CONFIDENTIAL

RM No. L6K18a

RESEARCH MEMORANDUM

EFFECTS OF 45° SWEEPBACK ON THE HIGH-SPEED CHARACTERISTICS OF A WING HAVING A MODIFIED NACA 16-012 AIRFOIL SECTION

By

Luke L. Liccini

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

July 18, 1947

CONFIDENTIAL

NACA RM No. L6K18a

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECTS OF 45° SWEEPBACK ON THE HIGH-SPEED CHARACTERISTICS OF A WING HAVING A MODIFIED NACA 16-012 AIRFOIL SECTION

By Luke L. Liccini

SUMMARY

The force characteristics of a wing with 0° sweepback and with 45° sweepback were investigated in the Langley 8-foot high-speed tunnel through a Mach number range of 0.4 to 0.875. The wing used had a modified NACA 16-012 airfoil section.

The results showed that, for angles of attack other than 0°, sweeping back the wing 45° reduced the lift coefficient to approximately 50 percent of the lift coefficient for the unswept-back wing. This reduction agrees with the theoretical considerations which indicate lift decreases of about 30 percent due to sweeping back the wing 45° and about 20 percent due to the accompanying decrease in aspect ratio. For low lift coefficients (less than approx. 0.20) the swept-back wing had better drag characteristics than the unswept-back wing throughout the speed range; but for high lift coefficients the swept-back wing had better drag characteristics only at high speeds. Sweepback delayed the onset of serious compressibility effects to beyond the speed range tested. The maximum lift-drag ratio for the unswept-back wing decreased rapidly when the force break was reached, whereas the maximum lift-drag ratio for the swept-back wing remained nearly constant. Since the critical speed of the swept-back wing was not attained, the wing did not vibrate.

INTRODUCTION

The large drag rise and changes in lift of wings which accompany the compressibility burble impose a great handicap in increasing the speed of airplanes. The refinement in airfoil sections and the use of thin airfoils have given limited increases in the speed at which the compressibility burble occurs. The use of swept-back wings at high speeds as proposed in reference 1 suggests even greater increases in the speed at which these adverse compressibility effects occur. The purpose of the present investigation is to show the delay of compressibility effects due to 45° sweepback and to indicate some of the significant advantages thereby gained.

The data presented herein were taken from tests of radio-mast antennas; but the antenna is of such a design that it can be considered a three-dimensional semispan wing having a modified NACA 16-012 airfoil section.

When these tests were made (August 1945) the effects of sweep had just been recognized. The tests were undertaken at that time as a quick over-all check of the predicted beneficial effects of sweep.

SYMBOLS

a	speed of sound in undisturbed stream, feet per second
S	wing area, square inches
D	drag of model, pounds
L	lift of model, pounds
M	free-stream Mach number (V/a)
q	free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
V	velocity in undisturbed stream, feet per second
α	angle of attack, degrees
Λ	angle of sweepback, degrees
ρ	mass density in undisturbed stream, slugs per cubic foot
C_L	lift coefficient (L/qS)
C_D	drag coefficient (D/qS)

APPARATUS AND METHODS

The tests were conducted in the Langley 8-foot high-speed tunnel, which is of the single-return closed-throat type. The Mach number at the throat is continuously controllable up to tunnel choking speeds. The air-stream turbulence in the tunnel is small but slightly higher than in free air.

The dimensions of the model are shown in figure 1. The wing has a taper ratio of 5:1 and a modified NACA 16-012 airfoil section (fig. 2). The aspect ratios of the unswept-back model and the swept-back model are 11.3 and 5.5, respectively. The models were fitted in wooden blocks as shown in figures 3 and 4 so that the models could be mounted in the end clamps of the tunnel balance system with $21\frac{1}{2}$ inches exposed to the air stream (measured from the root to the tip along the 50-percent-chord station). The sweepback was obtained by rotating the model in a horizontal plane about the 50-percent-chord station at the root chord.

The data presented herein include Mach numbers up to only 0.875 because the tests of the swept-back wing were conducted at a time when the limitations of the tunnel setup would not permit the tests to be carried beyond this Mach number. The wings were tested through a range of angle of attack from -2° to 6° measured in the direction of the air flow. The force data were obtained from the recording scales of the balance system; model vibrations were observed visually.

Because of the enlarged root chord with sweepback, the area enveloped by the tunnel-wall boundary layer on the swept-back wing was somewhat larger than the corresponding area enveloped by the tunnel-wall boundary layer on the unswept-back wing. However, since the difference (approx. 4 percent) in areas, in terms of wing area involved, is very small, the boundary-layer effects were not taken into consideration. The constriction effects at a Mach number of 0.875 are less than 0.1 percent; therefore, these effects were neglected. Because the choking Mach number was well above the maximum test Mach number, no measurable choking effects occurred.

The variation of model Reynolds number based on the mean geometric chord of the model wing (0.381 ft) is presented in figure 5 as a function of test Mach number.

RESULTS AND DISCUSSION

Lift and Drag Characteristics

The basic force data are presented in figure 6 as lift and drag coefficients plotted against Mach number. This figure indicates that sweepback reduces the lift force approximately 50 percent for a given angle of attack other than 0°. For example, at a Mach number of 0.50 and an angle of attack of 6° the value of the lift coefficient for the unswept-back wing is 0.615, whereas the value of the lift coefficient for the swept-back wing is 0.311. As given by the theory of reference 2, the lift coefficient of the unswept-back wing at a given

angle of attack for infinite aspect ratio would be expected to vary as $\cos \Lambda$. The lift coefficient of the unswept-back wing would thus be expected to be reduced about 30 percent by sweeping back the wing 45°. The accompanying decrease in aspect ratio accounts approximately for the remaining 20 percent lift decrease. At high Mach numbers (around $M = 0.75$), a large part of the variation in lift coefficients for the swept-back and unswept-back wings is caused by the compressibility effects of the unswept-back wing.

The drag force is reduced 50 percent by using a 45° angle of sweepback at a Mach number of 0.50 for an angle of attack of 6°; however, the reduction becomes smaller at the lower angles of attack (fig. 6).

