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EFFECTS OF CONICAL CAMBER ON THE LIFT, DRAG, AND PITCHING-MOMENT CHARACTERISTICS OF A TRIANGULAR WING OF ASPECT RATIO 3.0

By Victor L. Peterson and John W. Boyd

Ames Aeronautical Laboratory
Moffett Field, Calif.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECTS OF CONICAL CAMBER ON THE LIFT, DRAG, AND PITCHING-MOMENT CHARACTERISTICS OF A TRIANGULAR WING OF ASPECT RATIO 3.0

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SUMMARY

The results of an investigation to determine the effects of conical camber on the lift, drag, and pitching-moment characteristics of a wing-body combination employing a triangular wing of aspect ratio 3.0 are presented. The mean surface shape of the cambered wing was derived from lifting surface theory for a design lift coefficient of 0.33 at a Mach number of 1.0. A plane wing was also tested on the same body to provide a basis for comparison. Lift, drag, and pitching-moment data were obtained at Mach numbers from 0.7 to 1.90 through an angle-of-attack range from -6° to +18° at a constant Reynolds number of 3.6 million based on the wing mean aerodynamic chord.

The experimental results showed that at subsonic speeds the use of camber resulted in substantial reductions in drag coefficients at lift coefficients above 0.15. At supersonic speeds there were no reductions in drag coefficients below lift coefficients of 0.30. In the subsonic speed range the maximum lift-drag ratios of the cambered wing were considerably higher than those of the plane wing and approached those corresponding to the theoretical full leading-edge suction. The use of camber did not cause any major change in the lift and pitching-moment characteristics.

INTRODUCTION

The effectiveness of a conical form of camber in reducing the drag due to lift at subsonic and low supersonic speeds has been demonstrated experimentally in references 1 and 2 for several swept-wing and body combinations. It was shown that this type of camber satisfied the conditions necessary to the attainment of low drag due to lift for triangular wings having subsonic leading edges, namely that the span load distribution

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approximate an ellipse and that the equivalent of the theoretical leading-edge thrust be realized. In view of the continued interest in developing configurations that maintain the highest possible lift-drag ratios at high subsonic and low supersonic speeds, application of the conical camber to a number of wing plan forms was undertaken.

The purpose of the present brief investigation is to determine the benefits that could be realized by employing the conical camber on an aspect-ratio-3 triangular wing. The surface shape was derived in accordance with the design procedures outlined in reference 2 for a design lift coefficient of 0.33 at a Mach number of 1.0. A plane wing of the same plan form and aspect ratio was also tested to provide a basis for determining the effectiveness of conical camber.

SYMBOLS

b	local span
$\bar{c}$	mean aerodynamic chord
C_D	drag coefficient, $\frac{\text{drag}}{qS}$
C_L	lift coefficient, $\frac{\text{lift}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{pitching moment}}{qS\bar{c}}$, referred to the projection of the $0.25\,\bar{c}$ point on the fuselage reference line
$\left(\frac{L}{D}\right)_{max}$	maximum lift-drag ratio
M	free-stream Mach number
q	free-stream dynamic pressure
S	wing area formed by extending the leading and trailing edges to the plane of symmetry
α	angle of attack of wing root chord, deg
x,y,z	Cartesian coordinates in streamwise, spanwise, and vertical directions, respectively (The origin is at the wing apex.)

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APPARATUS AND MODEL

Test Facility

The experimental studies were conducted in the Ames 6- by 6-foot supersonic wind tunnel which is a closed circuit, variable-pressure type wind tunnel with a Mach number range continuous from 0.70 to 2.20. The transonic capabilities are the result of recent modifications wherein the floor and ceiling were perforated. A boundary-layer removal system was installed in order to maintain uniform flow in the test section. Also included in the modifications was the installation of injector flaps downstream of the test section to reduce the required compression ratio across the nozzle and to better match the weight flow characteristics of the nozzle with those of the compressor so that the upper Mach number limit could be extended to 2.20.

An extensive survey of the wind-tunnel stream characteristics was made upon completion of the modifications. Analysis of these results, although imcomplete, is sufficiently advanced to establish the validity of the results of the present investigation. A discussion of the various corrections applied to the data is included under the section "Test and Procedures."

Description of Models

The two models of the present investigation consisted of a plane and a cambered wing of triangular plan form and aspect ratio 3. The thickness distribution used for both wings was the NACA 0003-63. A sketch of the model plan form is shown in figure 1(a). The camber shape was determined according to the design procedures outlined in reference 2 for a design lift coefficient of 0.33 at a Mach number of 1.0. The camber extended over the outboard 20 percent of the local semispan. A sketch of the mean surface shape is shown in figure 1(b).

A Sears-Haack body was used in conjunction with the wings. To accommodate the internal strain-gage balance the body was truncated as shown in figure 1(a). The equation of the body is also given in figure 1(a).

