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RESEARCH MEMORANDUM

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AERODYNAMIC CHARACTERISTICS OF TWO DELTA WINGS AND TWO TRAPEZOIDAL WINGS AT MACH NUMBER 4.04

By Robert W. Dunning and Fred M. Smith

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS OF TWO DELTA WINGS AND TWO TRAPEZOIDAL WINGS AT MACH NUMBER 4.04

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SUMMARY

Tests were made to determine the aerodynamic characteristics of two aspect-ratio-2.31 delta wings and two aspect-ratio-0.91 trapezoidal wings, having modified hexagonal airfoil sections 3 percent thick at the root, at Mach number 4.04 and Reynolds number 9.3×10^6. Rounding the wedge leading edges of the delta and trapezoidal wings decreased the lift of the delta wing but had no effect on the lift of the trapezoidal wing. For both wings the drag increased and the maximum lift-drag ratio decreased. The pitching-moment coefficients and centers of pressure of the delta wing were unaffected by rounding the leading edge, whereas for the trapezoidal wing the pitching-moment coefficients were lower and the chordwise centers of pressure more rearward for the round-leading-edge wing than for the sharp-leading-edge wing. The wing-root bending-moment coefficients were lower and the spanwise centers of pressure closer to the wing root for both the delta and trapezoidal wings when the leading edge was rounded. The removal of the wing tips of the two delta wings produced lower lift and drag coefficients. The resultant maximum lift-drag ratios were unchanged for the sharp-leading-edge wings and higher for the round-leading-edge wings. The chordwise centers of pressure moved forward when the wing tips were removed to produce increased pitching-moment coefficients, while the percent-semispan centers of pressure moved outward to produce increased wing-root bending-moment coefficients.

INTRODUCTION

The bulk of the available design data for supersonic aircraft and missiles lies in the speed range up to a Mach number of roughly 2. A considerable increase has recently occurred in contemplated design speeds, and thus the need for research data in the speed range from Mach number 2 to about 5 has greatly increased. In order to provide some of the needed data, a wing program has been started in the Langley 9- by 9-inch Mach number 4 blowdown jet. This program has two objectives: first, to establish the performance at Mach number 4.04 of a number of related wings of particular interest in this speed range; and, second, to develop, if possible, means of correlation with the available results for other supersonic Mach numbers. In this program the effects of plan form, thickness ratio, maximum-thickness location (published in ref. 1), and leading- and trailing-edge profiles on wing force characteristics are being investigated.

This report presents the results of rounding the wedge-leading-edge profiles of a delta wing and a trapezoidal wing and the effects on two delta wings, differing only in that one has a wedge leading edge and the other a round leading edge, of changing the plan form by removing the tips at the 56.3-percent-semispan station.

SYMBOLS

Moments are presented about the wind or stability axes.

M	free-stream Mach number
q	free-stream dynamic pressure
c	wing root chord
b	wing span, twice semispan
S	semispan wing area
α	angle of attack
R	Reynolds number based on wing root chord
N	normal force of semispan wing
L	lift of semispan wing
D	drag of semispan wing
M'	pitching moment of semispan wing about two-thirds root chord
B	bending moment due to lift of semispan wing about root chord
C_N	normal-force coefficient, N/qS

C_L lift coefficient, L/qS

C_D drag coefficient, D/qS

C_m pitching-moment coefficient, M'/qSc

C_b wing-root bending-moment coefficient, $\frac{B}{qS\frac{b}{2}}$

$2/3 - \left(\frac{dC_m}{dC_N}\right)_{N=0}$ chordwise center of pressure at zero angle of attack

$\left(\frac{dC_b}{dC_L}\right)_{L=0}$ spanwise center of pressure at zero angle of attack

APPARATUS AND TESTS

The tests were conducted in the Langley 9- by 9-inch Mach number 4 blowdown jet which is described, and for which test-section flow calibration is presented, in reference 2. The settling-chamber pressure, which was held constant by a pressure-regulating valve, and the corresponding air temperature were continuously recorded on film during each run. An external side-wall-mounted strain-gage balance was used to measure the normal force, chord force, pitching moment, and wing-root bending moment of the models. The semispan models were mounted through a tunnel-wall boundary-layer bypass plate (fig. 1) shaped to preserve the basic tunnel flow without introducing detrimental disturbances and located far enough from the tunnel wall so as to eliminate tunnel-wall boundary-layer effects. Balance deflections under load necessitated about 0.10-inch clearance all around the models at the root chord. Force tests of a rectangular wing equipped with pressure orifices on its surface just outboard and inboard of the gap at the wing root showed that air flow in and out of the 0.10-inch gap caused large changes in the wing surface pressures at angles of attack, which caused erroneous force and moment readings. A sliding-plate gap-sealing mechanism was therefore developed (fig. 2) which allowed the wing to move freely under load and reduced the effects of gap leakage to a negligible amount. Force tests were made which showed that the small friction existing between the sliding and the stationary plates did not produce any measurable forces or moments.

The Reynolds number for the tests was 9.3×10^6, based on the model root chord. Because of adverse effects from choking behind the bypass plate at high angles of attack, the angle-of-attack range was limited to $\pm 14^\circ$. The tests were run at humidities below 5.0×10^{-6} pounds of water vapor per pound of dry air, which is believed to be low enough to eliminate water condensation effects. The test-section static temperature and static pressure did not reach the point where liquefaction of air would take place.

MODELS

The models (fig. 3) consisted of two wings of delta plan form and two wings of trapezoidal plan form. One delta wing had a 60° sweptback leading edge, aspect ratio of 2.31, and a modified symmetrical hexagonal section, 3 percent thick at the root, consisting of a wedge leading edge, parallel-sided midsection, and a half-blunt wedge trailing edge and having constant thickness out to the 56.3-percent-semispan station. The second delta wing had the same plan form and thickness variation but had the wedge leading edge replaced by a modified NACA 0003-63 section. The two aspect-ratio-0.91 trapezoidal wings (fig. 3(b)) were obtained by removing the tips of the two delta wings at the 56.3-percent-semispan station.

PRECISION OF DATA

The uncertainties involved in measuring the forces and moments and computing the aerodynamic coefficients and the center-of-pressure locations have been evaluated. The probable uncertainties are listed below. The center-of-pressure inaccuracies refer to the centers of pressure obtained by the slope method at zero angle of attack.

α, deg . . . . ± 0.1
$\Delta\alpha$ . . . . ± 0.05
C_L . . . . ± 0.005
C_D . . . . ± 0.001
C_m . . . . ± 0.001
C_b . . . . ± 0.003

Chordwise center of pressure, $\left(\frac{dC_m}{dC_N}\right)_{N=0}$, percent c . . . . ± 1

Spanwise center of pressure, $\left(\frac{dC_b}{dC_L}\right)_{L=0}$, percent b/2 . . . . ± 2

RESULTS AND DISCUSSION

The results (figs. 4 to 7) are presented as the variations of lift, drag, pitching-moment, and wing-root bending-moment coefficients and lift-drag ratios and centers of pressure with angle of attack. The centers of pressure at zero angle of attack, obtained by the slope method, are indicated by the short horizontal lines on the $\alpha = 0^{\circ}$ axis.