In order to illustrate the effects of sweepback, plots showing the variation of drag coefficient with lift coefficient for several Mach numbers are shown in figure 7. At low speeds ($M = 0.50$ and $M = 0.75$) the effects of the additional induced drag of the swept-back wing are illustrated by the more rapid rise in drag coefficient with increases in lift coefficient. At high speeds (above a Mach number of 0.80) the effects of compressibility are considerably larger than the effects of the increased induced drag associated with the reduction in aspect ratio. As a result, the rate of drag-coefficient rise with increases in lift coefficient at high speeds is less for the swept-back wing than for the unswept-back wing.

At constant lift coefficient, comparison of the swept-back wing with the unswept-back wing shows little difference in drag coefficients at low Mach numbers but large differences at Mach numbers above the critical Mach number of the unswept-back wing (fig. 8). For low lift coefficients (less than approx. 0.20) the swept-back wing has better drag characteristics throughout the speed range; but for high lift coefficients the swept-back wing has better drag characteristics only at high speeds. The difference in the drag coefficients at high speeds and at low lift coefficients may be explained by the fact that for the swept-back wing the decrease of the pressure drag is greater than the increase of the induced drag; however, at low speeds and at high lift coefficients the higher drag of the swept-back wing is caused by the fact that the decrease of the pressure drag is smaller than the increase of the induced drag.

In the present tests serious compressibility effects were delayed only a small amount by decreasing the aspect ratio and the thickness ratio in the air-stream direction, as compared with the delay caused by sweeping back the wing 45°. Calculations of the increase in critical speed due to the reduction in thickness ratio show a delay of the serious compressibility effects by a Mach number increment of 0.025. Results of tests in reference 3 indicate that a delay of

the onset of serious compressibility effects by the reduction in aspect ratio corresponds to a Mach number increment of 0.02. These calculations and results account for a total increment of 0.045 caused by the combined effects of the reduction in thickness ratio and aspect ratio. The data obtained, however, indicate a much greater Mach number increment of delay in the onset of serious compressibility effects. For example, in figure 6 changes in the lift-coefficient characteristics of the unswept-back wing occur at Mach numbers of the order of 0.75 to 0.80, whereas no significant changes in the lift-coefficient characteristics of the swept-back wing are found at the maximum test Mach number ($M = 0.875$). Even larger increments of Mach number beyond the points of abrupt drag-coefficient rise are indicated to be a result of sweepback, particularly at high angles of attack. These results thus show that the effects of sweepback provide a considerably larger delay in the onset of serious compressibility effects than are accounted for by the reduction in airfoil-section thickness ratio and by the reduction in aspect ratio from 11.3 to 5.5.

The theoretical analysis of reference 1 for infinite aspect ratio can be used to show that the critical Mach number increases inversely as the cosine of the sweepback angle, which fact indicates that the onset of compressibility effects would be delayed to Mach numbers of the order of 1.1 for the swept-back model. Since the experimental results for the swept-back wing do not reach the critical speed range, agreement of the experimental results with the theoretical calculations is not shown. Full realization of the calculated delay would not be expected, however, because the theory does not include effects caused by the flow at the wing root and at the wing tips.

Lift-Drag-Ratio Characteristics

Figure 9 shows the variation with Mach number of maximum lift-drag ratio and of lift coefficient corresponding to maximum lift-drag ratio. As was expected, the maximum lift-drag ratio for the unswept-back wing decreases rapidly when the force break is reached, whereas the maximum lift-drag ratio for the swept-back wing remains almost constant. At a Mach number of 0.875 the swept-back wing, thus, has a value of maximum lift-drag ratio approximately two and one-half times the corresponding value for the unswept-back wing. The values of C_L for maximum lift-drag ratio below the critical Mach number are about 0.25 for the swept-back wing and about 0.41 for the unswept-back wing. For the swept-back wing, the curve of C_L for the maximum lift-drag ratio against Mach number shows only slight variations. For the unswept-back wing, the curve of C_L for maximum lift-drag ratio against Mach number indicates large variations.

Vibration

Beyond the critical speed, vibrations occurred during the test of the unswept-back model and were caused by the unsteady flow conditions associated with strong formation of compression shock. As would be expected, when the critical speed of the swept-back wing was delayed to speeds beyond the test range, no vibration occurred throughout the test range for the swept-back model.

CONCLUSIONS

The results of high-speed force tests of a wing with 0° sweepback and with 45° sweepback indicated the following conclusions:

1. The lift coefficient of the 45° swept-back wing for angles of attack other than 0° was reduced to approximately 50 percent of the lift coefficient of the unswept-back wing throughout the speed range tested. This reduction agrees with theoretical predictions which indicate lift decreases of about 30 percent due to sweepback and about 20 percent due to the accompanying decrease in aspect ratio.

2. For low lift coefficients (less than approx. 0.20) the swept-back wing had better drag characteristics throughout the speed range; but for high lift coefficients the swept-back wing had better drag characteristics only at high speeds.

3. A large delay in the onset of adverse compressibility effects was indicated. Analysis of the data indicated that the greater part of the delay was due to sweepback and that the delaying effects of the simultaneous changes in aspect ratio and section thickness ratio were relatively small.

4. The maximum lift-drag ratio for the unswept-back wing decreased rapidly when the force break was reached, whereas the maximum lift-drag ratio for the swept-back wing remained nearly constant.

5. Because of the delay in the onset of compressibility effects, elimination of the vibration characteristics on the swept-back wing was obtained for the speed range investigated.

