NACA

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS EXTENDED TO HIGH ANGLES OF ATTACK AT TRANSONIC SPEEDS OF A SMALL-SCALE 0° SWEEP WING, 45° SWEPTBACK WING, AND 60° DELTA WING

By Harleth G. Wiley

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

November 18, 1952

 [redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS EXTENDED TO HIGH ANGLES OF ATTACK AT TRANSONIC SPEEDS OF A SMALL-SCALE 0° SWEEP WING, 45° SWEPTBACK WING, AND 60° DELTA WING

By Harleth G. Wiley

SUMMARY

In order to extend the scope of an NACA transonic research program to include the aerodynamic characteristics of wings at high angles of attack, a series of wings of various plan forms were investigated in the high-velocity field of the side-wall reflection plate of the Langley high-speed 7- by 10-foot tunnel at angles of attack of 0° to about 60° and Mach numbers of approximately 0.6 to 1.1.

This paper presents the aerodynamic characteristics from 0° to about 60° angle of attack of a 0° sweep wing of aspect ratio 4 and taper ratio 0.6, a 45° sweptback wing of aspect ratio 4 and taper ratio 0.6, and a 60° delta wing of aspect ratio 2.31 and taper ratio 0. Presented also are the effects of leading-edge roughness on the 0° sweep wing of a constant-thickness "flat-plate" airfoil section on the 45° sweptback wing, and of a fuselage on the 60° delta wing.

The data show that the maximum lift coefficients obtainable increased with increase in sweep angle and decreased with Mach number at the lower subsonic Mach numbers. The maximum lift coefficient for all wings increased with Mach number above a Mach number of 0.95 with less effect of sweep angle.

INTRODUCTION

The current trend in high-speed airplane and guided-missile design to incorporate high wing loadings and high operational flight ceilings necessitates careful consideration of the aerodynamic characteristics of the specific wing plan forms at high angles of attack. In order to

[redacted]

extend the range of available data at transonic speeds to include high angles of attack, a series of wing plan forms was investigated on the side-wall reflection plate of the Langley high-speed 7- by 10-foot tunnel.

Presented in this paper are the results of an investigation over an angle-of-attack range of approximately 0° to 60° of a 0° sweep and a 45° sweptback wing with an aspect ratio of 4, and a 60° delta wing with an aspect ratio of 2.31. The three wings had similar NACA 65-series airfoil sections with a thickness ratio of 6 percent in the plane of the air stream. Presented also are the effects of leading-edge roughness on the 0° sweep wing, and the effect of the presence of a fuselage on the 60° delta wing, and the aerodynamic characteristics of the 45° sweptback wing with a constant-thickness flat-plate airfoil section.

COEFFICIENTS AND SYMBOLS

The following standard NACA coefficients and symbols are used in this paper:

C_L lift coefficient, $\frac{\text{Twice lift of semispan model}}{qS}$

$C_{L_{max}}$ maximum lift coefficient

C_D drag coefficient, $\frac{\text{Twice drag of semispan model}}{qS}$

C_m pitching-moment coefficient referred to $0.25\bar{c}$,

$$\frac{\text{Twice pitching moment of semispan model}}{qS\bar{c}}$$

C_B bending-moment coefficient in plane of symmetry about axis parallel to free air stream,

$$\frac{\text{Bending moment of semispan model}}{\frac{qS}{2}\frac{b}{2}}$$

q effective dynamic pressure over span of model, $\frac{1}{2}\rho V^2$, lb/sq ft

S twice area of semispan model, sq ft

b twice span of semispan model, ft

$\bar{c}$ mean aerodynamic chord of wing, $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft

c local wing chord, ft

c_t chord at wing tip, ft

c_r chord at wing root, ft

y spanwise distance from plane of symmetry, ft

ρ mass density of air, slugs/cu ft

V average free-stream air velocity, fps

M effective Mach number over span of model

M_a average chordwise Mach number

M_l local Mach number

R Reynolds number of wing based on $\bar{c}$

α angle of attack, deg

$\alpha_{C_{L_{max}}}$ angle of attack at which maximum lift coefficient is obtained, deg

$\frac{\partial C_m}{\partial C_L}$ variation of pitching-moment coefficient with lift coefficient

$\frac{\partial C_B}{\partial C_L}$ variation of bending-moment coefficient with lift coefficient

C_{L_α} variation of lift coefficient with angle of attack, $\frac{\partial C_L}{\partial \alpha}$

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

MODELS AND APPARATUS

Sketches and geometric characteristics of the models as tested on the side-wall reflection-plate balance are shown in figure 1. The

0° sweep wing, also designated as 0-4-0.6-006, for 0° sweep of the quarter-chord line, an aspect ratio of 4, a taper ratio of 0.6, and an NACA 65A006 airfoil section parallel to free stream, respectively, was made of steel. For the leading-edge roughness tests on the 0° sweep wing, No. 60 carborundum grains were glued to the upper and lower surfaces of the wing from the leading edge to 0.05 chord.

Wing 45-4-0.6-006 had 45° of sweepback measured at the quarter-chord line, an aspect ratio of 4, a taper ratio of 0.6, and utilized an NACA 65A006 airfoil section parallel to free stream. Wing 45-4-0.6-PL., a flat-plate airfoil variation of the 45° sweptback wing, consisted essentially of a 0.25-inch flat steel plate with a radius leading edge. No attempt was made to fair the tip and trailing edge.

Wing 60° Δ-006 comprised a delta wing of 60° leading-edge sweepback, with an aspect ratio of 2.31, a taper ratio of 0, and an NACA 65-006 airfoil section parallel to free stream. The wing was made of a bismuth and tin alloy bonded to a tapered steel core. Wing contours were generated by straight-line elements from the tip to the airfoil section at the root. The half-fuselage, the ordinates of which are given in figure 1 and which was used in conjunction with the 60° delta wing for some of the tests, was made of brass.

The models were mounted on an electrical strain-gage balance which was enclosed within a sealed chamber behind the reflection-plate fairing. For these tests, each model was mounted with the wing-root chord 0.03 inch from the surface of the reflection plate. (This 0.03-inch clearance was also maintained between the half-fuselage and the reflection plate for tests of fuselage effect on the 60° delta wing.) The clearance hole in the reflection-plate turntable, through which the wing roots passed, was sealed with sponge rubber. The wing lift, drag, pitching moments, and bending moments were measured with a calibrated electrical potentiometer.

TESTS

The tests were made on the reflection plate mounted on the side wall of the Langley high-speed 7- by 10-foot tunnel, a description of which is given in reference 1. The technique involves placing the model in the local high-velocity field induced over the top surface of the reflection plate by the presence of the flow blockage between the plate and the tunnel wall.

Typical contours of the velocity field over the reflection plate with the model removed, but with model positions superimposed on the contour charts, are presented in figure 2. The contours indicate a maximum spanwise Mach number variation over the wing semispan of 0.08

and a maximum chordwise gradient of 0.07. The effective test Mach number was obtained from contour charts similar to those presented in figure 2 using the relationship

$$M = \frac{2}{S}\int_0^{b/2} cM_a\,dy$$

Force and moment data for the three basic wings were obtained over a Mach number range of approximately 0.6 to 1.10. Brief tests of the 0° sweep wing with roughness, the 45° sweptback wing with flat-plate airfoil, and the 60° delta wing with fuselage were made at several representative intermediate Mach numbers. The specific Mach numbers at which tests were made varied somewhat between models because constant tunnel dynamic pressure q, rather than a constant Mach number, was maintained for the tests. Reynolds number range for the 0° sweep and 45° sweptback wings, as presented in figure 3, varied from approximately 500,000 to 800,000, whereas for the 60° delta wing the Reynolds number range was 900,000 to 1,400,000.

All wings were investigated over an angle-of-attack range of 0° to 60° with the range extended to 69.5° for the 60° delta wing.

CORRECTIONS

The lift, drag, and pitching moments presented herein represent data for complete wings, whereas bending moment is presented in terms of wing semispan.

Small corrections to account for slight tunnel air-flow misalinement and for small balance interactions have been applied to the drag data. No jet-boundary corrections were applied because of the small size of the models relative to the size of the tunnel test section. Effects of the sponge-rubber seal on similar semispan wings have been found to be small as indicated in reference 1 and therefore have not been applied.

No corrections were made to the data of this paper to account for the effects of wing flexibility. Such corrections, though difficult to determine analytically, can be qualitatively compared to the corrections for wing flexibility as determined in reference 1. The predominant effects of wing flexibility, torsional deflection and spanwise change in angle of attack due to wing bending, increase in importance with increase in aspect ratio and sweep angle, respectively. The spanwise decrease in angle of attack for swept wings evidences itself as a loss of lift and consequent forward movement of the aerodynamic center.

Corrections of reference 1 for a 45° sweptback wing, geometrically and structurally similar to the 45° sweptback wing of this paper, reflect these loading changes with an increase in C_L of 4 to 7 percent at low angles of attack over the Mach number range of 0.6 to 0.95. Corresponding corrections to $\frac{\partial C_m}{\partial C_L}$ move the aerodynamic center rearward about $0.01\bar{c}$ throughout the Mach number range. The effects of wing flexibility on the aerodynamic characteristics of the 0° sweep wing and the 60° delta wing of this paper are believed to be of considerably less magnitude than the effects on the 45° sweptback wing.

RESULTS AND DISCUSSION

The discussion of the results of the present investigation will be predominately based upon the summary of the aerodynamic characteristics at high angles of attack of the individual wings (fig. 8) with detailed reference to the original data of figures 4, 5, 6, and 7 only when specific observed phenomena merit more detailed comment. (The data of this paper are not believed complete enough in the low ranges of angle of attack to determine accurately the aerodynamic parameters C_{L_α}, $\frac{\partial C_m}{\partial C_L}$, $\frac{\partial C_B}{\partial C_L}$, and $\frac{L}{D}$. These parameters may be obtained in references 1 to 5 for the 0° sweep wing, in references 1, 2, 6, and 7 for the 45° sweptback wing, and in references 8 to 10 for the 60° delta wing.)

