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RESEARCH MEMORANDUM

CHARACTERISTICS OF A 15-PERCENT-CHORD AND A 35-PERCENT-CHORD PLAIN FLAP ON THE NACA 0006 AIRFOIL SECTION AT HIGH SUBSONIC SPEEDS

By Richard J. Ilk

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

CHARACTERISTICS OF A 15-PERCENT-CHORD AND A 35-PERCENT-CHORD PLAIN FLAP ON THE NACA 0006 AIRFOIL SECTION AT HIGH SUBSONIC SPEEDS

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SUMMARY

Wind-tunnel tests have been made to determine the aerodynamic characteristics of a 15-percent- and a 35-percent-chord plain trailing-edge flap on the NACA 0006 airfoil section. Simultaneous measurements of section lift, drag, and pitching moment were made over a range of Mach numbers from 0.3 to approximately 0.9 at angles of attack ranging from -8° to 12° for flap deflections of 0°, 5°, and 10°. Increments of section lift coefficient and changes in airfoil angle of attack necessary to maintain constant lift with unit changes in flap deflection are presented as a measure of the effectiveness at high subsonic speeds of a plain flap employed on a very thin profile.

An analysis of the test results shows that, for small flap deflections, the increment of lift coefficient produced by a plain flap on the NACA 0006 airfoil at 0.875 Mach number is substantially the same as or greater than that realized at low speeds. A study of the relative effectiveness of two flap sizes indicates that, on thin airfoils, the loss in flap effectiveness at high subsonic speeds is considerably less for a large-chord than for a small-chord flap.

The effectiveness of the flaps of the present investigation has been compared with that of a 20-percent-chord plain flap on both a modified NACA 65,3-019 and the NACA 65-210 airfoils. From this comparison it appears that, at high subsonic speeds, the rate of decrease in effectiveness of a plain flap on these three airfoils is the least severe for the airfoil with the smallest thickness-chord ratio.

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INTRODUCTION

Various high-speed investigations of lift-control devices have indicated that a pronounced decrease in the effectiveness of such devices occurs at high subsonic speeds. A comparison is made in reference 1 of the effectiveness of three types of lift controls: a plain trailing-edge flap, a dive-recovery flap, and a spoiler. Although the experimental results presented for these controls show that each remains effective at Mach numbers between those for airfoil lift divergence and 0.875, it appears that the plain trailing-edge flap exhibits the least variation in lift-control effectiveness for Mach numbers from 0.3 to 0.875. The data of reference 1 also indicate that a reduction in airfoil thickness-chord ratio delays the onset of the abrupt loss in the plain-flap effectiveness to higher Mach numbers.

The present investigation was undertaken to provide information on the respective characteristics of relatively small-chord and large-chord flaps on a very thin profile at high subsonic speeds. Values of control effectiveness for two sizes of plain flap are obtained from lift-coefficient data. These values are compared to show the influence of a variation in flap-chord ratio on the flap effectiveness at high speeds. The change in the rate of decrease in effectiveness that can be expected to accompany a reduction in airfoil thickness-chord ratio is indicated by a comparison of the present data with the characteristics of a plain flap on two NACA airfoils of greater thicknesses. For airfoils having a design lift coefficient of 0.2 or less, it is believed that the airfoil camber has little effect on the characteristics of a plain flap at high subsonic speeds.

SYMBOLS

c_l section lift coefficient

Δc_l increment of section lift coefficient

c_d section drag coefficient

$c_{m_{c/4}}$ section pitching-moment coefficient about quarter-chord point

M free-stream Mach number

α section angle of attack, degrees

[redacted]

[redacted]

[redacted]

δ_f flap deflection, degrees

$\Delta\alpha/\Delta\delta_f$ section flap-effectiveness parameter, absolute value of the ratio of equivalent change in section angle of attack to change in flap deflection angle at a constant lift coefficient

APPARATUS AND TESTS

The tests were conducted in the Ames 1- by $3\frac{1}{2}$-foot high-speed wind-tunnel, a low-turbulence closed-throat tunnel. For this investigation, five 6-inch-chord models were constructed of duralumin to represent the unflapped NACA 0006 airfoil section and the NACA 0006 section with a 15-percent- and a 35-percent-chord plain flap deflected approximately 5° and 10°. Measurements of the flap deflections on the models revealed that the deflection angles were actually 5.5° and 10.5° for the 15-percent-chord flap and 4.9° and 10.2° for the 35-percent-chord flap. Ordinates for the NACA 0006 airfoil are given in table I and sketches of the models of the present investigation are shown in figure 1.