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

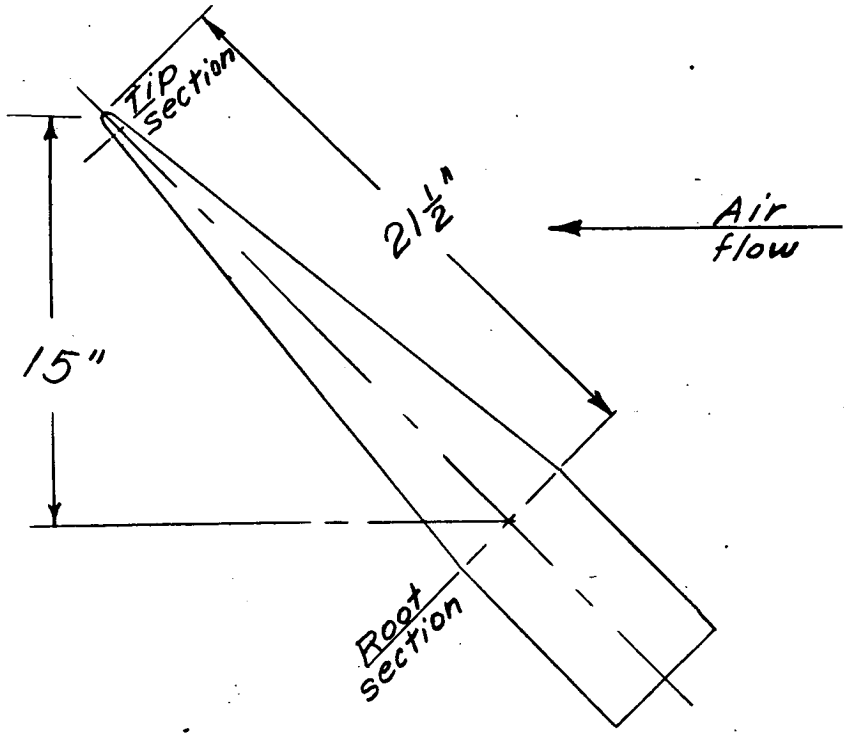
REFERENCES

1. Jones, Robert T.: Wing Plan Forms for High-Speed Flight. NACA TN No. 1033, 1946.

2. Betz, A.: Applied Airfoil Theory. Unsymmetrical and Non-Steady Types of Motion. Vol. IV of Aerodynamic Theory, div. J, ch. IV, sec. 2, W.F. Durand, ed., Julius Springer (Berlin), 1935, pp. 97-99.

3. Stack, John, and Lindsey, W.F.: Characteristics of Low-Aspect-Ratio Wings at Supercritical Mach Numbers. NACA ACR No. L5J16, 1945.

CONFIDENTIAL



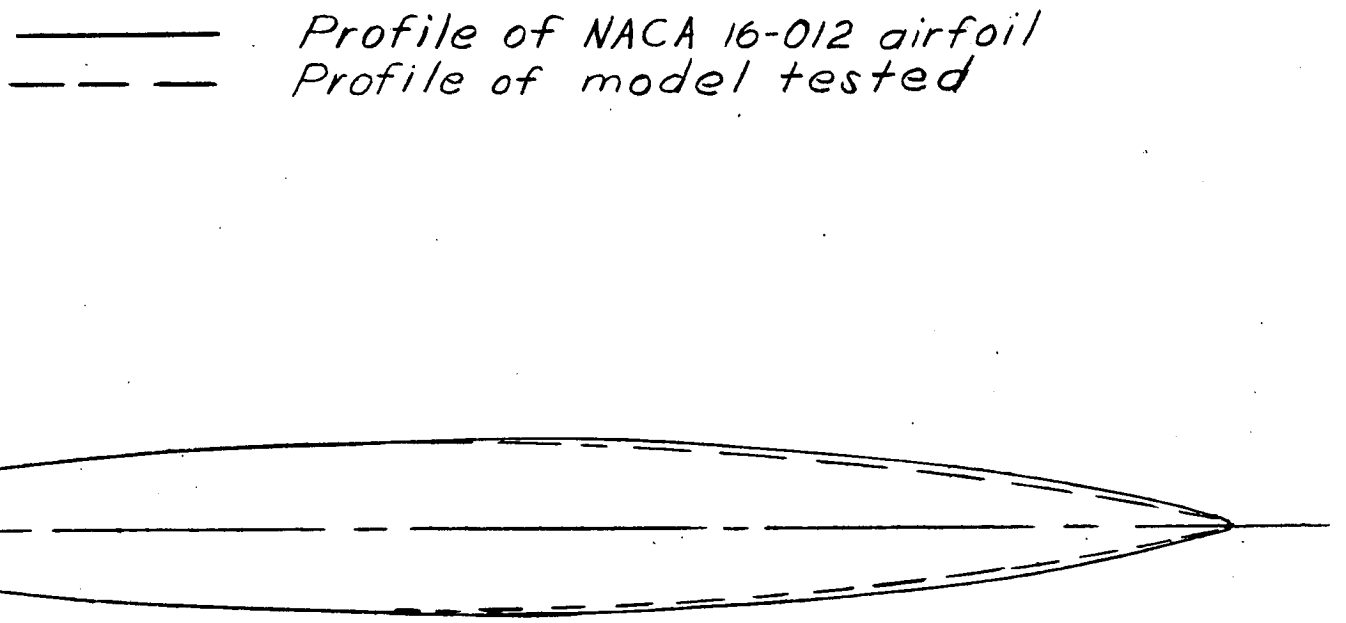
Thickness (percent chord)	Position of maximum thickness (percent chord)	Root chord (in.)	Tip chord (in.)
11.48	50	7.625	1.525

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 1.- Diagram of model showing dimensions.

CONFIDENTIAL

CONFIDENTIAL



CONFIDENTIAL

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 2. - Profile of model tested as compared with profile of NACA 16-012 airfoil section.