TEST AND PROCEDURES

Range of Test Variables

Mach numbers of 0.7, 0.9, 0.95, 1.0, 1.025, 1.05, 1.10, 1.30, 1.50, and 1.90 and angles of attack from -6° to +18° were covered in the investigation. Data were obtained for a Reynolds number of 3.6 million based on the mean aerodynamic chord.

At the relatively low Reynolds numbers (less than 10^7) at which most wind tunnels are forced to operate, extensive regions of laminar flow can exist on models at zero lift. At lifting conditions the transition point is usually moved forward to the wing leading edge, thus changing the magnitude of the friction drag. In order to isolate the effects of conical camber on the drag due to lift characteristics it is necessary to minimize the change in friction drag with changing lift coefficient. In the present investigation this was accomplished by placing a 0.010-inch diameter wire on the body and on the wing near the leading edge to induce transition. (See fig. 1(a).) The use of wire was based on the results of reference 3 wherein it was shown that such a device was effective in promoting turbulent flow.

Reduction of Data

The data presented herein have been reduced to standard NACA coefficient form. The pitching-moment coefficients were referred to the quarter point of the mean aerodynamic chord. Factors which affect the accuracy of the results are discussed in the following paragraphs.

Stream variations.- Extensive surveys of the stream characteristics were made recently in the Ames 6- by 6-foot wind tunnel throughout the available Mach number range. The surveys showed that in the region of the test section, essentially no stream curvature existed in the pitch plane of the model and that the axial static-pressure variations were usually less than ±1 percent of the dynamic pressure. For most models, including the ones reported on herein, this static-pressure variation resulted in negligible longitudinal-bouyancy corrections to the drag. Therefore, no corrections to the data for stream curvature or static-pressure variation were made in the present investigation.

A stream angle was found to exist in the vertical plane in the test section (the pitch plane of the model) which varied with Mach number. The magnitudes of the stream angles obtained from tests of the models of the present study in normal and inverted attitudes were in close agreement with those obtained from the cone survey. The data presented herein have been corrected for the stream angle, which was as much as 0.30° downflow at a Mach number of 1.10.

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Support interference.- The effects of model support interference on the aerodynamic characteristics were considered to consist primarily of a change in the base pressure of the model. The base pressure was measured, therefore, and the drag data were adjusted to correspond to a base pressure equal to the free-stream static pressure.

Tunnel wall interference.- The usefulness of a perforated wind tunnel as a test facility particularly at transonic and low supersonic speeds where reflected disturbances might affect the results must usually be established experimentally. This was done in the calibration phase which included testing models of various sizes and plan forms. These unpublished data indicate that reliable data could be obtained throughout the Mach number range of the facility if certain restrictions were imposed on the model size and attitude. Although the model geometric characteristics and range of model attitudes necessary to obtain interference-free data have not been completely defined, sufficient data are available to indicate that for the configurations of the present investigation, the data obtained at transonic and low supersonic speeds are reasonably free of wall interference effects. Thus, no correction for wall interference has been made.

RESULTS AND DISCUSSION

The objective of the present study was to evaluate the effectiveness of a conical form of camber in reducing the drag due to lift of an aspect-ratio-3 triangular wing. The results of this investigation are presented graphically in figures 2 through 6. The results comparing the plane and cambered wing drag polars for several of the test Mach numbers are presented in figure 2. Plots of the drag coefficient against Mach number are shown in figure 3 for several lift coefficients. Further comparisons showing the variation of maximum lift-drag ratio as a function of Mach number are shown in figure 4 and compared with theoretical values. Lift and moment data are presented in figures 5 and 6.

Drag Characteristics

It is evident from the results of figures 2 and 3 that the use of conical camber results in substantial reductions in the drag at lift coefficients above 0.15 at high subsonic speeds ($M = 0.70$ to 0.90). The reductions in the drag coefficient resulting from the camber amounts to more than 0.010 at lift coefficients of 0.30 and above. Needless to say, such drag reductions would greatly improve the efficiency of a vehicle designed to cruise in this speed range. At Mach numbers above 1.00 the benefits of camber diminish, with only small improvements resulting from the camber for lift coefficients above 0.30. Below this lift coefficient the drag coefficients of the cambered wing are somewhat greater than those for the plane wing.

As a means of further demonstrating the benefits of camber on the drag characteristics, the results of figure 4 are presented wherein the maximum lift-drag ratios of the plane and the cambered wing are compared with the theoretical maximum lift-drag ratios for a plane triangular wing having full and no leading-edge suction. The theoretical curves for full and no leading-edge suction were computed using the theoretical lift-curve slopes and the experimental minimum drag coefficients for the plane wing-body combination. The comparison shows that at subsonic speeds the wing with camber realizes values of maximum lift-drag ratios that are equivalent to those for a wing with approximately full leading-edge suction up to a Mach number of 0.90; whereas the plane wing realizes values equivalent to only about 50 percent of the theoretical possible leading-edge thrust. As shown by the data of figure 4, the experimental values of $(L/D)_{max}$ for the cambered wing for Mach numbers around 0.70 are actually somewhat greater than the theoretical values for full leading-edge suction. As pointed out previously, the theoretical curves were computed using theoretical lift-curve slopes. Thus, if an equivalent thrust force is developed on the cambered wing which approaches the theoretical value and the experimental lift-curve slope is greater than the theoretical value as is the case for an aspect-ratio-3 triangular wing (see ref. 1), such a result is possible. At the higher Mach numbers both the plane and the cambered wings fall below the value for full leading-edge thrust, the plane wing having somewhat higher lift-drag ratios that the cambered wing at Mach numbers above 1.30.

