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RESEARCH MEMORANDUM

LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A SEMISPAN AIRPLANE MODEL WITH A SWEPT-BACK TAIL FROM TESTS AT TRANSONIC SPEEDS BY THE NACA WING-FLOW METHOD

By

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RESEARCH MEMORANDUM

LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A SEMISPAN AIRPLANE MODEL WITH A SWEPT-BACK TAIL FROM TESTS AT TRANSONIC SPEEDS BY THE NACA WING-FLOW METHOD

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SUMMARY

An investigation was made by the NACA wing-flow method to determine the longitudinal stability and control characteristics at transonic speeds of a semispan airplane model having a wing of conventional plan form and a horizontal tail swept back 45°. The wing and tail had NACA 65-series airfoil sections with thicknesses of 10 and 8 percent chord, respectively. The model was mounted in such a way as to permit it to assume a position of zero pitching moment about the center of gravity at 27 percent of the mean aerodynamic chord. Measurements were made of lift and angle of attack for trim for several stabilizer and elevator settings.

Because of the chordwise variation of Mach number in the test region, the effective Mach number for the wing of the model was lower than that for the tail of the model. The tests were made at effective Mach numbers at the wing of the model from 0.55 to 1.09. The interpretation of the results in terms of full-scale flight conditions is subject to some uncertainty because of the difference in the Mach number of the flow at the wing and at the tail and because of the low Reynolds number of the tests.

The results of the tests are compared with the results of previous tests of the same model equipped with an unswept horizontal tail. The lift coefficient and angle of attack for trim with various stabilizer and elevator angles showed about the same general variation with Mach number up to a Mach number of 0.88 as was obtained with the unswept tail. Although fairly abrupt changes in trim occurred at higher Mach numbers, the trim changes were considerably smaller and occurred at Mach numbers which were, on the average, 0.05 higher than for the unswept tail. The effectiveness of the stabilizer in changing the lift coefficient and angle of attack for

trim decreased fairly steadily with increase in Mach number above 0.65. No sudden loss of effectiveness was indicated such as was indicated for the unswept tail when the Mach number was increased from 0.85 to 0.90. The elevator was ineffective for deflections of 1.4° to -2° over the entire Mach number range of the tests probably because of the effects of low Reynolds number and sweepback combined or of the effect of sweepback alone. The change in trim obtained by deflecting the elevator from -2° to -6° decreased steadily with increase in Mach number above 0.70 and became zero for deflections from -2° to -4° at a Mach number of 0.97 or a Mach number about 0.05 higher than that for which the elevator of the unswept tail became ineffective at small deflections. The results indicated that with the swept-back tail an airplane of configuration similar to that of the model could be trimmed for level flight through the Mach number range investigated with considerably smaller and more gradual variation of stabilizer angle than with an unswept tail; the variation of elevator angle also would be smaller provided the range of ineffective elevator angle were avoided.

INTRODUCTION

An investigation of the longitudinal stability and control characteristics of a semispan airplane model has been undertaken by means of the NACA wing-flow method in order to obtain some information on the longitudinal stability and control problems that may be encountered in flight at speeds up to and through the speed of sound. Results of tests of the model fitted with an unswept wing and a horizontal tail having airfoil sections with thicknesses of 10 and 8 percent chord, respectively, were reported in reference 1. These results indicated that the principal difficulties would be encountered at Mach numbers between 0.90 and 0.95 where sharp changes in trim occurred apparently as a result of compressibility effects on the tail. In particular the elevator suffered a complete loss of effectiveness for small deflections in this Mach number range. Because the results of tests on swept-back airfoils (references 2 and 3) indicated better lift characteristics than may be obtained for unswept airfoils in the transonic-speed range, the present tests were made with a swept-back tail installed on the model. The tail had the same span, aspect ratio, and airfoil section as the original tail, no taper, a sweepback of 45° and a 30-percent-chord elevator. The tests reported herein were made as described in reference 1. Measurements were made of lift and angle of attack at trim for several stabilizer and elevator settings. The tests covered a range of effective Mach number at the wing of the model from 0.55 to 1.09.

SYMBOLS

α_{trim}	angle of attack of fuselage for trim
$\alpha_{C_L=0}$	angle of attack of fuselage at zero lift
i_t	incidence of stabilizer
δ_e	deflection of elevator
y	stabilizer ordinate
x	distance along chord of stabilizer
M_w	effective Mach number at wing
M_t	effective Mach number at tail
q_w	effective dynamic pressure
S	wing area (semispan), 6 square inches
L_{trim}	lift for trim
$C_{L_{trim}}$	lift coefficient for trim $\left(\frac{L_{trim}}{q_w S}\right)$
R_w	Reynolds number of wing based on mean aerodynamic chord of wing, 1.556 inches
R_t	Reynolds number of tail based on mean aerodynamic chord of tail, 0.942 inch
$\left(\frac{dC_{L_{trim}}}{d\alpha_{trim}}\right)_m$	mean slope of lift curve of model for C_L from 0 to 0.4
$\left(\frac{dC_{L_{trim}}}{di_t}\right)_m$	mean rate of change of model lift coefficient with tail incidence for i_t from 0.7° to 3.7°

APPARATUS AND TESTS

The tests were made, as described in reference 1, by the NACA wing-flow method in which the model is mounted in the high-speed flow over the wing of a P-51D airplane.

The semispan model equipped with a swept-back horizontal tail is shown in figures 1 to 3. Except for the horizontal tail, the model was the same as that used for the tests of reference 1. The tails in both cases had the same area, aspect ratio, and airfoil section in planes normal to the tail span. The elevator chords, however, were 20 and 30 percent of the chords of the straight and swept-back tails, respectively. The arrangement of the unswept tail of reference 1 is shown in figure 3 for comparison with the present tail. The geometric characteristics of the model with the swept-back horizontal tail are given in table I. Dimensions of a corresponding full-scale airplane with a scale of 50:1 relative to the model are also shown in table I in order that the proportions of the airplane may be more easily visualized. The horizontal tail was arranged to permit adjustment of the stabilizer angle. The surfaces of the tail were grooved at 70 percent of the chord in order that the tail could be bent sharply along this line to simulate deflection of the elevator. A section profile of the horizontal tail with the elevator deflected -6° is shown in figure 4. The tail and elevator chords and the stabilizer and elevator deflections are considered in planes normal to the span of the tail. The model was mounted in such a way as to permit it to assume a position of zero pitching moment about the center of gravity at 27 percent of the mean aerodynamic chord. Other details of the model and the testing technique are described in reference 1.

Measurements of lift and angle of attack of the model at trim were made with elevator neutral and stabilizer settings of -1.3°, 0.7°, 2.7°, and 3.7° and with a stabilizer setting of 3.7° and elevator settings of 1.4°, -2°, -4°, and -6°. In order to cover a range of Reynolds number the tests with each tail setting were made in two dives, one at high and one at medium altitude, and in a level flight run at low altitude. The average relation between the Reynolds number at the wing R_w and the Reynolds number at the tail R_t with the Mach number at the wing M_w for the three altitude conditions is shown in figure 5. The Reynolds number corresponding to a given Mach number in a given nominal altitude range varied somewhat among different tests but the variations did not exceed 5 percent. Also shown in figure 5 is the variation of the Mach number at the tail M_t with the Mach number at the wing M_w.

The Mach number at the tail was higher than the Mach number at the wing because of the chordwise variation of Mach number in the test region (reference 1).

PRESENTATION OF RESULTS

The results of the investigation are presented in figures 6 to 15. The variation of lift coefficient and angle of attack of the model for trim with Mach number is shown in figure 6 for stabilizer settings of -1.3°, 0.7°, 2.7°, and 3.7° with elevator neutral and in figure 7 for a stabilizer setting of 3.7° with elevator deflections of 1.4°, -2°, -4°, and -6°. The variation of lift coefficient with angle of attack obtained from the data of figures 6 and 7 and from corresponding data of reference 1 is shown in figure 8 for various Mach numbers. Inasmuch as the change in configuration of the horizontal tail of the model between the present tests and the tests of reference 1 would be expected to have little or no effect on the relation between lift coefficient and angle of attack, both sets of data were used to determine the fairing indicated by the solid line. The slope of the lift curve $\left(\frac{dC_{L_{trim}}}{d\alpha_{trim}}\right)_m$ taken over a range of lift coefficient from 0 to 0.4 and the angle of attack of the fuselage at zero lift were determined from the faired curves of figure 8 and are plotted against Mach number at the wing M_w in figure 9. The variations of angle of attack and lift coefficient for trim with stabilizer setting for various Mach numbers are shown in figures 10 and 11, respectively, and with elevator deflection in figures 12 and 13, respectively. The mean rate of change of lift coefficient with stabilizer angle $\left(\frac{dC_{L_{trim}}}{di_t}\right)_m$ for stabilizer settings i_t from 0.7° to 3.7° is plotted in figure 14 against Mach number at the wing M_w and Mach number at the tail M_t. From the data of figures 11 and 13 the stabilizer angles (elevator neutral) and the elevator deflections (stabilizer setting of 3.7°) required for trim in level flight through the Mach number range have been determined for an airplane of the same configuration as the model and are shown in figure 15. The wing loading was taken as 50 and the altitude as 30,000 feet. The corresponding variation of lift coefficient C_L with Mach number is also shown in figure 15. In order to facilitate comparison of the longitudinal stability and control characteristics indicated by the present tests for the model having the swept-back tail with the characteristics indicated in reference 1 for the unswept tail, data from reference 1 are included in figures 11, 13, 14, and 15.

DISCUSSION AND RESULTS

The angles of attack and lift coefficients at which the model trimmed for various stabilizer settings with elevator neutral (fig. 6) showed no appreciable effect of the difference in Reynolds number obtained from the low-altitude and medium-altitude runs. Some scale effect, however, appeared to be indicated in the data obtained from the high-altitude run at Mach numbers of 0.77 to 0.92. With the elevator deflected (fig. 7) the results indicated some effect of the difference in Reynolds number obtained in the low-altitude and medium-altitude runs at Mach numbers less than 0.70 and a large scale effect in the high-altitude run at Mach numbers less than 0.95. No scale effect was indicated at Mach numbers greater than 0.95. In view of these results only low-altitude and medium-altitude data are considered herein except for Mach numbers above 0.95.

The lift coefficient and angle of attack for trim with various stabilizer and elevator settings showed about the same general variation with Mach number up to a Mach number of about 0.88, as was obtained in reference 1 for the model with the unswept tail. That is, the lift coefficient and angle of attack for trim decreased fairly steadily at Mach numbers from about 0.70 to 0.85, probably as a result of shock stalling at or near the wing-fuselage juncture. At Mach numbers from 0.85 to 0.88 the angle of attack for trim increased probably as a result of a change in angle of attack for zero lift and in zero-lift pitching moment for the entire wing. With a further increase in Mach number the lift coefficient and angle of attack decreased steadily up to a Mach number of 0.97 or 0.98 and then decreased fairly abruptly. This abrupt change was considerably smaller than the trim changes encountered with the unswept tail of reference 1 and occurred, on the average, at a Mach number that was 0.05 higher.