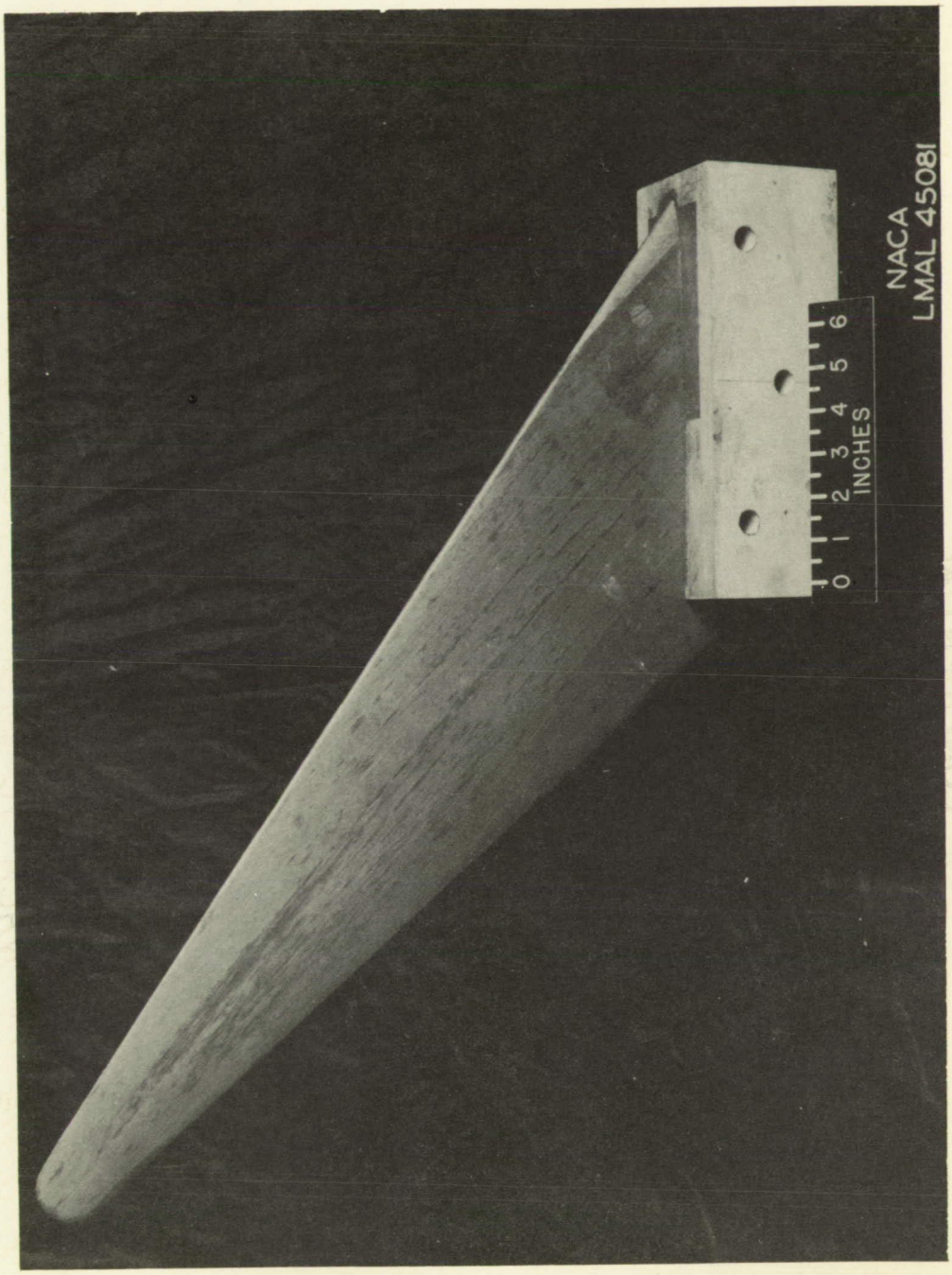


Figure 3.- Swept-back model.

