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THE EFFECT OF MACH NUMBER ON THE AERODYNAMIC

CHARACTERISTICS OF A SINGLE-ENGINE PURSUIT

AIRPLANE AS DETERMINED FROM TESTS OF A

1/3-SCALE MODEL

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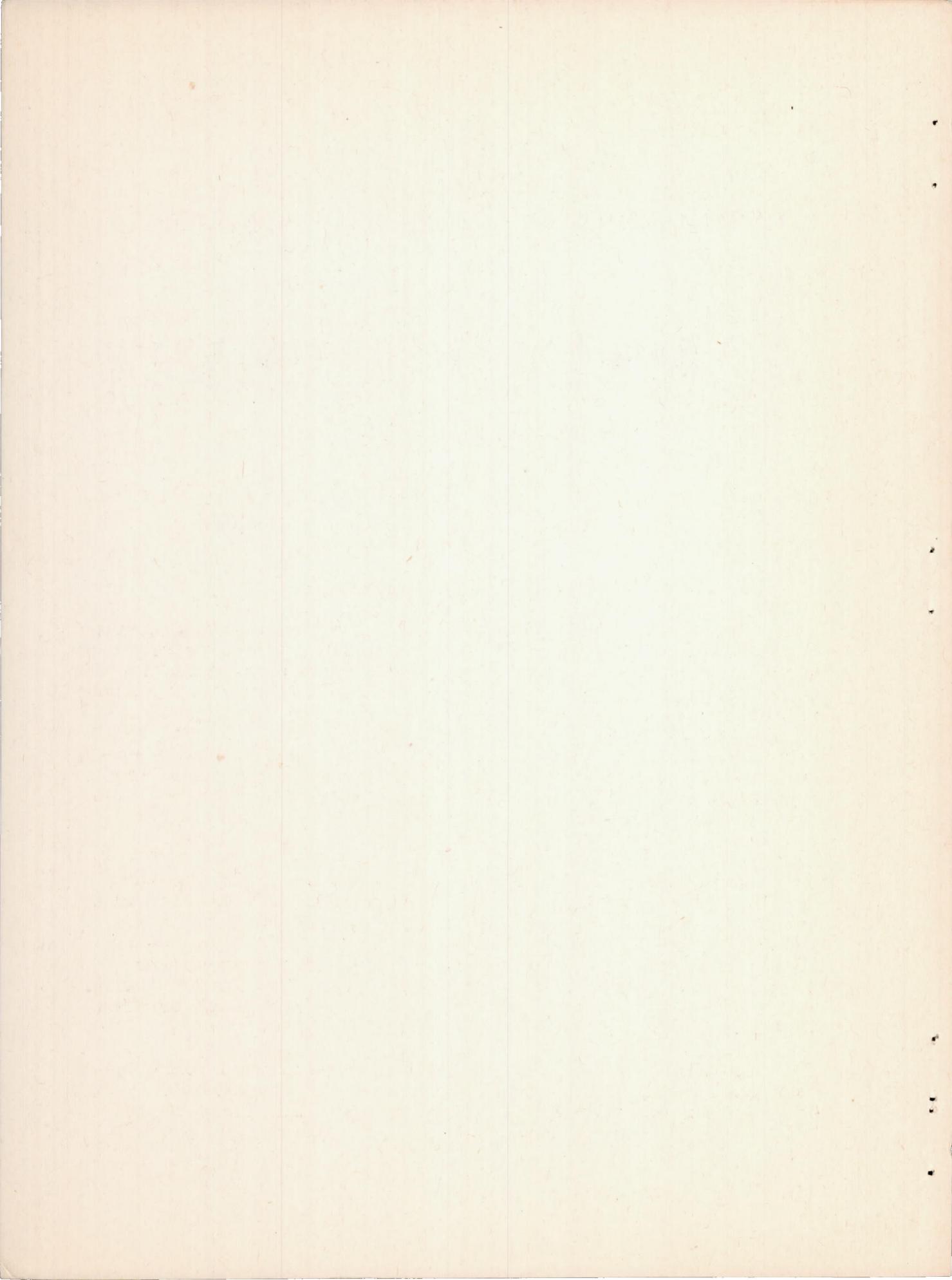
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

<u>MEMORANDUM REPORT</u>

for the

Air Technical Service Command, U. S. Army Air Forces

THE EFFECT OF MACH NUMBER ON THE AERODYNAMIC

CHARACTERISTICS OF A SINGLE-ENGINE PURSUIT AIRPLANE

AS DETERMINED FROM TESTS OF A

1/3-SCALE MODEL

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SUMMARY

Presented herein are the results of tests to determine
the effects of Mach number on the aerodynamic characteristics
of an Allison powered single-engine pursuit airplane. The
lift, drag, and pitching-moment characteristics at high speed
are discussed and data are included to show the variation
of stability, tail effectiveness, and elevator effectiveness
with Mach number. The increments of drag and pitching moment
due to a deflector vane in front of the radiator scoop are
presented.

INTRODUCTION

Although a model of a Merlin powered version of the
airplane had been tested previously in the Ames 16-foot wind
tunnel (reference 1), it was desired to obtain data on a
model of the Allison version of the airplane for corre-
lation with the results of flight tests under way at the
Langley Memorial Aeronautical Laboratory. The investigation
was carried out at the request of the Air Technical Service
Command, U. S. Army Air Forces.

Both pressure-distribution measurements and force tests
were included. This report deals with the aerodynamic
characteristics in pitch as obtained from the force tests.

Data are included to show the effects of Mach number on the
stability and on the elevator and horizontal-tail effective-
ness.

On some early versions of the airplane, a retractable
deflector vane was used in front of the radiator scoop to
prevent overcooling during dives. Pilots have reported that,
in dives with this vane extended, longitudinal oscillations
of the airplane develop at a higher Mach number than with the
vane retracted. Tests were made at lift coefficients ranging
from -0.04 to 0.4 with the vane attached to the model in
order to investigate its effects on drag and pitching-moment
coefficients.

Dive-recovery flaps were present on the airplane making
the flight tests. In order that the model would more closely
represent the airplane, tests were made with a simulation of
these flaps, in the retracted position, attached to the model.

Most of the figures presented are cross plots from the
data plotted against Mach number and elevator angle, and
consequently the experimental points are not shown.

APPARATUS

The 1/3-scale model was designed and built at the Ames
Aeronautical Laboratory and is similar in construction to the
model described in reference 1. The two models represented air-
planes which differed mainly in the lines of the forward part
of the fuselage and the vertical location of the wing. Changing
from the Allison engine to the Merlin engine (reference 1) made
it necessary to change the forward lines of the fuselage, the
carburetor air scoop being moved from the top to the bottom of
the nose. Also, for the Merlin version of the airplane the
wing was lowered 1 inch (model dimension) and the size and
lines of the cooling-air duct were changed. The horizontal
tail on the model in this report was the same as the standard
tail of reference 1. Sealed gun openings in the wings, dummy
gun cowlings on the forward part of the fuselage, and an
optograph cover on the top of the aft portion of the

fuselage were added to the basic model. The exit flaps of
the cooling-air ducts were in the flush position for all
tests. A three-view drawing of the model is shown in
figure 1, and the wind-tunnel setup is illustrated in the
photograph of figure 2. Figure 3 shows the radiator
deflector vane in place on the model.

The model was mounted in the tunnel on a three-strut
support system with two 5-percent-thick front struts and a
7-percent-thick rear strut. The front struts were spaced
80 inches apart and the trunnion was 25 percent of the
chord aft of the leading edge.

The following is a list of pertinent dimensions of the
model:

Wing area, sq ft 25.91

Span, ft 12.34

Mean aerodynamic chord, ft 2.21

Aspect ratio of wing 5.89

Tail length (25 percent M.A.C. to elevator hinge
    line), ft 5.75

Horizontal-tail area, sq ft. 4.66

Horizontal-tail span, ft 4.39

Aspect ratio of horizontal tail plane. 4.14

Normal stabilizer incidence relative to fuselage

    reference line, deg 2

Elevator area aft of hinge line (each), sq ft. . . . 0.723

Mass-balance paddle area (each), sq ft 0.028

Elevator-tab area (each), sq ft. 0.106

Elevator span at hinge line (each), ft 2.043

Normal center-of-gravity location

      Percent mean aerodynamic chord 26.0

      Distance below fuselage reference line, in 3.18

SYMBOLS

      The symbols used in this report are defined as follows:

V free-stream velocity, feet per second

ρ mass density of air, slugs per cubic foot

q free-stream dynamic pressure $(\frac{1}{2}\rho V^2)$, pounds per square foot

M Mach number $\left(\dfrac{V}{\text{velocity of sound}}\right)$

S wing area, square feet

M.A.C.   mean aerodynamic chord, feet

C_L lift coefficient $\left(\dfrac{\text{lift}}{qS}\right)$

C_D drag coefficient $\left(\dfrac{\text{drag}}{qS}\right)$

$C_{m_{c.g.}}$ pitching-moment coefficient about the center of gravity $\left(\dfrac{\text{pitching moment about the center of gravity}}{q\,S\,M.A.C.}\right)$

α angle of attack of fuselage reference line corrected for tunnel-wall effects and upflow due to support struts, degrees

α_u uncorrected angle of attack of fuselage reference line, degrees

i_t incidence of horizontal stabilizer with respect to the fuselage reference line, degrees

ΔC_m increment of pitching-moment coefficient

ΔC_D increment of drag coefficient

WIND-TUNNEL CALIBRATION AND CORRECTIONS

The dynamic pressures and Mach numbers were determined by means of a static-pressure survey in the region of the tunnel occupied by the model. All three struts were in place during the survey. The results obtained were corrected for the constriction effect of the model. A detailed description of the survey method and the constriction correction are given in reference 2.

Tunnel-wall, tare, and upflow corrections were applied to all the data. The tunnel-wall corrections were calculated by the method of reference 3. Drag and pitching-moment tares due to the support struts were evaluated from force tests of the struts alone. In order to find the upflow effects caused by the front struts, tests were made with the model erect and inverted. One-half the difference between the angles of zero lift for the two conditions was taken as the upflow angle. The following table lists the corrections that have been applied:

M	$\Delta C_{D_{upflow}}$	$\Delta \alpha_{upflow}$ (deg)
0.4 – 0.690	0.00175 C_L	0.10
.7	.00320 C_L	.18
.725	.00545 C_L	.31
.75	.00735 C_L	.42
.775	.00925 C_L	.53
.8	.01135 C_L	.64
.81	.01205 C_L	.69

Angle-of-attack correction = $1.019\ C_L + \Delta\alpha_{upflow}$

Drag-coefficient correction = $0.0178\ C_L{}^2 + \Delta C_{D_{upflow}} + \Delta C_{D_{tare}}$

$\qquad\qquad\qquad\qquad = 0.0178\ C_L{}^2 + \Delta C_{D_{upflow}} - 0.010$

Pitching-moment-coefficient

$\qquad\qquad$ correction = $0.0118\ C_L + \Delta C_{m_{tare}}$

$\qquad\qquad\qquad\qquad = 0.0118\ C_L + 0.0220$

RESULTS AND DISCUSSION

Longitudinal Characteristics

The lift coefficient for the model without and with the tail surfaces (figs. 4 and 5, respectively) has been plotted in carpet form to show simultaneously its variation with Mach number and angle of attack. The pitching-moment coefficient is also plotted in carpet form (fig. 6) to show its variation with lift coefficient for various Mach numbers. Figure 6 shows that the static longitudinal stability $-\partial C_m/\partial C_L$ at the lift coefficient for balance with the elevators neutral changed from 0.078 at a Mach number of 0.4 to 0.203 at a Mach number of 0.8 - an increase of 160 percent. For the same range of Mach numbers the lift coefficient for balance decreased from 0.065 to -0.125.

The variation of drag coefficient with lift coefficient is shown in figure 7 for several Mach numbers, and the effect of Mach number on the drag and pitching-moment coefficients for various lift coefficients is shown in figure 8.

The above Mach number effects are similar to those found for the model of the Merlin powered version of the airplane, and their influence on the longitudinal-control characteristics is discussed in reference 1.