The variation of lift coefficient with angle of attack at all Mach numbers indicated in figure 8 agreed within experimental error with the data of reference 1. The slopes of the lift curves (fig. 9) derived from the combined data of the present tests and the tests of reference 1 are slightly different in absolute value than the slopes presented in reference 1 but the general variation with Mach number is unaltered. The angle of attack of the fuselage at zero lift (fig. 9) was essentially constant at a value of about -2.2° for Mach numbers from 0.60 to 0.80. With a further increase in Mach number the angle of attack at zero lift decreased to -0.9° at a Mach number of about 0.89 and then increased again to approximately the lower speed value at Mach numbers from 0.96 to 1.07.

The slopes of the curves of angle of attack and lift coefficient against stabilizer incidence in figures 10 and 11, respectively, indicated that the variation of fixed-control pitching moment with angle of attack at a given Mach number was always stable over the range of conditions covered. The curves showed a generally decreasing slope with increasing Mach number probably as a result of increase in the stability of the model or of decrease in the stabilizer effectiveness. No sudden decrease appeared, however, in the slope of the curves, such as appeared with increase in Mach number from 0.85 to 0.90 for the model with the unswept tail. (See fig. 11.) The comparison of the variation with Mach number of $\left(\frac{dC_{L_{trim}}}{di_t}\right)_m$ for the unswept and swept-back tails, as given in figure 14, indicated a similar result. Both curves show approximately the same variation for Mach numbers up to about 0.87 and beyond 0.94 but between these values the curve for the unswept tail indicates fairly large and abrupt changes which did not appear in the curve for the swept-back tail. The larger values of $\left(\frac{dC_{L_{trim}}}{di_t}\right)_m$ for the swept-back tail than for the unswept tail at Mach numbers less than about 0.90 may be caused by both the increased tail length of the swept-back tail and the fact that the slope, although taken over apparently the same range of stabilizer setting, covers a somewhat different range of lift coefficient for the two sets of data.

For elevator deflections from 1.4° to -2° the elevator of the swept-back tail was ineffective in changing the angle of attack and lift coefficient of the model over the entire Mach number range of the tests (figs. 12 and 13). Whether this ineffectiveness at small deflections was a result of the effects of low Reynolds number and sweepback combined or of the effect of sweepback alone is not known. This ineffectiveness apparently was not due solely to the low Reynolds number at which the tail was operating inasmuch as no similar result was obtained with the elevator of the unswept tail even at the lowest Reynolds number of the tests. (See reference 1.) In the deflection range from -2° to -6° the effectiveness of the elevator in changing the trim condition of the model decreased fairly steadily as the Mach number was increased above 0.70 and became zero for deflections of -2° to -4° at a Mach number of 0.97. This Mach number is about 0.05 higher than that at which the elevator of the unswept tail became ineffective at small deflections.

Because of the chordwise variation of Mach number in the test region the Mach number of the flow at the tail may be greater than the values quoted in the preceding discussion by the amount indicated in figure 5, although the wake of the wing may reduce the tail Mach number somewhat. The changes in the characteristics of the model attributable to the effects of compressibility on the tail would probably occur in free air at somewhat higher Mach numbers than the values quoted.

The results of the tests indicated, as shown in figure 15, that an airplane of configuration similar to that of the model having a wing loading of 50 and flying at an altitude of 30,000 feet could be trimmed with a stabilizer or, in effect, with an all-movable tail for level flight throughout the Mach number range from 0.60 to 1.06 with an over-all deflection range of about 1.2°. For a stabilizer setting of 3.7°, trim could be maintained with the elevator alone with a deflection range of about 1.1° at Mach numbers from 0.60 to 0.92, but for Mach numbers from 0.92 to 1.00 or 1.05 an increase in up elevator deflection of 3° would be required. With stabilizer settings less than 3.7°, trim with elevator alone may require operation through the ineffective range of elevator angle and, hence, the variation of elevator angle for trim with Mach number may be more rapid and of larger magnitude than shown for the stabilizer setting of 3.7°. The variation with Mach number of the stabilizer and elevator angles for trim appears to be stable at Mach numbers from 0.60 to 0.75, unstable at Mach numbers from 0.75 to 0.88, and alternately stable and unstable at higher Mach numbers. Comparison of these results with similar results obtained in reference 1 for the unswept tail indicated that the change from the unswept tail to the swept-back tail would result in a considerably smaller and more gradual variation with Mach number of the stabilizer angle required for level flight; the variation of elevator angle would also be smaller provided the ineffective range of elevator angle is avoided.

CONCLUDING REMARKS

The results of NACA wing-flow tests of a semispan airplane model having a wing of conventional plan form and a 45° swept-back horizontal tail indicated an appreciable improvement in the longitudinal stability and control characteristics above a Mach number of about 0.88 as compared with the results of previous tests of the model equipped with an unswept horizontal tail. The lift coefficient and angle of attack for trim with various stabilizer and elevator angles showed about the same general variation with Mach number up to a Mach number of 0.88 as was obtained with the unswept tail. Although fairly abrupt changes in trim occurred at higher Mach numbers, the trim changes were considerably smaller and occurred at Mach numbers which were, on the average, 0.05 higher than for the unswept tail. The effectiveness of the stabilizer in changing the lift coefficient and angle of attack for trim decreased fairly steadily with increase in Mach number above 0.65; no sudden loss of effectiveness was indicated such as was indicated for the unswept tail when the Mach number was increased from 0.85 to 0.90. The elevator was ineffective for deflections from 1.4° to -2° over the entire Mach number range of the tests probably because of the effects of low Reynolds number and sweepback combined or of the effect of sweepback alone. The change in trim obtained by deflecting the elevator from -2° to -6° decreased steadily with increase in Mach number above 0.70 and became zero for deflections from -2° to -4° at a Mach number of 0.97 or a Mach number about 0.05 higher than that for which the elevator of the unswept tail became ineffective at small deflections. The results indicated that with a swept-back tail an airplane of configuration similar to that of the model could be trimmed for level flight through the Mach number range investigated with considerably smaller and more gradual variation of stabilizer angle than with an unswept tail; the variation of elevator angle also would be smaller provided the range of ineffective elevator angle were avoided.

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1. Zalovcik, John A., and Sawyer, Richard H.: Longitudinal Stability and Control Characteristics of a Semispan Airplane Model at Transonic Speeds from Tests by the NACA Wing-Flow Method. NACA ACR No. L6E15, 1946.

2. Zalovcik, John A., and Adams, Richard E.: Preliminary Tests at Transonic Speeds of a Model of a Constant-Chord Wing with a Sweepback of 45° and an NACA $65_{(112)}$-210, a = 1.0 Airfoil Section. NACA ACR No. L5J16a, 1945.

3. Daum, Fred L., and Sawyer, Richard H.: Tests at Transonic Speeds of the Effectiveness of a Swept-Back Trailing-Edge Flap on an Airfoil Having Parallel Flat Surfaces, Extreme Sweepback, and Low Aspect Ratio. NACA CB No. L5H01, 1945.

TABLE I

GEOMETRIC CHARACTERISTICS OF MODEL AND CORRESPONDING FULL-SCALE AIRPLANE

	Model	Full-scale airplane
Wing:		
Section	NACA $65_{(112)}$-110	NACA $65_{(112)}$-110
Semispan	4.00 in.	16 ft 8 in.
Mean aerodynamic chord	1.56 in.	78.0 in.
Chord at tip	1.00 in.	50 in.
Chord at plane of symmetry	2.00 in.	100 in.
Area (of semispan wing)	6 sq in.	104 sq ft
Aspect ratio	5.33	5.33
Taper ratio	2:1	2:1
Incidence at root	2° 30'	2° 30'
Incidence at tip	2° 00'	2° 00'
Dihedral	0°	0°
Horizontal tail:		
Section	NACA 65(112)-008	NACA 65(112)-008
Semispan	1.66 in.	6 ft 11 in.
Chord	0.94 in.	47 in.
Area (of semispan tail)	1.56 sq in.	27.0 sq ft
Aspect ratio	3.5	3.5
Taper ratio	1:1	1:1
Chord of elevator	0.28 in.	14.1 in.
Sweepback	45°	45°
Fuselage length	7.97 in.	33 ft 2 in.
Maximum fuselage diameter	1.20 in.	60 in.
Tail length (c.g. to 1/4 M.A.C. of horizontal tail)	4.29 in.	17 ft 10 in.
Location of center of gravity	27 percent M.A.C.	27 percent M.A.C.

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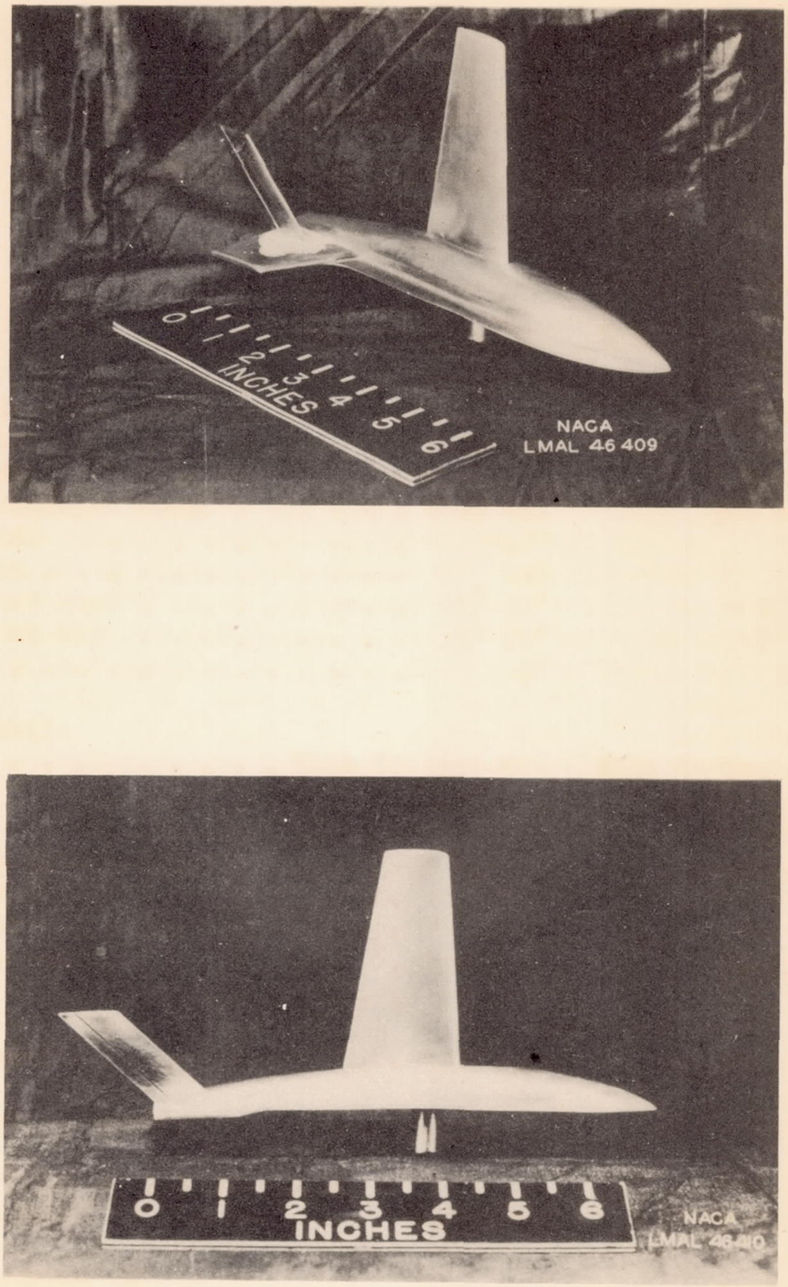

Figure 1.- Semispan airplane model.