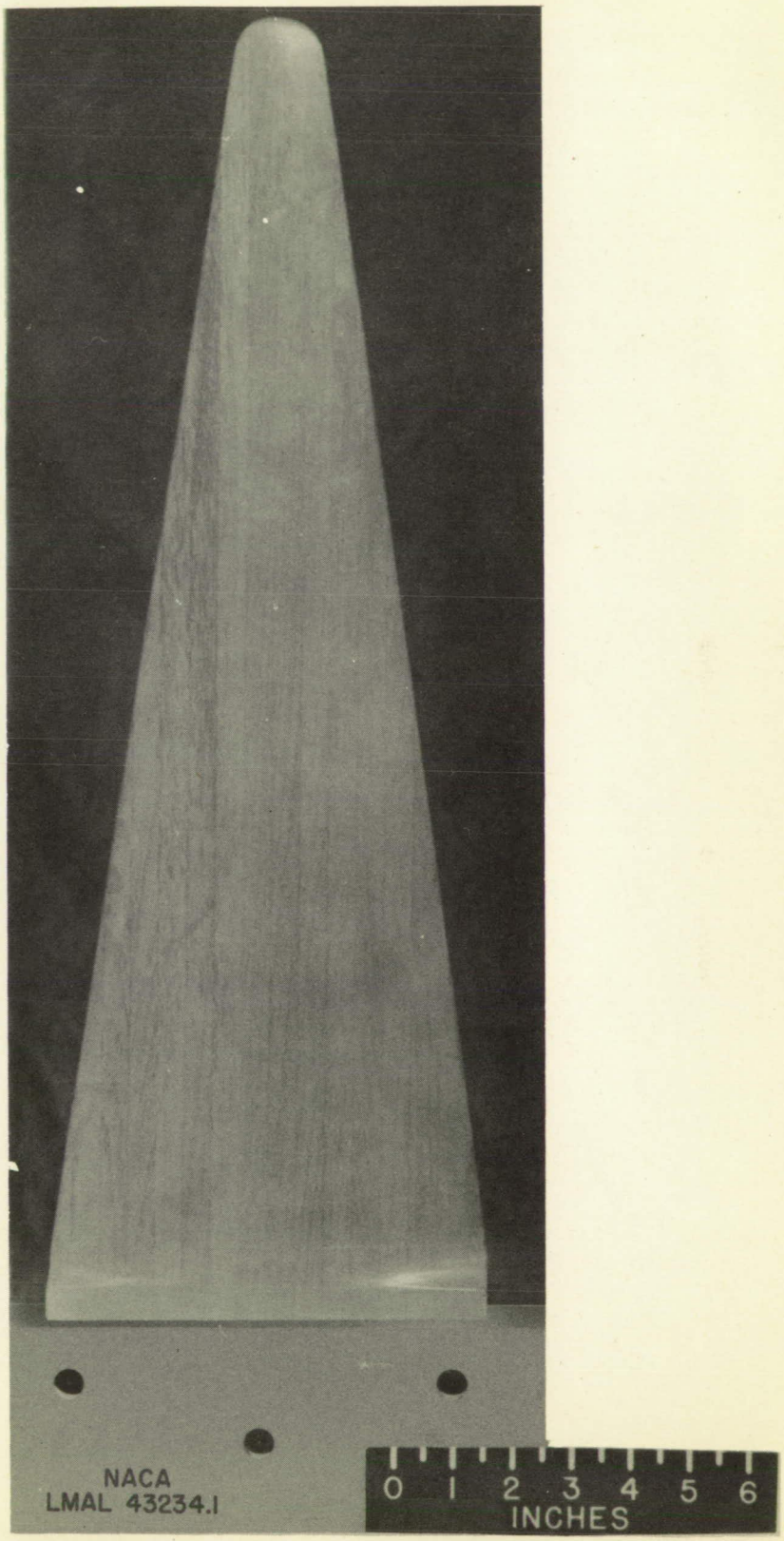


Figure 4.- Unswept-back model.

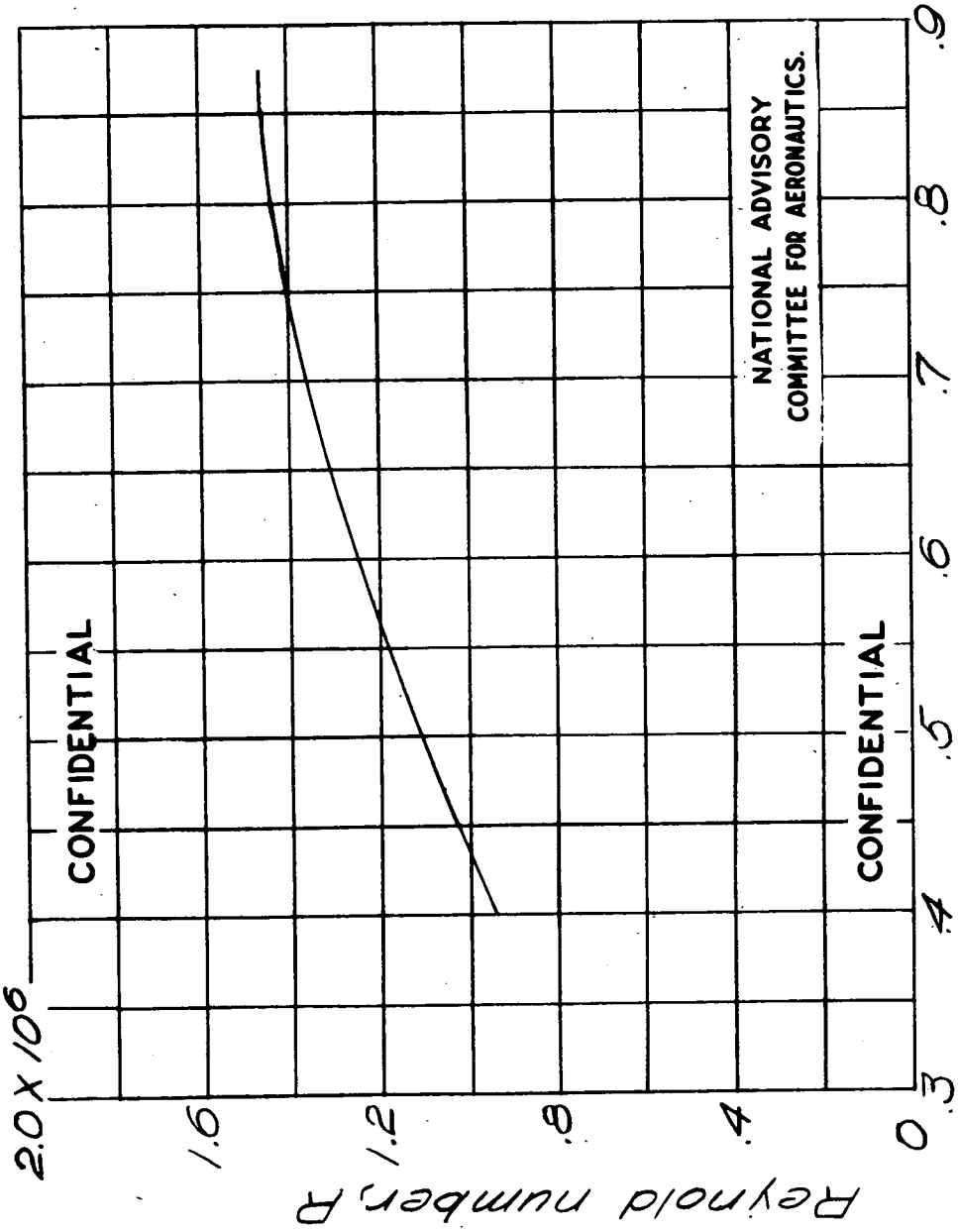


Figure 5.- Variation of test Reynolds number with Mach number.