Elevator and Tail Effectiveness

The effect of elevator deflection upon the pitching-moment coefficient is presented in figures 9(a) to 9(g). For the same elevator deflections ($-8°$ to $3°$) the change of

lift coefficient was roughly 0.006 per degree. The maximum
change of drag coefficient due to the 11° change of elevator
deflection varied from 0.002 to 0.015, depending on the angle
of attack and Mach number. From figure 10 it can be seen
that the decrease of elevator effectiveness with Mach number
was small enough to be unimportant.

The increment of pitching-moment coefficient resulting
from changes in stabilizer incidence and the effect of Mach
number on tail effectiveness are shown in figures 11 and 12.
For negative stabilizer angles and the higher Mach numbers,
the tail effectiveness decreased for large negative angles
of attack. This decrease was evidently due to shock stalling
of the horizontal tail caused by the large angle of attack
and high Mach number.

With the standard stabilizer incidence and for small
angles of attack, the tail effectiveness increased slightly
with Mach number up to 0.765. At 0.4 Mach number the tail
effectiveness was about 1.5 times as great as that for the
elevator, and at 0.765 it was about 2.1 times as great.
The fact that the elevator has less effect on the pressure
distribution over the stabilizer at high Mach numbers and
the increase of lift-curve slope with Mach number for the
horizontal tail with elevator neutral account for this change.
It appears that, as higher Mach numbers are reached, a control-
lable stabilizer or an all-movable tail plane will become
more desirable from purely aerodynamic considerations.

Effects of Deflector Vane and Retracted

Dive-Recovery Flaps

Extension of the deflector vane in front of the cooling-
air scoop caused a positive increment in pitching-moment
coefficient of about 0.008 which was practically unaffected
by Mach number or small changes of angle of attack. The drag
increment was negligible up to a Mach number of about 0.75,
but at 0.8 it varied from 0.004 to -0.006, depending on the
angle of attack. However, the variation with angle of attack
was rather inconsistent, as shown in figure 13. Neither the
drag nor pitching-moment-coefficient increments offer an
explanation for the effect the deflector vane was reported to
have on the airplane in dives.

The additional drag coefficient caused by the retracted
dive-recovery flaps was small and its variation with Mach
number is shown in figure 14.

CONCLUSIONS

High-speed tests of a 1/3-scale model of a single-
engine pursuit airplane showed the following effects of Mach
number on the longitudinal stability and on the effectiveness
of the tail and the elevator:

1.   An increase in the Mach number from 0.4 to 0.8
caused an increase of 160 percent in the static longitudinal
stability.   There was a corresponding decrease of 0.19 in the
lift coefficient for balance with the elevators neutral.

2.   Changes of tail and elevator effectiveness with
Mach number were small but sufficient to cause the ratio of
tail to elevator effectiveness to increase from 1.5 at 0.4
Mach number to 2.1 at 0.765 Mach number for small angles of
attack.

3.   The small increments in drag and pitching-moment
coefficients caused by the cooling-air deflector vane do not
explain the effect this vane was reported to have on longi-
tudinal oscillations of the airplane when diving.

Ames Aeronautical Laboratory,
     National Advisory Committee for Aeronautics,
          Moffett Field, Calif., May 3, 1945.

REFERENCES

1. Hall, Charles F.: The Effect of Modifications to the
    Horizontal Tail Profile on the High-Speed Longi-
    tudinal Control of a Pursuit Airplane. NACA TN
    No. 1302, 1947.

2. Nissen, James M., Gadeberg, Burnett L., and Hamilton,
    William T.: Correlation of the Drag Characteristics
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    1945.

3. Silverstein, Abe, and White, James A.: Wind-Tunnel
    Interference With Particular Reference to Off-
    Center Positions of the Wing and to the Downwash
    at the Tail. NACA Rep. No. 547, 1935.
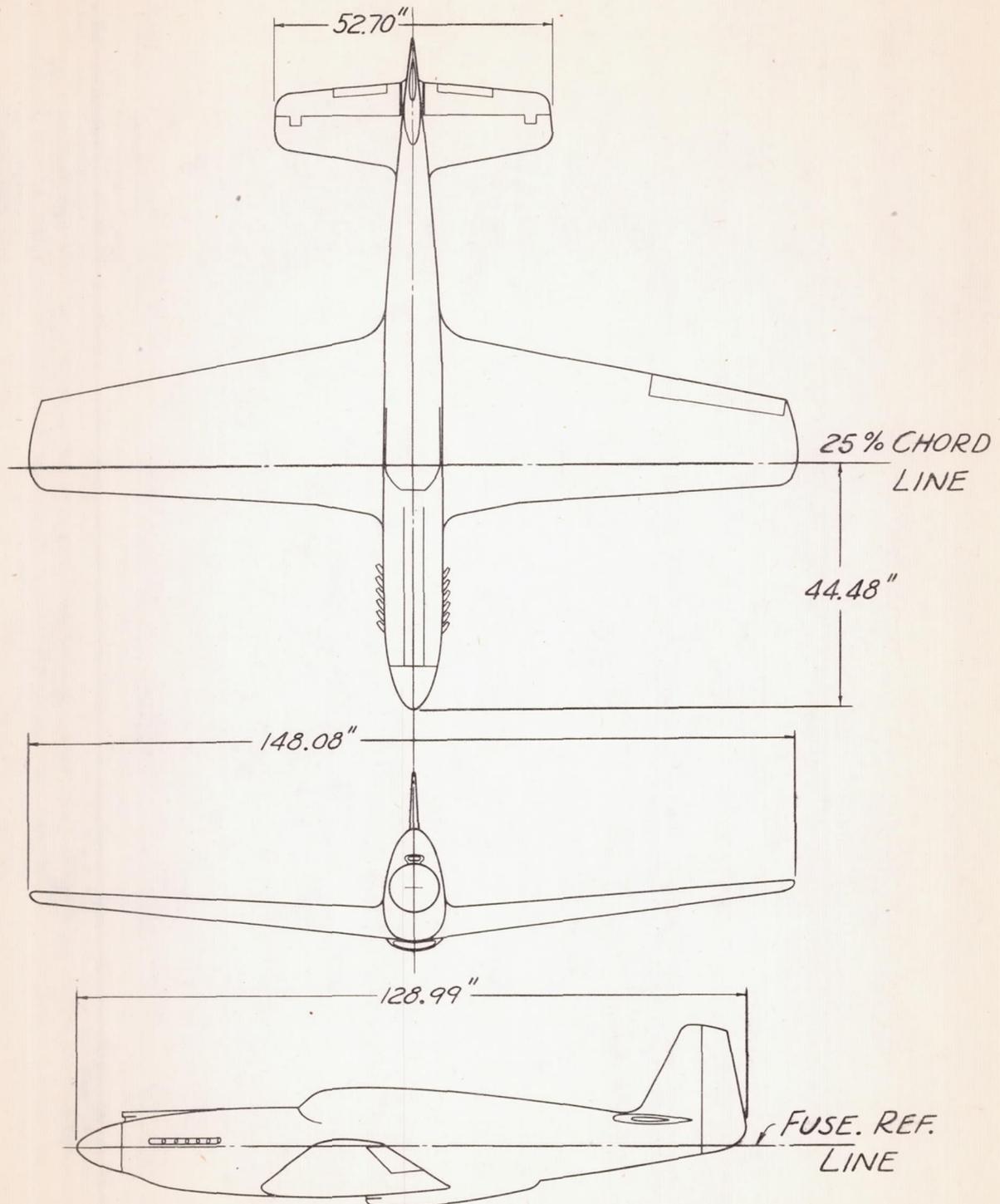
FIGURE 1. - THREE-VIEW DRAWING OF THE
$\frac{1}{3}$-SCALE MODEL.
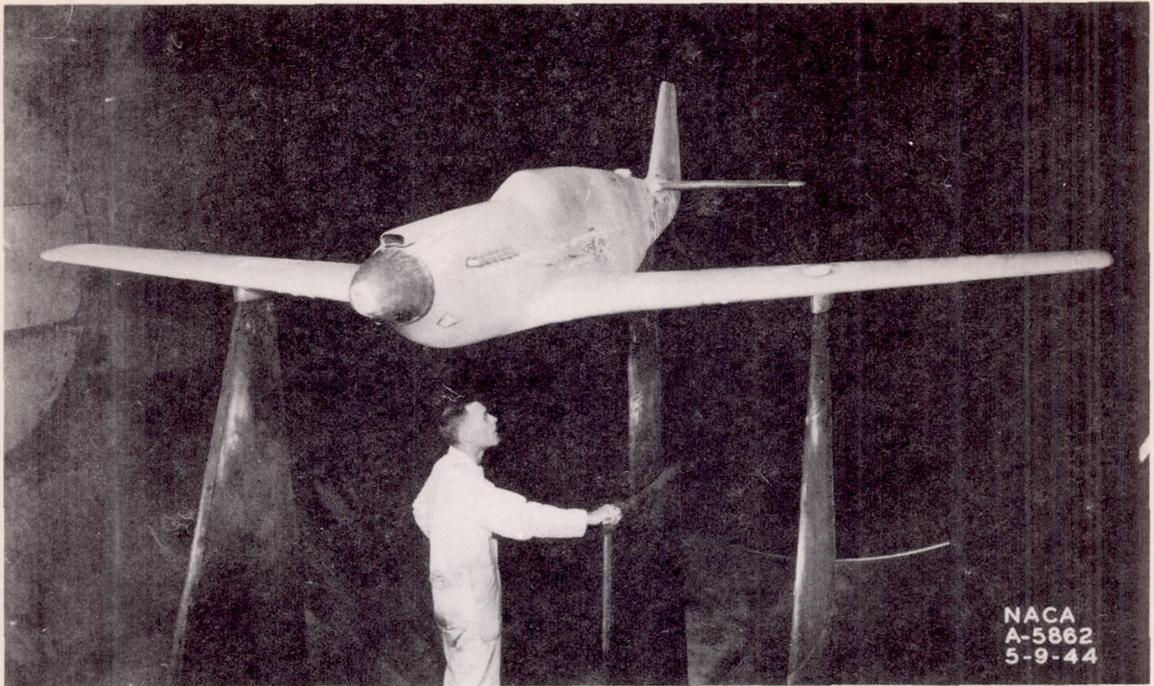
Figure 2.- The 1/3-scale model in the 16-foot wind tunnel
(5-percent-thick front struts spaced 80 inches,
7-percent-thick rear strut).
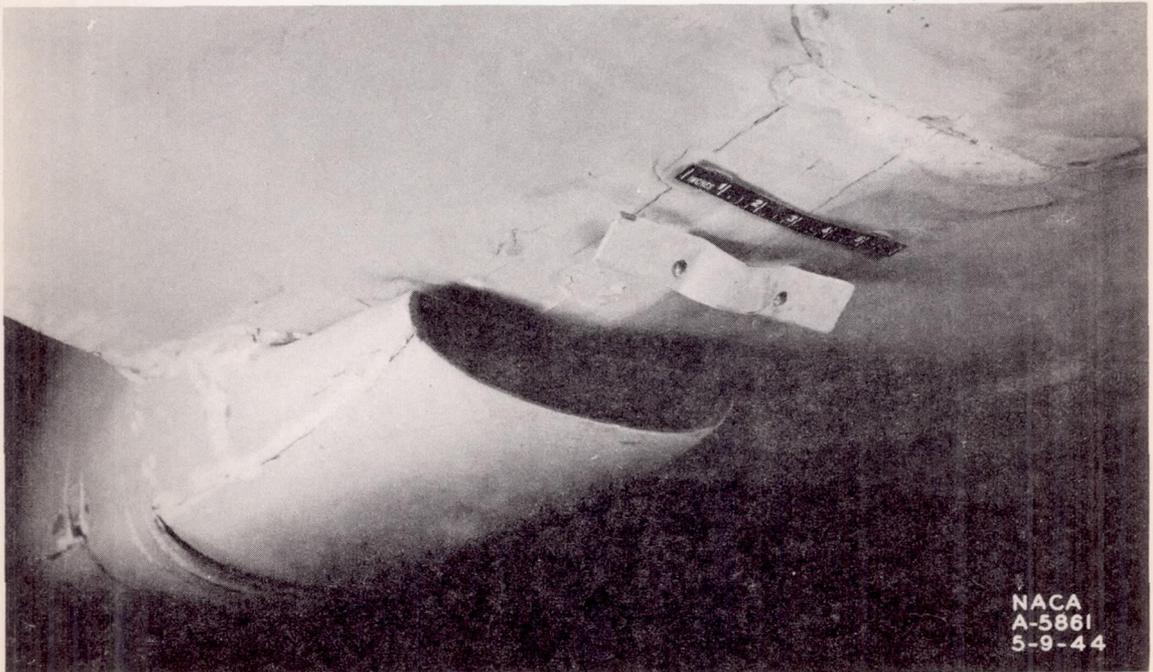
Figure 3.- Deflector vane in front of the cooling duct on
the model.

