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MEMORANDUM REPORT NO. 1981

# DRAG AND STABILITY PROPERTIES OF THE XM144 FLECHETTE WITH VARIOUS HEAD SHAPES

by

L. C. MacAllister

May 1969

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B A L L I S T I C  R E S E A R C H  L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1981

MAY 1969

# DRAG AND STABILITY PROPERTIES OF THE XM144 FLECHETTE WITH VARIOUS HEAD SHAPES

L. C. MacAllister

Exterior Ballistics Laboratory

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B A L L I S T I C  R E S E A R C H  L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1981

LCMacAllister/pp
Aberdeen Proving Ground, Md.
May 1969

# DRAG AND STABILITY PROPERTIES OF THE XM144 FLECHETTE WITH VARIOUS HEAD SHAPES

## ABSTRACT

The drag and stability properties of a family of flechettes with conical heads are presented; cone semi-angles varied from 5 to 90 degrees. The data cover a range from Mach 2 to Mach 4 and were determined from free flight spark range tests. Limited results on a spike-nosed configuration are also given.

TABLE OF CONTENTS


| | Page |
|---|---|
| ABSTRACT | 3 |
| LIST OF SYMBOLS | 7 |
| INTRODUCTION | 9 |
| TEST OUTLINE | 10 |
| RESULTS | 12 |
| 1. Test Family | 17 |
| Drag Coefficient | 17 |
| Static Moment | 20 |
| Normal Force Slope | 24 |
| Damping Moment Coefficient | 26 |
| 2. Component Properties | 26 |
| Drag | 26 |
| Static Moment | 31 |
| Normal Force Slope | 32 |
| 3. Spike-Nosed Projectile | 37 |
| REFERENCES | 42 |
| DISTRIBUTION LIST | 43 |

## LIST OF SYMBOLS

| | |
|---|---|
| $C_D$ | Drag coefficient, $\dfrac{\text{Drag force}}{\frac{\rho V^2}{2} S}$ |
| $C_{N_\alpha}$ | Normal force slope, $\dfrac{\text{Normal force}}{\frac{\rho V^2}{2} S\alpha}$ |
| $C_{M_\alpha}$ | Static moment slope, $\dfrac{\text{Pitching moment}}{\frac{\rho V^2}{2} Sd\alpha}$ |
| $C_{M_q}$ | Pitch damping derivative, $\dfrac{\text{Pitching moment}}{\frac{\rho V^2}{2} Sd \frac{\delta d}{V}}$ |
| $C_{M_{\dot\alpha}}$ | Pitch damping derivative, $\dfrac{\text{Yawing moment}}{\frac{\rho V^2}{2} Sd \frac{\dot\alpha d}{V}}$ |
| $d$ | Body diameter |
| $\ell$ | Projectile length |
| $W$ | Projectile weight |
| $I_y$ | Transverse moment of inertia |
| $S$ | Cross sectional area, $\frac{\pi d^2}{4}$ |
| c.g. | Center of gravity from base |
| $\theta_s$ | Nose cone semi-angle |
| $\rho$ | Air density |
| $V$ | Projectile velocity |
| $M$ | Mach number |
| $\alpha$ | Angle of attack |
| $\dot\alpha$ | Rate of change of $\alpha$ |
| $q$ | Pitch rate |

## INTRODUCTION

The conventional small flechette designed for use in a rifle system usually has a long conical or ogival head, a long cylindrical section, fins with a span of two to three calibers, and is of a single material. The long nose and the minimal fin size are usually dictated in order to maintain a low drag and, hence, a low retardation. This need, or desire, for a low drag configuration imposes some difficulties in the design of flechettes for other systems. Among these can be: desirable round length may be difficult to achieve with a high $\ell/d$ flechette of adequate weight, mechanical failure is more of a problem with a high $\ell/d$ body, and a homogeneous long projectile with minimal fins often has a small static stability margin, hence, a high sensitivity to initial launch disturbance. This latter problem has been recognized in the design of fin-stabilized anti-tank projectiles for many years and there have been two quite different solutions: low drag projectiles that are subcaliber and have a sabot that launches them consistently with very small yaw so that accuracy is preserved in spite of high sensitivity to launch disturbance, and projectiles with high drag noses which can be relatively compact, have adequate stability and low sensitivity to initial disturbance.

The testing of some fully blunted short flechettes in a multiple launch system demonstrated the higher accuracy expected compared with more conventional flechettes, and also the expected higher retardation. In order to provide information that would assist in evaluating intermediate designs, some free flight range tests were made using XM144 flechettes[1] with various conical head shapes having cone semi-angles from 5 to 90°. A few non-conical nose shapes were also tested.

The XM144 was selected as the basic component for modification because of its availability and because it is, for such a small projectile, very well made and has relatively thin, clean fins. These features would make the round-to-round data more consistent, which is quite desirable for a basic program, yet because of these features it also usually has a laminar boundary layer in flight and the flow in the area of the fins is relatively undisturbed. Some of the aerodynamic properties ascribed to the flechette as a whole and derived for the tail section in this report could well be different for a more crudely made vehicle.

## TEST OUTLINE

The developmental XM144 flechette is made of steel, is 1.78mm in body diameter, has a fin span of about 5.33mm, and has a simple conical or a compound conical head. The projectiles for the present tests were fabricated from the parent models by remachining the head using a fixed length of 27.94mm from the base of the projectile to the shoulder of the conical head shape. Because of this restriction set by the basic projectile, the final projectiles used in this test varied in both weight and length as the head shape varied. The nominal dimensions of the projectiles tested are given in Figure 1 and the measured physical properties in Table I.

The projectiles were all launched from 7.62mm smoothbore tubes through the spark shadowgraphic Aerodynamics Range[2]. At the higher velocities, the Special Purpose Individual Weapon (SPIW) puller-sabot system was utilized while at the lower speeds a plastic-metal pusher sabot was used.

The basic test was conducted at Mach 4, but there was considerable velocity dispersion resulting in data at lower velocities as well. After this occurred and the major point

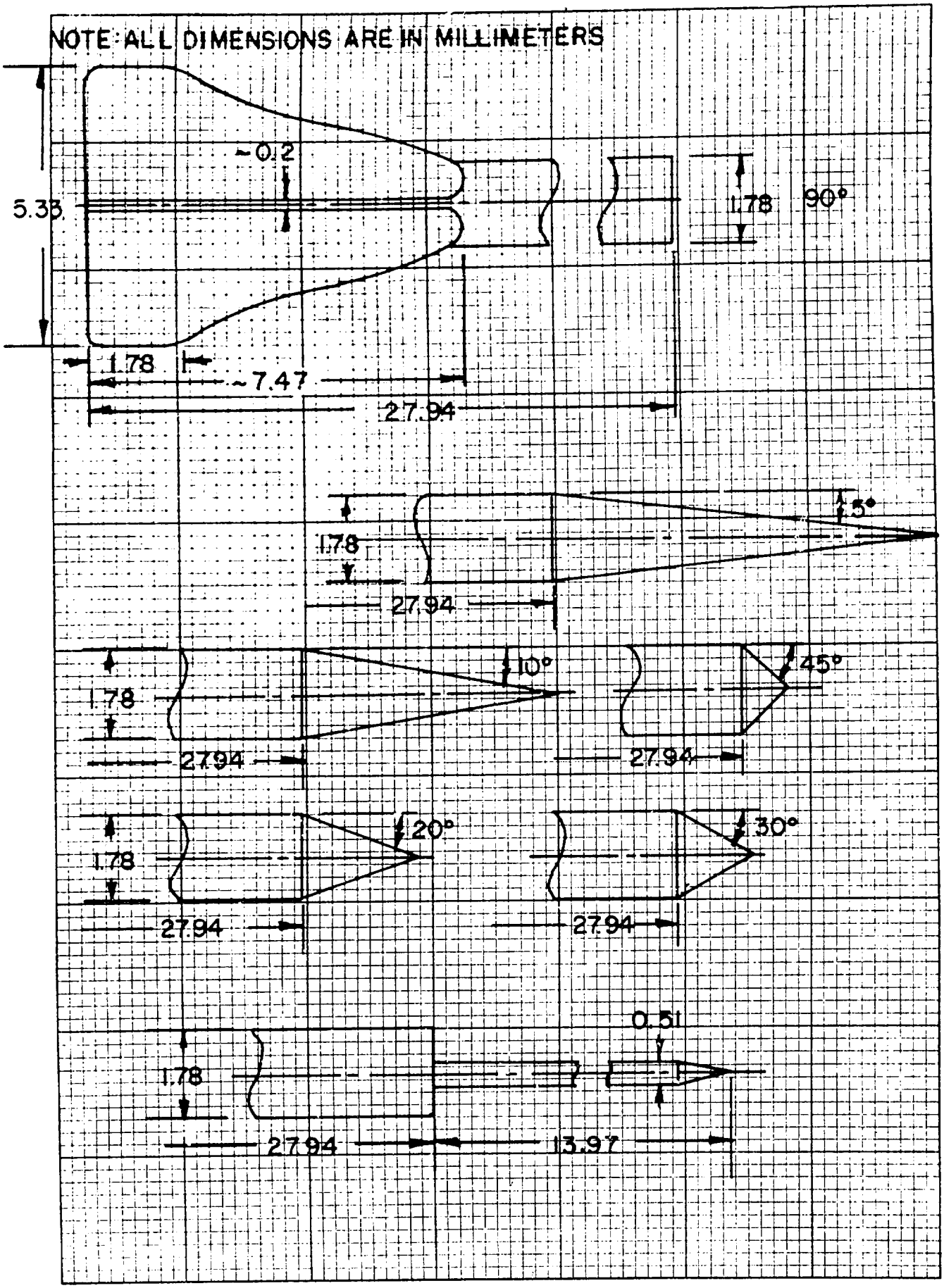



Figure 1. Projectile Configurations

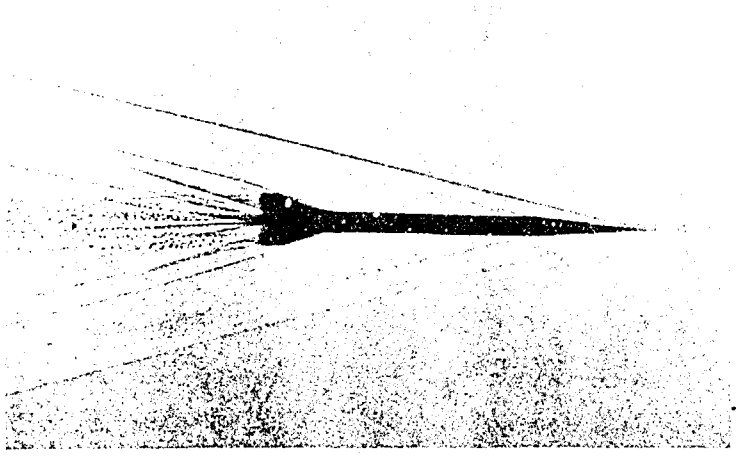
was covered, the surplus models were deliberately launched at lower velocities to yield a semblance of a Mach number test between Mach 1.5 and 4 although the coverage below Mach 3 is sparse. Flight shadowgraphs of each type tested are given in Figures 2a-i.

Table I. Physical Properties of Modified XM144 Flechettes

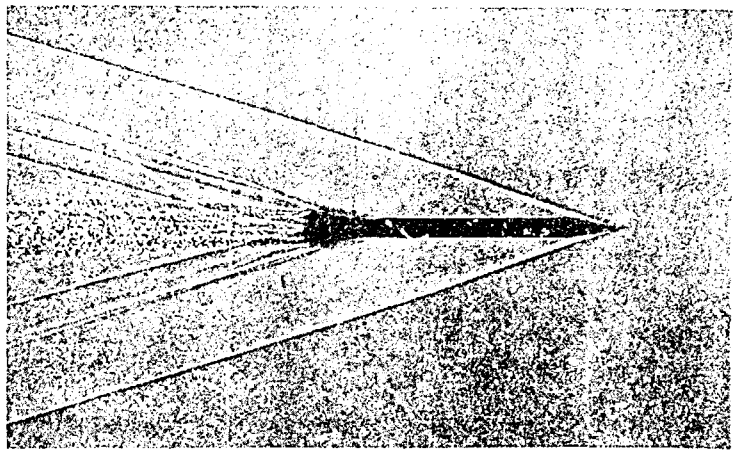
| Nose Type | Head Length (cal.) | Total Length (cal.) | Wt. (gram) | d (mm) | $I_y$ (gm cm$^2$) | c.g. (cal. from base) | $d_{fin}$ (mm) |
|---|---|---|---|---|---|---|---|
| Spike | 7.87 | 23.5 | .526 | 1.793 | .406 | 9.06 | 5.309 |
| 90° | 0 | 15.7 | .4945 | 1.788 | .297 | 8.46 | 5.283 |
| 45° | .49 | 16.2 | .5029 | 1.783 | .319 | 8.50 | 5.283 |
| 30° | .86 | 16.6 | .5083 | 1.788 | .320 | 8.63 | 5.283 |
| 20° | 1.34 | 17.1 | .5072 | 1.783 | .322 | 8.74 | 5.283 |
| 15° | 1.83 | 17.5 | .5142 | 1.781 | .338 | 8.84 | 5.283 |
| 10° | 2.84 | 18.6 | .5252 | 1.786 | .359 | 9.06 | 5.283 |
| 5° | 5.64 | 21.4 | .5651 | 1.788 | .444 | 9.54 | 5.283 |