Basic Wings

Maximum lift coefficient $C_{L_{max}}$ at Mach numbers less than about 0.95 increases with increase in sweep angle as evidenced at $M = 0.7$ by values of $C_{L_{max}}$ of 0.73, 0.86, and 1.04 for the 0° sweep, 45° sweptback, and 60° delta wings, respectively, (fig. 8). This trend is also shown in reference 2. Increase in Mach number in the lower subsonic speed range decreases the value of $C_{L_{max}}$ obtainable for each of the three wings, but above about $M = 0.85$, $C_{L_{max}}$ increases with increase in Mach number, the 0° sweep wing exhibiting a high value of 1.35 at $M = 1.1$.

The angle of attack at which $C_{L_{max}}$ was obtained increased with increase in Mach number for the 0° sweep and 60° delta wings. A sharp increase from $\alpha_{C_{L_{max}}} = 23^{\circ}$ at $M = 0.8$ to 34° at $M = 0.9$ occurred for the 45° sweptback wing.

Comparison of the results obtained in the present investigation with those obtained for similar wings in other test facilities (fig. 9) shows generally good agreement for $C_{L_{max}}$.

Effect of Modifications to Basic Wings

Effect of leading-edge roughness on the 0° sweep wing.- Application of leading-edge roughness to fix transition on the 0° sweep wing had negligible effect at $M = 0.81$ on $C_{L_{max}}$ and on $\alpha_{C_{L_{max}}}$.

Effect of constant-thickness flat-plate airfoil on the aerodynamic characteristics of the 45° sweptback wing.- The 45° sweptback wing with constant-thickness flat-plate airfoil section exhibits in figure 6 an increase of 14 and 18 percent in C_L over that of the original wing (fig. 5) at an angle of attack of 8° and Mach numbers of 0.605 and 0.815, respectively. A lesser increase occurs at other angles of attack and Mach numbers investigated. Use of the flat-plate airfoil increased the value of $C_{L_{max}}$ obtainable at all Mach numbers. The angle of attack at which $C_{L_{max}}$ was obtained increased slightly below $M = 0.815$, but decreased about 5° to 8° at $M = 0.910$ and 1.084, respectively, over that obtained for the basic 45° sweptback wing (fig. 8).

Effect of fuselage on the 60° delta wing.- The presence of the fuselage had slight effect on most of the aerodynamic characteristics of the 60° delta wing (fig. 7), tending to increase C_D a generally constant amount at low lift coefficients. There was a small decrease in $C_{L_{max}}$ obtainable, and little or no effect on $\alpha_{C_{L_{max}}}$ (fig. 8).

CONCLUSIONS

Results of tests at transonic speeds and high angles of attack of a 0° sweep, a 45° sweptback, and a 60° delta wing indicate that maximum lift coefficients obtainable increased with increase in sweep angle and decreased with Mach number at the lower subsonic Mach numbers. The maximum lift coefficient increased with increase in Mach number above a Mach number of 0.95 with less effect of sweep angle. The angle of attack at which maximum lift coefficient was obtained, generally increased with

Mach number. A thickened flat-plate airfoil section used in place of the original NACA 65-series airfoil section increased the value of maximum lift coefficient obtainable for the 45° sweptback wing.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Donlan, Charles J., Myers, Boyd C., II, and Mattson, Axel T.: A Comparison of the Aerodynamic Characteristics at Transonic Speeds of Four Wing-Fuselage Configurations as Determined From Different Test Techniques. NACA RM L50H02, 1950.

2. Turner, Thomas R.: Effects of Sweep on the Maximum-Lift Characteristics of Four Aspect-Ratio-4 Wings at Transonic Speeds. NACA RM L50H11, 1950.

3. Goodson, Kenneth W., and Morrison, William D., Jr.: Aerodynamic Characteristics of a Wing With Unswept Quarter-Chord Line, Aspect Ratio 4, Taper Ratio 0.6, and NACA 65A006 Airfoil Section. Transonic-Bump Method. NACA RM L9H22, 1949.

4. Cahn, Maurice S., and Bryan, Carroll R.: A Transonic-Wing Investigation in the Langley 8-Foot High-Speed Tunnel at High Subsonic Mach Numbers and at a Mach Number of 1.2. Wing-Fuselage Configuration Having a Wing of 0° Sweepback, Aspect Ratio 4.0, Taper Ratio 0.6, and NACA 65A006 Airfoil Section. NACA RM L51A02, 1951.

5. Wiggins, James W., and Kuhn, Richard E.: Wind-Tunnel Investigation of the Aerodynamic Characteristics in Pitch of Wing-Fuselage Combinations at High-Subsonic Speeds. Sweep Series. NACA RM L52D18, 1952.

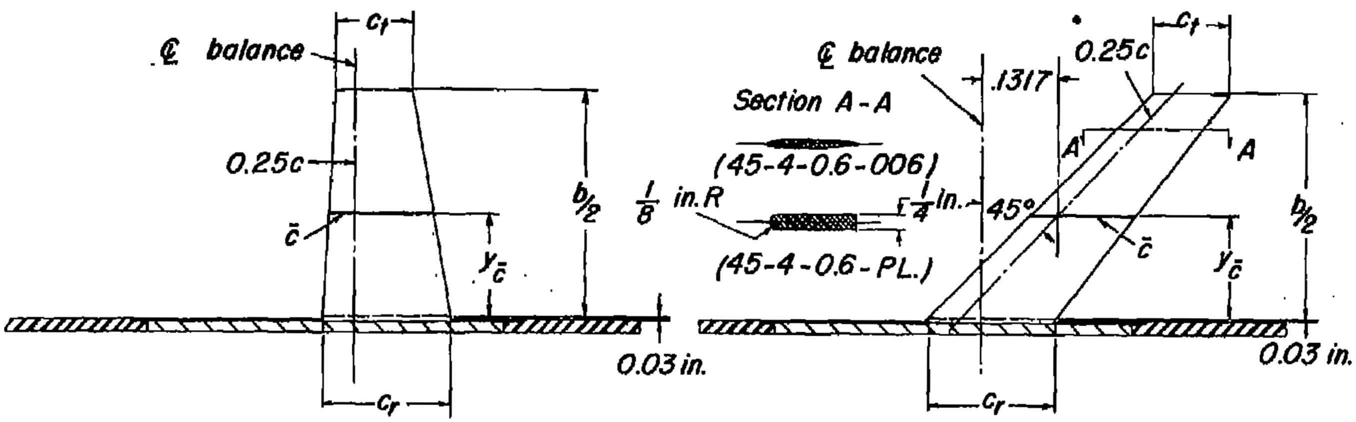
6. Osborne, Robert S.: A Transonic-Wing Investigation in the Langley 8-Foot High-Speed Tunnel at High Subsonic Mach Numbers and at a Mach Number of 1.2. Wing-Fuselage Configuration Having a Wing of 45° Sweepback, Aspect Ratio 4, Taper Ratio 0.6, and NACA 65A006 Airfoil Section. NACA RM L50H08, 1950.

7. Kuhn, Richard E., and Wiggins, James W.: Wind-Tunnel Investigation of the Aerodynamic Characteristics in Pitch of Wing-Fuselage Combinations at High Subsonic Speeds. Aspect-Ratio Series. NACA RM L52A29, 1952.

8. Hall, Albert W., and McKay, James M.: The Effects on the Aerodynamic Characteristics of Varying the Wing Thickness Ratio of a Triangular Wing-Body Configuration at Transonic Speeds From Tests by the NACA Wing-Flow Method. NACA RM L52B18, 1952.

9. Mitcham, Grady L., Crabill, Norman L., and Stevens, Joseph E.: Flight Determination of the Drag and Longitudinal Stability and Control Characteristics of a Rocket-Powered Model of a 60° Delta-Wing Airplane From Mach Numbers of 0.75 to 1.70. NACA RM L51I04, 1951.

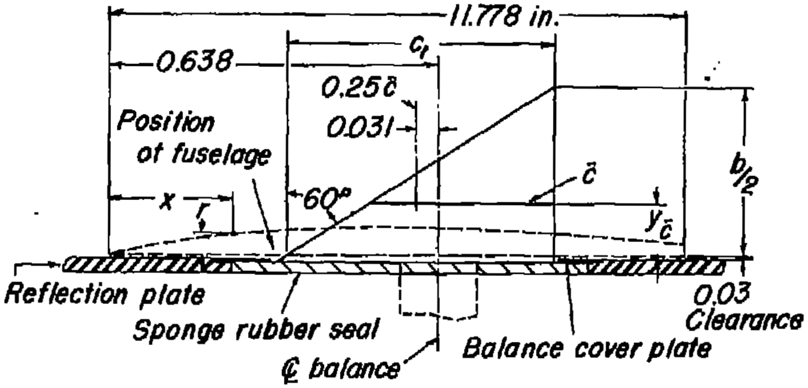
10. Lowry, John G., and Cahill, Jones F.: Review of the Maximum-Lift Characteristics of Thin and Swept Wings. NACA RM L51E03, 1951.



0° Sweep wing (0-4.0-0.6-006)

45° Sweptback wing (45-4.0-0.6-006)

(45-4.0-0.6-PL.)



60° Delta wing (60° Δ-006)

(All dimensions in feet unless otherwise specified.)

