 | 22.50 | .12- | 2.92761 | 2.22629- | .14422  | .81908- | .08348 | .30075 |
| 63 | 08 | 1.25 | .01   | 22.50 | .00  | .01521  | .01616-  | .02096- | .06653  | .01504 | .25448 |
| 64 | 09 | 1.10 | .00   | 22.50 | .01  | .01292- | .10021   | .00613  | .01111  | .03051 | .24302 |
| 65 | 00 | 1.10 | 8.13  | 22.50 | .00  | .65039  | .72423-  | .09633  | .18704- | .01697 | .25735 |
| 66 | 01 | 1.10 | 12.20 | 22.50 | .04- | 1.09159 | 1.30540- | .16525  | .53572- | .00290 | .25520 |
| 67 | 02 | 1.10 | 16.31 | 22.50 | .09- | 1.53394 | 1.01663- | .26932  | .00937- | .02280 | .26489 |
| 68 | 03 | 1.10 | 20.49 | 22.50 | .11- | 2.04934 | 1.90504- | .26440  | .10753- | .06519 | .27542 |
| 69 | 04 | 1.10 | 22.65 | 22.50 | .12- | 2.53712 | 2.08678- | .26016  | .12482- | .07354 | .28876 |
| 70 | 05 | 1.10 | .50   | 22.50 | .00  | .00349- | .05609   | .01131  | .00804- | .02026 | .25627 |
| 71 | 06 | 1.00 | .00   | 22.50 | .00  | .00916- | .01765   | .00442  | .00035- | .01837 | .11593 |
| 72 | 07 | 1.00 | 8.10  | 22.50 | .00  | .58922  | .75823-  | .06741  | .16855- | .00921 | .11833 |
| 73 | 08 | 1.00 | 12.17 | 22.50 | .03- | 1.02276 | 1.47003- | .14531  | .47264- | .00696 | .11865 |
| 74 | 09 | 1.00 | 16.24 | 22.50 | .06- | 1.48050 | 2.09593- | .22632  | .97076- | .03505 | .11032 |
| 75 | 00 | 1.00 | 20.37 | 22.50 | .08- | 1.95655 | 2.45719- | .21285  | .85645- | .09383 | .10409 |
| 76 | 01 | 1.00 | 22.48 | 22.50 | .02- | 2.28386 | 2.53883- | .24065  | .93530- | .11663 | .10190 |
| 77 | 02 | 1.00 | .01-  | 22.50 | .00  | .00091- | .00047   | .00047  | .00604- | .01251 | .11826 |

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|       |      |       |       |      |         |          |         |         |        |        |
|-------|------|-------|-------|------|---------|----------|---------|---------|--------|--------|
| 61 01 | 1.90 | 6.99  | 22.50 | .00  | .59238  | .61740-  | .06880  | .17852- | .00866 | .10249 |
| 61 02 | 0.90 | 12.13 | 22.50 | .01- | .58830  | 1.46671- | .14377  | .47683- | .00194 | .10149 |
| 62 03 | 0.90 | 16.20 | 22.50 | .07- | 1.39322 | 1.99279- | .41873  | .65580- | .03638 | .09724 |
| 62 04 | 0.90 | 20.30 | 22.50 | .07- | 1.32145 | 2.31670- | .19909  | .80210- | .09959 | .09033 |
| 62 05 | 0.90 | 22.37 | 22.50 | .00- | 2.04911 | 2.50680- | .17967  | .79319- | .11894 | .08298 |
| 63 02 | 0.60 | .01-  | 22.50 | .00  | .00515- | .01279   | .00259- | .00219  | .03950 | .07972 |
| 63 03 | 0.60 | 5.05  | 22.50 | .01- | .56247  | .78129-  | .03787  | .14946- | .03934 | .08117 |
| 63 04 | 0.60 | 12.08 | 22.50 | .02- | .92544  | 1.40934- | .10658  | .40341- | .03376 | .08338 |
| 63 05 | 0.60 | 16.15 | 22.50 | .05- | 1.33682 | 2.07661- | .22931  | .83498- | .05015 | .07476 |
| 63 06 | 0.60 | 20.18 | 22.50 | .08- | 1.72246 | 2.52152- | .28181  | .18584- | .10116 | .07202 |
| 63 07 | 0.60 | 22.21 | 22.50 | .08- | 1.90897 | 2.71211- | .28031  | .22981- | .13238 | .06778 |
| 63 08 | 0.60 | .00   | 22.50 | .00  | .00925- | .02373   | .01798- | .01776  | .04961 | .07826 |

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|    |    |      |       |       |      |         |          |         |         |        |        |
|----|----|------|-------|-------|------|---------|----------|---------|---------|--------|--------|
| 54 | 02 | 1.25 | 01-   | 33.75 | .00  | .01353  | .00096-  | .02501- | .07102  | .02474 | .24505 |
| 54 | 03 | 1.25 | 014   | 33.75 | .00  | .72305  | .00025-  | .04291  | .09555- | .01875 | .27442 |
| 54 | 04 | 1.25 | 12.14 | 33.75 | .04- | 1.15085 | 1.26395- | .13116  | .40554- | .01418 | .28693 |
| 54 | 05 | 1.25 | 16.56 | 33.75 | .10- | 1.65260 | 1.89712- | .22496  | .91166- | .03213 | .29442 |
| 54 | 06 | 1.25 | 20.64 | 33.75 | .13- | 2.49587 | 2.43773- | .24770  | .10400- | .06053 | .30013 |
| 54 | 07 | 1.25 | 22.65 | 33.75 | .12- | 3.03750 | 3.07725- | .12267  | .80413- | .07622 | .29254 |
| 54 | 08 | 1.25 | .00   | 33.75 | .01  | .01653  | .00007-  | .02268- | .07271  | .01475 | .25049 |
| 55 | 01 | 1.00 | 01-   | 33.75 | .00  | .01370- | .02723   | .00661  | .00465- | .02938 | .10834 |
| 55 | 02 | 1.00 | 009   | 33.75 | .00  | .62249  | .00077-  | .05925  | .15684- | .01802 | .11537 |
| 55 | 03 | 1.00 | 11.17 | 33.75 | .03- | 1.07043 | 1.05001- | .13910  | .47204- | .01228 | .11727 |
| 55 | 04 | 1.00 | 16.25 | 33.75 | .07- | 1.60114 | 2.01490- | .25222  | .91675- | .03545 | .10697 |
| 55 | 05 | 1.00 | 20.35 | 33.75 | .09- | 2.09385 | 3.02087- | .27203  | .05939- | .08266 | .08916 |
| 55 | 06 | 1.00 | 22.44 | 33.75 | .10- | 2.30897 | 3.22215- | .20716  | .93964- | .10514 | .07420 |
| 55 | 07 | 1.00 | .01-  | 33.75 | .00  | .01215- | .02616   | .00230  | .00117  | .02974 | .11170 |
| 56 | 01 | 0.90 | 01-   | 33.75 | .00  | .00947- | .01914   | .00247  | .00156- | .01772 | .09178 |
| 56 | 02 | 0.90 | 008   | 33.75 | .01- | .01397  | .30313-  | .05503  | .15513- | .00367 | .09841 |
| 56 | 03 | 0.90 | 12.13 | 33.75 | .02- | 1.04205 | 1.66574- | .15091  | .49216- | .00545 | .09982 |
| 56 | 04 | 0.90 | 16.20 | 33.75 | .07- | 1.43024 | 2.28298- | .28151  | .00489- | .04008 | .09761 |
| 56 | 05 | 0.90 | 20.29 | 33.75 | .09- | 1.92354 | 2.75393- | .28371  | .07684- | .09138 | .08753 |
| 56 | 06 | 0.90 | 22.35 | 33.75 | .07- | 2.16165 | 2.95512- | .22792  | .97479- | .12248 | .07411 |
| 57 | 01 | 0.80 | 01-   | 33.75 | .00  | .01134- | .02541   | .00505- | .00842  | .03242 | .07991 |
| 57 | 02 | 0.80 | 005   | 33.75 | .01- | .01102  | .34092-  | .04415  | .15399- | .03955 | .08411 |
| 57 | 03 | 0.80 | 12.09 | 33.75 | .02- | .93406  | 1.60133- | .12437  | .44718- | .03425 | .08814 |
| 57 | 04 | 0.80 | 16.11 | 33.75 | .03- | 1.40229 | 2.06453- | .26662  | .95952- | .04266 | .08494 |
| 57 | 05 | 0.80 | 20.16 | 33.75 | .07- | 1.82049 | 2.93613- | .38935  | .48435- | .09430 | .07864 |
| 57 | 06 | 0.80 | 22.10 | 33.75 | .09- | 2.04176 | 3.19404- | .41916  | .59433- | .11709 | .07435 |
| 57 | 07 | 0.80 | .01-  | 33.75 | .00  | .00414- | .01173   | .00664- | .01064  | .04795 | .07716 |

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|       |      |       |       |      |         |          |         |         |         |        |
|-------|------|-------|-------|------|---------|----------|---------|---------|---------|--------|
| 68 01 | 1.00 | .00   | 45.00 | .01  | .01655  | .00377-  | .02116- | .07190  | .02474  | .24530 |
| 68 02 | 1.25 | .14   | 45.00 | .01  | .74384  | 1.04044- | .03611  | .02723- | .01650  | .27778 |
| 68 03 | 1.25 | 12.24 | 45.00 | .01- | 1.00751 | 1.05010- | .07685  | .20931- | .01616  | .29294 |
| 68 04 | 1.10 | 16.56 | 45.00 | .04- | 1.71037 | 1.11901- | .24300  | .65177- | .00525  | .29625 |
| 68 05 | 1.25 | 20.82 | 45.00 | .00- | 2.02074 | 2.02771- | .15140  | .09546- | .00454  | .29450 |
| 68 06 | 1.25 | 22.83 | 45.00 | .07- | 3.03742 | 2.82155- | .13113  | .00557- | .01906  | .28438 |
| 68 07 | 1.25 | .00   | 45.00 | .01  | .002775 | .02214-  | .02493- | .07271  | .01468  | .24570 |
| 69 02 | 1.10 | .00   | 45.00 | .01  | .00559- | .10054   | .00797  | .00972  | .02509  | .24516 |
| 69 03 | 1.10 | 8.15  | 45.00 | .01  | .70771  | .09905-  | .02062  | .05542- | .01672  | .25623 |
| 69 04 | 1.10 | 12.21 | 45.00 | .01  | 1.19355 | 1.71457- | .11560  | .23025- | .01100  | .26587 |
| 69 05 | 1.10 | 16.30 | 45.00 | .02- | 1.69543 | 2.04311- | .23277  | .60203- | .00486  | .27115 |
| 69 06 | 1.10 | 20.47 | 45.00 | .07- | 2.27366 | 2.70300- | .34953  | .00550- | .02187  | .28921 |
| 69 07 | 1.10 | 22.82 | 45.00 | .00- | 2.73797 | 3.01477- | .22051  | .74026- | .00565  | .29227 |
| 69 08 | 1.10 | .00   | 45.00 | .01  | .01001- | .10324   | .00932  | .01075  | .01662  | .24960 |
| 70 01 | 1.00 | .01-  | 45.00 | .00  | .01415- | .00330   | .00640  | .00705- | .01507  | .11332 |
| 70 02 | 1.00 | 8.10  | 45.00 | .01  | .69622  | .89511-  | .04986  | .06418- | .00697  | .11852 |
| 70 03 | 1.00 | 12.15 | 45.00 | .00  | 1.12046 | 1.79740- | .10358  | .22891- | .00316- | .12289 |
| 70 04 | 1.00 | 16.22 | 45.00 | .01- | 1.65254 | 2.72995- | .21523  | .55801- | .00970- | .11390 |
| 70 05 | 1.00 | 20.33 | 45.00 | .04- | 2.21431 | 3.03860- | .30053  | .00955- | .01170  | .09093 |
| 70 06 | 1.00 | 22.42 | 45.00 | .00- | 2.54717 | 3.72204- | .26363  | .84738- | .02224  | .06981 |
| 70 07 | 1.00 | .01-  | 45.00 | .00  | .00000- | .01493   | .00423  | .00540- | .00520  | .11811 |

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|            |       |       |      |         |          |         |         |        |        |
|------------|-------|-------|------|---------|----------|---------|---------|--------|--------|
| 71 02 0.90 | .01-  | 45.00 | .00  | .00125  | .00036-  | .00136- | .00114- | .03036 | .08921 |
| 71 04 0.90 | 8.09  | 45.00 | .00  | .64096  | .90021-  | .02955  | .05641- | .04083 | .09535 |
| 71 05 0.90 | 12.13 | 45.00 | .00  | 1.10093 | 1.80533- | .10610  | .23771- | .01071 | .09899 |
| 71 06 0.90 | 16.19 | 45.00 | .00  | 1.61593 | 2.79933- | .24213  | .69175- | .01384 | .09425 |
| 71 07 0.90 | 20.23 | 45.00 | .00  | 2.11670 | 3.41397- | .36513  | .13419- | .05669 | .08142 |
| 71 08 0.90 | 24.34 | 45.00 | .07- | 2.39322 | 3.01510- | .34833  | .13545- | .08151 | .06633 |
| 71 09 0.90 | .00   | 45.00 | .00  | .00095  | .00534   | .00193- | .00104- | .02406 | .09109 |
| 72 02 0.60 | .00   | 45.00 | .00  | .00442- | .02060   | .00877- | .00667  | .04374 | .07739 |
| 72 03 0.60 | 8.09  | 45.00 | .00  | .61503  | .91327-  | .02318  | .06054- | .05932 | .08474 |
| 72 04 0.60 | 12.08 | 45.00 | .00  | 1.02404 | 1.72221- | .03077  | .21711- | .03375 | .09145 |
| 72 05 0.60 | 16.11 | 45.00 | .02- | 1.51158 | 2.60539- | .21049  | .62145- | .03254 | .08418 |
| 72 06 0.60 | 20.16 | 45.00 | .00  | 2.01110 | 3.50734- | .41243  | .36112- | .05466 | .07789 |
| 72 07 0.60 | 24.23 | 45.00 | .07- | 2.25186 | 3.90204- | .46131  | .22426- | .06508 | .07176 |
| 72 08 0.60 | .01-  | 45.00 | .00  | .00401  | .00627   | .01803- | .01305  | .04816 | .07719 |

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|       |      |       |       |     |         |          |         |         |         |        |
|-------|------|-------|-------|-----|---------|----------|---------|---------|---------|--------|
| 72 01 | 1.25 | .00   | 67.50 | .01 | .01890  | .00000-  | .01000- | .06787  | .01976  | .24833 |
| 73 02 | 1.25 | .010  | 67.50 | .02 | .71971  | .00000-  | .01000- | .25530  | .02012  | .27944 |
| 73 03 | 1.25 | 12.25 | 67.50 | .07 | 1.10040 | 1.25000- | .00000- | .37659  | .01029- | .29030 |
| 73 04 | 1.25 | 10.40 | 67.50 | .03 | 1.71244 | 1.05000- | .00240  | .19761  | .05927- | .29260 |
| 73 05 | 1.25 | 20.67 | 67.50 | .03 | 2.40345 | 2.12000- | .00000- | .17978  | .08619- | .29355 |
| 73 06 | 1.25 | 21.01 | 67.50 | .03 | 1.90090 | 2.19000- | .04136- | .43209  | .07402- | .29035 |
| 73 07 | 1.25 | .00   | 67.50 | .01 | .00073  | .00000-  | .00110- | .00291  | .00900  | .25552 |
| 74 02 | 1.00 | .01-  | 67.50 | .00 | .00004  | .00000-  | .00040  | .00002  | .02977  | .10992 |
| 74 03 | 1.00 | 8.11  | 67.50 | .02 | .00037  | .00000-  | .01144- | .12882  | .01950  | .11901 |
| 74 04 | 1.00 | 12.17 | 67.50 | .03 | 1.05129 | 1.47000- | .02000- | .33544  | .00070  | .12078 |
| 74 05 | 1.00 | 16.19 | 67.50 | .07 | 1.61031 | 2.29000- | .00000- | .32707  | .01049- | .10537 |
| 74 06 | 1.00 | 20.40 | 67.50 | .03 | 2.10000 | 2.09000- | .07149  | .27039  | .00004- | .08451 |
| 74 07 | 1.00 | 22.60 | 67.50 | .07 | 2.47004 | 2.00000- | .08714  | .24821  | .05256- | .07118 |
| 74 08 | 1.00 | .01-  | 67.50 | .00 | .00851  | .01000-  | .00000- | .01130- | .02401  | .11573 |
| 75 02 | 0.90 | .00   | 67.50 | .02 | .00000  | .00000-  | .00040  | .00000- | .03041  | .06928 |
| 75 03 | 0.90 | 8.11  | 67.50 | .02 | .62077  | .01000-  | .01000- | .16011  | .02617  | .09751 |
| 75 04 | 0.90 | 12.14 | 67.50 | .03 | 1.02923 | 1.45000- | .04200- | .30979  | .00775  | .09978 |
| 75 05 | 0.90 | 16.22 | 67.50 | .00 | 1.50000 | 2.17000- | .01000- | .33000  | .01463- | .08800 |
| 75 06 | 0.90 | 20.34 | 67.50 | .08 | 2.04551 | 2.82000- | .10000  | .09739  | .05271- | .06697 |
| 75 07 | 0.90 | 22.38 | 67.50 | .03 | 2.29000 | 3.00000- | .17714  | .00034  | .05921- | .05680 |
| 75 08 | 0.90 | .01-  | 67.50 | .00 | .00075  | .00000-  | .00000  | .00001- | .02727  | .09121 |
| 76 02 | 0.50 | .00   | 67.50 | .00 | .01095- | .02000-  | .00000- | .00702  | .03073  | .07966 |
| 76 03 | 0.50 | 8.04  | 67.50 | .01 | .50000  | .77000-  | .02000- | .15710  | .00000  | .08870 |
| 76 04 | 0.50 | 12.10 | 67.50 | .03 | .90001  | 1.39000- | .00000- | .33000  | .01789  | .09469 |
| 76 05 | 0.50 | 16.13 | 67.50 | .03 | 1.40047 | 1.14000- | .00000- | .40753  | .00000  | .08497 |
| 76 06 | 0.50 | 20.17 | 67.50 | .03 | 1.07070 | 2.01000- | .00000  | .40319  | .01230- | .06406 |
| 76 07 | 0.50 | 22.22 | 67.50 | .07 | 1.10100 | 3.00000- | .02000  | .40132  | .01227- | .05566 |

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|    |    |      |       |       |     |         |          |         |         |         |        |
|----|----|------|-------|-------|-----|---------|----------|---------|---------|---------|--------|
| 77 | 02 | 1.25 | .00   | 90.00 | .01 | .01851  | .00007   | .01405- | .06430  | .01748  | .25348 |
| 77 | 03 | 1.25 | 6.14  | 90.00 | .02 | .60085  | .71752-  | .00057- | .06582  | .02306  | .27967 |
| 77 | 04 | 1.25 | 12.26 | 90.00 | .02 | 1.11340 | 1.12145- | .04186  | .01888- | .09863  | .29236 |
| 77 | 05 | 1.25 | 16.43 | 90.00 | .02 | 1.63315 | 1.70312- | .12777  | .18565- | .02216- | .29875 |
| 77 | 06 | 1.25 | 20.70 | 90.00 | .03 | 2.42333 | 1.64315- | .18222  | .28857- | .02144- | .29752 |
| 77 | 07 | 1.25 | 22.93 | 90.00 | .04 | 2.92302 | 1.76250- | .15345  | .29644- | .00565  | .29305 |
| 77 | 08 | 1.25 | .00   | 90.00 | .01 | .02221  | .00911-  | .01917- | .07475  | .01259  | .25824 |
| 78 | 02 | 1.00 | .01-  | 90.00 | .00 | .00420  | .00300-  | .00239  | .00410- | .02692  | .11116 |
| 78 | 03 | 1.00 | 6.10  | 90.00 | .01 | .57739  | .59952-  | .00187  | .02416  | .02554  | .11209 |
| 78 | 04 | 1.00 | 12.19 | 90.00 | .01 | .99037  | 1.11520- | .04139  | .02247- | .01189  | .11665 |
| 78 | 05 | 1.00 | 16.29 | 90.00 | .02 | 1.46951 | 1.01000- | .11858  | .16596- | .00319  | .10881 |
| 78 | 06 | 1.00 | 20.42 | 90.00 | .02 | 2.04436 | 2.09212- | .20356  | .36044- | .00279  | .09573 |
| 78 | 07 | 1.00 | 22.55 | 90.00 | .02 | 2.33253 | 2.06122- | .23490  | .42465- | .02539  | .08915 |
| 78 | 08 | 1.00 | .00   | 90.00 | .00 | .00000  | .00017   | .00433  | .00550- | .01541  | .11653 |
| 79 | 02 | 0.50 | .02-  | 90.00 | .00 | .00080  | .00024-  | .00044  | .00009- | .03361  | .08914 |
| 79 | 03 | 0.50 | 6.06  | 90.00 | .01 | .57172  | .62302-  | .00176- | .03475  | .03261  | .09483 |
| 79 | 04 | 0.50 | 12.16 | 90.00 | .01 | .96931  | 1.14151- | .01860  | .02121  | .02082  | .09579 |
| 79 | 05 | 0.50 | 16.24 | 90.00 | .02 | 1.41314 | 1.62233- | .08520  | .10843- | .01480  | .08744 |
| 79 | 06 | 0.50 | 20.37 | 90.00 | .02 | 1.90980 | 2.00003- | .17945  | .30335- | .01790  | .07837 |
| 79 | 07 | 0.50 | 22.44 | 90.00 | .03 | 2.16033 | 2.06129- | .15067  | .29672- | .03617  | .07579 |
| 79 | 08 | 0.50 | .01-  | 90.00 | .00 | .00032  | .00016   | .00257  | .00446- | .02755  | .09617 |
| 80 | 02 | 0.60 | .01-  | 90.00 | .00 | .01085- | .02532   | .00880- | .00692  | .03936  | .07768 |
| 80 | 03 | 0.60 | 6.04  | 90.00 | .00 | .53740  | .60905-  | .01708- | .04360  | .04258  | .08241 |
| 80 | 04 | 0.60 | 12.11 | 90.00 | .00 | .90125  | 1.12142- | .00305  | .00077  | .03146  | .08414 |
| 80 | 05 | 0.60 | 16.13 | 90.00 | .00 | 1.29971 | 1.62591- | .03541  | .06312- | .03276  | .07870 |
| 80 | 06 | 0.60 | 20.20 | 90.00 | .00 | 1.70750 | 2.10125- | .10666  | .23071- | .03404  | .07514 |
| 80 | 07 | 0.60 | 22.23 | 90.00 | .00 | 1.91375 | 2.24080- | .12956  | .23733- | .04283  | .06796 |
| 80 | 08 | 0.60 | .02-  | 90.00 | .00 | .00410- | .01195   | .00879- | .00689  | .03938  | .07807 |