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C_L

1.0

0.8

$\alpha_U = 6°$

0.6

4°

0.4

2°

0.2

0°

-2°

-4°

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-0.4

-4°	0°	4°	8°	12°	16°	α_U AT $M=0.4$
	0.4	0.5	0.6	0.7	0.8	M AT $\alpha_U = 0°$
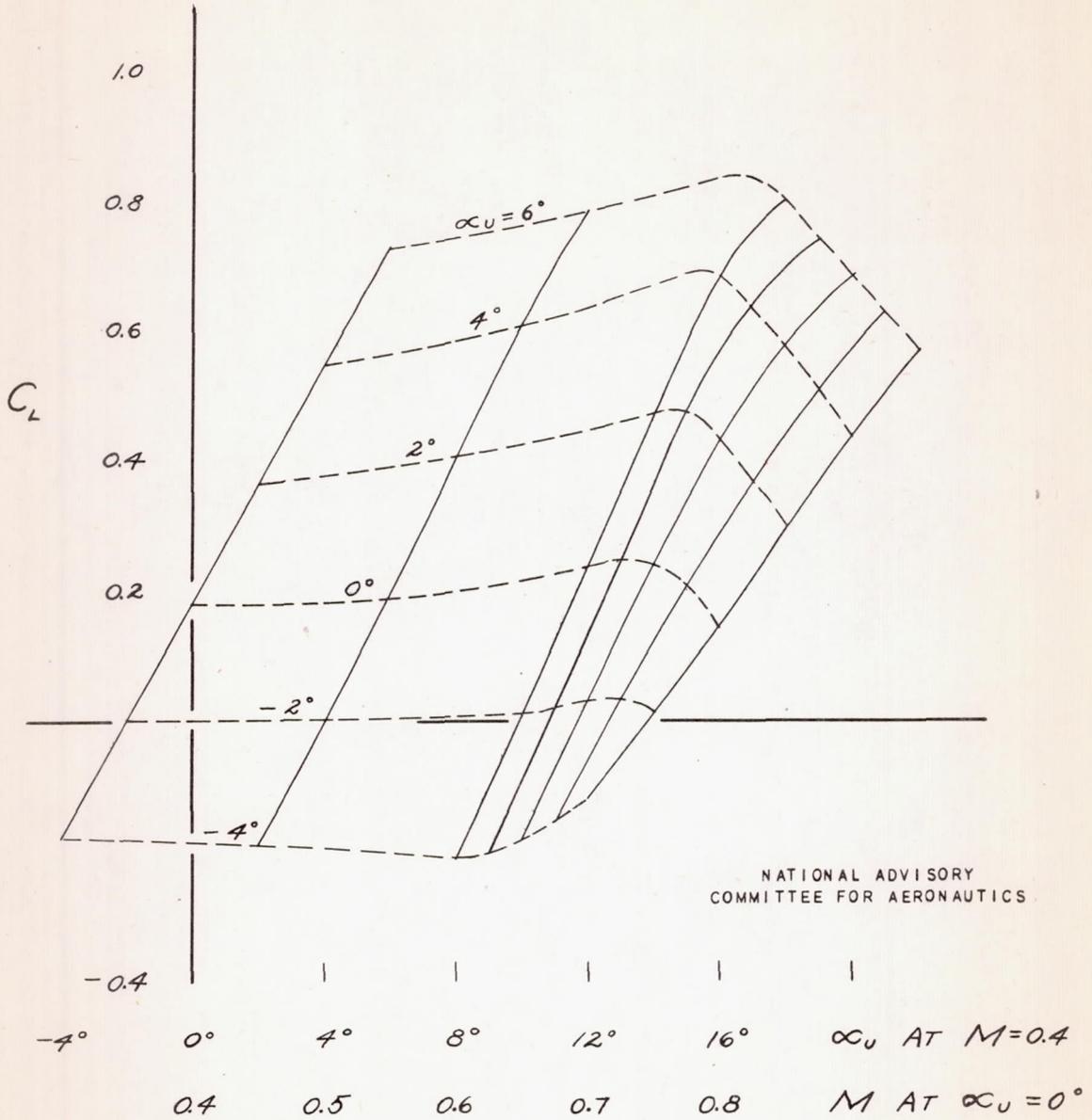
FIGURE 4.- THE LIFT COEFFICIENT CARPET FOR THE
$\frac{1}{3}$ -SCALE MODEL WITHOUT A TAIL.

A-76
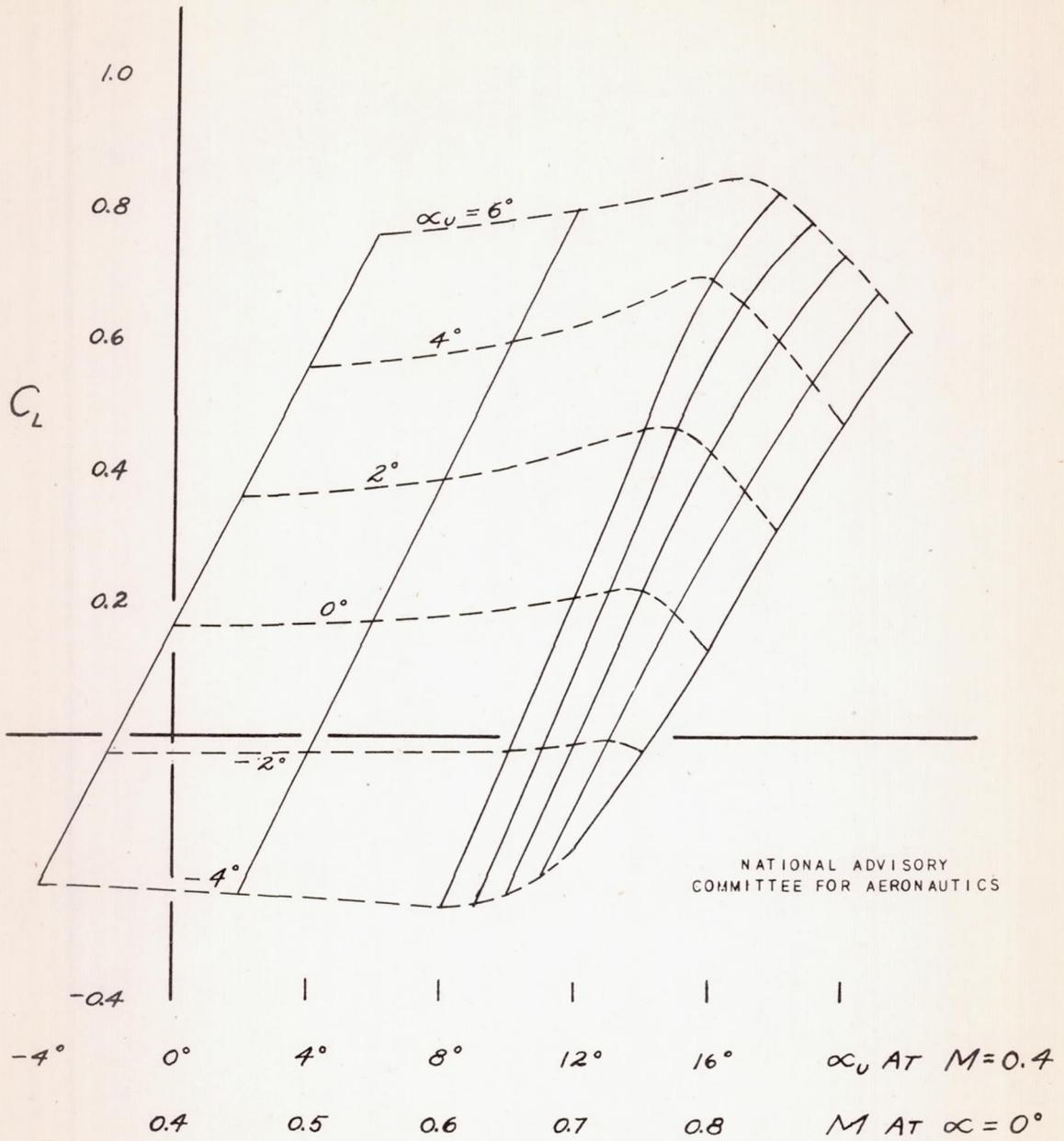
FIGURE 5.— THE LIFT COEFFICIENT CARPET FOR
THE $\frac{1}{3}$-SCALE MODEL. i_t, 2° ; δ_e, 0°.
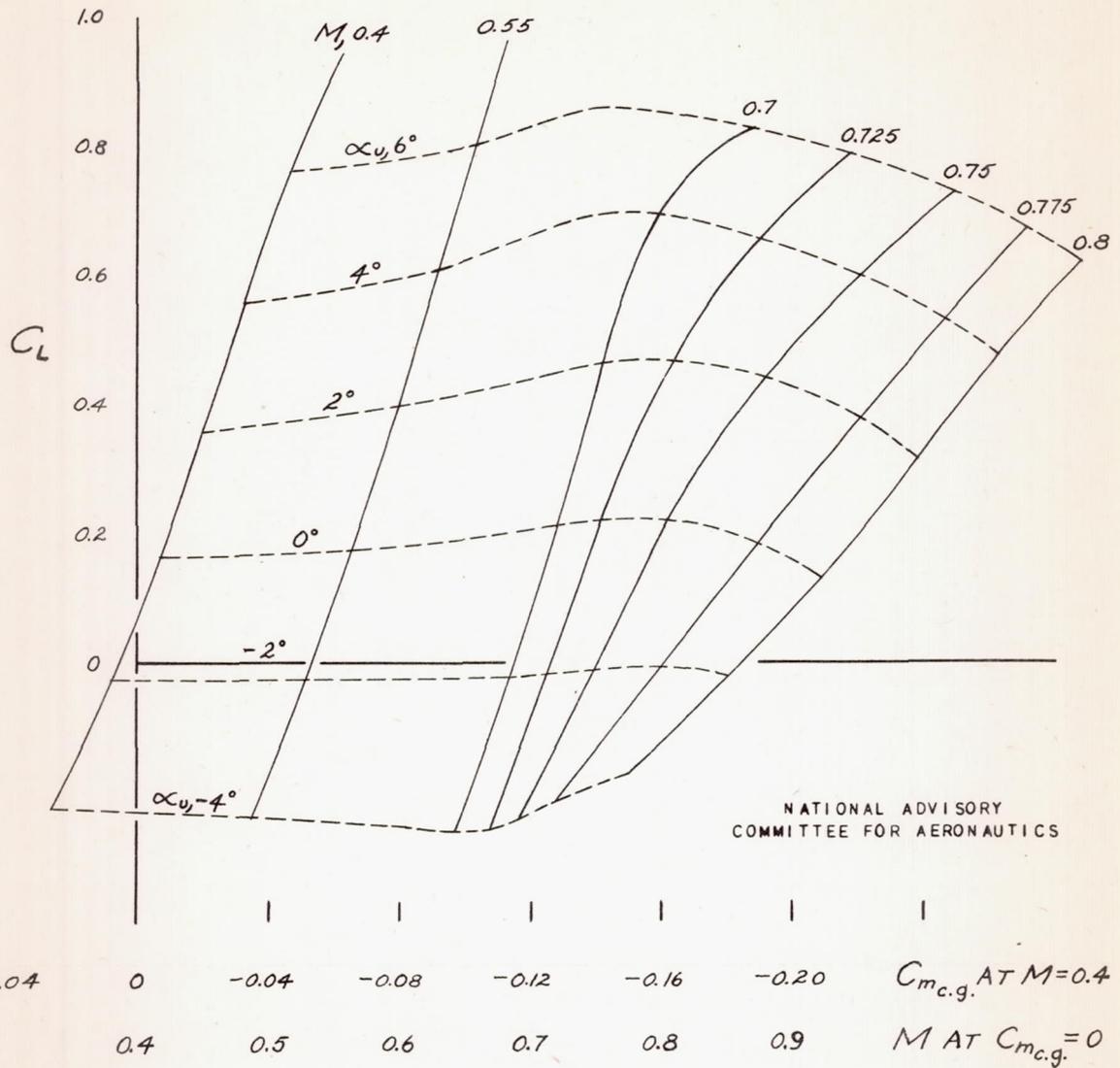
FIGURE 6.— THE PITCHING-MOMENT-COEFFICIENT CARPET FOR THE $\frac{1}{3}$-SCALE MODEL. i_t, $2°$; δ_e, $0°$.