Rounding the wedge leading edges of the delta and trapezoidal wings (figs. 4 and 5) had no effect on the lift coefficients of the trapezoidal wing but for the delta wing it resulted in lower lift coefficients. As shown in figures 4(b) and 5(b), the minimum drag coefficients were increased by 51 percent for the delta wing and 32 percent for the trapezoidal wing when the leading edges were rounded, and the maximum lift-drag ratios were 18 percent lower for the delta wing and 11 percent lower for the trapezoidal wing. The chordwise centers of pressure and pitching-moment coefficients of the delta wing were unaffected by rounding the leading edge, but in the case of the trapezoidal wing the chordwise centers of pressure moved slightly rearward and produced lower pitching-moment coefficients. The spanwise centers of pressure of the round-leading-edge delta wing were in general closer to the wing root than those of the sharp-leading-edge delta wing and this, in combination with the lower lift coefficients, resulted in lower wing-root bending-moment coefficients for the round-leading-edge delta wing. The trapezoidal wing exhibited the same inward movement of the spanwise centers of pressure when the leading edge was rounded but as there was no change in lift coefficients, the resultant decreases in wing-root bending-moment coefficients were much smaller than those of the delta wing.

The removal of the tips from the two delta wings at the 56.3-percent-semispan station (figs. 6 and 7) resulted in reductions in lift-curve slope (figs. 6(a) and 7(a)) of 9 percent for the sharp-leading-edge wing and 6 percent for the round-leading-edge wing. At the same time, the minimum drag coefficient of the sharp-leading-edge wing (fig. 6(b)) was reduced by 12 percent, whereas that of the round-leading-edge wing (fig. 7(b)) was reduced by 23 percent. This is in the direction to be expected and is a result of the removal of the 6.9-percent-thick tips. The lower lift and lower drag produced maximum lift-drag ratios that were unchanged in the case of the sharp-leading-edge wing and 9 percent higher for the round-leading-edge wing. The chordwise centers of pressure moved forward, increasing the pitching-moment coefficients, while the percent-semispan centers of pressure moved outward to produce higher wing-root bending-moment coefficients.

SUMMARY OF RESULTS

An investigation of the aerodynamic characteristics of two delta wings and two trapezoidal wings, having modified hexagonal airfoil sections 3 percent thick at the root, has been made at a Mach number of 4.04 and Reynolds number of 9.3×10^6. The results have been analyzed and indicate that:

1. Rounding the wedge leading edges of the delta and trapezoidal wings decreased the lift of the delta wing but had no effect on the lift of the trapezoidal wing. For both wings the drag increased and the maximum lift-drag ratio decreased. The pitching-moment coefficients and centers of pressure of the delta wing were unaffected by rounding the leading edge, whereas for the trapezoidal wing the pitching-moment coefficients were lower and the chordwise centers of pressure more rearward for the round-leading-edge wing than for the sharp-leading-edge wing. The wing-root bending-moment coefficients were lower and the spanwise centers of pressure closer to the wing root for both the delta and trapezoidal wings when the leading edge was rounded.

2. Removing the tips from the two delta wings at the 56.3-percent-semispan station produced lower lift and drag coefficients. The resultant maximum lift-drag ratios were unchanged for the sharp-leading-edge wing and higher for the round-leading-edge wing. The chordwise centers of pressure moved forward, increasing the pitching-moment coefficients, while the percent-semispan centers of pressure moved outward to produce higher wing-root bending-moment coefficients.

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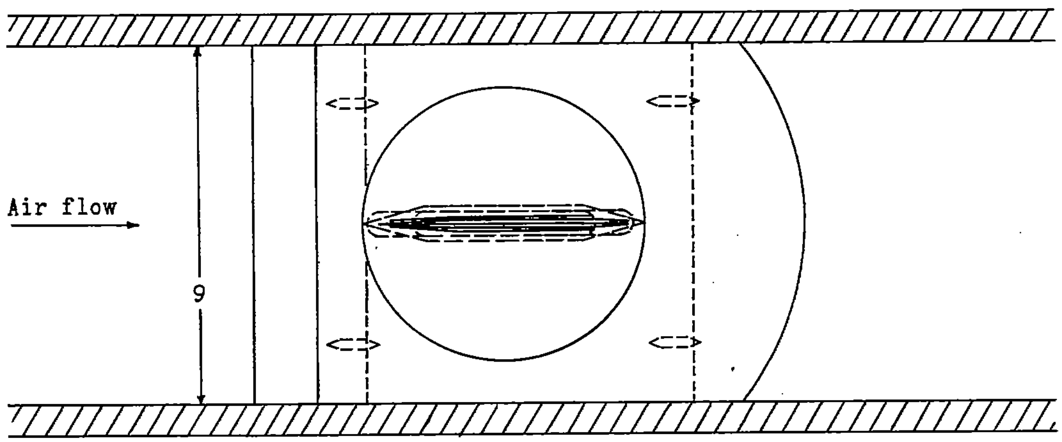
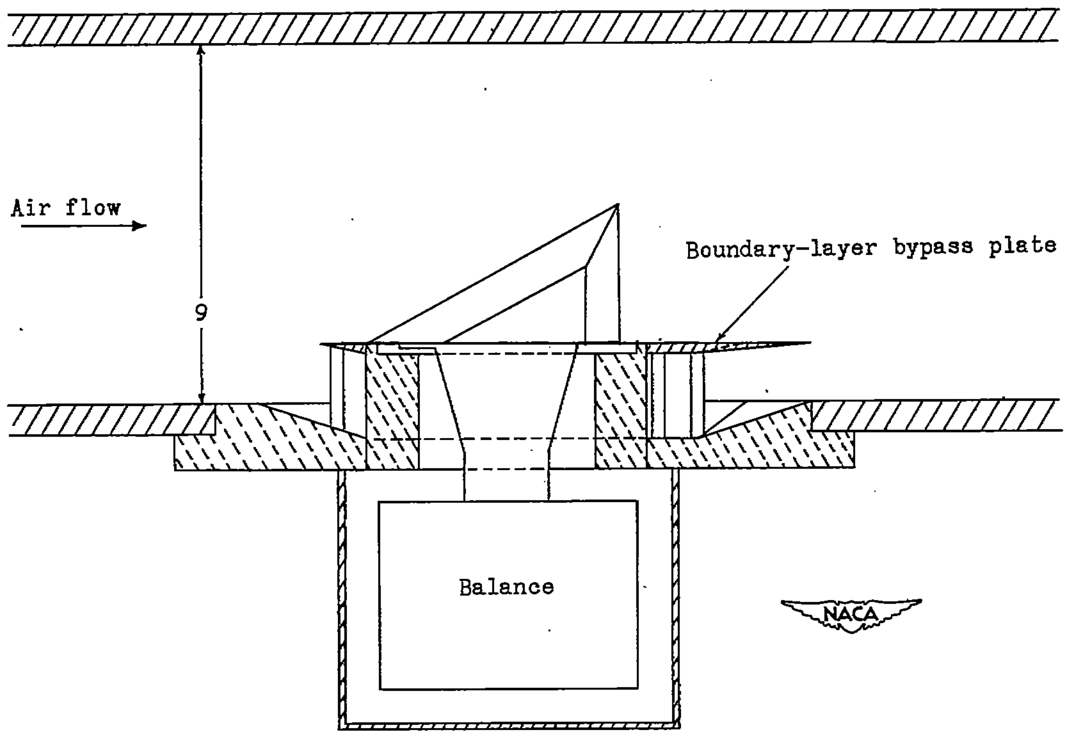
REFERENCES

1. Ulmann, Edward F., and Dunning, Robert W.: Aerodynamic Characteristics of Two Delta Wings at Mach Number 4.04 and Correlations of Lift and Minimum-Drag Data for Delta Wings at Mach Numbers from 1.62 to 6.9. NACA RM L52K19, 1952.

2. Ulmann, Edward F., and Lord, Douglas R.: An Investigation of Flow Characteristics at Mach Number 4.04 Over 6- and 9-Percent-Thick Symmetrical Circular-Arc Airfoils Having 30-Percent-Chord Trailing-Edge Flaps. NACA RM L51D30, 1951.



Side view



Top view

Figure 1.- Schematic diagram of test section of Langley 9- by 9-inch Mach number 4 blowdown jet and balance arrangement. All dimensions are in inches.