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|    |    |      |       |        |      |         |          |         |         |        |        |
|----|----|------|-------|--------|------|---------|----------|---------|---------|--------|--------|
| 31 | 32 | 1.25 | .01   | 112.50 | .01  | .02224  | .01250   | .01778- | .05475  | .02000 | .25339 |
| 31 | 04 | 1.25 | 12.28 | 112.50 | .05- | 1.15277 | 1.33132- | .10563  | .45067- | .03235 | .29709 |
| 31 | 03 | 1.25 | 16.41 | 112.50 | .09- | 1.64135 | 1.62235- | .22067  | .89042- | .06783 | .30637 |
| 31 | 06 | 1.25 | 20.56 | 112.50 | .12- | 2.42009 | 1.90061- | .24763  | .04754- | .07271 | .31247 |
| 31 | 07 | 1.25 | 22.88 | 112.50 | .12- | 3.01145 | 2.17506- | .22012  | .98065- | .09579 | .30736 |
| 31 | 08 | 1.25 | 25.14 | 112.50 | .01- | .70771  | .82044-  | .52728  | .10261- | .01936 | .28763 |
| 31 | 09 | 1.25 | .01   | 112.50 | .01  | .02501  | .00033-  | .01565- | .06525  | .31521 | .25939 |
| 32 | 03 | 1.00 | .01-  | 112.50 | .00  | .00503  | .00827-  | .00449- | .01095- | .02989 | .11095 |
| 32 | 03 | 1.00 | 9.10  | 112.50 | .02- | .61067  | .73662-  | .03840  | .16305- | .02992 | .11565 |
| 32 | 04 | 1.00 | 12.20 | 112.50 | .05- | 1.05195 | 1.42954- | .13495  | .52697- | .03585 | .11853 |
| 32 | 06 | 1.00 | 16.26 | 112.50 | .09- | 1.52948 | 2.01097- | .24562  | .96288- | .07067 | .11944 |
| 32 | 07 | 1.00 | 20.33 | 112.50 | .08- | 2.00571 | 2.43194- | .27202  | .99655- | .12919 | .11260 |
| 32 | 08 | 1.00 | 22.50 | 112.50 | .08- | 2.25505 | 2.59540- | .26871  | .01898- | .16065 | .10147 |
| 32 | 09 | 1.00 | .01-  | 112.50 | .00  | .00844  | .01683-  | .00852  | .01131- | .02095 | .11106 |
| 33 | 01 | 0.90 | .01-  | 112.50 | .00  | .01003  | .01926-  | .00246  | .00438- | .01807 | .09441 |
| 33 | 02 | 0.90 | 9.06  | 112.50 | .02- | .59452  | .75842-  | .02837  | .14579- | .02462 | .10030 |
| 33 | 03 | 0.90 | 12.15 | 112.50 | .05- | 1.01875 | 1.42508- | .11691  | .50035- | .03106 | .10635 |
| 33 | 04 | 0.90 | 15.21 | 112.50 | .09- | 1.44100 | 1.93955- | .22168  | .92225- | .07825 | .10670 |
| 33 | 05 | 0.90 | 20.33 | 112.50 | .07- | 1.88905 | 2.24370- | .18455  | .79617- | .16003 | .10003 |
| 33 | 06 | 0.90 | 22.41 | 112.50 | .07- | 2.17540 | 2.53115- | .17996  | .75471- | .18199 | .09122 |
| 33 | 07 | 0.90 | .02-  | 112.50 | .00  | .01546  | .02965-  | .00199- | .00180  | .01800 | .09384 |
| 34 | 03 | 0.60 | .01-  | 112.50 | .00  | .00425- | .01185   | .00890- | .00700  | .03088 | .08072 |
| 34 | 04 | 0.60 | 9.05  | 112.50 | .01- | .56409  | .73021-  | .01579  | .14043- | .03545 | .08734 |
| 34 | 05 | 0.60 | 12.08 | 112.50 | .03- | .92558  | 1.34255- | .08403  | .41091- | .04334 | .09271 |
| 34 | 06 | 0.60 | 16.12 | 112.50 | .06- | 1.34701 | 2.01057- | .20721  | .89132- | .06902 | .09561 |
| 34 | 07 | 0.60 | 20.17 | 112.50 | .09- | 1.75197 | 2.55434- | .26355  | .23181- | .14665 | .08967 |
| 34 | 08 | 0.60 | 22.22 | 112.50 | .09- | 1.99600 | 2.92266- | .22366  | .11139- | .12640 | .08748 |
| 34 | 09 | 0.60 | .01-  | 112.50 | .00  | .00361- | .01146   | .01193- | .00929  | .03508 | .07975 |

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|    |     |       |     |        |     |         |          |        |        |       |       |
|----|-----|-------|-----|--------|-----|---------|----------|--------|--------|-------|-------|
| 02 | 00  | 1.25  | 00  | 135.00 | 00  | 02795   | 00310    | 02854- | 07726  | 02485 | 24972 |
| 03 | 01- | 1.25  | 01- | 135.00 | 01- | 72985   | 97307-   | 00940- | 00412- | 03728 | 28598 |
| 04 | 01- | 1.25  | 01- | 135.00 | 01- | 1.20144 | 1.61444- | 01020  | 07635- | 03453 | 30174 |
| 05 | 03- | 1.25  | 03- | 135.00 | 03- | 1.75261 | 2.13924- | 04937  | 25590- | 03570 | 30730 |
| 06 | 04- | 1.25  | 04- | 135.00 | 04- | 2.61112 | 2.75857- | 04151  | 25379- | 02209 | 30195 |
| 07 | 04- | 1.25  | 04- | 135.00 | 04- | 3.11585 | 2.93396- | 0143-  | 13790- | 04535 | 29377 |
| 08 | 00  | 1.25  | 00  | 135.00 | 00  | 03845   | 00885-   | 02477- | 06464  | 01741 | 25357 |
| 09 | 00  | 1.01- | 01- | 135.00 | 00  | 00079   | 00045-   | 00036  | 00006  | 02682 | 11043 |
| 10 | 01- | 1.01  | 01- | 135.00 | 01- | 02770   | 09448-   | 01145  | 07737- | 03615 | 12033 |
| 11 | 02- | 1.01  | 02- | 135.00 | 02- | 1.11015 | 1.79256- | 03016  | 14004- | 03857 | 12680 |
| 12 | 03- | 1.01  | 03- | 135.00 | 03- | 1.55600 | 2.72394- | 06551  | 29452- | 05219 | 11952 |
| 13 | 05- | 1.01  | 05- | 135.00 | 05- | 2.25915 | 3.45855- | 10150  | 44874- | 06428 | 10084 |
| 14 | 06- | 1.01  | 06- | 135.00 | 06- | 2.57905 | 3.78564- | 09461- | 07300- | 05196 | 08241 |
| 15 | 00  | 1.01  | 01- | 135.00 | 00  | 00529   | 00922-   | 00026  | 00241- | 02132 | 11858 |
| 16 | 00  | 0.50  | 01- | 135.00 | 00  | 00293   | 01026-   | 00028  | 03275- | 02152 | 09547 |
| 17 | 01- | 0.50  | 01- | 135.00 | 01- | 02457   | 02854-   | 00929  | 07475- | 02641 | 10784 |
| 18 | 02- | 0.50  | 02- | 135.00 | 02- | 1.09010 | 1.84990- | 02219  | 13520- | 03744 | 11255 |
| 19 | 03- | 0.50  | 03- | 135.00 | 03- | 1.50123 | 2.77673- | 04532  | 27109- | 04914 | 10630 |
| 20 | 03- | 0.50  | 03- | 135.00 | 03- | 2.12612 | 3.61110- | 00104- | 12455- | 06139 | 08535 |
| 21 | 01- | 0.50  | 01- | 135.00 | 01- | 2.59214 | 3.85113- | 06477- | 07841  | 05592 | 07650 |
| 22 | 00  | 0.50  | 00  | 135.00 | 00  | 00548   | 01600-   | 00249  | 00457- | 01058 | 09980 |
| 23 | 00  | 0.50  | 00  | 135.00 | 00  | 00321   | 01449-   | 00505- | 00467  | 02649 | 07970 |
| 24 | 01- | 0.50  | 01- | 135.00 | 01- | 05632   | 09929-   | 00466- | 05115- | 03979 | 02803 |
| 25 | 01- | 0.50  | 01- | 135.00 | 01- | 1.02050 | 1.71641- | 01021  | 11103- | 03891 | 09741 |
| 26 | 02- | 0.50  | 02- | 135.00 | 02- | 1.43945 | 2.61177- | 03390  | 23622- | 05051 | 09439 |
| 27 | 03- | 0.50  | 03- | 135.00 | 03- | 1.96644 | 3.50455- | 04538  | 32279- | 06564 | 08021 |
| 28 | 03- | 0.50  | 03- | 135.00 | 03- | 2.23184 | 3.95943- | 00261  | 18960- | 07470 | 07188 |
| 29 | 00  | 0.50  | 01- | 135.00 | 00  | 00277   | 00219-   | 01195- | 01316  | 03059 | 07771 |

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|       |      |       |        |     |         |          |         |         |         |        |
|-------|------|-------|--------|-----|---------|----------|---------|---------|---------|--------|
| 89 02 | 1.29 | .00   | 157.50 | .00 | .02295  | .00254   | .02149- | .05842  | .02007  | .25363 |
| 89 03 | 1.29 | .016  | 157.50 | .01 | .71737  | .37862-  | .05052- | .14569  | .03875  | .28338 |
| 89 04 | 1.29 | 12.25 | 157.50 | .04 | 1.13239 | 1.37752- | .11768- | .45243  | .02882  | .29917 |
| 89 05 | 1.29 | 13.39 | 157.50 | .03 | 1.64922 | 1.75240- | .19358- | .75310  | .01389- | .30520 |
| 89 06 | 1.29 | 20.66 | 157.50 | .09 | 2.49242 | 2.25373- | .21761- | .86570  | .05286- | .30380 |
| 89 07 | 1.29 | 22.43 | 157.50 | .09 | 2.95765 | 2.44716- | .20883- | .82812  | .07498- | .29786 |
| 89 08 | 1.29 | .01   | 157.50 | .00 | .05166  | .01264-  | .02156- | .05355  | .01525  | .25842 |
| 90 02 | 1.00 | .01-  | 157.50 | .00 | .00502  | .00307-  | .00251  | .00159- | .03264  | .10943 |
| 90 03 | 1.00 | 8.08  | 157.50 | .00 | .60472  | .82828-  | .01589- | .03519  | .02796  | .11353 |
| 90 04 | 1.00 | 12.15 | 157.50 | .03 | 1.01927 | 1.46515- | .05832- | .35744  | .03500  | .11734 |
| 90 05 | 1.00 | 18.24 | 157.50 | .07 | 1.48935 | 2.07524- | .17036- | .73434  | .00777  | .11528 |
| 90 06 | 1.00 | 20.49 | 157.50 | .07 | 1.97237 | 2.39077- | .17906- | .73277  | .04522- | .09744 |
| 90 07 | 1.00 | 22.47 | 157.50 | .07 | 2.31135 | 2.59322- | .18129- | .75391  | .06063- | .08695 |
| 90 08 | 1.00 | .01-  | 157.50 | .00 | .00469  | .01478-  | .00445  | .00301- | .02102  | .11352 |
| 91 01 | 0.90 | .01-  | 157.50 | .00 | .01032  | .01972-  | .00028  | .00007  | .02125  | .09514 |
| 91 02 | 0.90 | 8.09  | 157.50 | .00 | .51536  | .37827-  | .02362- | .00685  | .03329  | .09917 |
| 91 03 | 0.90 | 12.15 | 157.50 | .03 | 1.00026 | 1.49759- | .11131- | .42694  | .02715  | .10477 |
| 91 04 | 0.90 | 16.20 | 157.50 | .06 | 1.58571 | 1.69055- | .17440- | .71021  | .01779- | .10286 |
| 91 05 | 0.90 | 20.30 | 157.50 | .06 | 1.81934 | 2.21646- | .15783- | .65676  | .05469- | .09154 |
| 91 06 | 0.90 | 22.38 | 157.50 | .06 | 2.09685 | 2.45162- | .16395- | .66302  | .07773- | .07735 |
| 91 08 | 0.90 | .01-  | 157.50 | .00 | .01537  | .02982-  | .00191- | .00455  | .02126  | .09624 |
| 92 02 | 0.60 | .01-  | 157.50 | .00 | .00189  | .00107-  | .00578- | .00462  | .03087  | .03084 |
| 92 03 | 0.60 | 5.07  | 157.50 | .00 | .56243  | .79570-  | .04714- | .10568  | .04322  | .08593 |
| 92 04 | 0.60 | 12.03 | 157.50 | .02 | .92951  | 1.42419- | .11650- | .39464  | .04397  | .09058 |
| 92 05 | 0.60 | 16.12 | 157.50 | .04 | 1.34756 | 2.07685- | .20920- | .76350  | .02653  | .08930 |
| 92 07 | 0.60 | 20.16 | 157.50 | .07 | 1.73474 | 1.67420- | .29153- | .17428  | .00500- | .07869 |
| 92 08 | 0.60 | 22.21 | 157.50 | .06 | 2.01569 | 2.39461- | .32451- | .31296  | .01842- | .07056 |
| 92 09 | 0.60 | .01-  | 157.50 | .00 | .00306  | .00186-  | .01195- | .00327  | .03503  | .07618 |

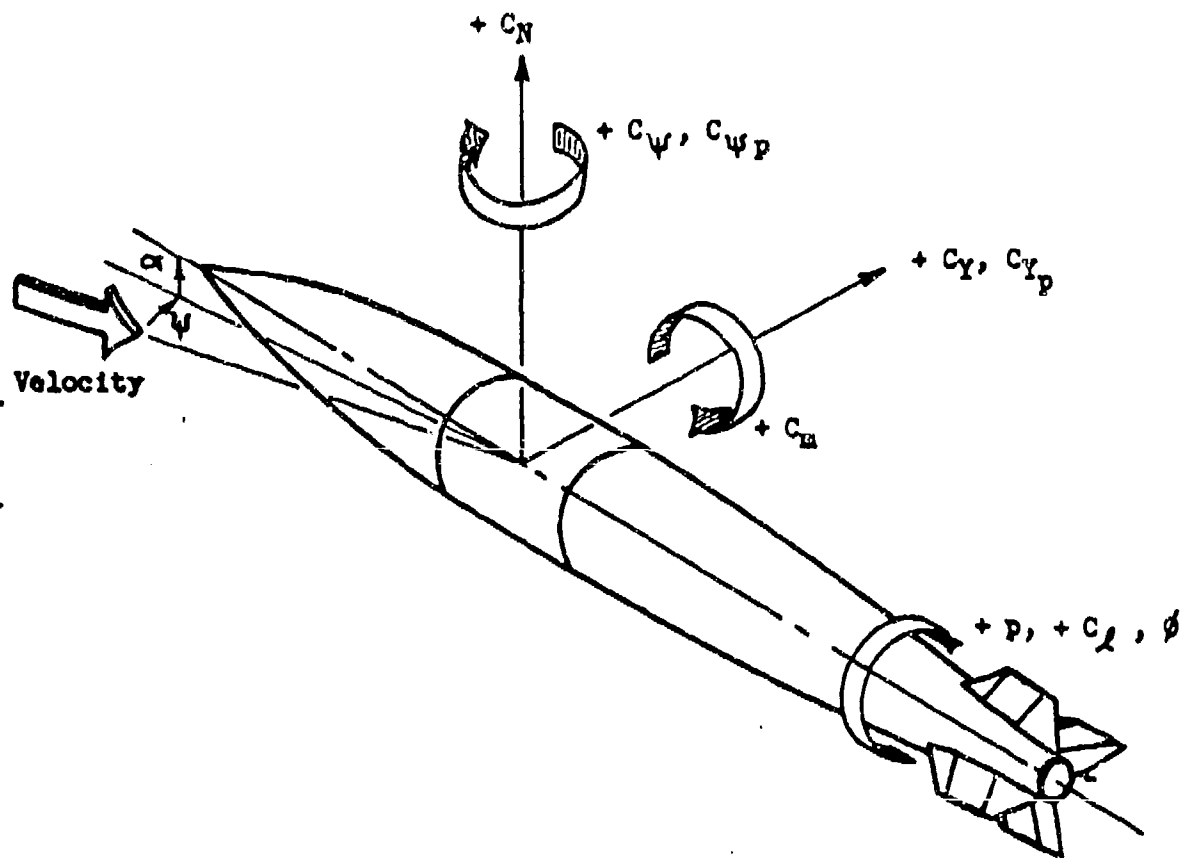
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|       |      |       |        |      |         |          |         |         |         |        |
|-------|------|-------|--------|------|---------|----------|---------|---------|---------|--------|
| 92 02 | 1.25 | .00   | 180.00 | .00  | .02257  | .00033   | .02130- | .04666  | .02011  | .25496 |
| 92 03 | 1.25 | 6.15  | 180.00 | .00  | .68352  | .75502-  | .02312- | .07175  | .03227  | .27747 |
| 92 04 | 1.25 | 12.27 | 180.00 | .00  | 1.09741 | 1.16893- | .04024- | .08840  | .02419  | .28799 |
| 92 05 | 1.25 | 16.40 | 180.00 | .00  | 1.52626 | 1.41592- | .04397- | .10352  | .02155  | .29470 |
| 92 06 | 1.25 | 20.70 | 180.00 | .00  | 2.41425 | 1.77779- | .04029- | .07365  | .00269- | .29217 |
| 92 08 | 1.25 | .00   | 180.00 | .00  | .03092  | .01114-  | .01550- | .03761  | .01274  | .25779 |
| 94 02 | 1.20 | .00   | 180.00 | .01- | .04520  | .09303-  | .01110  | .03321- | .02366  | .25104 |
| 94 03 | 1.20 | 3.11  | 180.00 | .02- | .72062  | 1.00013- | .01070  | .10102- | .04049  | .27173 |
| 94 04 | 1.20 | 12.22 | 180.00 | .02- | 1.13578 | 1.46865- | .01246  | .11490- | .03681  | .28579 |
| 94 05 | 1.20 | 16.38 | 180.00 | .02- | 1.61603 | 1.73917- | .01633  | .13028- | .02630  | .29057 |
| 94 06 | 1.20 | 20.60 | 180.00 | .02- | 2.35745 | 1.09245- | .00254- | .07534- | .01928  | .28353 |
| 94 07 | 1.20 | 22.78 | 180.00 | .01- | 2.88344 | 2.32879- | .03633- | .03693  | .01740  | .27671 |
| 94 08 | 1.20 | .00   | 180.00 | .01- | .04455  | .10223-  | .01475  | .08843- | .01848  | .25441 |
| 95 01 | 1.10 | .00   | 180.00 | .00  | .00429  | .36722   | .00727  | .00275- | .02021  | .25513 |
| 95 02 | 1.10 | 6.15  | 180.00 | .00  | .64099  | .55263-  | .01475  | .03614- | .03083  | .26043 |
| 95 03 | 1.10 | 12.22 | 180.00 | .00  | 1.03960 | 1.14180- | .00445- | .00022  | .03214  | .26745 |
| 95 04 | 1.10 | 16.35 | 180.00 | .01- | 1.52697 | 1.54400- | .01574  | .05560- | .02472  | .27474 |
| 95 05 | 1.10 | 20.52 | 180.00 | .02- | 2.07460 | 1.63857- | .03554  | .15651- | .01340  | .28051 |
| 95 06 | 1.10 | 22.66 | 180.00 | .02- | 2.51735 | 1.72527- | .05477  | .20966- | .00411  | .28000 |
| 95 07 | 1.10 | .00   | 180.00 | .00  | .00342  | .07734   | .00778  | .00227  | .01464  | .25603 |