M
○ 0.398
△ 0.545
□ 0.687
▽ 0.711
◇ 0.735
♂ 0.758
△ 0.782
⬠ 0.806

C_L

1.0

0.8

0.6

0.4

0.2

0

-0.2

0.02   0.04   0.06   0.08   0.10   0.12   0.14

C_D
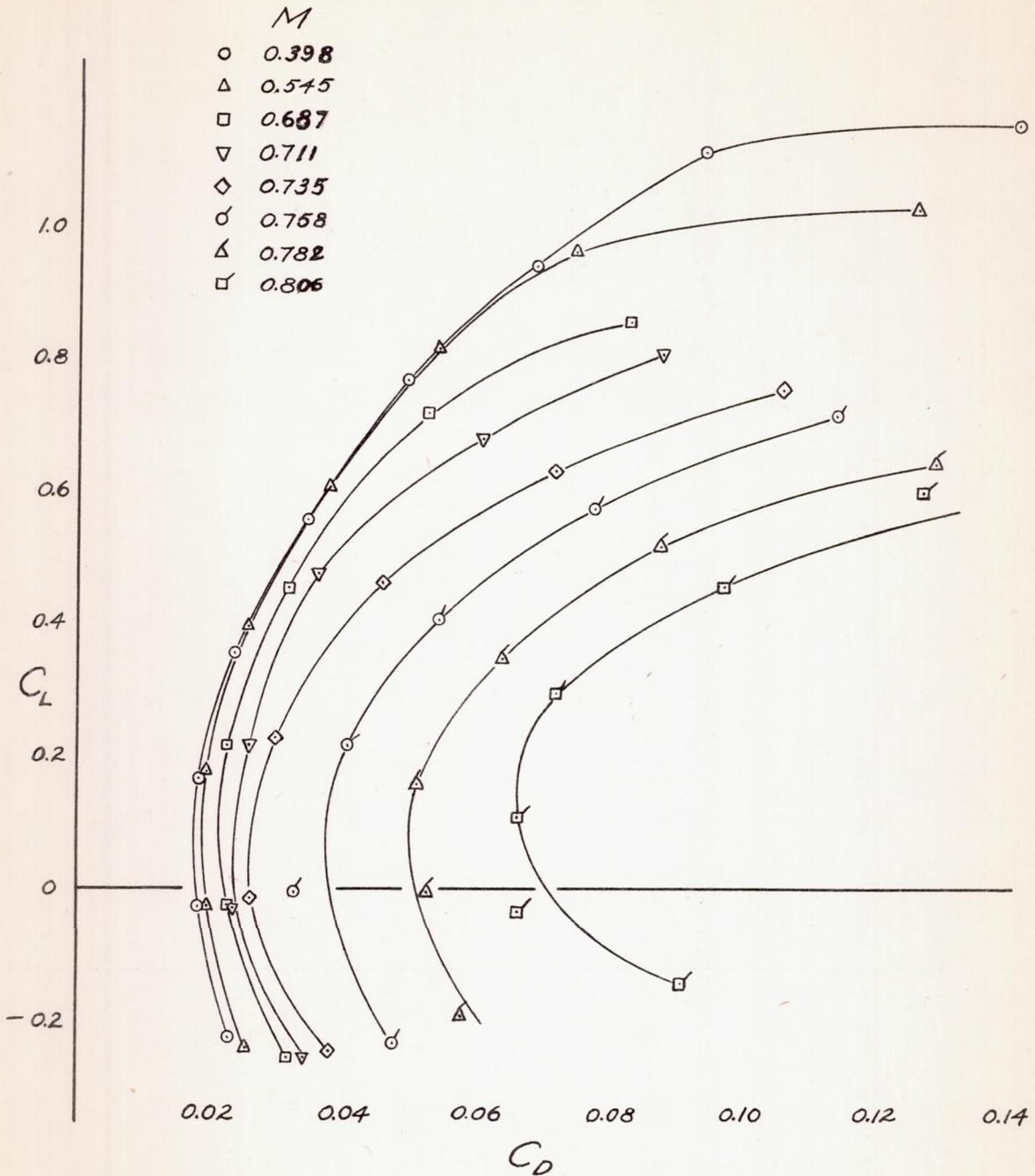
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FIGURE 7.- THE VARIATION OF DRAG COEFFICIENT
WITH LIFT COEFFICIENT FOR SEVERAL VALUES
OF MACH NUMBER.

A-76
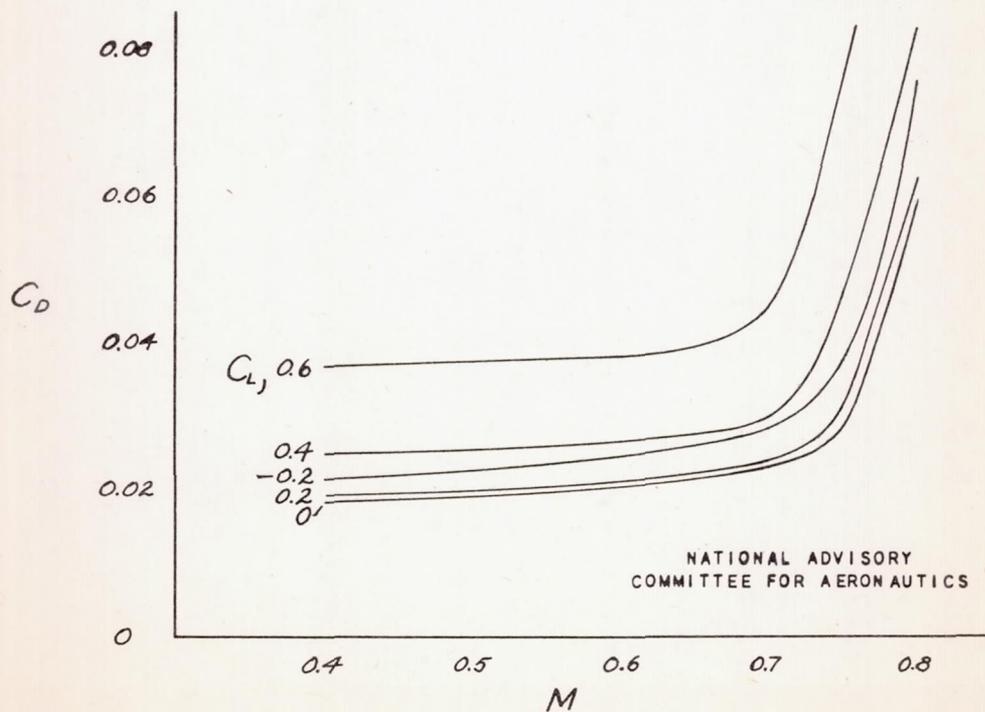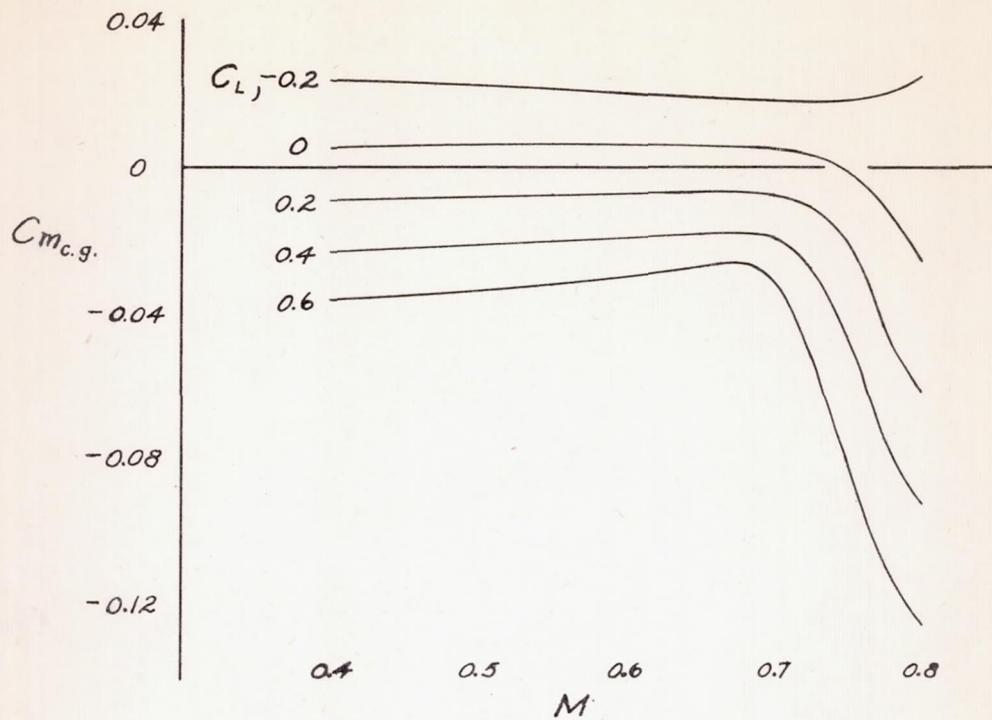
FIGURE 8.— THE VARIATION OF PITCHING-MOMENT AND DRAG
COEFFICIENTS WITH MACH NUMBER AT SEVERAL
VALUES OF LIFT COEFFICIENT.
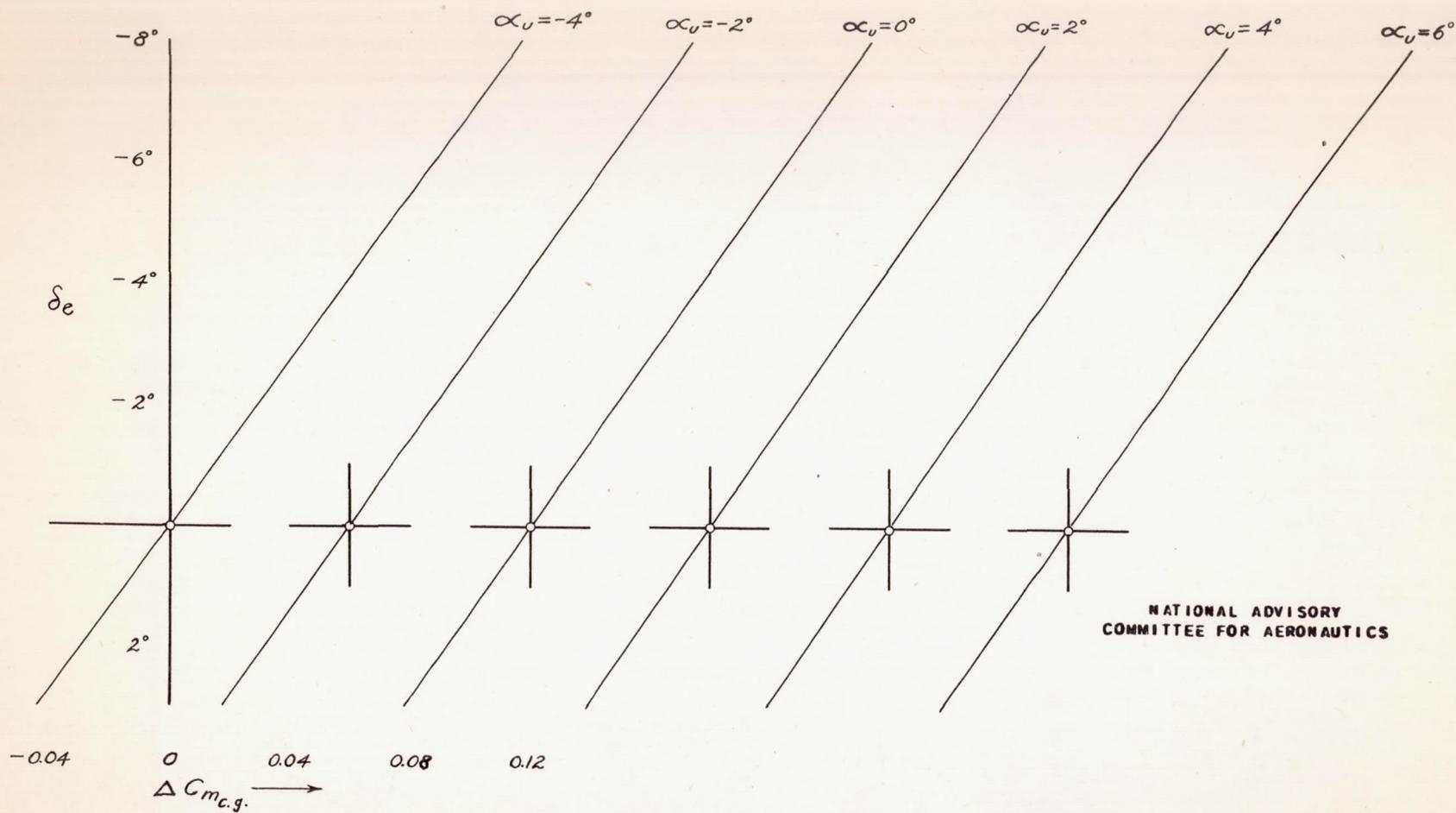
(a) $M = 0.4$

FIGURE 9.– THE INCREMENT IN PITCHING–MOMENT COEFFICIENT DUE TO ELEVATOR DEFLECTION FOR SEVERAL ANGLES OF ATTACK.