## RESULTS

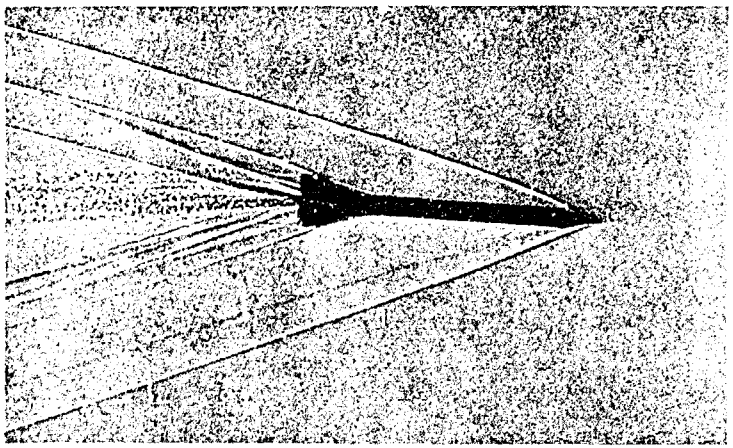
The aerodynamic data collected consists primarily of drag and static moment coefficients, although some values of the normal force slope and the damping moment derivatives were also obtained. The range data were processed assuming that the projectile was symmetric,[3] although even well made flechettes have sufficient manufacturing asymmetries to develop measureable trim yaws and spin. The projectiles are so small that it is difficult to accurately determine the



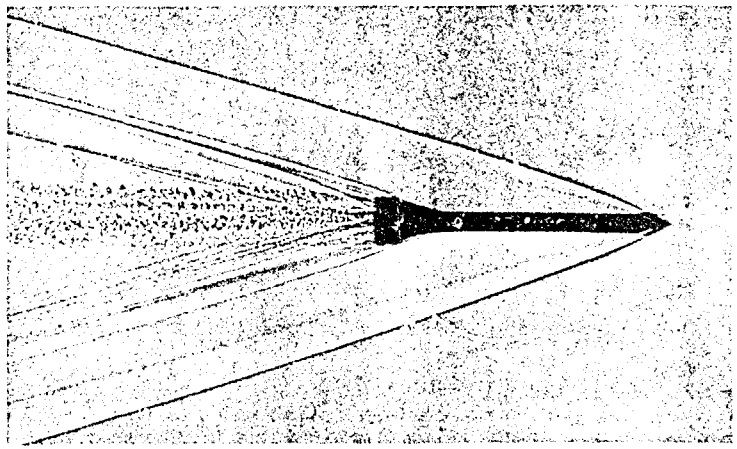
a. $\theta_s = 5^\circ$ M = 4.2



b. $\theta_s = 10^\circ$ M = 3.6

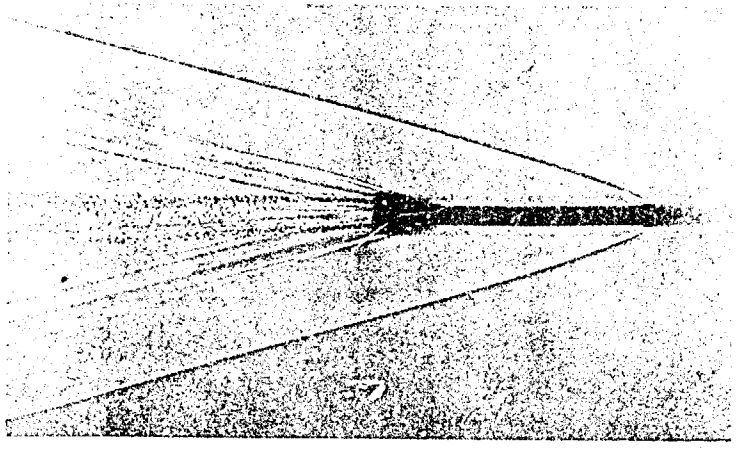


c. $\theta_s = 15^\circ$ M = 3.5

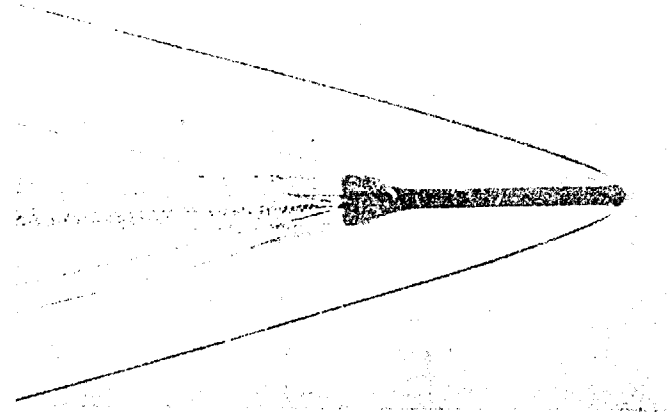


d. $\theta_s = 20^\circ$ M = 3.7

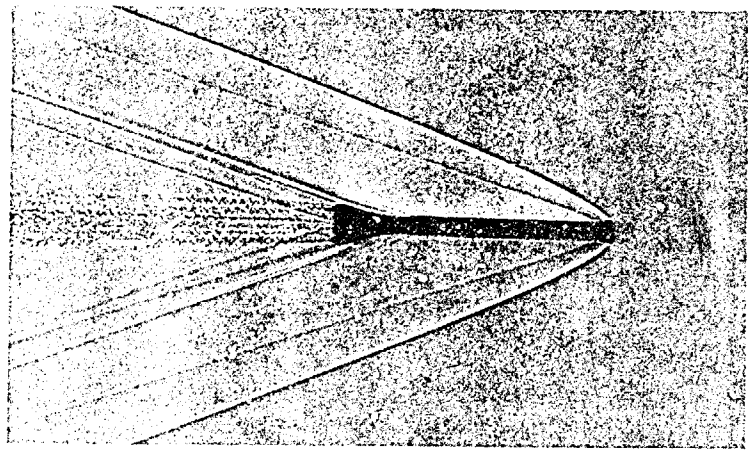
Figure 2. Shadowgraphs



e. $\theta_s = 30^\circ$ M = 4.1

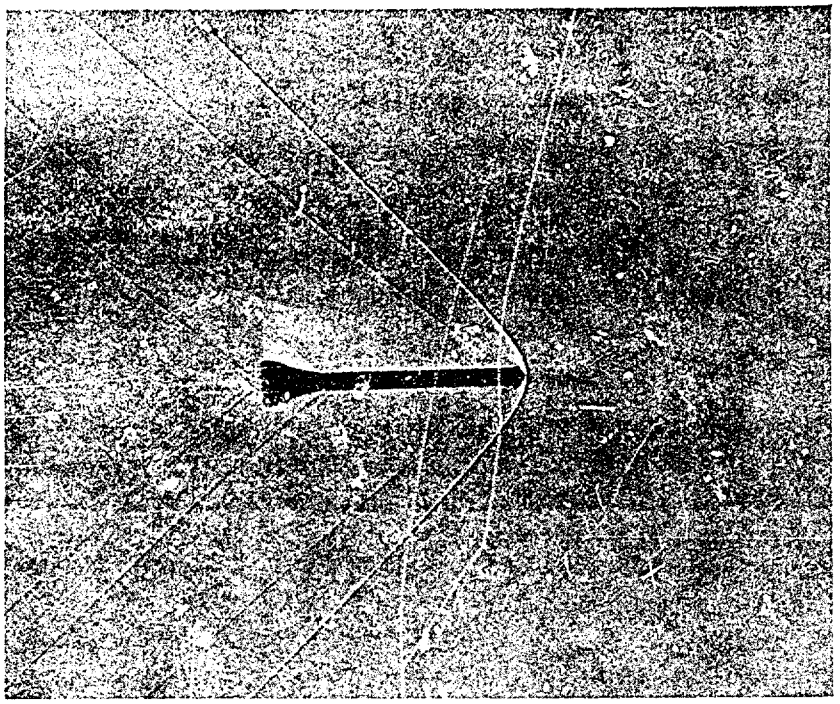


f. $\theta_s = 45^\circ$ M = 4.0

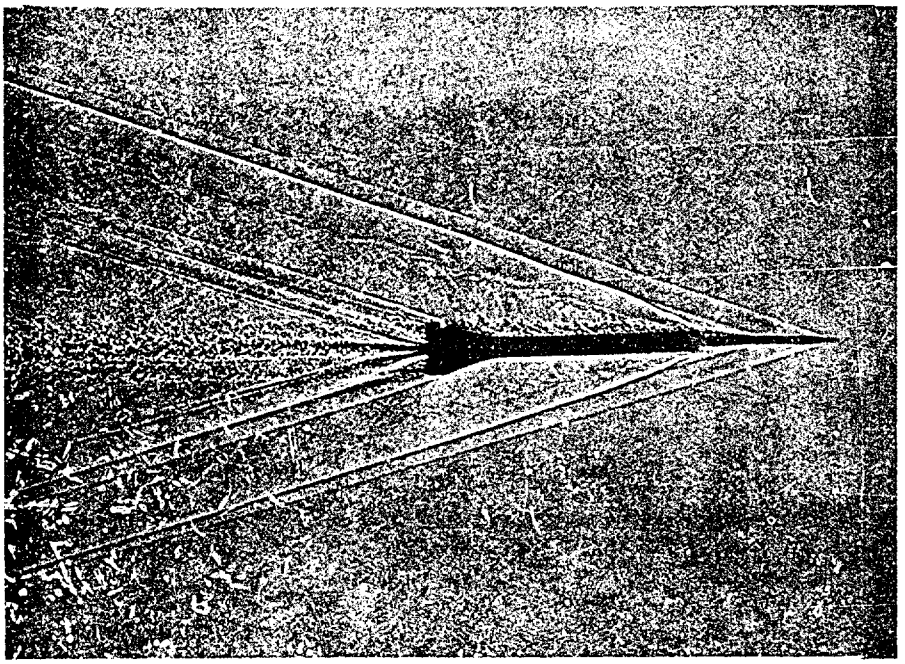


g. $\theta_s = 90^\circ$ M = 3.0

Figure 2. Shadowgraphs (Continued)



h. $\theta_s = 10^\circ$, M = 1.4 - Subsonic Fins



i. Spike-Nose M = 3.5

Figure 2. Shadowgraphs (Continued)

rolling motion and this determination is necessary if the asymmetric yawing motion is to be processed adequately. Because of this condition, there is a low percentage of $C_{N_\alpha}$ and $(C_{M_q} + C_{M_{\dot{\alpha}}})$ determinations.

The basic data independently establish the aerodynamic properties of the various configurations only at Mach 4. At the lower Mach numbers, it was necessary to devise a method to consider the data from several types together. The method selected was to compute the aerodynamic properties of the body alone using Van Dyke's second order theory[4] for the potential flow with a boundary layer thickness correction based on boundary layer computations of an insulated flat plate. This computation yields $C_{D_o}$, $C_{D_{\delta^2}}$, $C_{N_\alpha}$, and $CP_N$, for the body. The validity limits permitted computations of the $5^\circ$ and $10^\circ$ $\theta_s$ cases at Mach 2, 3, and 4 but restricted the $15^\circ$ $\theta_s$ case to less than Mach 3.5, the $20^\circ$ $\theta_s$ case to Mach 2.5, and the $30^\circ$ $\theta_s$ case to Mach 1.8. As a result, the desynthesis attempt could be made only on the first three cases initially. The subtraction of the body properties from the measured total properties yields the aerodynamic properties of the fin section which should be much more nearly the same than the total configuration properties. It should be noted, however, that the fin properties now include both the body-on-fin interference and any fin-on-body interference effects. This stripping process did seem to show that the tail section properties were invariant for the $5^\circ$, $10^\circ$, and $15^\circ$ $\theta_s$ cases. The results were faired together and the process reversed to reconstruct curves for the whole configuration. Thus, the final data curves result both from direct and indirect inferences. The procedure inherently opened up the possibility of discussing the component properties as well as the total properties. The

component properties are interesting in that they permit the synthesis of flechette families other than the one tested; with the caution that the mutual interference between the body and tail may change if the bodies used are considerably different than those used in this test.

The process employed for the $5^\circ$ to $15^\circ$ $\theta_s$ cases seemed worthwhile to carry on for the other cases as at least a consistency check, but the lack of computations at the higher Mach numbers for the $20^\circ$ and $30^\circ$ $\theta_s$ conditions and at all Mach numbers for the remaining cases posed a problem. This was resolved for the conical head shapes by utilizing tabled values for the drag and normal force for cones, and using the previously determined skin friction and boundary layer corrections to $C_{N_\alpha}$ as approximations for these cases. Cruder approximations had to be used for the $90^\circ$ $\theta_s$ and spike-nosed cases. The drag for the $90^\circ$ nose was taken from the design curves of reference 5 (Vol. II), while the drag of the spike-nosed configuration and the normal force of both configurations were estimated from data on larger projectiles of similar head shapes. The estimates of the body contributions probably are decreasing in accuracy from the $5^\circ$-$15^\circ$ cases to the blunt cases.

The results for the test family are presented first and the component data follow. The results for the spike-nosed projectile are presented separately because it is not a logical parametric member of the family of configurations.