Lift and Moment Characteristics

It has been shown on numerous occasions that the aerodynamic center and lift-curve slope near zero lift are primarily functions of wing geometry and are not affected by wing camber. This result is substantiated in figures 5 and 6 wherein the variation of lift with angle of attack and the longitudinal stability of the cambered wing are essentially the same as those of the plane wing. The small positive shift in the angle of zero lift due to camber is of little consequence but the small positive shift in pitching moment reduces the moment needed for trim and, therefore, the trim drag of the configuration. The results of figure 6 show also that the use of camber delays to a higher lift coefficient the slight pitch-up tendency of the triangular wing at a Mach number of 0.70.

CONCLUSIONS

An experimental investigation made to determine the effectiveness of conical camber on the aerodynamic characteristics of a wing-body combination employing a triangular wing of aspect ratio 3.0 showed that:

1. The use of camber resulted in appreciable reductions in drag coefficients above a lift coefficient of 0.15 at subsonic speeds.

2. At supersonic speeds the drag coefficients of the cambered wing exceeded those of the plane wing below a lift coefficient of 0.30.

3. The use of camber resulted in large increases in the maximum lift-drag ratio above that of the plane wing at subsonic speeds, the cambered wing approaching the maximum lift-drag-ratio value equivalent to that for full leading-edge thrust.

4. The lift and pitching-moment characteristics were not significantly affected by camber.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Dec. 18, 1956

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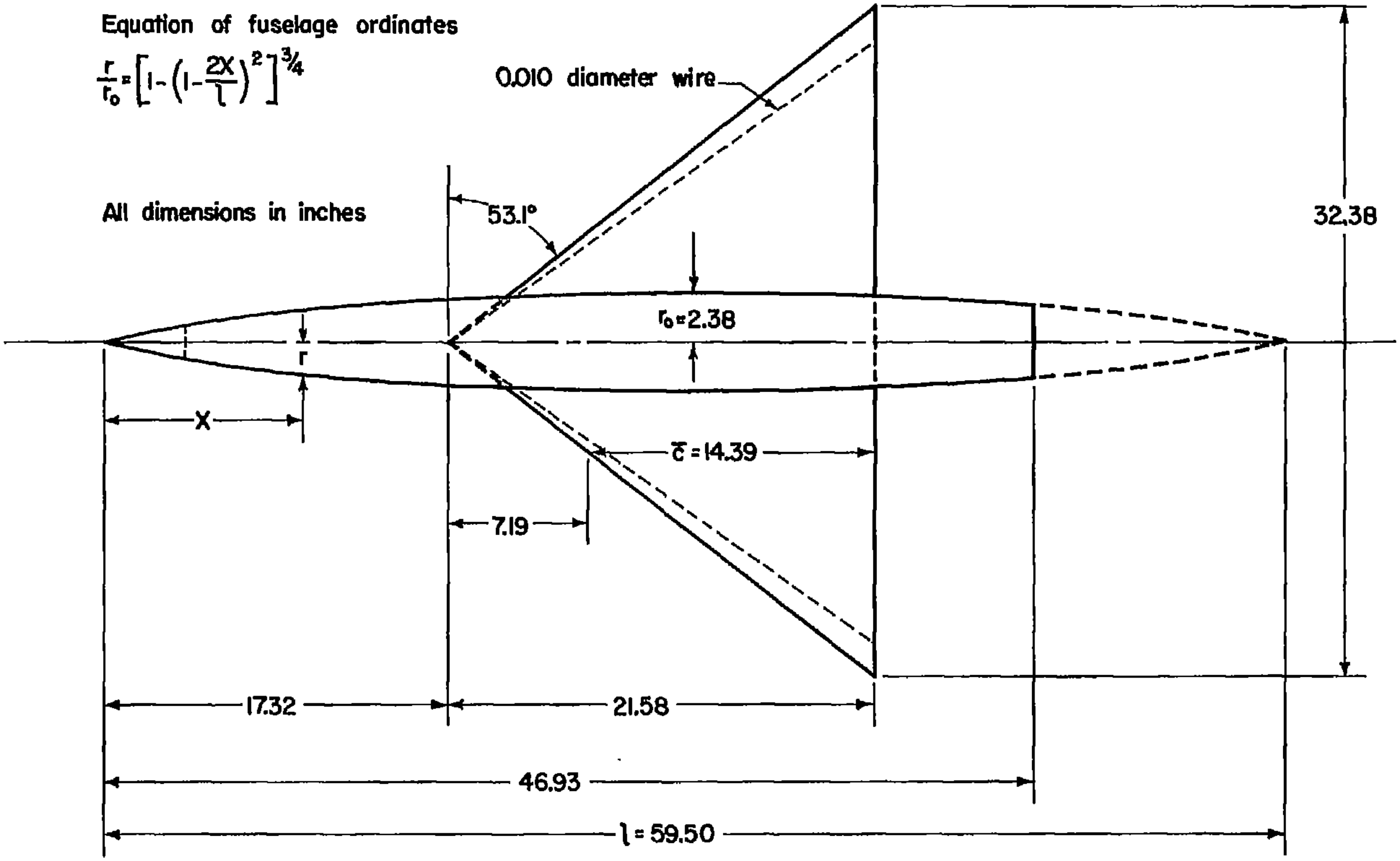