The models were mounted so as to completely span the 1-foot dimension of the tunnel test section. Sponge-rubber gaskets were compressed between the tunnel walls and the ends of the models to prevent end leakage, thus preserving two-dimensional flow and assuring the measurement of section characteristics.

Lift, drag, and pitching-moment data for the NACA 0006 airfoil were obtained at Mach numbers from 0.3 to approximately 0.9 for angles of attack ranging from -2° to 12° by 2° increments. Corresponding measurements were made at angles of attack from -6° to 6° for the airfoil with a 15-percent-chord flap and from -8° to 4° for the airfoil with a 35-percent-chord flap. The Reynolds numbers of the tests ranged from 1×10^6 to nearly 2×10^6, respectively, for Mach numbers from 0.3 to approximately 0.9.

Airfoil lift and pitching moment were obtained by integrating the pressure distribution along the ceiling and floor of the tunnel. Drag forces were measured by the wake-survey method employing a rake of total-head tubes.

TEST RESULTS

Section characteristics of lift, drag, and pitching moment for each of the models tested are presented as a function of Mach number

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in figures 2 to 10, inclusive. Cross plots (figs. 11, 12, and 13) at constant Mach numbers illustrate the respective variations of section lift coefficient with angle of attack, section drag coefficient with lift coefficient and section moment coefficient with lift coefficient for the NACA 0006 airfoil. Dashed lines at the high-speed extremities of the curves of figures 2 to 13 serve to indicate that some uncertainty exists regarding the validity of data observed at speeds in the vicinity of the tunnel choking velocity. All data have been corrected for tunnel-wall interference by the methods of reference 2. Increments of section lift coefficient at constant Mach numbers are presented as a function of flap deflection in figures 14 and 15 for several angles of attack of the NACA 0006 airfoil with a 15-percent- and a 35-percent-chord flap, respectively. These increments, for the airfoil with a 15-percent-chord flap, were determined for airfoil angles of attack corresponding to lift coefficients of 0, 0.2, and 0.4 at zero flap deflection. For the airfoil with a 35-percent-chord flap, lift-coefficient increments were determined for angles of attack corresponding to lift coefficients of 0 and 0.2 at zero flap deflection. The increments of section lift coefficient of figures 14 and 15 are cross-plotted against Mach number in figures 16 and 17 for constant flap deflections and for the same angles of attack as those of figures 14 and 15.

In figures 18 and 19 values of the flap-effectiveness parameter $\Delta\alpha/\Delta\delta_f$ are given as a function of Mach number for the NACA 0006 airfoil with a 15-percent- and a 35-percent-chord flap, respectively, at constant lift coefficients. To determine the value of $\Delta\alpha/\Delta\delta_f$ for a particular Mach number, a curve of angle of attack versus flap deflection, at a constant lift coefficient, was prepared for the same Mach number. The absolute value of the average slope of this curve over a deflection range from 0° to 10° was taken as the value of $\Delta\alpha/\Delta\delta_f$.

In figure 20, the effectiveness of the plain flaps on the airfoil of the present report is shown with that of a plain flap on both a 19-percent- and a 10-percent-thick NACA 65-series airfoil section.

DISCUSSION

Drag and moment characteristics of the NACA 0006 airfoil with and without flaps, as given in figures 5 through 10 and figures 12 and 13, have been included in the present report solely to make this information available to the reader and will not be discussed here. The following remarks are concerned with the lift-control effectiveness of plain flaps as determined from an analysis of the lift coefficient data presented in figures 2, 3, 4, and 11.