Sweep angle	0° (C/4)	45° (C/4)	45° (C/4)	60° (L.E.)
Aspect ratio	4.0	4.0	4.0	2.31
Taper ratio	0.6	0.6	0.6	0
Wing semispan, b/2, ft.	0.354	0.354	0.354	0.267
Wing semispan area, S/2, ft.^{2}	0.062	0.062	0.062	0.062
Mean aerodynamic chord, $\bar{c}$, ft.	0.181	0.181	0.181	0.308
Lateral location of aerodynamic center, $y_{\bar{c}}$, ft.	0.162	0.162	0.162	0.089
Root chord, c_r, ft.	0.221	0.221	0.221	0.463
Tip chord, c_t, ft.	0.133	0.133	0.133	0
Airfoil section parallel to free stream	NACA 65A006	NACA 65A006	1/4in.flat plate	NACA 65-006

Table of Fuselage Ordinates

(Dimensions in inches)

x	r	x	r	x	r
0	0	2.121	.367	7.777	.584
.071	.033	2.828	.437	8.484	.569
.099	.042	3.535	.490	9.191	.542
.177	.061	4.242	.528	9.898	.503
.354	.102	4.947	.556	10.605	.442
.707	.170	5.656	.573	11.312	.357
.909	.228	6.363	.586	11.778	.307
1.414	.279	7.070	.589		

Figure 1.- Dimensional characteristics of wings as mounted on the reflection plate.

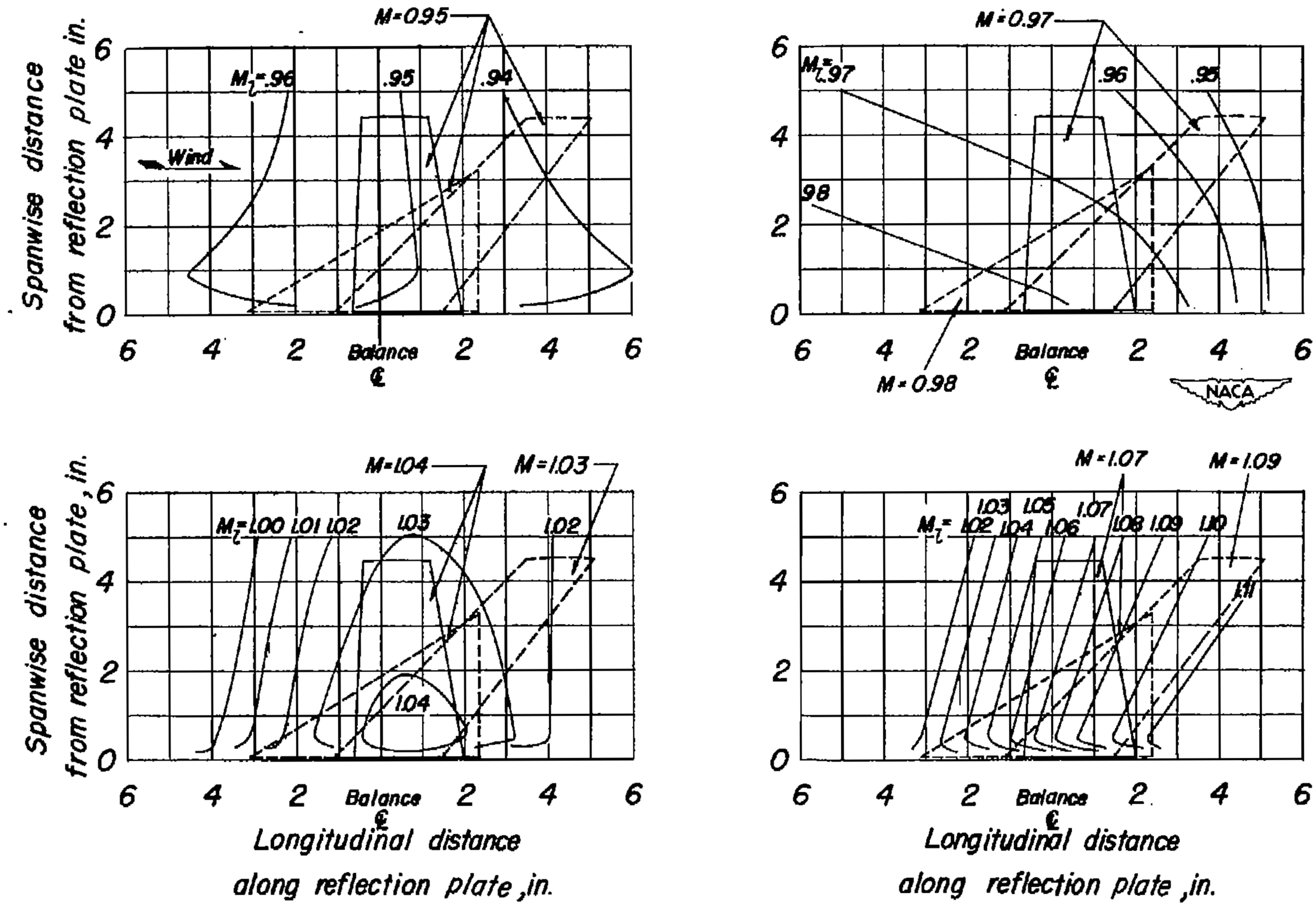


Figure 2.- Typical Mach number contours over side-wall reflection plate in region of model location.

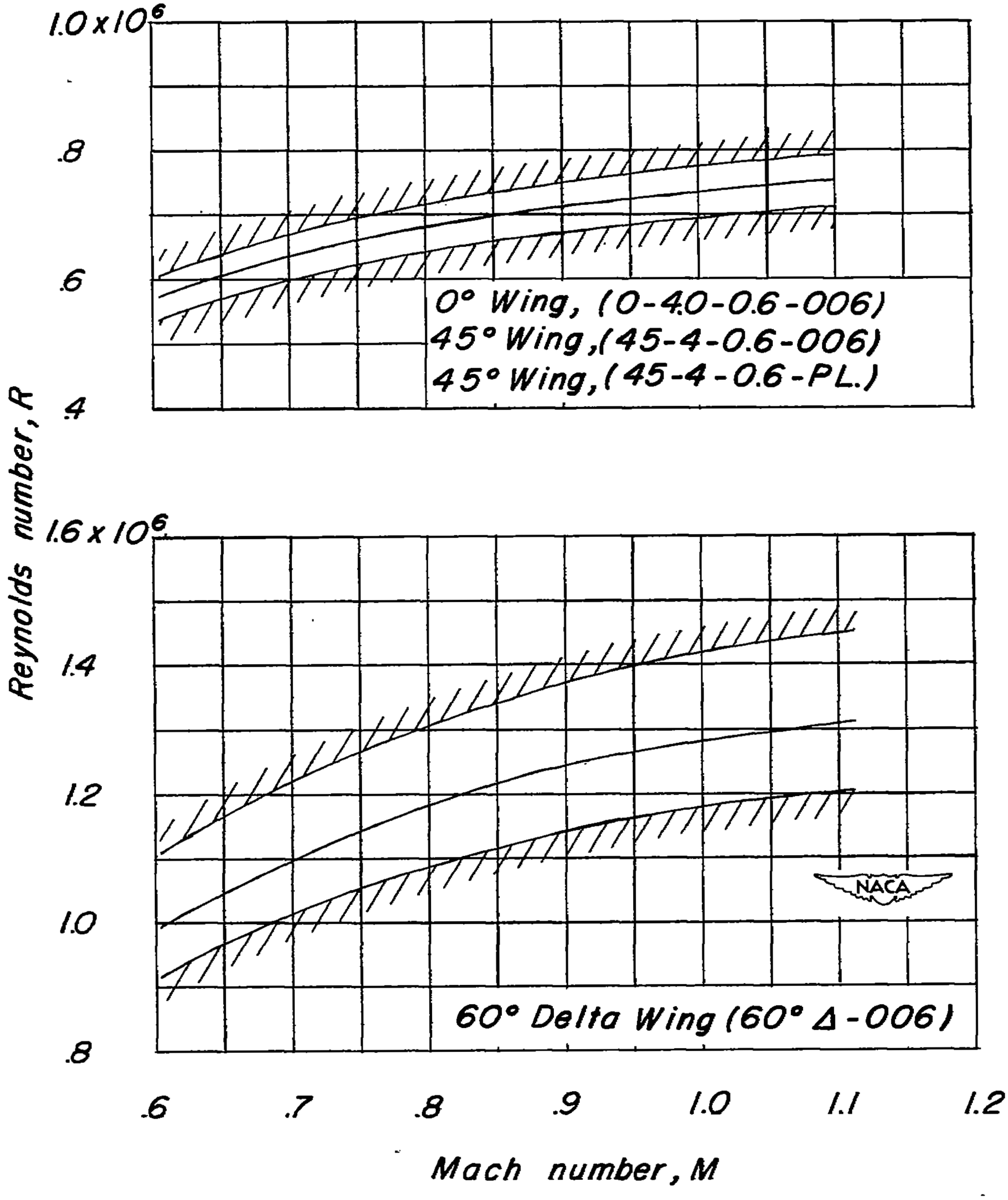


Figure 3.- Variation of test Reynolds number with Mach number for models of 0° and 45° swept wings and 60° delta wing.