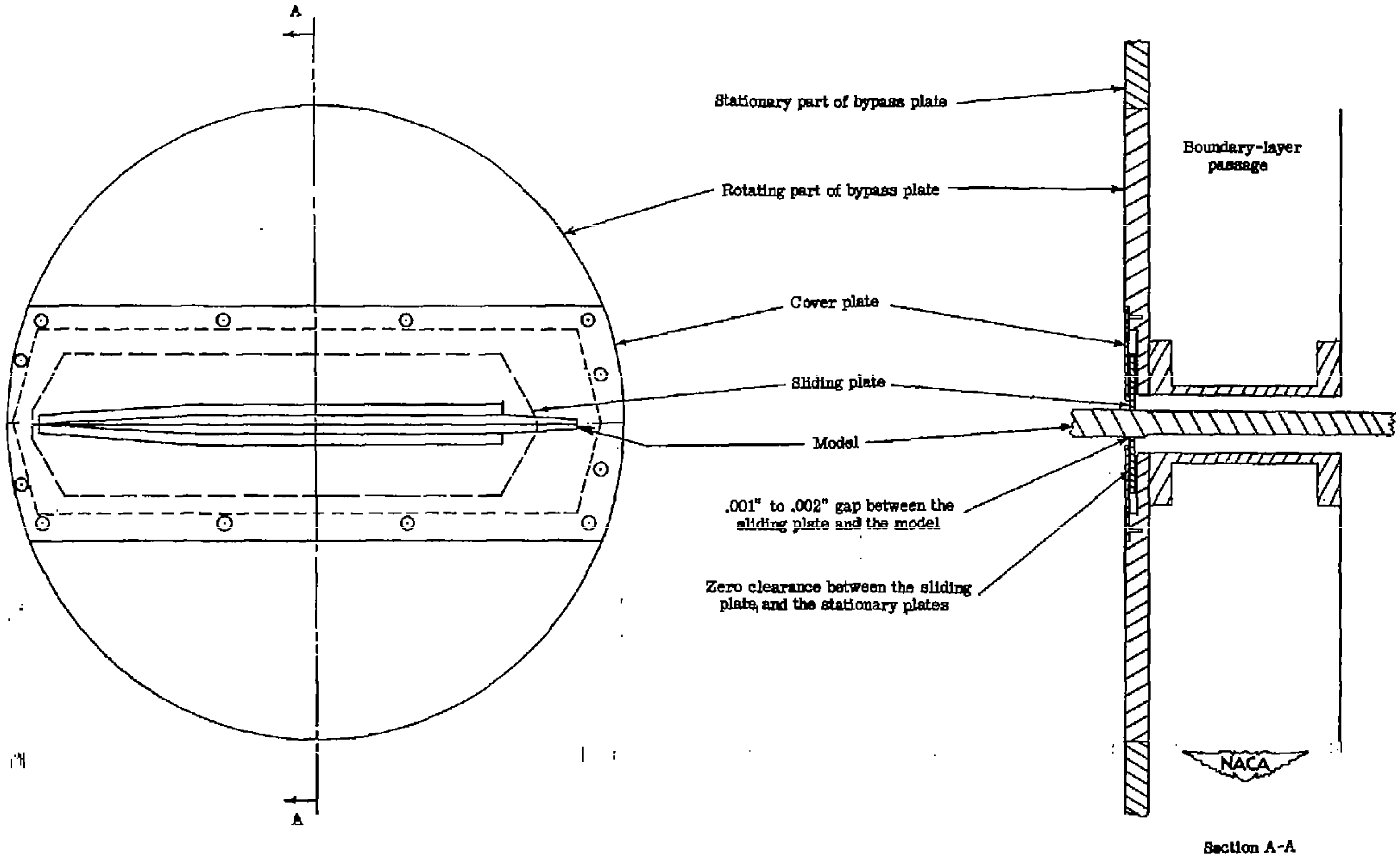
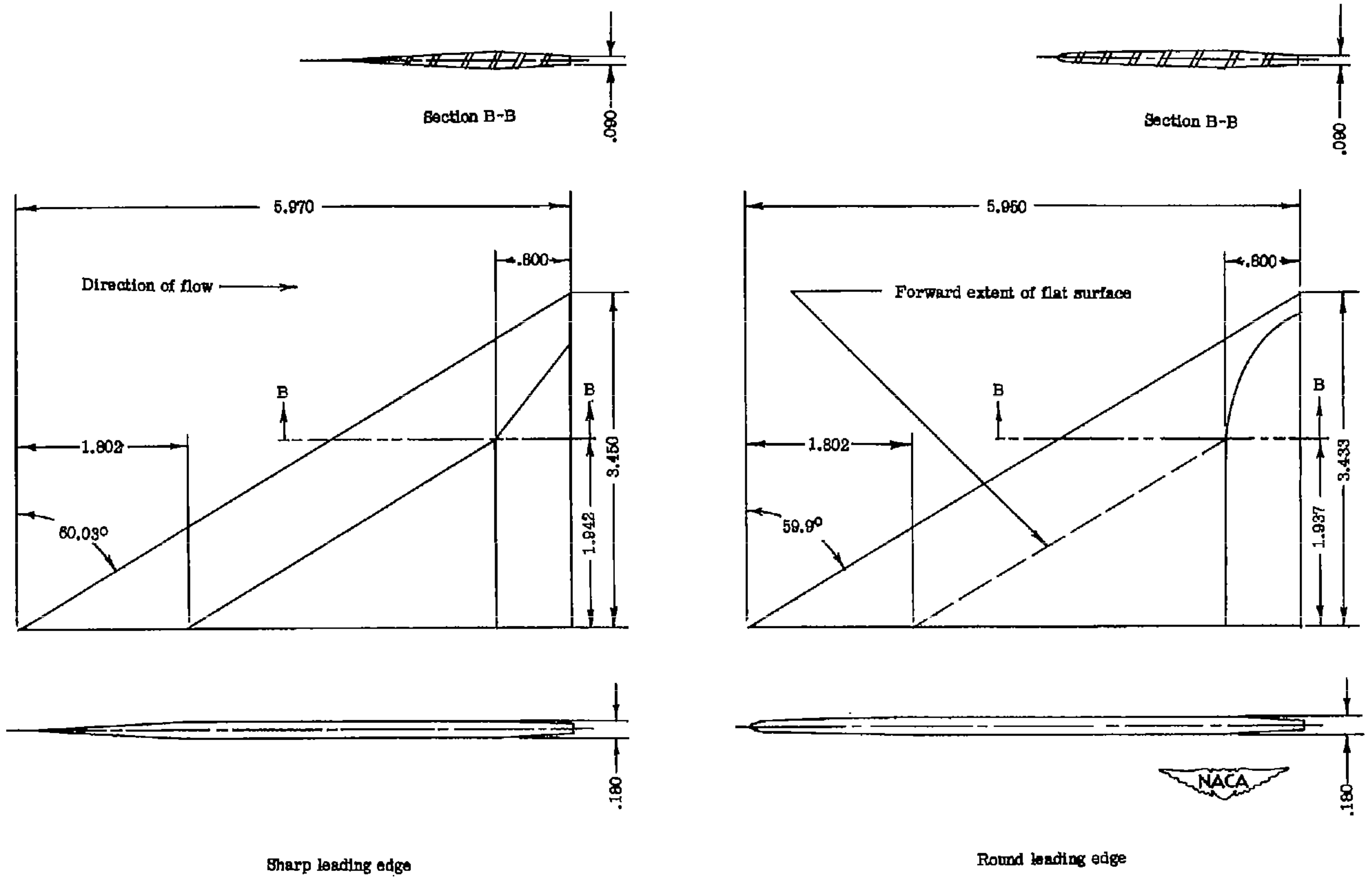
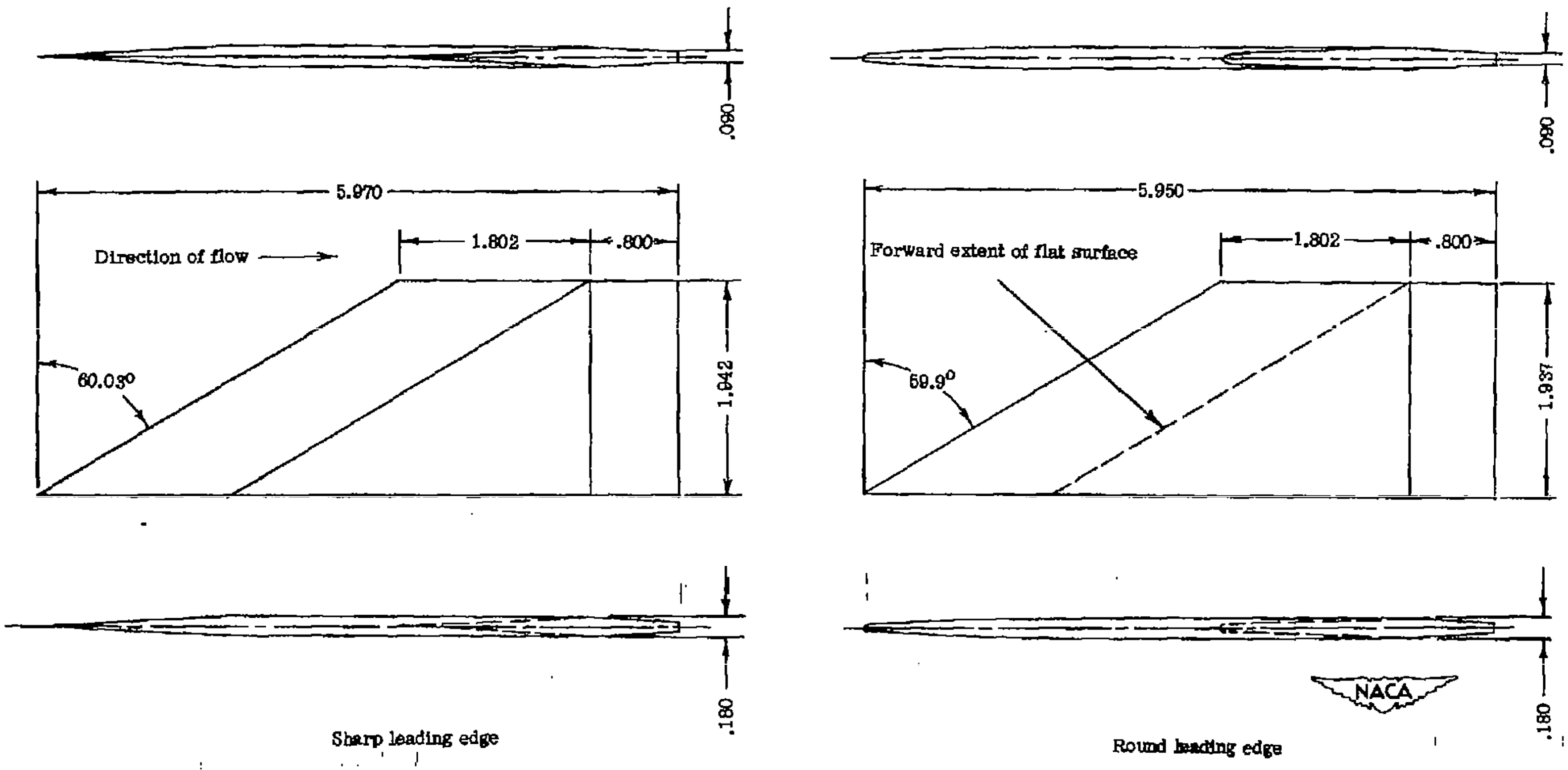