Figure 2.- Semispan airplane model mounted above wing of P-51D airplane.

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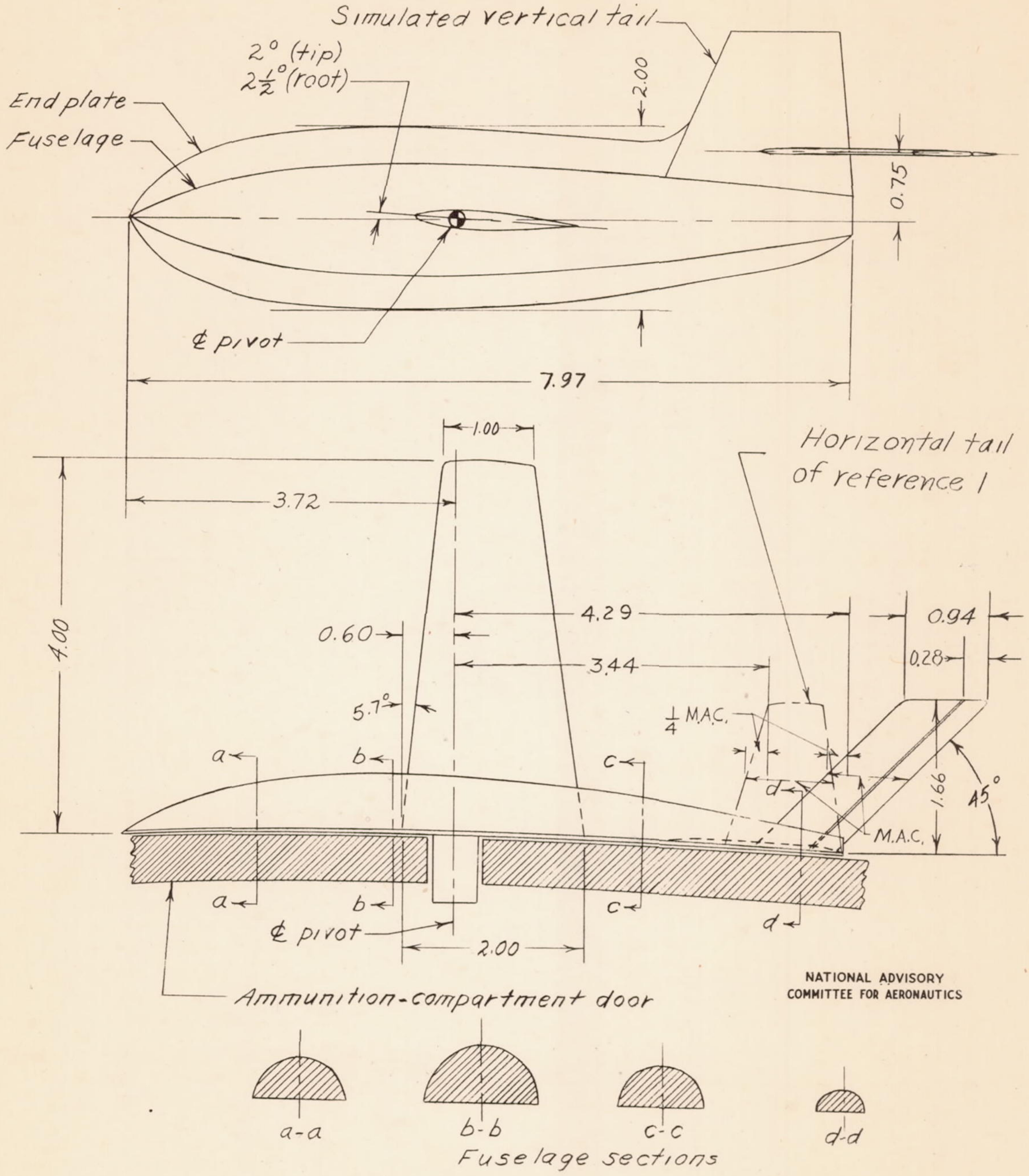

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Figure 3.- Details of semispan airplane model. All dimensions are in inches.

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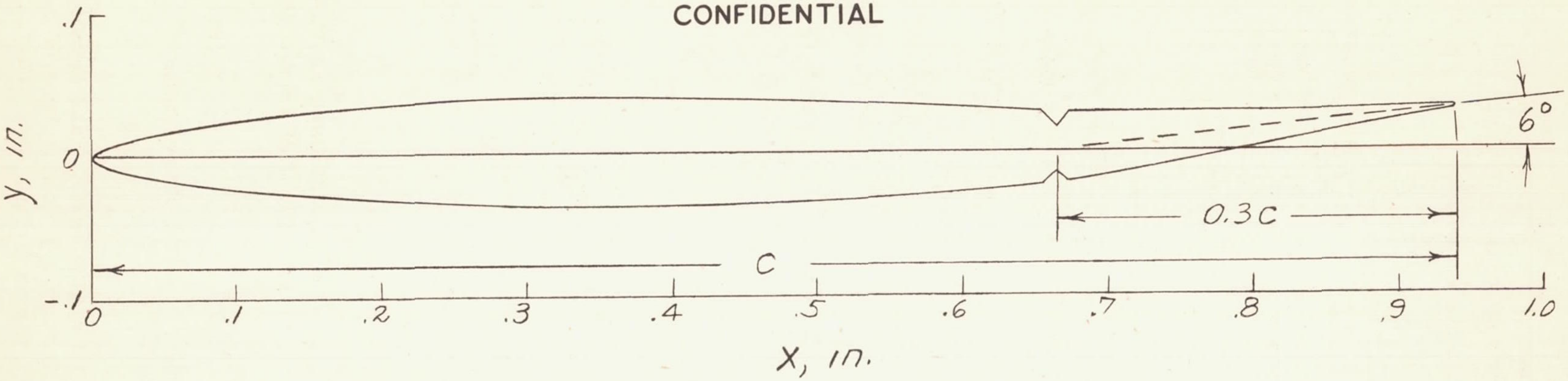

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Figure 4.- Measured profile of horizontal tail with elevator deflected 6°. Mean line shown dashed.

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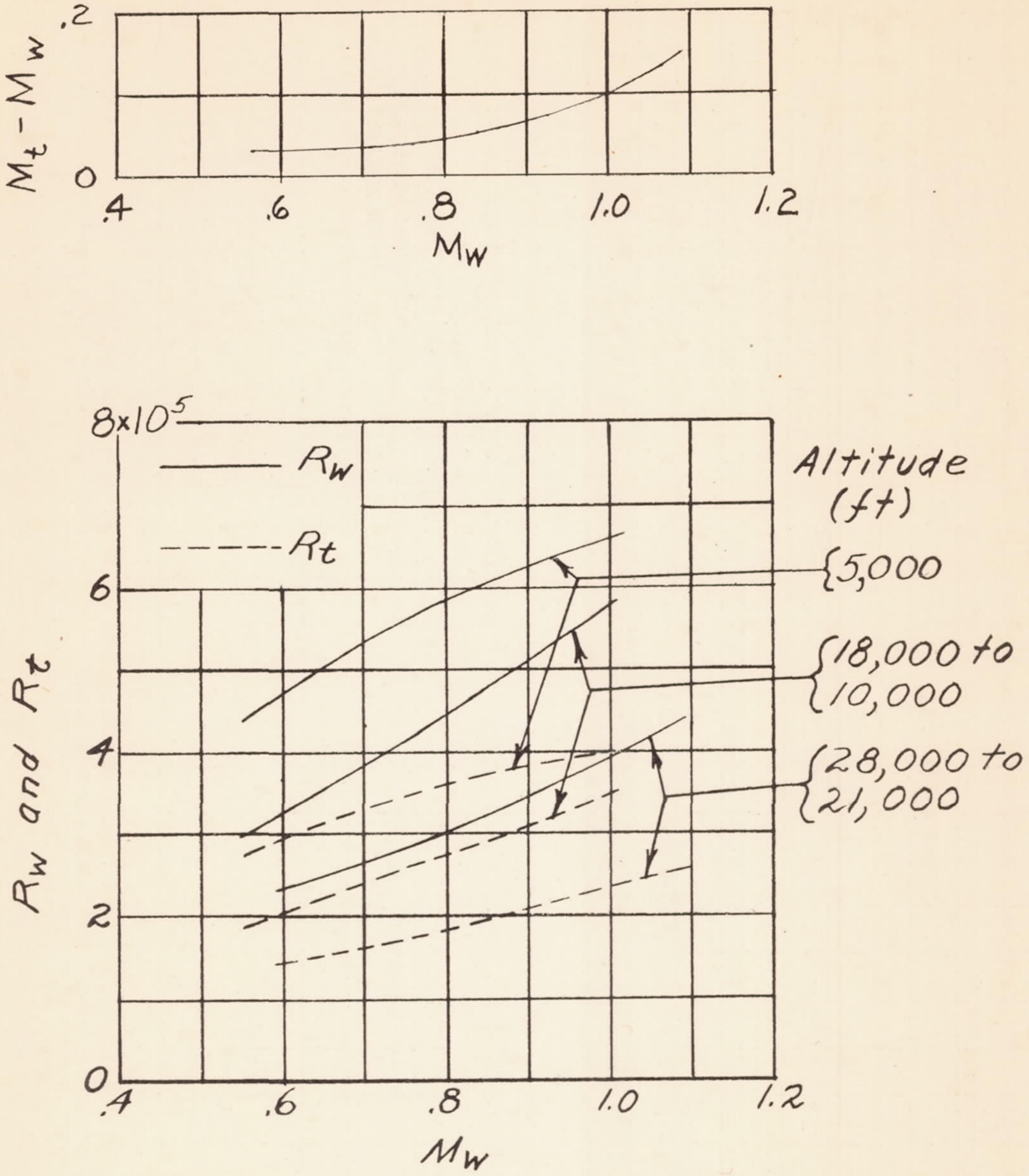

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Figure 5.- Variation of Reynolds number of wing R_w and Reynolds number of tail R_t with Mach number for tests at three ranges of altitude. Difference between Mach number of wing and tail also shown.