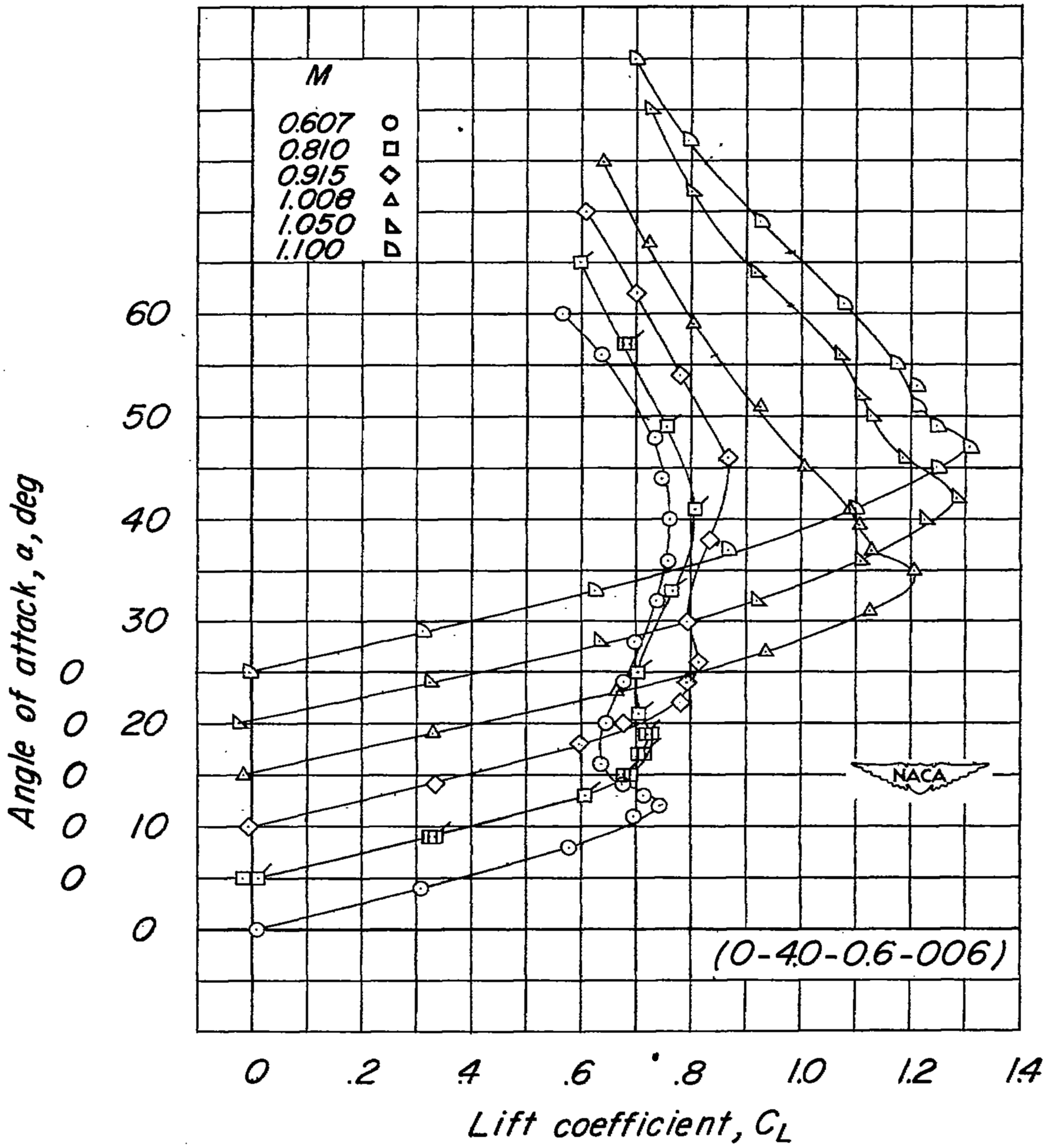


Figure 4.- Aerodynamic characteristics of an aspect ratio 4.0, taper ratio 0.6, 0° swept wing with an NACA 65A006 airfoil section parallel to free stream with and without transition. (Flagged symbols denote tests with roughness.)

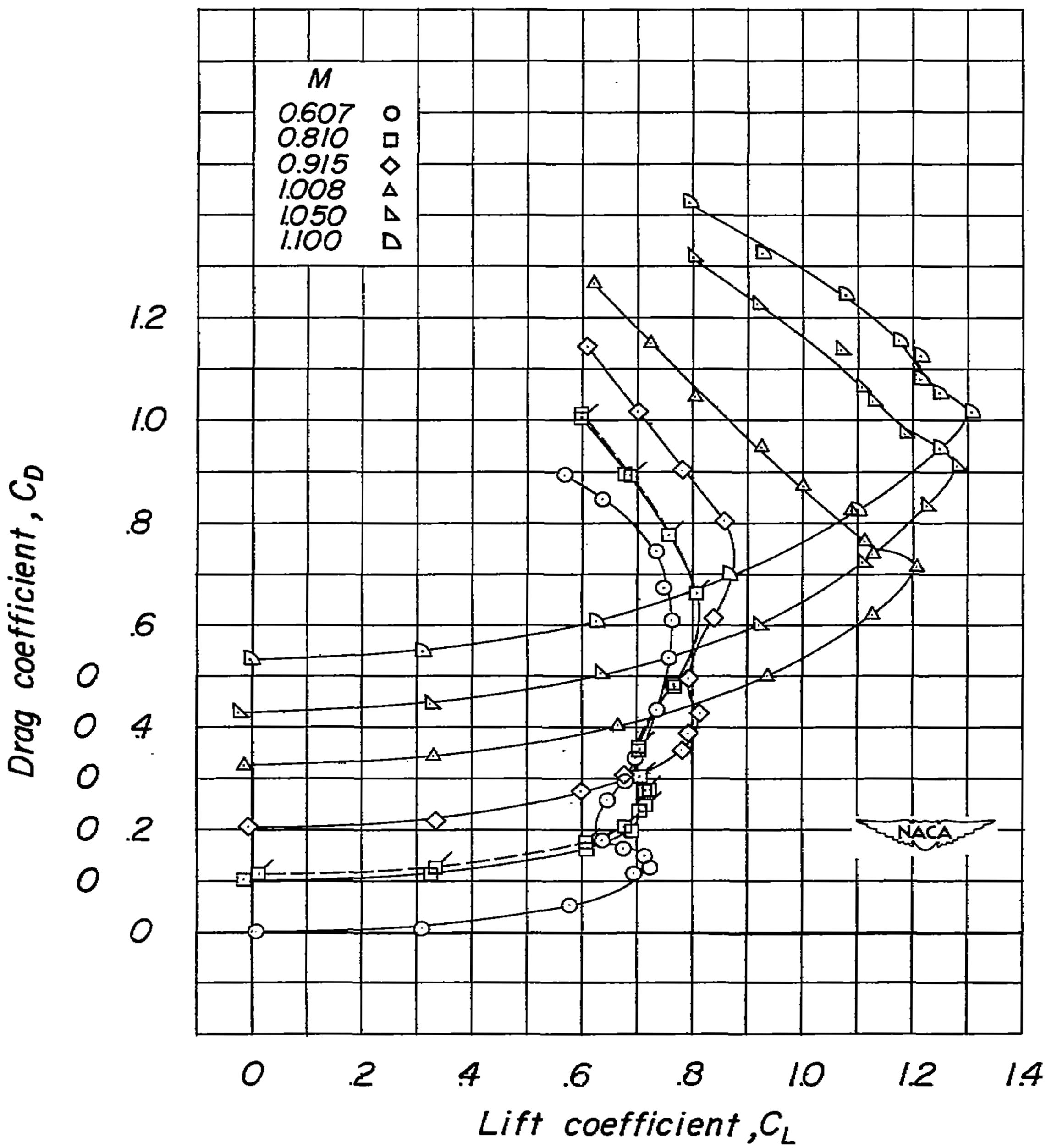


Figure 4.- Continued.

[redacted]

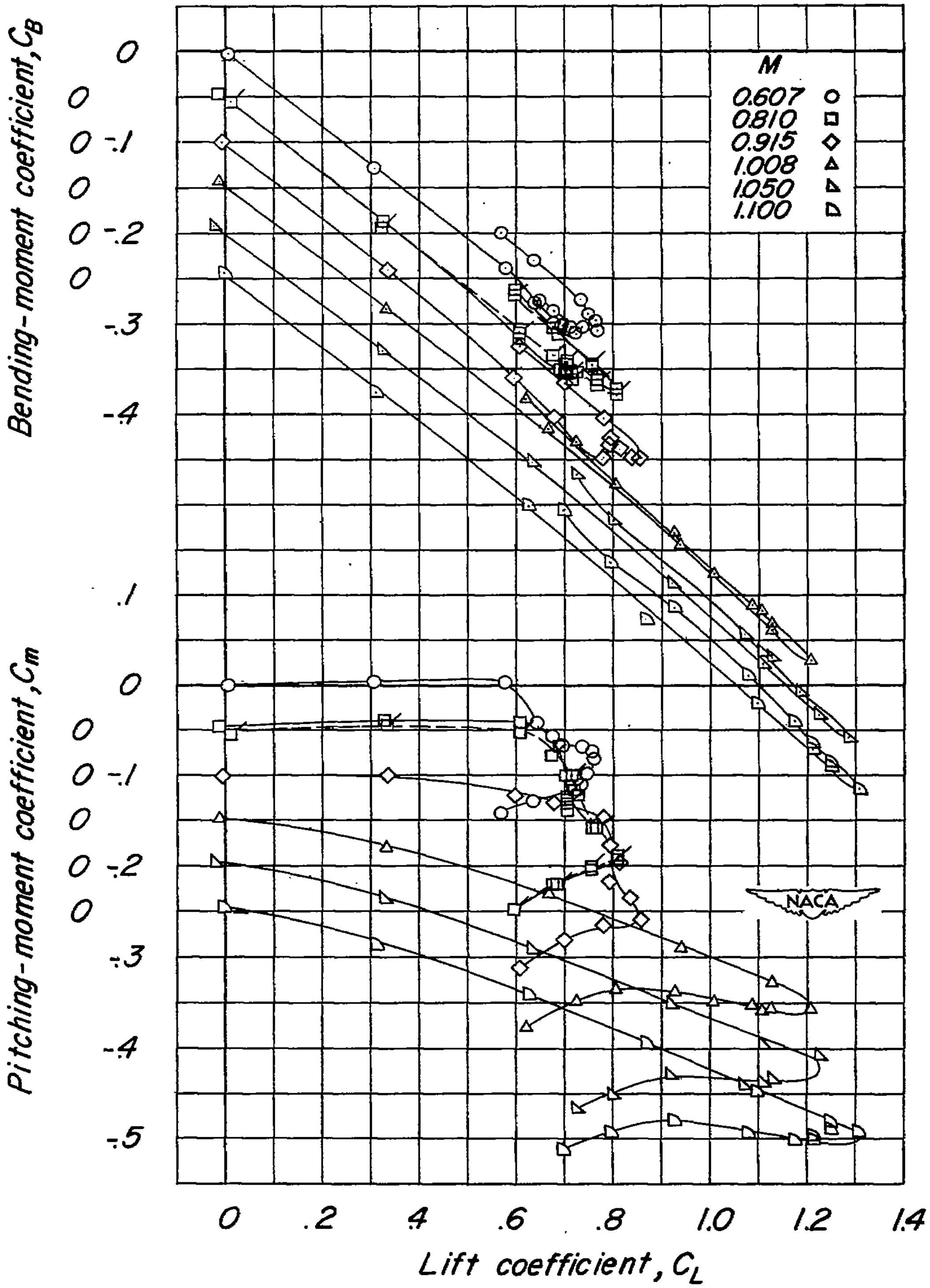


Figure 4.- Concluded.