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$\alpha_u = -4°$ $\alpha_u = -2°$ $\alpha_u = 0$ $\alpha_u = 2°$ $\alpha_u = 4°$ $\alpha_u = 6°$

δ_e

$-8°$

$-6°$

$-4°$

$-2°$

$2°$

-0.04 0 0.04 0.08 0.12

$\Delta C_{m_{c.g.}}$ ⟶
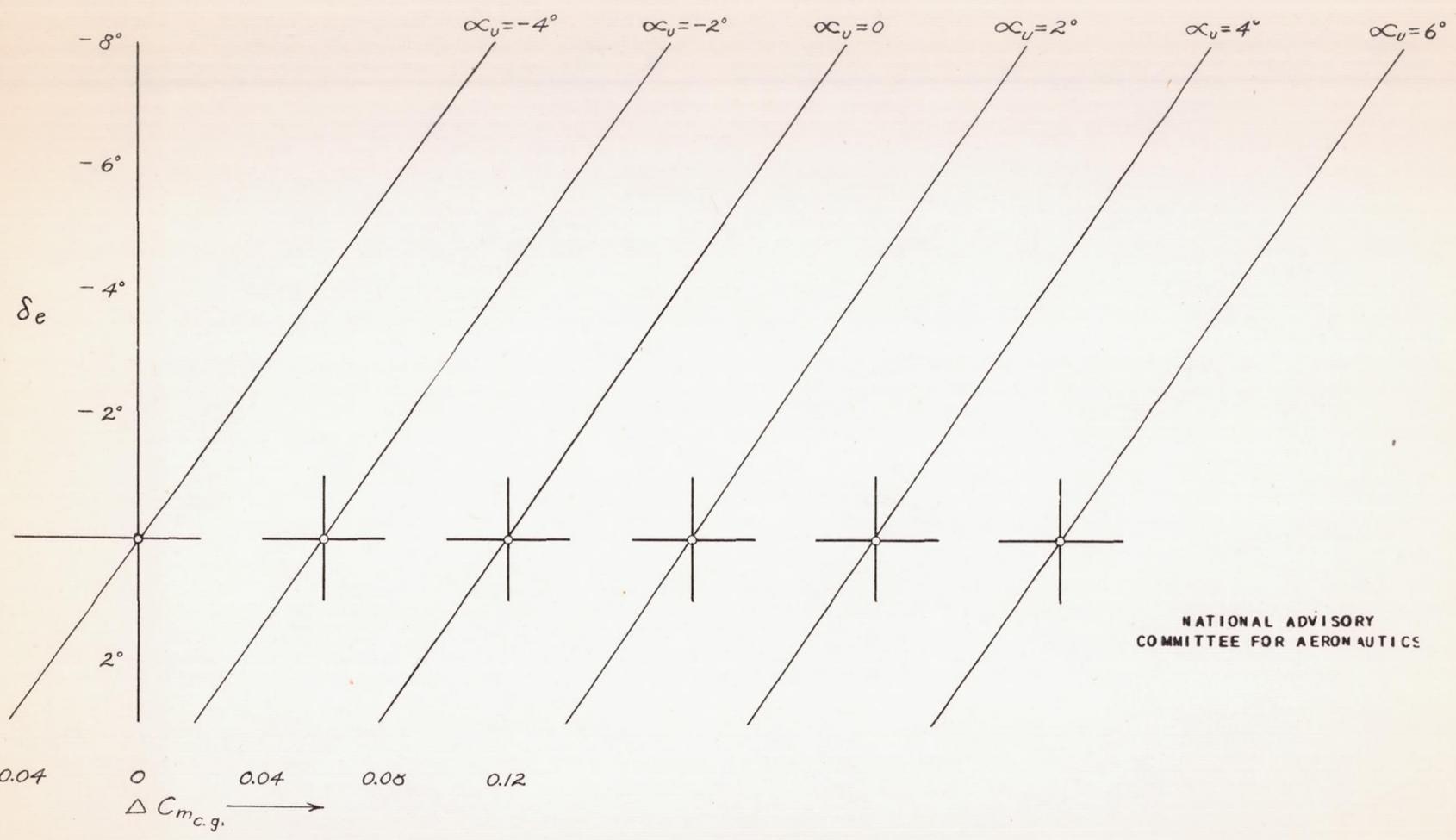
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(b) $M = 0.55$.

FIGURE 9.—   CONTINUED.
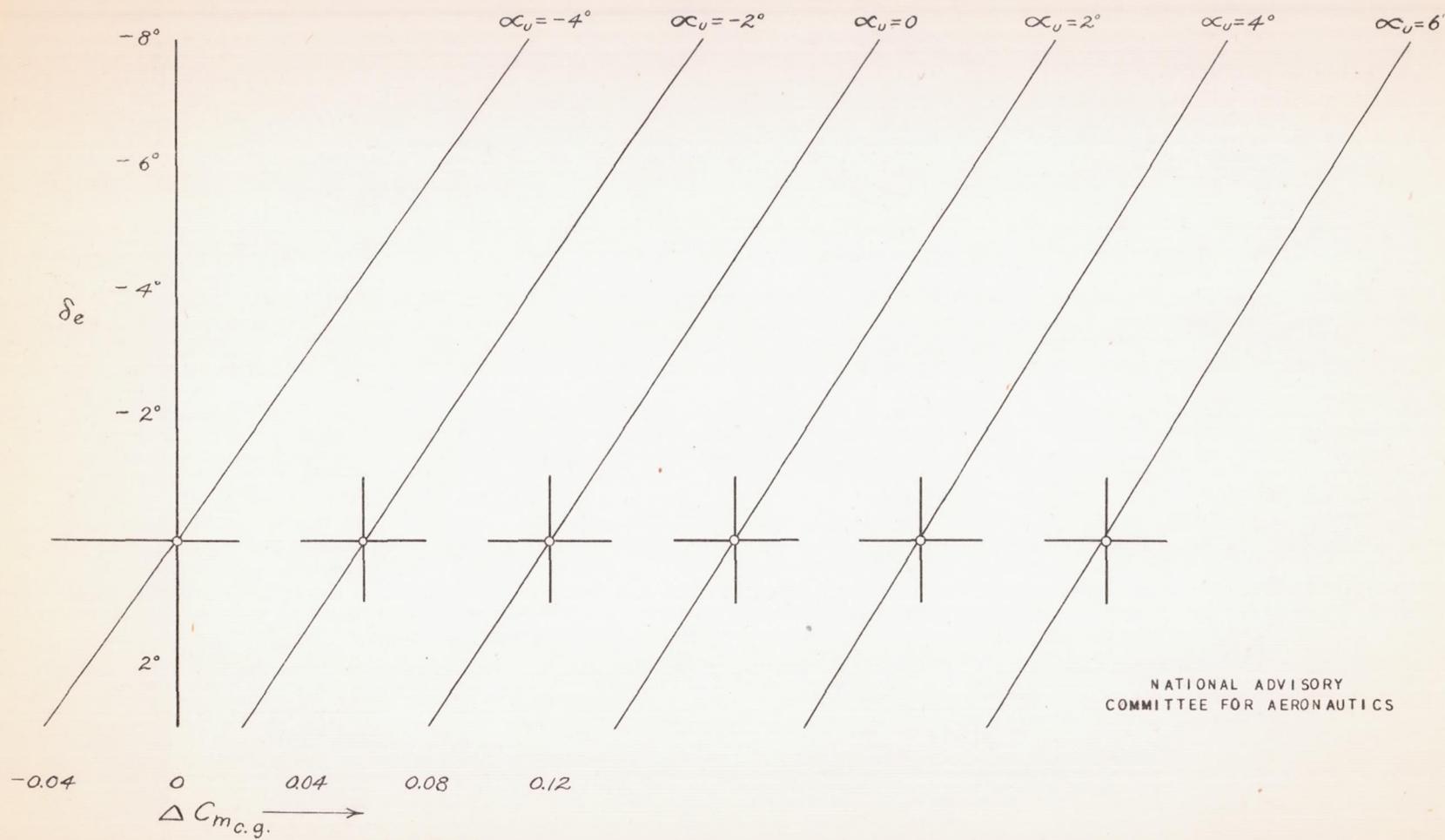
(c) $M = 0.7$

FIGURE 9.— CONTINUED.
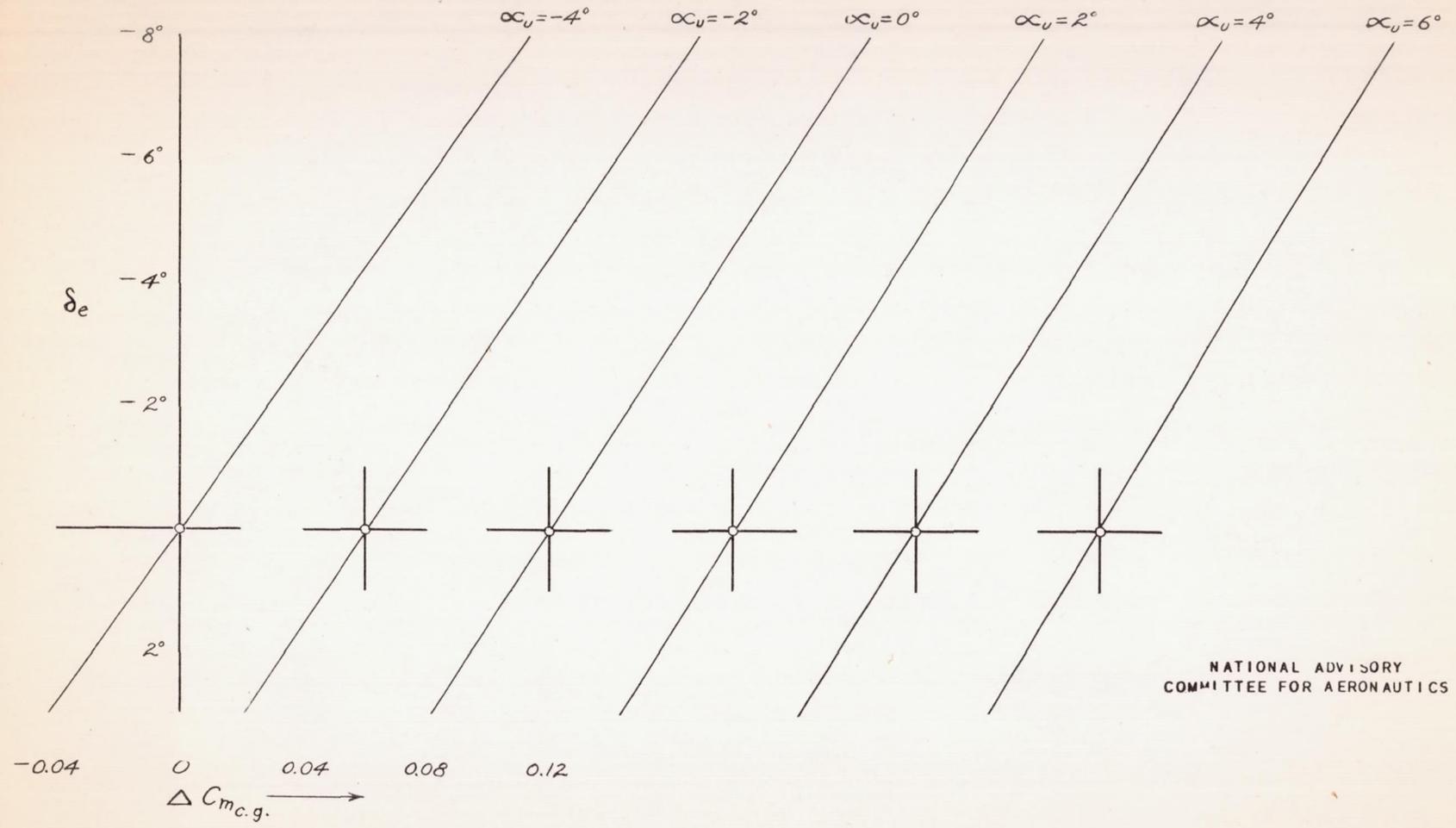
$\alpha_u = -4°$ $\alpha_u = -2°$ $\alpha_u = 0°$ $\alpha_u = 2°$ $\alpha_u = 4°$ $\alpha_u = 6°$