1. Test Family

Drag Coefficient. The drag coefficient data as determined from each individual test is given in Table II and the $C_D$ is plotted in Figure 3 as a function of Mach number utilizing the test values adjusted to a zero yaw value where possible. The variation of $C_D$ with yaw level

Table II. Aerodynamic Data

| Round No. | $\theta_s$ (deg) | Mach No. | $\sqrt{\overline{\delta^2}}$ (deg) | $C_D$ | $-C_{M_\alpha}$ | $-(C_{M_q} + C_{M_{\dot\alpha}})$ | $C_{N_\alpha}$ |
|---|---|---|---|---|---|---|---|
| 1-7654 | 5 | 4.22 | 1.8 | 0.313 | 40.8 | 1260 | 10.4 |
| 7653 | 5 | 4.20 | 1.1 | 0.318 | 44.3 | 1150 | |
| 7675 | 5 | 3.45 | 1.0 | 0.329 | 55.5 | -- | |
| 7688 | 5 | 2.60 | 1.0 | 0.483 | 74.4 | 1400 | |
| 7684 | 5 | 2.00 | 0.7 | 0.581 | 47.2 | -- | |
| 1-7651 | 10 | 4.33 | 4.2 | 0.415 | 38.6 | 940 | 11.3 |
| 7665 | 10 | 4.26 | 1.6 | 0.339 | 35.5 | 600 | 11.4 |
| 7652 | 10 | 4.20 | 1.1 | 0.324 | 34.0 | 900 | |
| 7676 | 10 | 3.57 | 2.7 | 0.479 | 39.4 | 630 | |
| 7685 | 10 | 1.51 | 1.3 | 0.875 | 28.8 | -- | |
| 1-7649 | 15 | 4.27 | 2.3 | 0.460 | 30.3 | 860 | |
| 7666 | 15 | 4.21 | 1.3 | 0.437 | 29.4 | 740 | |
| 7650 | 15 | 3.91 | 4.6 | 0.541 | 28.9 | 680 | 11.3 |
| 7674 | 15 | 3.50 | 8.1 | 0.581 | 37.3 | 1360 | 11.9 |
| 7687 | 15 | 2.42 | 2.1 | 0.692 | 75.1 | 1250 | 14.4 |
| 1-7647 | 20 | 4.37 | 4.0 | 0.639 | 27.8 | 640 | 10.2 |
| 7648 | 20 | 4.35 | 3.3 | 0.578 | 24.7 | 710 | 8.9 |
| 7672 | 20 | 3.70 | 1.7 | 0.707 | 40.2 | -- | |
| 7686 | 20 | 2.59 | 0.4 | 0.729 | 65.5 | -- | |
| 1-7646 | 30 | 4.27 | 2.4 | 0.832 | 28.9 | 590 | 11.4 |
| 7645 | 30 | 4.13 | 1.5 | 0.774 | 30.4 | 700 | |
| 7677 | 30 | 3.97 | 2.7 | 0.859 | 28.1 | 750 | 10.7 |
| 7683 | 30 | 3.46 | 1.0 | 0.890 | 36.9 | -- | |
| 7689 | 30 | 2.32 | 1.7 | 1.139 | 76.3 | 1200 | |
| 1-7679 | 45 | 4.10 | 0.8 | 1.321 | 31.3 | 660 | |
| 7643 | 45 | 4.01 | 2.0 | 1.386 | 33.1 | 700 | 5.5 |
| 7644 | 45 | 3.96 | 1.5 | 1.369 | 33.7 | 570 | |
| 7681 | 45 | 3.30 | 2.5 | 1.410 | 46.5 | 840 | 10.2 |
| 7680 | 45 | 2.86 | 7.4 | 1.866 | 45.3 | -- | 7.5 |
| 7692 | 45 | 1.49 | 5.6 | 1.838 | 13.6 | 1600 | 5.4 |
| 1-7642 | 90 | 4.24 | 2.7 | 1.757 | 37.8 | 480 | 6.4 |
| 7641 | 90 | 4.00 | 1.5 | 1.858 | | | |
| 7682 | 90 | 3.09 | 3.0 | 1.746 | 56.2 | 1090 | |
| 7671 | 90 | 2.96 | 2.8 | 1.642 | | | |
| 7693 | 90 | 2.43 | 2.0 | 1.612 | 73.8 | 610 | 8 |
| 7694 | 90 | 2.43 | 3.0 | 1.568 | 65.5 | 1300 | |
| 1-7664 | Spike | 4.08 | 2.0 | 0.540 | 24.7 | -- | Short spike |
| 7697 | " | 3.44 | 1.4 | 0.564 | 50.1 | 930 | 8.2 |
| 7698 | " | 2.85 | 3.4 | -- | 62.3 | 1220 | 14.1 |
| 7691 | " | 2.16 | 1.3 | 0.863 | 83.0 | 1500 | |
| 7690 | " | 2.10 | 2.1 | 0.945 | 86.4 | 1530 | |

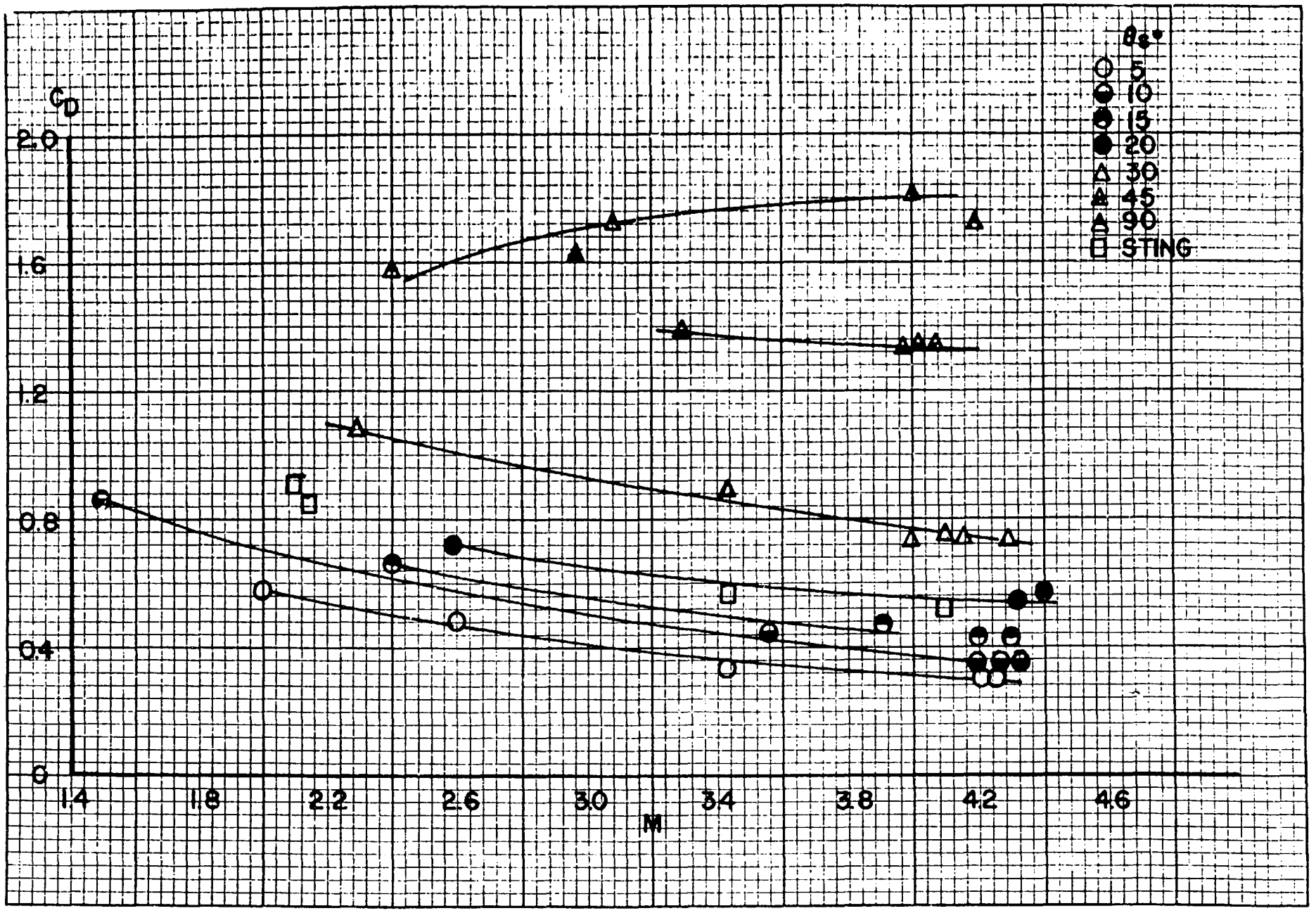



Figure 3. $C_D$ versus Mach Number for Configurations

for small yaw is:

$$C_D = C_{D_o} + C_{D_{\delta^2}} \delta^2$$

In some cases, there were several models of the same type at the same Mach number but with different yaw levels and the $C_{D_o}$ value could be determined directly by plotting the data as a function of yaw level. In cases where this was not possible, $C_{D_{\delta^2}}$ was assumed to be adequately represented by $C_{N_\alpha}$ of the fins and a computed $C_{D_{\delta^2}}$ for the body, for the purpose of the small correction. The curves for the lower values of $\theta_s$ exhibit a typical supersonic behavior for a fin stabilized dart and the drag increases are modest until the semi-angle exceeds $15^\circ$. The drag increases rapidly for higher semi-angles and the blunt flechette exhibits the continuously increasing drag curve of a blunt body. The data above a Mach number of 3.5 were adjusted to a Mach number of 4.2 and the result plotted as a function of cone angle in Figure 4. This shows the nature of the variation more clearly, the data can be quite closely represented by a $(1 - \cos \theta_s)$ variation up to $\theta_s = 45^\circ$.

<u>Static Moment</u>. The static moment slope $C_{M_\alpha}$ is a function of the center of mass position of the model, and for the test projectiles this is the center of volume; hence, the indicated variation is strictly valid only for the particular parametric family tested. The values of $C_{M_\alpha}$ from the tests are plotted in Figure 5a-b as a function of Mach number. The data were also plotted as a function of yaw in an effort to determine the nature of any variation with yaw. There were not adequate data to establish a reliable correction factor for any type and the variations do not appear to be large. There is a distinct trend in