Figure 2.- Sliding-plate gap-sealing mechanism.



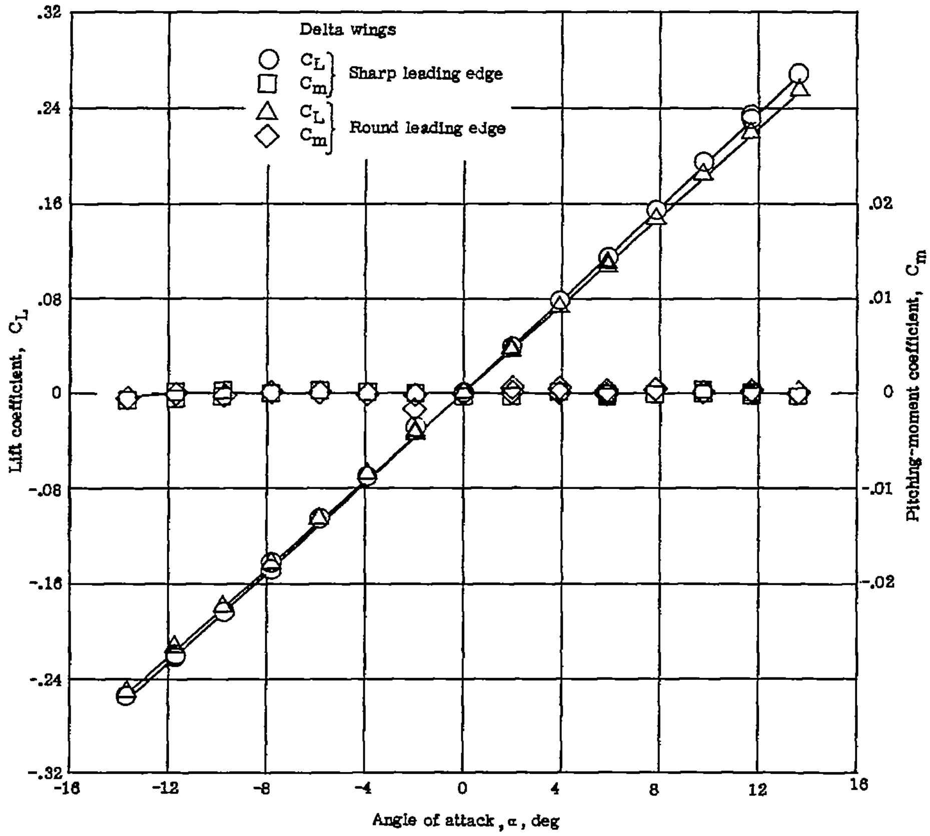
(a) Delta wings.

Figure 3.- Diagram of the models. All dimensions are in inches.

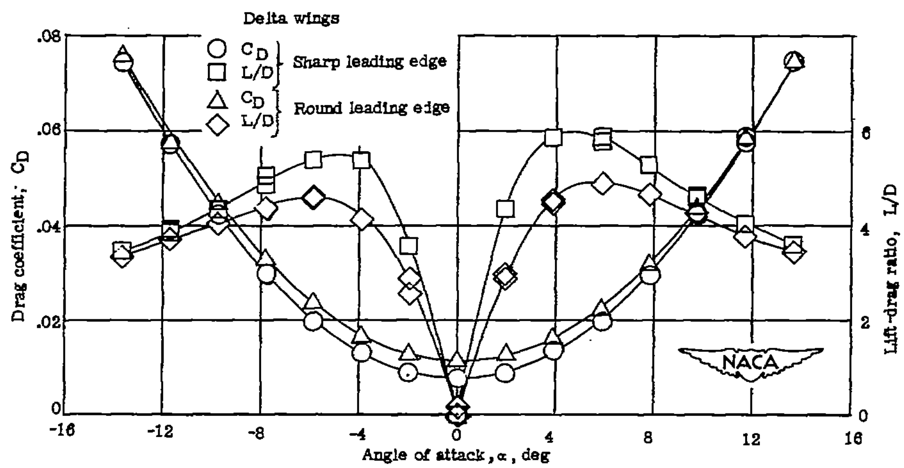


(b) Trapezoidal wings.