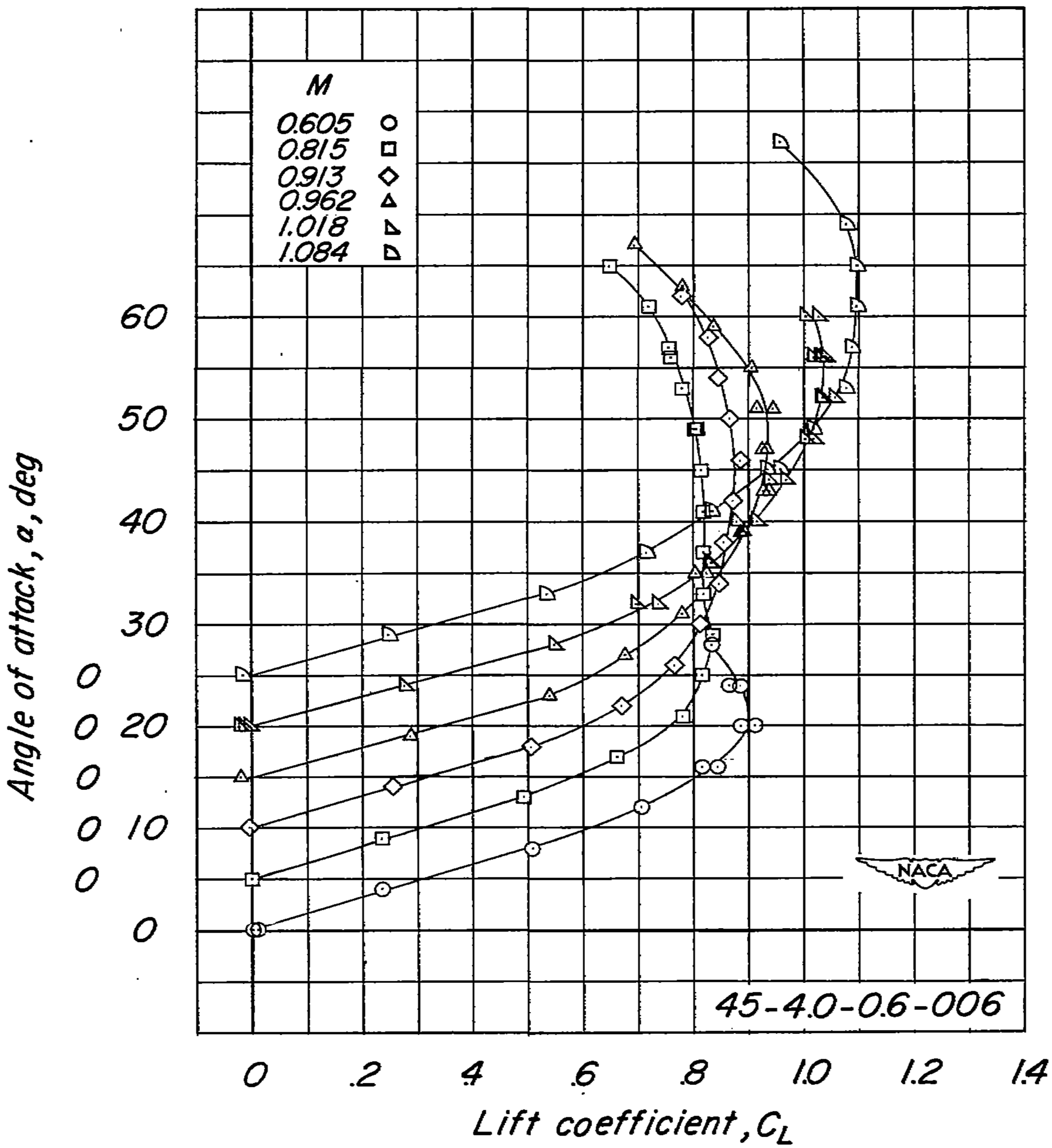


Figure 5.- Aerodynamic characteristics of an aspect ratio 4.0, taper ratio 0.6, 45° sweptback wing with an NACA 65A006 airfoil section parallel to free stream.

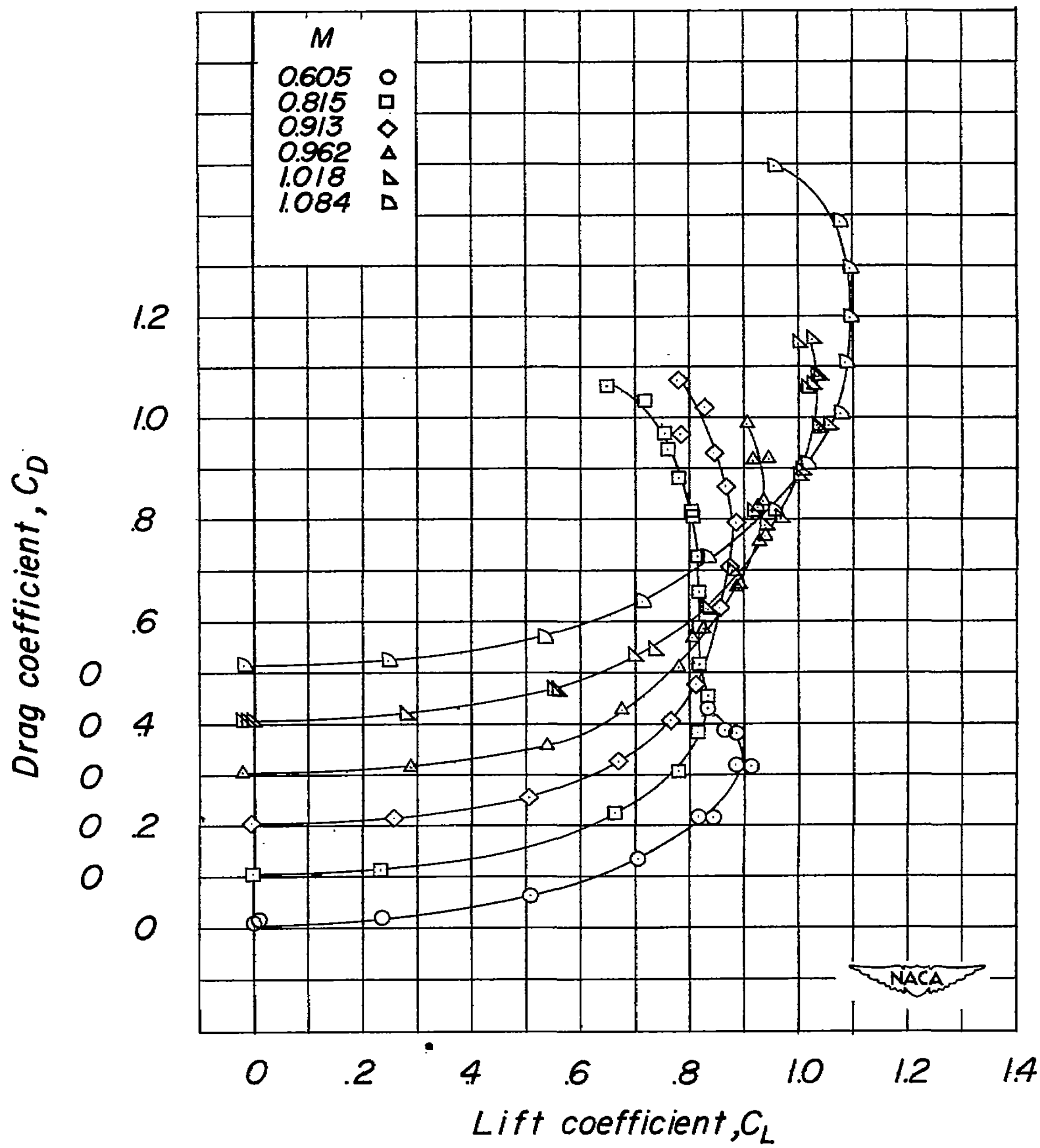


Figure 5.- Continued.