(a) Plan form.

Figure 1.- Model geometry.

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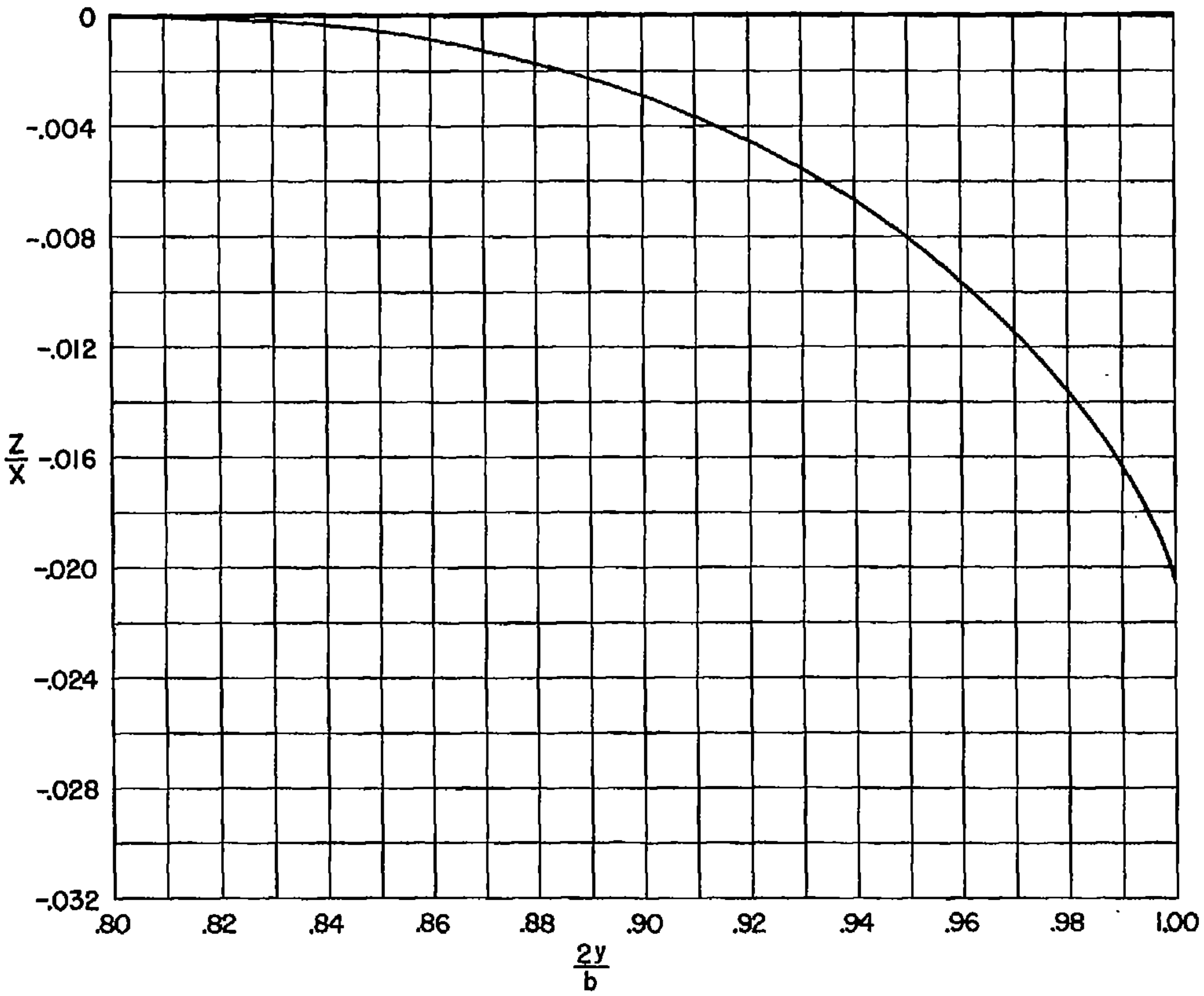

(b) Ordinates of the mean camber line.

Figure 1.- Concluded.