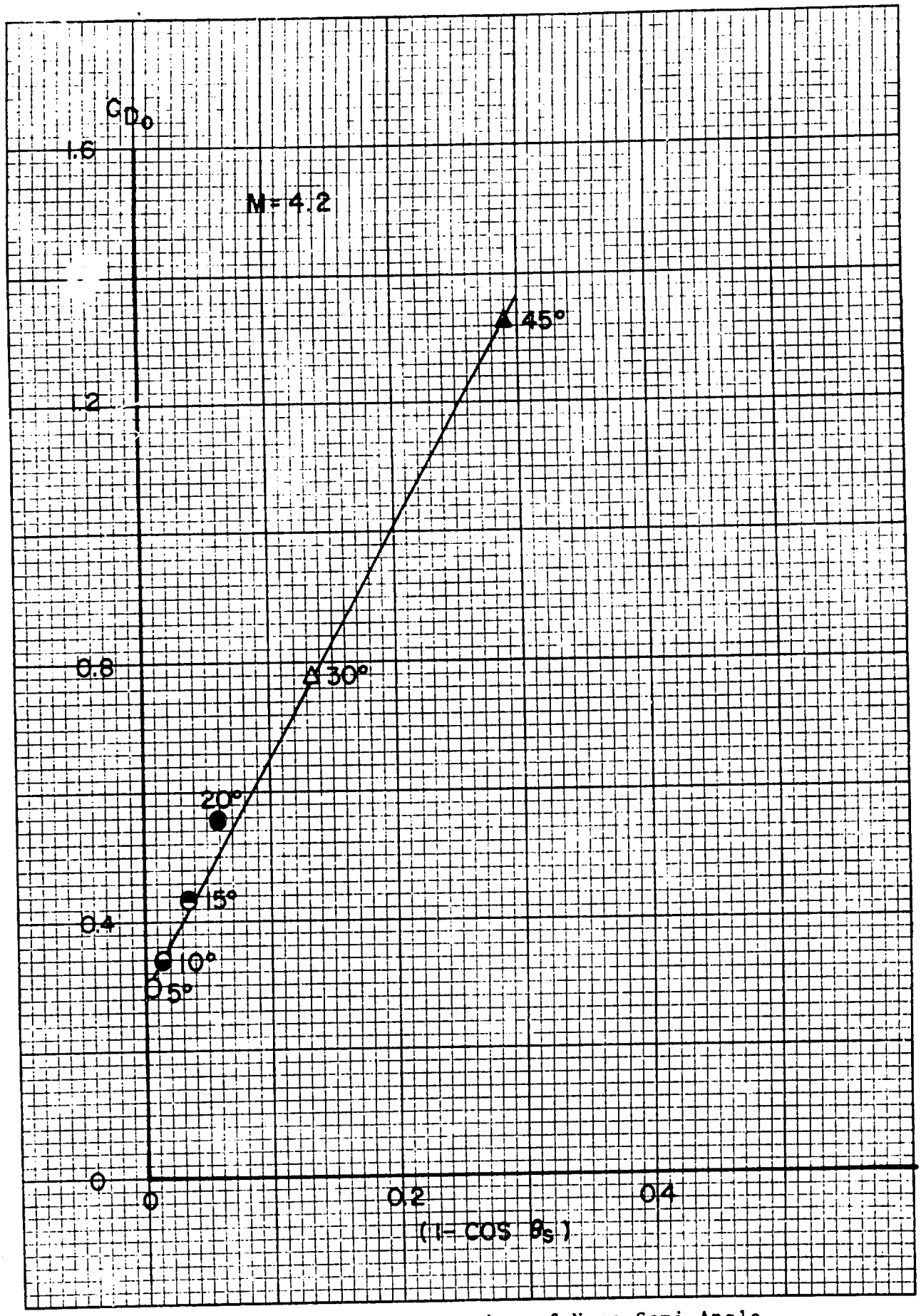



Figure 4. $C_D$ as a Function of Nose Semi-Angle

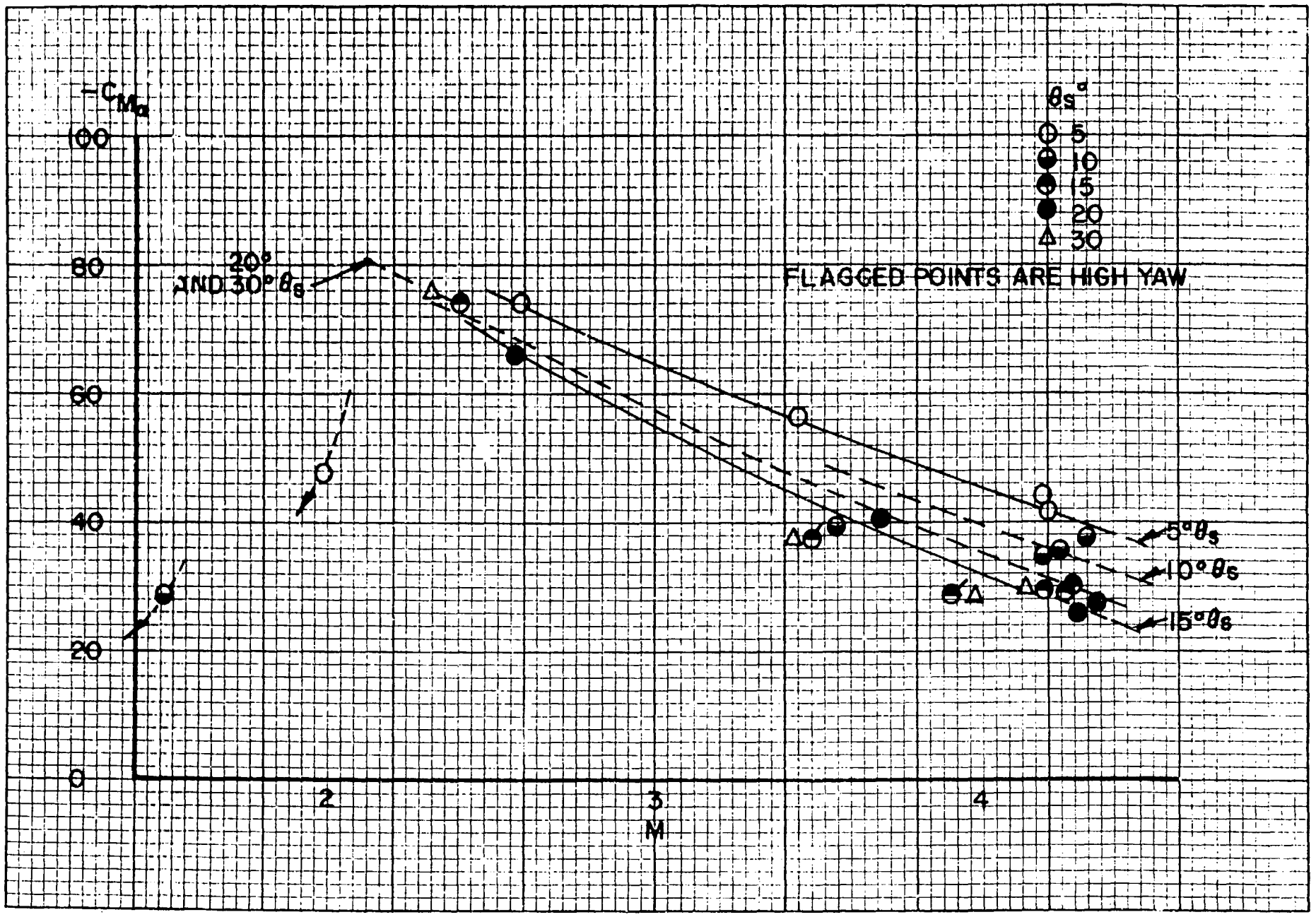



Figure 5a. Static Moment Slope for Configurations

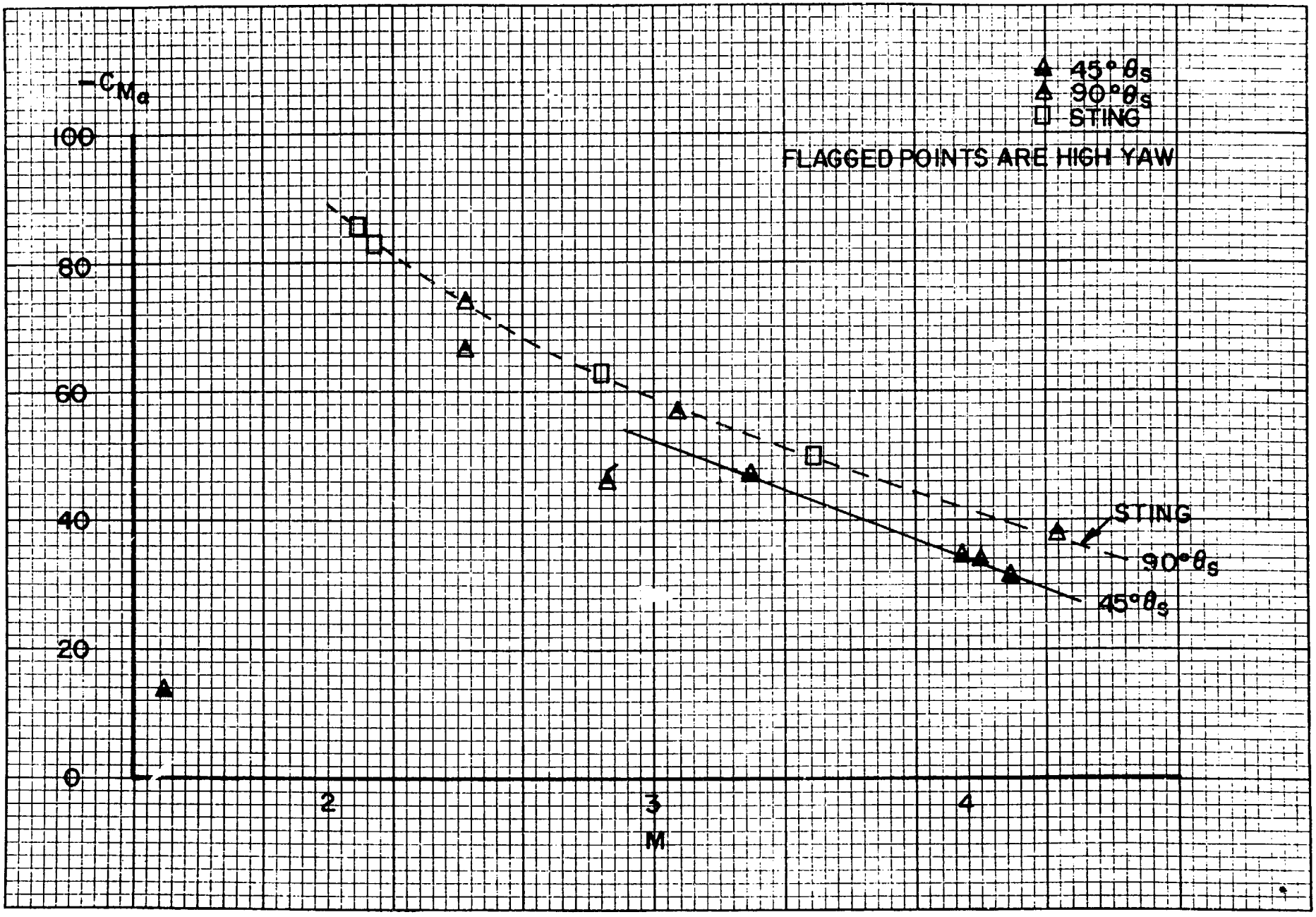



Figure 5b. Static Moment Slope for Configurations

that the values of $C_{M_\alpha}$ for rounds with yaws above about three degrees are significantly smaller in magnitude than those for rounds with two to three degrees of yaw. The rounds with the smallest yaw levels also seem to have smaller values, but this variation is not clearly beyond the data scatter.

The general uniformity of the data as a function of Mach number is somewhat surprising; the variation with Mach number is almost linear for all types from just above Mach 2 to beyond Mach 4 and a bandwidth of about ten units in $C_{M_\alpha}$ would encompass almost all of the smaller yaw data. In fact, only the blunt projectiles and the most pointed ones ($\theta_s = 5^\circ$) appear to have a trend that is distinguishable from the general mass of data and both of these have a greater negative slope by eight to ten units. There are only three data points between Mach 1.5 and 2 and these represent two of the more pointed projectiles and one blunt version; all indicate that the static moment slope is becoming much smaller in magnitude below Mach 2. The stability level decreases with increasing Mach number from Mach 2 up, as is characteristic of fin stabilized projectiles. Extrapolation of the present data would indicate that most of the types would become unstable between about Mach 5.5 and 6; such a linear extrapolation is not really valid and was done only to indicate a probable upper bound for the utility of this particular family.

<u>Normal Force Slope</u>. The normal force slope values are given in Figure 6. In the cases of the drag and static moment, the raw data served a purpose in defining the types but this is not the case for the fewer data on $C_{N_\alpha}$. The direct data indicate only that all the cases except the 45° and 90° $\theta_s$ cases are similar. The latter two cases lie

about 40% below the other data. The $C_{N_\alpha}$ curves in Figure 6 are derived from the stripped-out tail moment results by assuming the tail center of pressure position. One can only say that the direct data generally agree. The more pointed models show a trend from a $C_{N_\alpha}$ of 15 at Mach 2 down to about 11 at Mach 4. The 45° $\theta_s$ model shows values perhaps a little more than half as large while the blunt model seems to have even slightly lower values that show little changes with Mach number. The direct and indirect indications for $M \leq 2$ are that there is a decrease in $C_{N_\alpha}$ from that of the $M \doteq 2$ level.

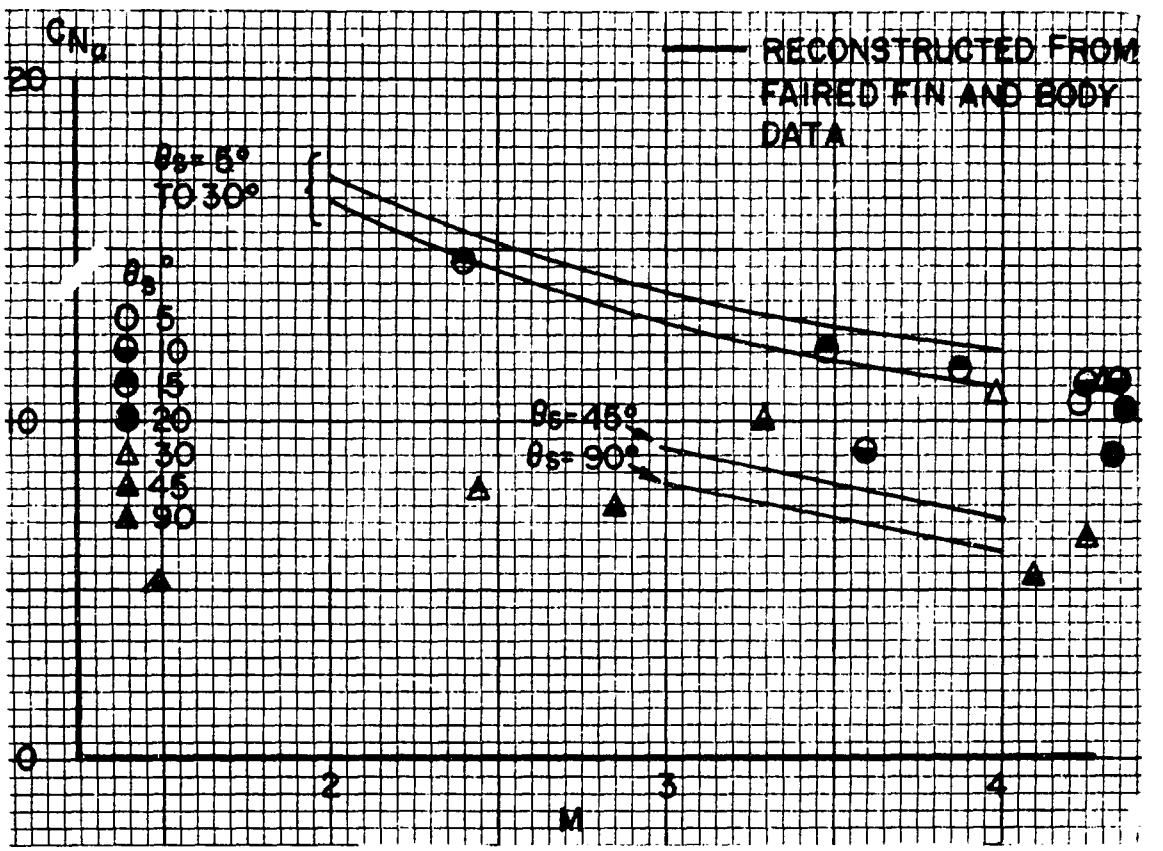



Figure 6. Normal Force Slope for Configurations

Damping Moment Coefficient. The better values of the damping moment derivatives ($C_{M_q} + C_{M_{\dot{\alpha}}}$) are given in Figure 7. There is a general trend from a level of ($C_{M_q} + C_{M_{\dot{\alpha}}}$) = -1400 at Mach 2 to -700 at Mach 4 with no clear definition between types.