δ_e

$-8°$
$-6°$
$-4°$
$-2°$
$2°$

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-0.04 O 0.04 0.08 0.12

$\Delta C_{m_{c.g.}} \longrightarrow$

(d) $M = 0.725$

FIGURE 9.— CONTINUED.
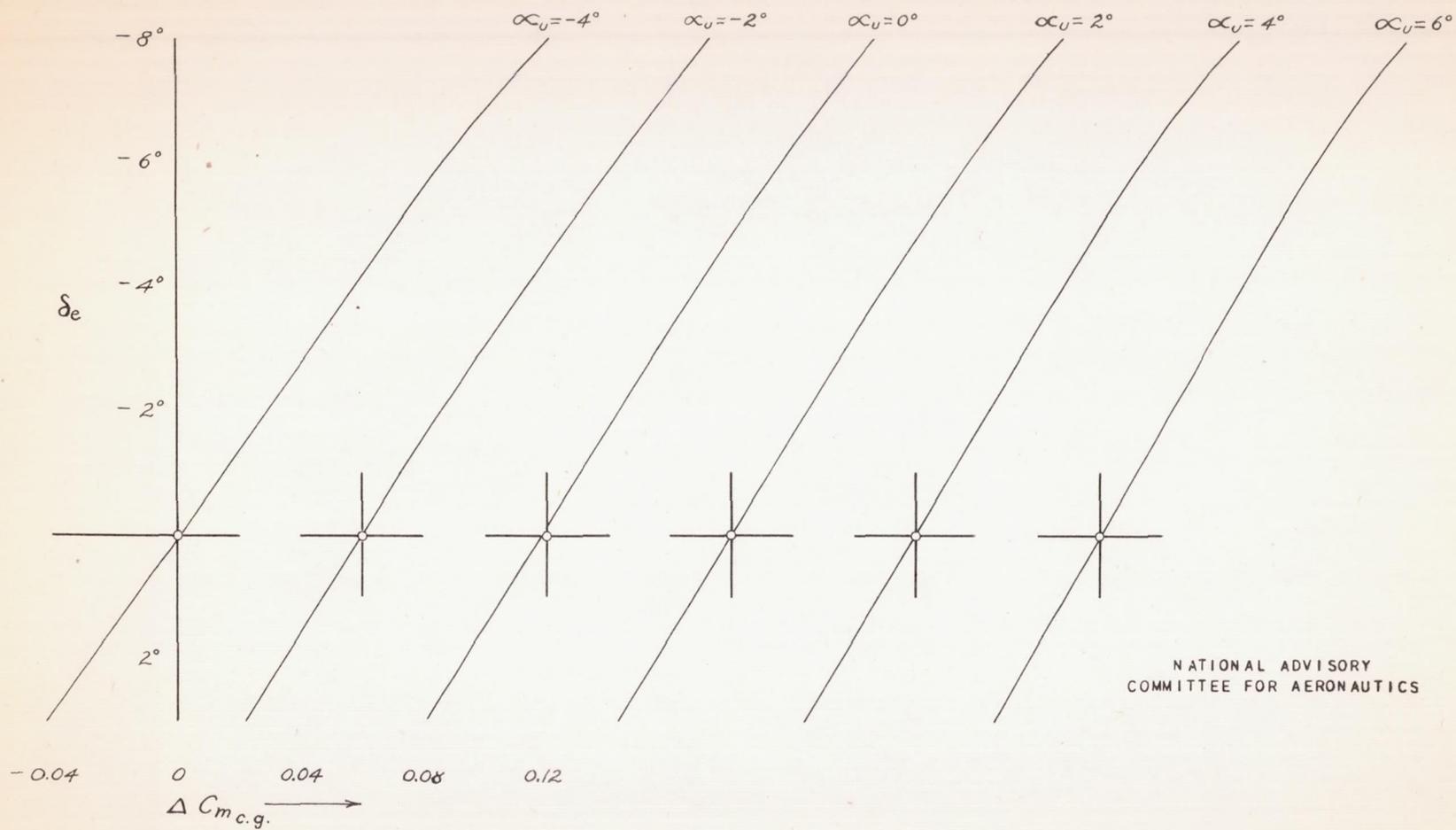
(e) $M = 0.75$

FIGURE 9.- CONTINUED.
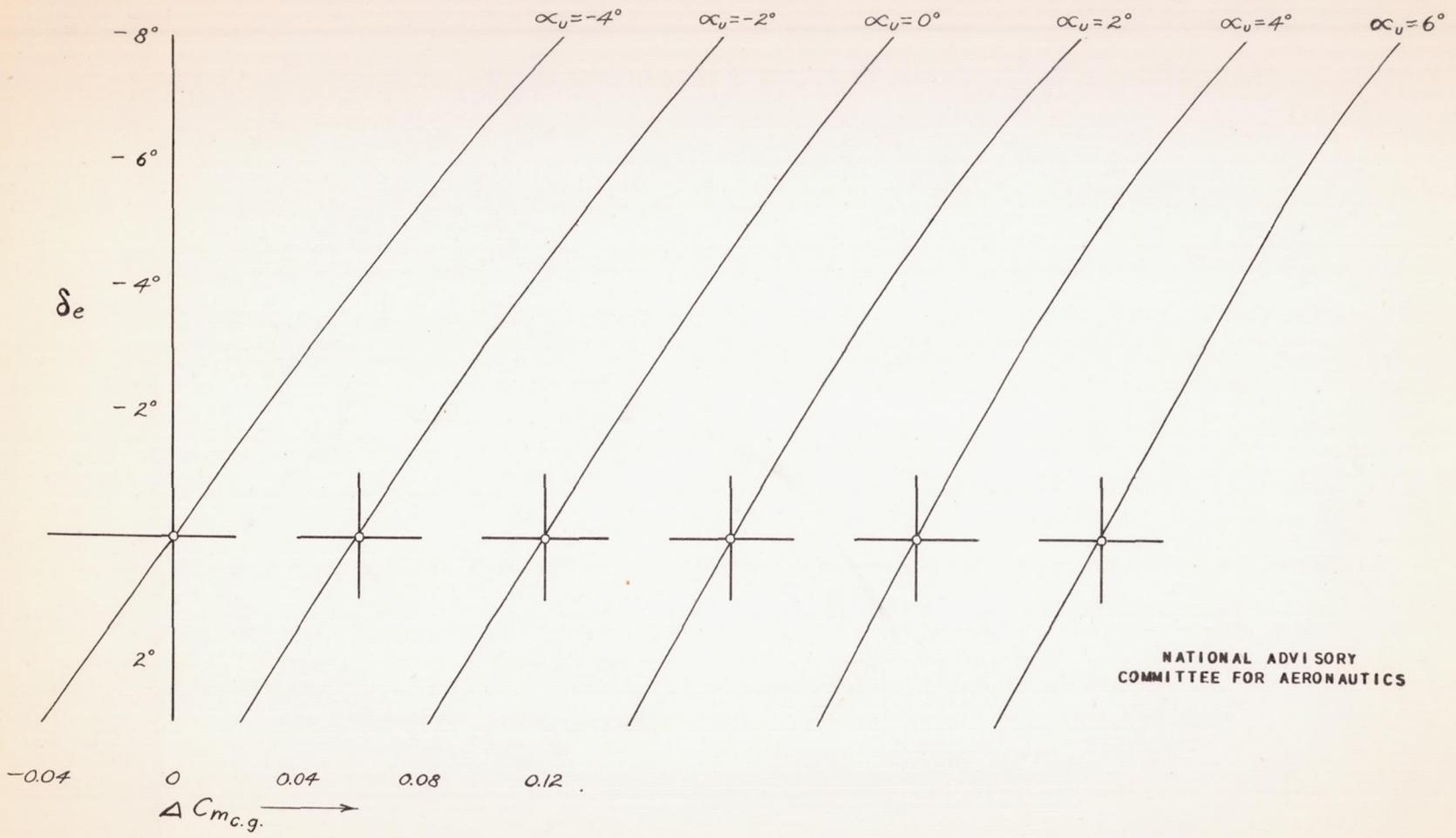
(f) M = 0.775

FIGURE 9.— CONTINUED.
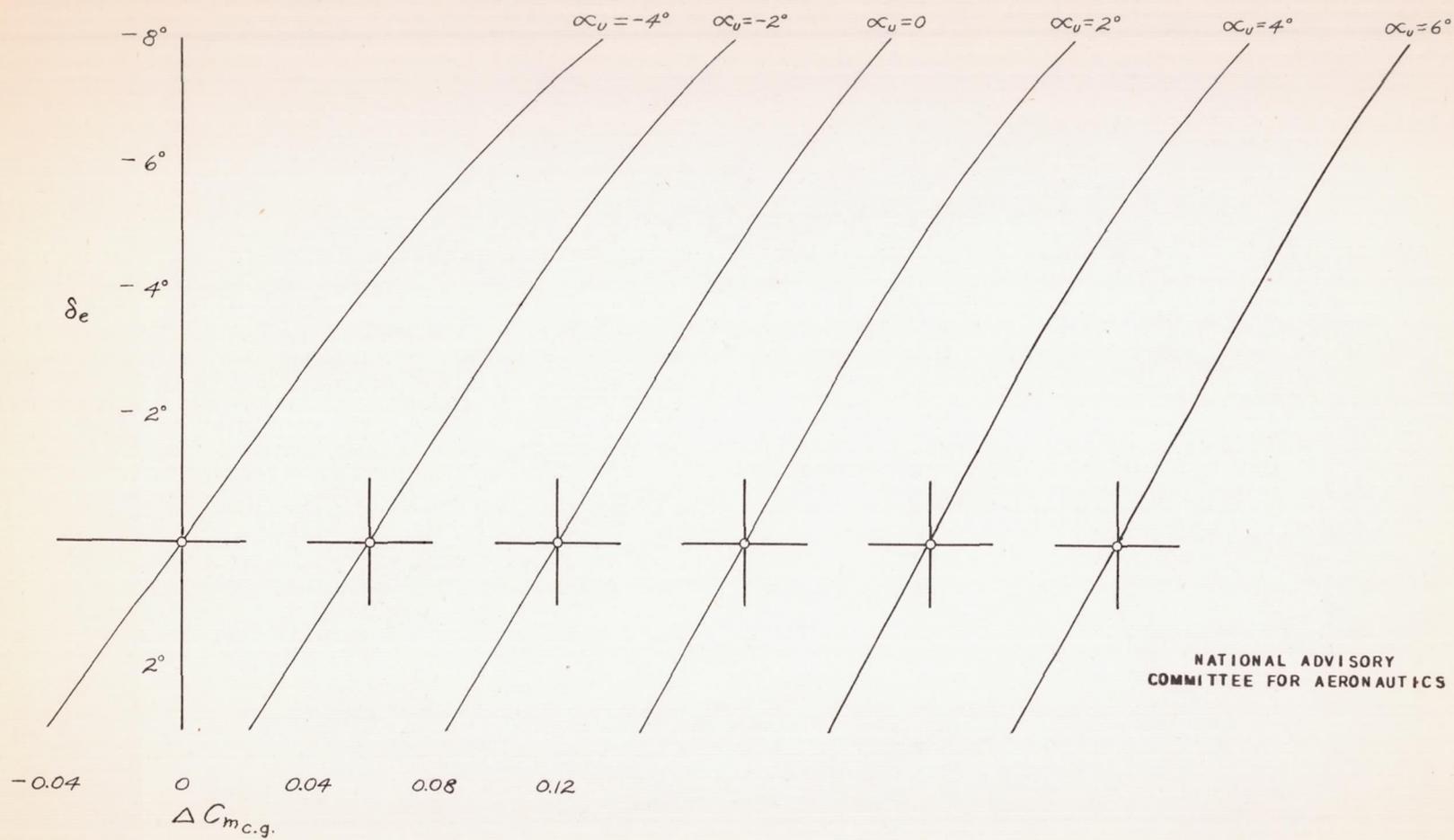
(9) $M = 0.8$

FIGURE 9.— CONCLUDED.