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Examination of the curves of figures 14 through 17 indicates that, in the subcritical-speed range, the magnitude of the lift-coefficient increments produced by the deflected flaps increases steadily with an increase in Mach number. Maximum values of the lift increments occur at Mach numbers approximately equal to those for lift divergence of the airfoil-flap combination. As the speeds increase above those at which the maximum increments occur for a constant flap deflection, the magnitudes of the lift increments decrease in varying amounts. At 0.875 Mach number, the highest Mach number for which data is presented, the lift-increment value for a given flap deflection is substantially the same as or greater than that exhibited at the lowest speeds.

A more significant measure of lift-control effectiveness than the lift-producing capacity of the flap is the change in airfoil angle of attack necessary to maintain constant lift with a unit change in flap deflection. The parameter $\Delta\alpha/\Delta\delta_f$ therefore, is used in the present report to indicate flap effectiveness.

The data of figures 18 and 19 show that, at low Mach numbers, the change in magnitude of the flap-effectiveness parameter $\Delta\alpha/\Delta\delta_f$ with change in Mach number or lift coefficient is small. At the highest Mach numbers, an appreciable decrease in the value of $\Delta\alpha/\Delta\delta_f$ is shown for an increase in Mach number but the rate of this decrease is not great. The reduction in $\Delta\alpha/\Delta\delta_f$ due to an increase in lift coefficient is small, except for the airfoil with the 35-percent-chord flap (fig. 19), for a change in lift coefficient from 0.2 to 0.4. At zero lift coefficient, the effectiveness of the 15-percent-chord flap at a Mach number of 0.875 is approximately 58 percent of the low-speed value; whereas, for the 35-percent-chord flap at the same Mach number, the effectiveness is nearly 80 percent of that at low speeds. Since both the 15-percent- and the 35-percent-chord flaps retain high values of effectiveness at this Mach number, the data indicate that a plain flap on the NACA 0006 airfoil is adequate for control applications up to a Mach number of 0.875. It is also evident that, at high subsonic speeds, large-chord flaps lose a smaller percentage of the low-speed effectiveness than do small-chord flaps. Thus, satisfactory control effectiveness may be maintained to higher speeds by the use of large-chord small-span flaps.

The severity of the loss in effectiveness of a plain flap at high subsonic speeds appears to be appreciably influenced by the thickness-chord ratio of the airfoil on which the flap is employed. (See fig. 20.) The data presented for the 19-percent-thick airfoil were obtained from a report of the investigation of a 20-percent-chord flap on a modified NACA 65,3-019 airfoil. (See reference 3.)

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Neglecting the small influence of camber on the characteristics of airfoils having a design lift coefficient of 0.2 or less, the curves of figure 20 would indicate that considerable improvement in control effectiveness may be realized by decreasing the airfoil thickness-chord ratio from 0.19 to 0.10. A similar comparison of the data for the 20-percent-chord flap on the NACA 65-210 airfoil with that for the 15-percent- and 35-percent-chord flaps on the NACA 0006 airfoil indicates that the rate of decrease in flap effectiveness at supercritical speeds becomes smaller with a reduction in thickness-chord ratio from 0.10 to 0.06.

CONCLUSIONS

From an analysis of the high-speed characteristics of a plain flap employed on a very thin profile, as determined from wind-tunnel tests of a 15-percent- and a 35-percent-chord plain flap on the NACA 0006 airfoil section, the following conclusions can be made:

1. The data indicate that both the 15-percent- and the 35-percent-chord plain flaps on the NACA 0006 airfoil are adequate, insofar as control effectiveness is concerned, for control applications up to a Mach number of at least 0.875.

2. The loss in effectiveness of a plain flap on a thin airfoil at Mach numbers up to 0.875 is less severe for a large-chord than for a small-chord flap.

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REFERENCES

1. Stivers, Louis S., Jr.: The Effectiveness At High Speeds Of A 20-Percent-Chord Plain Trailing-Edge Flap On The NACA 65-210 Airfoil Section. NACA CRM No. A7A17, 1947.

2. Allen, H. Julian, and Vincenti, Walter G.: Wall Interference In A Two-Dimensional-Flow Wind Tunnel With Consideration Of The Effect of Compressibility. NACA ARR No. 4K03, 1944.

3. Lindsey, W. F.: Effect Of Compressibility On The Pressures And Forces Acting On A Modified NACA 65,3-019 Airfoil Having A 0.20-Chord Flap. NACA ACR No. L5G31a, 1946.