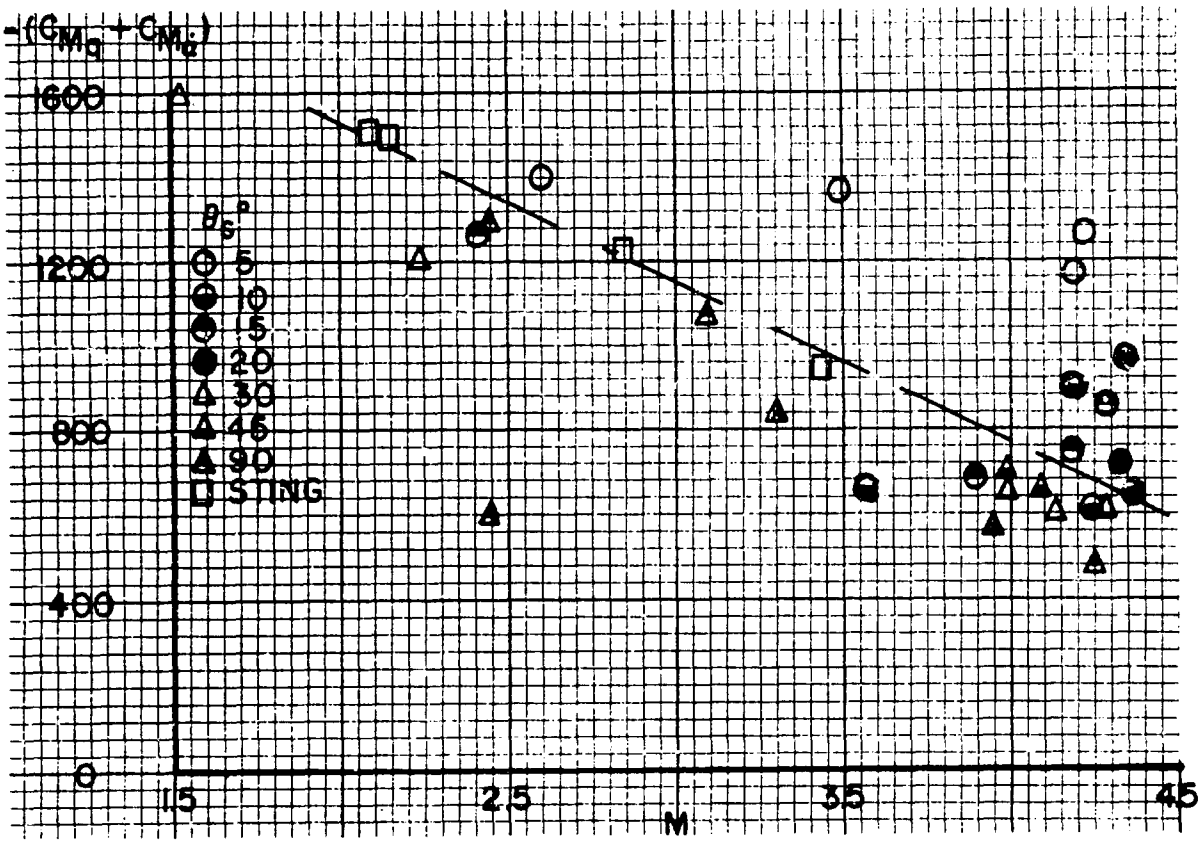



Figure 7. Damping Moment Slopes for Configurations

## 2. Component Properties

Drag. The drag elements for the various types are given in Figures 8a-g. The drag difference ascribed to the fins is four times the body pressure drag and laminar friction drag for the 5° semi-angle body at Mach 4. In effect, however, all the base drag is being assigned to the fins by this method. The base drag component for the body

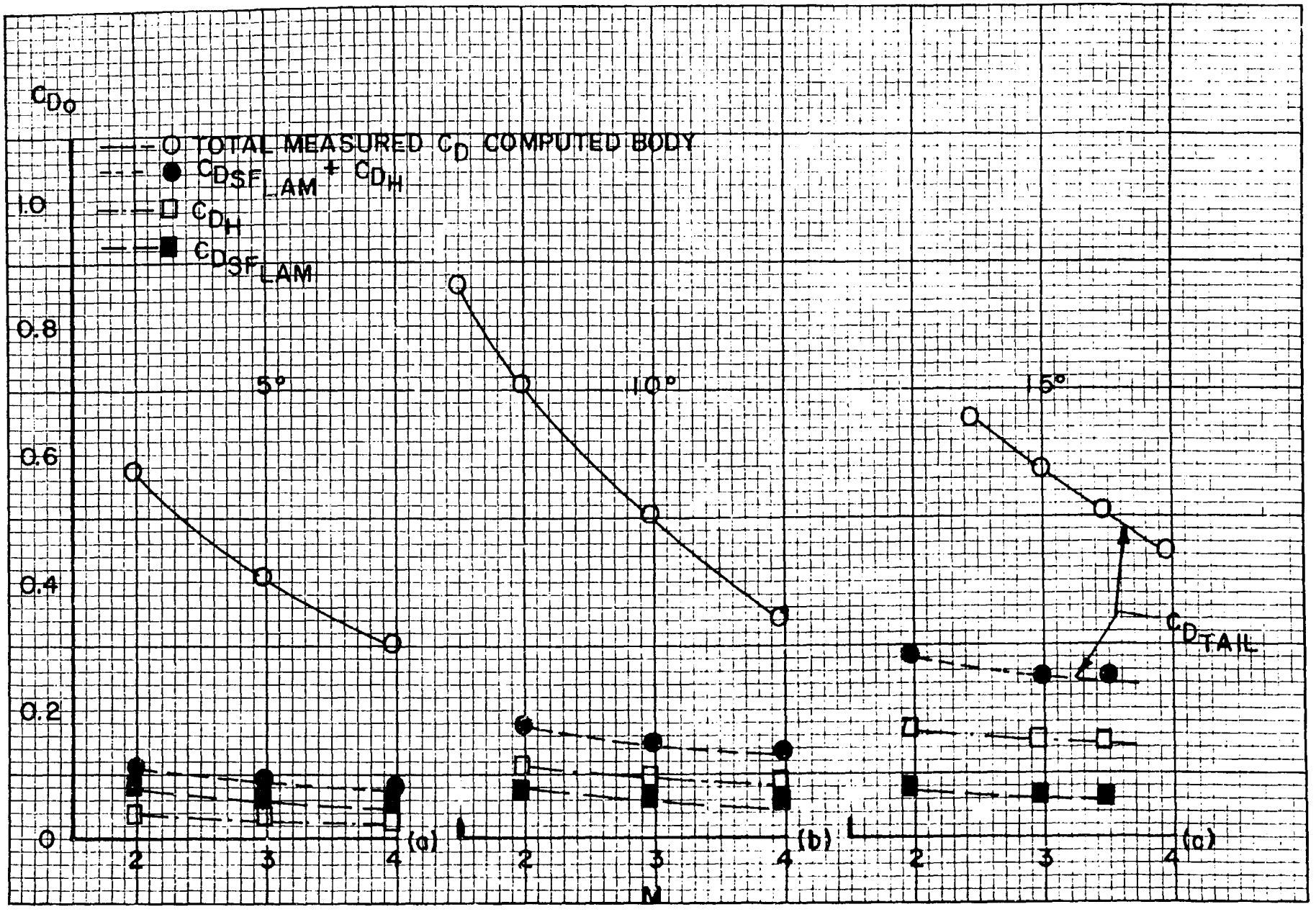



Figure 8. Component Drag Coefficients

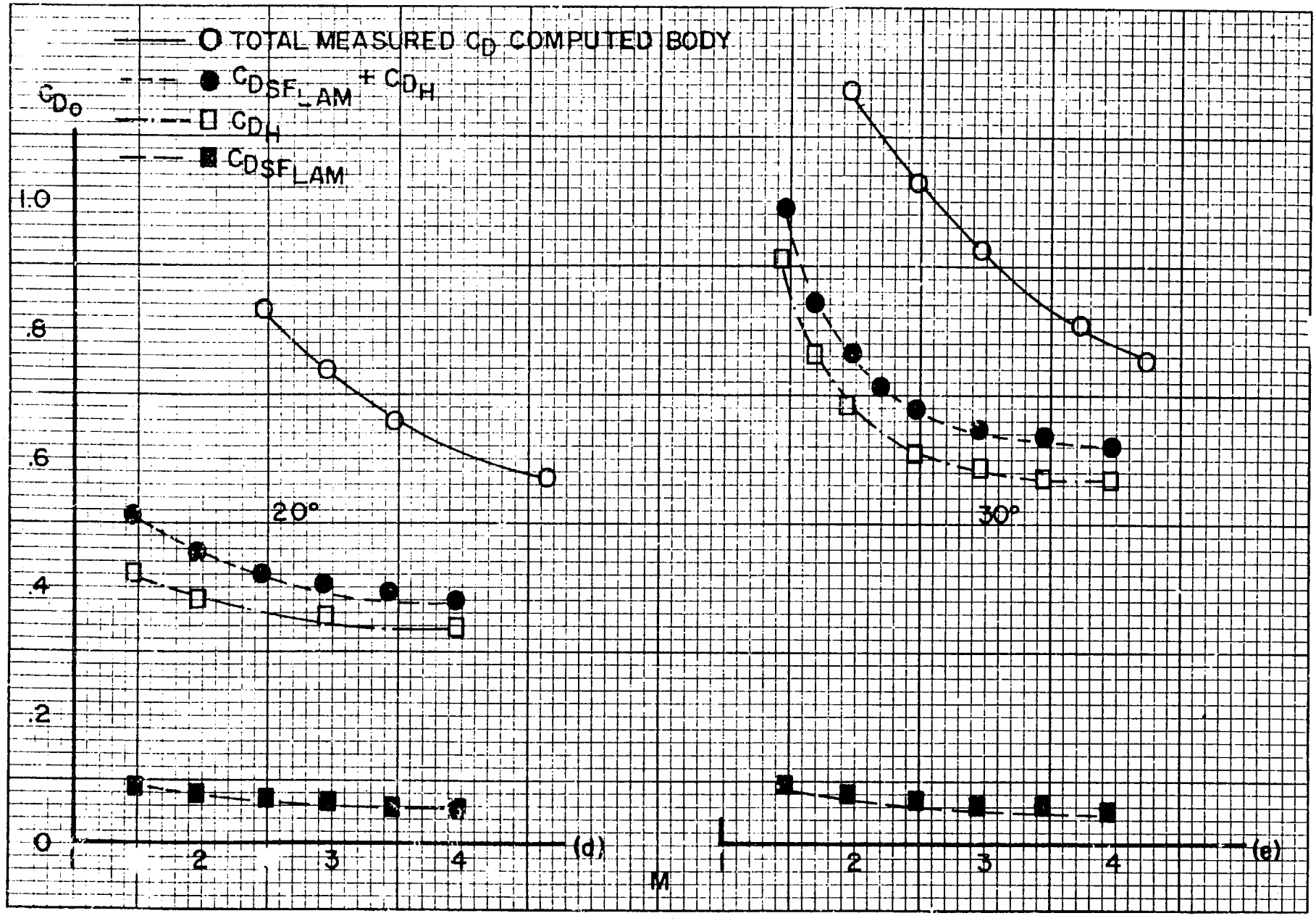



Figure 8. Component Drag Coefficients (Continued)

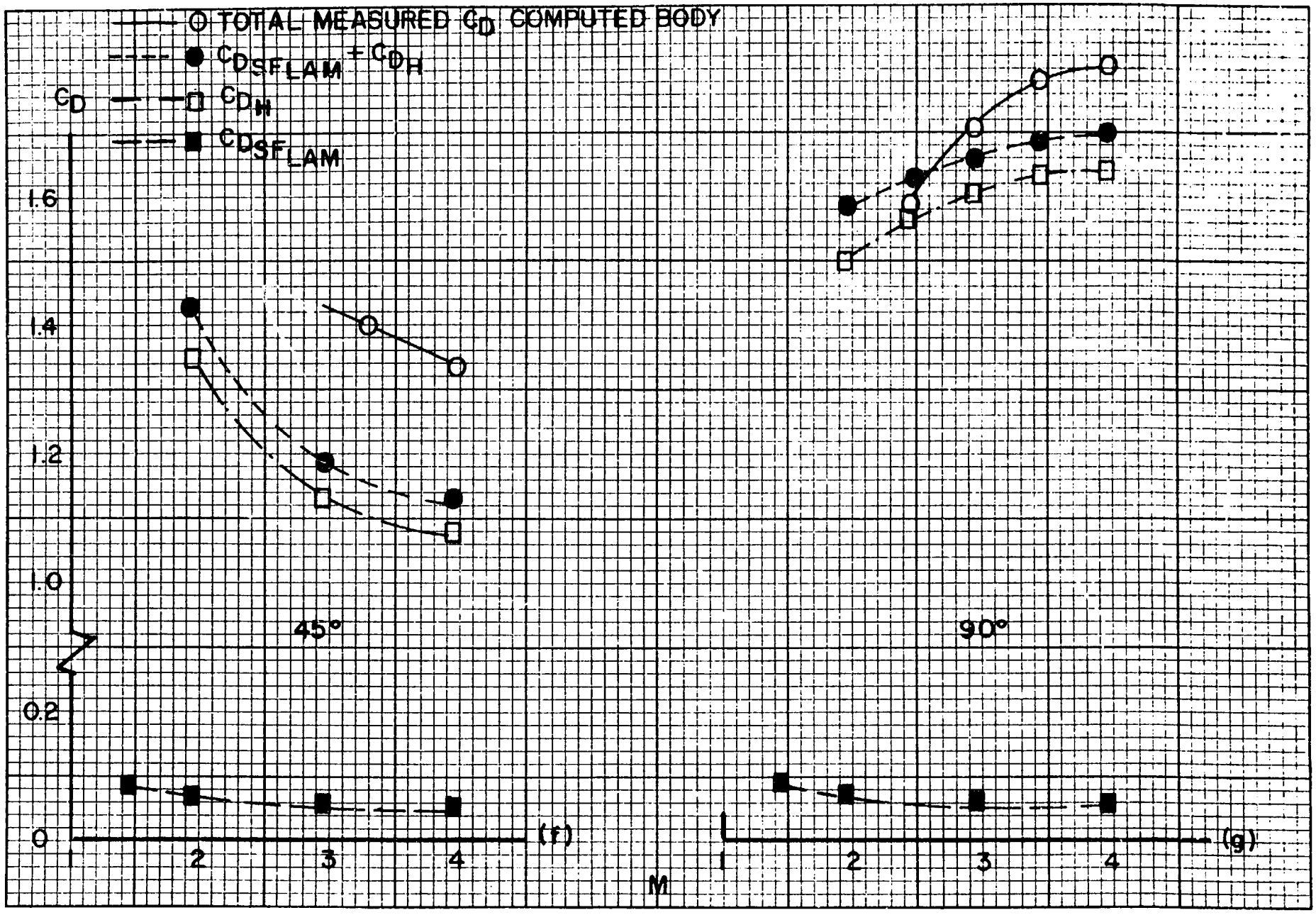



Figure 8. Component Drag Coefficients (Continued)