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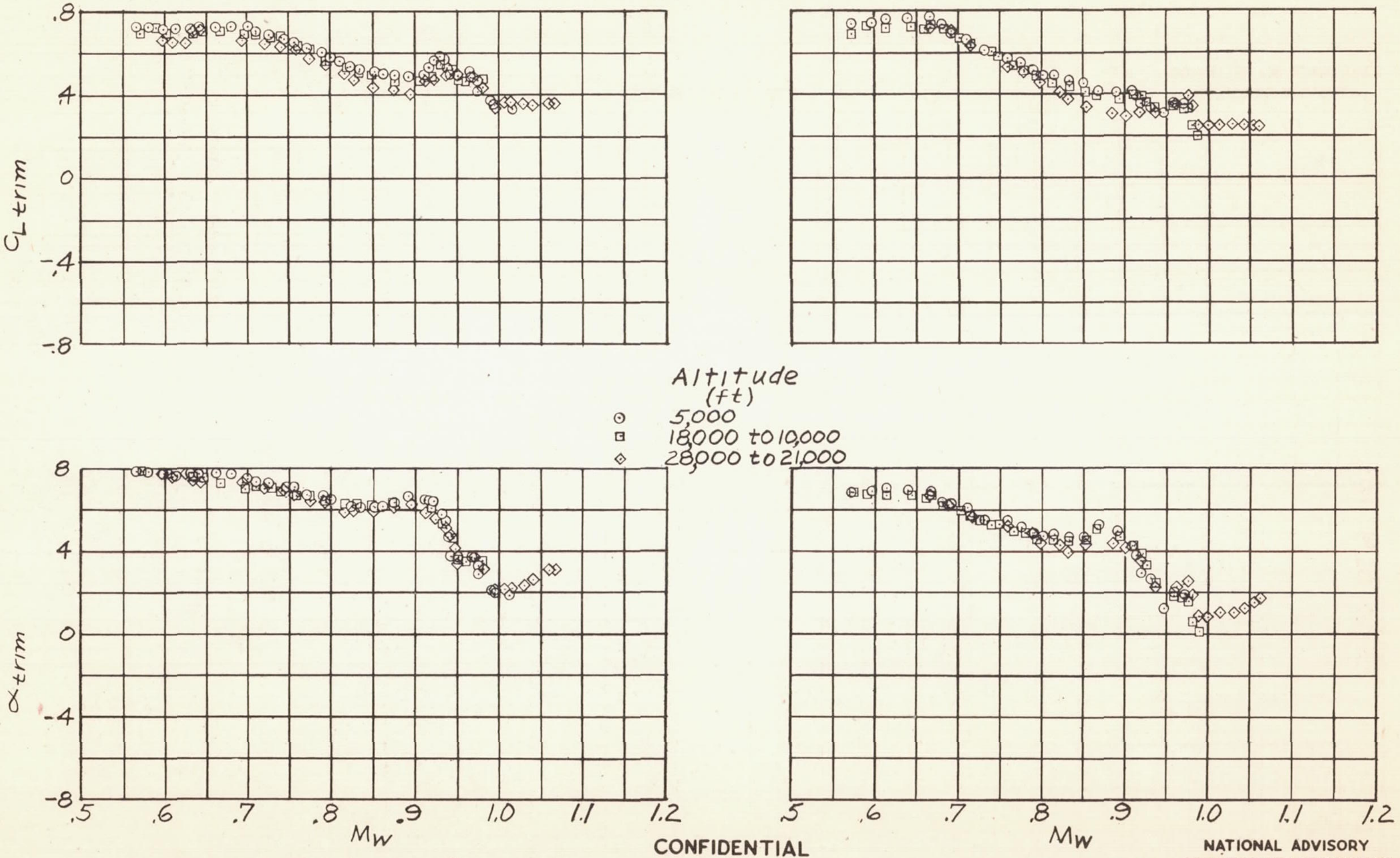

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(a) $i_t = -1.3°$.

(b) $i_t = 0.7°$.

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Figure 6.- Variation with Mach number of lift coefficient and angle of attack for trim with various stabilizer settings and elevator neutral.

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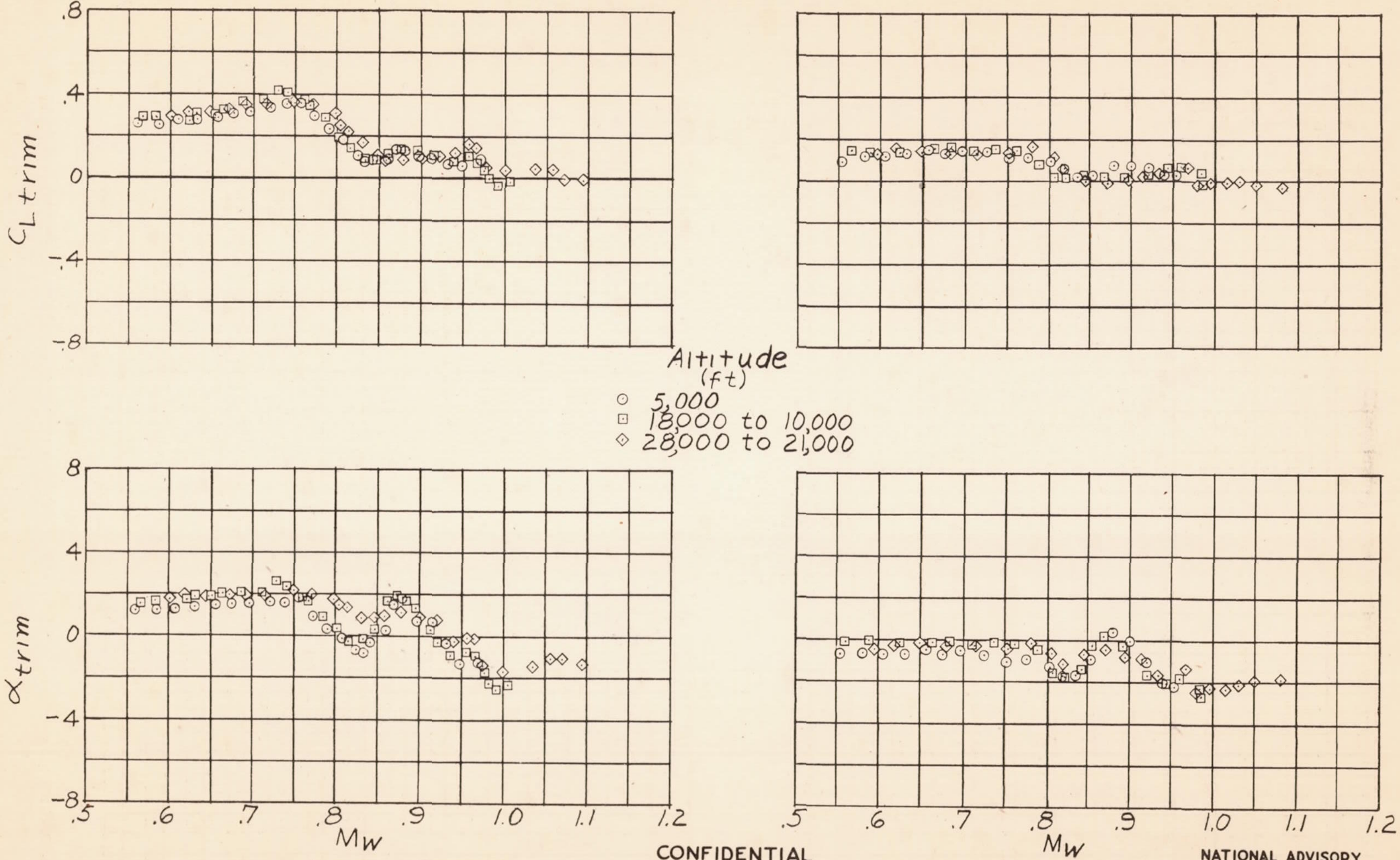

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(c) $i_t = 2.7°$.

(d) $i_t = 3.7°$.

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Figure 6.- Concluded.

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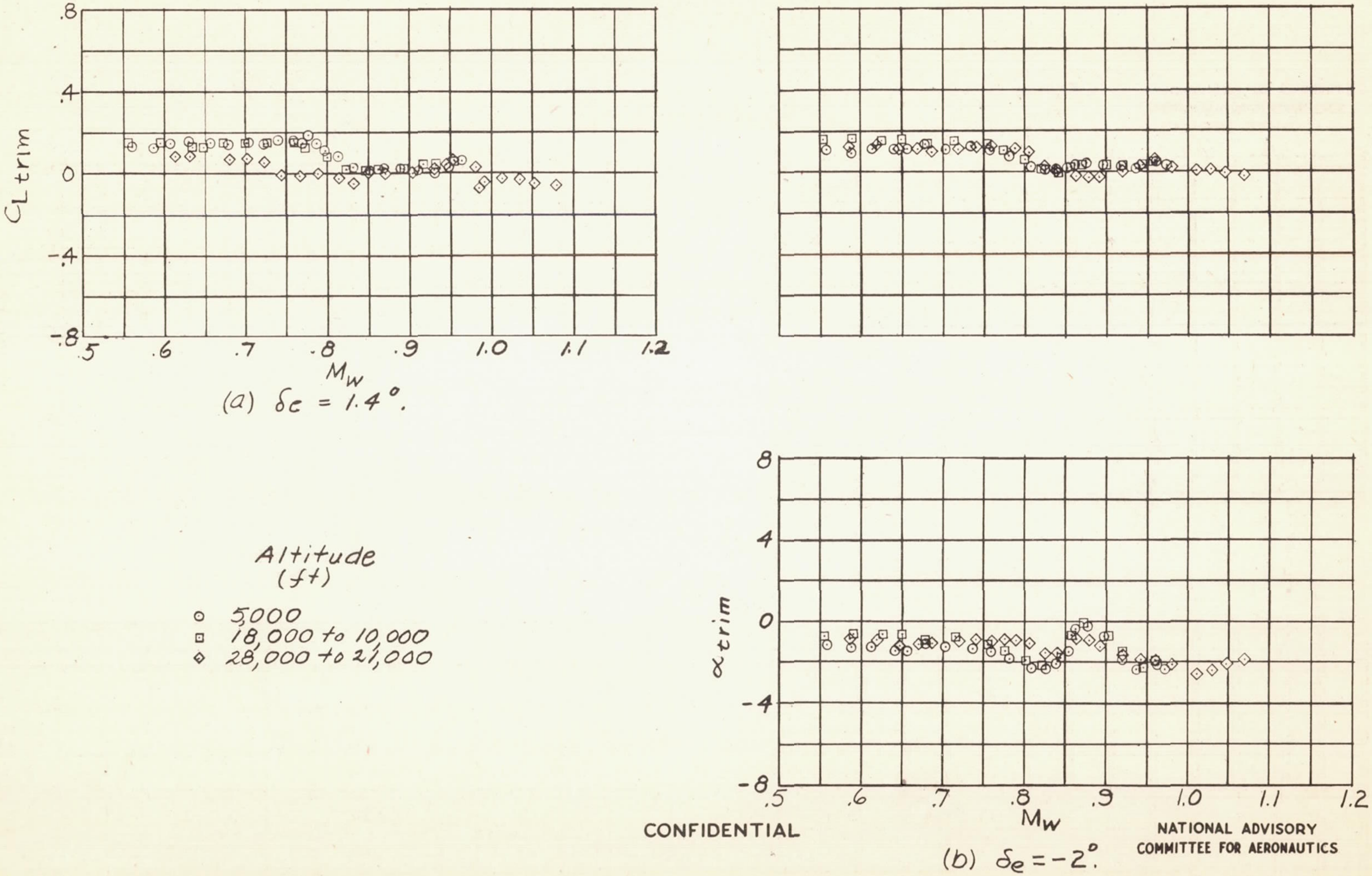

(a) $\delta_e = 1.4°$.