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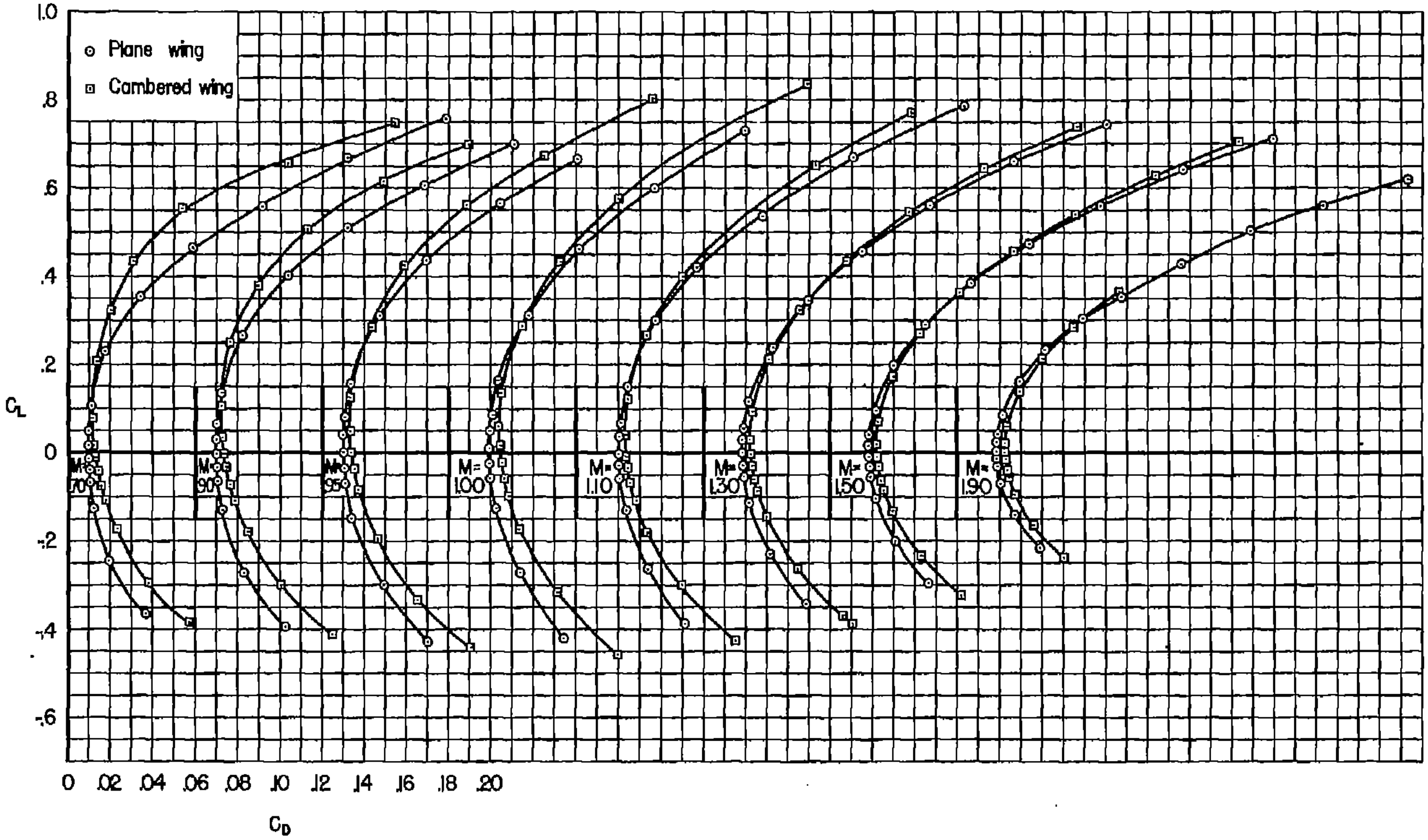

Figure 2.- Effect of conical camber on the variation of drag coefficient with lift coefficient.