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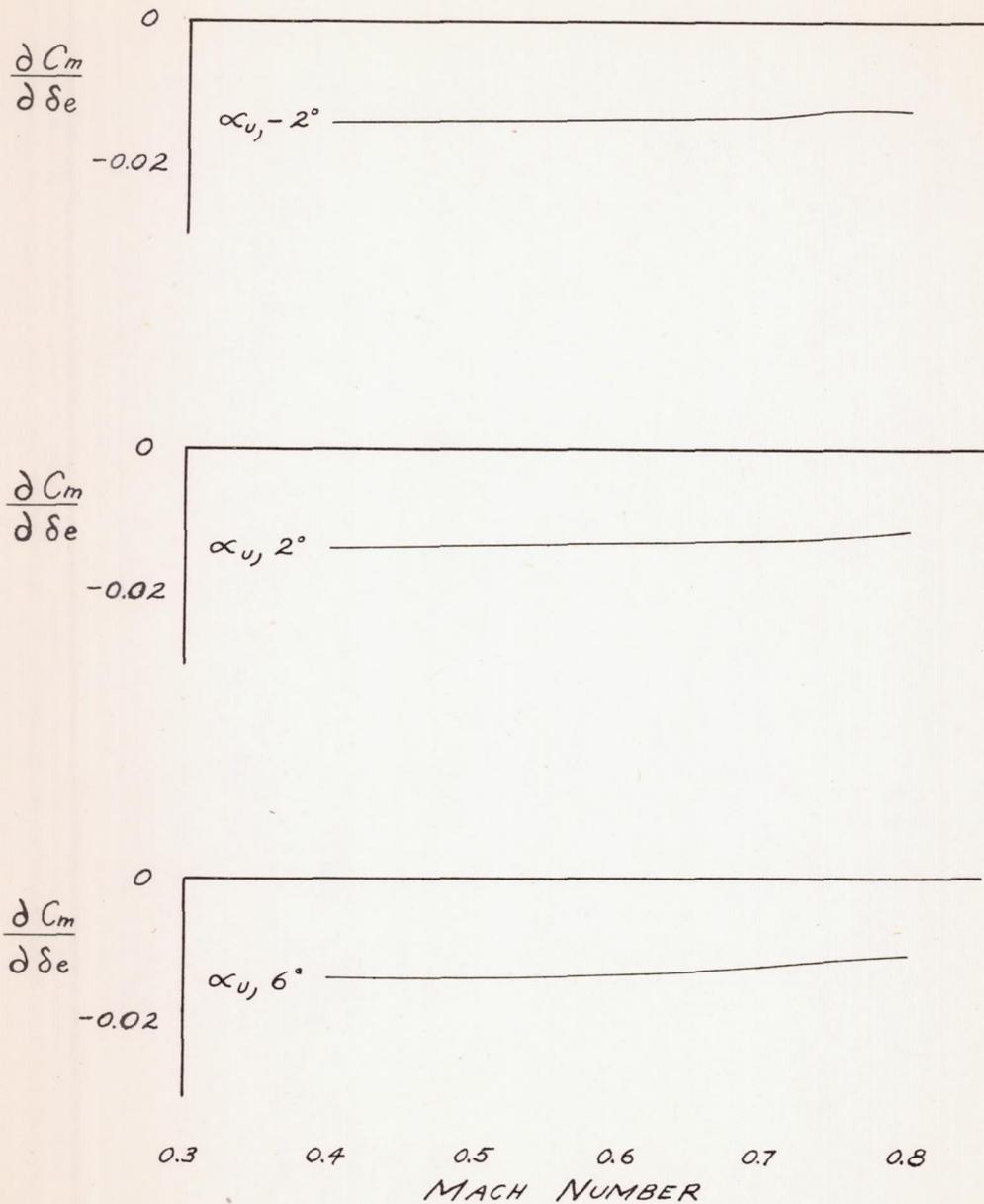
FIGURE 10.— THE VARIATION OF ELEVATOR EFFECTIVENESS
WITH MACH NUMBER FOR THREE ANGLES OF
ATTACK. i_t, 2°
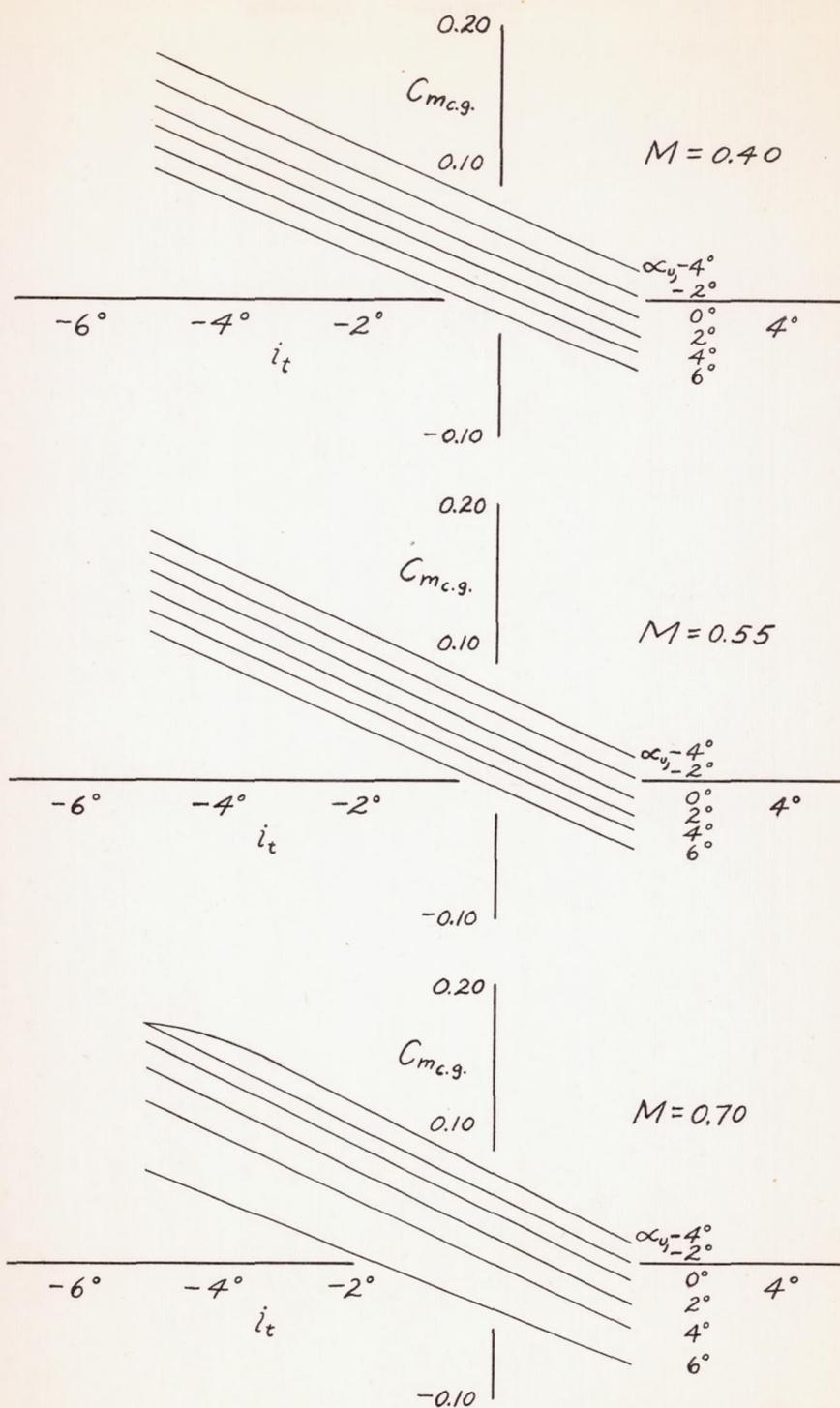
(a) M = 0.4, 0.55, AND 0.7.

FIGURE 11.- THE VARIATION OF PITCHING - MOMENT
COEFFICIENT WITH TAIL INCIDENCE FOR
SEVERAL ANGLES OF ATTACK. δ_e, 0°.
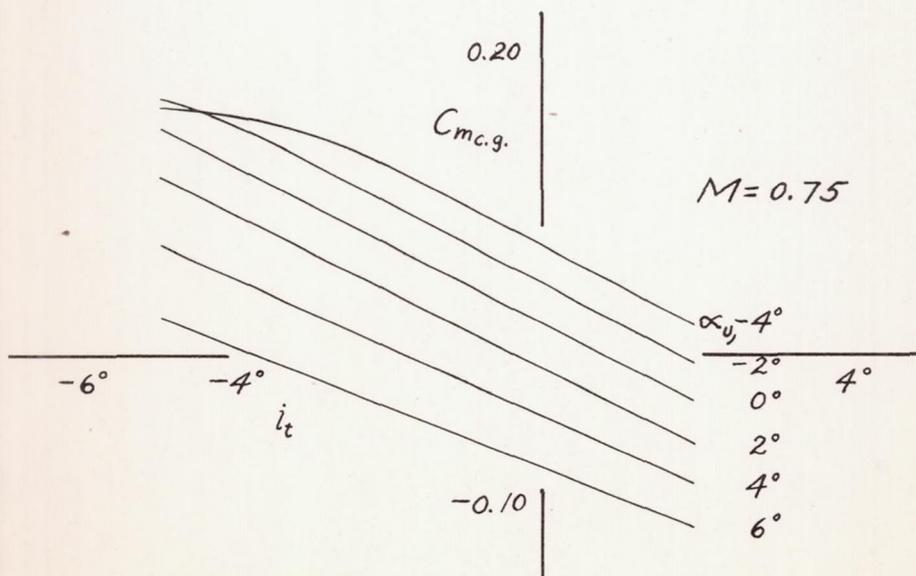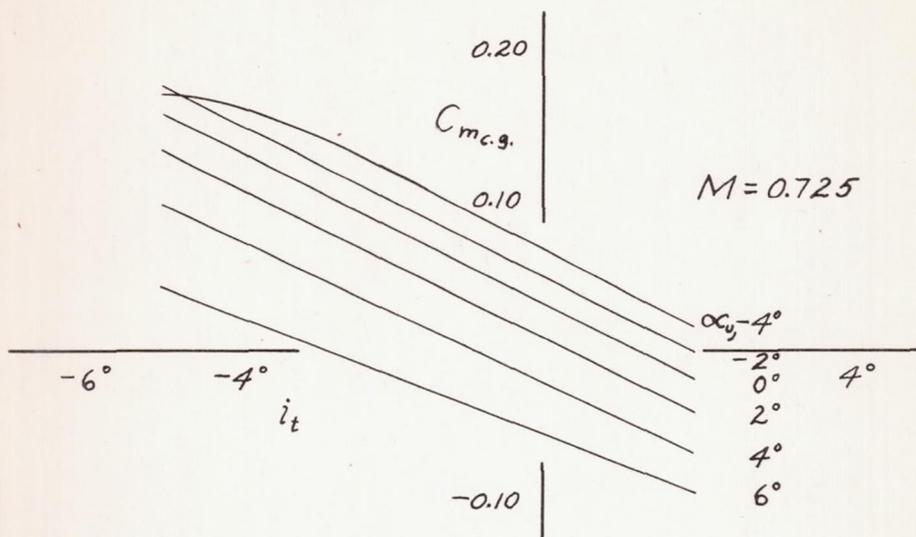
(b) $M = 0.725$ AND 0.75

FIGURE 11.-   CONTINUED.