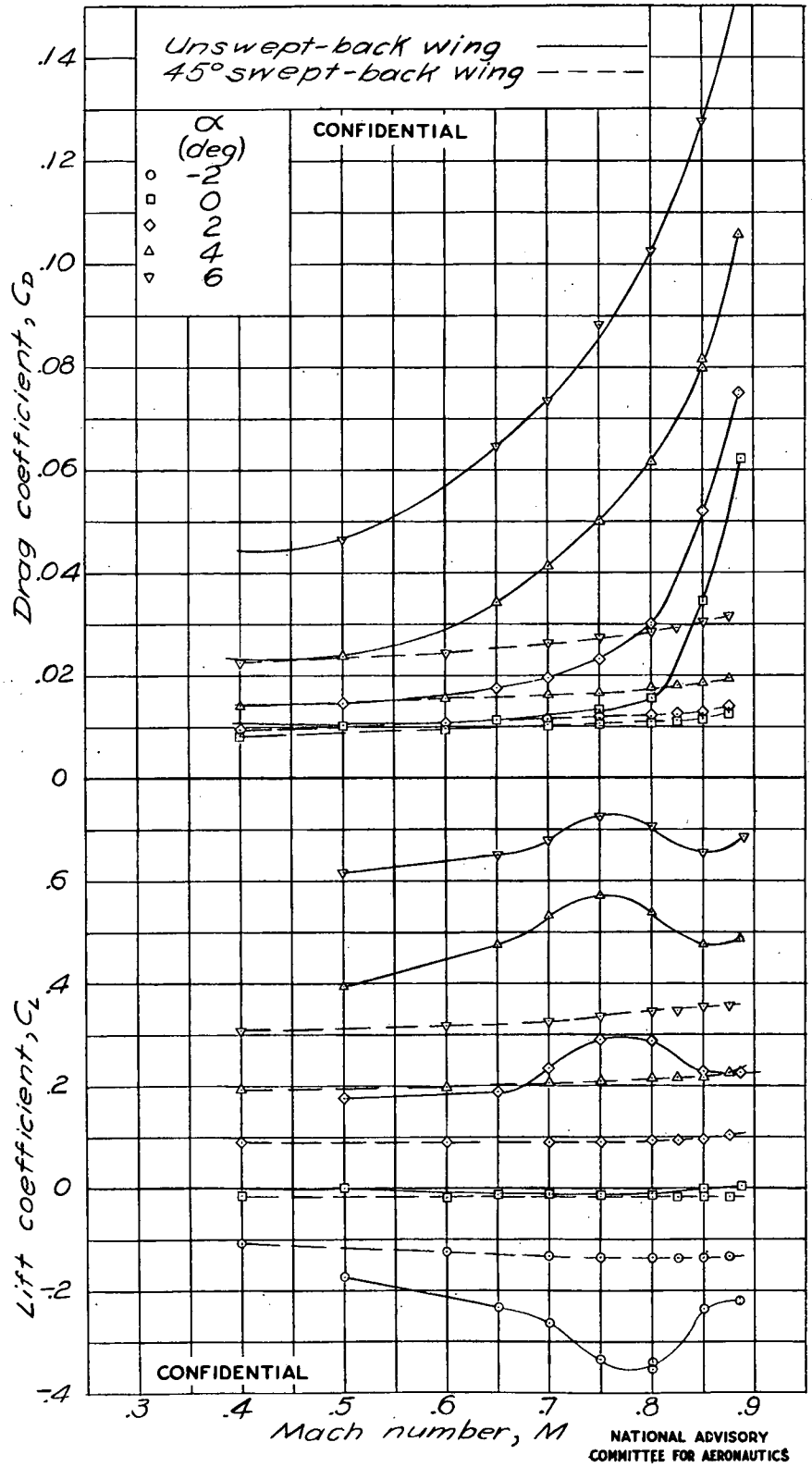


Figure 6. — Variation of lift and drag coefficients with Mach number.

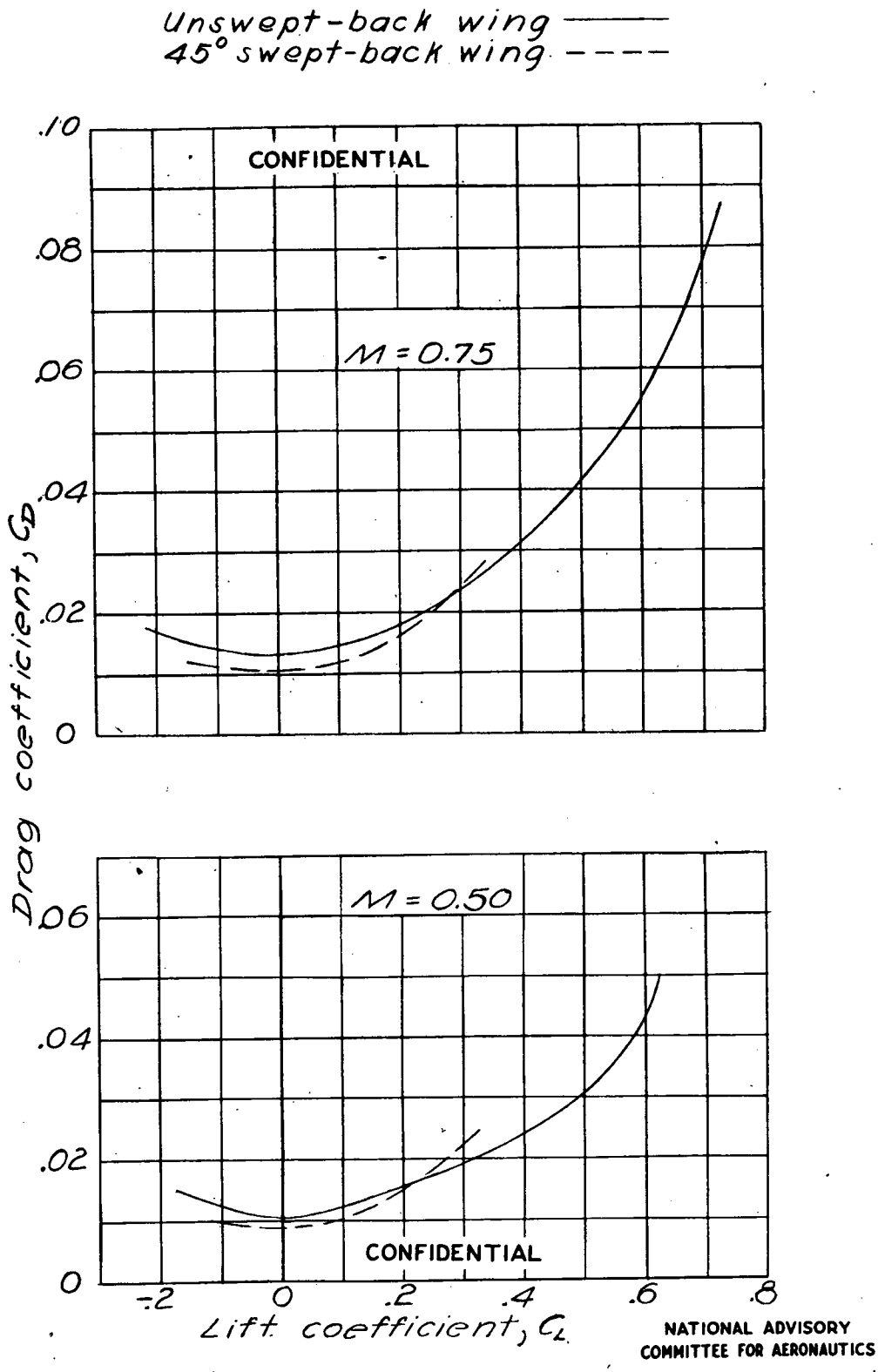


Figure 7.—Variation of drag coefficient with lift coefficient for several Mach numbers.