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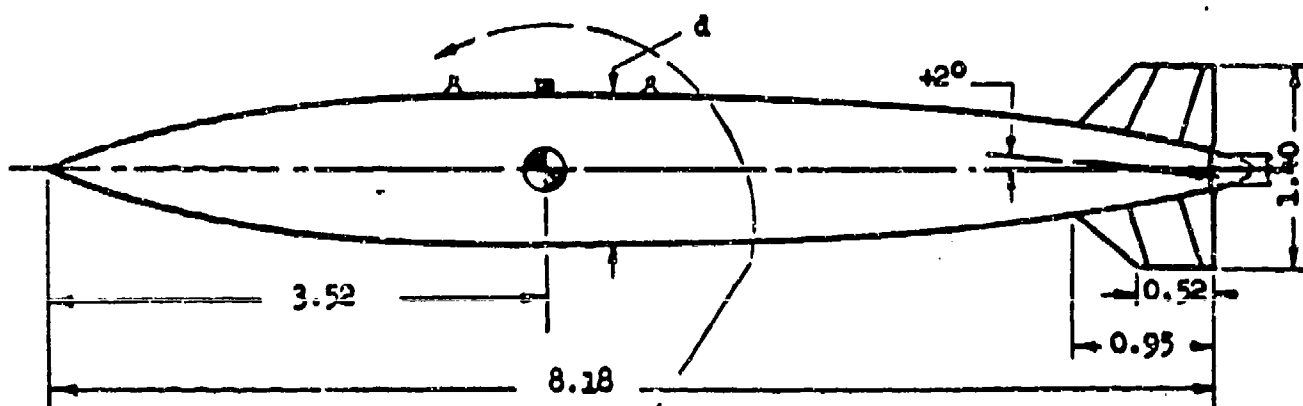
|       |      |       |        |      |         |          |         |         |        |        |
|-------|------|-------|--------|------|---------|----------|---------|---------|--------|--------|
| 96 02 | 1.00 | .01-  | 125.00 | .00  | .00339- | .00262   | .00042  | .00001  | .02972 | .10902 |
| 96 03 | 1.00 | 3.09  | 130.00 | .00  | .52273  | .70708-  | .00417  | .02449- | .04054 | .10754 |
| 96 04 | 1.00 | 12.16 | 180.00 | .01- | .96525  | 1.25474- | .00077  | .03275- | .03584 | .10430 |
| 96 05 | 1.00 | 16.27 | 100.00 | .00  | 1.43327 | 1.00983- | .00095  | .03281- | .02747 | .10037 |
| 96 06 | 1.00 | 20.40 | 180.00 | .01- | 1.96050 | 2.14153- | .00498  | .05332- | .01523 | .08336 |
| 96 07 | 1.00 | 22.49 | 155.00 | .02- | 2.22520 | 2.20475- | .03267  | .16111- | .00075 | .07626 |
| 96 08 | 1.00 | .01-  | 180.00 | .00  | .00079  | .00043-  | .00036  | .00000  | .02673 | .10992 |
| 97 01 | 0.90 | .01-  | 180.00 | .00  | .00580  | .01056-  | .00189- | .00454  | .02432 | .09298 |
| 97 02 | 0.90 | 8.08  | 180.00 | .00  | .56144  | .71662-  | .00399- | .00585- | .03594 | .08806 |
| 97 03 | 0.90 | 12.13 | 180.00 | .00  | .54211  | 1.27053- | .00143  | .02152- | .03103 | .09014 |
| 97 04 | 0.90 | 15.21 | 180.00 | .00  | 1.35033 | 1.74195- | .00696- | .00369  | .02638 | .08414 |
| 97 05 | 0.90 | 20.33 | 180.00 | .01- | 1.78813 | 1.95924- | .01796  | .10314- | .00951 | .07483 |
| 97 06 | 0.90 | 22.40 | 180.00 | .02- | 2.00063 | 2.03052- | .05069  | .24068- | .00326 | .06764 |
| 97 07 | 0.90 | .00   | 150.00 | .00  | .00015  | .00027-  | .00260  | .00112  | .02431 | .09404 |
| 98 02 | 0.00 | .01-  | 180.00 | .00  | .00404  | .00297-  | .01805- | .01779  | .03953 | .07933 |
| 98 03 | 0.00 | 8.04  | 180.00 | .00  | .54390  | .71296-  | .01366- | .00999  | .05591 | .07738 |
| 98 04 | 0.00 | 12.06 | 180.00 | .00  | .88621  | 1.22073- | .01167- | .00347- | .05370 | .08125 |
| 98 05 | 0.00 | 15.14 | 180.00 | .00  | 1.27441 | 1.74477- | .01613- | .01116  | .04615 | .07518 |
| 98 06 | 0.00 | 20.18 | 180.00 | .01- | 1.60113 | 2.14495- | .01219- | .01577- | .02978 | .07052 |
| 98 07 | 0.00 | 22.23 | 180.00 | .01- | 1.86845 | 2.26739- | .01063  | .06859- | .02545 | .06293 |
| 98 08 | 0.00 | .00   | 180.00 | .00  | .00240  | .00164-  | .00071- | .01069  | .04376 | .07591 |

Coordinate Axes and Sign Convention

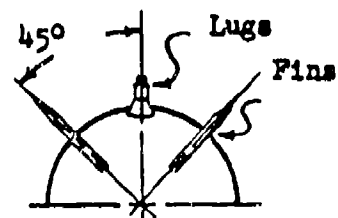
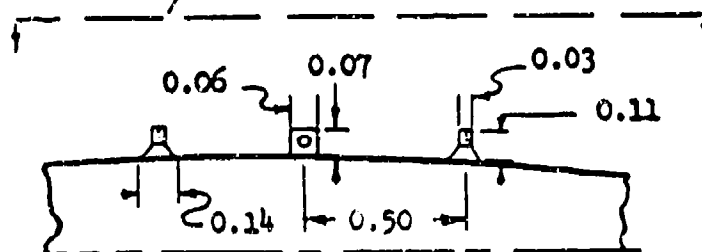


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0.214-Scale Model of the U. S. Navy  
1000 lb Mk 81 Low-Drag Bomb



Note: All dimensions are in units  
of maximum body diameters ( $d$ )  
 $d = 3.00$  inches

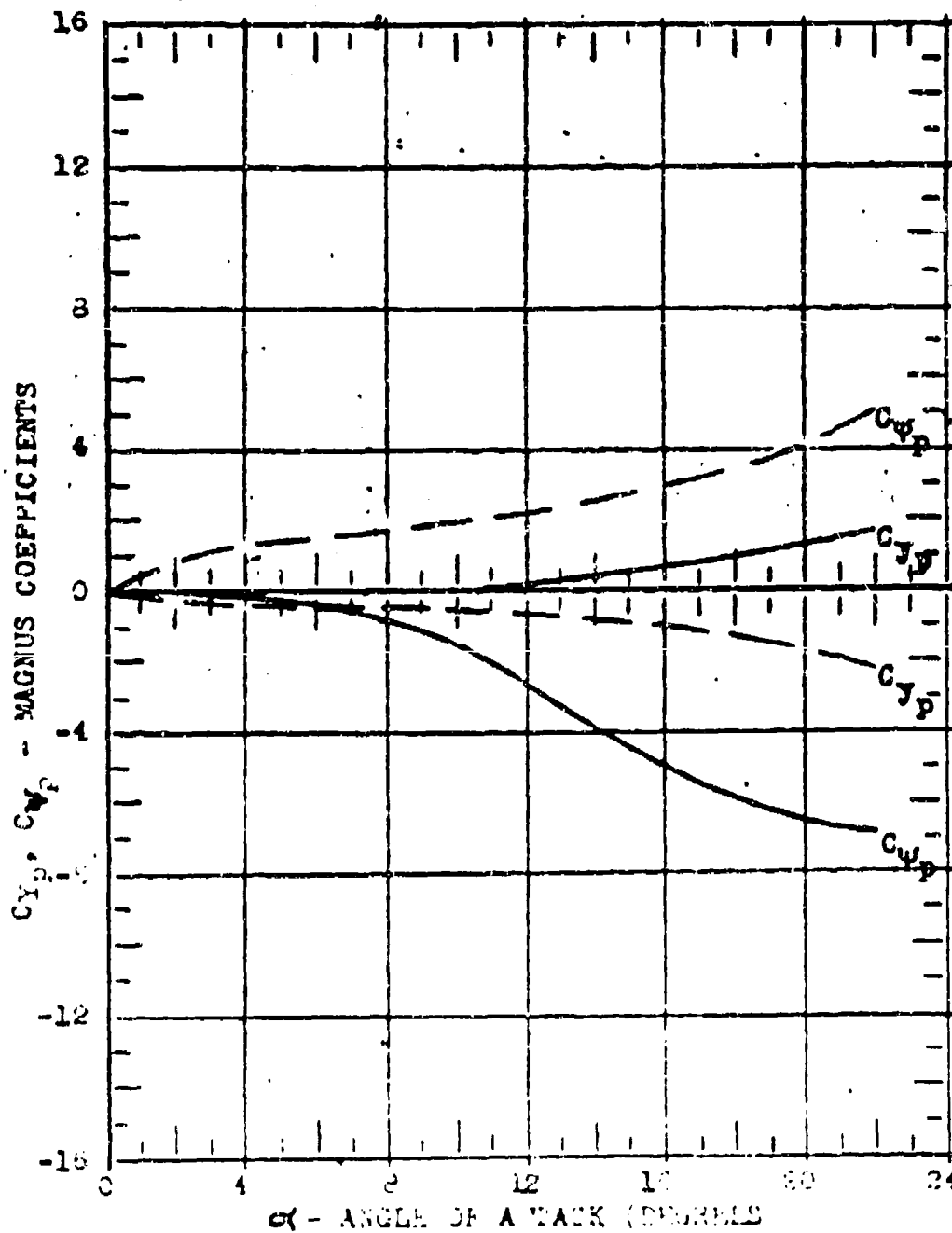


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LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT  
COEFFICIENT WITH ANGLE OF ATTACK

$M = 1.25$

—  $Re = 2 \times 10^6$   
- -  $Re = 4 \times 10^6$   
—  $Re = 6 \times 10^6$



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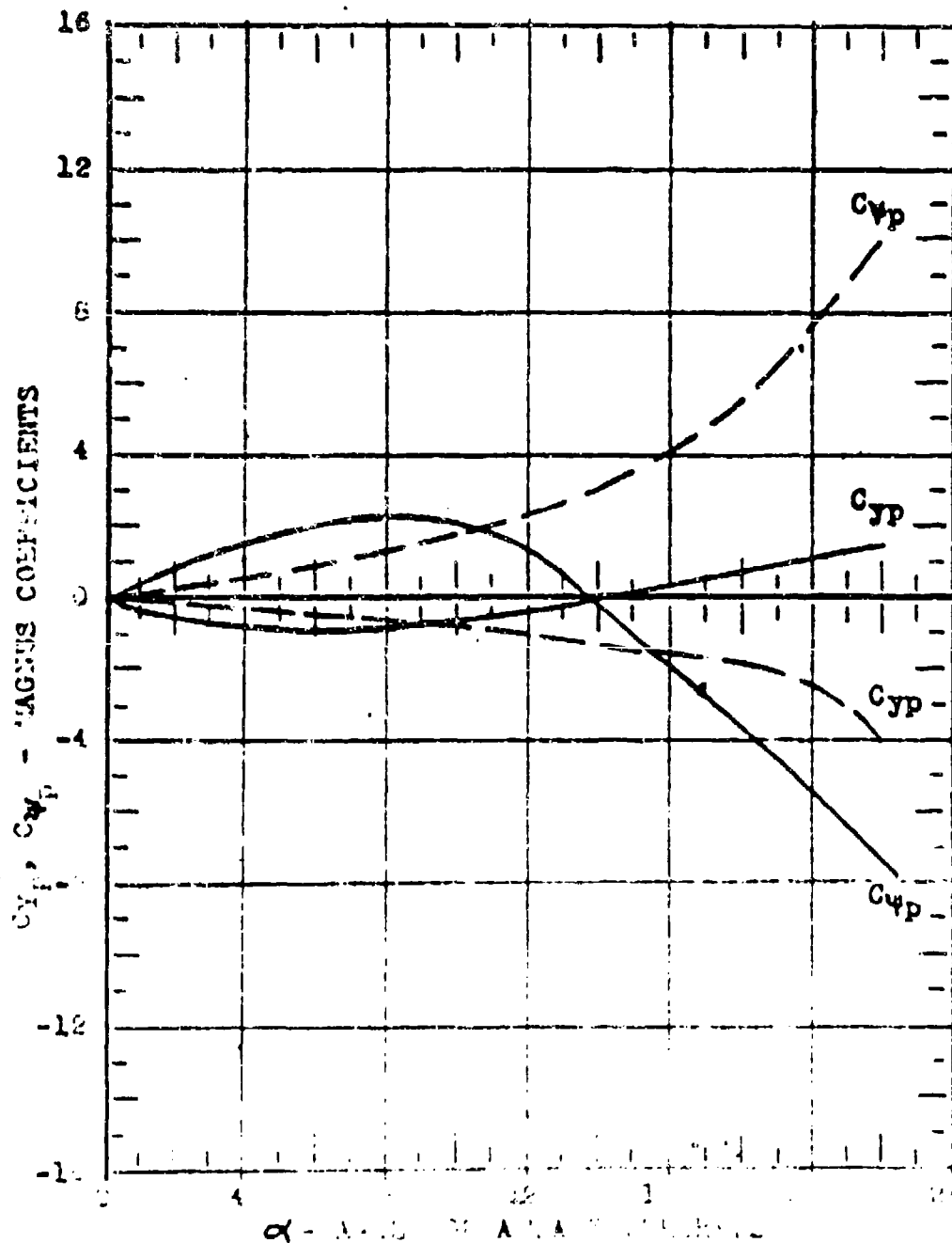
FIGURE 3

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LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT  
COEFFICIENT WITH ANGLE OF ATTACK

$M = 1.20$

—  $Re = 2 \times 10^6$   
- -  $Re = 4 \times 10^6$   
—  $Re = 6 \times 10^6$

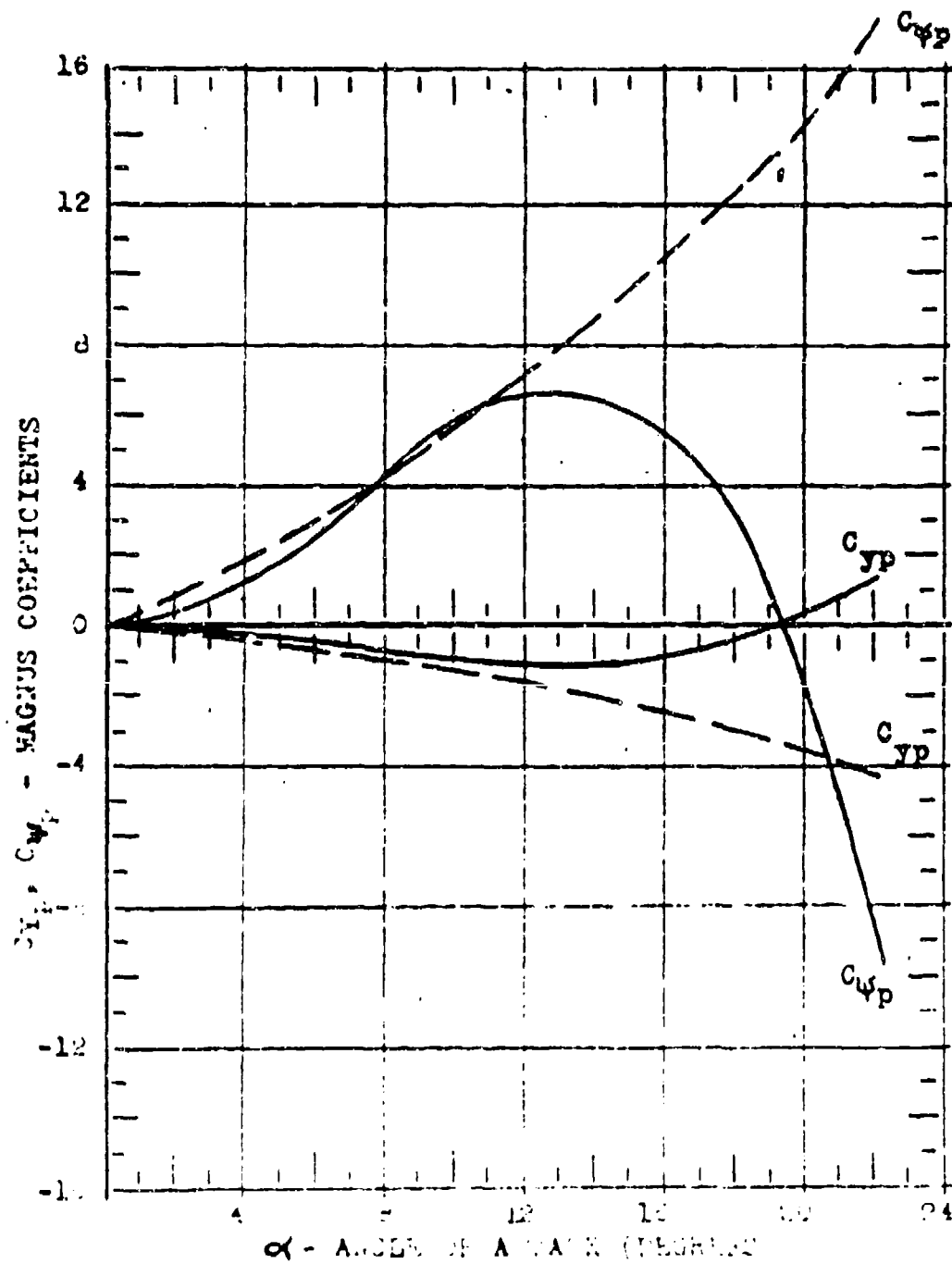


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LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT  
COEFFICIENT WITH ANGLE OF ATTACK

