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MEMORANDUM

THE EFFECTS OF STREAMWISE-DEFLECTED WING TIPS ON THE AERODYNAMIC CHARACTERISTICS OF AN ASPECT-RATIO-2 TRIANGULAR WING, BODY, AND TAIL COMBINATION

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b wing span, ft

$\bar{c}$ mean aerodynamic chord of the complete triangular wing, ft

C_D drag coefficient, $\frac{\text{drag}}{qS}$

C_{D_o} drag coefficient at $C_L = 0$

$\frac{C_D}{C_L{}^2}$ drag due to lift, determined as average rate of change of C_D with $C_L{}^2$ between $C_L = 0$ and $C_L = 0.1$

C_L lift coefficient, $\frac{\text{lift}}{qS}$

$C_{L_{opt}}$ lift coefficient for maximum lift-drag ratio

C_{L_α} lift-curve slope taken through 0° angle of attack, per deg

C_m pitching-moment coefficient referred to the projection of the $0.33\bar{c}$ point on the fuselage reference line, $\frac{\text{pitching moment}}{qS\bar{c}}$

$\frac{dC_m}{dC_L}$ rate of change of pitching moment with lift coefficient at $C_L = 0$, defined as the zero lift stability, percent $\bar{c}$

C_l rolling-moment coefficient, $\frac{\text{rolling moment}}{qSb}$

C_n yawing-moment coefficient, $\frac{\text{yawing moment}}{qSb}$

C_Y side-force coefficient, $\frac{\text{side force}}{qS}$

$\frac{\Delta C_l}{\beta}$ difference between rolling moment at 5° sideslip and 0° sideslip divided by 5°, per deg

$\frac{\Delta C_n}{\beta}$ difference between yawing moment at 5° sideslip and 0° sideslip divided by 5°, per deg

[redacted]

$\frac{\Delta C_Y}{\beta}$ difference between side force at 5° sideslip and 0° sideslip divided by 5°, per deg

l theoretical length of body, in.

$\frac{L}{D}$ lift-drag ratio, $\frac{C_L}{C_D}$

M free-stream Mach number

q free-stream dynamic pressure, lb/sq ft

r local body radius, in.

r_o maximum body radius, in.

S area of the complete triangular wing formed by extending the leading and trailing edges to the plane of symmetry, sq ft

x distance measured aft of body nose, in.

α angle of attack of wing root chord, deg

β sideslip angle measured between the relative wind and vertical plane of symmetry, deg

Subscripts

max maximum value of quantity

t value obtained with the configuration trimmed

Δ value for the complete triangular wing configuration

APPARATUS AND MODEL

Test Facility

The experimental data were obtained in the Ames 6- by 6-foot supersonic wind tunnel which is a closed-circuit variable-pressure type with a Mach number range continuous from 0.70 to 2.22. The tunnel floor and

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By Victor L. Peterson

SUMMARY

An investigation has been conducted on a triangular wing and body combination to determine the effects on the aerodynamic characteristics resulting from deflecting portions of the wing near the tips 90° to the wing surface about streamwise hinge lines. Experimental data were obtained for Mach numbers of 0.70, 1.30, 1.70, and 2.22 and for angles of attack ranging from -5° to $+18^{\circ}$ at sideslip angles of 0° and 5°.

The results showed that the aerodynamic center shift experienced by the triangular wing and body combination as the Mach number was increased from subsonic to supersonic could be reduced by about 40 percent by deflecting the outboard 4 percent of the total area of each wing panel. Deflection about the same hinge line of additional inboard surfaces consisting of 2 percent of the total area of each wing panel resulted in a further reduction of the aerodynamic center travel of 10 percent. The resulting reductions in the stability were accompanied by increases in the drag due to lift and, for the case of the configuration with all surfaces deflected, in the minimum drag. The combined effects of reduced stability and increased drag of the untrimmed configuration on the trimmed lift-drag ratios were estimated from an analysis of the cases in which the wing-body combination with or without tips deflected was assumed to be controlled by a canard. The configurations with deflected surfaces had higher trimmed lift-drag ratios than the model with undeflected surfaces at Mach numbers up to about 1.70.

Deflecting either the outboard surfaces or all of the surfaces caused the directional stability to be increased by increments that were approximately constant with increasing angle of attack at each Mach number. The effective dihedral was decreased at all angles of attack and Mach numbers when the surfaces were deflected.

*Title, Unclassified

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Estimations of the effects of the deflected surfaces on the longitudinal and directional stability were in reasonably good agreement with experimental results.

INTRODUCTION

Two aerodynamic problems associated with the characteristics of supersonic aircraft are the increases in longitudinal stability and the reductions in directional stability resulting from increasing the Mach number from subsonic to supersonic. As a result of the first problem, that of increased longitudinal stability, the minimum static margins of configurations generally occur at subsonic speeds. If aerodynamic stability is to be assured throughout the Mach number range, the out-of-trim moments for given lifts are large at the supersonic speeds and therefore can lead to excessively large control surfaces to provide sufficient maneuverability. The second problem, concerning the reduced directional stability, can lead to excessively large stabilizing surfaces to provide an acceptable level of directional stability. Therefore, solutions to both of the problems can cause increases in the drag and thus reduce the lift-drag ratio of the configuration.

One solution to both problems that has appeared attractive for triangular wing configurations is the deflection of the wing tips about essentially streamwise hinge lines at supersonic speeds. The rearward movement of the aerodynamic center is thereby reduced as a result of removing lifting surface area near the trailing edge of the wing. At the same time, additional vertical stabilizing area is introduced in the Mach number range where it is needed.

A study was undertaken, therefore, to determine the effects on the aerodynamic characteristics of an aspect-ratio-2 triangular wing and body configuration resulting from deflecting the wing tips 90° to the surface about streamwise hinge lines. Comparisons of the experimentally determined effects on the aerodynamic characteristics due to the deflected surfaces with those estimated from linearized theory are presented.

NOTATION

a.c. aerodynamic center determined at $C_L = 0$, percent $\bar{c}$

Δa.c. aerodynamic center location of a configuration with surfaces deflected minus that for the complete triangular wing model, percent $\bar{c}$

ceiling have perforations to permit transonic testing. A somewhat more detailed description is given in reference 1.

Description of Model and Balance

The sting-mounted model (fig. 1) consisted of an aspect-ratio-2 triangular wing and a low-aspect-ratio vertical tail mounted on a fineness ratio 12.5 Sears-Haack body. A dimensional sketch of the configuration is shown in figure 1(c). The wing and vertical tail had NACA 0005-63 and NACA 0003-63 sections streamwise, respectively. Each wing panel was built with two movable surfaces. The larger of the two surfaces consisted of the area of the triangular wing panel outboard of the 80-percent semispan location and could be deflected downward (see fig. 1(a)) about a streamwise hinge line at that spanwise location. A smaller triangular surface, extending inboard to the 60-percent semispan location, could be deflected upward about the same streamwise hinge line when the outboard surface was deflected downward (see fig. 1(b)). Two pairs of the smaller triangular surfaces were built. The thickness distribution of the first pair was the afterportion of an NACA 0005-63 section so that when undeflected the surfaces faired smoothly with the wing; when deflected the leading edge was blunt. The thickness distribution of the second pair was similar to the first except that the leading edges were beveled to form streamwise wedges of 6.9° included angles. In both cases the trailing edge of the wing adjacent to the leading edges of the small triangular surfaces was blunt. The total area of the outboard movable surfaces was 4 percent of the total wing area and the combined areas of all movable surfaces were 6 percent of the total wing area. All of the model parts were constructed of solid steel to minimize aeroelastic effects.

The body was cut off as shown in figure 1 to accommodate the sting and the internal, six-component, strain-gage balance which measured forces and moments on the entire configuration.

TEST AND PROCEDURES

Range of Test Variables

Mach numbers of 0.70, 1.30, 1.70, and 2.22 and angles of attack ranging from -5° to $+18^{\circ}$ at 0° and 5° sideslip were covered in the investigation. The test Reynolds number based on the triangular wing mean aerodynamic chord was 3.68 million. Wires of 0.010-inch diameter were placed on the wing and body and wires of 0.005-inch diameter on the vertical tail at the locations shown in figure 1(c) in order to induce transition.

Reduction of Data

The data presented herein have been reduced to standard coefficients based on the geometry of the complete triangular wing. The pitching- and yawing-moment coefficients have been referred to the projection, on the body center line, of the 0.33 point of the wing mean aerodynamic chord. Lift and drag coefficients were referred to the wind axes while all other coefficients have been referred to the body axes. The results have been corrected for the following effects in accordance with the procedures presented in reference 1.

Base drag.- The base pressure was measured and the data were adjusted to correspond to a base pressure equal to the free-stream static pressure.

Stream inclination.- The data have been adjusted for the stream angles found to exist in the pitch planes at 0° and 5° sideslip. These angles, determined from tests of the model in the normal and inverted attitudes, were less than $\pm 0.4^{\circ}$ throughout the Mach number range.

RESULTS AND DISCUSSION

The purpose of this investigation was to determine the effects on the aerodynamic characteristics of a triangular wing and body combination resulting from deflecting portions of the wing near the tips 90° to the wing surface about streamwise hinge lines. Results are presented for three configurations: one comprising a complete triangular wing, another with the outboard 4 percent of the total area of each panel of the triangular wing deflected, and a third having smaller surfaces inboard of the hinge line deflected in conjunction with the tips about the same hinge line. Two of the configurations were tested with both blunt and sharp leading edges on the smaller inboard surfaces; however, for reasons to be pointed out later, all of the data used in the discussion of the effects on the aerodynamic characteristics resulting from deflecting portions of the triangular wing are for the configurations with the blunt leading edges on the smaller surfaces. All of the coefficients have been based on the geometry of the complete triangular wing in order to make a direct analysis of the effects on the forces and moments resulting from deflecting portions of the triangular wing. The results are first presented as a function of either lift coefficient or angle of attack for Mach numbers from 0.70 to 2.22. The summarized results shown in the figures are presented only for the supersonic Mach numbers where the surfaces would likely be deflected. The estimated results were obtained from linearized theory with wing-body interference effects accounted for by the methods outlined in reference 2.

Longitudinal Characteristics

The lift, drag, and pitching-moment coefficients of the configurations with deflected surfaces are compared with those for the triangular wing model in figure 2. Summarized in figure 3 are the drag coefficients at zero lift, drag due to lift, lift-curve slopes, and aerodynamic center positions of the three configurations as a function of Mach number.

Stability considerations.- One of the undesirable characteristics of a triangular wing and body combination is the rearward shift in the aerodynamic center location with increasing Mach number from subsonic to supersonic. Examination of figure 4 reveals that the difference between the aerodynamic center location at 0.70 Mach number and supersonic Mach numbers was quite large and attained the greatest value at a Mach number of 1.30 where it amounted to $0.104\bar{c}$. This difference decreased with increasing supersonic Mach number to $0.074\bar{c}$ at a Mach number of 2.22.

One way to reduce the difference between the subsonic and supersonic aerodynamic center locations is to shift the aerodynamic center forward at supersonic speeds by removing lift from regions of the triangular wing behind the center of moments of the configuration. This was accomplished in the present investigation by deflecting portions of the triangular wing near the tips 90° to the wing surface about streamwise hinge lines. The effects on the aerodynamic center position of the wing-body combination due to deflecting the surfaces are shown in figures 3 and 5. Deflecting just the tips of the triangular wing moved the aerodynamic center of the wing-body combination forward 4.6-percent $\bar{c}$ at a Mach number of 1.30. The amount of the forward shift decreased with increasing speed to 2.9-percent $\bar{c}$ at Mach number of 2.22. A further forward shift of the aerodynamic center amounting to about 1-percent $\bar{c}$ throughout the Mach number range was achieved by deflecting the inboard surfaces in conjunction with the tips (fig. 5(b)). Thus, the aerodynamic center travel of the triangular wing and body combination resulting from increasing the Mach number from 0.70 to supersonic Mach numbers was reduced about 40 percent by deflecting just the tips (4 percent of the triangular wing area) and approximately 10 percent more by deflecting all of the surfaces (6 percent of the wing area).

The significance of these reductions of the aerodynamic center travel between subsonic and supersonic speeds for the triangular wing is measured by their effects on the longitudinal stability of the configuration being studied. These effects are shown in figure 6 for a triangular wing and body combination with the center of moments located at $0.33\bar{c}$ (static margin of $0.07\bar{c}$ at $M = 0.70$) to insure stability throughout the Mach number and lift-coefficient range. The results show that the stability of the configuration was reduced at supersonic Mach numbers by about 20 percent with the tips deflected and slightly more with all surfaces deflected.

It is of interest to determine how well estimations based upon linearized theory can predict these reductions of the stability of the configuration that result from deflecting portions of the triangular wing at supersonic speeds. In this analysis theory will be used to predict both the change in the aerodynamic center position experienced by the complete triangular wing configuration when the Mach number is increased from 0.70 to supersonic (fig. 4) and the forward shifts of the aerodynamic center resulting from deflecting the movable surfaces (fig. 5).

The experimental change in the aerodynamic center of the triangular wing and body resulting from increasing the Mach number from 0.70 to 1.30 can be estimated to within 10 percent (1-percent $\bar{c}$) as shown in figure 4. However, the theory indicates that the aerodynamic center location should continue to move aft with increasing supersonic Mach number as a result of wing-body interference effects while the opposite trend was obtained experimentally. The over-all movement of the aerodynamic center position was thereby overestimated by as much as 37 percent (2.7-percent $\bar{c}$) at the highest Mach number.

Estimations of the effects on the aerodynamic center location of the wing-body combination resulting from deflecting portions of the triangular wing at supersonic speeds are compared with the experimental effects in figure 5. Because the flow conditions at the wing tip with the surfaces deflected were unknown, the estimations were made for two possible conditions. In the one, the planar tip effect (ref. 3) was omitted when the surfaces were deflected so that there was no change in the loading on the undeflected portion of the wing resulting from deflecting the surfaces. In the other, the tip effect was included when the surfaces were deflected so that the loading on the undeflected portion of the wing behind the Mach line from the leading edge of the hinge line was reduced and became zero at the hinge line. The results of figure 5 show that the estimations made by omitting tip effects agreed fairly well with the experimental data whereas the estimations including tip effects were too large by about a factor of 2. This result is rather surprising since with only the tips deflected, tip effects would be expected at least on the upper surface of the wing. The agreement of the estimation with tip effects omitted and the experimental results can probably be attributed to two factors. First, it is probable that with the surfaces deflected partial tip effects resulted. Second, the use of linear theory results in an overestimate of the loading near the leading edge of a triangular wing at outboard locations (see ref. 4), and hence, an overestimate of the loss in lift resulting from deflection of the surfaces, so that neglecting the loss in lift due to tip effects compensates for this overestimation.