Figure 3.- Concluded.

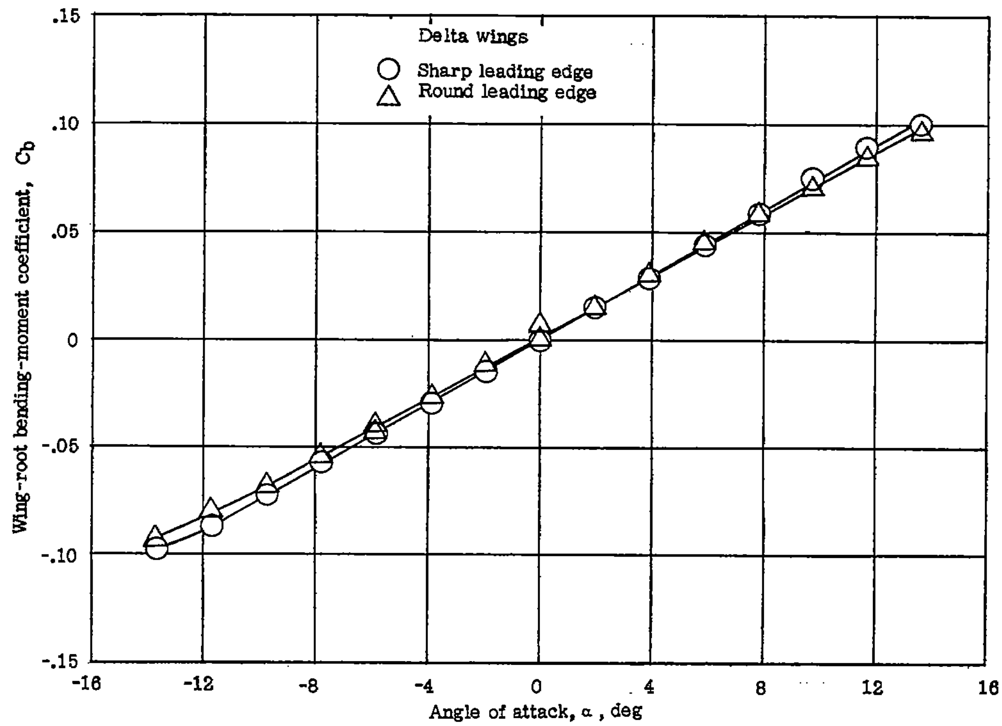


(a) Lift coefficients and pitching-moment coefficients.

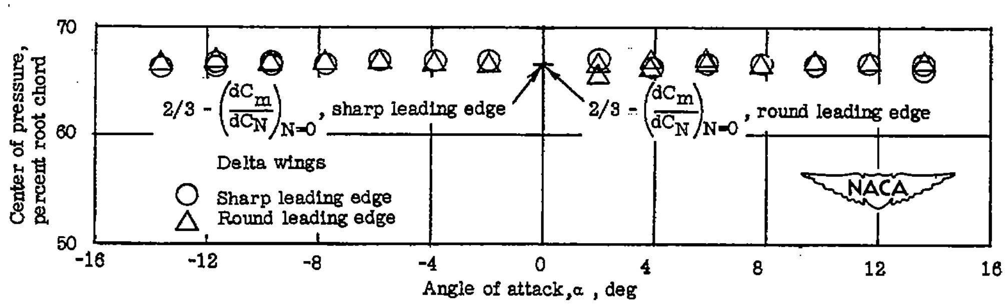


(b) Drag coefficients and lift-drag ratios.

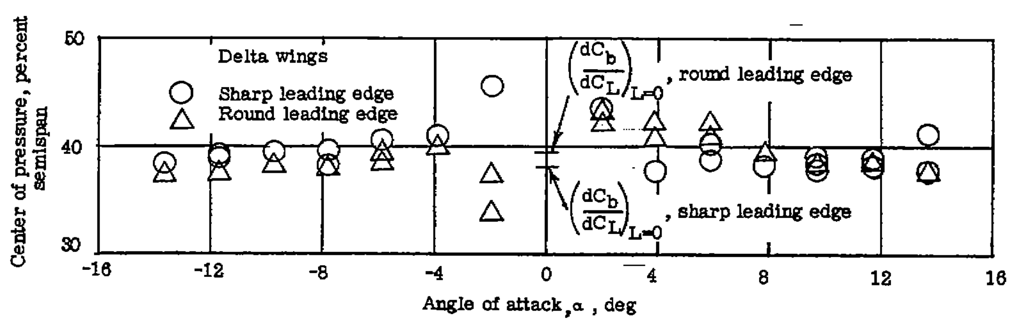
Figure 4.- Aerodynamic characteristics of two 3-percent-thick delta wings. $M = 4.04$; $R = 9.3 \times 10^6$ based on wing root chord.



(c) Wing-root bending-moment coefficients.

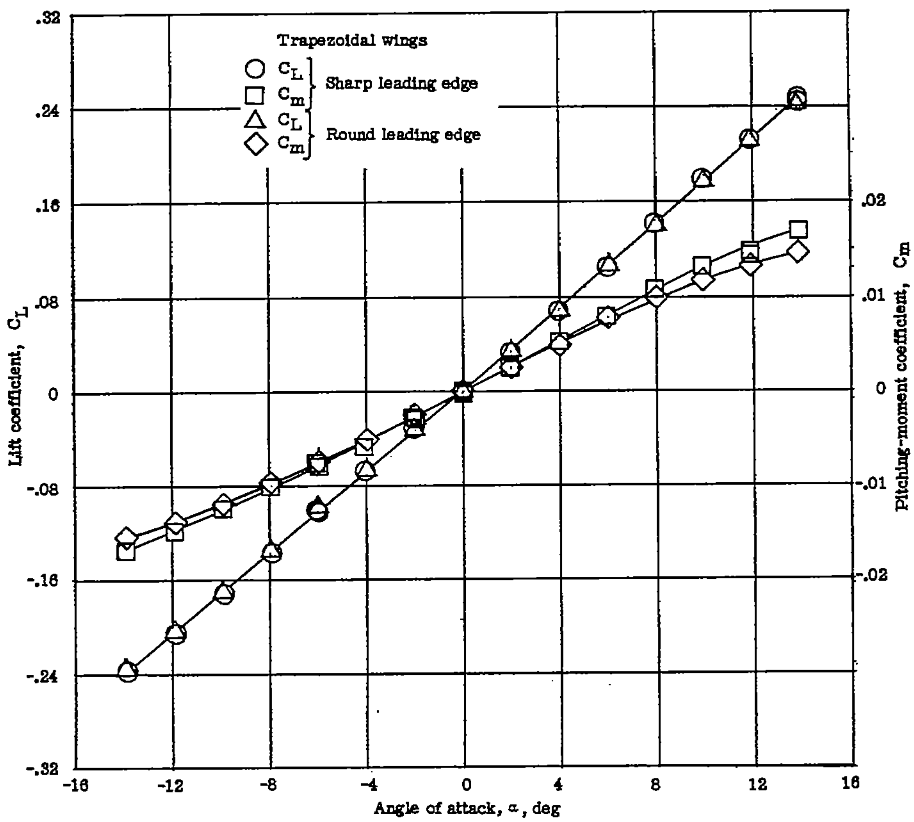


(d) Chordwise centers of pressure.