$M = 1.19$

—  $Re = 2 \times 10^6$   
--  $Re = 4 \times 10^6$   
---  $Re = 6 \times 10^6$

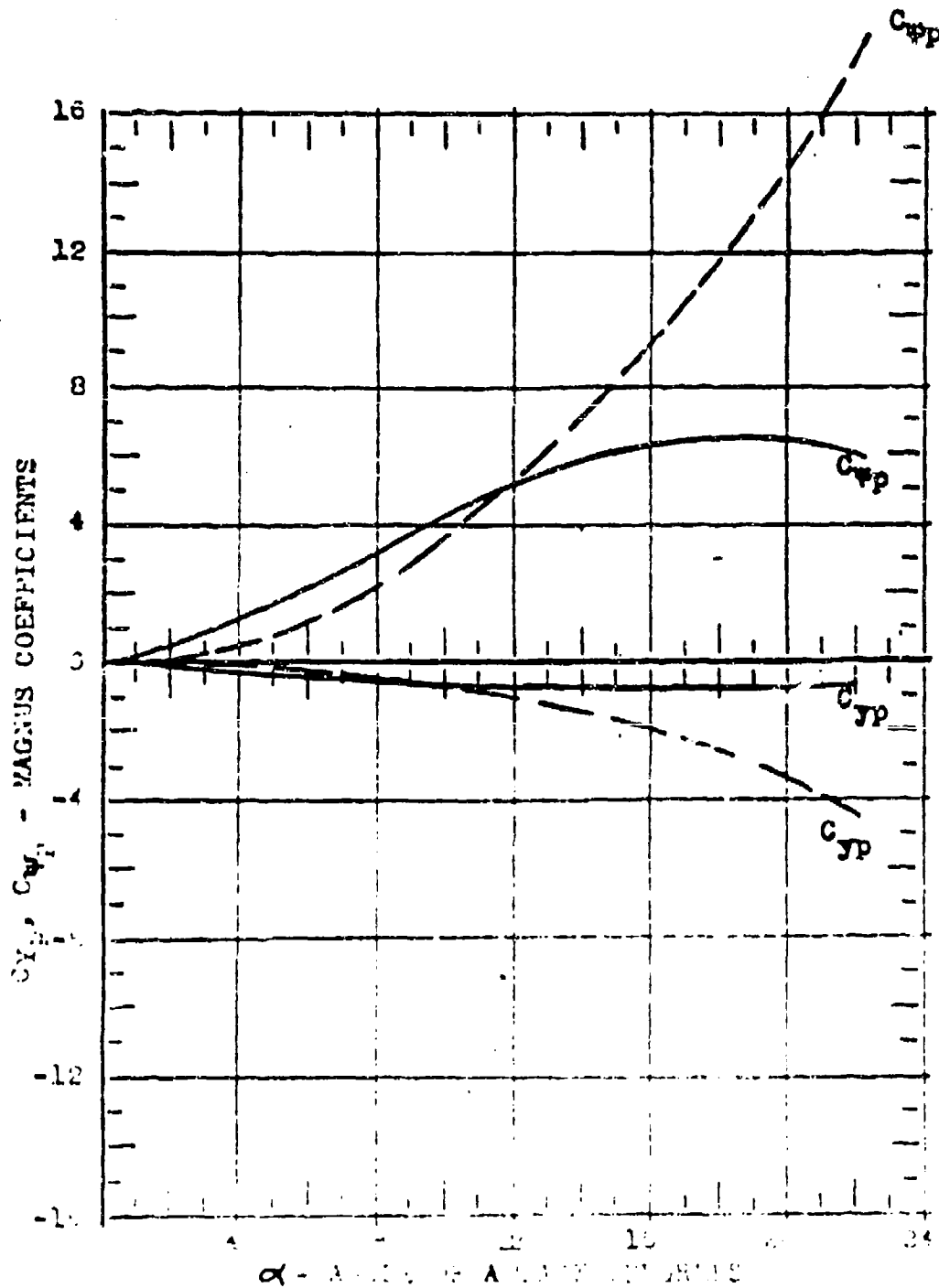


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LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT  
COEFFICIENT WITH ANGLE OF ATTACK

$M = 1.00$

—  $Re = 2 \times 10^6$   
--  $Re = 4 \times 10^6$   
---  $Re = 6 \times 10^6$

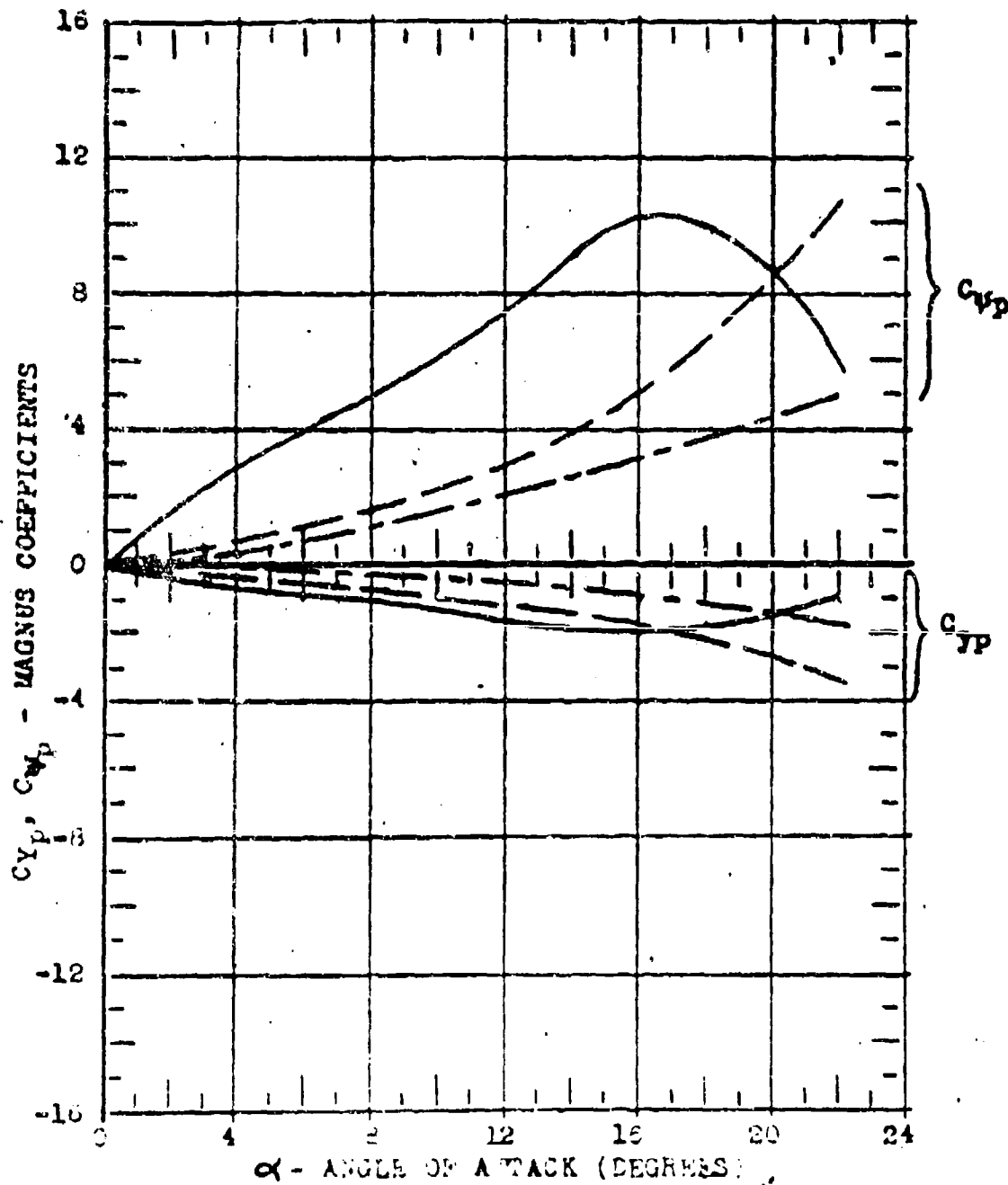


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 LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT  
 COEFFICIENT WITH ANGLE OF ATTACK

$M = 0.95$

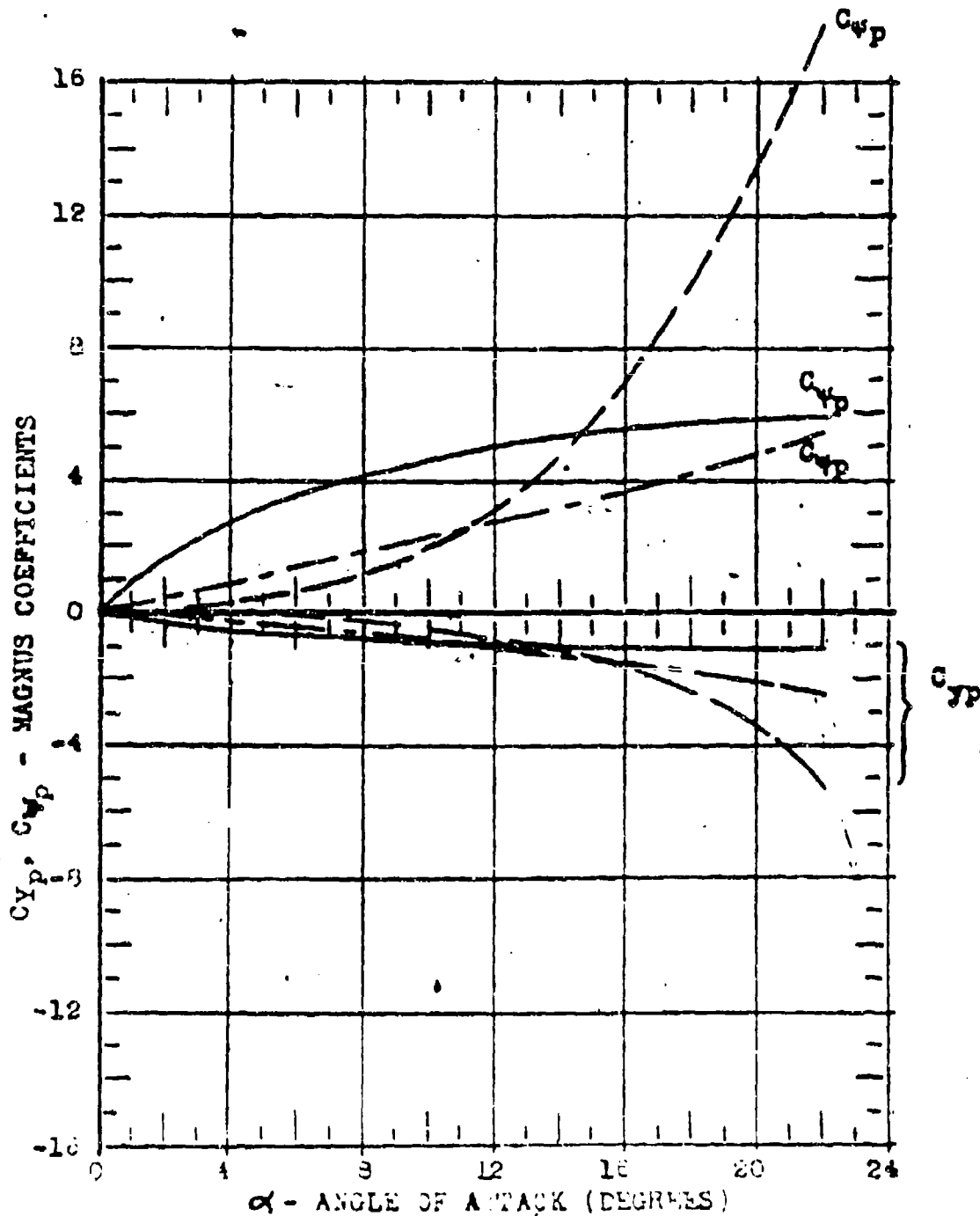
—  $Re = 2 \times 10^6$   
 - -  $Re = 4 \times 10^6$   
 —  $Re = 6 \times 10^6$



VARIATION OF MAGNUS FORCE AND MOMENT  
COEFFICIENT WITH ANGLE OF ATTACK

$M = 0.90$

—  $Re = 2 \times 10^5$   
- -  $Re = 4 \times 10^5$   
- -  $Re = 6 \times 10^5$

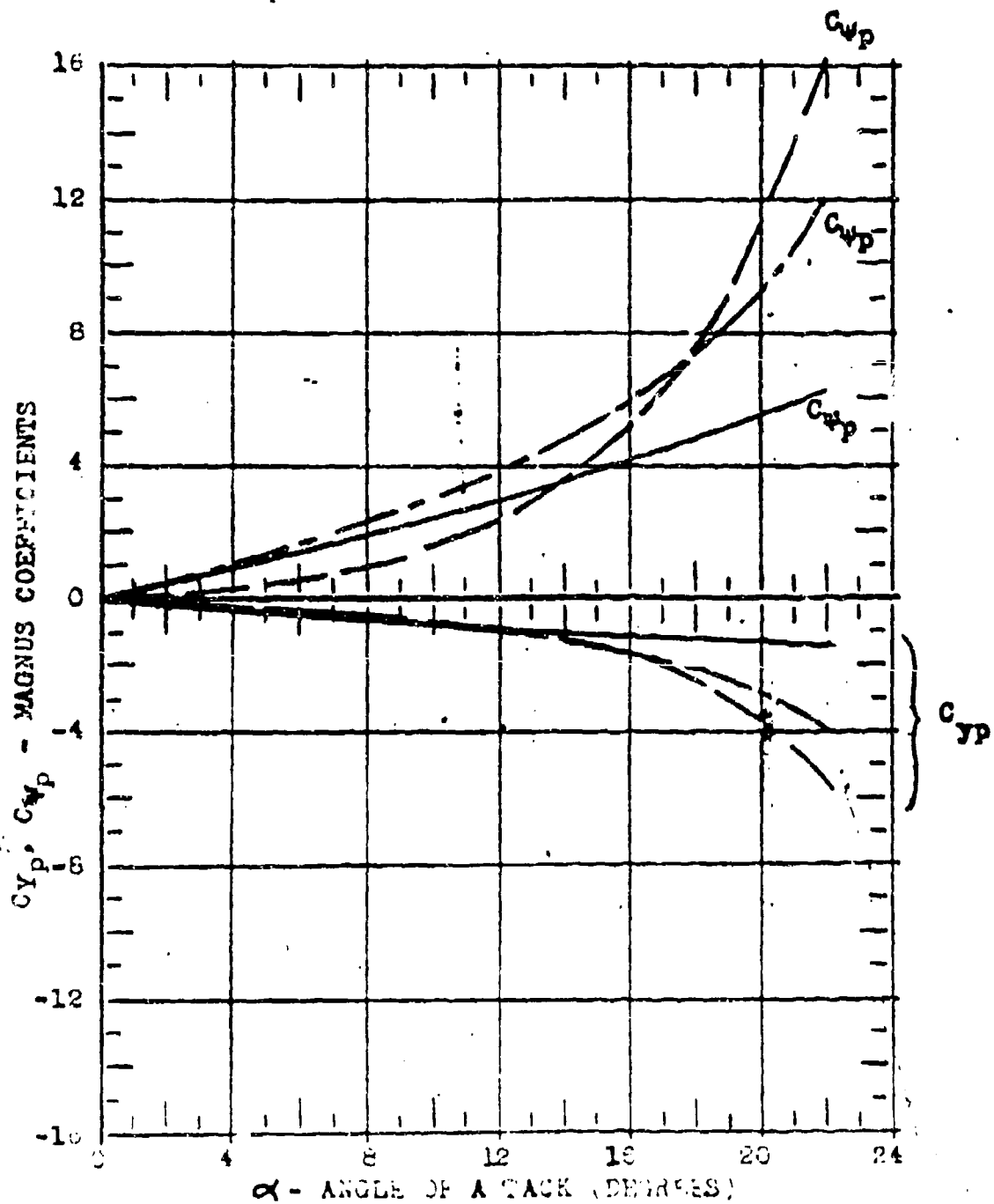


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LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT  
COEFFICIENT WITH ANGLE OF ATTACK

$M = 0.80$

—  $Re = 2 \times 10^6$   
- -  $Re = 4 \times 10^6$   
—  $Re = 6 \times 10^6$

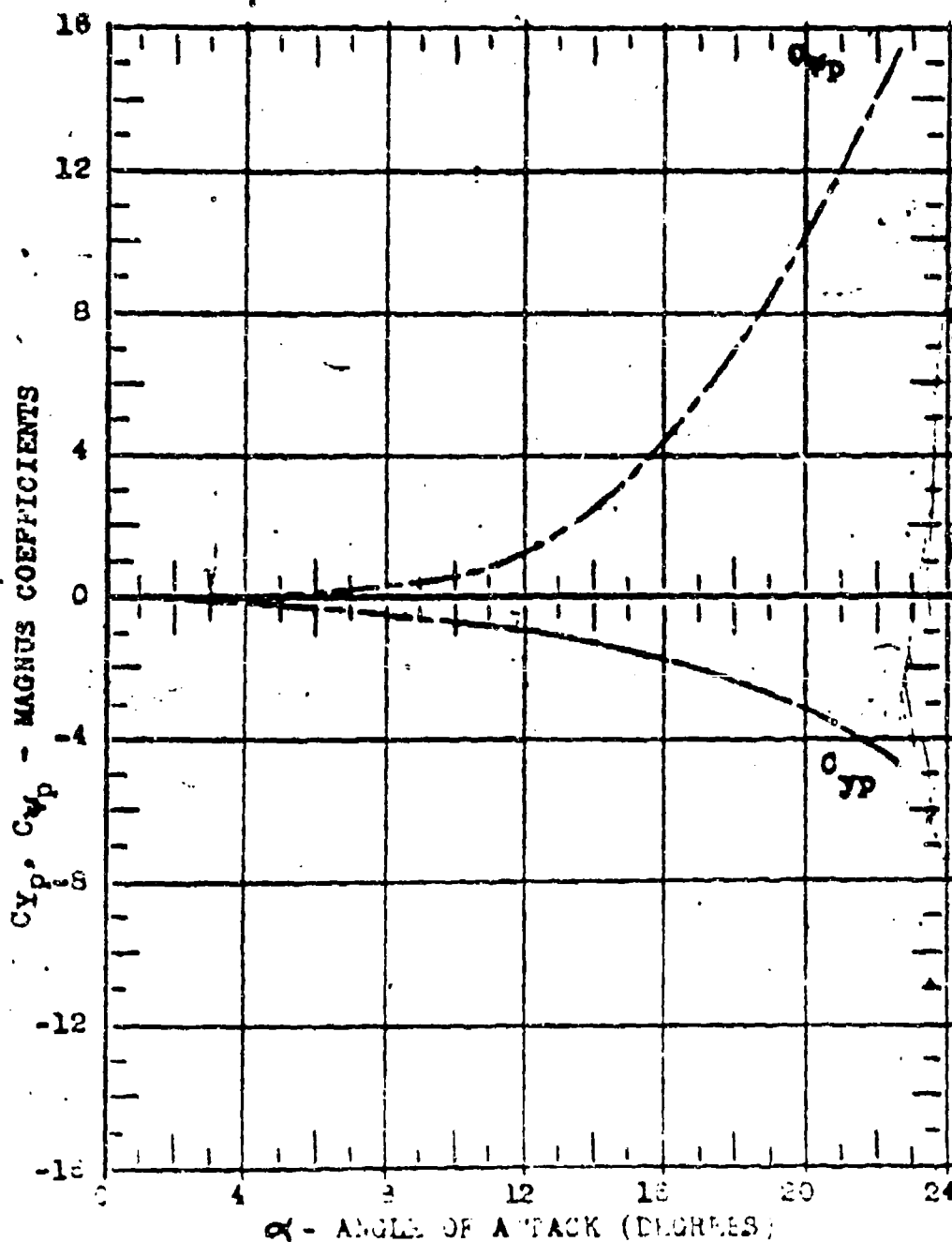


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LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT  
COEFFICIENT WITH ANGLE OF ATTACK

$M = 0.60$

—  $Re = 2 \times 10^6$   
- -  $Re = 4 \times 10^6$   
—  $Re = 6 \times 10^6$



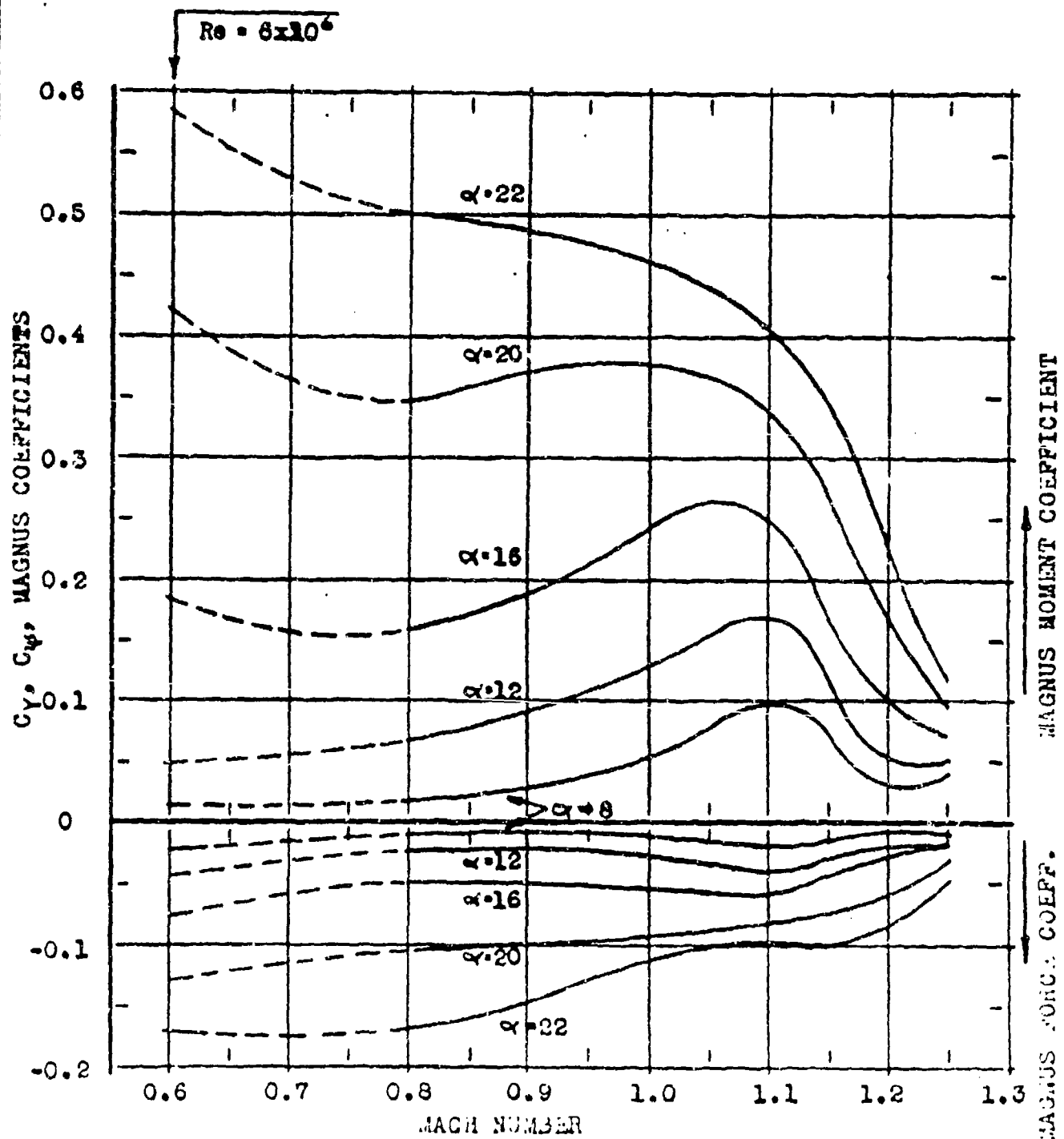
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FIGURE 12