The estimated effects of the deflected surfaces on the stability of the wing-body combination are compared with the experimentally determined effects in figure 6. For the particular center-of-moments location of this investigation, corresponding to a zero-lift static margin of 7-percent $\bar{c}$ at a Mach number of 0.70, the reductions of the supersonic stability were estimated to within 7 percent of the experimental values throughout the Mach number range when tip effects were omitted. This agreement is obtained as a result of the compensating errors in the estimation of the aerodynamic center travel with increasing Mach number of the triangular wing configuration (fig. 4) and estimations of the forward shift of the aerodynamic center caused by deflecting the surfaces (fig. 5).

Lift and drag characteristics.- Deflecting portions of the triangular wing resulted in reductions of the lift-curve slope throughout the Mach number range (fig. 7), the greatest reduction being obtained when all surfaces were deflected. The experimental results show increases with increasing Mach number in the ratios of lift-curve slopes of the configurations having deflected surfaces to those of the triangular wing and body. These effects probably result from the fact that with increasing Mach number the Mach wave from the leading edge of the hinge sweeps more rearward, thus reducing the area on the undeflected portion of the triangular wing wherein a reduction in loading due to tip effects can occur. It would appear, therefore, that the effect of the tips on the lift-curve slope of the wing with deflected surfaces is significant. Nevertheless, the estimation with tip effects omitted agreed much better with the experimental results than the estimation with tip effects included. As discussed in conjunction with the stability characteristics, this apparent contradiction is believed to be the result of the two compensating factors, an overestimation of loss of loading on the deflected surfaces and an underestimation of the loss of loading due to tip effects by neglecting such effects.

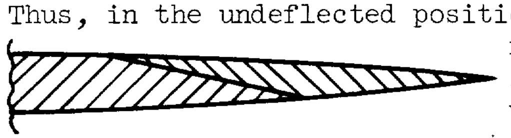
The results of figure 8 show that deflecting the surfaces resulted in increases in drag due to lift throughout the Mach number range. The increases amounted to between 8 and 3 percent in the Mach number range from 1.30 to 2.22, respectively, when just the tips were deflected (fig. 8(a)) and slightly more when all surfaces were deflected (fig. 8(b)). The trend of smaller increases at the higher Mach numbers is in agreement with the previously discussed effects on the lift-curve slopes resulting from deflection of the surfaces. However, the increases in drag due to lift were considerably less than would be obtained if lift-curve slopes were the only factors affecting the characteristic.

Estimations of the effects on the drag due to lift resulting from deflecting the surfaces are compared with the experimentally obtained effects in figure 8. Good estimations of the drag due to lift are difficult to make because of the inability of the theory to predict the amount of effective force in the thrust direction that is obtained experimentally. The problem is further complicated in this investigation by the unknown flow conditions at the wing tips when the surfaces are deflected. For these reasons, the estimations were made for both full and no theoretical leading-edge thrust with tip effects included and omitted. Examination of figure 8 reveals that the experimentally obtained increases of the drag due to lift resulting from deflecting the surfaces were less than the minimum possible increases predicted by the theory. It appears that good estimations of the effects on the drag due to lift resulting from deflecting the surfaces cannot be made.

It has been shown that the effects of deflecting the surfaces on the wing-body lift-curve slopes and drag due to lift were detrimental. In figure 3 the drag coefficients at zero lift are shown for the three configurations as a function of Mach number. It can be seen that practically no change in the drag at zero lift resulted from deflecting just the tips. However, when the inboard surfaces were deflected in conjunction with the tips, the drag at zero lift was increased by about 12 percent over that for the triangular wing configuration throughout the Mach number range. The increase in the drag at zero lift for this configuration is evidently a result of the additional leading and trailing edges not present on the triangular wing.

In order to determine if it was possible to reduce the penalties in the drag at zero lift resulting from deflecting the inboard surfaces, the leading edges of these surfaces were beveled to form sharp wedges and the resulting configurations were tested with the inboard surfaces undeflected and deflected. Selected results of these tests in the form of drag coefficients at zero lift as a function of Mach number are presented in figure 9. The zero-lift drag of the configuration with sharp edges on the inboard surfaces was higher than that for the configuration with blunt leading edges when the surfaces were undeflected (fig. 9(a)). This trend might be expected since sharpening these leading edges, as in the present case, caused discontinuities in the wing surface to be present along the leading edges of the inboard surfaces.[1]

[1]During the course of analyzing the data it became apparent that the zero-lift drag penalty due to sharpening the leading edges of the undeflected inboard movable surfaces could be eliminated by a different design. It would be possible to design both the wing trailing edge and the inboard-surface leading edge to be beveled as shown in the sketch. Thus, in the undeflected position a lap joint would be formed so that no discontinuities would be present and in the deflected position no blunt edges would be present.



When the surfaces were deflected there was practically no difference between the zero-lift drag of the sharp and blunt leading-edge configurations (fig. 9(b)) indicating that the aforementioned penalties in the drag at zero lift were due mostly to the additional sections of leading edge and blunt trailing edge rather than the shapes of the leading edges themselves. The results show that the configuration with the blunt leading edges on the inboard movable surfaces was better from the standpoint of zero-lift drag considerations than that having the sharp leading edges since no minimum drag penalty was imposed at subsonic Mach numbers where the surfaces would be undeflected, and sharpening the edges did not reduce the minimum drag at supersonic speeds where the surfaces were deflected.

Trimmed characteristics.- In order to determine whether or not deflecting portions of the triangular wing increases over-all configuration performance it is necessary to combine the benefits of reduced stability with the penalties of increased drag and study the resulting effects on the lift-drag ratios of the configurations trimmed with some type of control. For this analysis, pertinent data from reference 1 have been superimposed on the data presented herein to allow a study to be made of the effects of the deflected surfaces on the characteristics of the configurations trimmed with a canard control. The model of reference 1 is identical to the triangular wing configuration of the present investigation with the exception of the added canard and a 2 percent thinner wing. For the purpose of comparison, the zero-lift static margin of each of the configurations trimmed with the canard was set at $0.07\bar{c}$ at a Mach number of 0.70.

Comparisons of the trimmed lift and drag characteristics of the three configurations are made in figure 10. At Mach numbers of 1.30 and 1.70 both of the configurations with deflected surfaces had higher maximum trimmed lift-drag ratios than did the complete triangular wing model (fig. 10(c)), the best results being obtained by deflecting only the tips. Furthermore, as shown in figure 10(a), the trimmed lift-drag ratios obtained with the surfaces deflected become increasingly better than those for the complete triangular wing model at trim lift coefficients above those for maximum lift-drag ratios. At a Mach number of 2.22 the deflected surface configurations had lower maximum trim lift-drag ratios than did the complete triangular wing model. Throughout the Mach number range the configurations with the surfaces deflected had higher values of trimmed $C_{L_{opt}}$ than did the complete triangular wing model (fig. 10(b)).

The effects on the maximum trimmed lift-drag ratios due to deflecting portions of the triangular wing result from a combination of the effects on the configuration stability, drag due to lift, and minimum drag. The reductions of the stability resulting from deflecting the surfaces decrease with increasing Mach number as shown in figure 6. At the same time, the drag due to lift was higher at all Mach numbers when the surfaces were deflected, as shown in figure 8. When the beneficial effects resulting from reduced stability are overcome by the detrimental effects of increased drag due to lift and minimum drag, the maximum trimmed lift-drag ratios for the configurations with the deflected surfaces are no longer higher than those for the complete triangular wing model. The highest maximum trimmed lift-drag ratios for the configurations with deflected surfaces were obtained by deflecting only the tips even though the largest stability reductions were obtained with all surfaces deflected. This is due in part to the small increase in the drag due to lift resulting from deflecting the inboard surfaces but mostly to the large increases in the minimum drag (fig. 3) when those surfaces were deflected.

Lateral and Directional Characteristics

The rolling-moment, side-force, and yawing-moment coefficients for the three configurations are compared in figure 11 as a function of angle of attack at constant sideslip angles of 0° and 5°. These data are summarized in figure 12 wherein the incremental derivatives, with respect to sideslip angle, are presented as a function of Mach number for several angles of attack.

The effectiveness of the deflected surfaces in performing their second function, that of increasing the directional stability at supersonic speeds, may be assessed by examination of figures 11 and 12. Deflecting the tips downward increased the yawing-moment coefficients and hence the directional stability over that for the complete triangular wing configuration by an increment that was approximately constant with increasing angle of attack at each Mach number (see fig. 11). An additional constant incremental increase in directional stability was realized when the inboard surfaces were deflected in conjunction with the tips. This constant increment result is similar to that which has been obtained from the addition of a ventral (see ref. 5) but is in contrast to the reduction, with increasing angle of attack, of the vertical tail contribution to the directional stability (see ref. 6). The decreasing effectiveness of the vertical tail is caused by unfavorable sidewash in the vicinity of the tail produced by body vorticity and the fact that the tail is partially in a region of reduced dynamic pressure from the wing expansion field, as discussed in reference 7. The tips, being deflected below the wing chord plane, are not influenced by body vorticity and also are not in a region of reduced dynamic pressure. In addition, the inboard surfaces which are deflected above the wing chord plane are sufficiently far removed from the body vorticity to be essentially unaffected, and apparently there is little effect of reduced dynamic pressure at this outboard location.

Deflecting the tips resulted in a slightly lower effective dihedral than that for the triangular wing model by reason of an additional side force being developed below the wing chord plane causing a rolling moment in opposition to that produced by the vertical tail and yawed wing panels. When the inboard surfaces are deflected in conjunction with the tips, the rolling moment due to the side force acting on the smaller upward deflected surfaces tends to counteract, but does not overcome, that resulting from the larger downward deflected tips. Consequently, this configuration had a slightly greater effective dihedral than did the tip-deflected model but less than the plane wing configuration.

The experimental ratios of $\Delta C_Y/\beta$ and $\Delta C_n/\beta$ for the configuration with the tips deflected to $\Delta C_Y/\beta$ and $\Delta C_n/\beta$ for the triangular wing configuration are compared with estimated values at 0° angle of attack in figure 13. For the purpose of making the estimation it was assumed that the wing acts as a reflection plane for the loading on the inboard side of each of the deflected tips while the loading on the outboard side of each tip was assumed to correspond to that which the surface would carry in a free-stream environment. The agreement between the estimated and experimental results is reasonably good throughout the Mach number range. No attempt was made to estimate the ratios for the configuration with the tips and inboard surfaces deflected since the interactions between the loadings on the individual surfaces are quite complex; however, the experimental results are shown for comparison. When the inboard surfaces were deflected in conjunction with the tips, the directional stability was increased over the level of the triangular wing configuration by increments nearly twice as large as those obtained by deflecting just the tips. These comparatively large increases in the directional stability probably resulted from the mutual interference of the loadings on the individual surfaces as well as the differences between the aspect ratios and moment arms of the two surfaces.

CONCLUDING REMARKS

The results of the investigation showed that the aerodynamic center shifts experienced by the triangular wing and body combination as the Mach number was increased from subsonic to supersonic could be reduced by as much as 50 percent by deflecting portions of the triangular wing near the tips, which comprised 6 percent of the total triangular wing area. The resulting reductions in the stability were accompanied by increases in the drag due to lift and, for the case of the configuration with all surfaces deflected, in minimum drag. The combined effects of reduced longitudinal stability and increased drag on the trimmed lift-drag ratios, provided the configuration was trimmed by a canard control, allowed the configurations with deflected surfaces to have higher trimmed lift-drag ratios than the triangular wing model at Mach numbers up to about 1.70.

[redacted]

Deflecting the surfaces caused the directional stability to be increased by increments that were approximately constant with increasing angle of attack at each Mach number. The effective dihedral was decreased at all angles of attack and Mach numbers when the surfaces were deflected.

Estimations of the effects on the longitudinal and directional stability resulting from deflecting the surfaces were in reasonably good agreement with experimental results.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Feb. 17, 1959

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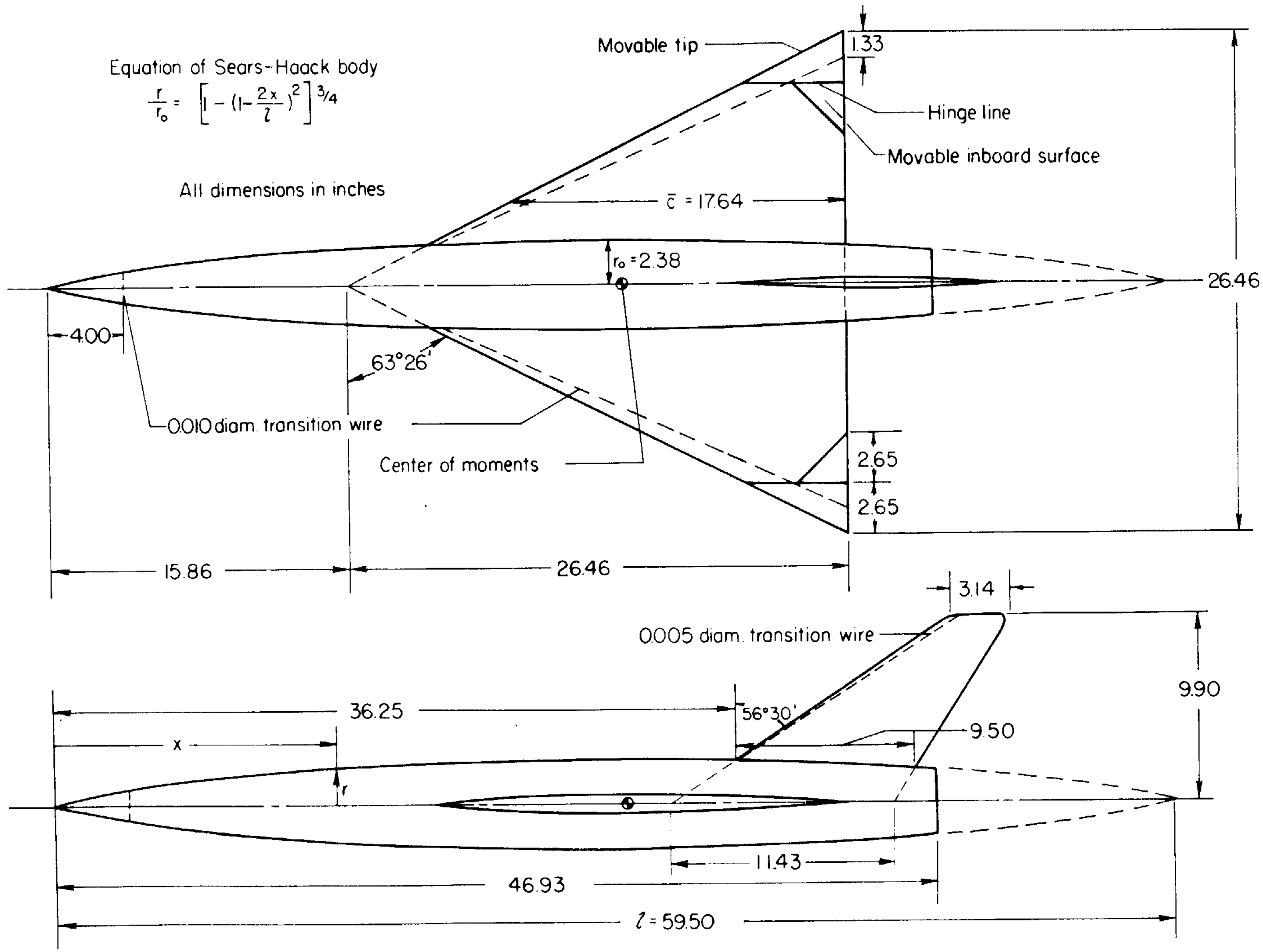
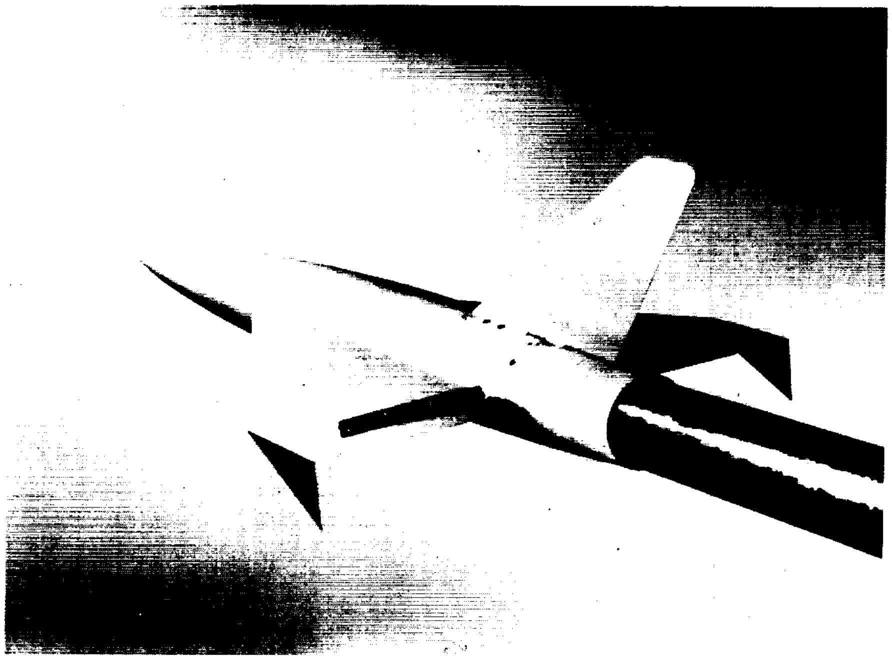