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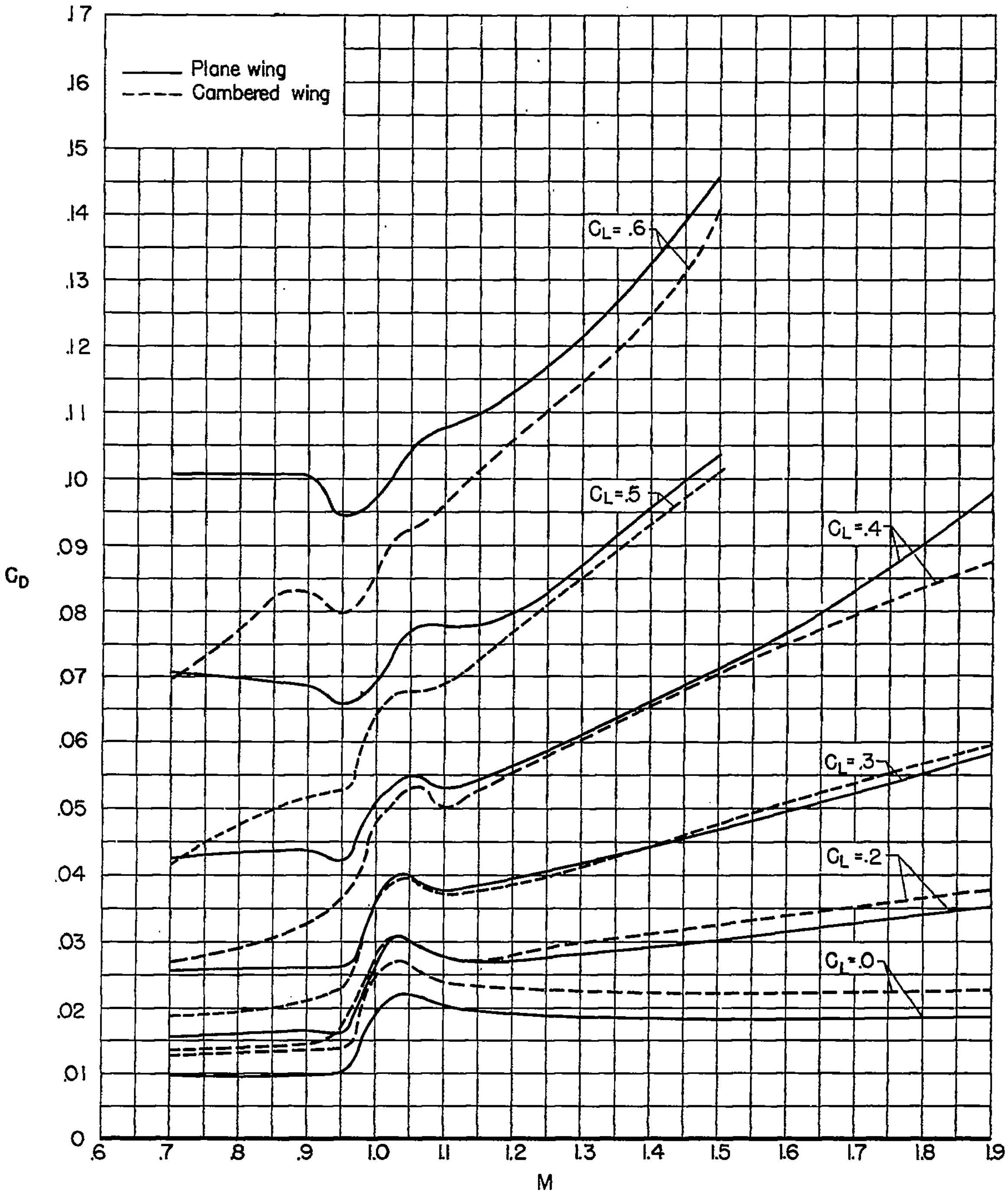

Figure 3.- Effect of conical camber on the variation of drag coefficient with Mach number.