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TABLE I

NACA 0006 AIRFOIL

[Stations and ordinates given in percent of airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
1.25	.95	1.25	-.95
2.5	1.31	2.5	-1.31
5.0	1.78	5.0	-1.78
7.5	2.10	7.5	-2.10
10	2.34	10	-2.34
15	2.67	15	-2.67
20	2.87	20	-2.87
25	2.97	25	-2.97
30	3.00	30	-3.00
40	2.90	40	-2.90
50	2.65	50	-2.65
60	2.28	60	-2.28
70	1.83	70	-1.83
80	1.31	80	-1.31
90	.72	90	-.72
95	.40	95	-.40
100	(.06)	100	(-.06)
100	0	100	0
L. E. Radius: 0.40			

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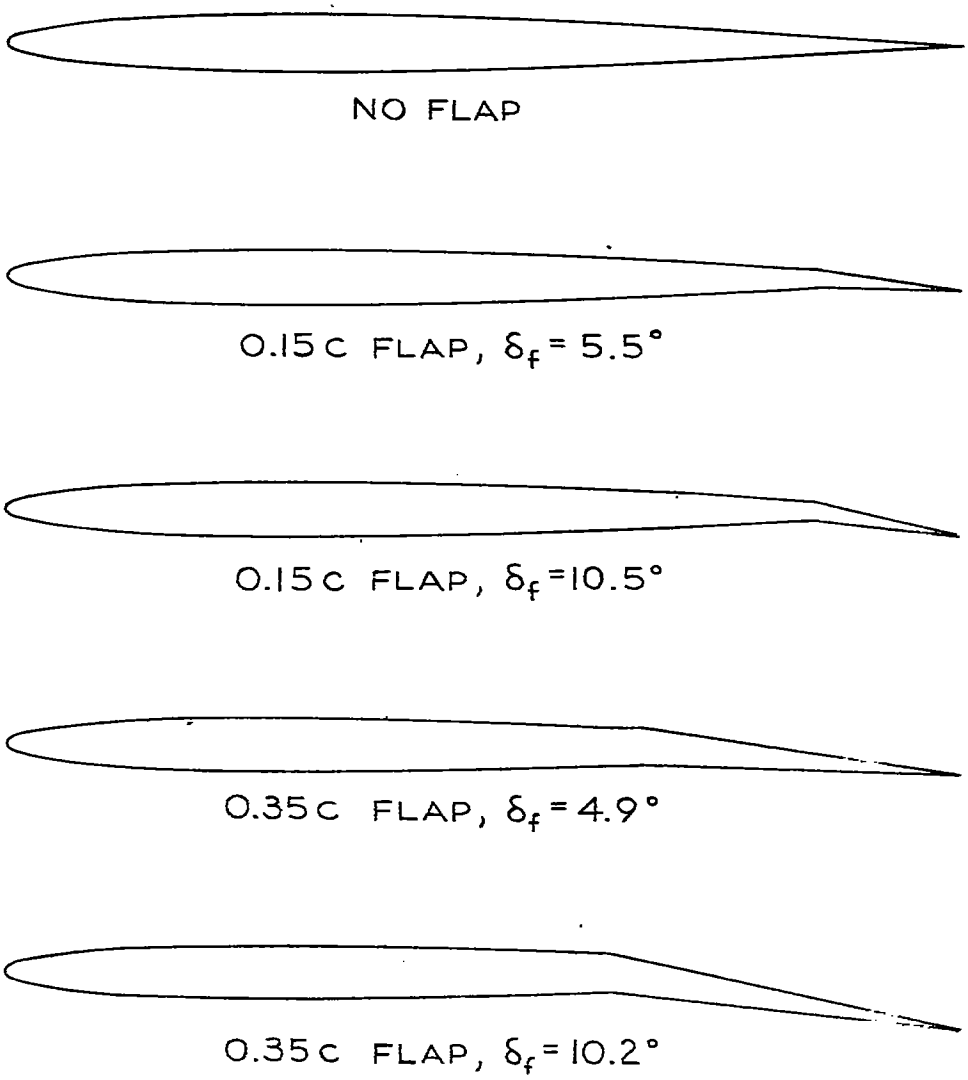

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FIGURE 1.- THE NACA 0006 AIRFOIL SECTION WITH PLAIN TRAILING-EDGE FLAPS OF TRUE AIRFOIL CONTOUR.