(c) Dimensional sketch of complete model.

Figure 1.- Concluded.

[redacted]

[redacted]



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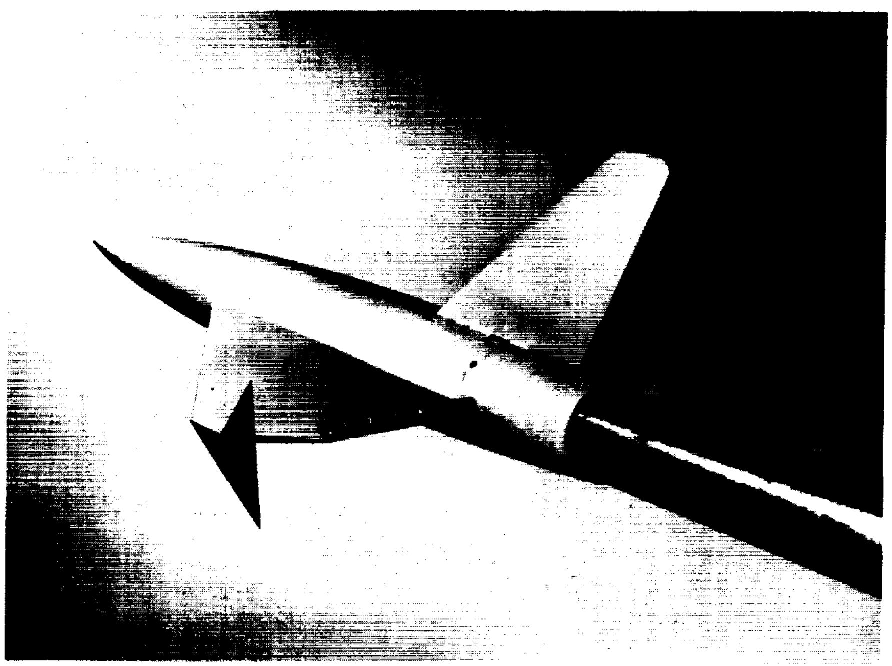
(a) Photograph of model with tips deflected.



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(b) Photograph of model with tips and inboard surfaces deflected.

Figure 1.- Model details and dimensions.

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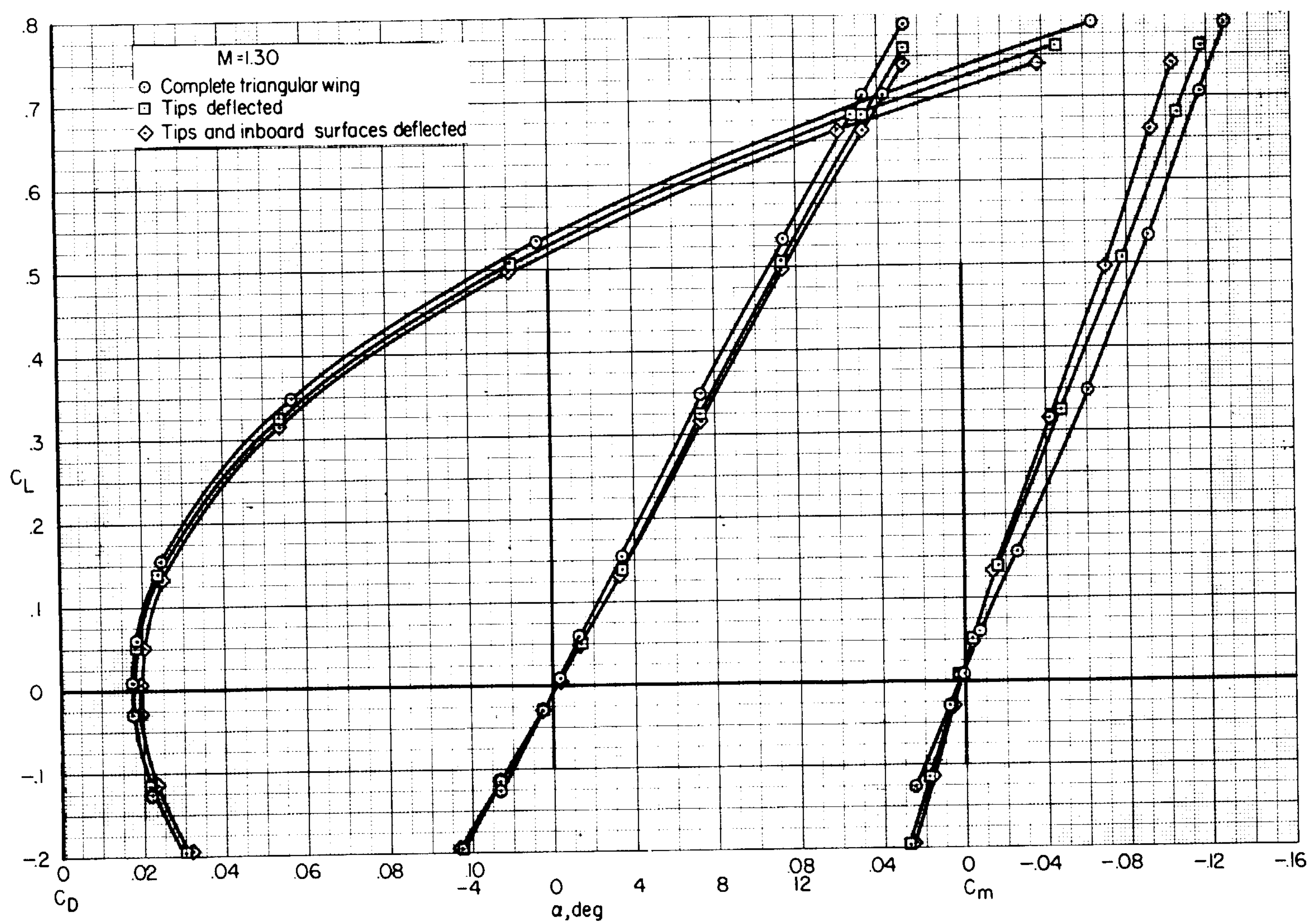
[redacted]



(b) M = 1.30

Figure 2.- Continued.

[redacted]

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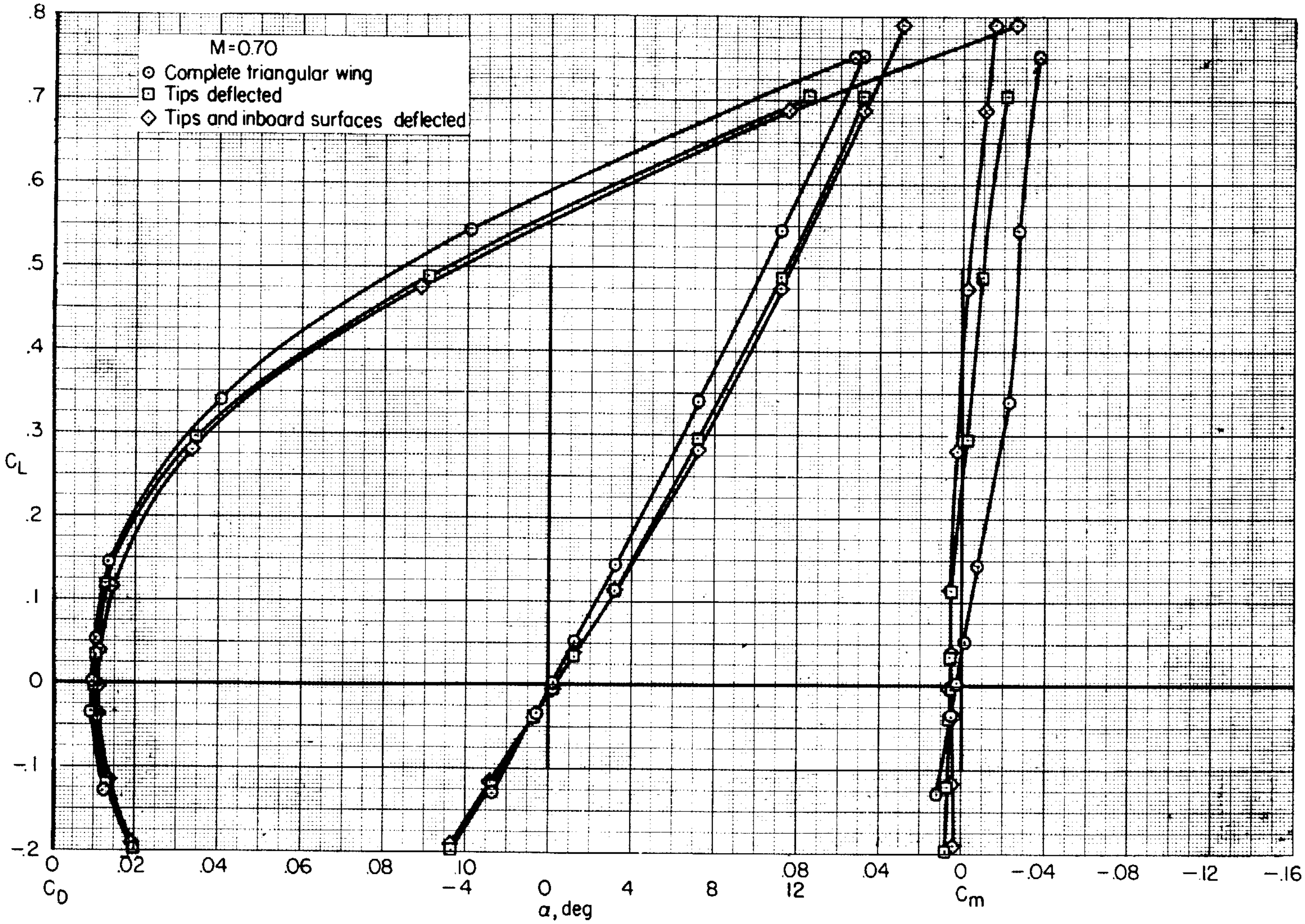
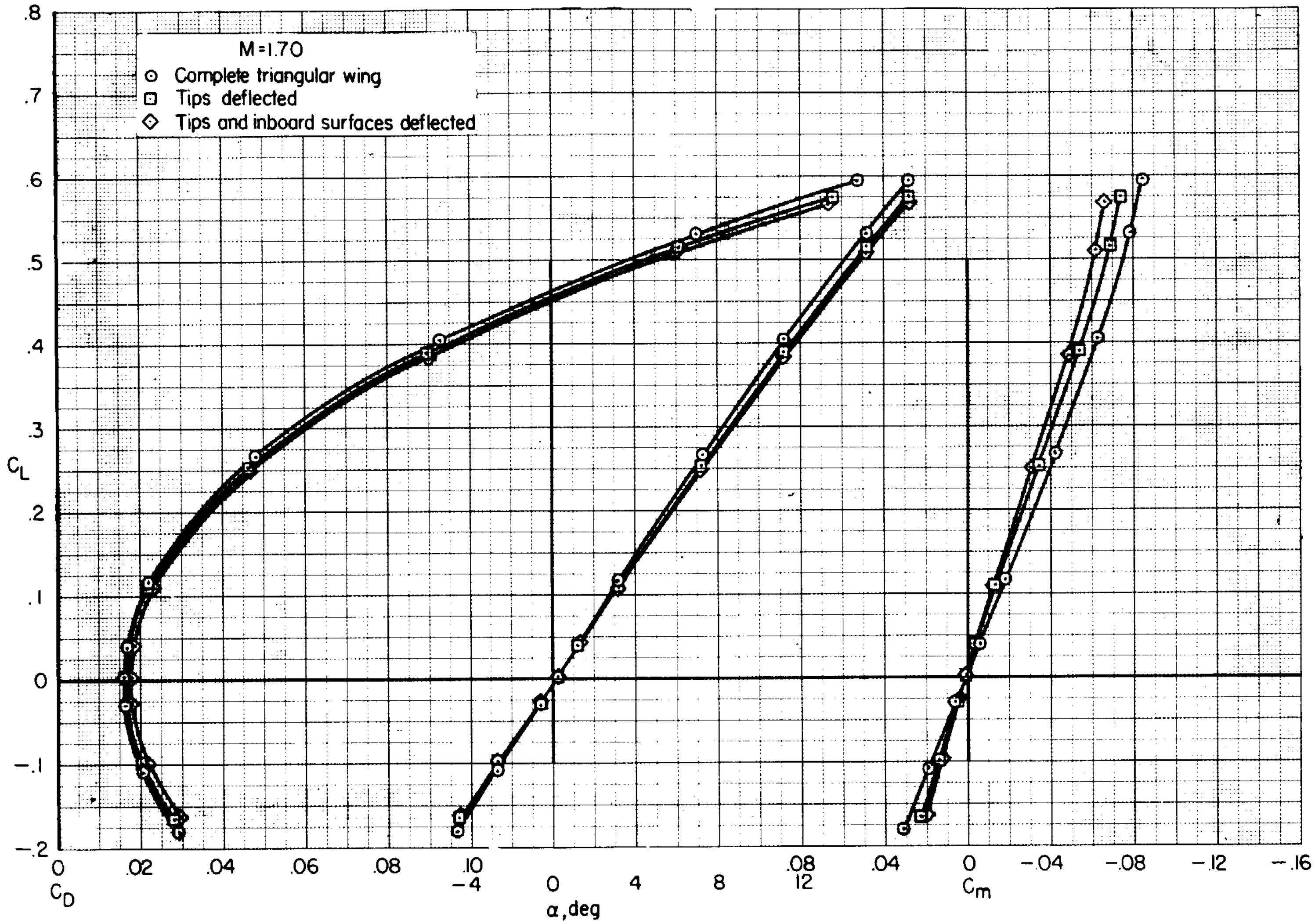


(a) M = 0.70

Figure 2.- Lift, drag, and pitching-moment characteristics for models with the surfaces undeflected and deflected.