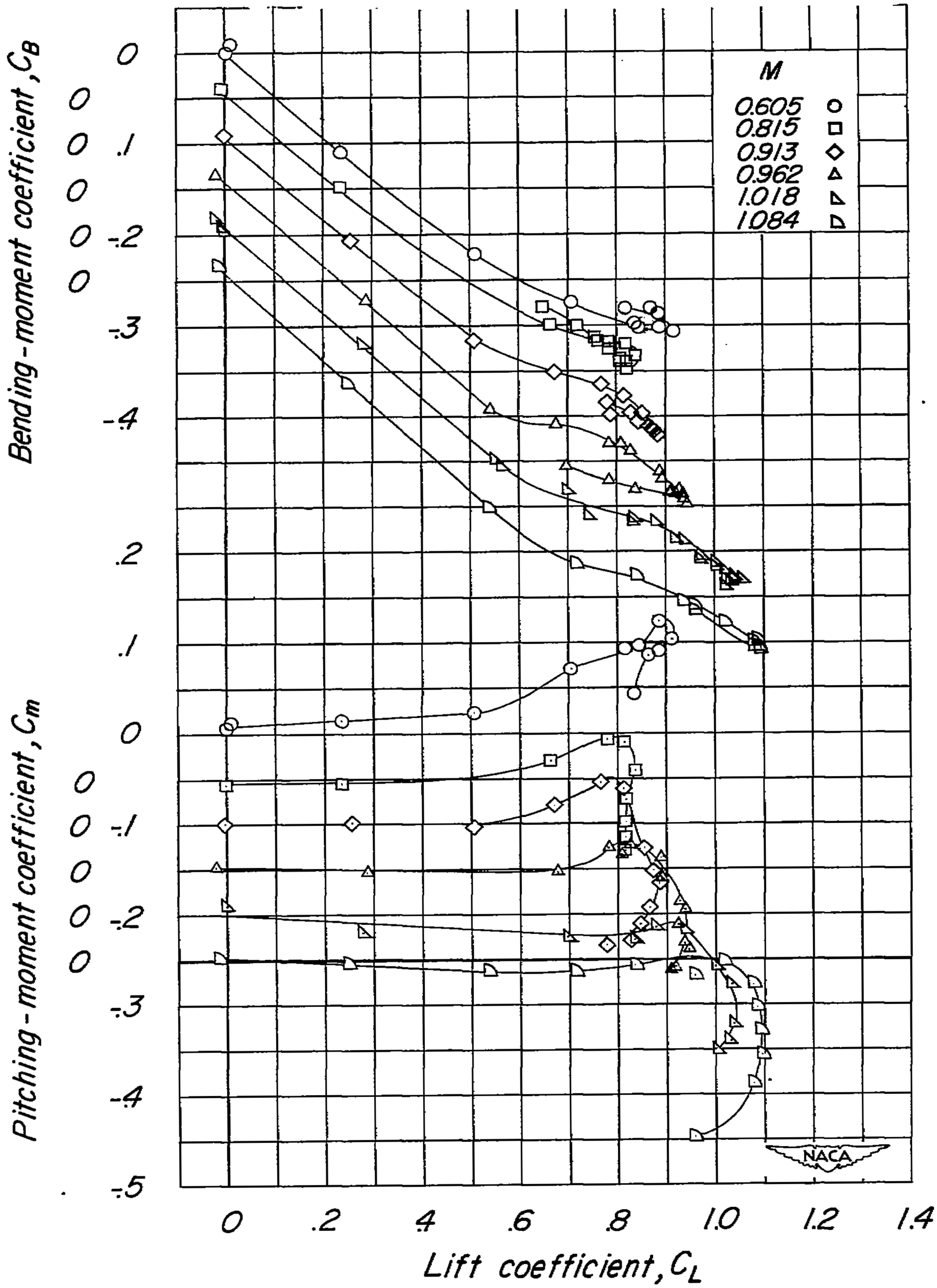


Figure 5.- Concluded.

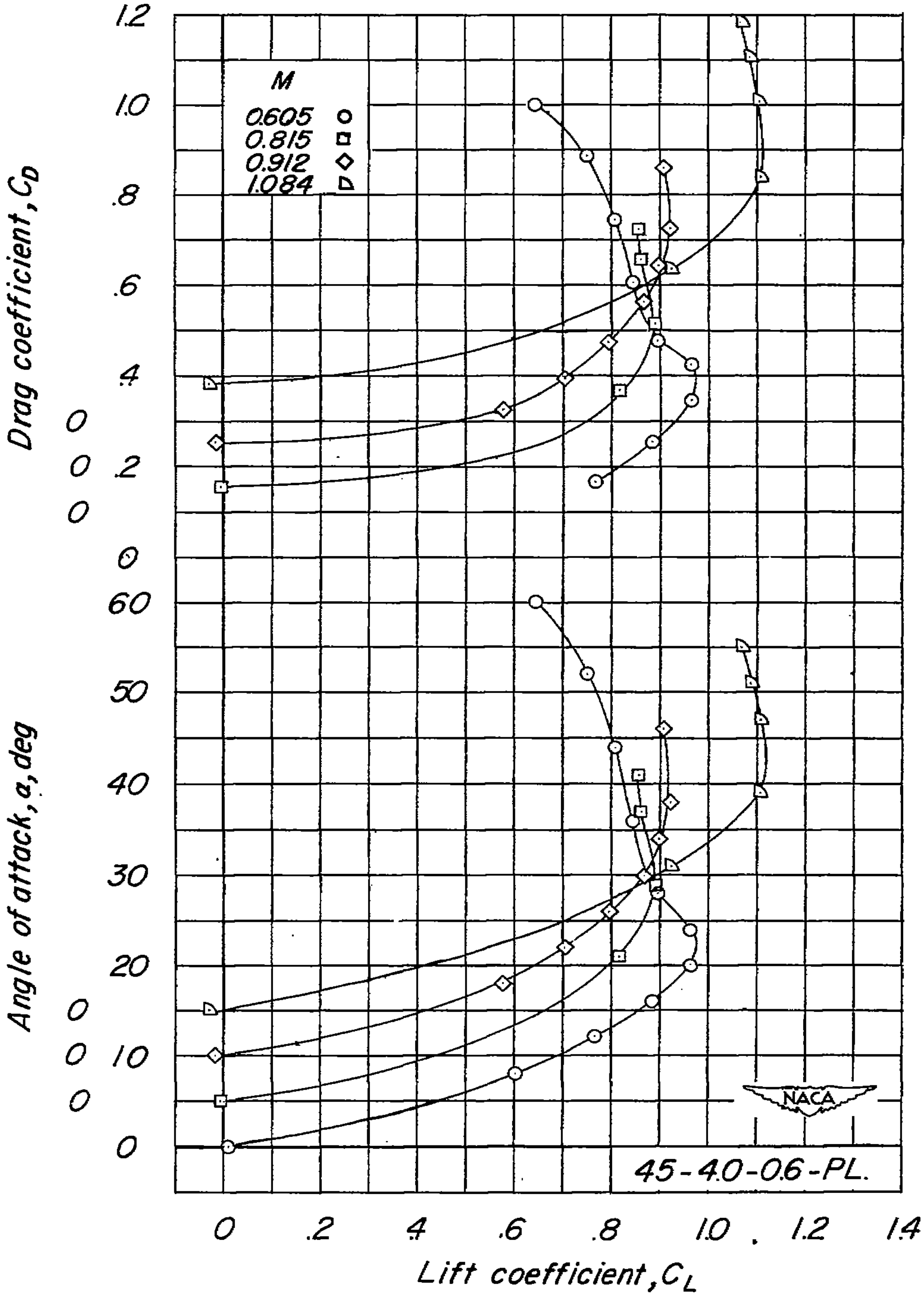


Figure 6.- Aerodynamic characteristics of an aspect ratio 4.0, taper ratio 0.6, 45° sweptback wing with a constant-thickness "flat-plate" airfoil section.

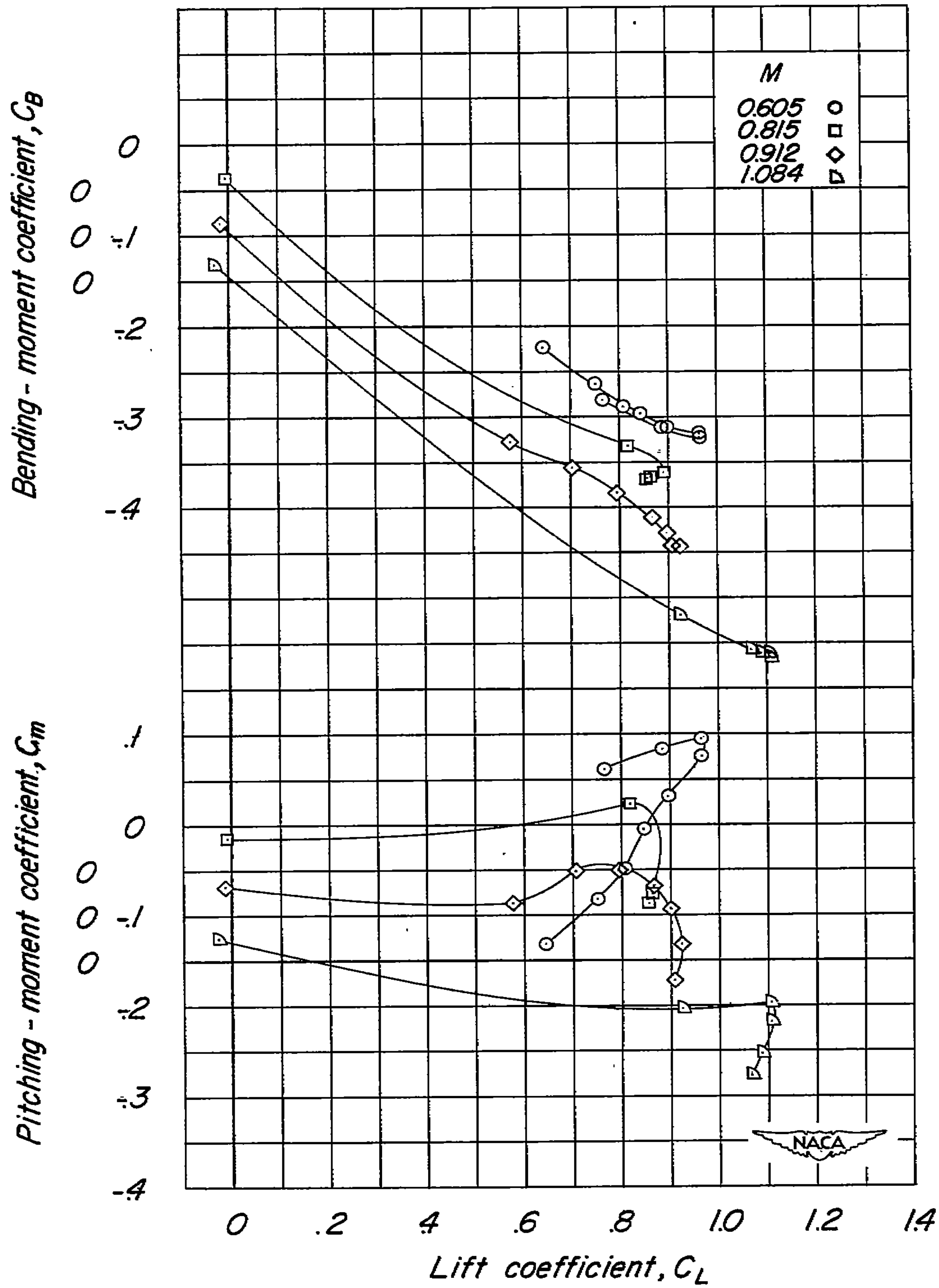


Figure 6.- Concluded.