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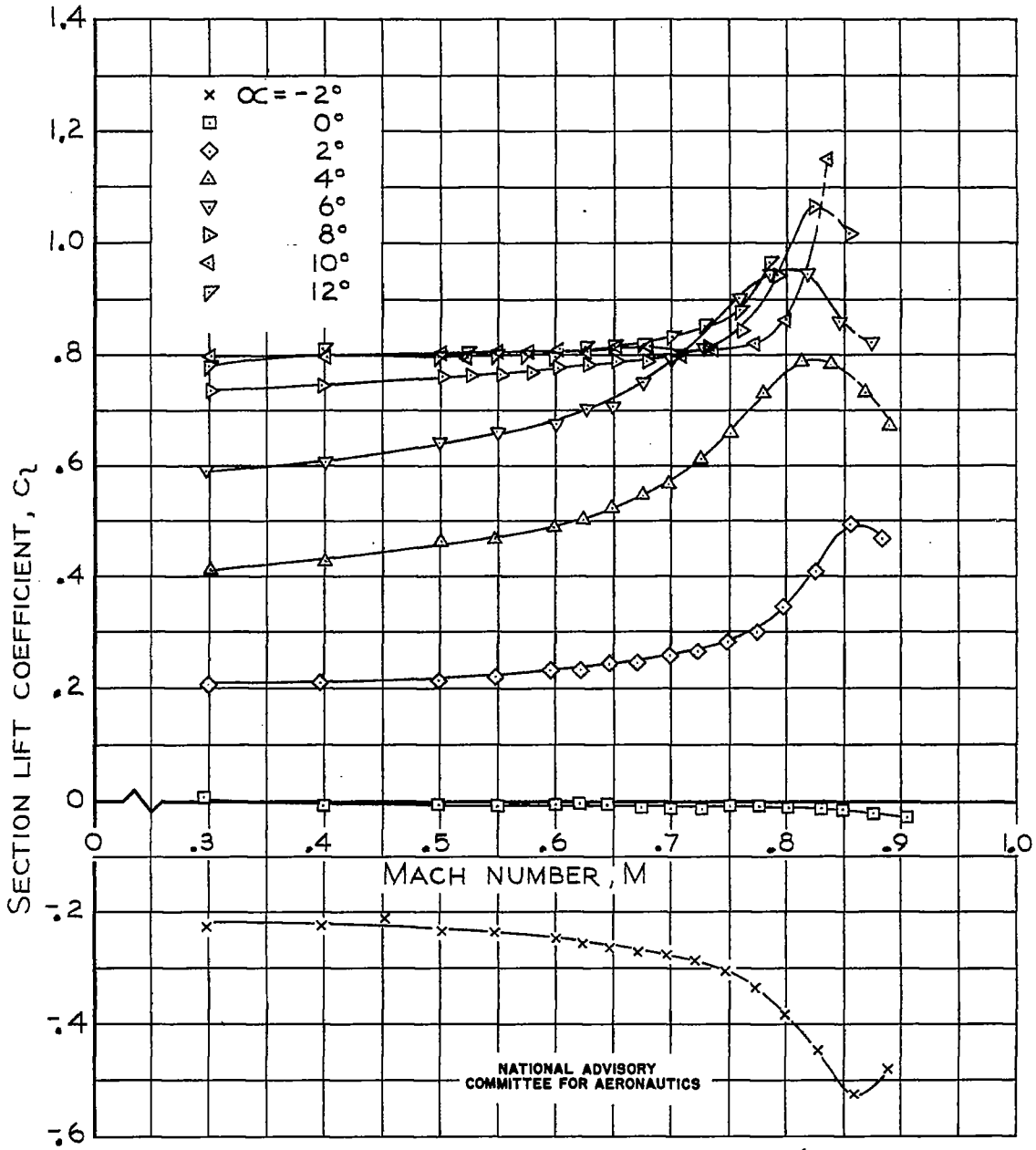

FIGURE 2.- THE VARIATION OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL.