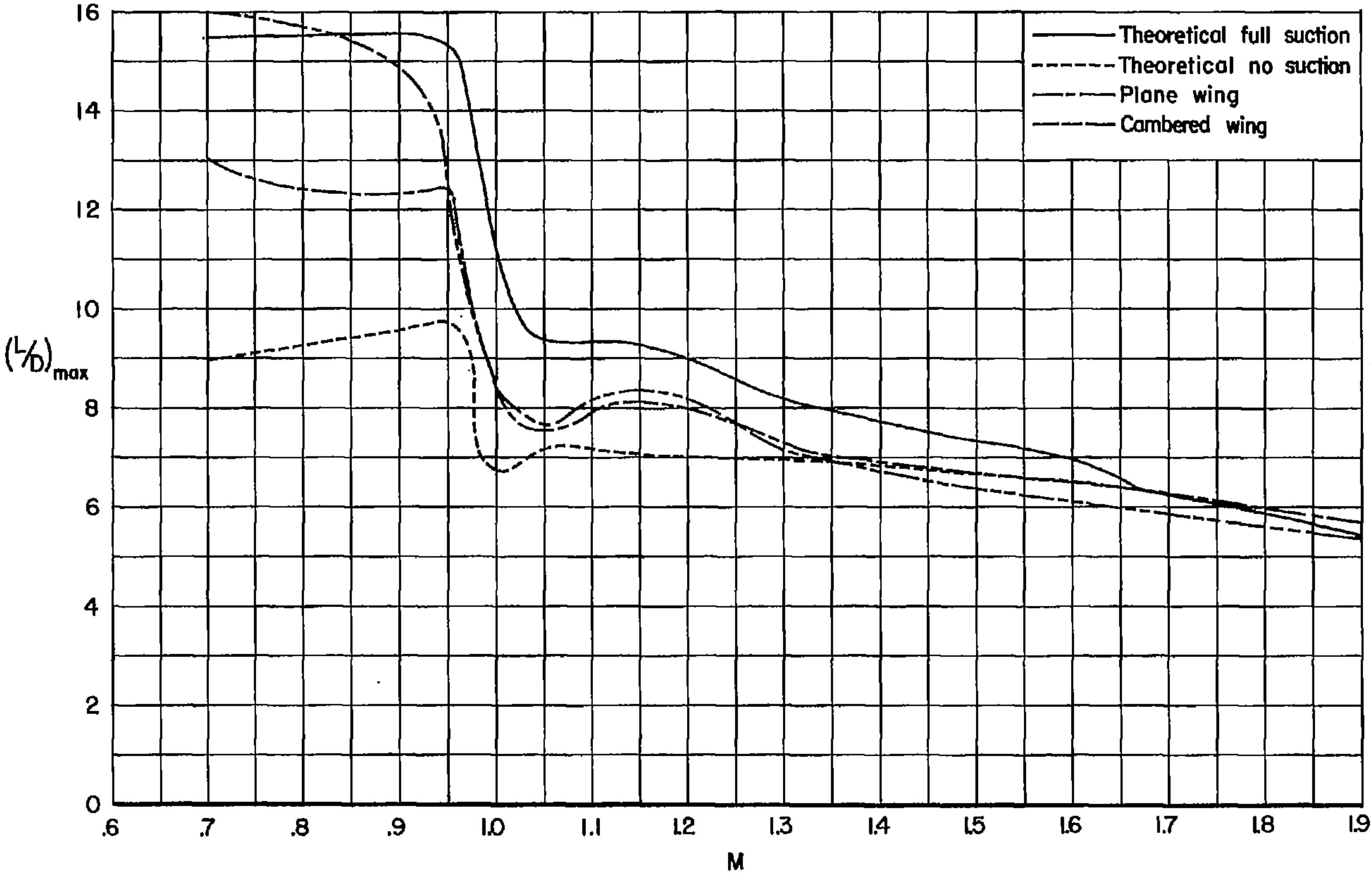

Figure 4.- Effect of conical camber on the variation of maximum lift-drag ratio with Mach number.