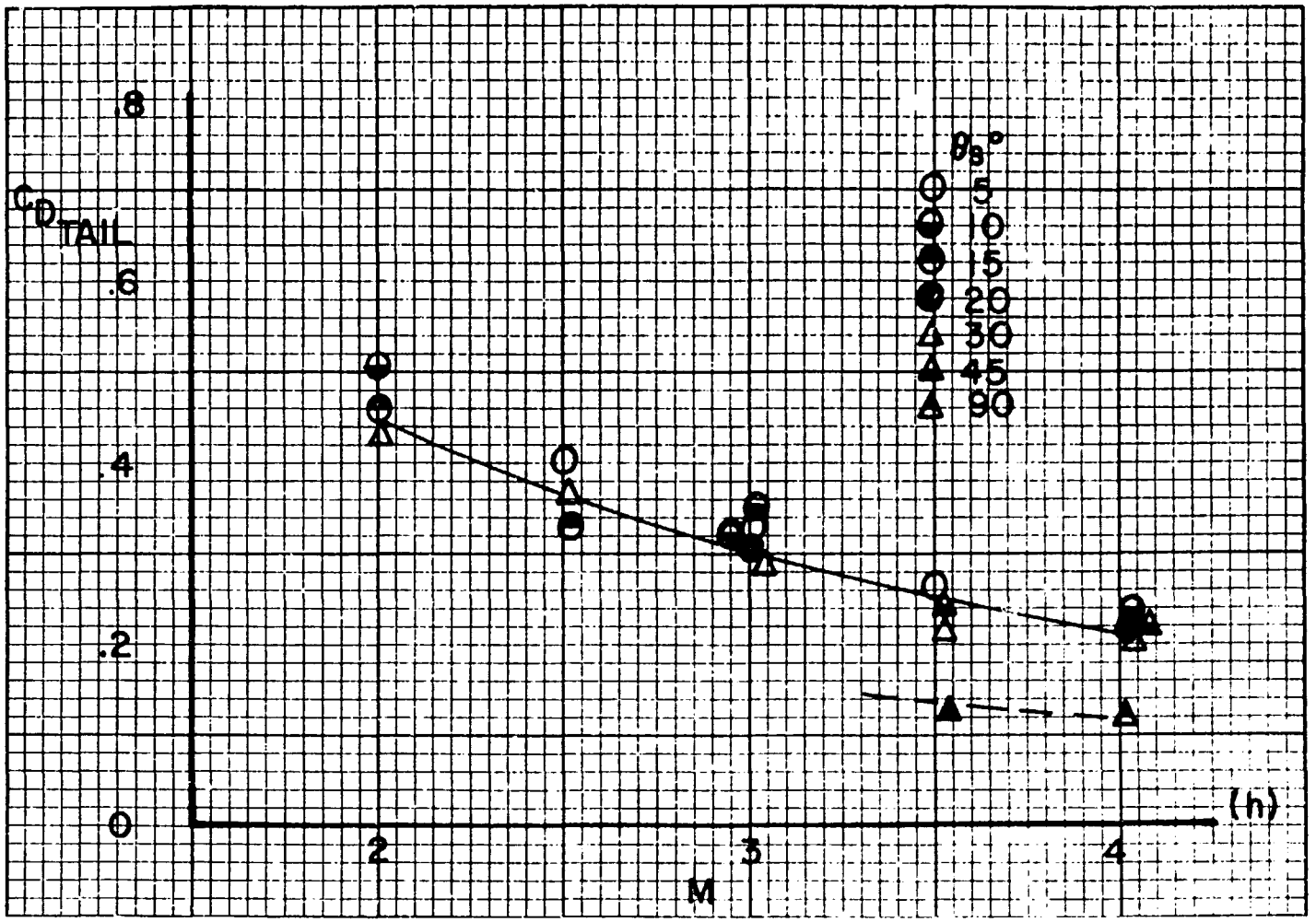



Figure 8. Component Drag Coefficients (Continued)

without fins is larger than the other elements. Including the base drag of the body in the ratio the total measured drag coefficient for the body with fins is only about 50% higher than the computed total drag of the finless body. As the nose becomes blunter, the relative proportions of the elements change slowly until the cone semi-angle exceeds $15^{\circ}$ and then rapidly until the tail section drag becomes a small portion of the total drag for $\theta_s > 30^{\circ}$.

The difference between a laminar or turbulent flow over the body is about 0.1 in $C_D$ so that for the more pointed bodies the existence of a turbulent boundary layer, or a cruder fin section, could result in relatively large drag increases. Conversely, for the blunter projectiles, cruder tail assemblies or turbulent flow are less critical to the total drag value.

The result of the subtraction process for total fin section drag coefficient is given in Figure 8h for the conical configurations. The values derived from the various types are consistent to within a total spread of about ± 5% and the differences do not appear systematic. A similar process for the blunt, or $90^{\circ}$ $\theta_s$ configuration will not yield a consistent value and this is apparent from Figure 8g. However, an error in the estimated body drag of only 6 to 10% would remove this discrepancy and in this particular case such an error is quite probable.

Static Moment. The aerodynamic moment created by the various components is not a basic property since they relate to the particular center of mass position of the total configuration. However, the static moment slope of the total configuration is one of the most accurately determined quantities from a spark range test and thus it serves as a good consistency check and also is one method of estimating the normal force slope of the tail section of this particular

family of flechettes. The computer program used for evaluating the body normal force slope and center of pressure of the 5, 10, and 15° $\theta_s$ over the range of Mach number and the 20 and 30° $\theta_s$ models at the lower Mach numbers usually agrees with experiment to within about 10%. The more approximate methods used for the other cases with conical heads could have higher errors. The body force estimates for the blunt models, and later for the spiked-nosed model, may be in error by as much as 50% but in these cases the body moment contribution is small.

The body moment, the measured moment and, by summation, the inferred moment coefficient slope of the tail section is presented in Figures 9a-g. In general, the body contribution is small at Mach 2 but by Mach 4 nearly half of the available tail moment is being utilized to overcome the destabilizing body moment for the conical nosed models.

The resultant $C_{M_{\alpha F}}$'s are recollected in Figure 9h. The curve for the 5° $\theta_s$ model is above the rest and in general the curves for the various types are distinct. This, however, is primarily the influence of the different moment arms of the configurations. By assuming a center of pressure of the tail assembly, the moment coefficient can be reduced to a tail assembly force coefficient as is done in the next section.

Normal Force Slope. The center of pressure of low aspect ratio supersonic fins is usually near the center of area and this assumption was made to reduce the moment data. The result is the normal force slope of the fin section and this is plotted in Figure 10. Type identification essentially disappears except that the 45° $\theta_s$ and the blunt model show lower values. This may be due to dynamic pressure losses in the local flow caused by the blunter noses.

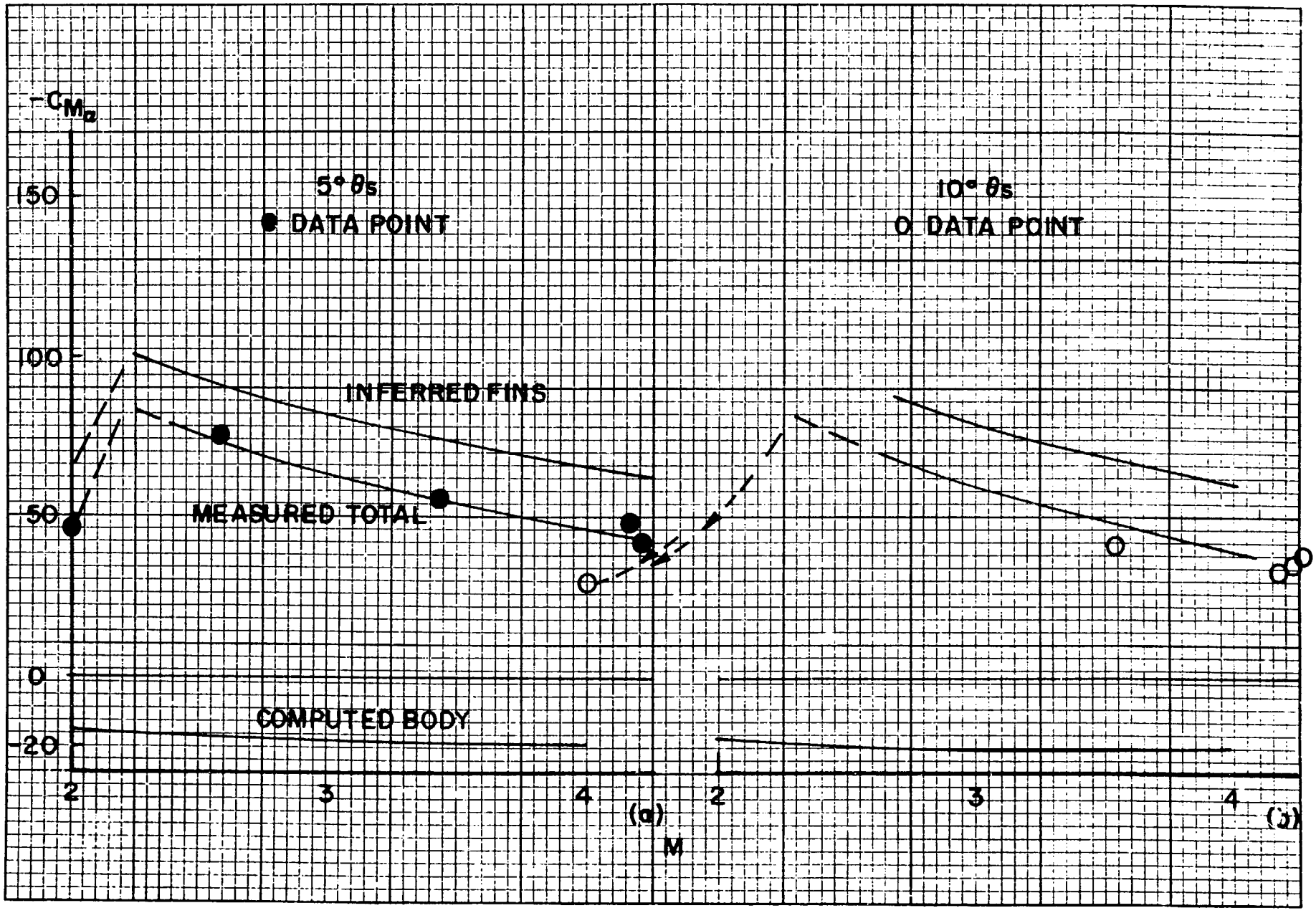



Figure 9. Static Moment Slope Components

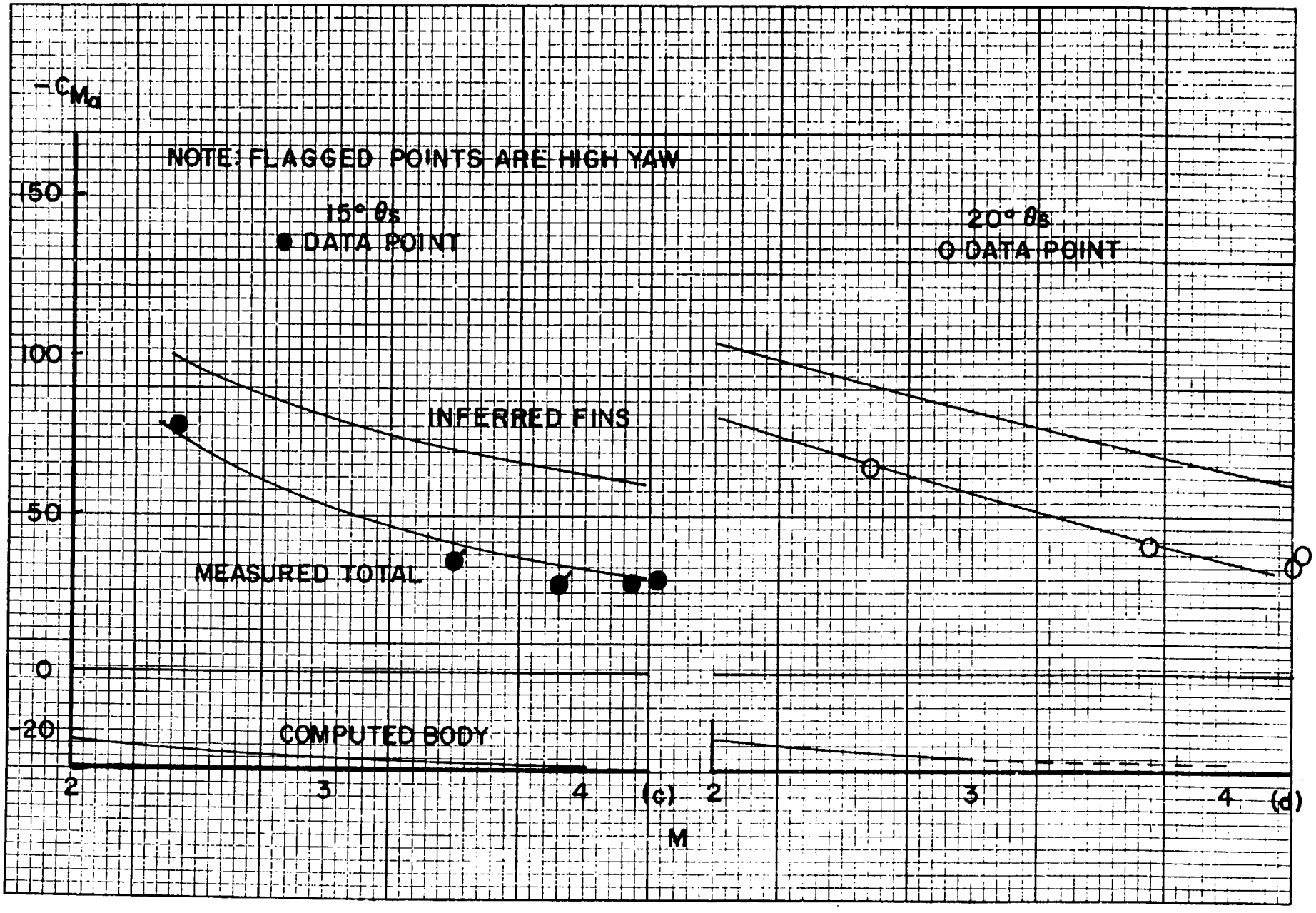



Figure 9. Static Moment Slope Components (Continued)