(b) $\delta_e = -2°$.

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Figure 7.- Variation with Mach number of lift coefficient and angle of attack for trim with various elevator deflections and stabilizer set at 3.7°. Angle of attack not determined for $\delta_e = 1.4°$.

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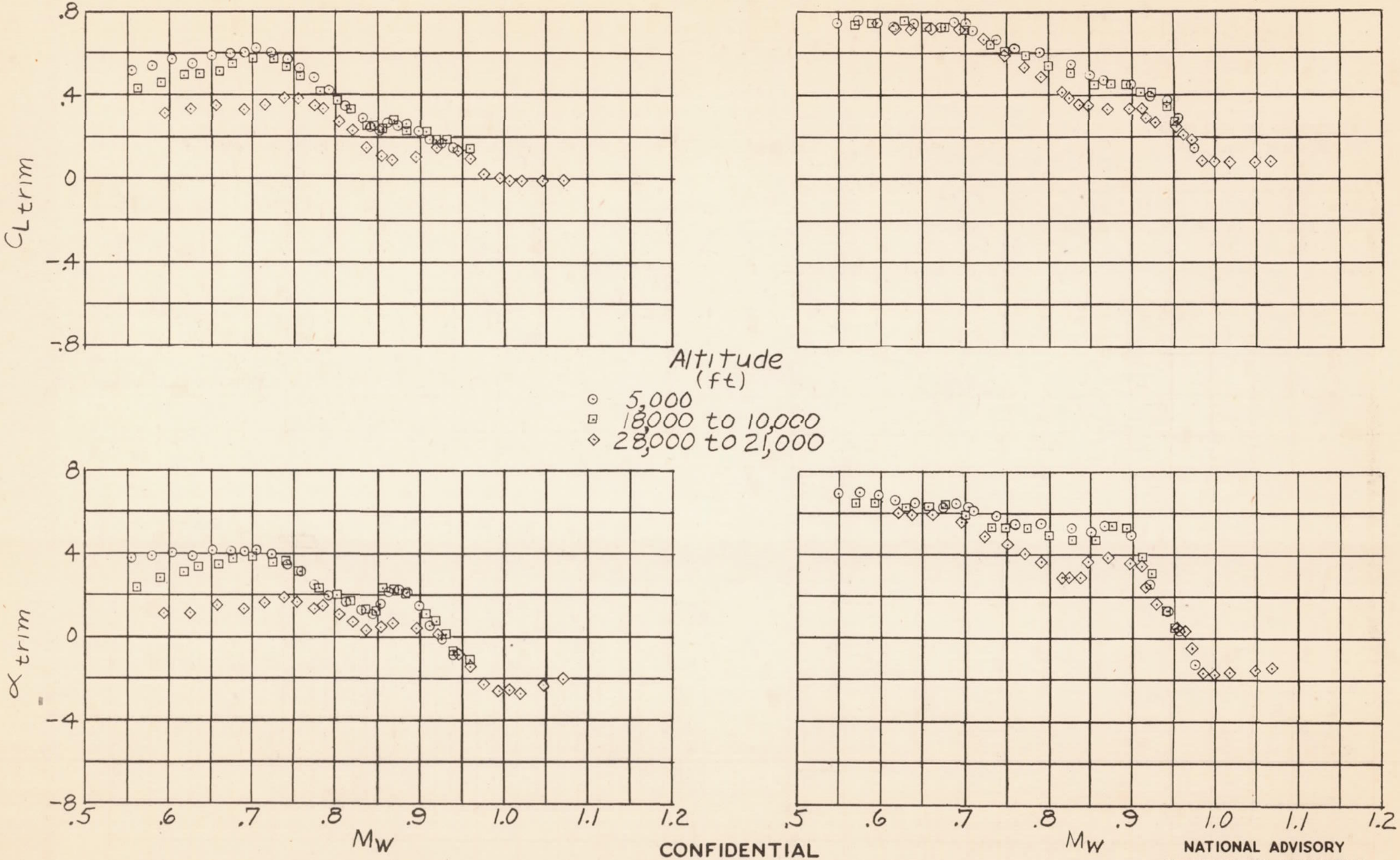

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(c) $\delta_e = -4°$

(d) $\delta_e = -6°$.

Figure 7.- Concluded.

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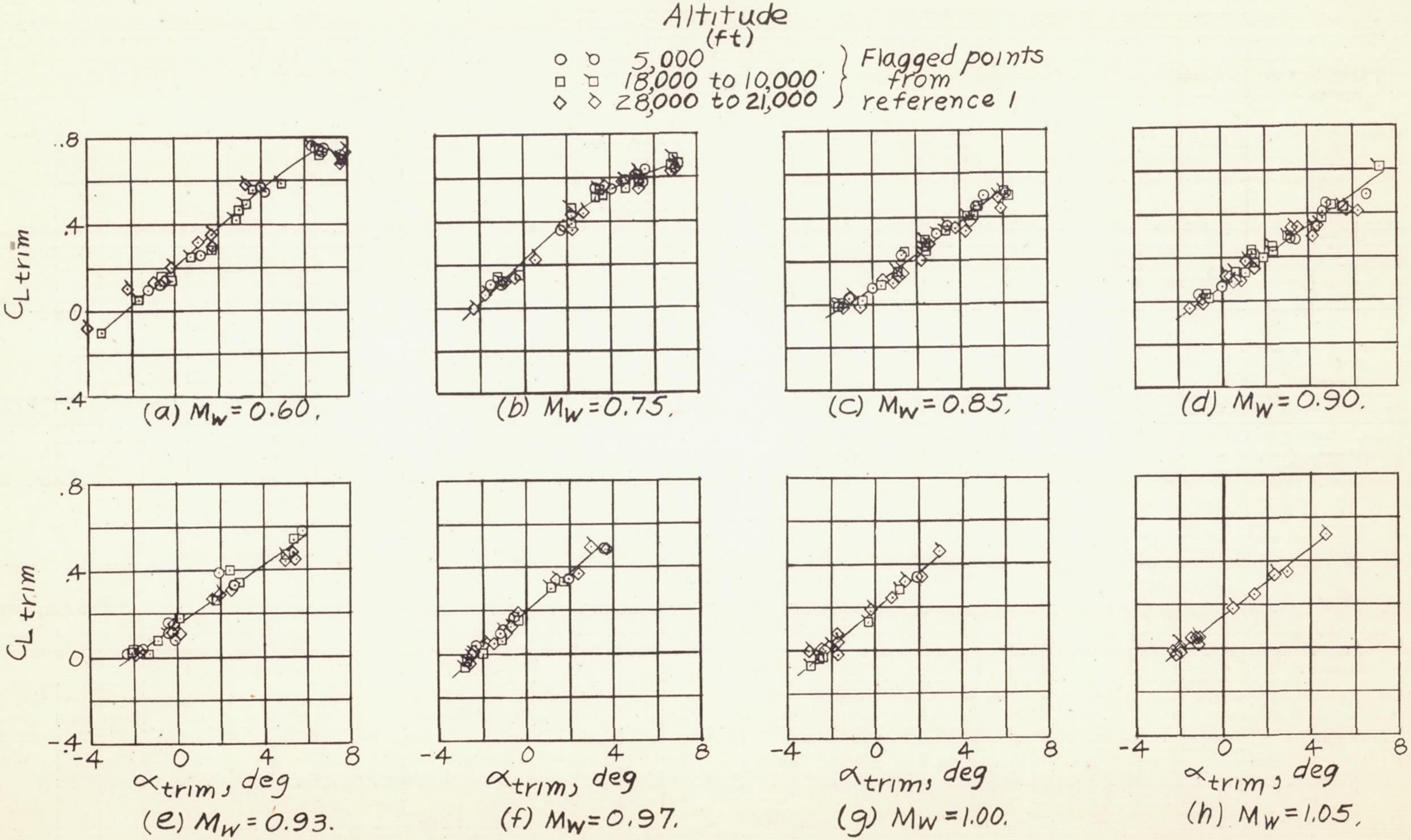

(a) $M_W = 0.60$.

(b) $M_W = 0.75$.

(c) $M_W = 0.85$.

(d) $M_W = 0.90$.

(e) $M_W = 0.93$.

(f) $M_W = 0.97$.

(g) $M_W = 1.00$.

(h) $M_W = 1.05$.

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Figure 8.- Variation of lift coefficient with angle of attack for various Mach numbers.