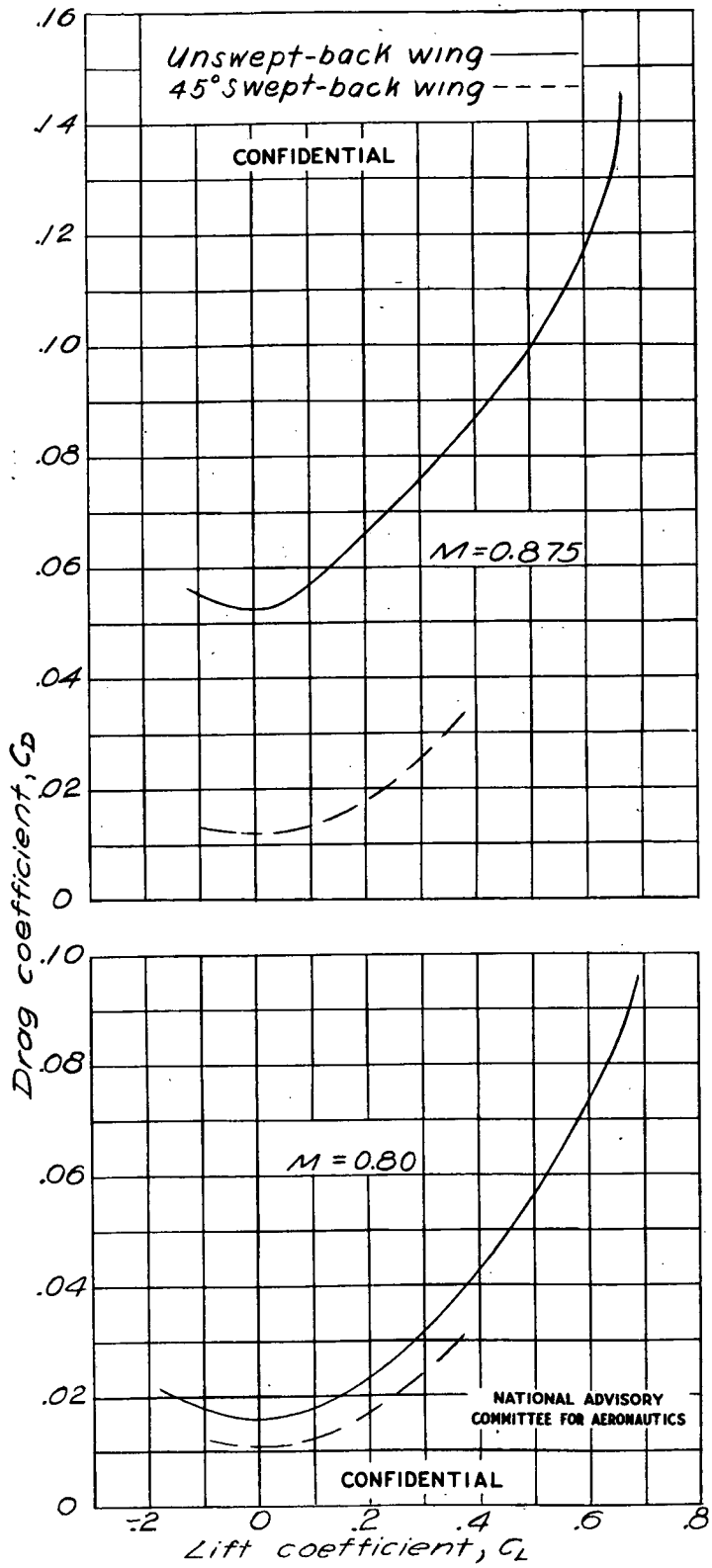


Figure 7.- Concluded.