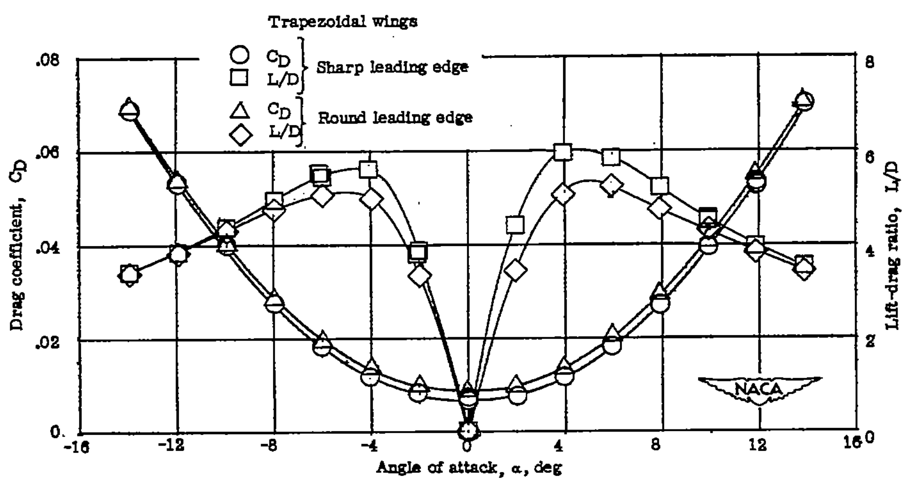


(e) Spanwise centers of pressure.

Figure 4.- Concluded.

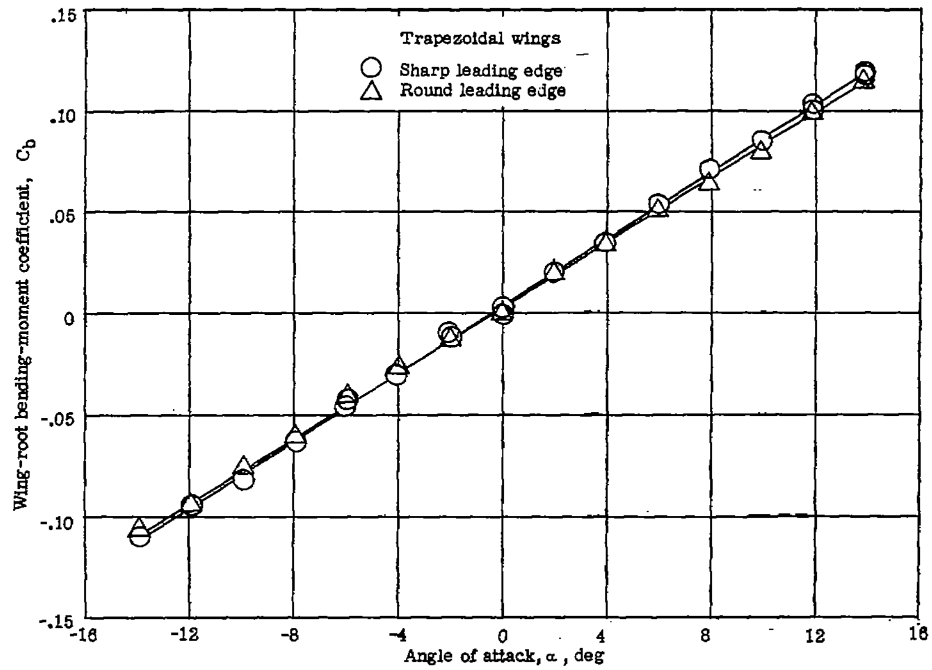


(a) Lift coefficients and pitching-moment coefficients.

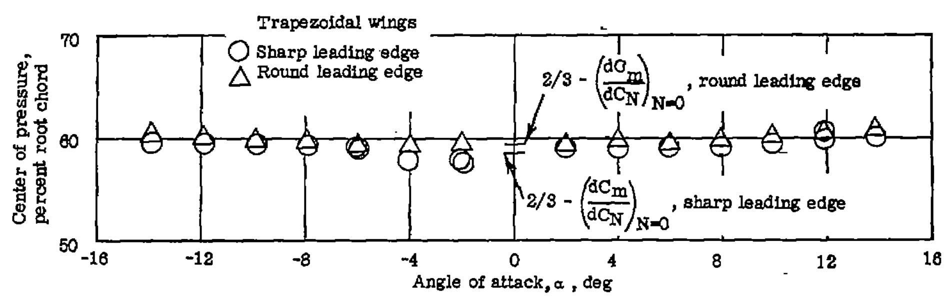


(b) Drag coefficients and lift-drag ratios.

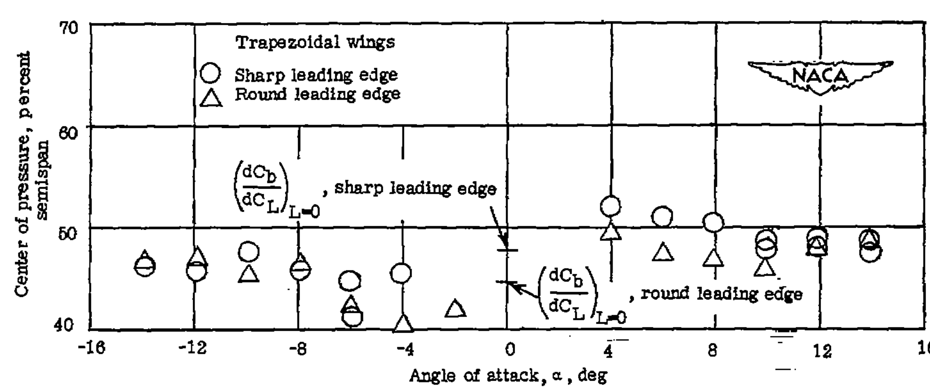
Figure 5.- Aerodynamic characteristics of two 3-percent-thick trapezoidal wings. $M = 4.04$; $R = 9.3 \times 10^6$ based on wing root chord.



(c) Wing-root bending-moment coefficients.

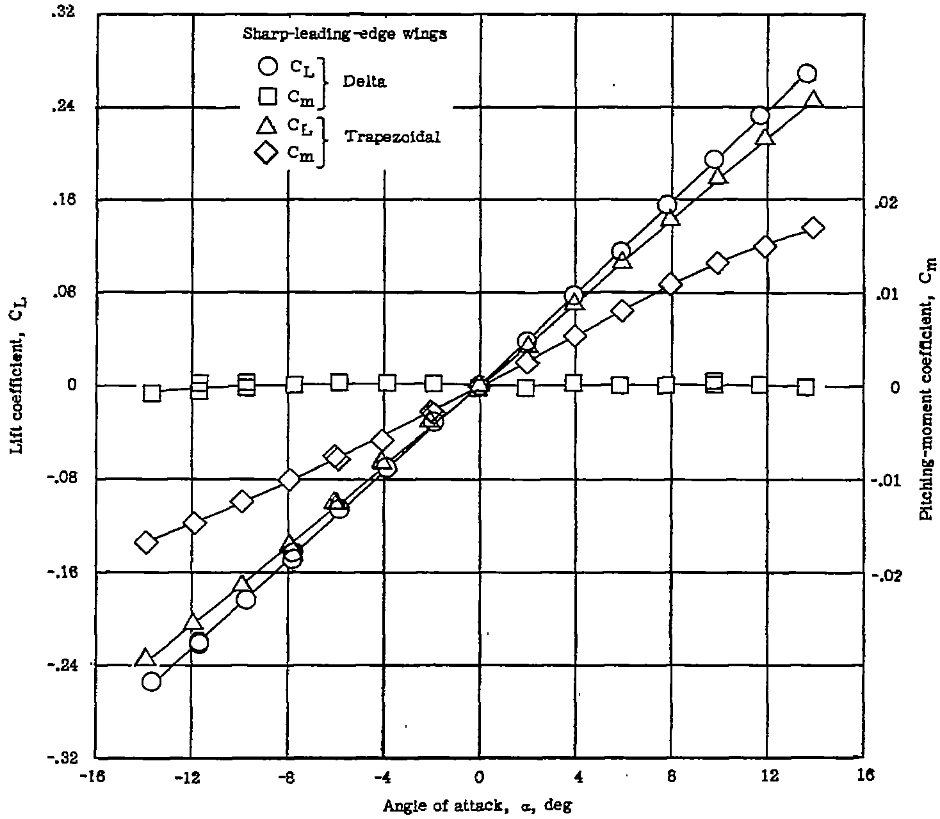


(d) Chordwise centers of pressure.