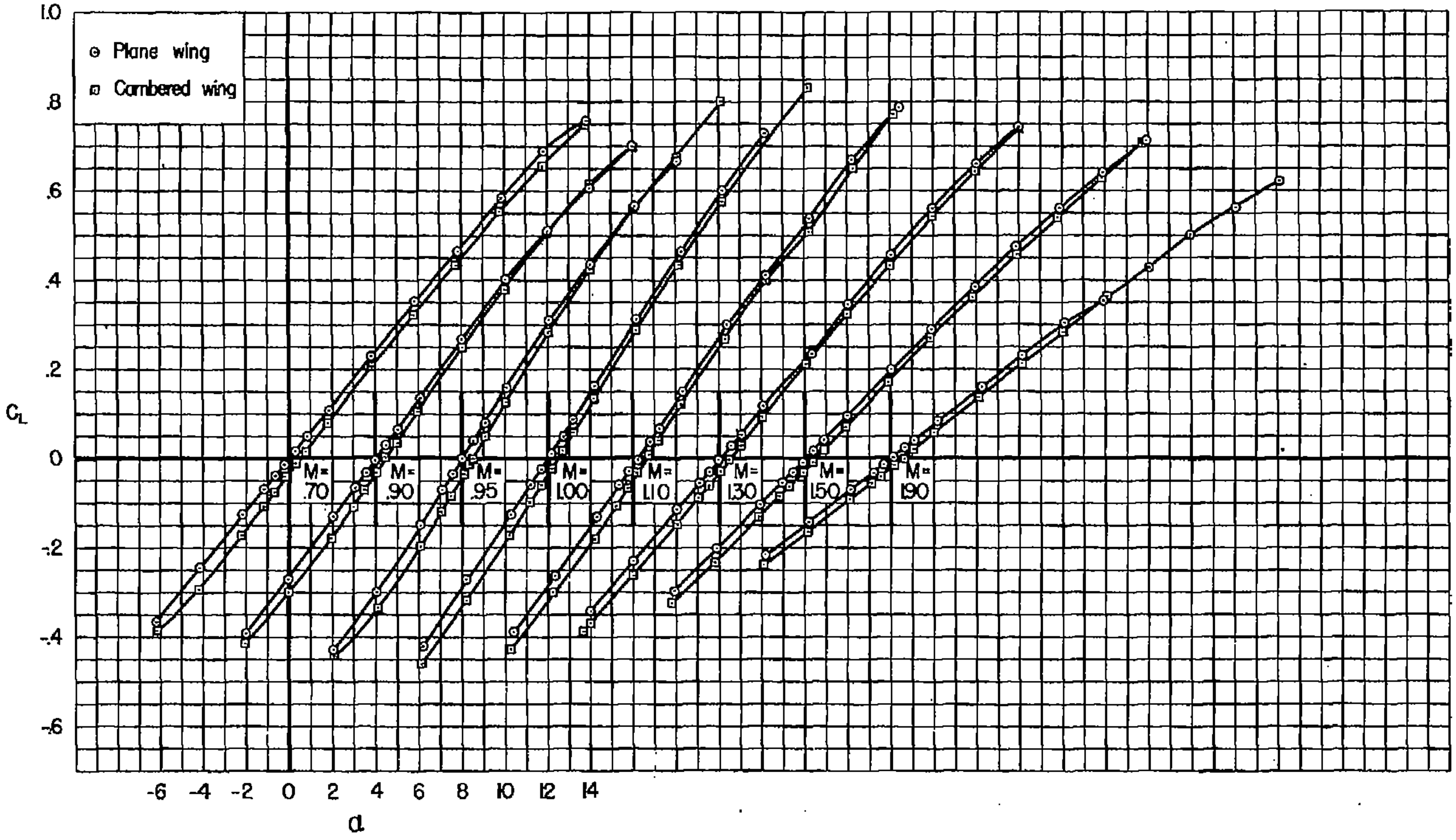

Figure 5.- Effect of conical camber on the variation of lift coefficient with angle of attack.

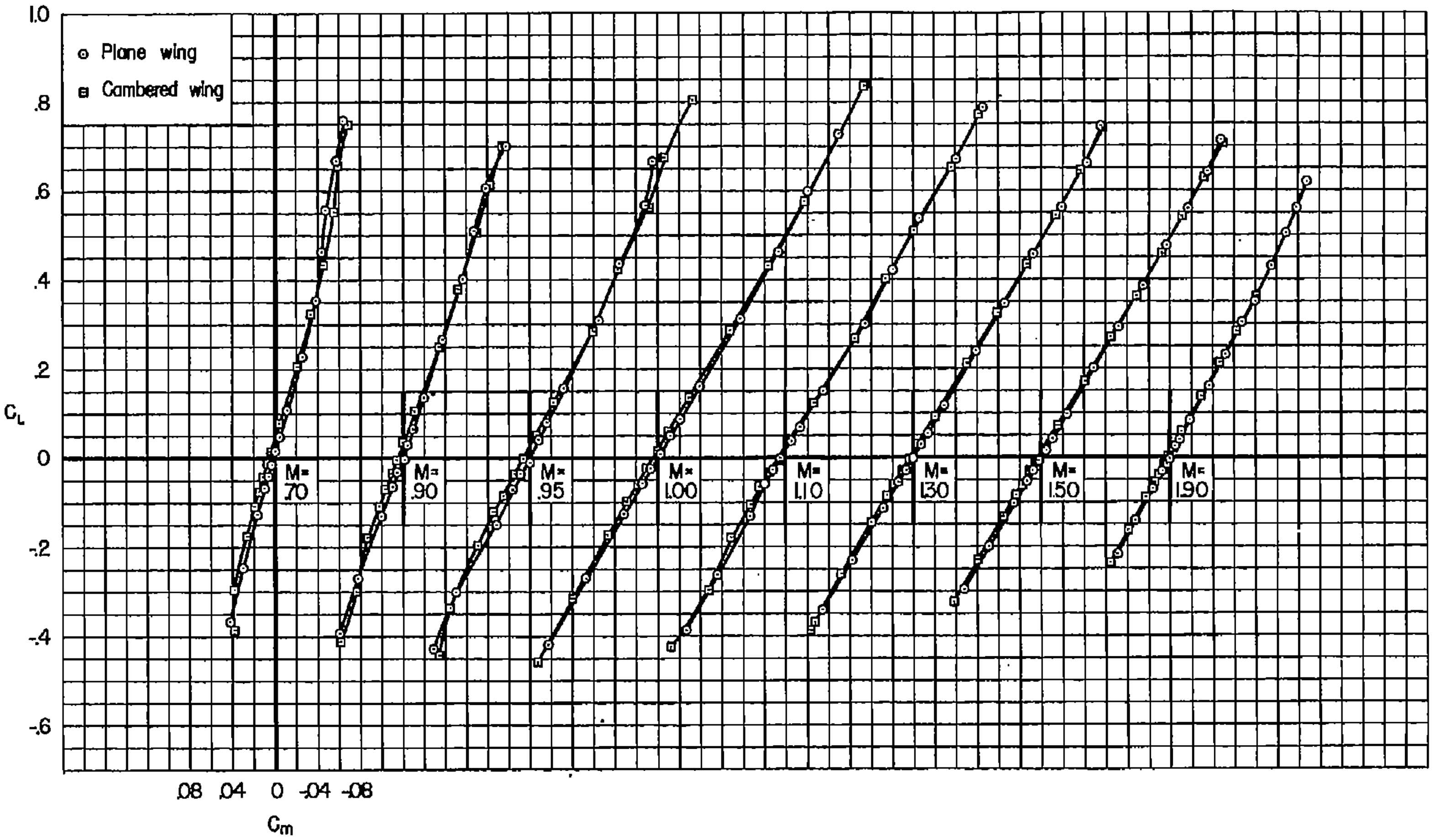

Figure 6.- Effect of conical camber on the variation of lift coefficient with pitching-moment coefficient.