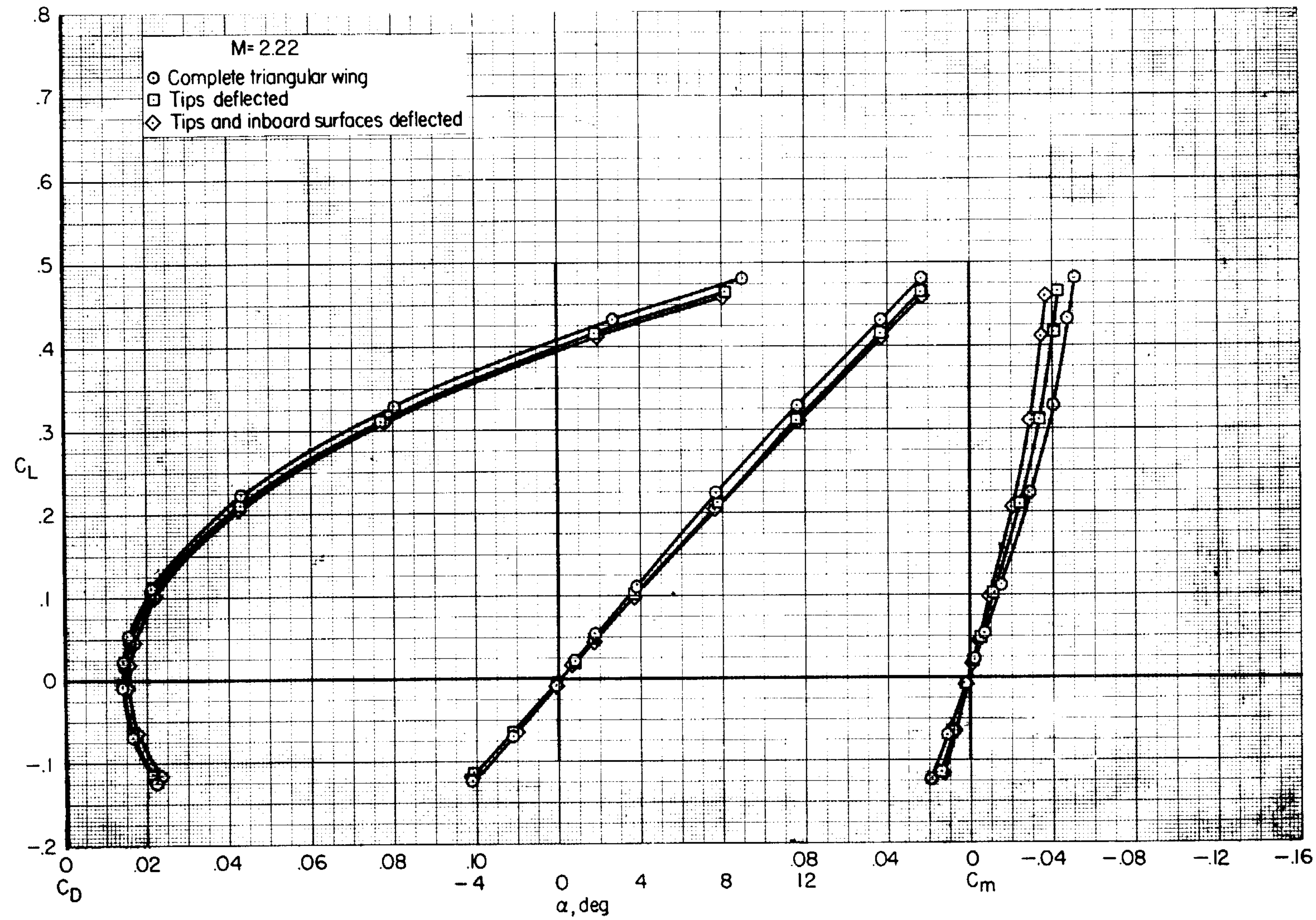
[redacted]



(c) M = 1.70

Figure 2.- Continued.

[redacted]



(d) M = 2.22

Figure 2.- Concluded.

[redacted]

[redacted]

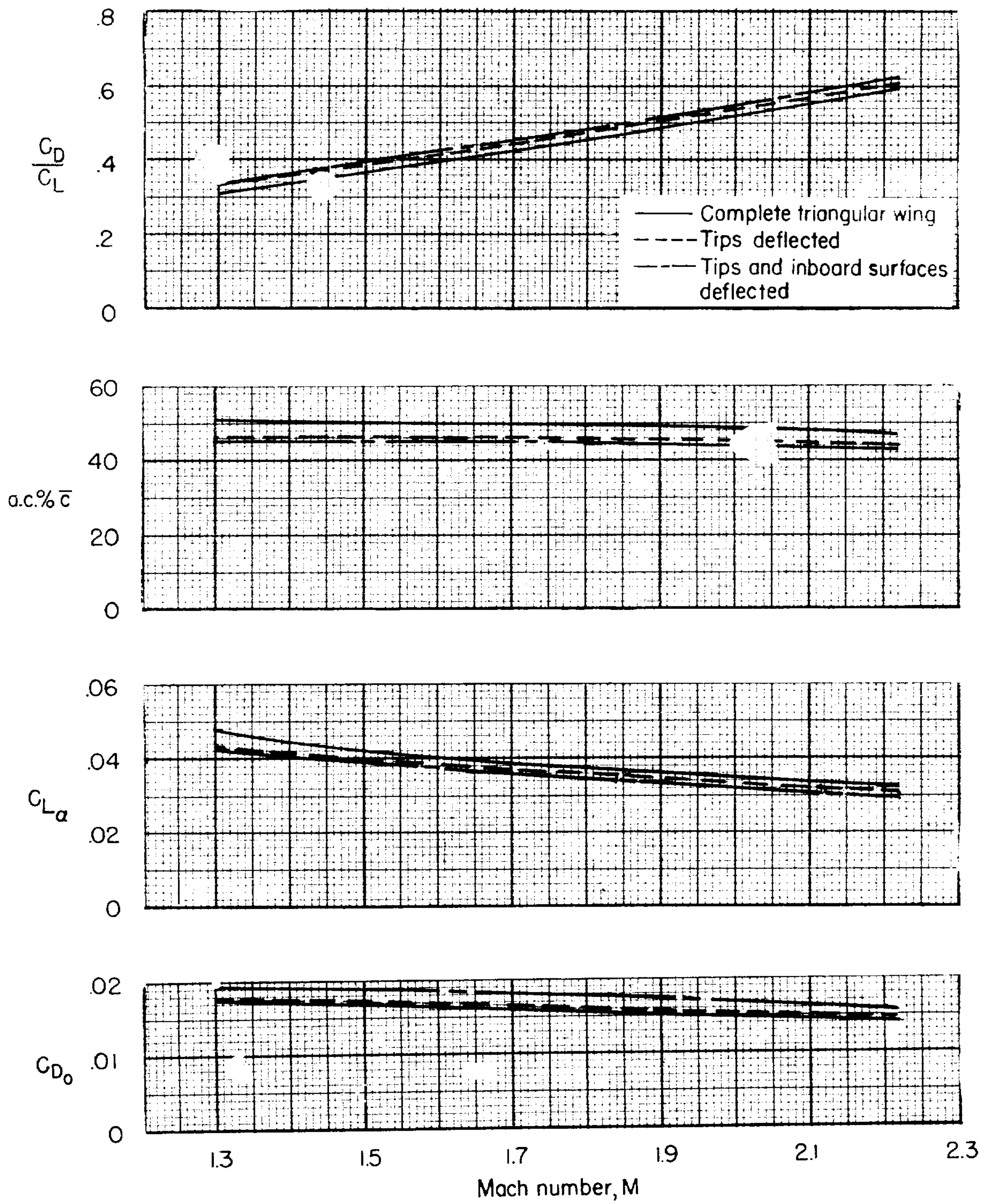


Figure 3.- Variation with Mach number of drag due to lift, aerodynamic-center locations, lift-curve slopes, and minimum drag coefficients for models with surfaces undeflected and deflected.

[redacted]

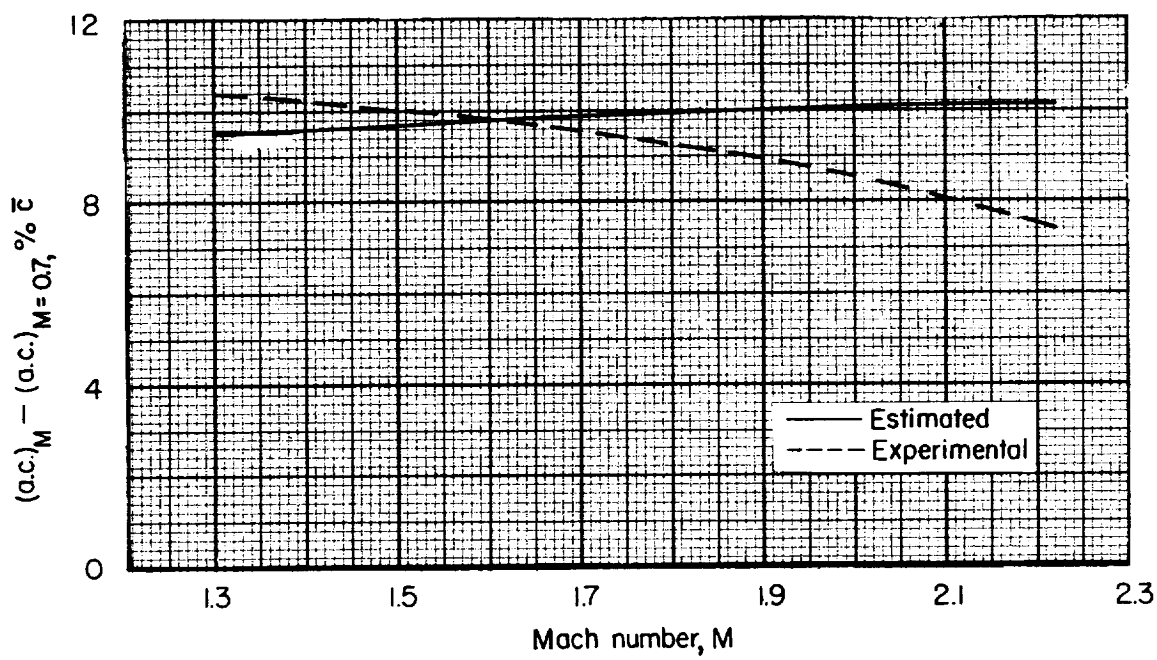
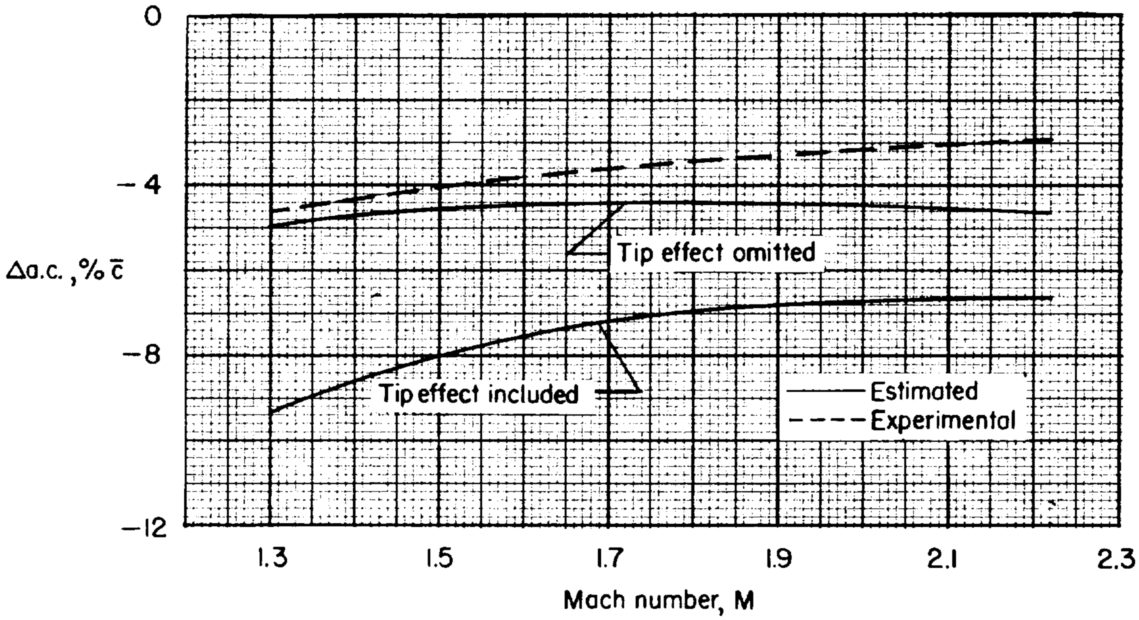
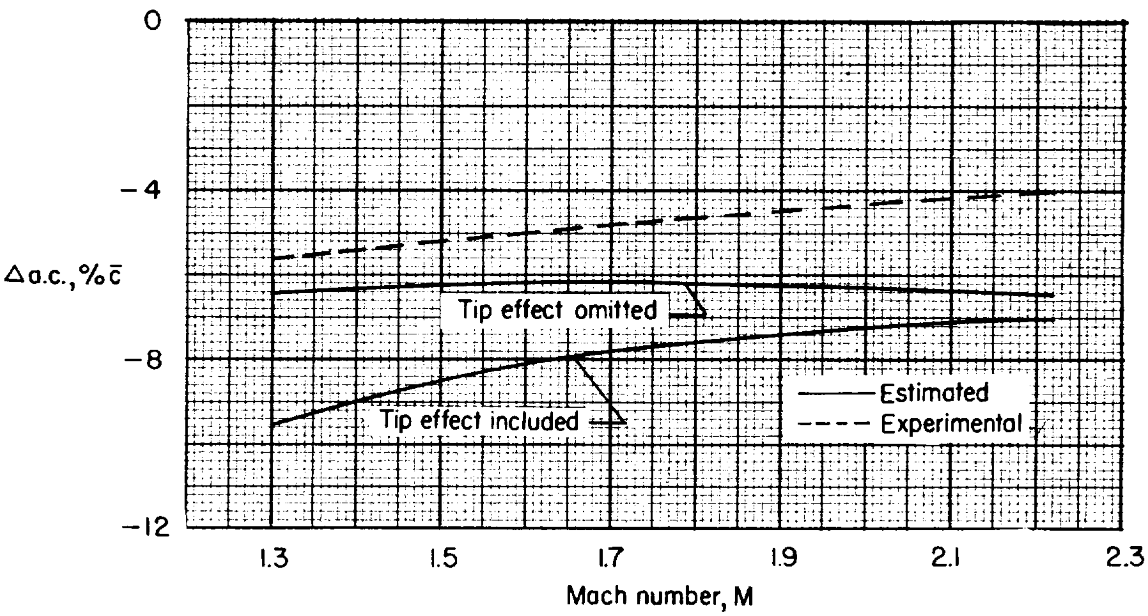


Figure 4.- Effect of Mach number on the aerodynamic-center location for the complete triangular wing.