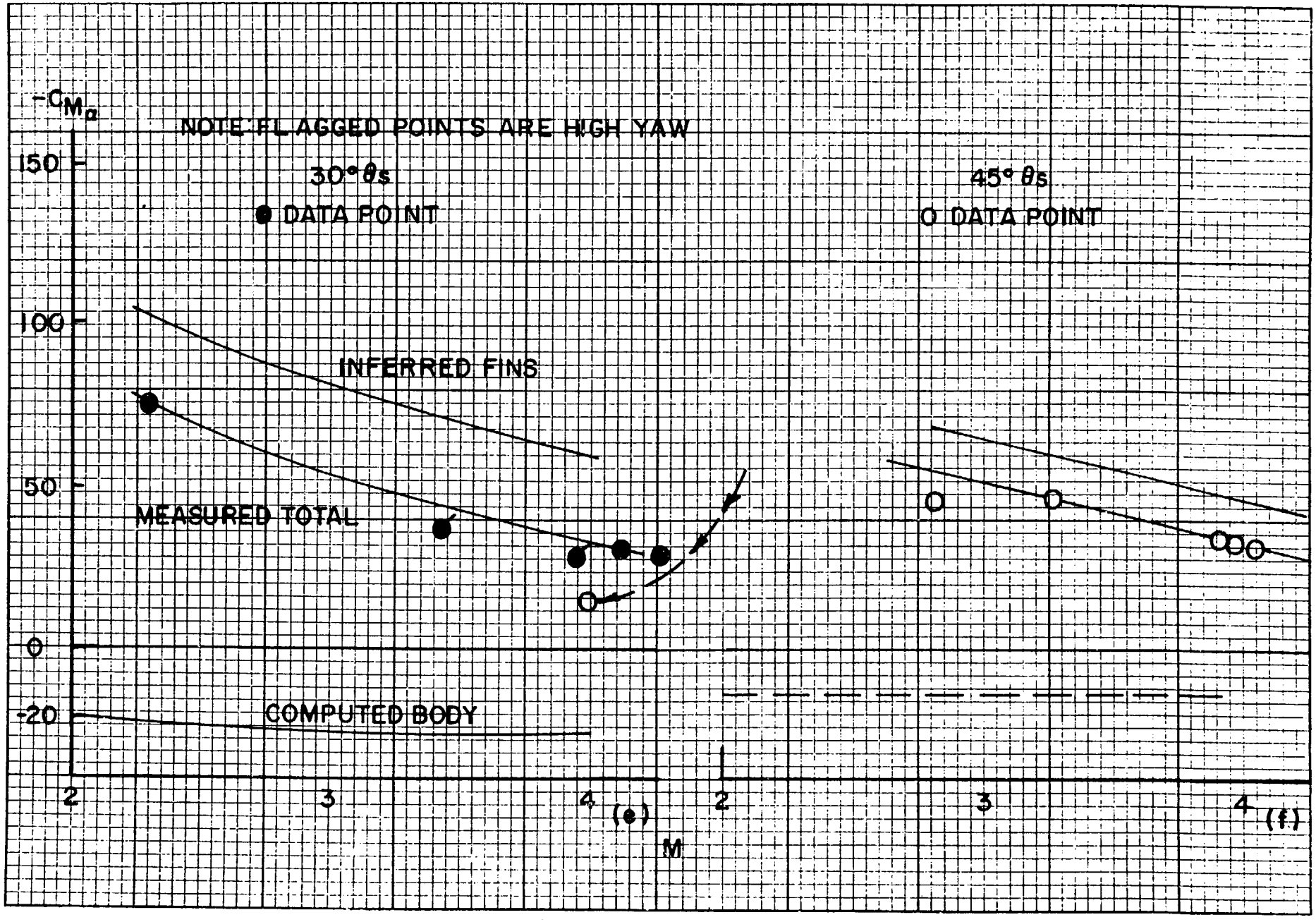



Figure 9. Static Moment Slope Components (Continued)

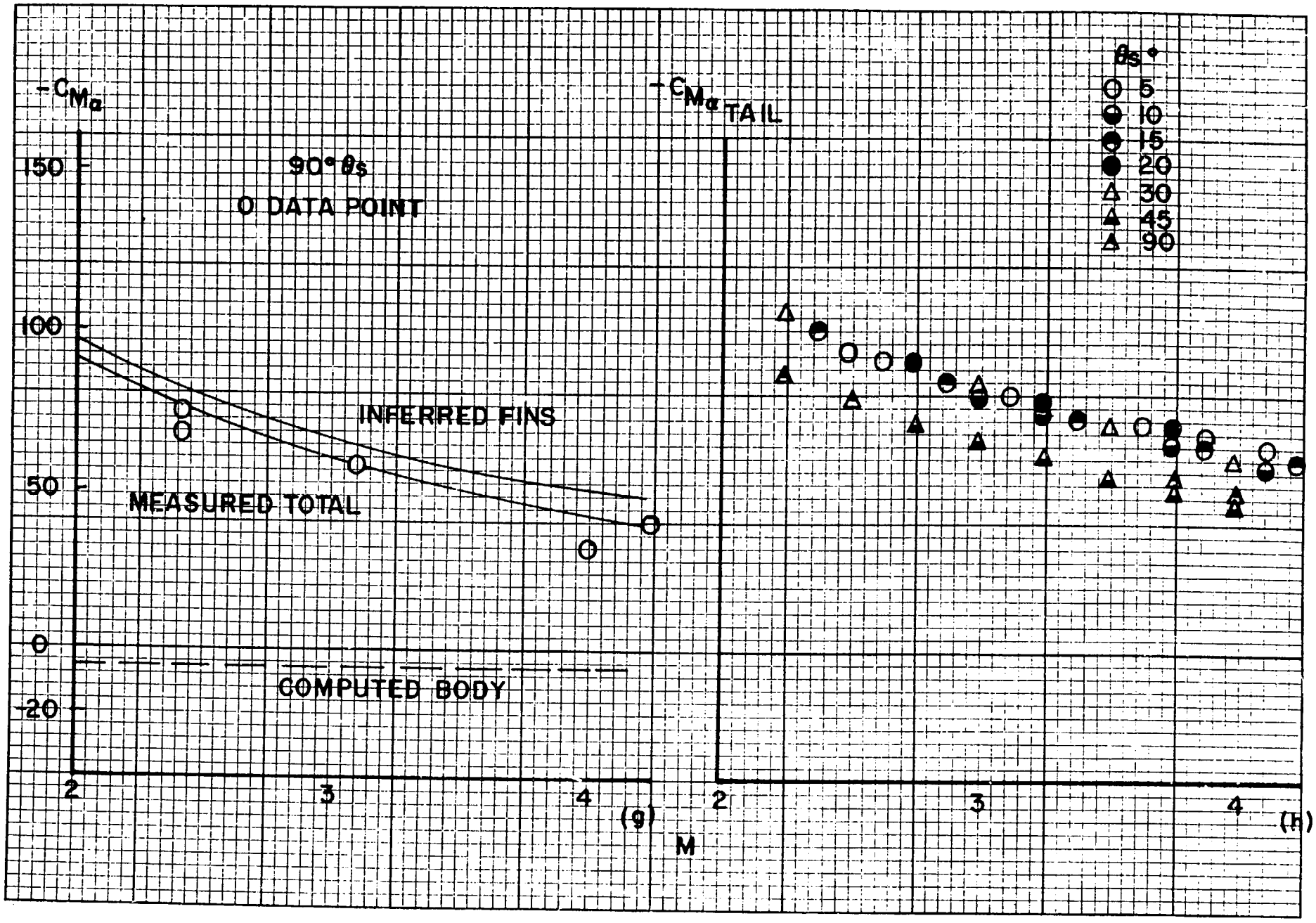



Figure 9. Fin Assembly Static Moment Slope

The fin $C_{N_\alpha}$ may also be obtained by subtracting the body $C_{N_\alpha}$ from the measured $C_{N_\alpha}$ for the configuration. This, again, results in assigning all the interference effects to the fin assembly. These data are also plotted in Figure 10.

The few values below Mach 2 are at a lower level and in part this should be true because of a change in flow pattern. A swept fin undergoes a loss of lift when the fin leading edge lies behind the apex shock wave. Although the existing fins are stamped and a curved ogee plan form results, the plan form can be enclosed by a tri-angular fin that would have subsonic leading edges at Mach 2 and below. Figure 2i is a shadowgraph of one of the projectiles at Mach 1 and the fin leading edge is clearly behind the shock. The indicated loss is larger than would be predicted by linear theory for a tri-angular fin alone. This may be due to body-fin interference effects or, more probably, represents the fact that the sharpened, flat, fins are efficient supersonic airfoils but are poorer subsonic sections.

3. Spike-Nosed Projectile

It was of interest to check the feasibility of using spike-nosed projectiles in flechette sizes. On larger shell, the spike reduces the drag level while retaining the high stability properties of the fin stabilized flat nosed projectile. The price of the improvement offered by the spike depends on the nature of the flow separation area formed by the spike[5]. On larger projectiles, trip devices can be used to control the flow. On a very small projectile, it is not clear that the spike alone is mechanically practical and trip mechanisms affixed to the tiny spike certainly would not be. In the case of larger projectiles, the flow before separation is usually turbulent while the boundary layer on the flechette is laminar.

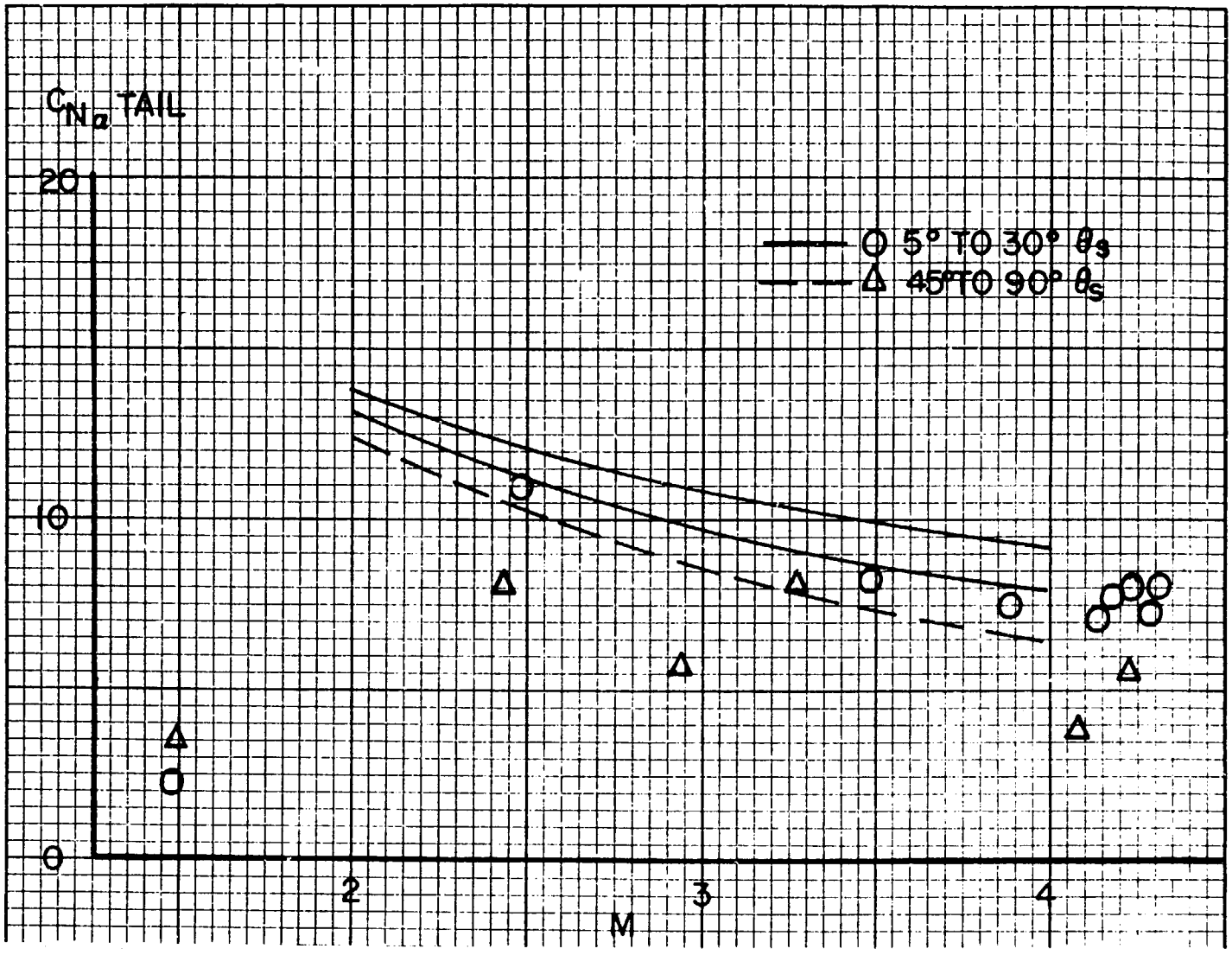



Figure 10. Fin Assembly Normal Force Slope

In order to obtain an indication of possible performance a few spike-nosed flechettes were manufactured, and a few of these were launched successfully. A sketch of the projectile and an inflight shadowgraph are given in Figures 1 and 2h.