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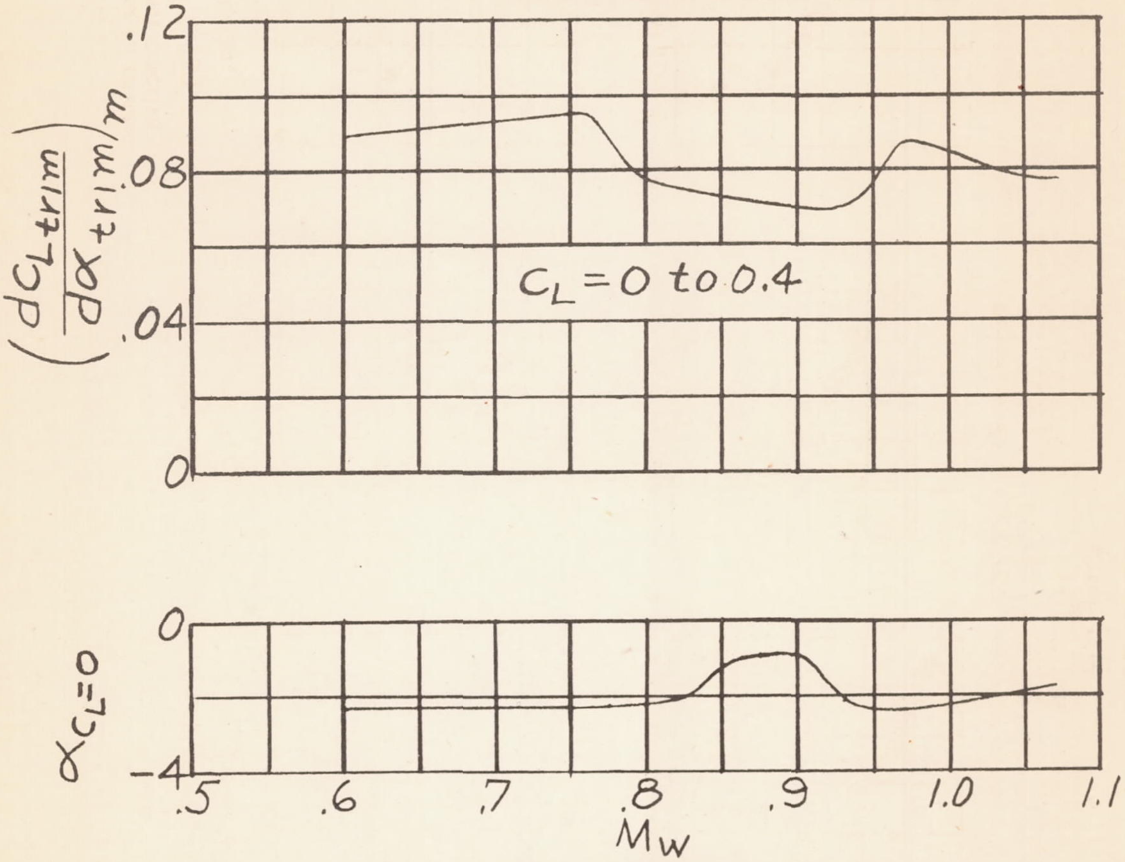

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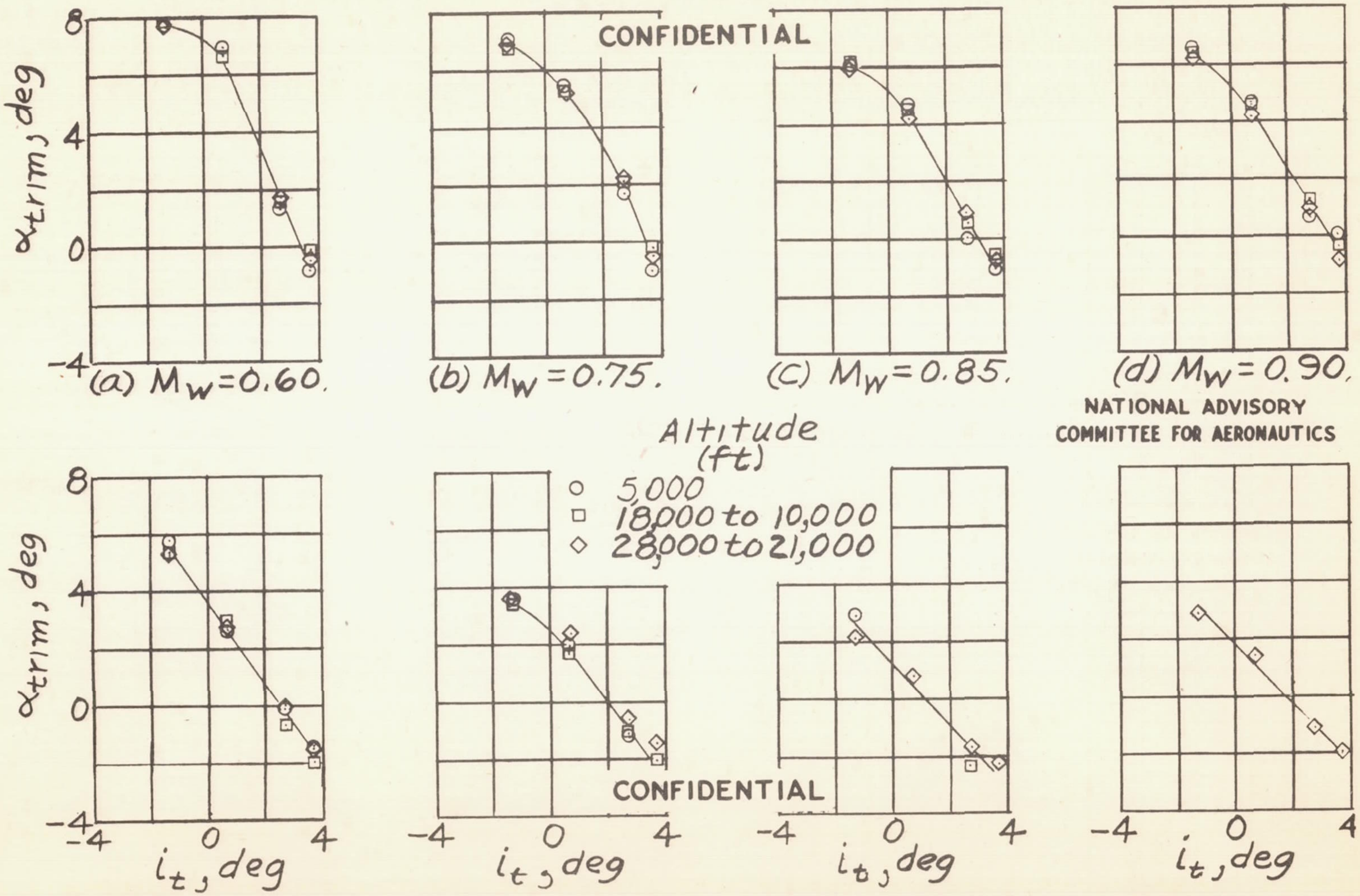
Figure 9.- Variation with Mach number of slope of lift curve and angle of zero lift.



(a) $M_W = 0.60$.

(b) $M_W = 0.75$.

(c) $M_W = 0.85$.

(d) $M_W = 0.90$.

(e) $M_W = 0.93$.

(f) $M_W = 0.97$.

(g) $M_W = 1.00$.

(h) $M_W = 1.05$

Figure 10.- Variation of angle of attack for trim with stabilizer setting for various Mach numbers. $\delta_e = 0$.

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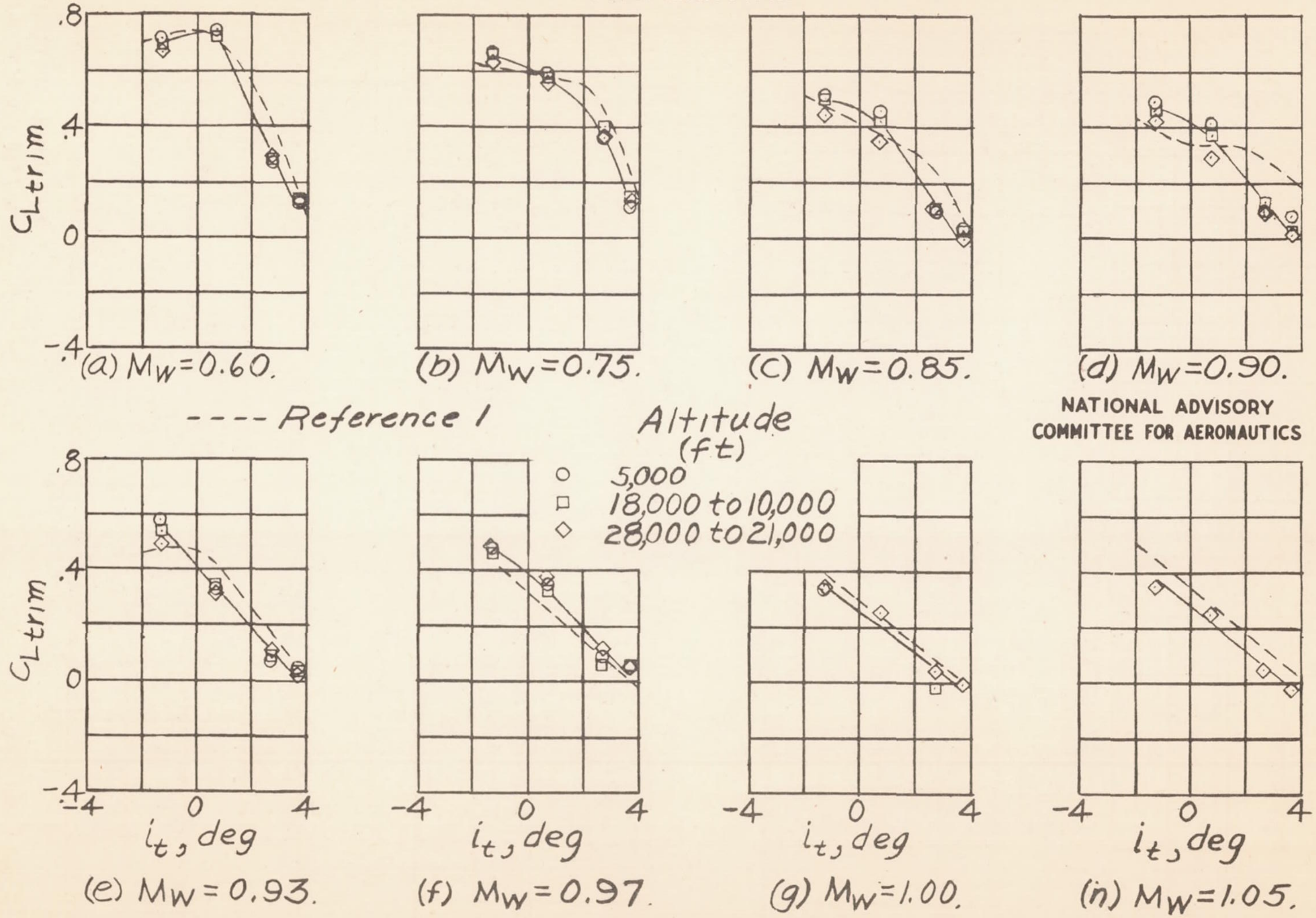

(a) $M_W = 0.60$. (b) $M_W = 0.75$. (c) $M_W = 0.85$. (d) $M_W = 0.90$.

(e) $M_W = 0.93$. (f) $M_W = 0.97$. (g) $M_W = 1.00$. (h) $M_W = 1.05$.

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Figure 11.- Variation of lift coefficient for trim with stabilizer setting for various Mach numbers and $\delta_e = 0$. Results for unswept tail from reference 1 shown for comparison.