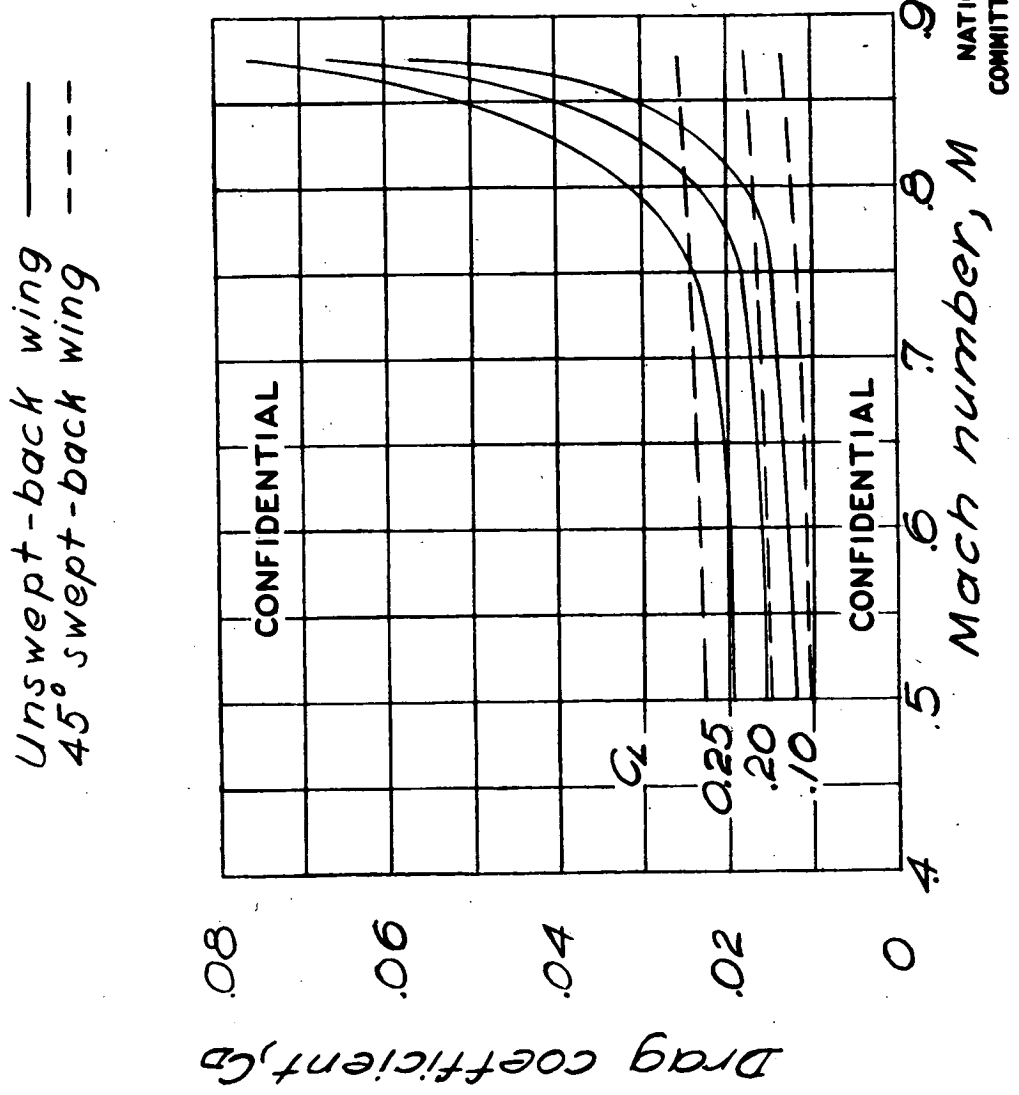


Figure 8.- Variation of drag coefficient with Mach number for constant lift coefficients.

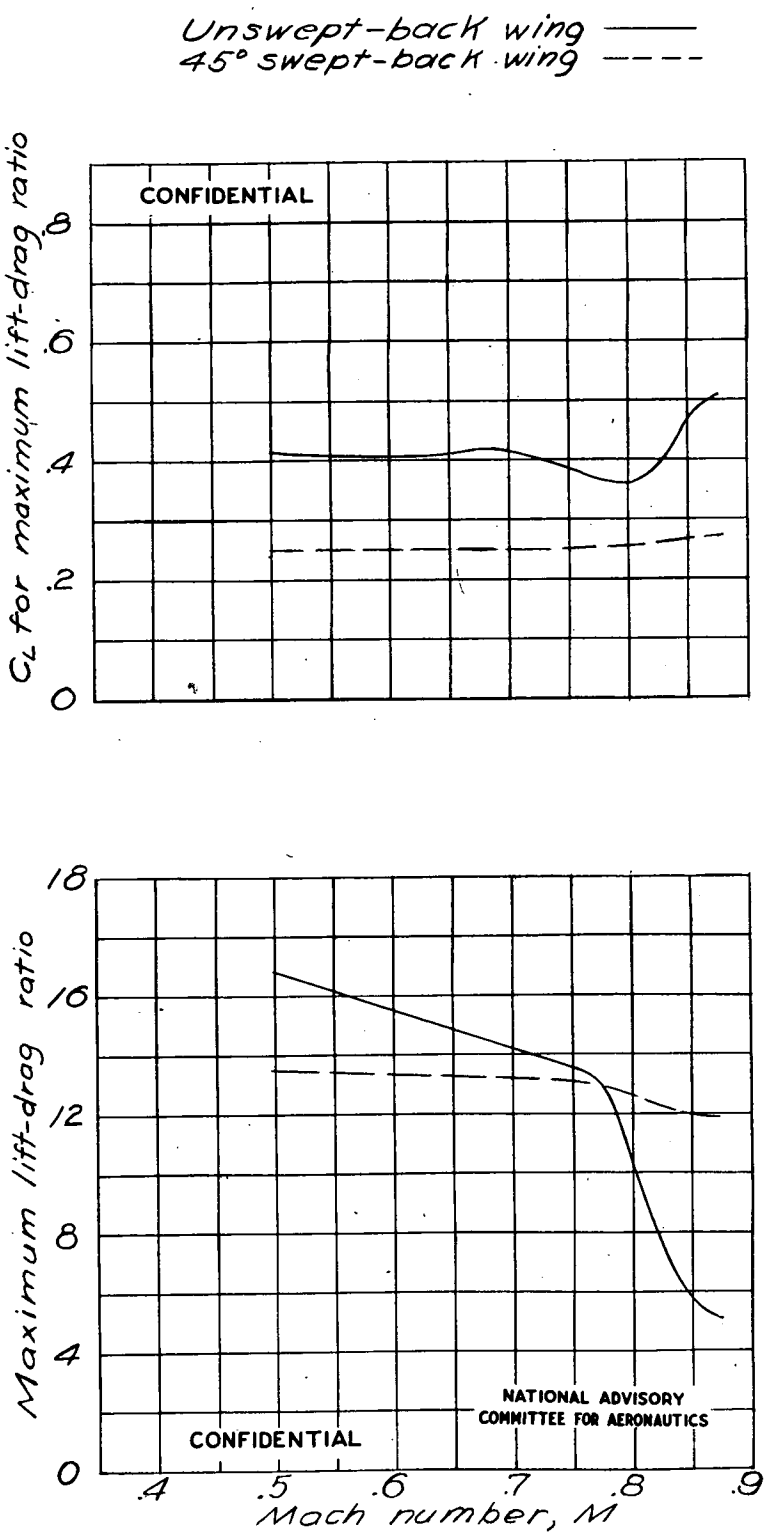


Figure 9. — Variation with Mach number of maximum lift-drag ratio and of lift coefficient corresponding to maximum lift-drag ratio.