[redacted]

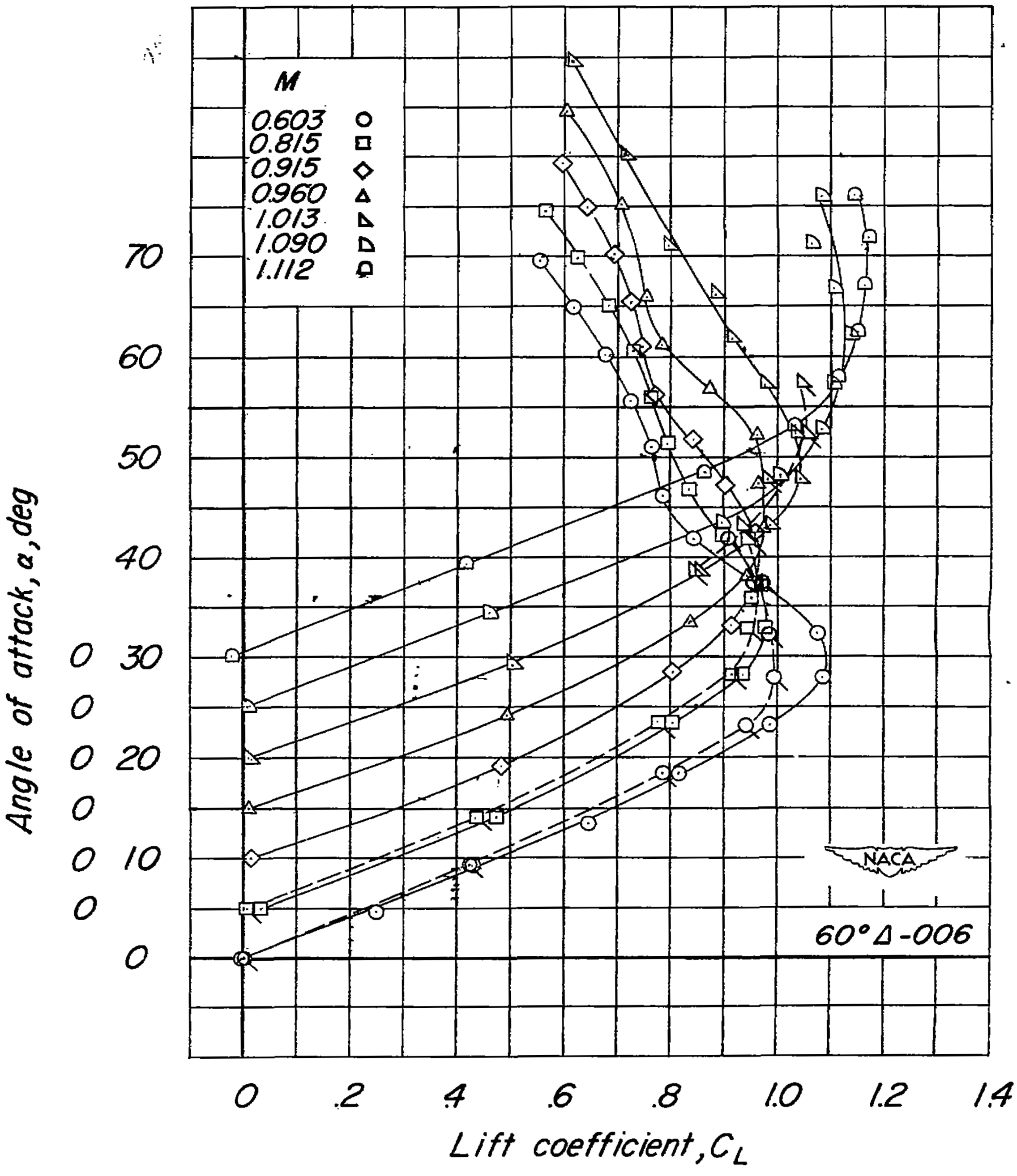


Figure 7.- Aerodynamic characteristics with and without a fuselage, of an aspect ratio 2.31, taper ratio 0, 60° delta wing with an NACA 65-006 airfoil section parallel to free air stream. (Flagged symbols denote tests with fuselage.)

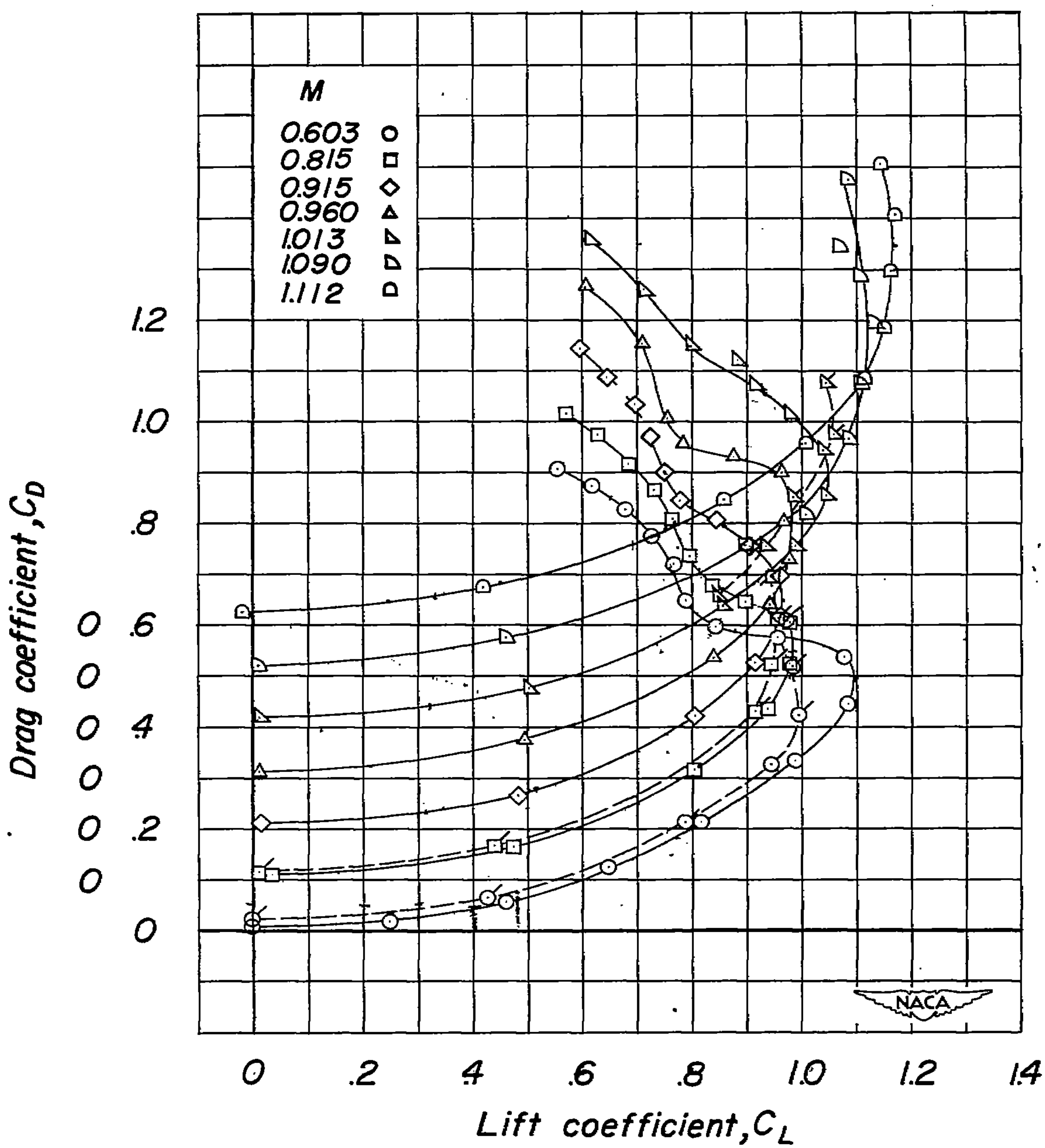


Figure 7.- Continued.