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LOW-DRAG BOMB

VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH MACH NUMBER FOR MODEL  
REYNOLDS NUMBER OF  $4 \times 10^5$

$p = 2000$  RPM



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FIGURE 11

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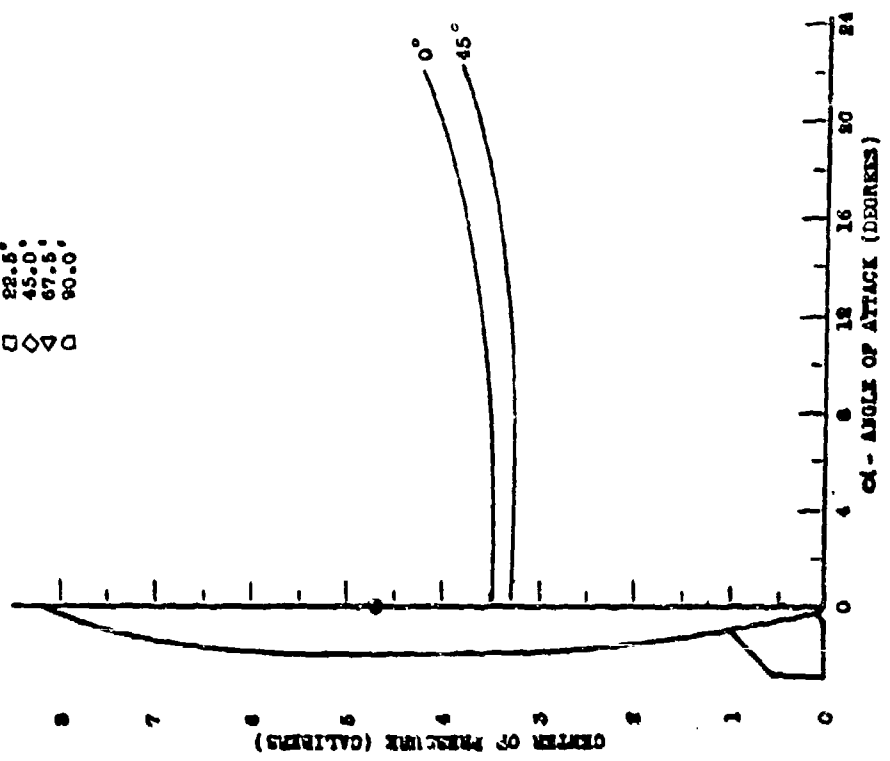
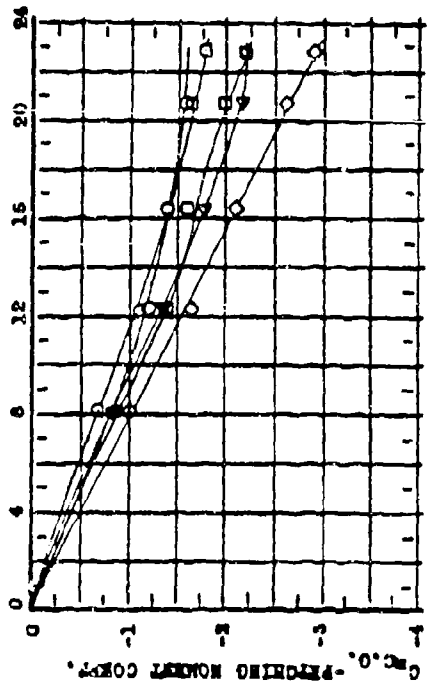
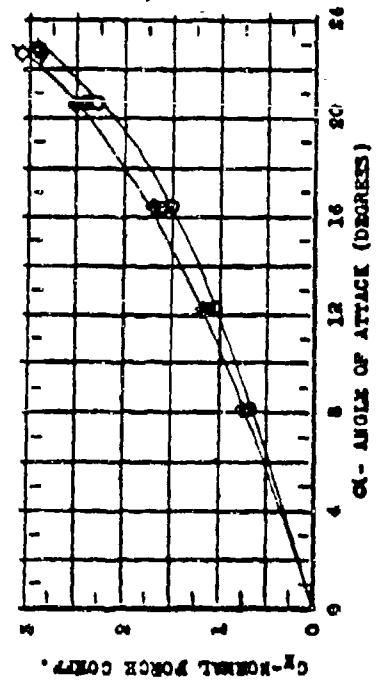
LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH ANGLE OF ATTACK  
AT VARIOUS MODEL-ROLL ANGLES

$M = 1.25$

$\phi$   
0  
22.5  
45.0  
67.5  
90.0

□ Δ ◇ □



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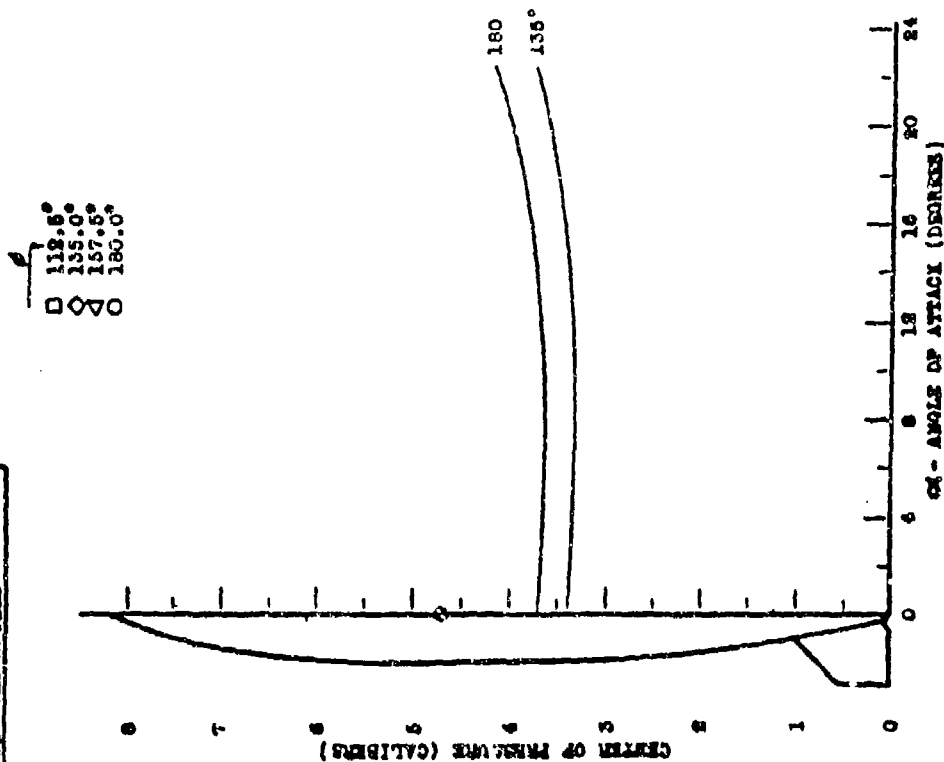
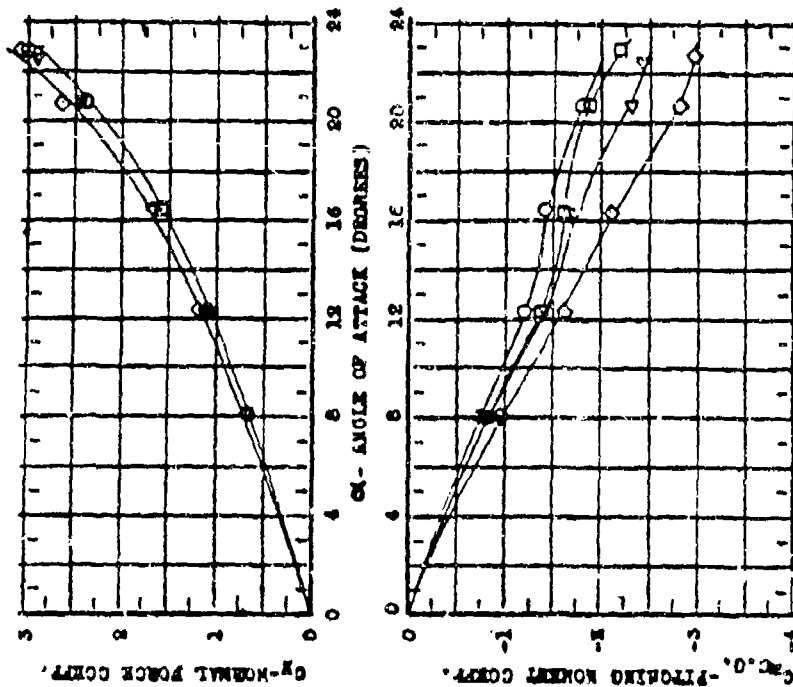
FIGURE 12

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LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENTS WITH ANGLE OF ATTACK  
AT VARIOUS NOSE-ROLL ANGLES

N = 1.25



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FIGURE 23

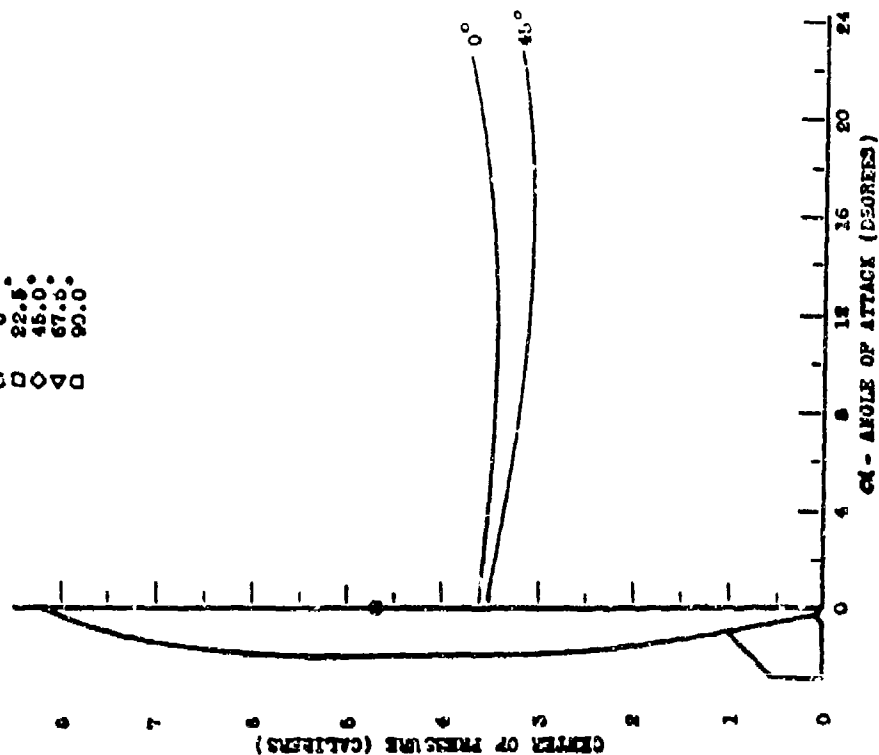
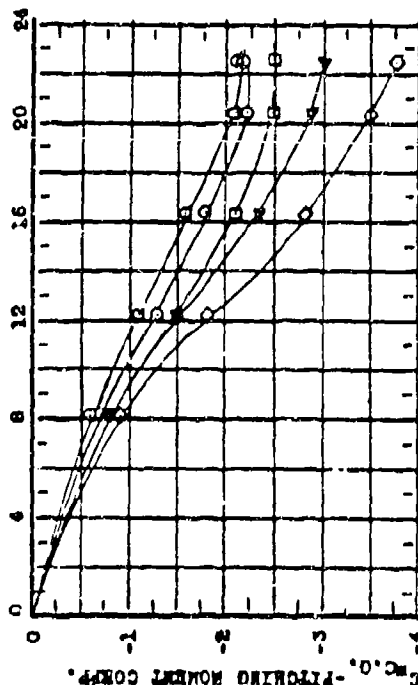
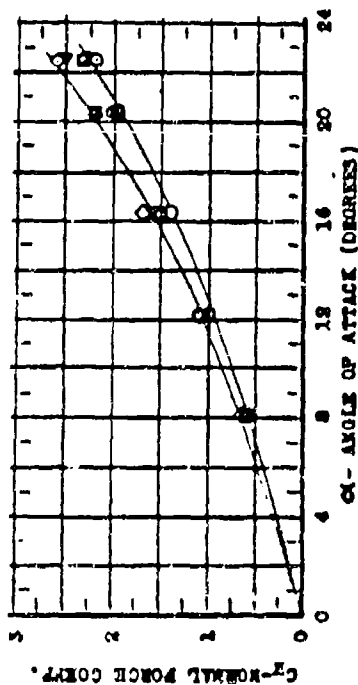
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LOW-DRAW BOMB

VARIAION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH ANGLE OF ATTACK  
AT VARIOUS MODEL-ROLL ANGLES

$M = 1.00$

$\phi$   
0°  
22.5°  
45.0°  
67.5°  
90.0°



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FIGURE 14

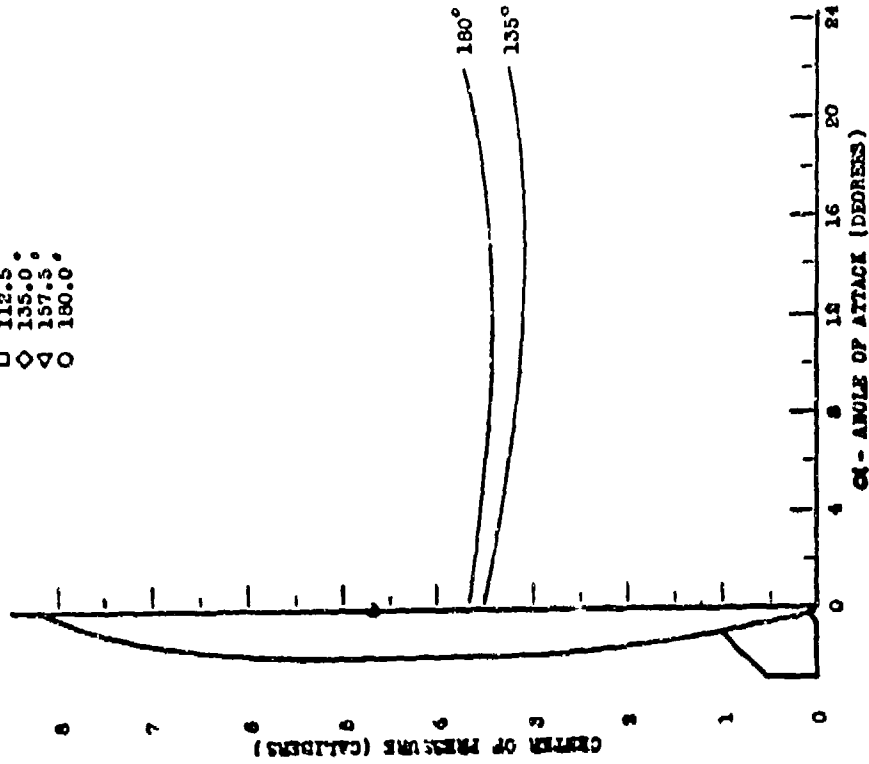
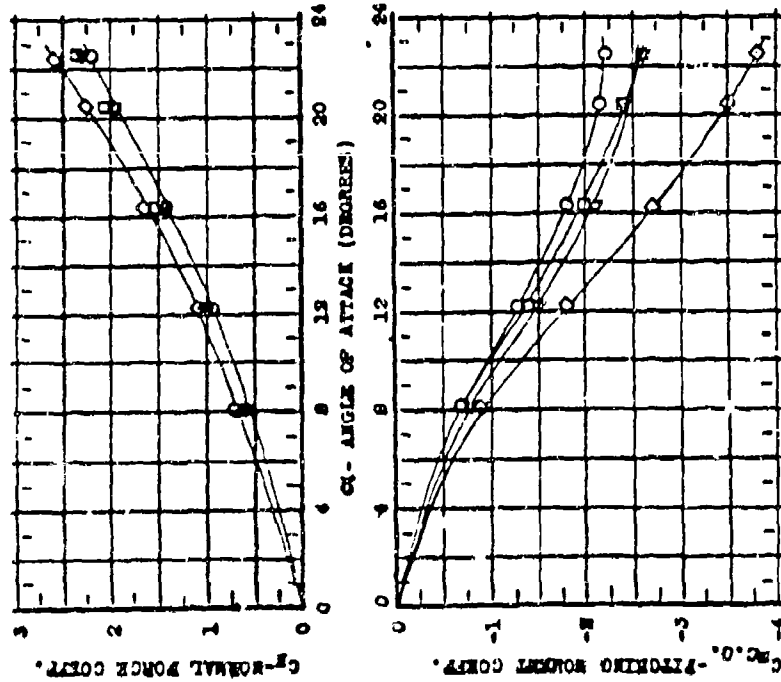
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LOW-DRAG BOX

VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH ANGLE OF ATTACK  
AT VARIOUS MODEL-ROLL ANGLES

$M = 1.00$

$\phi$   
□ 112.5°  
◇ 135.0°  
◊ 157.5°  
○ 180.0°



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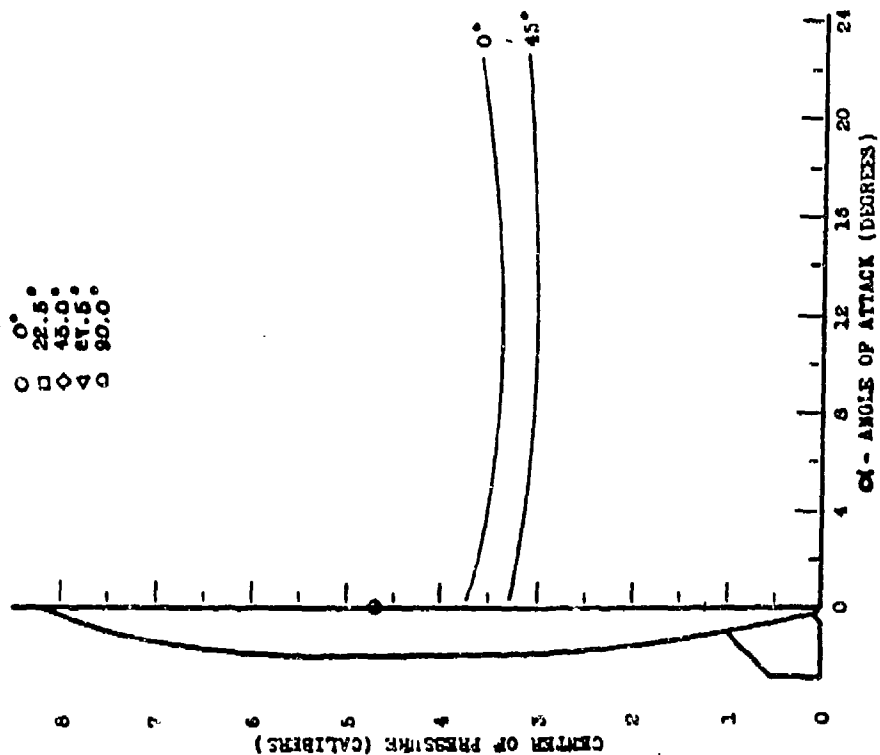
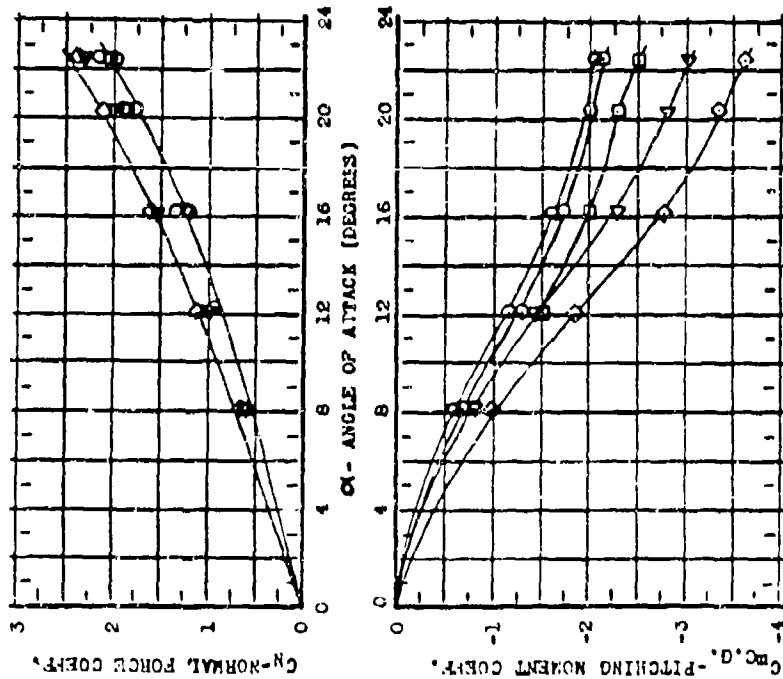
FIGURE 16