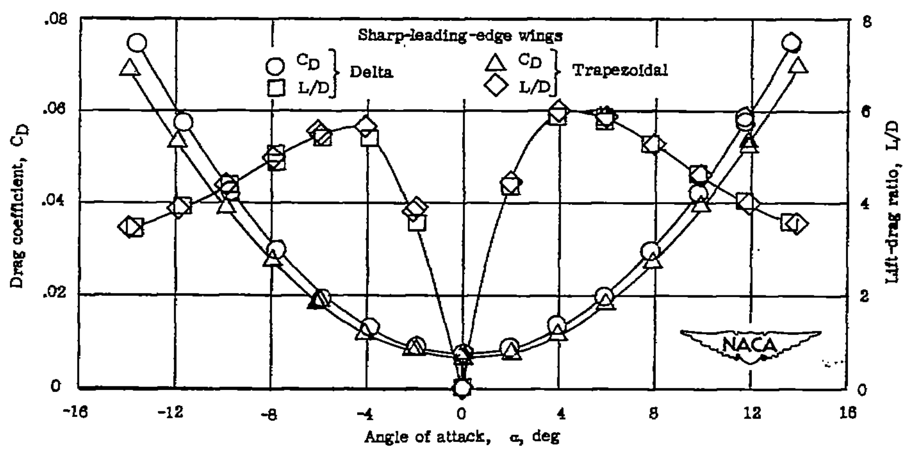


(e) Spanwise centers of pressure.

Figure 5.- Concluded.

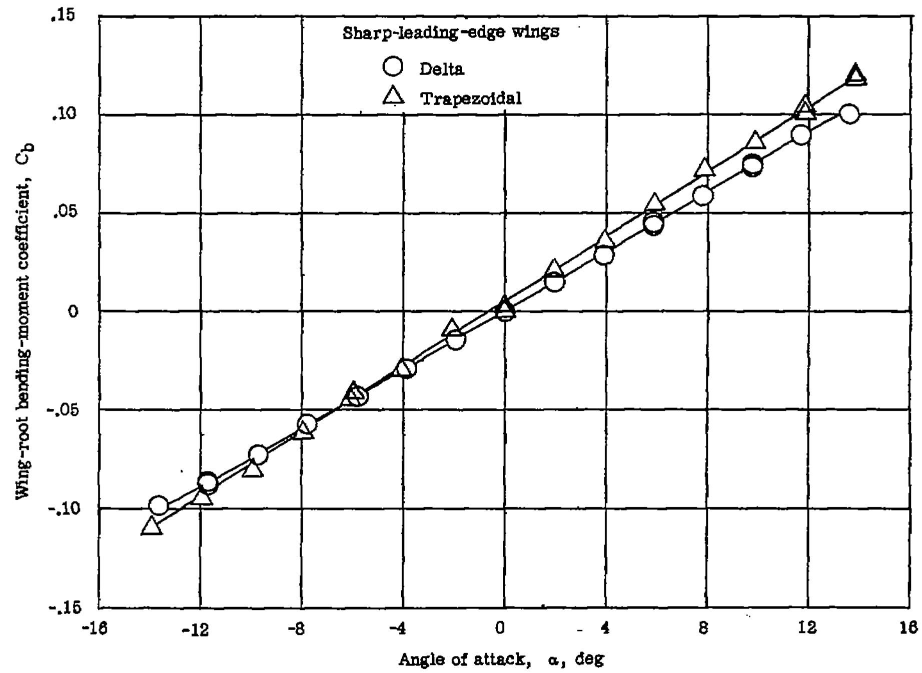


(a) Lift coefficients and pitching-moment coefficients.

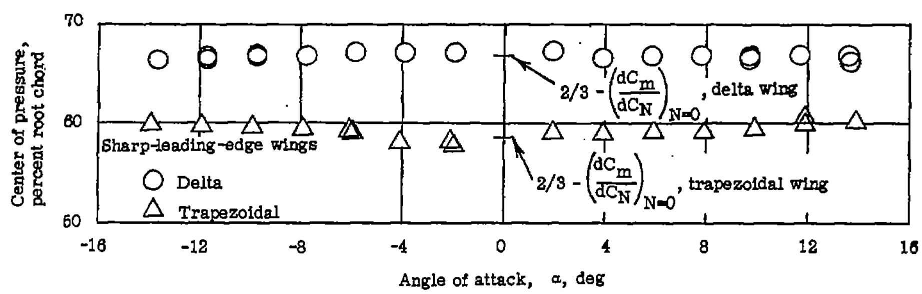


(b) Drag coefficients and lift-drag ratios.

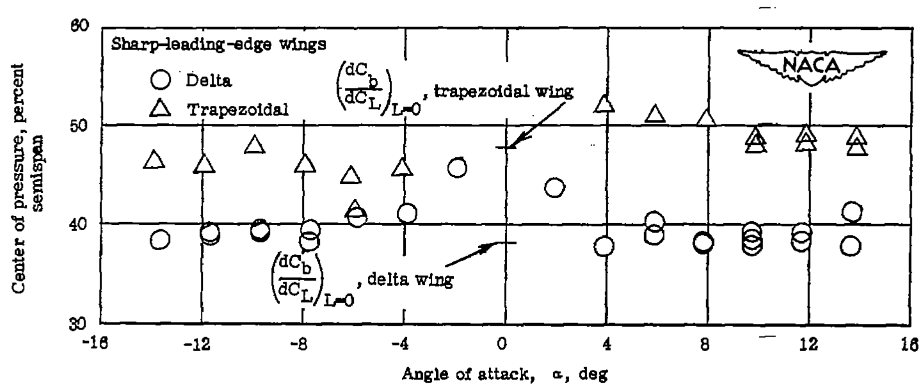
Figure 6.- Aerodynamic characteristics of a 3-percent-thick sharp-leading-edge delta wing and a 3-percent-thick sharp-leading-edge trapezoidal wing. $M = 4.04$; $R = 9.3 \times 10^6$ based on wing root chord.



(c) Wing-root bending-moment coefficients.