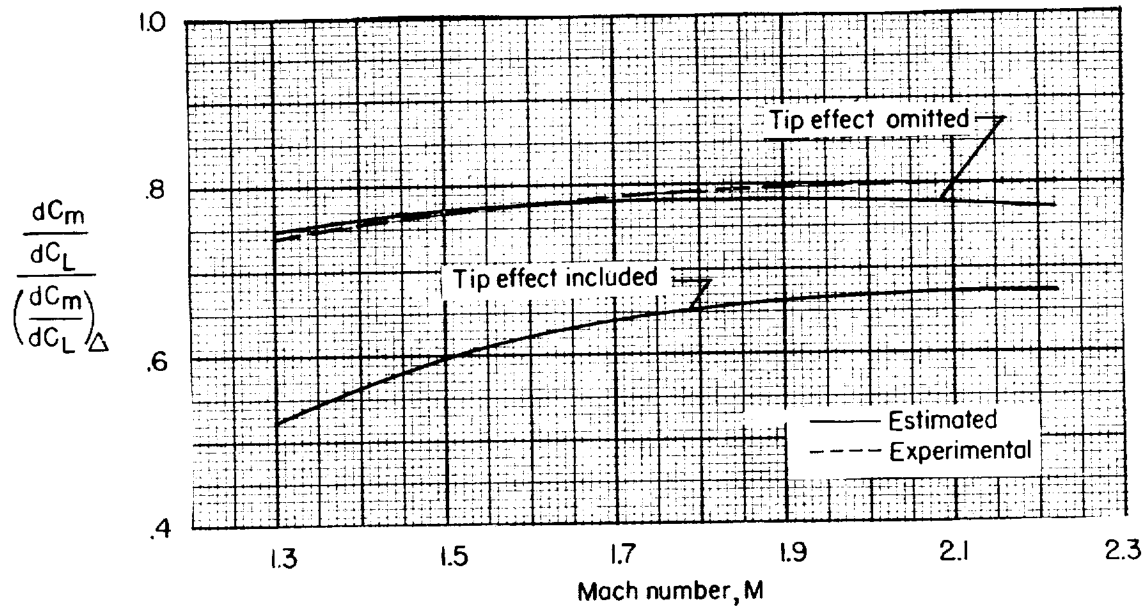
(a) Tips deflected.



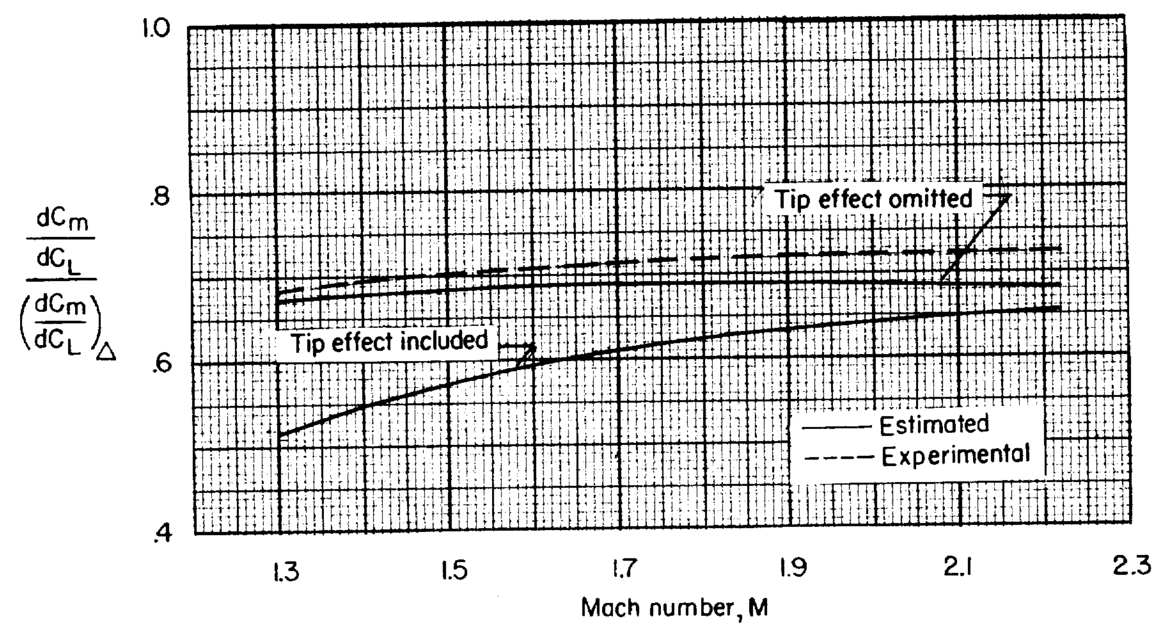
(b) Tips and inboard surfaces deflected.

Figure 5.- Variation with Mach number of the effect of deflecting portions of the triangular wing on the aerodynamic-center location.

[redacted]



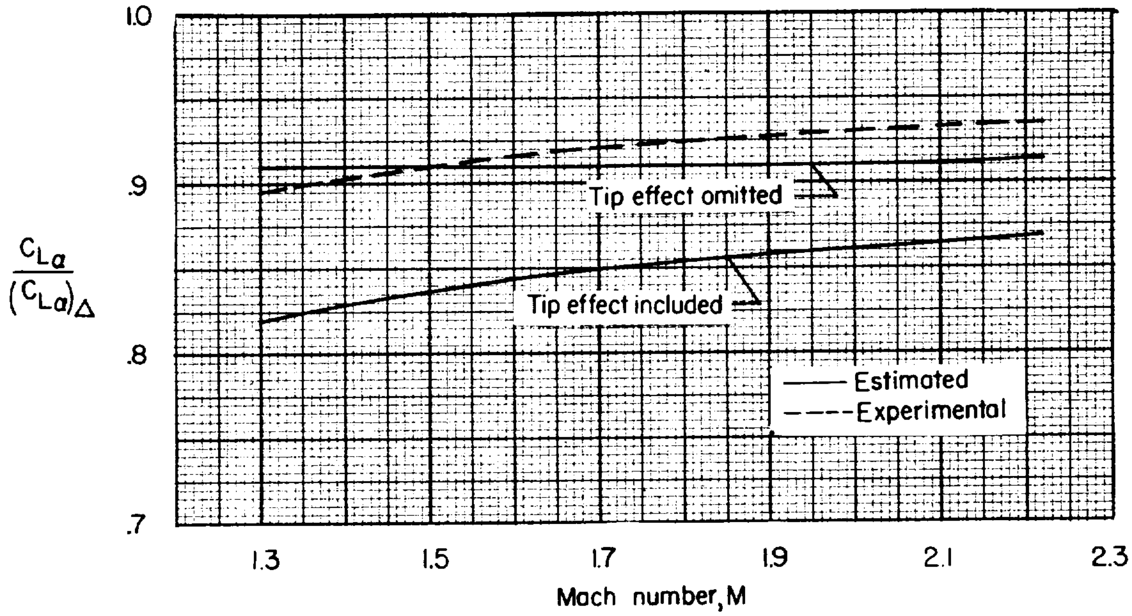
(a) Tips deflected.



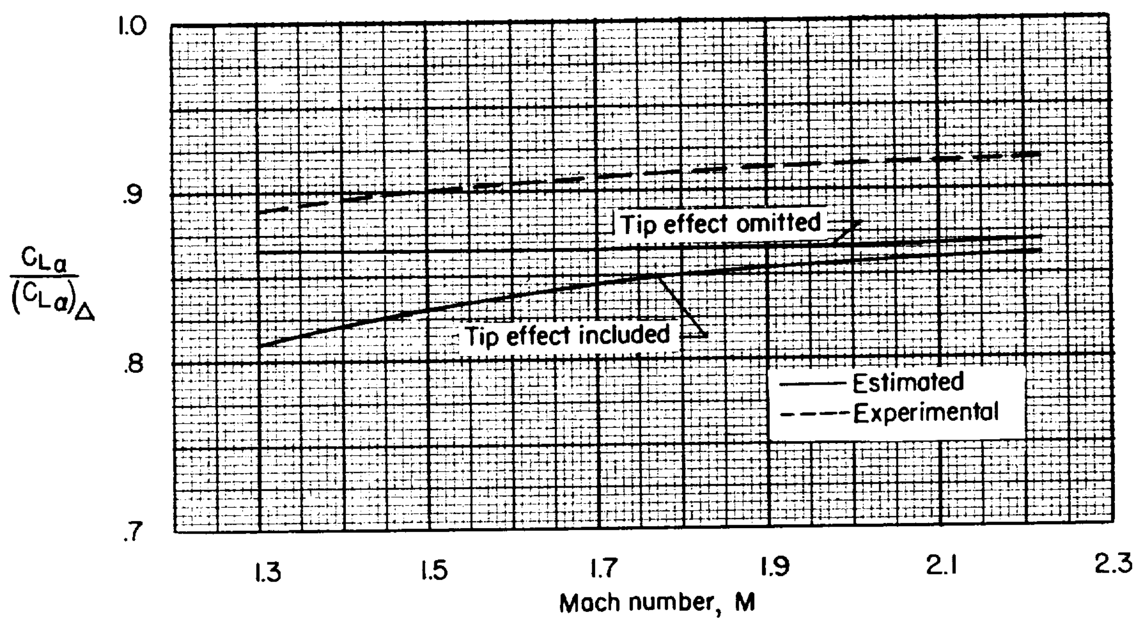
(b) Tips and inboard surfaces deflected.

Figure 6.- Variation with Mach number of the effect of deflecting portions of the triangular wing on the longitudinal stability.

[redacted]



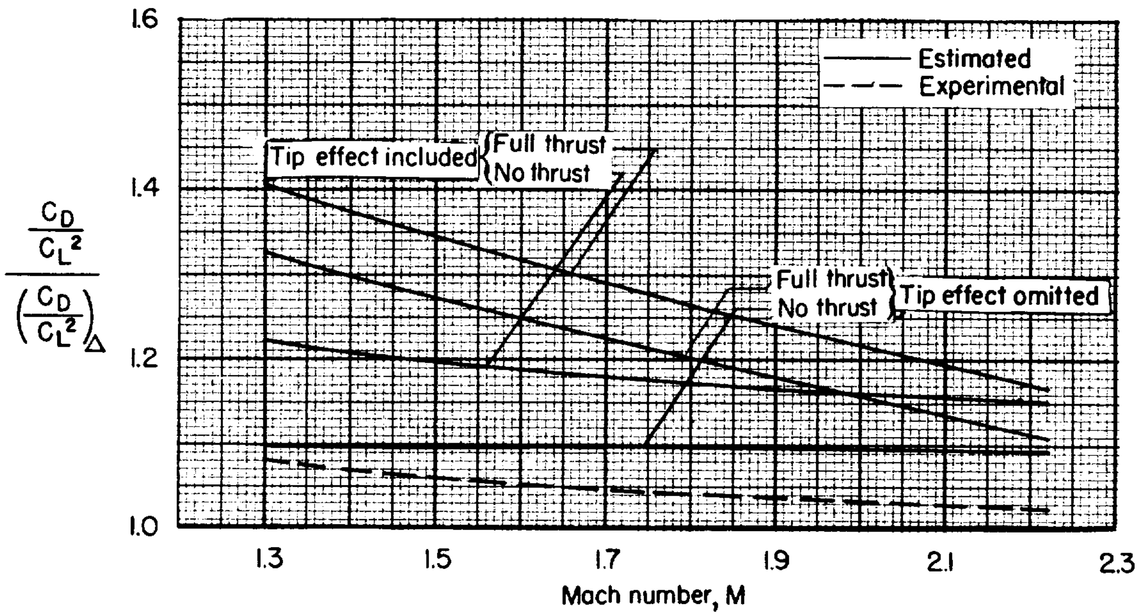
(a) Tips deflected.