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LOW-DRAG BOAT

VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH ANGLE OF ATTACK  
AT VARIOUS MODEL-HULL ANGLES

$M = 0.80$



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FIGURE 16

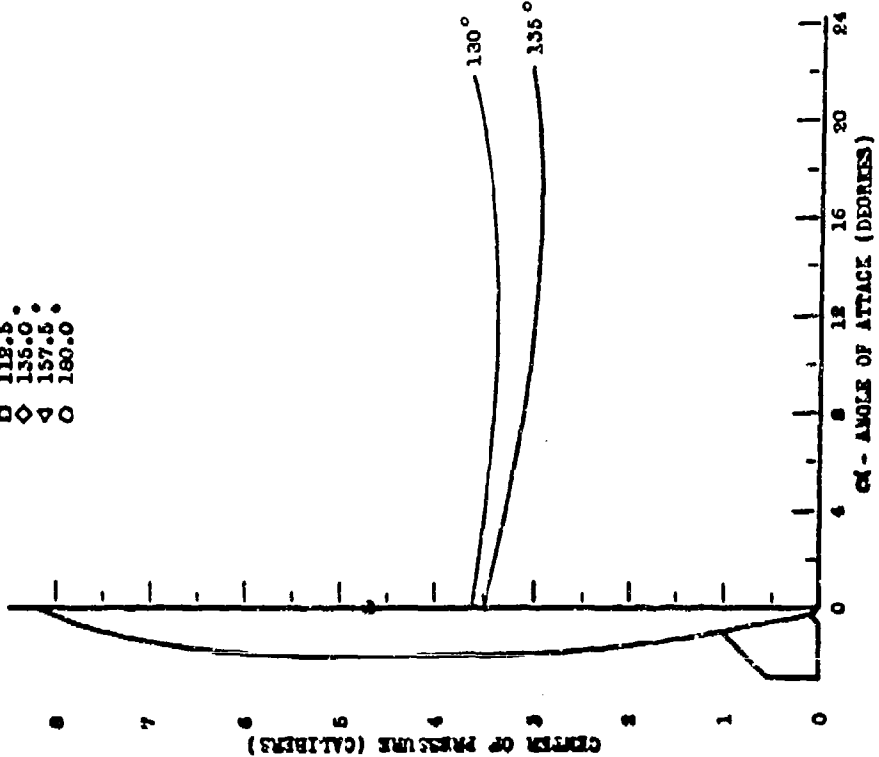
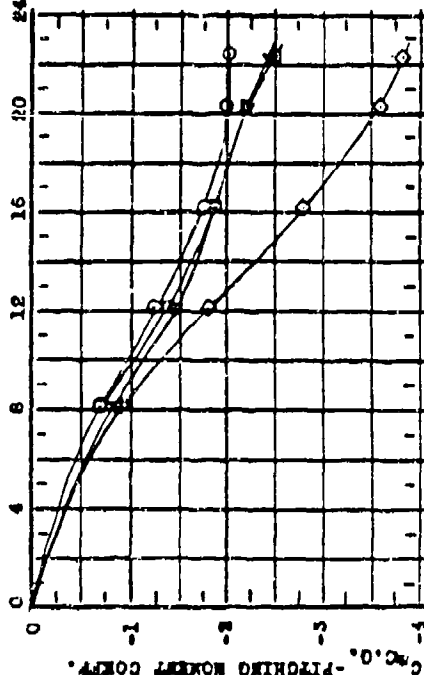
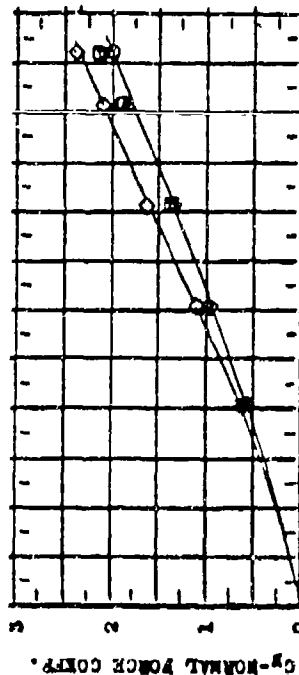
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LOW-DRAG BOXES

VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH ANGLE OF ATTACK  
AT VARIOUS MODEL-ROLL ANGLES

$M = 0.90$

$\theta$   
□ 112.5°  
◇ 135.0°  
△ 157.5°  
○ 180.0°



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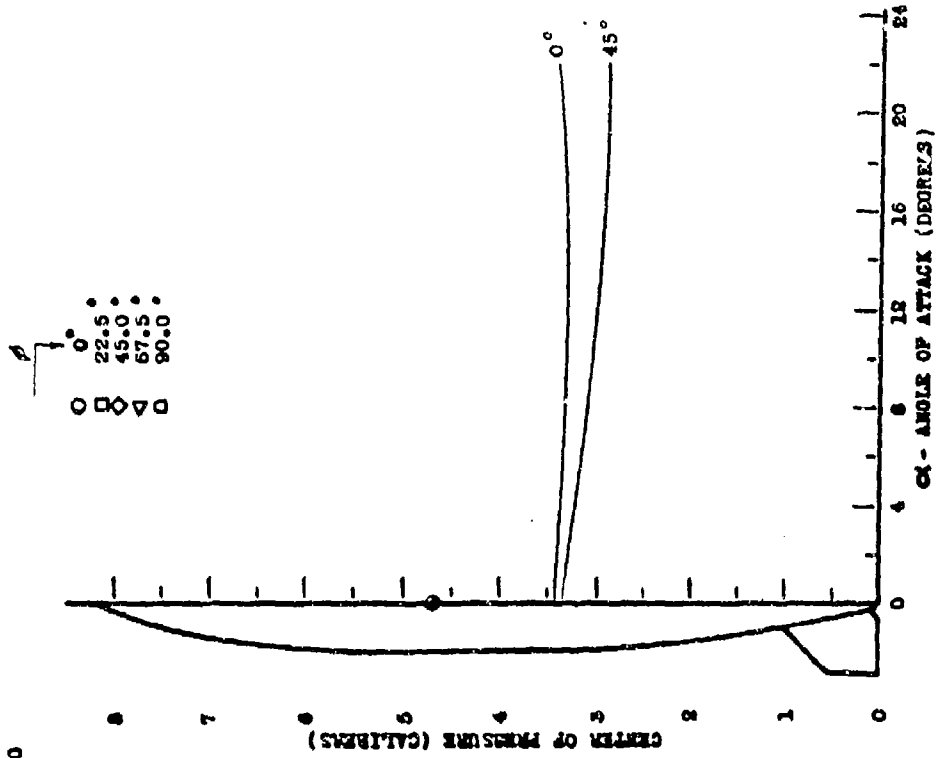
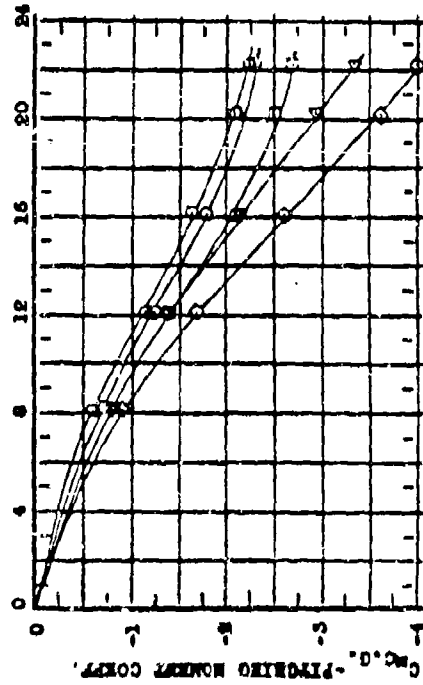
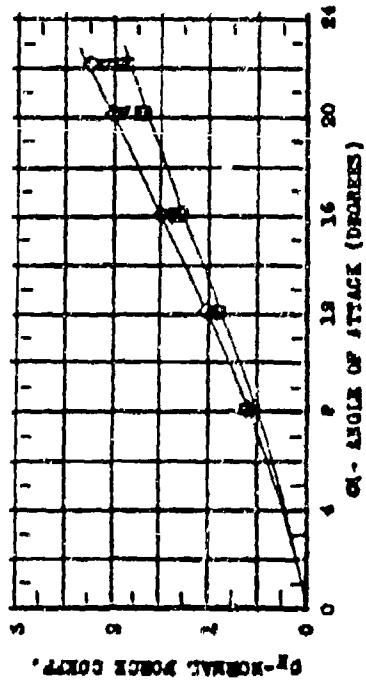
FIGURE 17

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LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH ANGLE OF ATTACK  
AT VARIOUS MODEL-ROLL ANGLES

$M = 0.60$



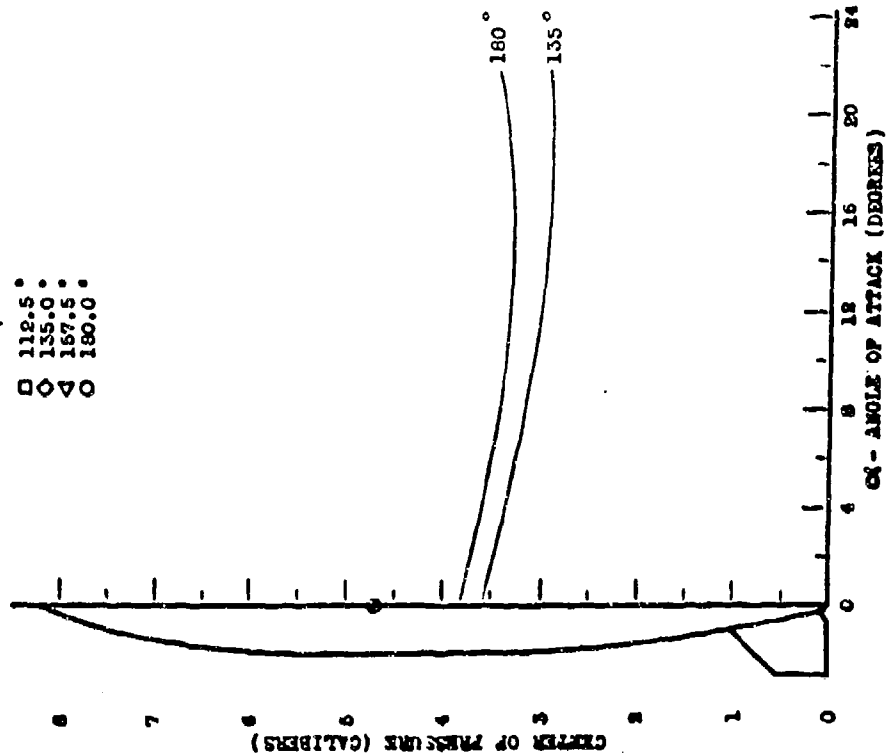
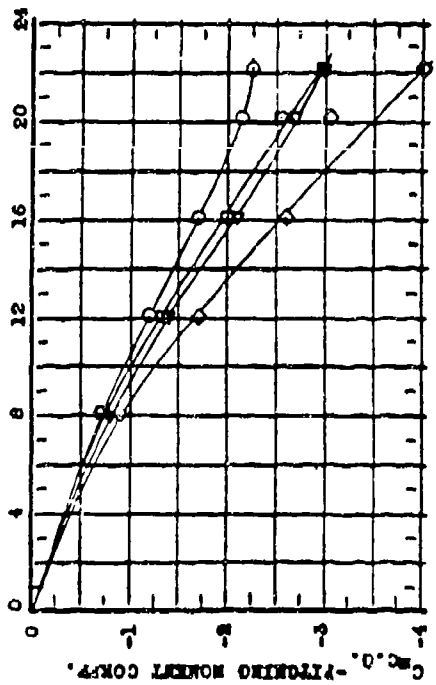
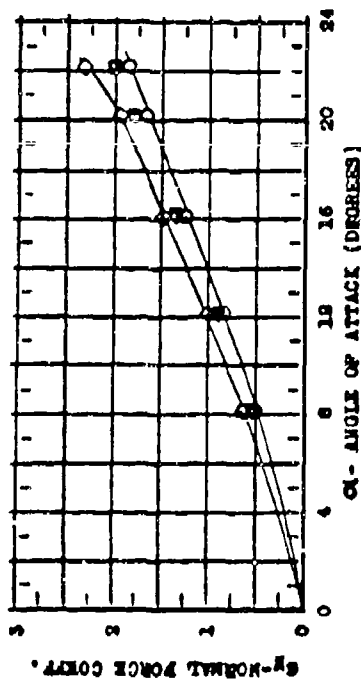
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FIGURE 18

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LOW-DRAG 2013

VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH ANGLE OF ATTACK  
AT VARIOUS MODEL-ROLL ANGLES

$M = 0.60$



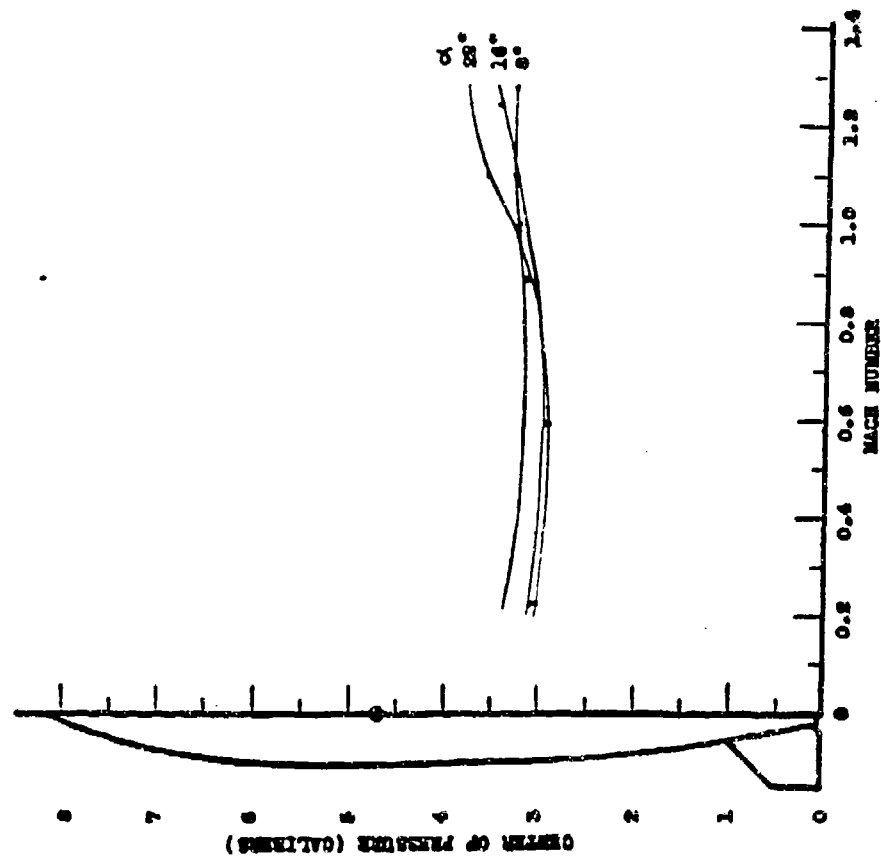
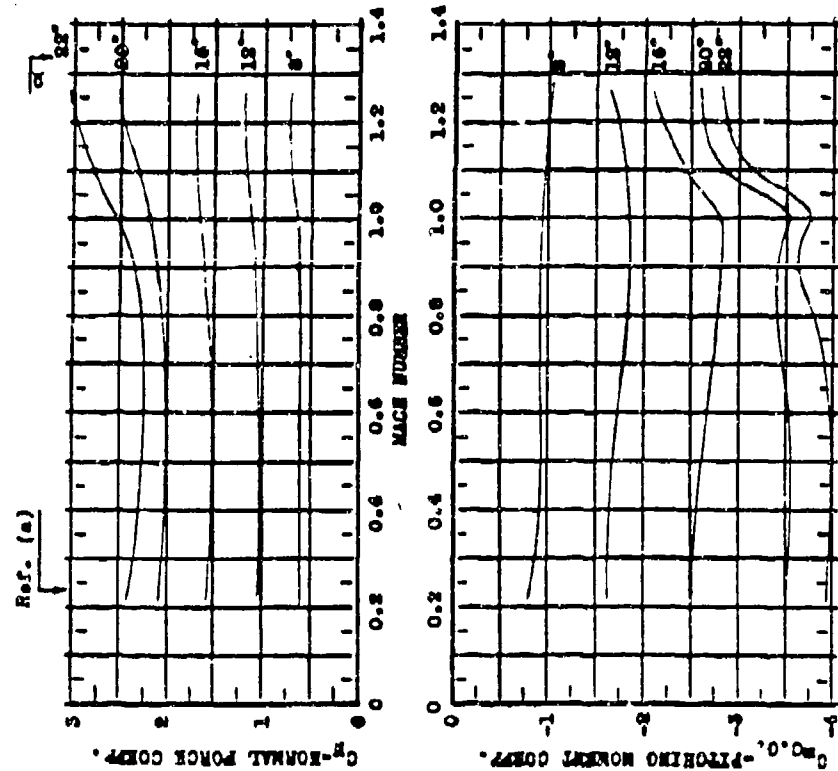
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FIGURE 19

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LOW-DRAO BOMB

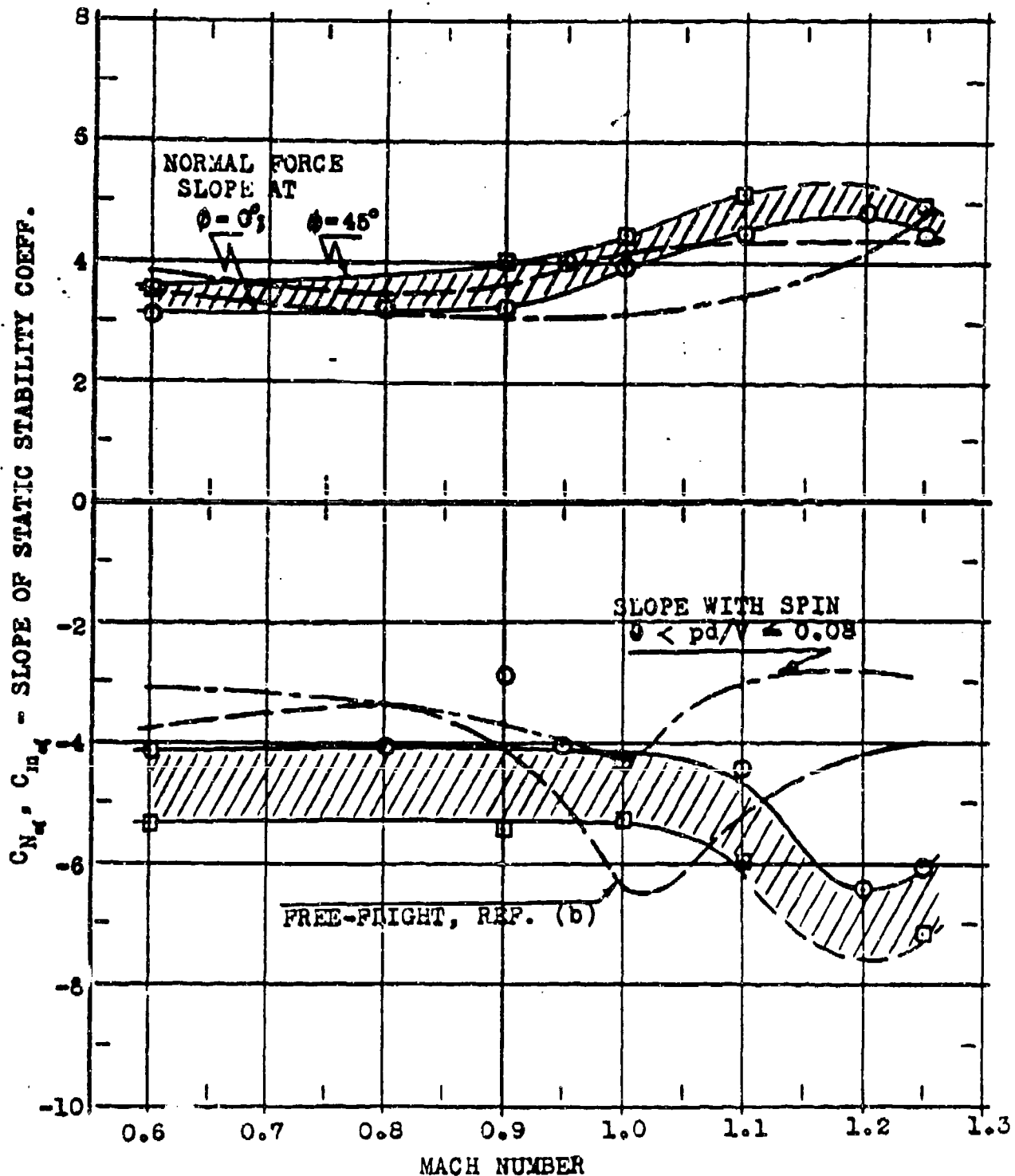
VARIATION OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT WITH MACH NUMBER AT  $\beta=45^\circ$