A-76

0.20

$C_{m_{c.g.}}$

$M = 0.775$

$\alpha_u - 4°$

-6°

i_t

-2°   4°

0°

2°

-0.10

4°

6°

0.20

$C_{m_{c.g.}}$

$M = 0.80$

0.10

$\alpha_u - 4°$

-6°

i_t

-2°   4°

0°

2°

-0.10

4°

6°
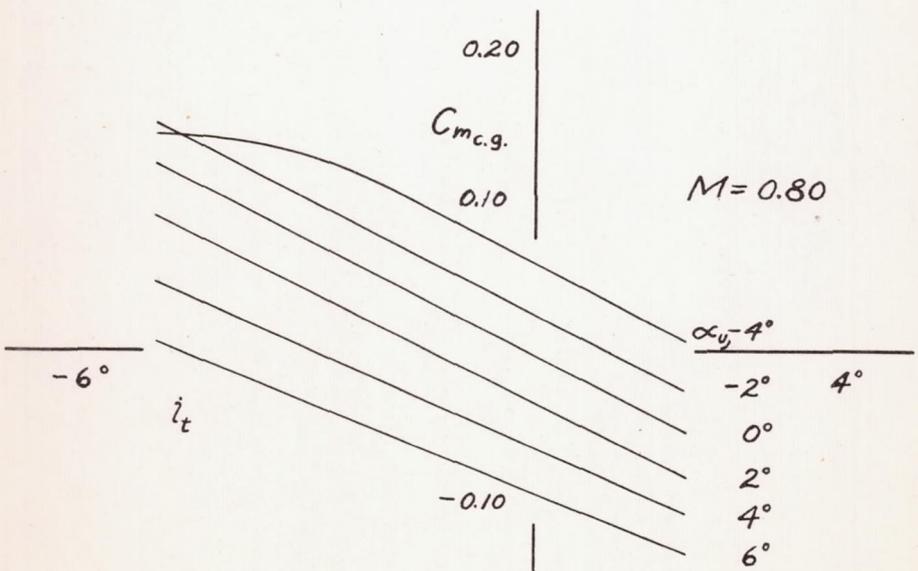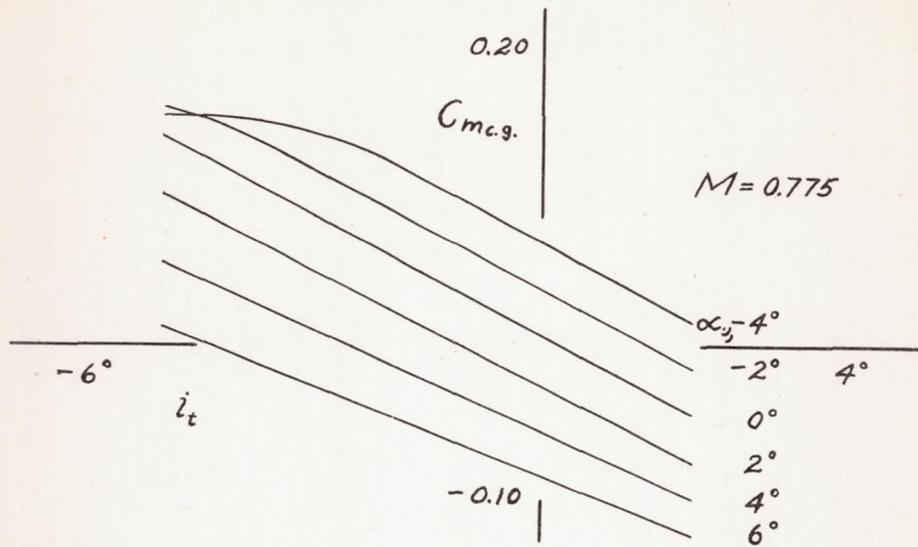
(C) $M = 0.775$ AND 0.8

FIGURE 11.—   CONCLUDED.
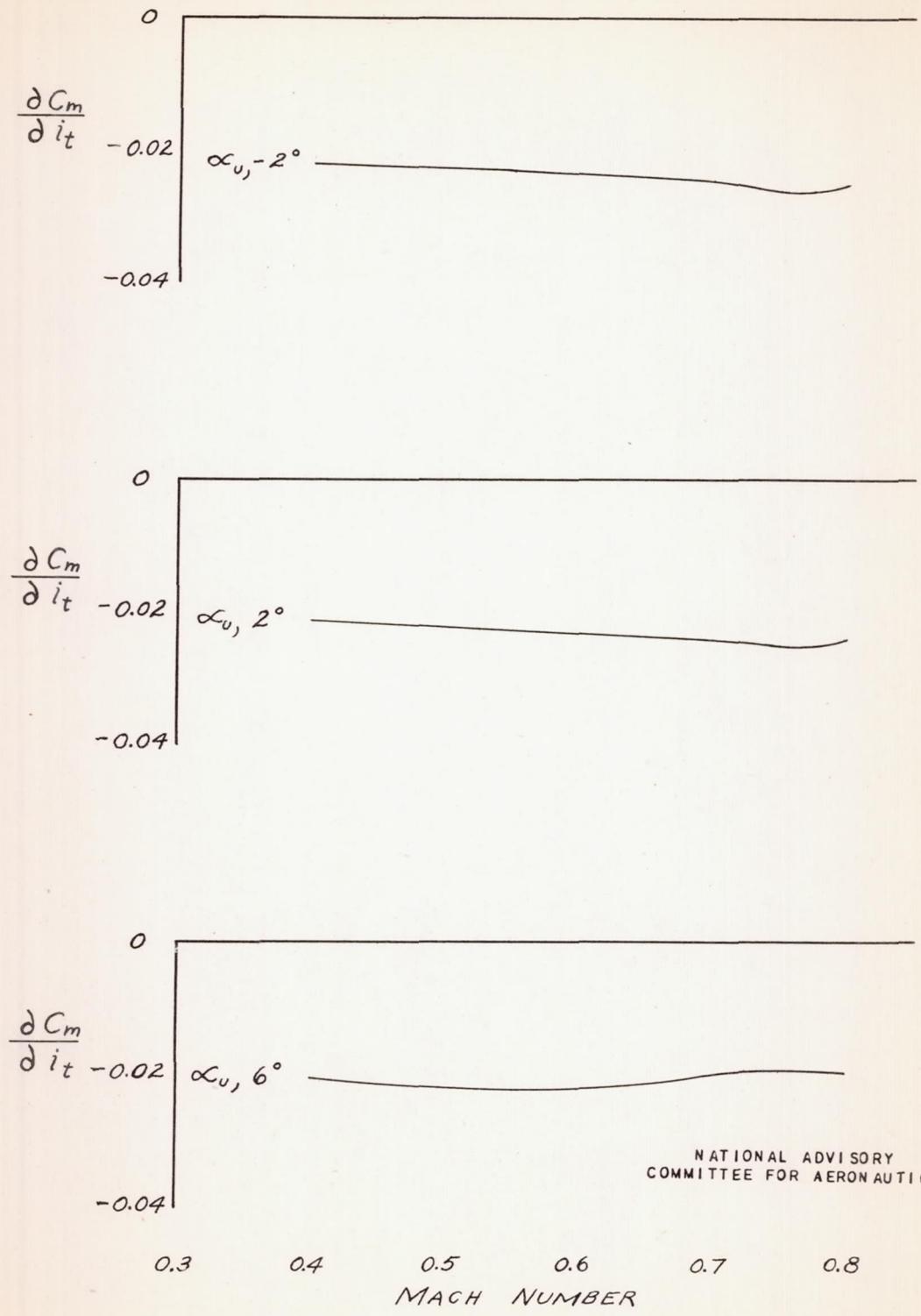
FIGURE 12.– THE VARIATION OF TAIL EFFECTIVENESS
WITH MACH NUMBER FOR THREE ANGLES
OF ATTACK. $\delta_e, 0°$.
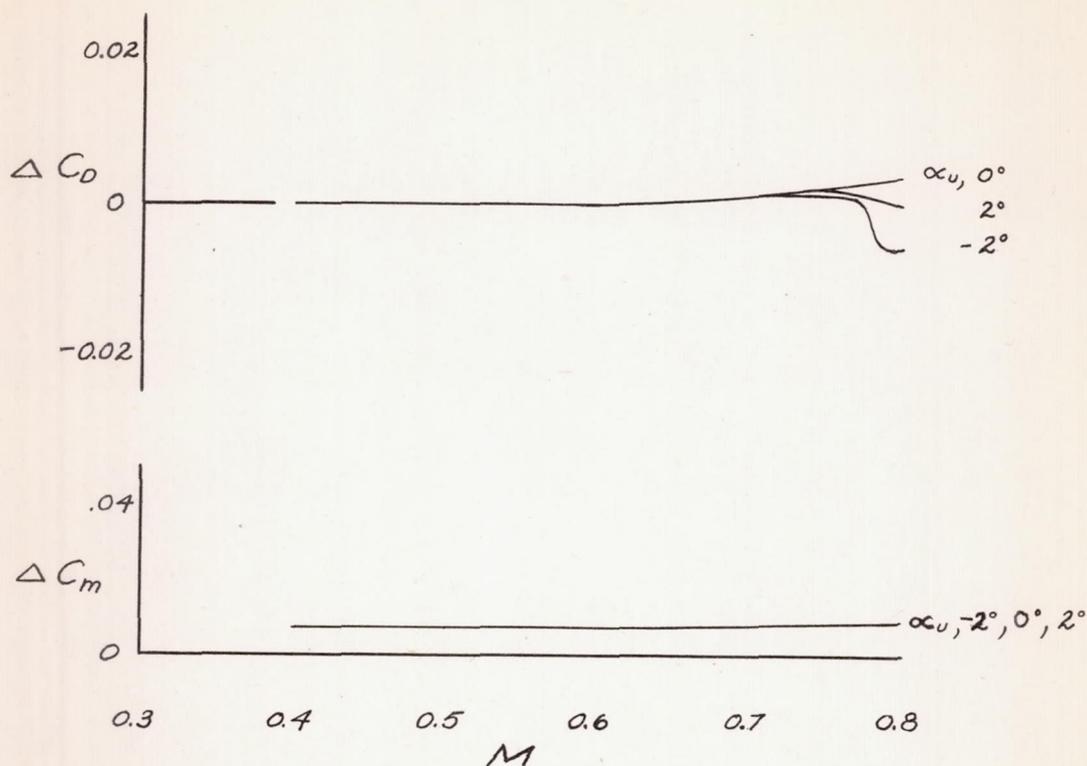
FIGURE 13.- ADDITIONAL DRAG AND PITCHING-MOMENT
COEFFICIENT FROM THE DEFLECTOR VANE.
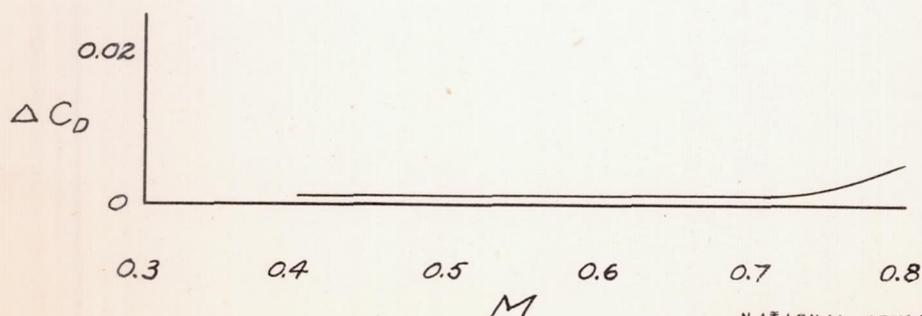
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FIGURE 14.- ADDITIONAL DRAG COEFFICIENT FROM
THE RETRACTED DIVE-RECOVERY FLAPS.