The spike did produce a lower drag value than the blunter conical nose. The drag coefficient was comparable with that of the $15^{\circ}$ $\theta_s$ model and the data are shown with this curve in Figure 11a. Separation was not maintained over the full length of the sting and the length of the separated region approximated the head length of the $15^{\circ}$ conical nose. If the separation region could be lengthened by trip devices the drag could be further reduced. The moment coefficient and the normal force coefficients for the spike-nosed models are shown in Figures 11b and 11c. The model has a relatively high moment and a low normal force compared with the conical models of comparable drag. As a result, the sensitivity of the projectile to launch disturbance should be lower. The damping moment slopes are given in Figure 11d.

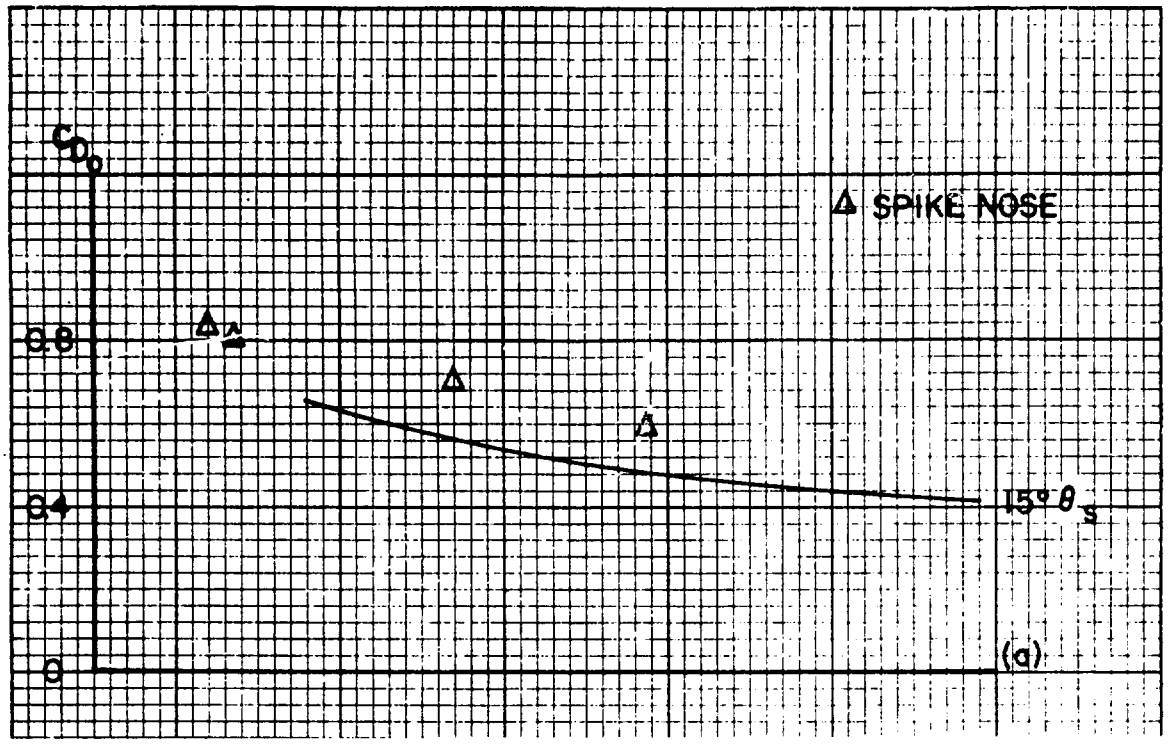



Figure 11a. Drag Coefficient of Spike-Nosed Configuration

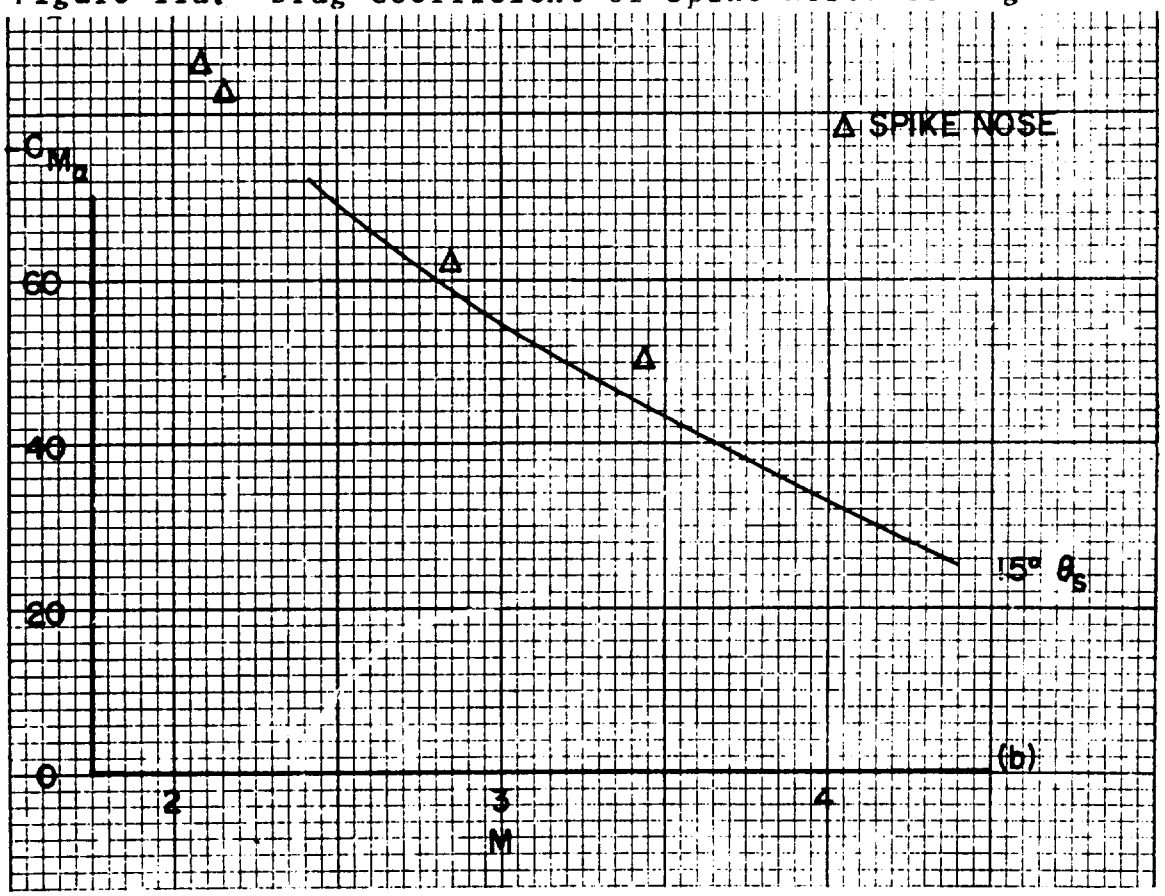



Figure 11b. Static Moment Slope of Spike-Nosed Configuration

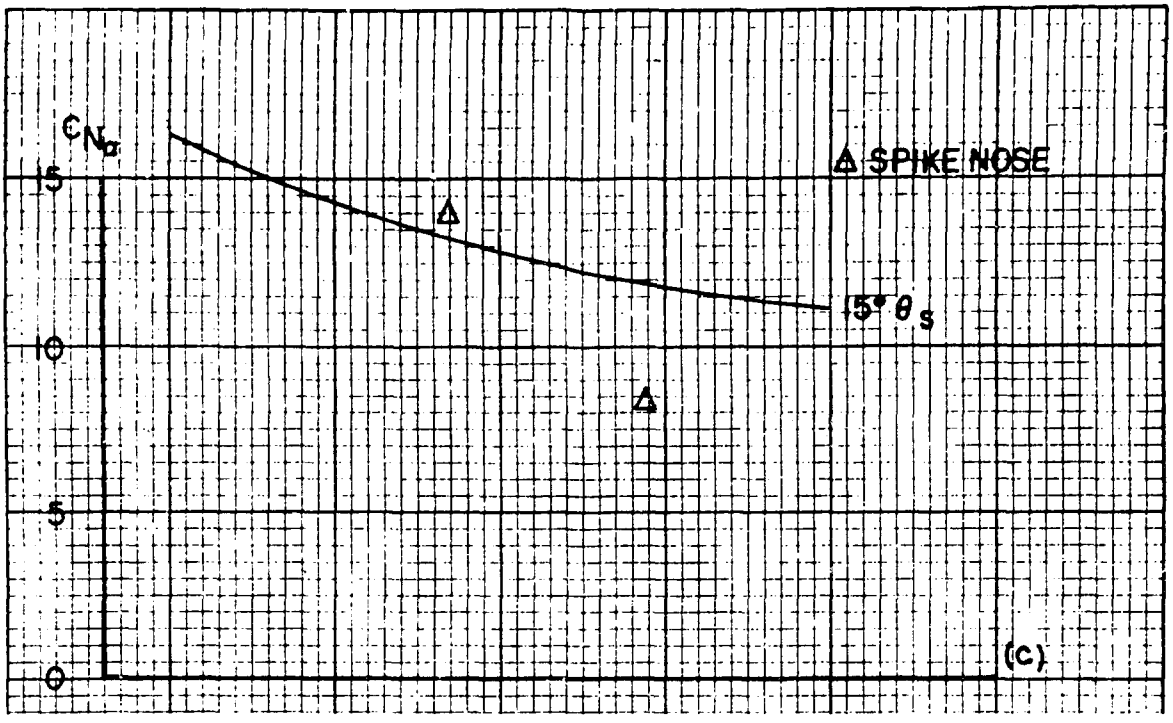



Figure 11c. Normal Force Slope of Spike-Nosed Configuration

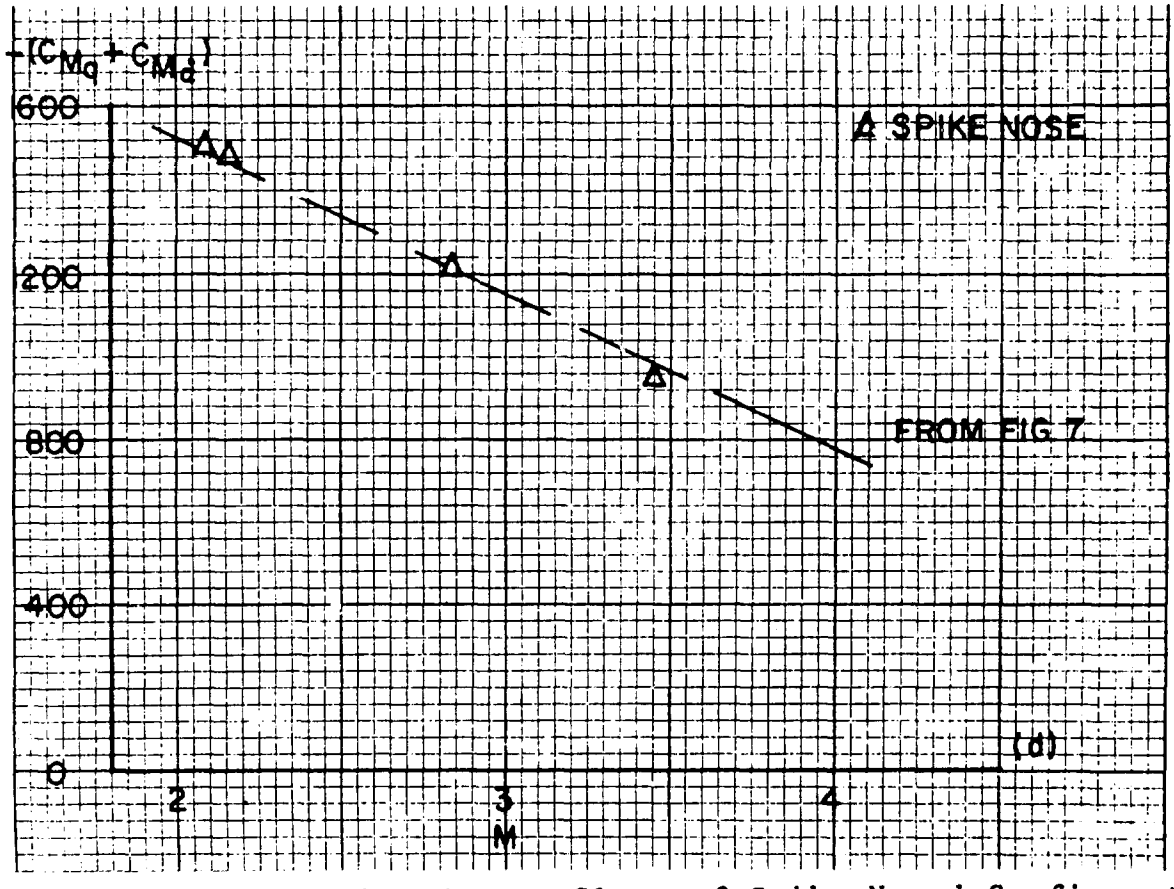



Figure 11d. Damping Moment Slope of Spike-Nosed Configuration

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13. ABSTRACT

The drag and stability properties of a family of flechettes with conical heads are presented; cone semi-angles varied from 5 to 90 degrees. The data cover a range from Mach 2 to Mach 4 and were determined from free flight spark range tests. Limited results on a spike-nosed configuration are also given.

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