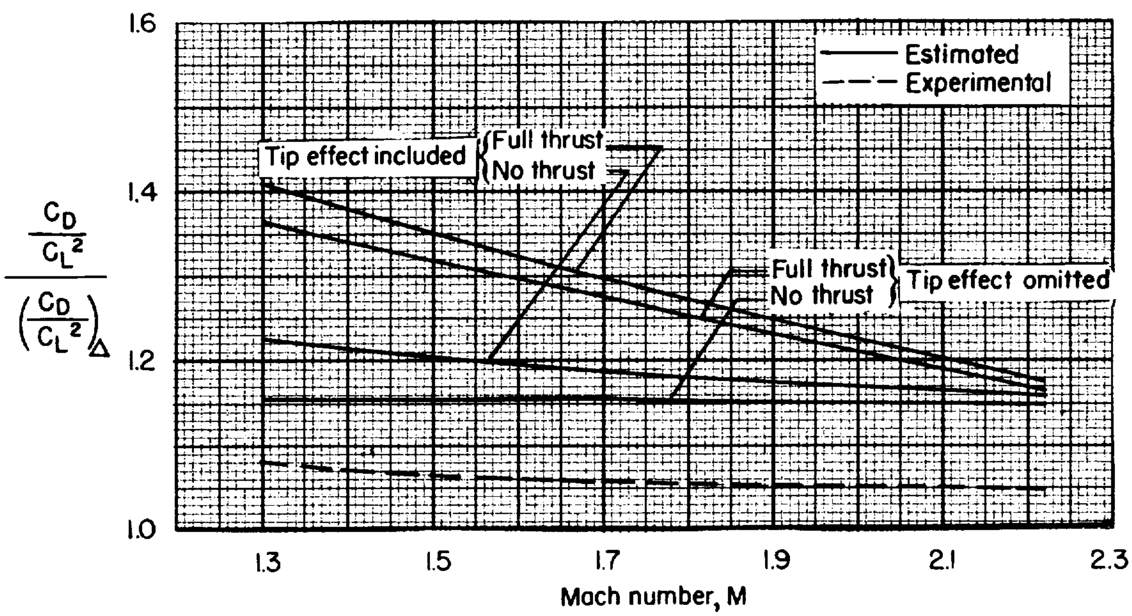
(b) Tips and inboard surfaces deflected.

Figure 7.- Variation with Mach number of the effect of deflecting portions of the triangular wing on the lift-curve slope.

[redacted]



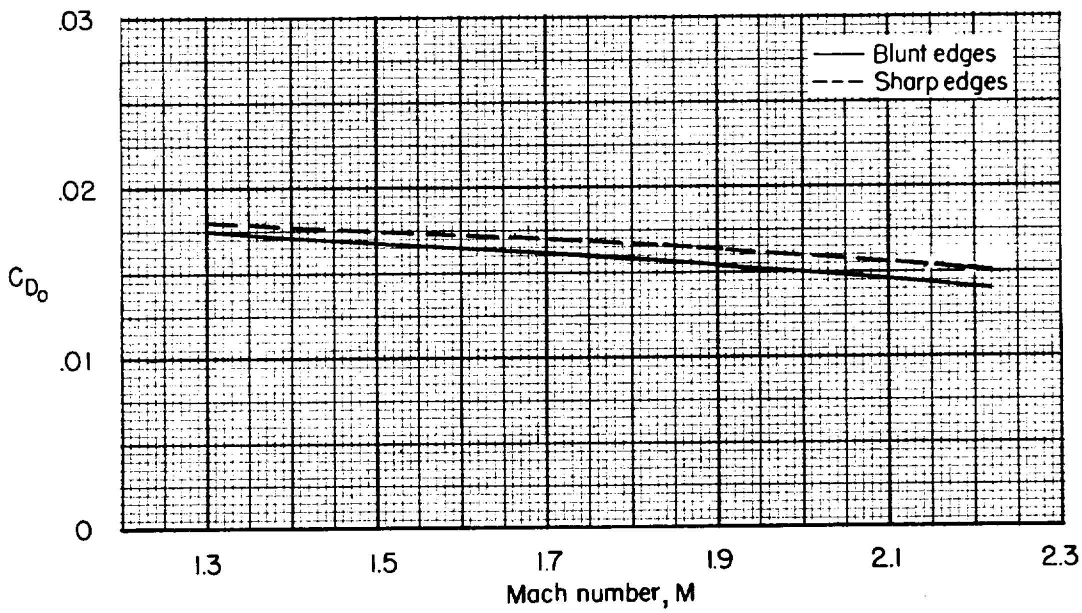
(a) Tips deflected.



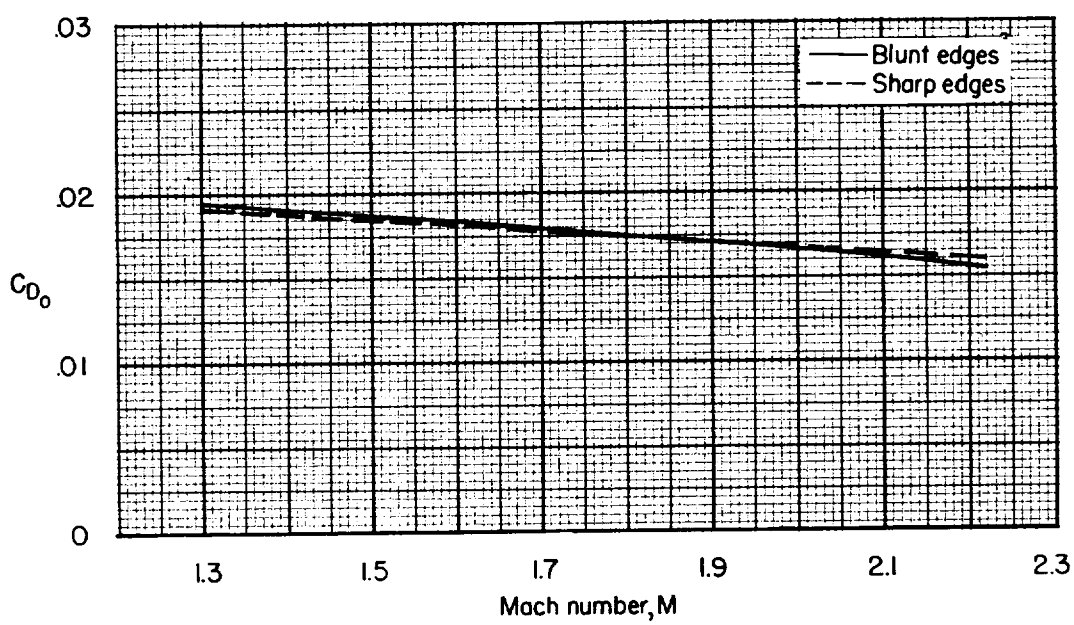
(b) Tips and inboard surfaces deflected.

Figure 8.- Variation with Mach number of the effect of deflecting portions of the triangular wing on the drag due to lift.

[redacted]



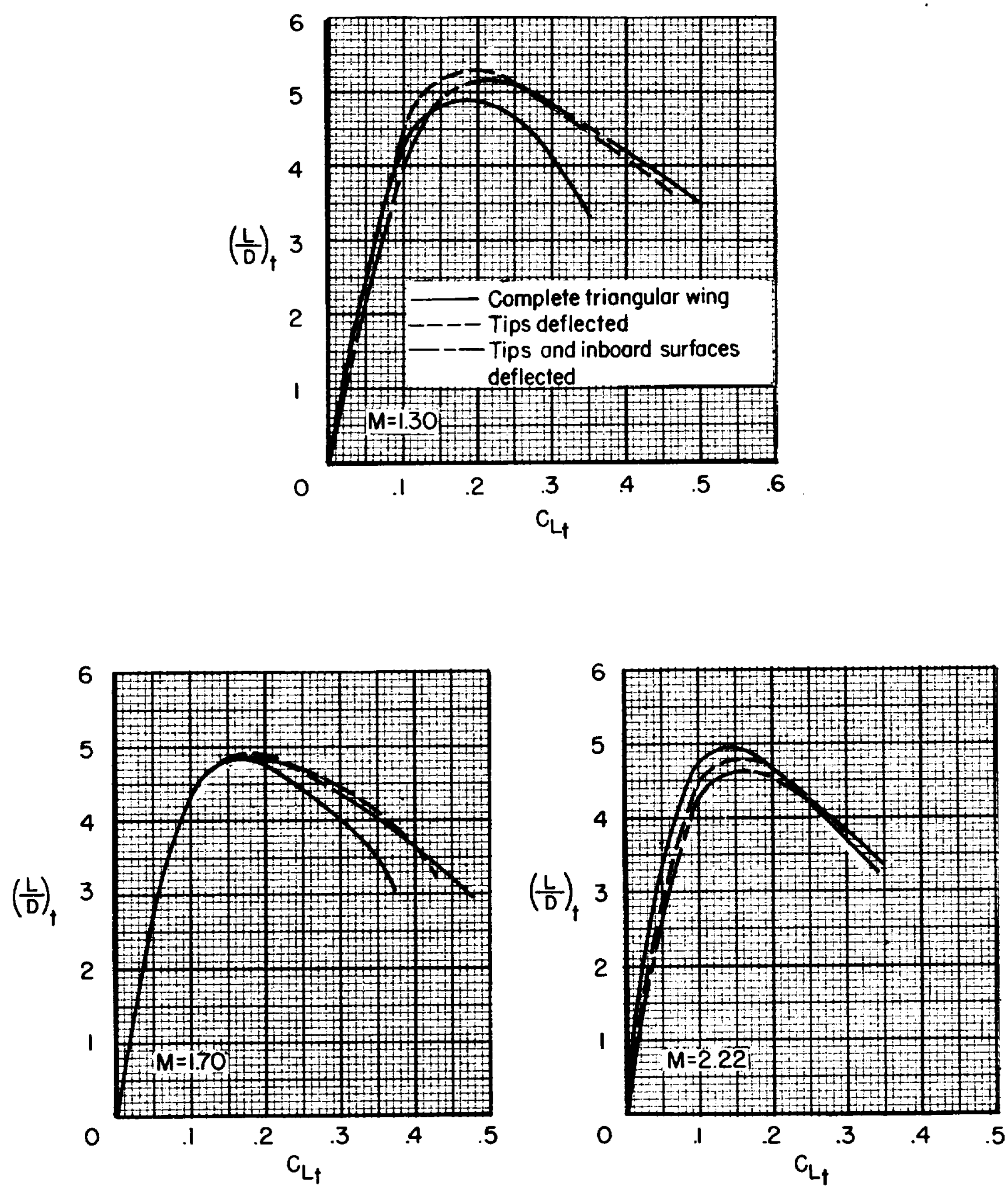
(a) Complete triangular wing.



(b) Tips and inboard surfaces deflected.

Figure 9.- Variation with Mach number of the effect of the shape of the leading edges of the inboard movable surfaces on the minimum drag coefficient.

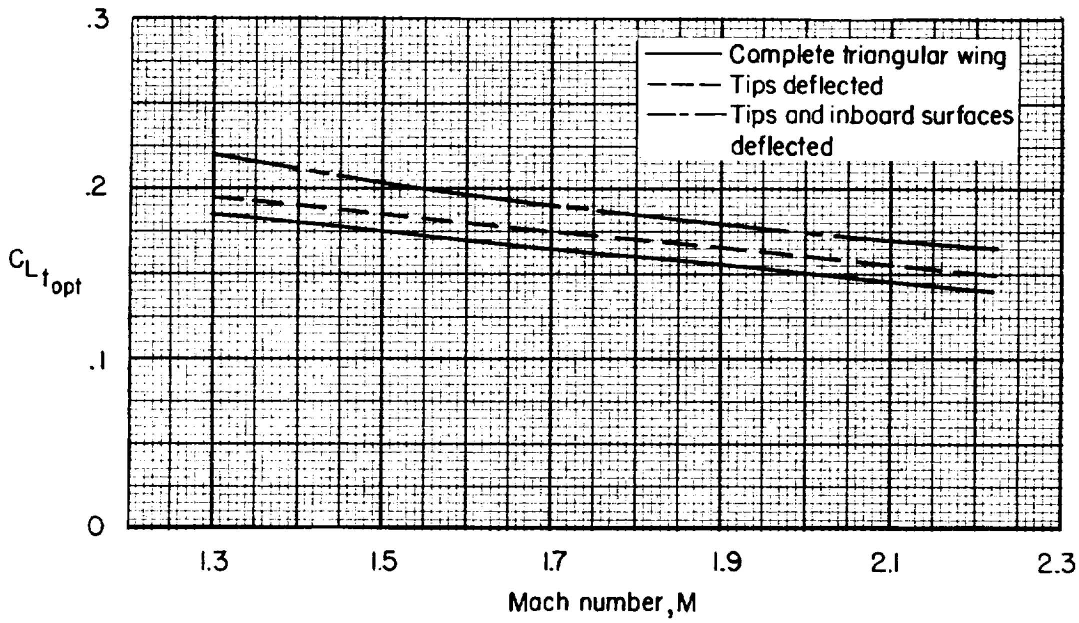
[redacted]



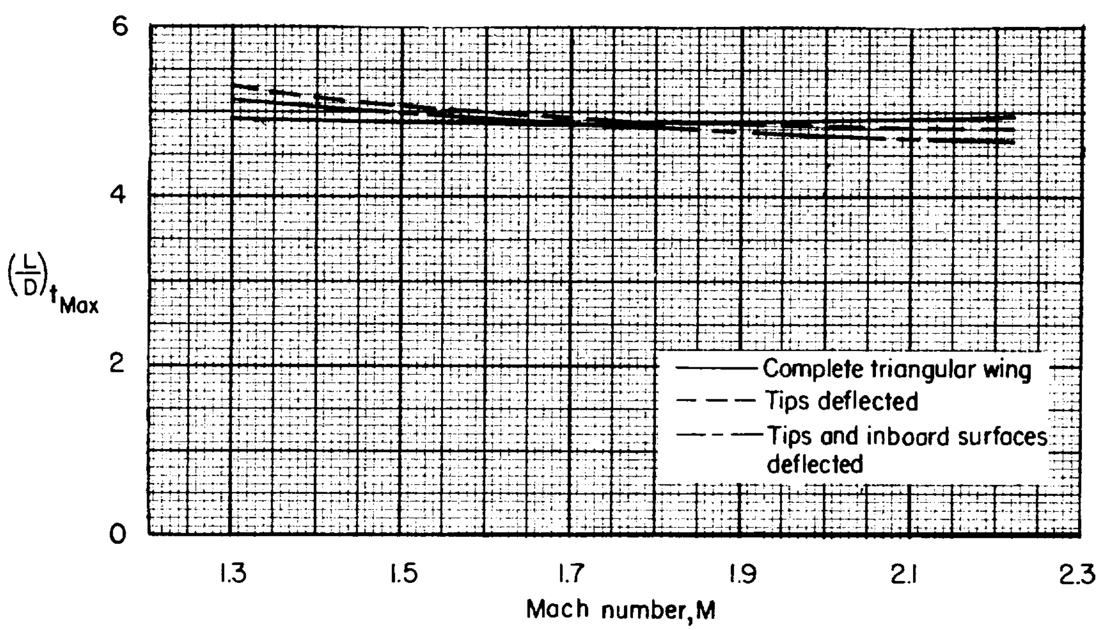
(a) Variation of trimmed lift-drag ratio with lift coefficient.

Figure 10.- Effects of deflecting portions of the triangular wing on the trimmed lift and drag characteristics (obtained by superposing canard data of reference 1).