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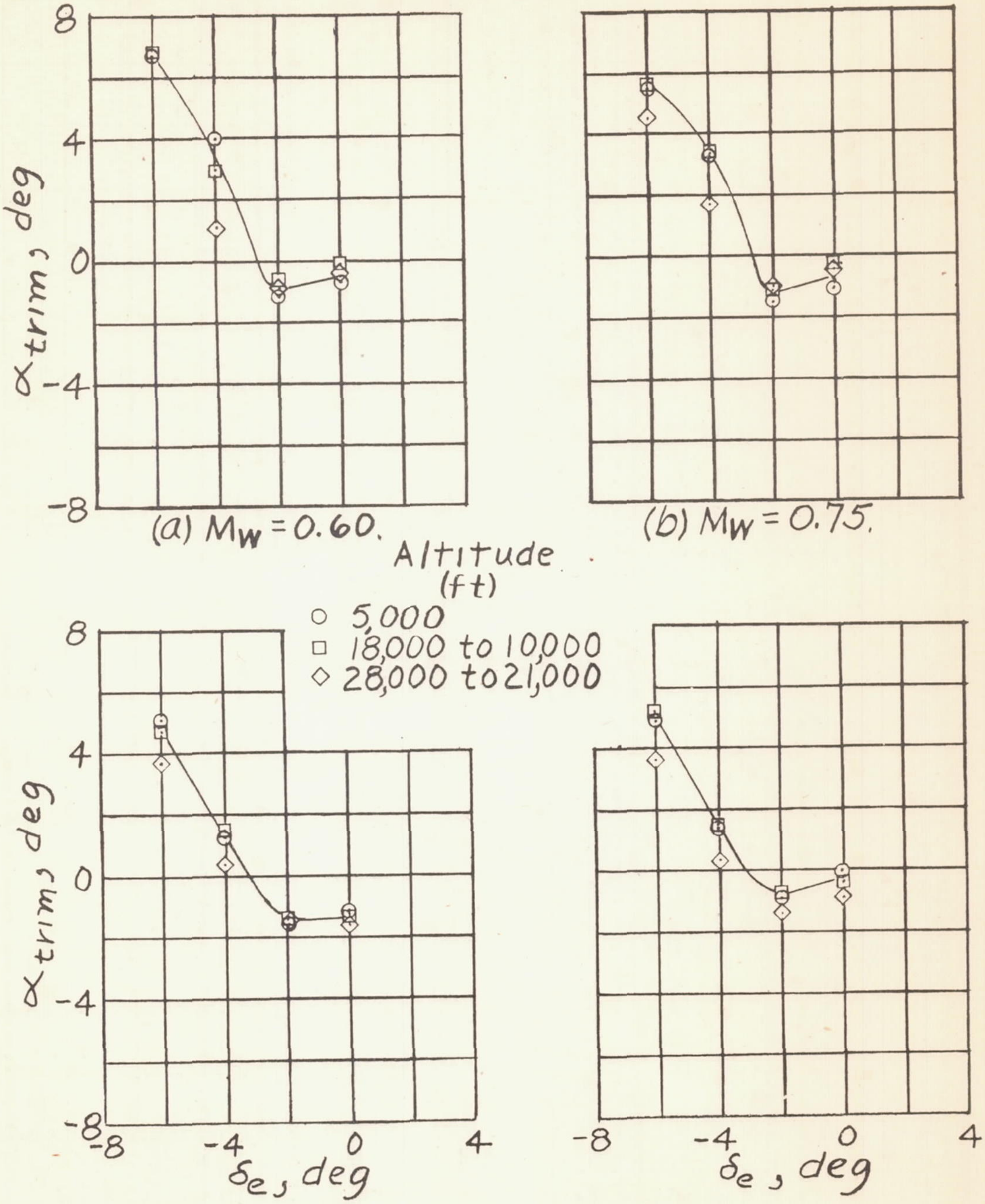

(a) $M_W = 0.60$.

(b) $M_W = 0.75$.

(c) $M_W = 0.85$.

(d) $M_W = 0.90$.

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Figure 12.- Variation of angle of attack for trim with elevator deflection for various Mach numbers. $i_t = 3.7^\circ$.

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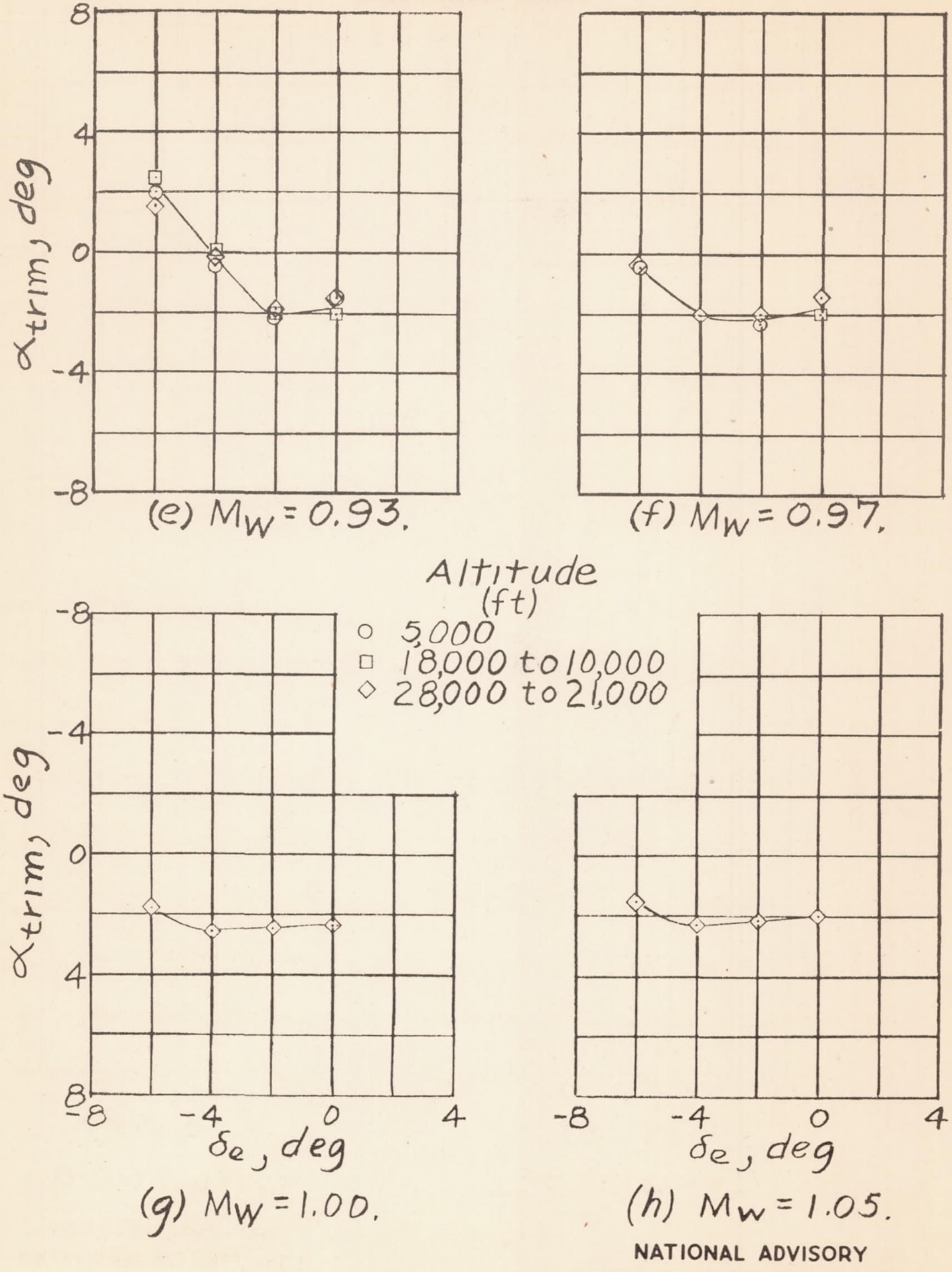

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Figure 12.- Concluded.

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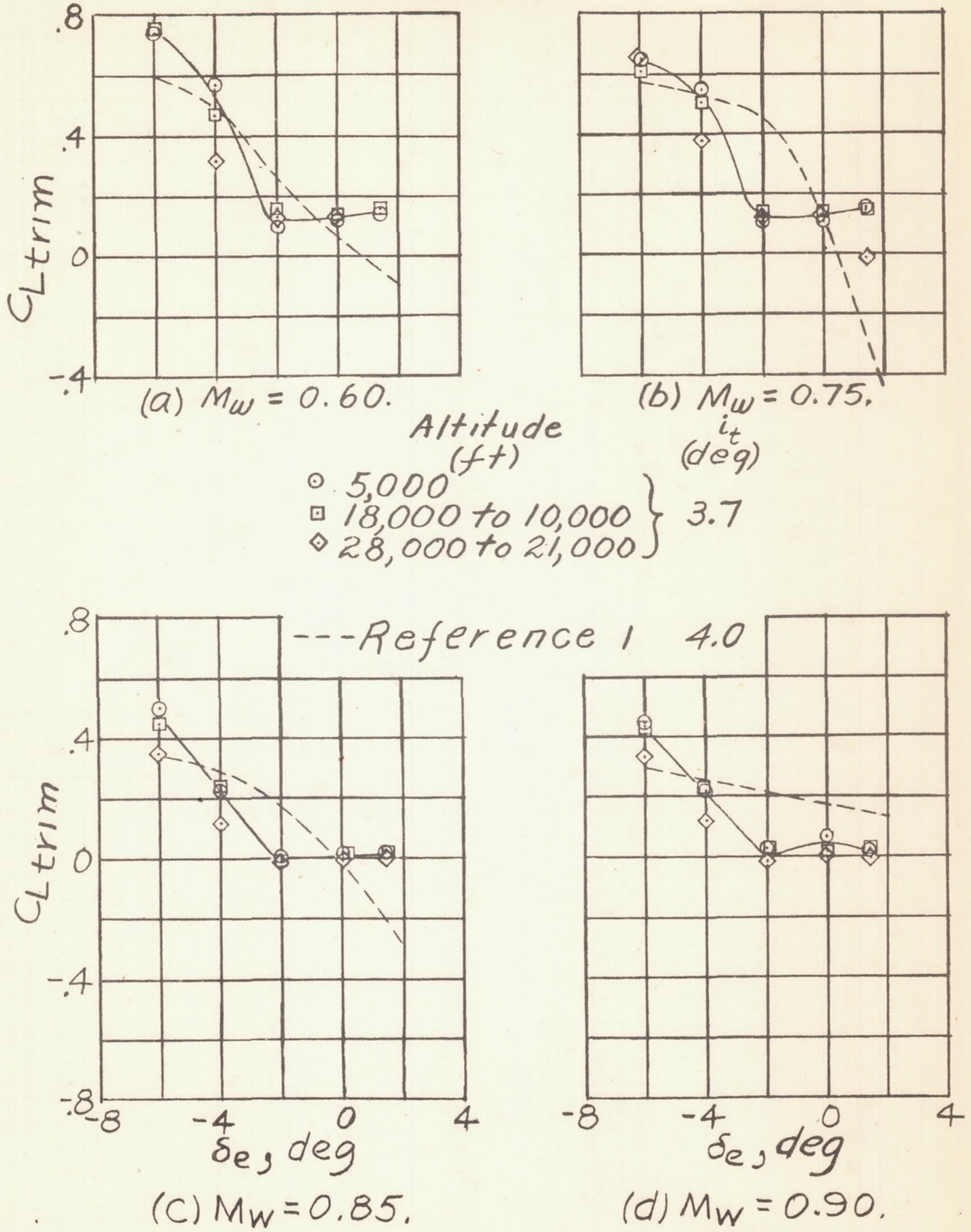