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FIGURE 80

COMPARISON OF NORMAL FORCE AND PITCHING  
MOMENT COEFFICIENT SLOPES FROM WIND TUNNEL  
AND FREE-FLIGHT RANGE MEASUREMENTS



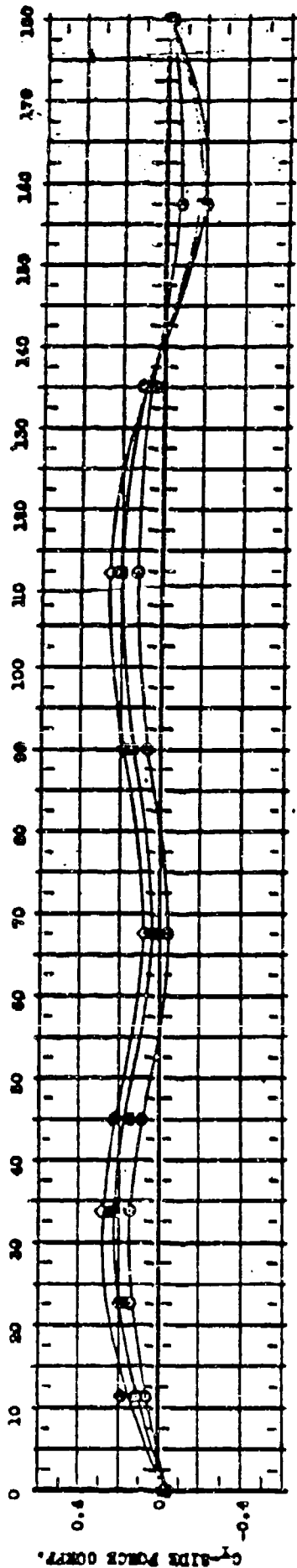
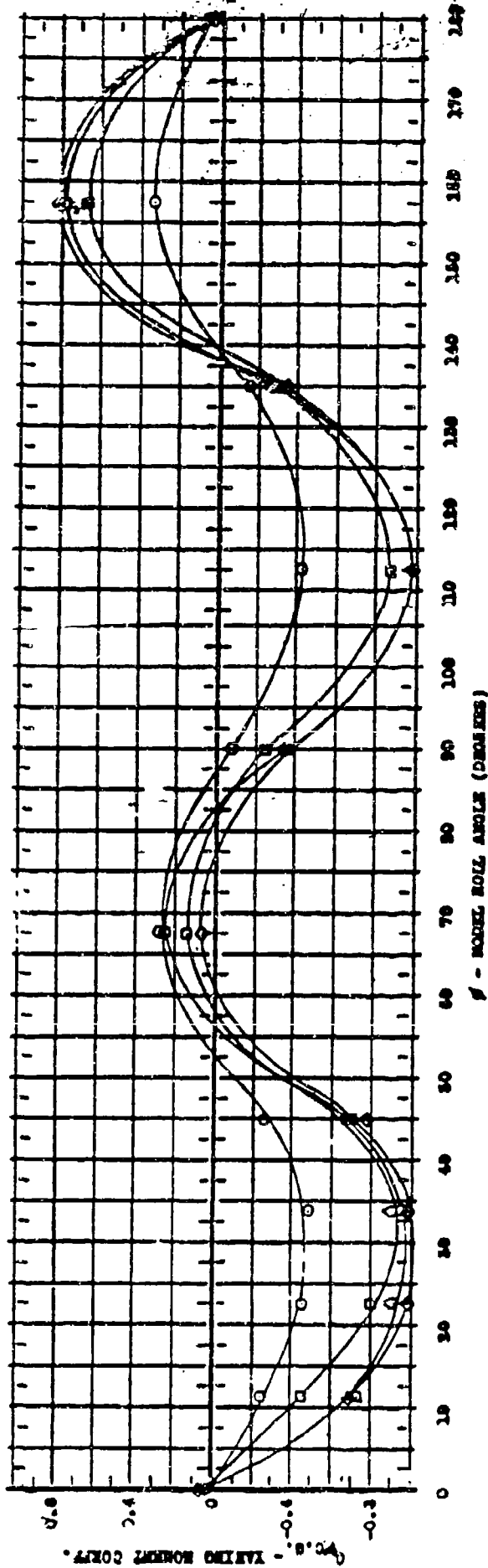
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NAVED REPORT 4349

LOW-DRAG BOMB

N-1,25

$\alpha$   
12°  
16°  
20°  
22°

VARIATION OF SIDE FORCE AND YAWING  
MOMENT COEFFICIENT WITH MODEL ROLL  
ANGLE AT VARIOUS ANGLES OF ATTACK



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FIGURE 25

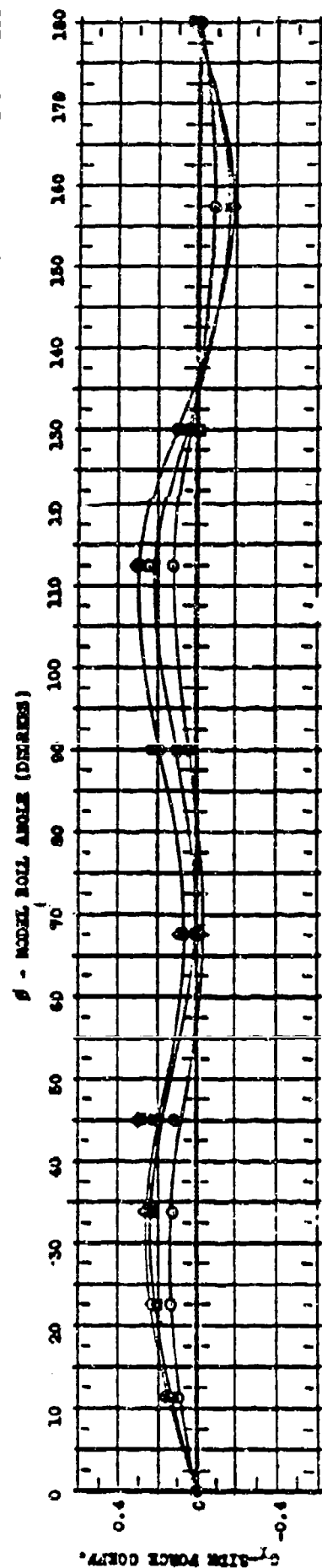
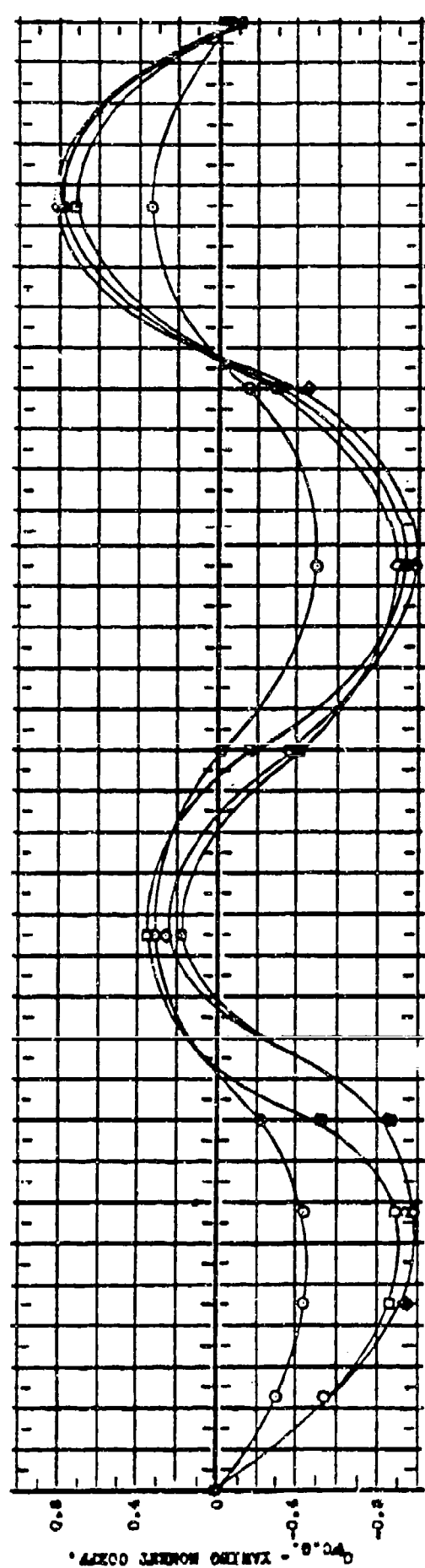
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NAVJAG REPORT 6389

LOW-SEAAG BONE

$\alpha$   
○ 12°  
○ 16°  
○ 20°  
○ 22°

VARIATION OF SIDE FORCE AND YAWING  
MOMENT COEFFICIENT WITH ROOT-ROLL  
ANGLE AT VARIOUS ANGLES OF ATTACK

$M = 1.00$



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FIGURE 28

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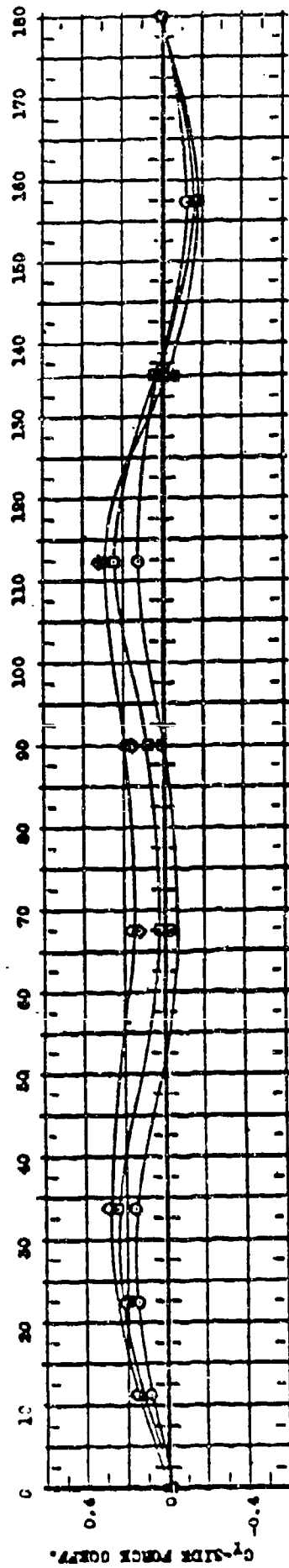
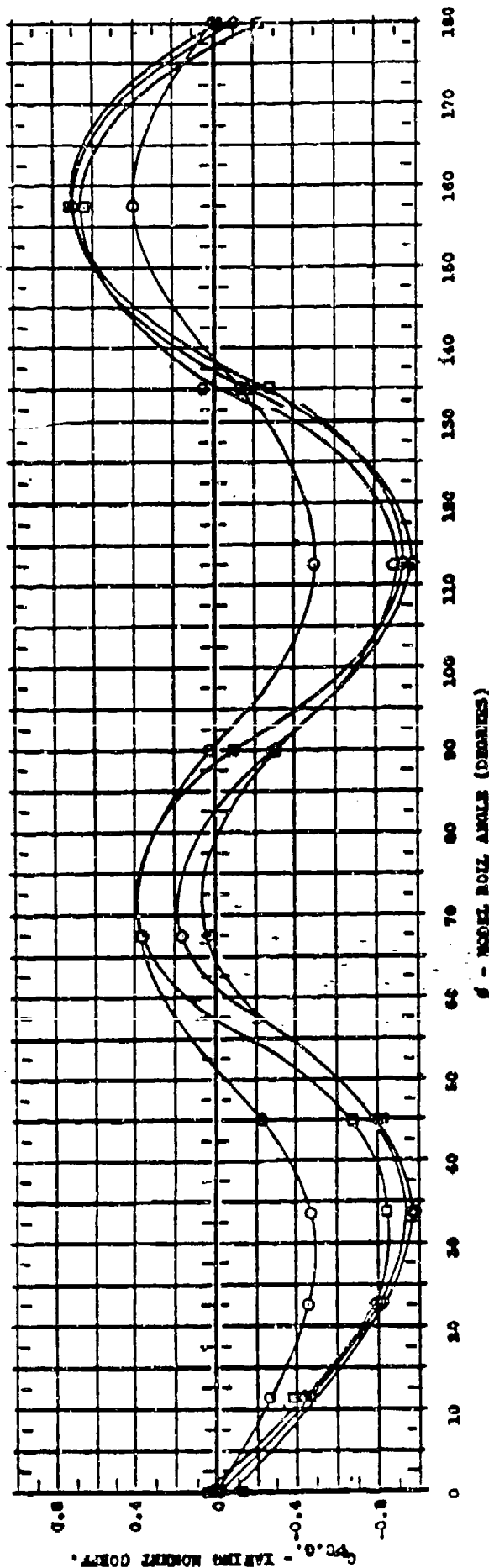
LOW-DRAW BOMB

VARIATION OF SIDE FORCE AND YAWING  
MOMENT COEFFICIENT WITH MODEL ROLL  
ANGLE AT VARIOUS ANGLES OF ATTACK

$M = 0.90$

$\alpha$   
12°  
16°  
20°  
24°

○ □ ◇



CONFIDENTIAL

FIGURE 84

CONFIDENTIAL  
NAVED REPORT 4388

LOW-DEAD BONE

VARIATION OF SIDE FORCE AND YAWING  
MOMENT COEFFICIENT WITH MODEL ROLL  
ANGLE AT VARIOUS ANGLES OF ATTACK

$M = 0.60$

$\alpha$   
12°  
16°  
20°  
22°  
○ □ ◇ ○

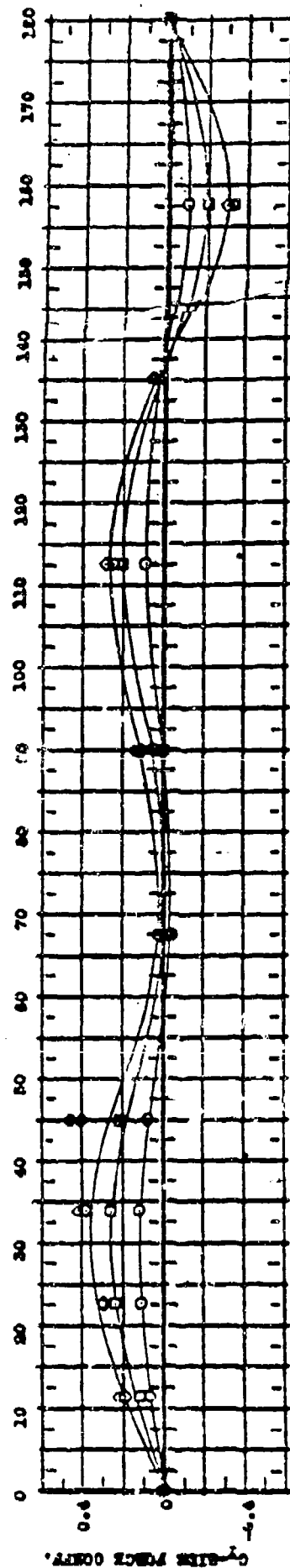
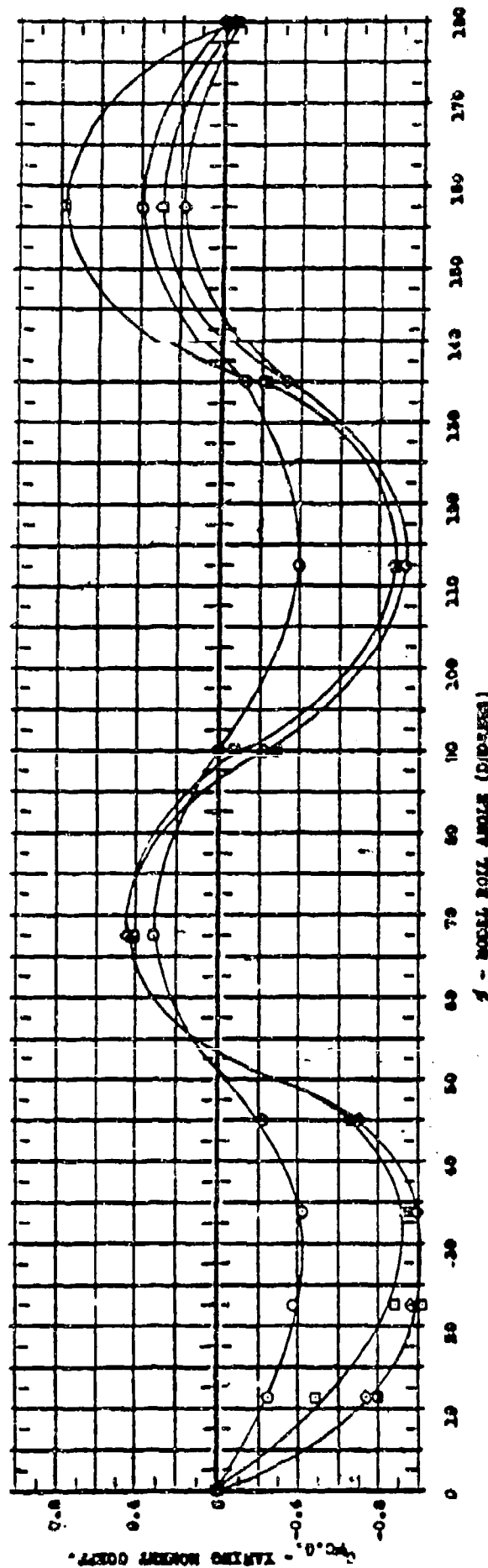