[redacted]



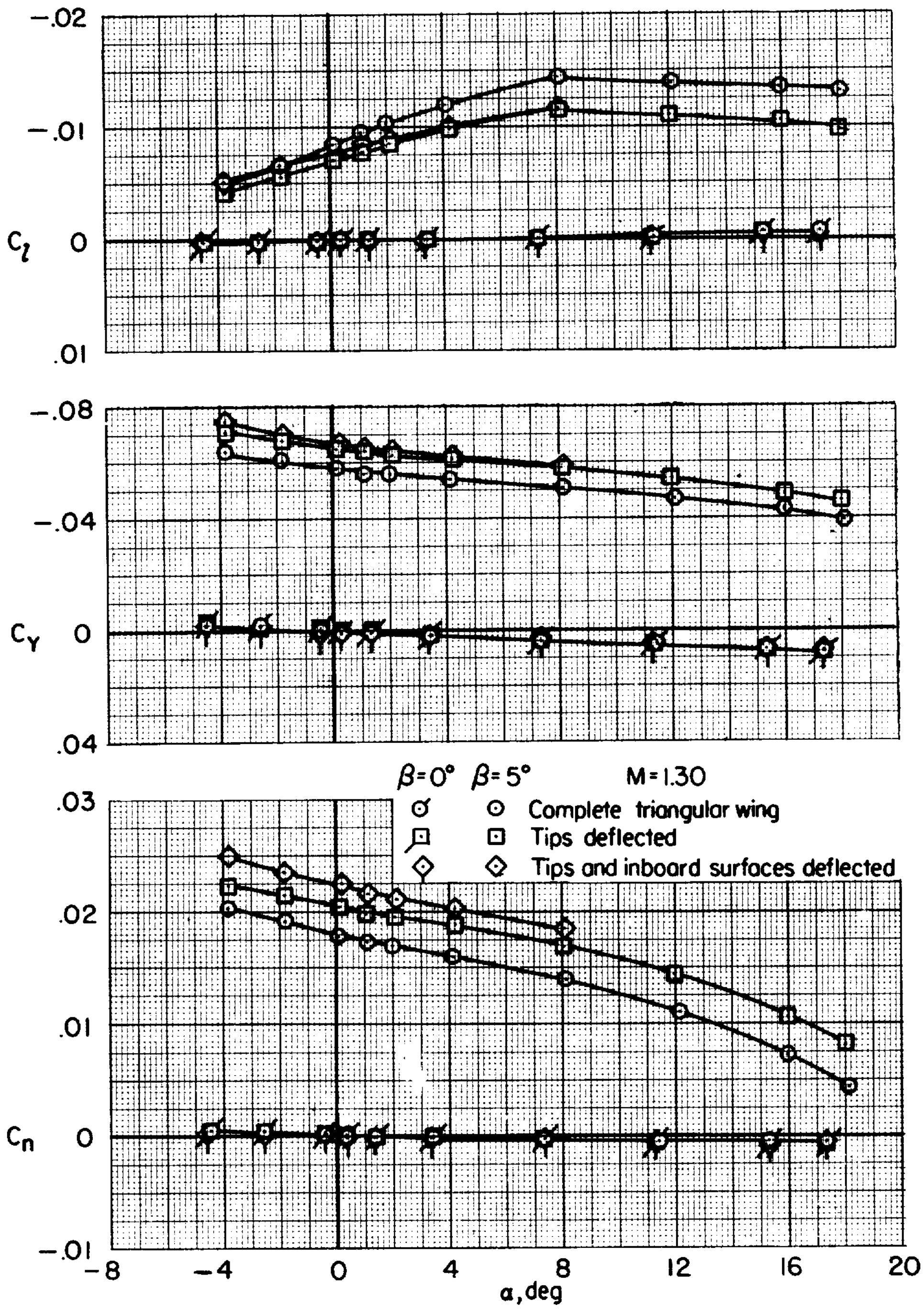
(b) Variation of optimum trimmed lift coefficient with Mach number.



(c) Variation of maximum trimmed lift-drag ratio with Mach number.

Figure 10.- Concluded.

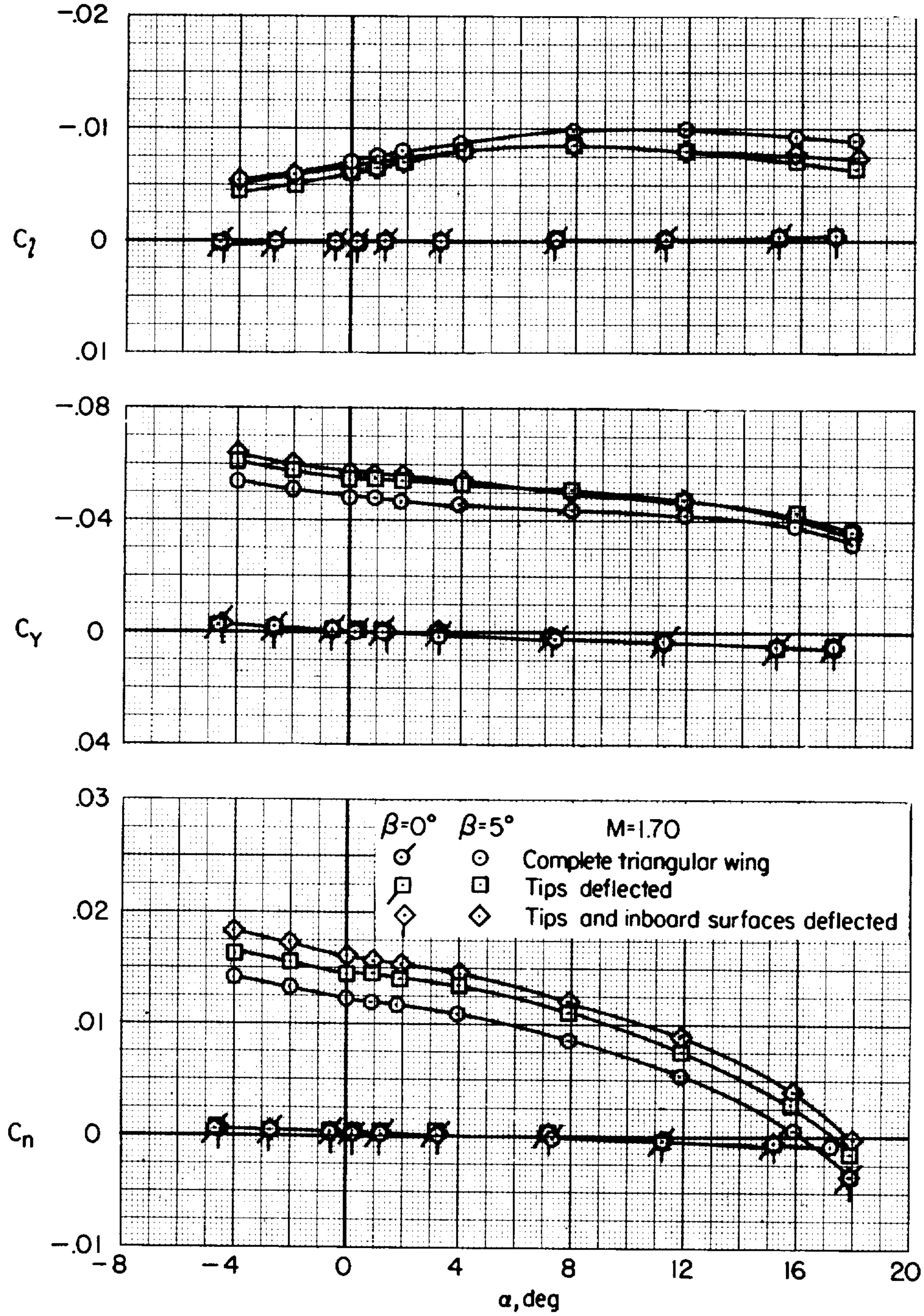
[redacted]



(a) M = 1.30

Figure 11.- Rolling-moment, side-force, and yawing-moment characteristics for the models with surfaces undeflected and deflected.

[redacted]

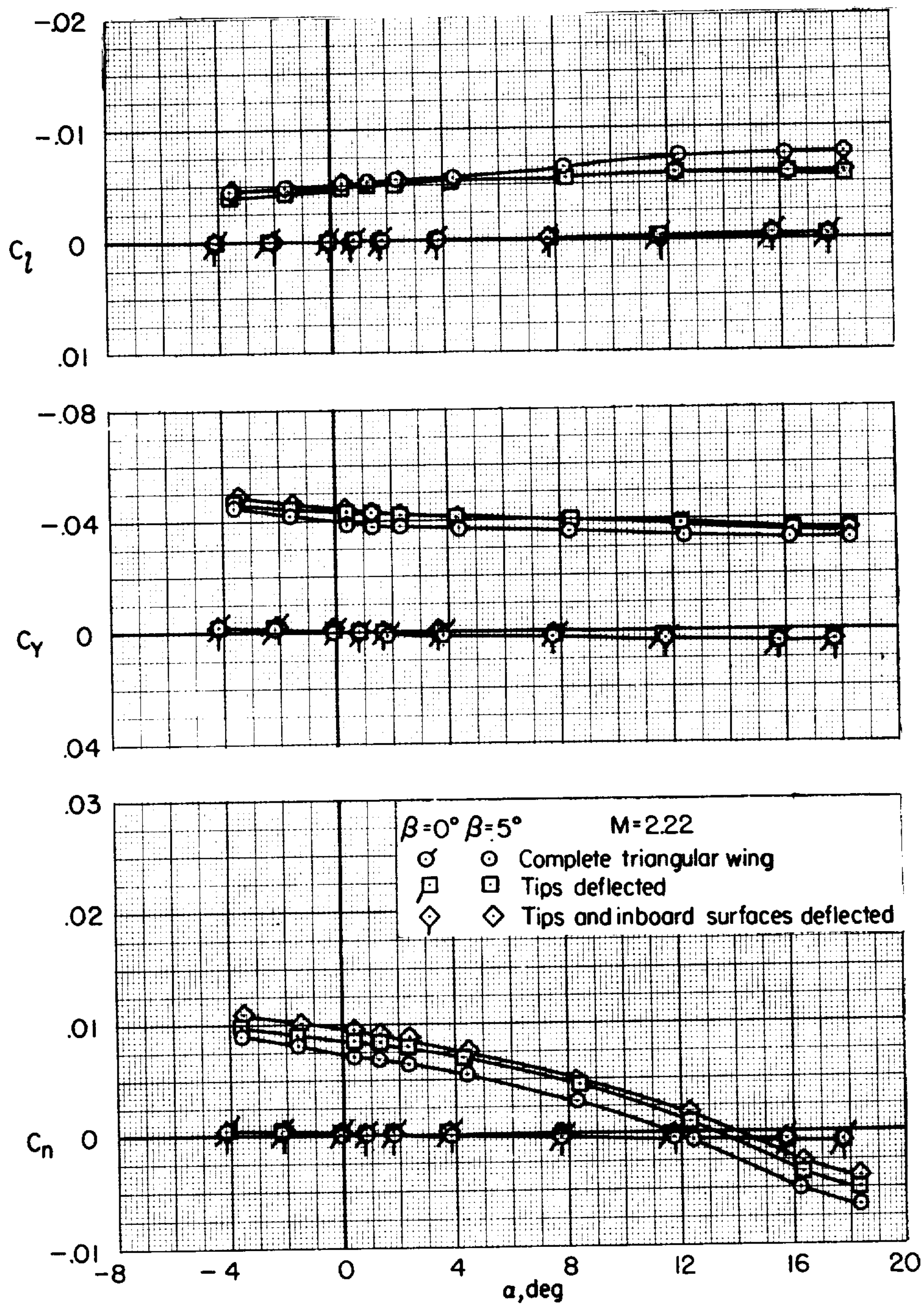


(b) M = 1.70

Figure 11.- Continued.

[redacted]

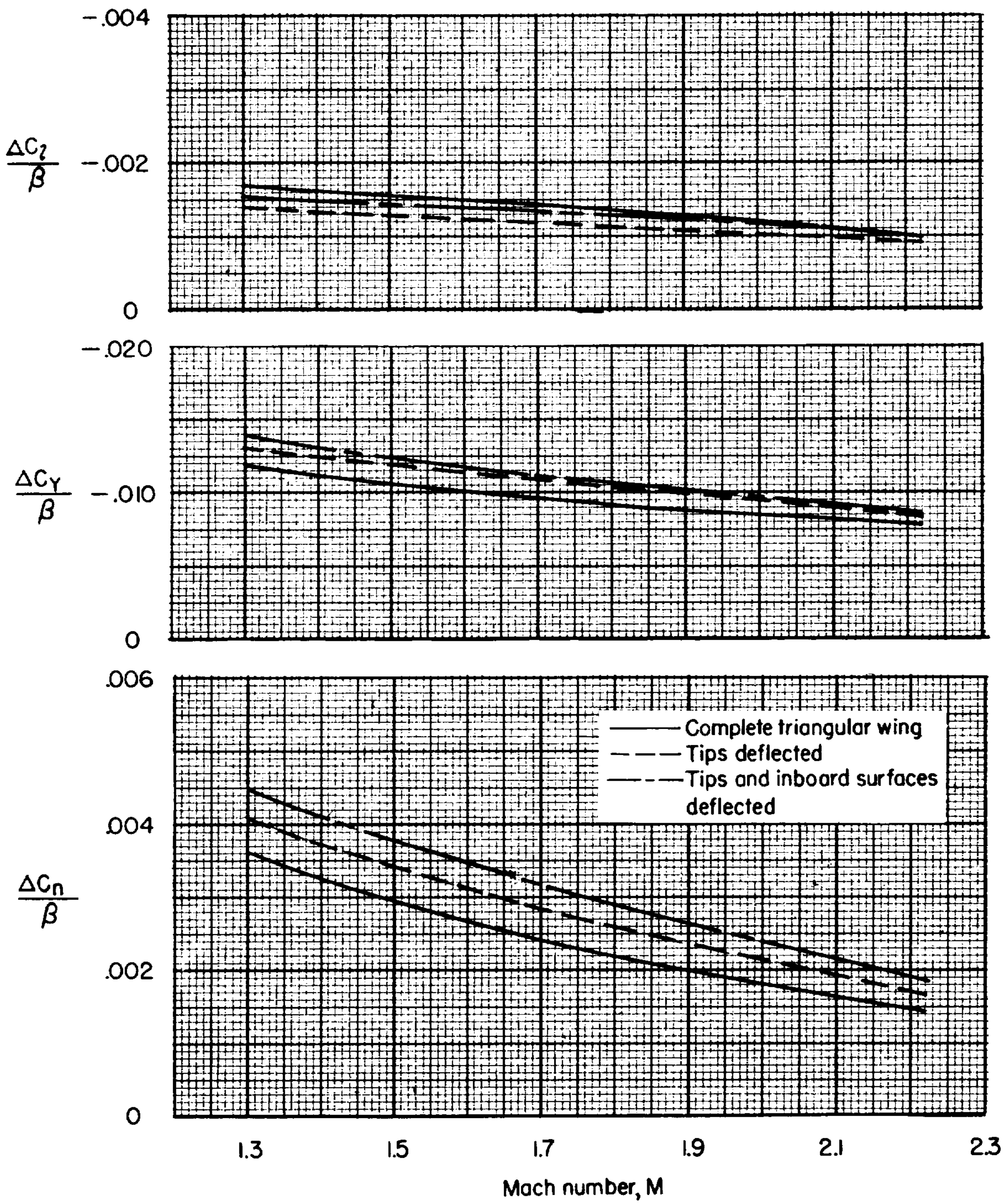
[redacted]



(c) M = 2.22

Figure 11.- Concluded.