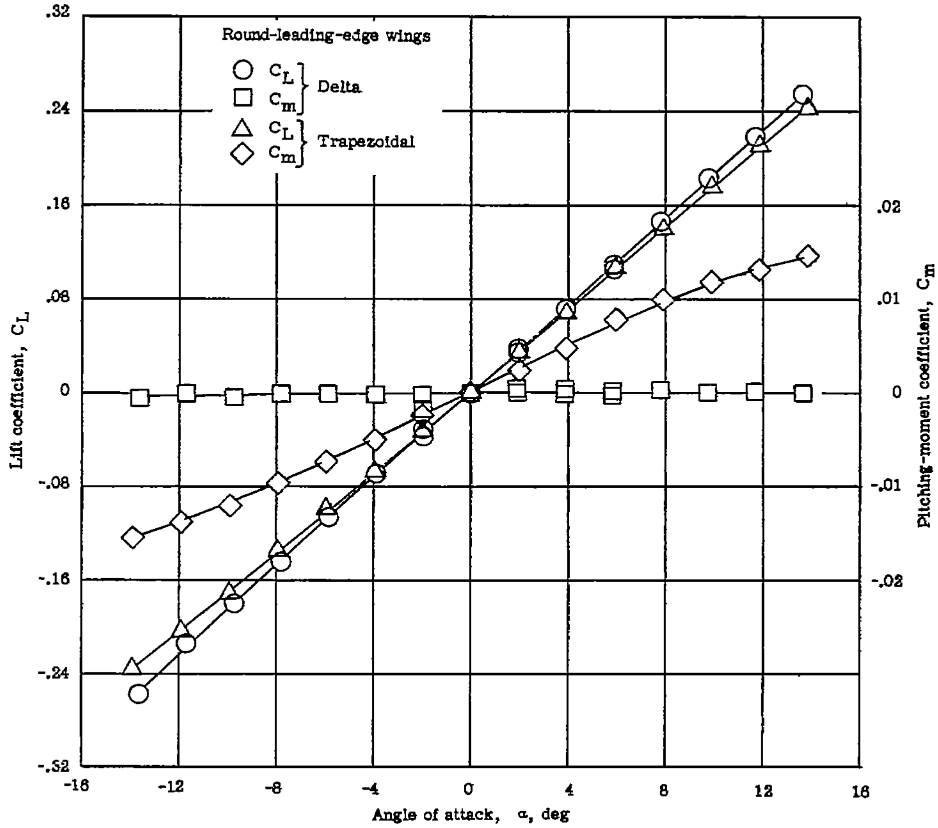


(d) Chordwise centers of pressure.

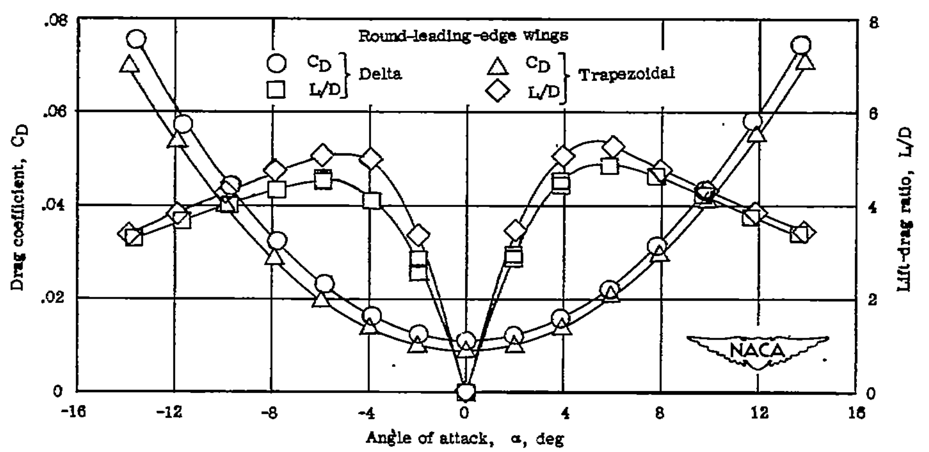


(e) Spanwise centers of pressure.

Figure 6.- Concluded.

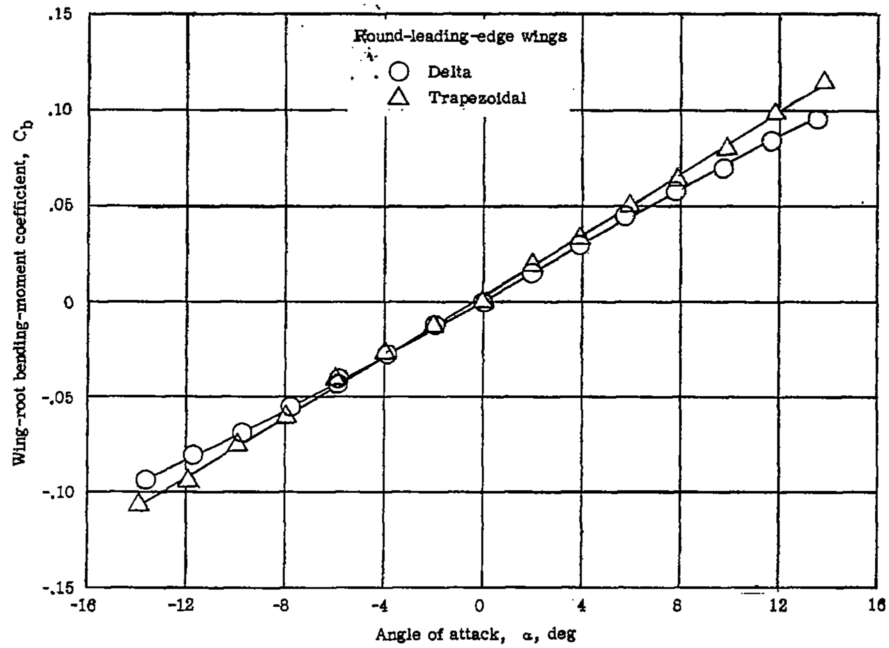


(a) Lift coefficients and pitching-moment coefficients.

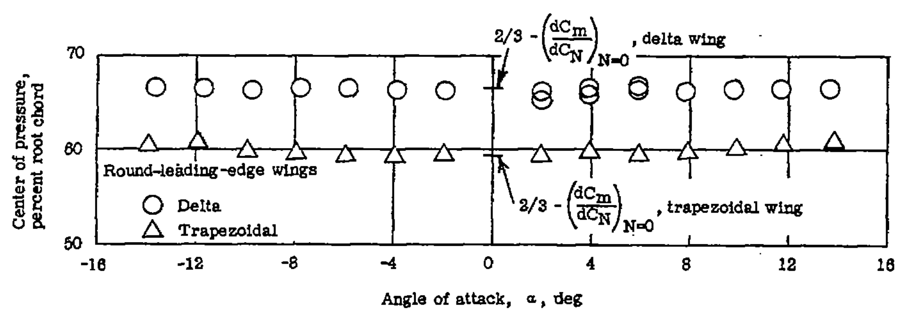


(b) Drag coefficients and lift-drag ratios.

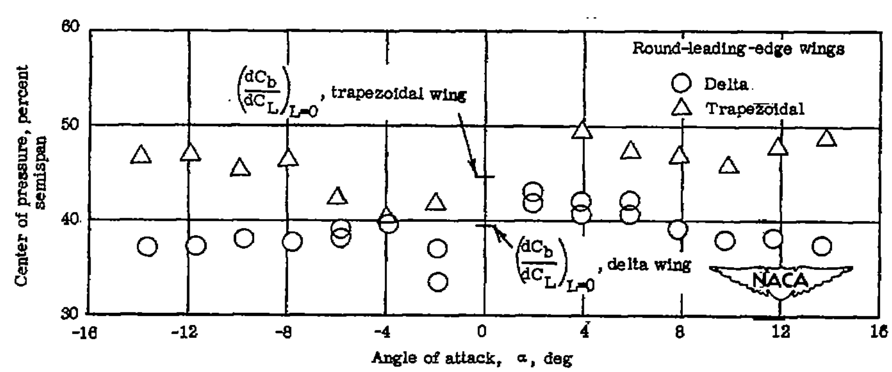
Figure 7.- Aerodynamic characteristics of a 3-percent-thick round-leading-edge delta wing and a 3-percent-thick round-leading-edge trapezoidal wing. $M = 4.04$; $R = 9.3 \times 10^6$ based on wing root chord.



(c) Wing-root bending-moment coefficients.



(d) Chordwise centers of pressure.



(e) Spanwise centers of pressure.

Figure 7.- Concluded.

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