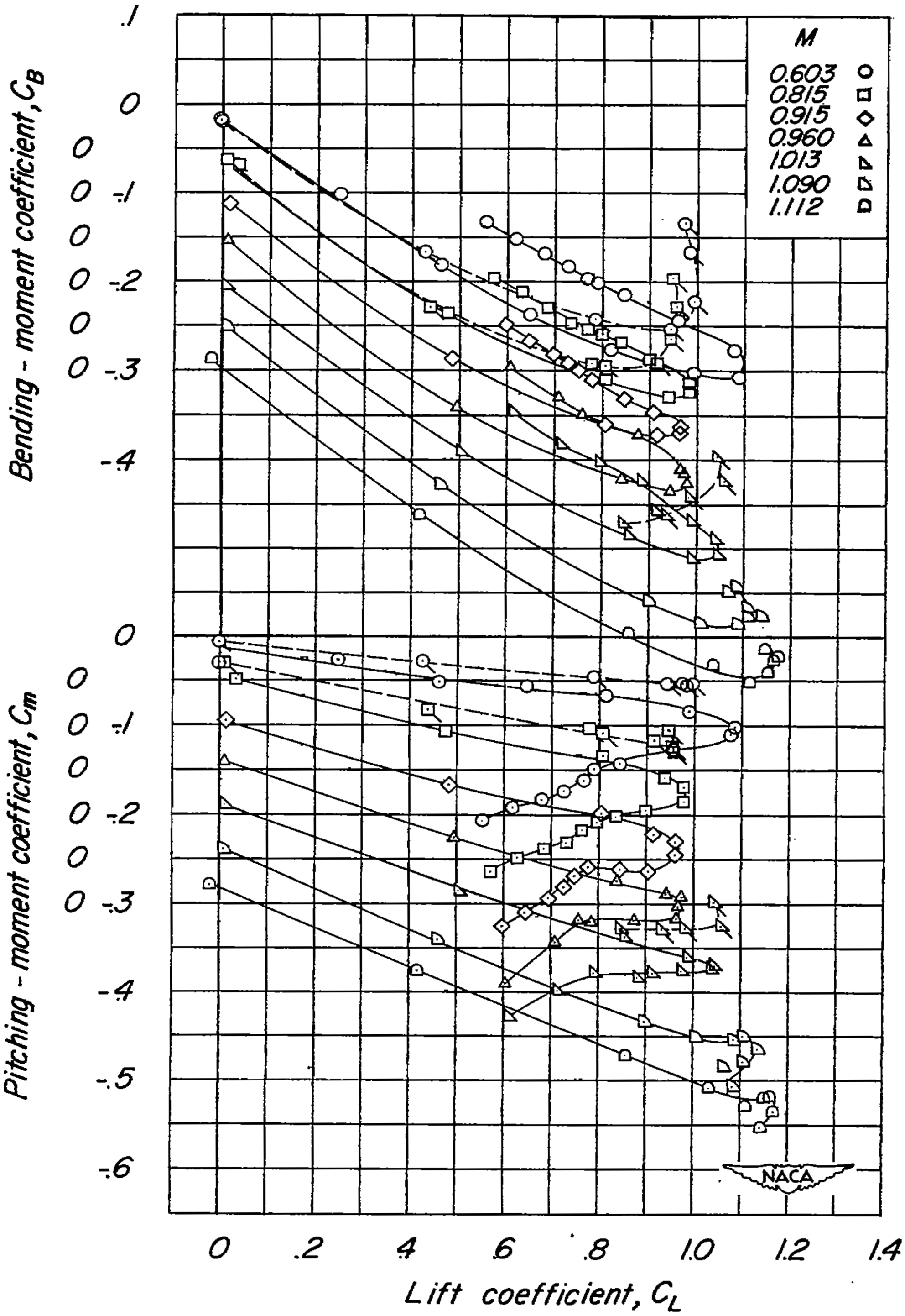


Figure 7.- Concluded.

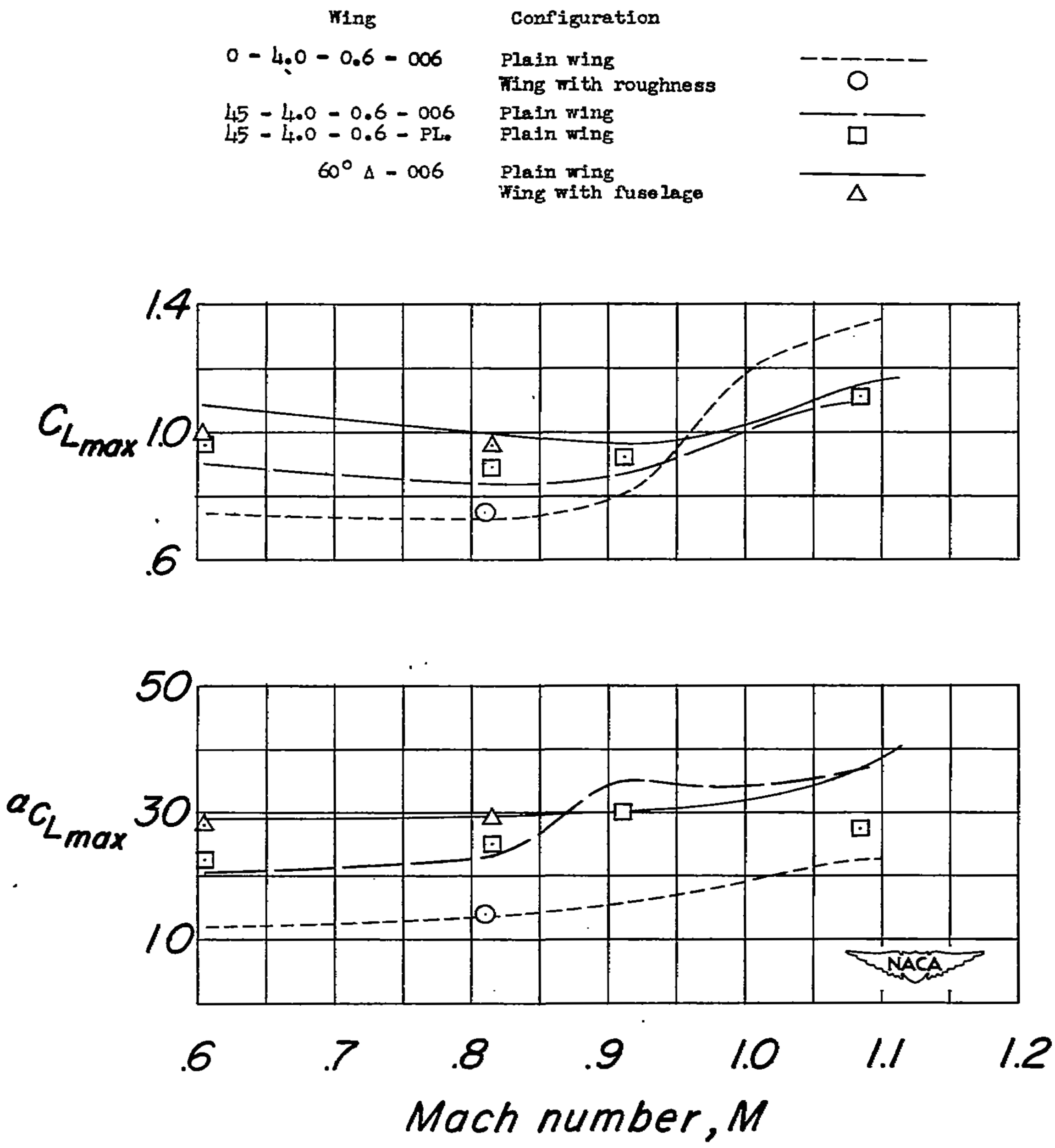


Figure 8.- Variation of aerodynamic characteristics with Mach number for 0° and 45° sweptback wings and a 60° delta wing.

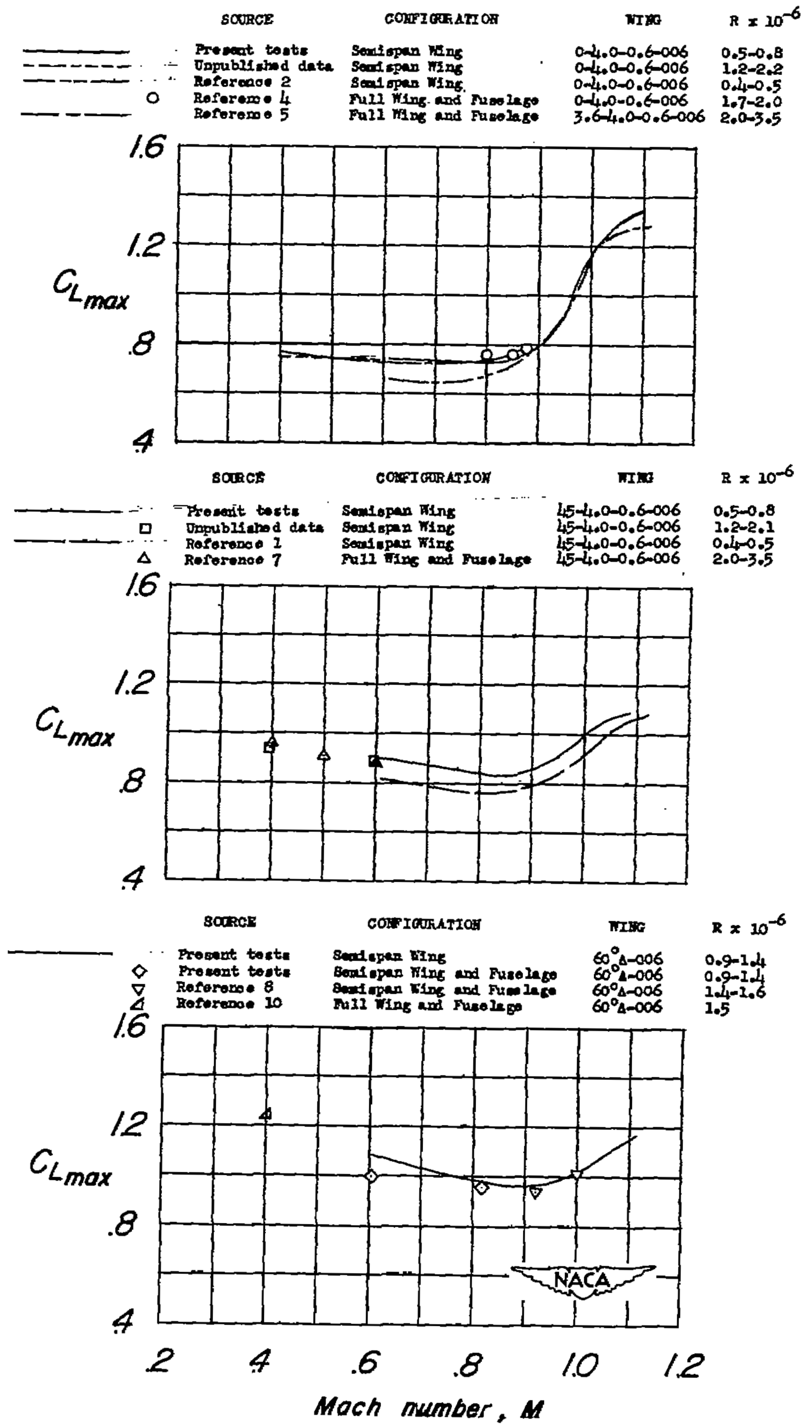


Figure 9.- Comparisons of the variations of aerodynamic characteristics with Mach number as obtained in several test facilities.

[redacted]