FIGURE 25

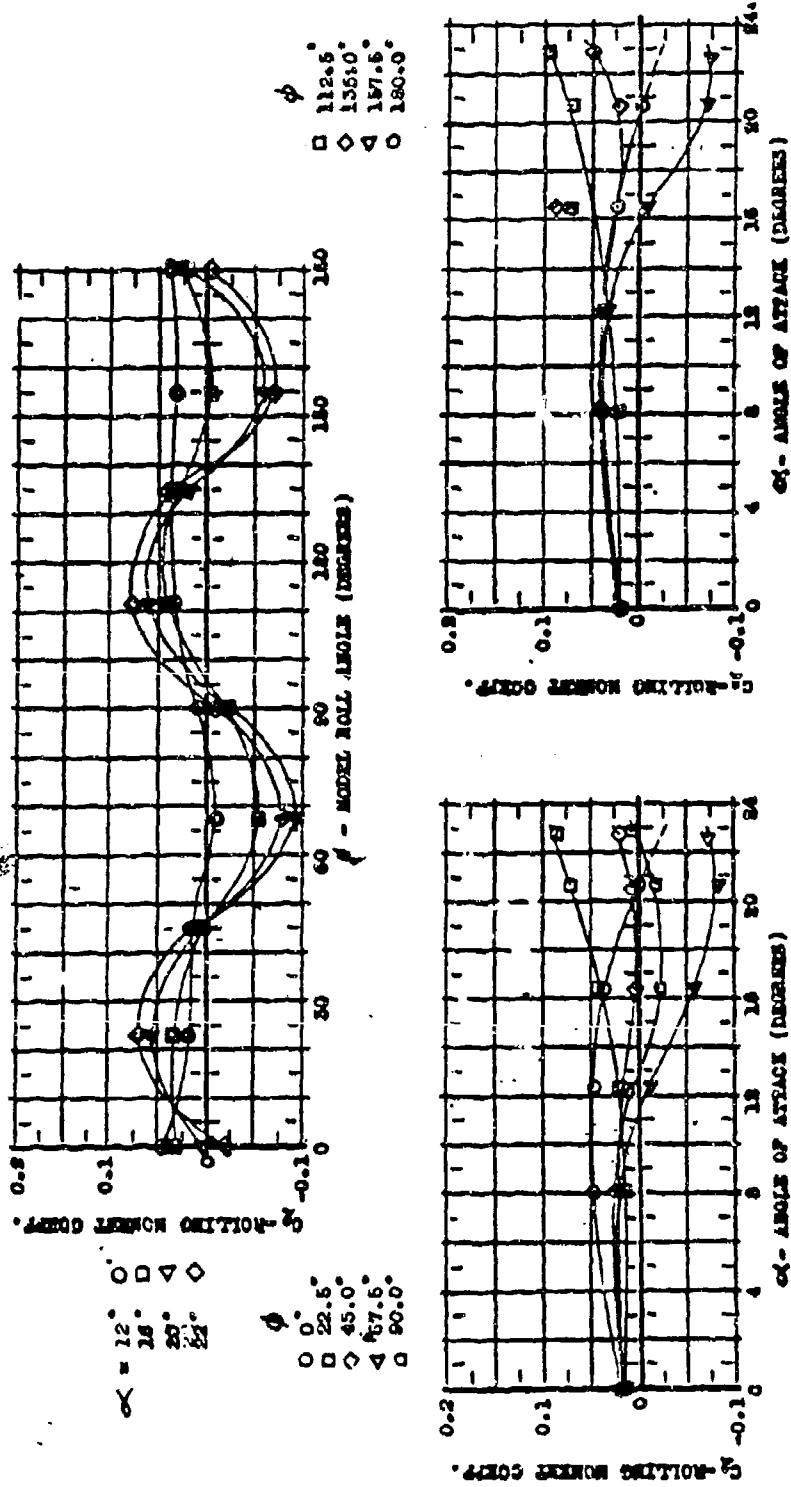
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LOW-DRAG BOMB

VARIATION OF ROLLING MOMENT COEFFICIENT  
WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE

M = 1.25



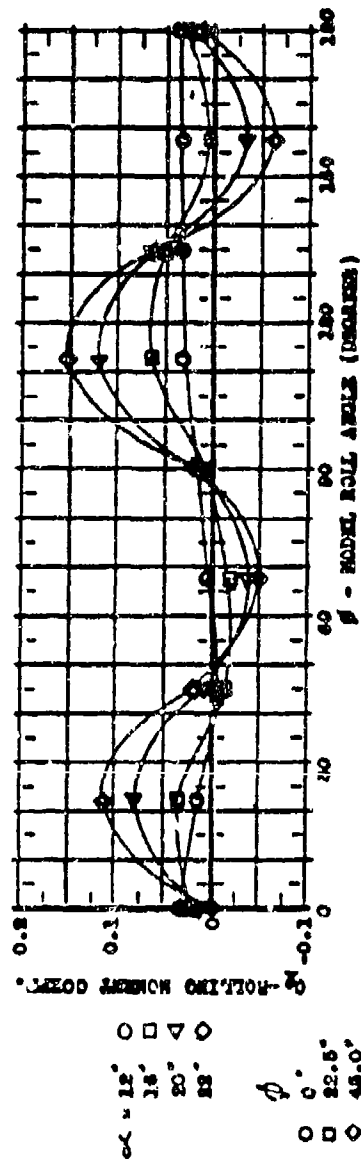
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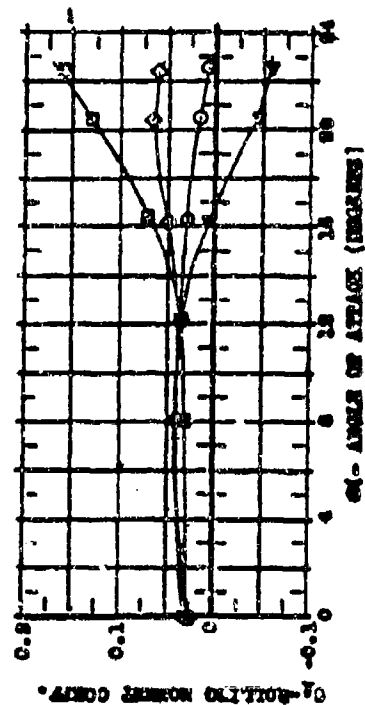
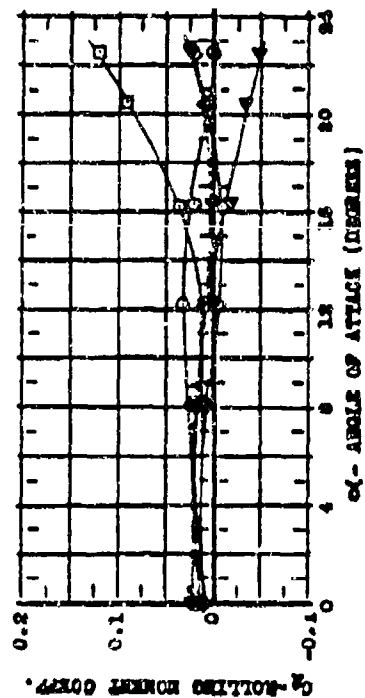
LOW-DRAG BOMB

$M = 1.00$

VARIATION OF ROLLING MOMENT COEFFICIENT  
WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE



$\phi$   
 □ 112.5°  
 ○ 135.0°  
 △ 157.5°  
 ○ 180.0°



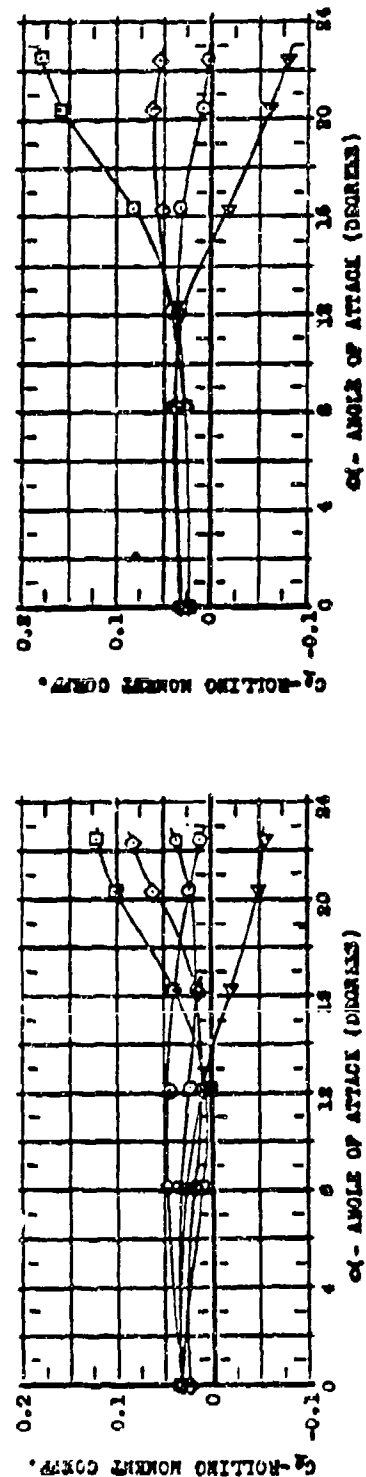
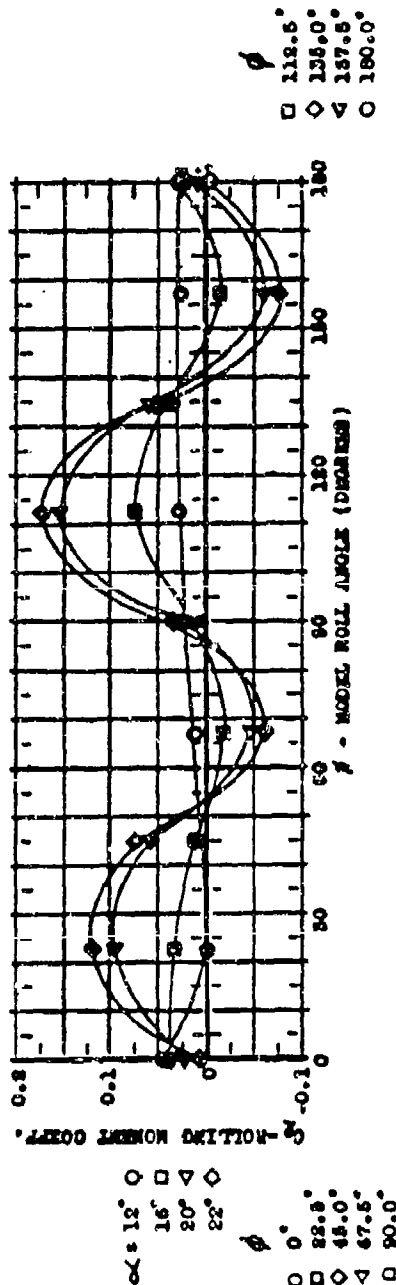
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NAVJAG REPORT 4229

LOW-DRAG BOMB

VARIATION OF ROLLING MOMENT COEFFICIENT  
WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE

$M = .90$



CONFIDENTIAL

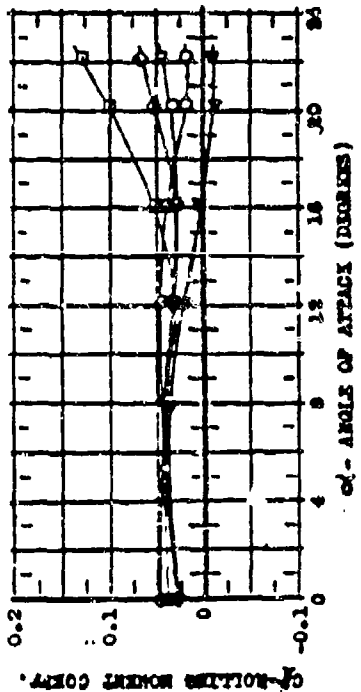
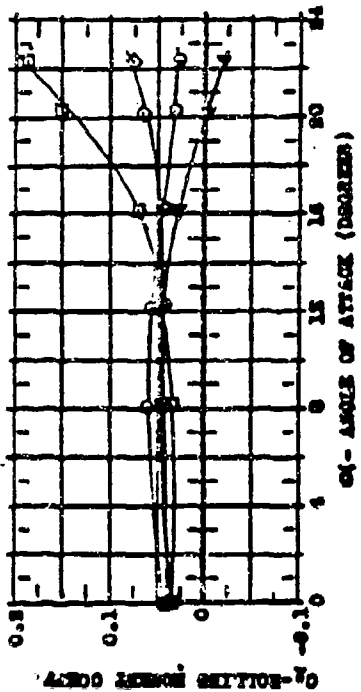
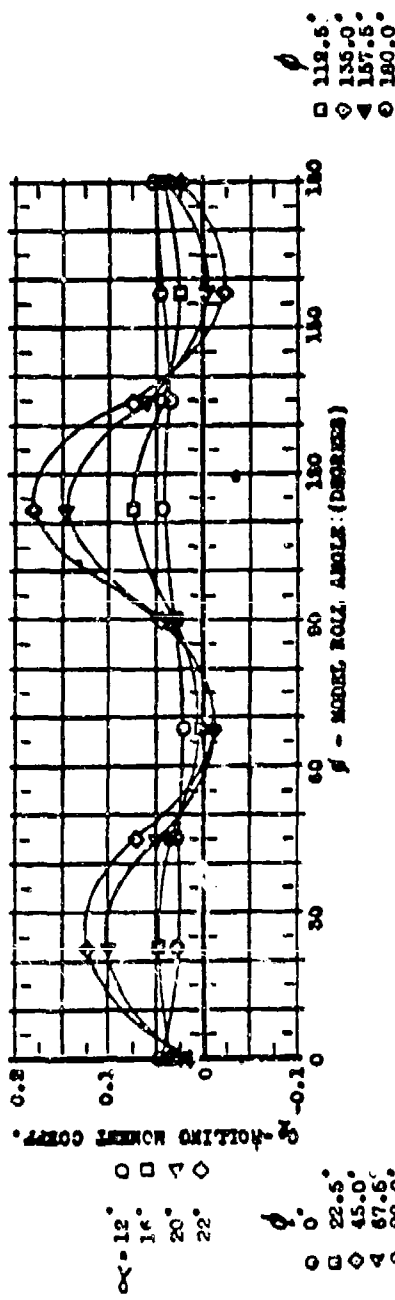
FIGURE 2

NAVORD REPORT 4389

LOW-DRAG ZONE

VARIAION OF ROLLING MOMENT COEFFICIENT  
WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE

M = .60



LOW-DRAG BOMB

VARIATION OF SPIN PARAMETER,  $pd/2V$ ,  
WITH ANGLE OF ATTACK AT VARIOUS  
FREE-STREAM MACH NUMBERS

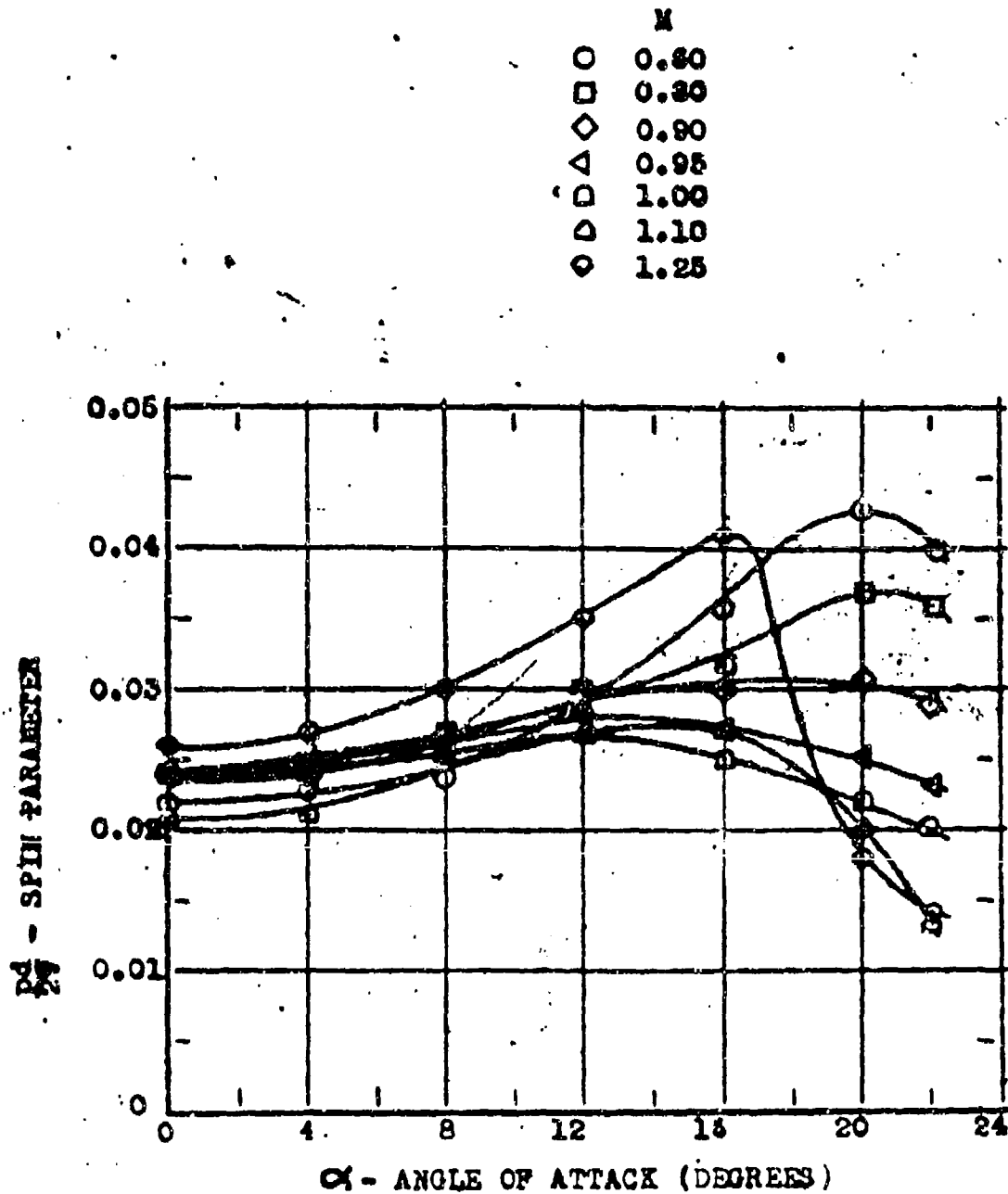


FIGURE 30

VARIATION OF DRAG COEFFICIENT WITH  
 MACH NUMBER AT ZERO DEGREE ANGLE OF  
 ATTACK

○ Re - 4x10<sup>6</sup>, LUGS ON (BASE DRAG COMPONENT REMOVED)  
 □ Re - 4x10<sup>6</sup>, LUGS OFF (BASE DRAG COMPONENT REMOVED)  
 -- 1.52x10<sup>6</sup> Re ± 3.45x10<sup>6</sup> (FREE-FLIGHT, REF (b) )

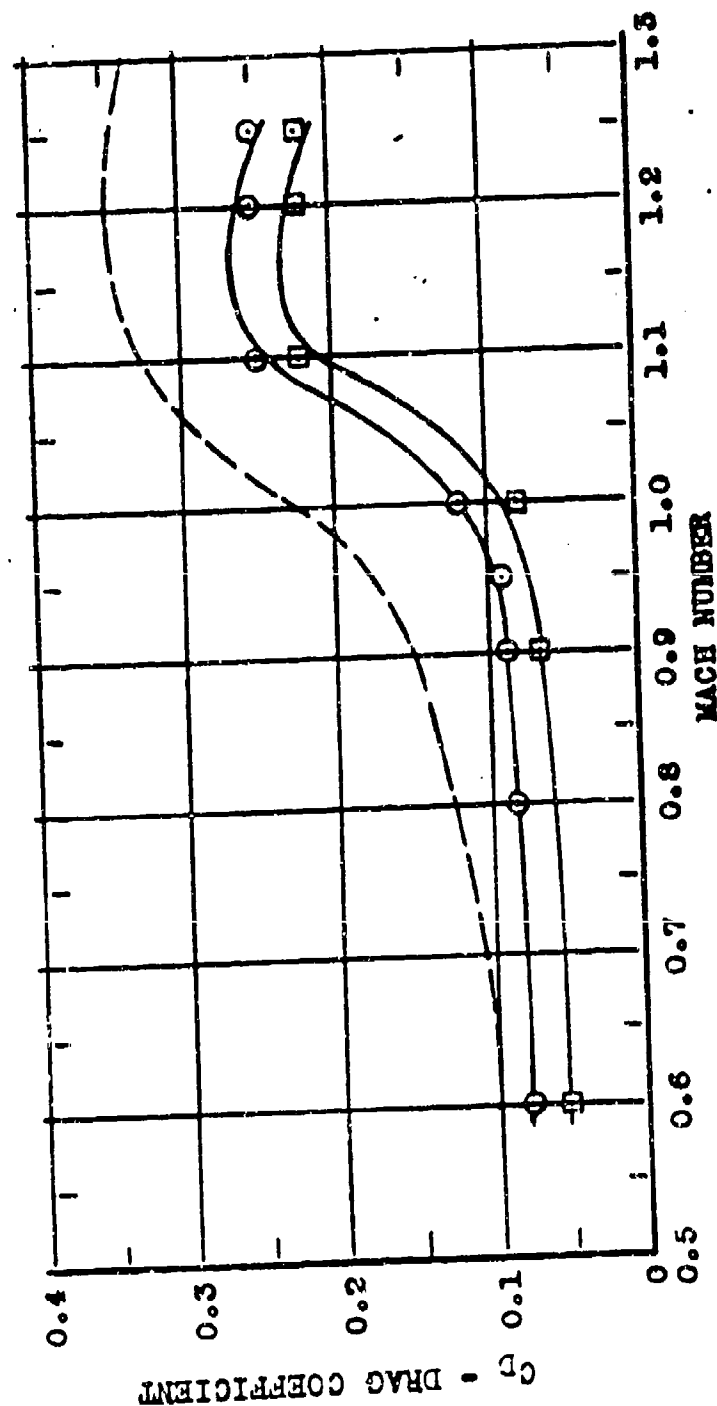


FIGURE 31

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