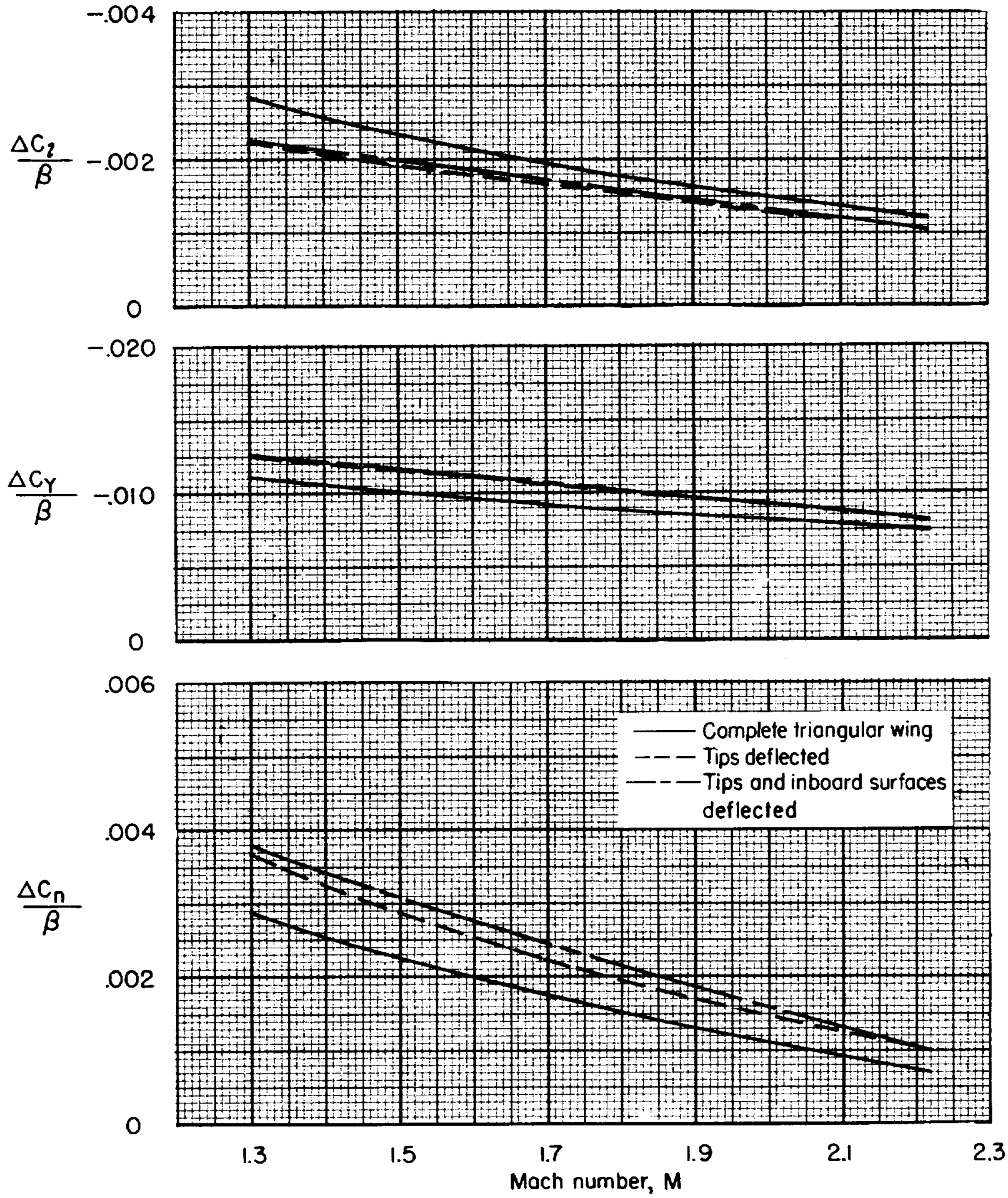
[redacted]



(a) $\alpha = 0^{\circ}$

Figure 12.- Variation with Mach number of the lateral-directional incremental derivatives at constant angle of attack resulting from deflecting the outboard portions of the triangular wing.

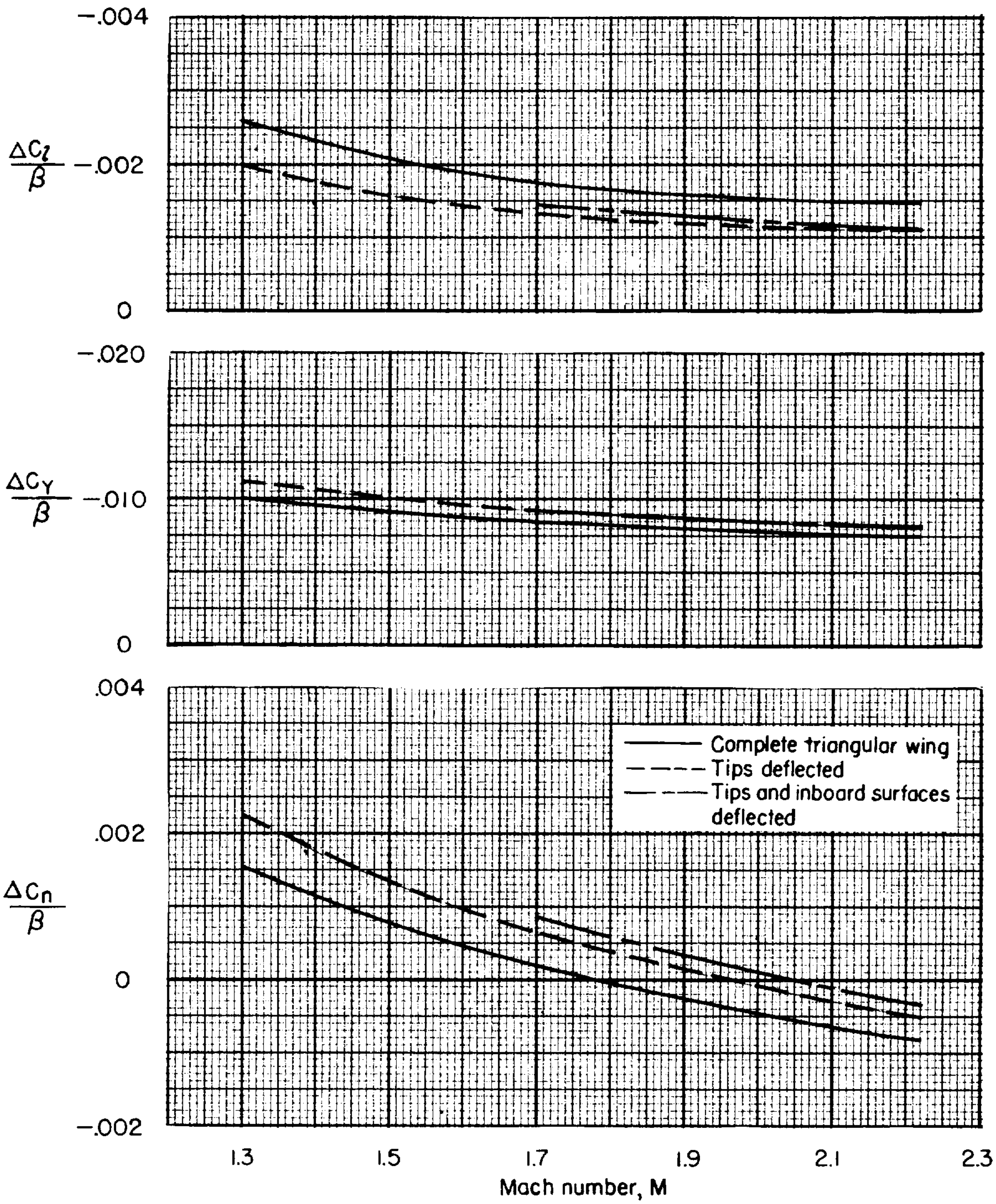
[redacted]



(b) $\alpha = 8^{\circ}$

Figure 12.- Continued.

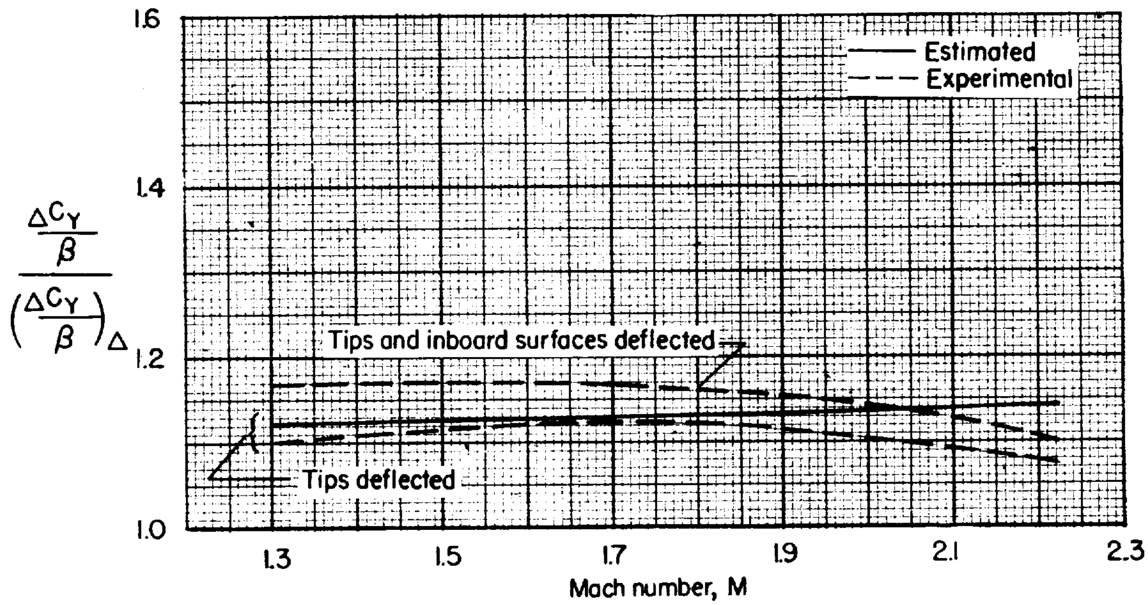
[redacted]



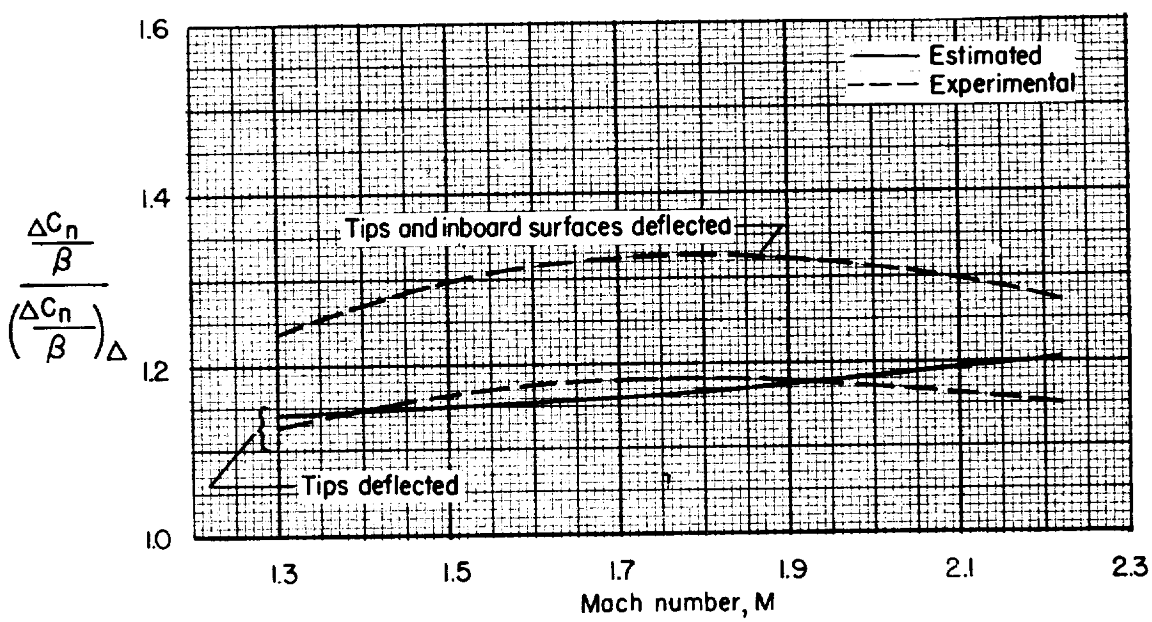
(c) $\alpha = 16^{\circ}$

Figure 12.- Concluded.

[redacted]



(a) Effect on $\frac{\Delta C_Y}{\beta}$.



(b) Effect on $\frac{\Delta C_n}{\beta}$.

Figure 13.- Variation with Mach number of the effects of deflecting portions of the triangular wing on the directional incremental derivatives at 0° angle of attack.

[redacted]

NASA MEMO 5-18-59A
National Aeronautics and Space Administration.
THE EFFECTS OF STREAMWISE-DEFLECTED WING TIPS ON THE AERODYNAMIC CHARACTERISTICS OF AN ASPECT-RATIO-2 TRIANGULAR WING, BODY, AND TAIL COMBINATION. Victor L. Peterson. May 1959. 36p. diagrs., photos. (NASA MEMORANDUM 5-18-59A) CONFIDENTIAL
(Title, Unclassified)

Aerodynamic forces and moments of a model having two combinations of outboard sections of the wing deflected along streamwise hinge lines for the purpose of decreasing the longitudinal stability and increasing the directional stability at supersonic speeds are compared with those for a complete triangular wing configuration. Mach numbers of 0.70, 1.30, 1.70, and 2.22 and angles of attack ranging from -5° to $+18^{\circ}$ at sideslip angles of 0° and 5° were covered in the investigation. Comparisons between estimated and experimental results are made.

Copies obtainable from NASA, Washington

CONFIDENTIAL

1. Tail-Wing-Fuselage Combinations - Airplanes (1.7.1.1.3)
2. Stability, Longitudinal - Static (1.8.1.1.1)
3. Stability, Directional - Static (1.8.1.1.3)

I. Peterson, Victor L.
II. NASA MEMO 5-18-59A

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