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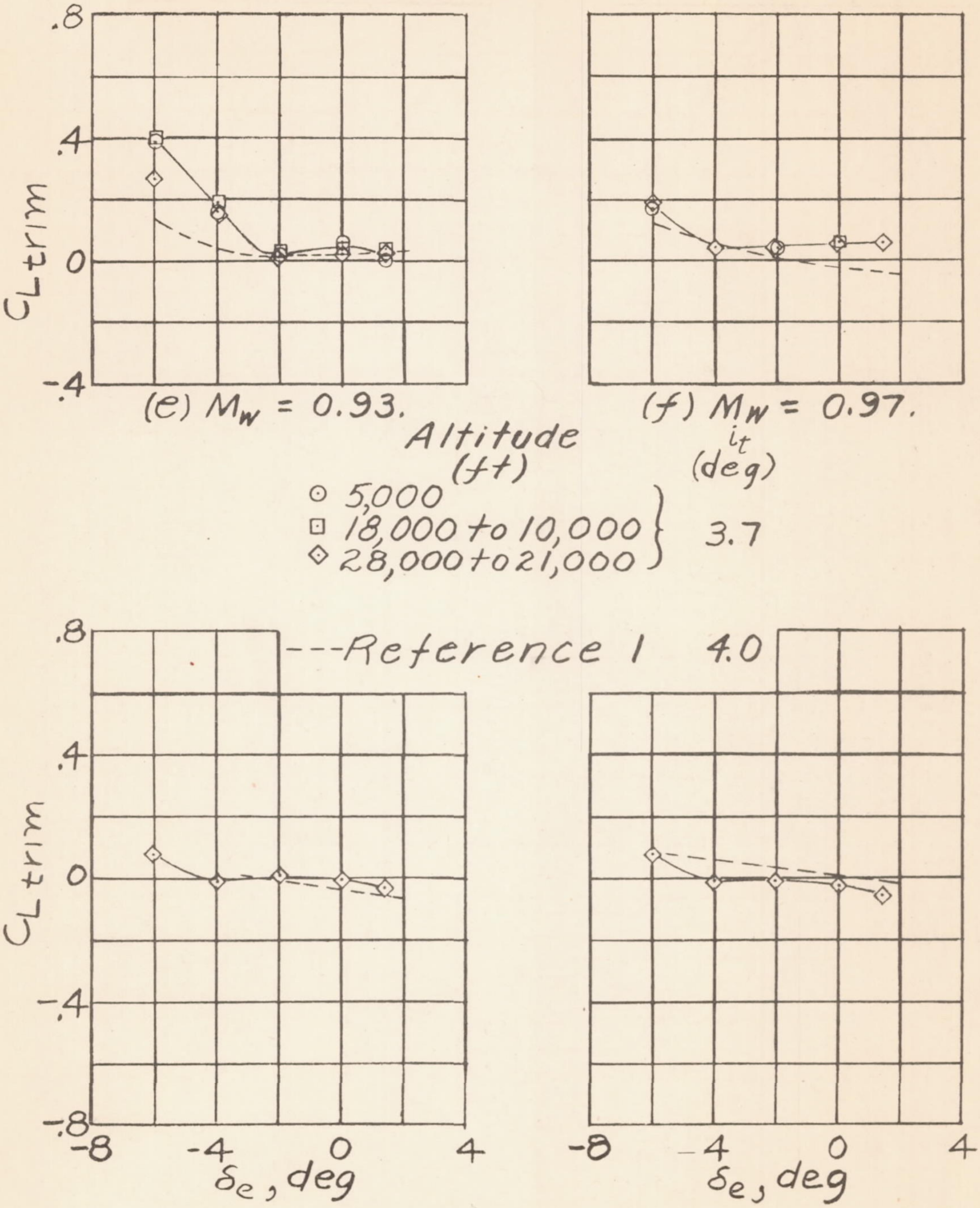
Figure 13.- Variation of lift coefficient for trim with elevator deflection for various Mach numbers. Results for unswept tail from reference 1 shown for comparison.



(e) $M_W = 0.93$.

(f) $M_W = 0.97$.

(g) $M_W = 1.00$.

(h) $M_W = 1.05$.

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Figure 13.- Concluded.

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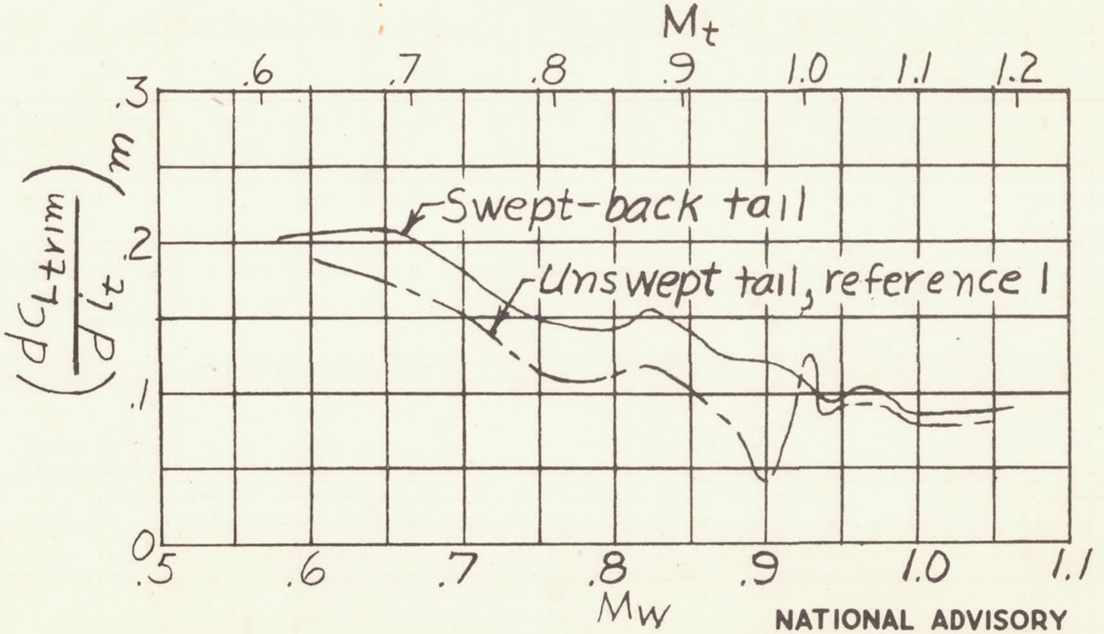

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Figure 14.- Variation of $\left(dC_{L_{trim}}/di_t\right)_m$, for $i_t = 0.7^\circ$ to 3.7°, with Mach numbers M_w and M_t. Results for unswept tail from reference 1 shown for comparison.

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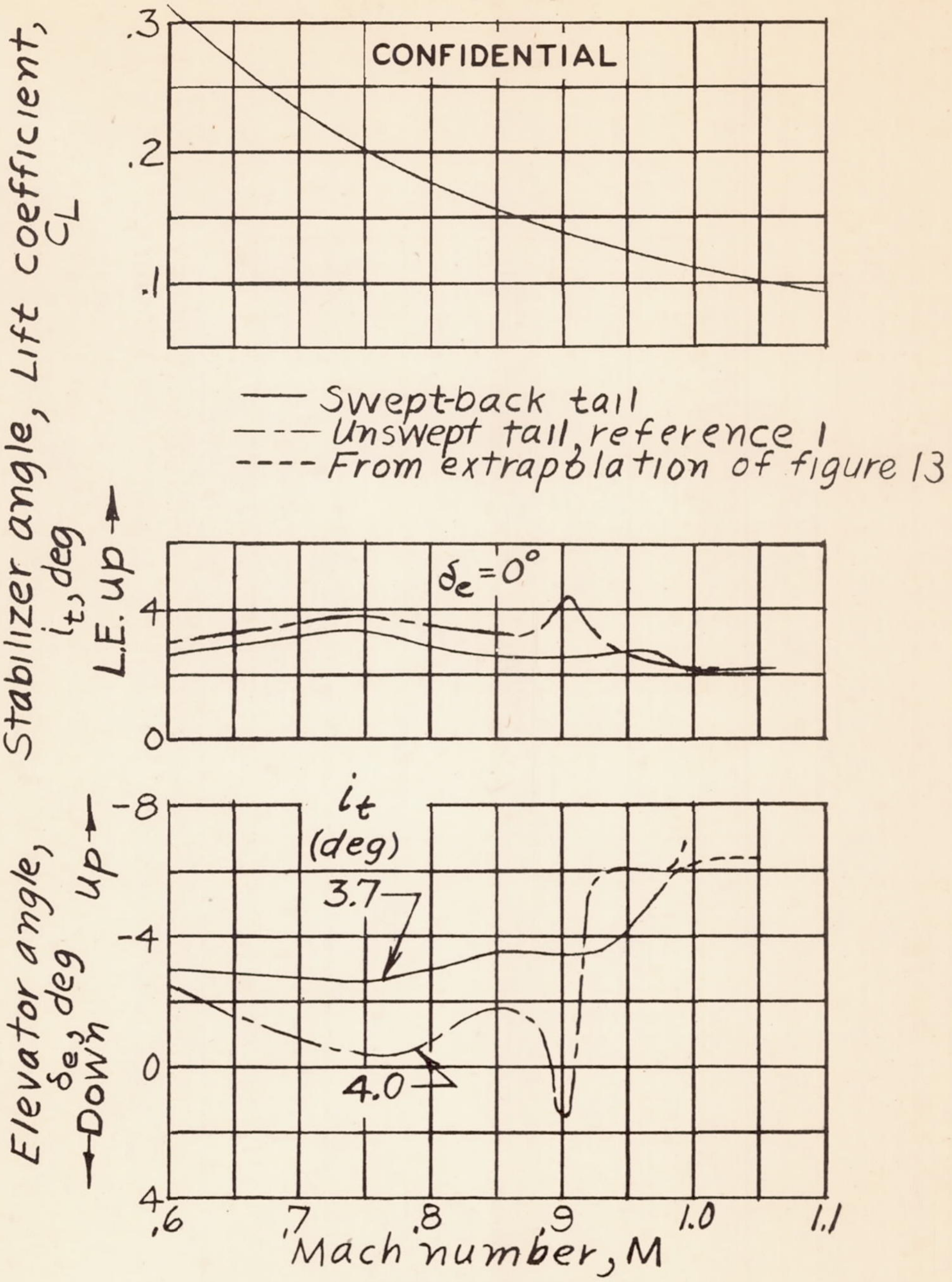

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Figure 15.- Variation with Mach number of stabilizer angle and elevator deflection required for trim in level flight at altitude of 30,000 feet and wing loading of 50. Lift coefficient for level flight also shown. Results for unswept tail from reference 1 shown for comparison.