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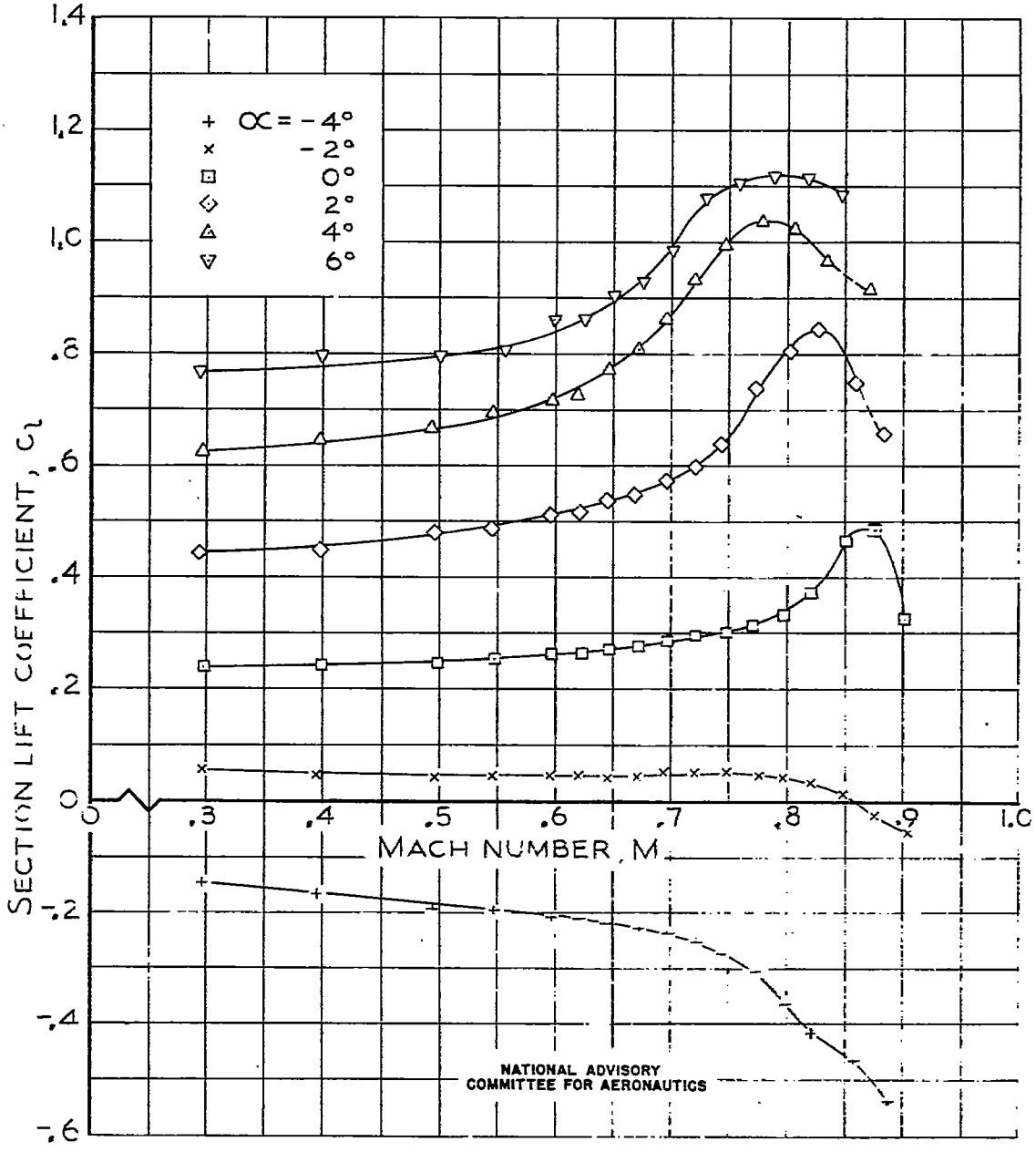

(a) $\delta_f = 5.5°$

FIGURE 3.- THE VARIATION OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

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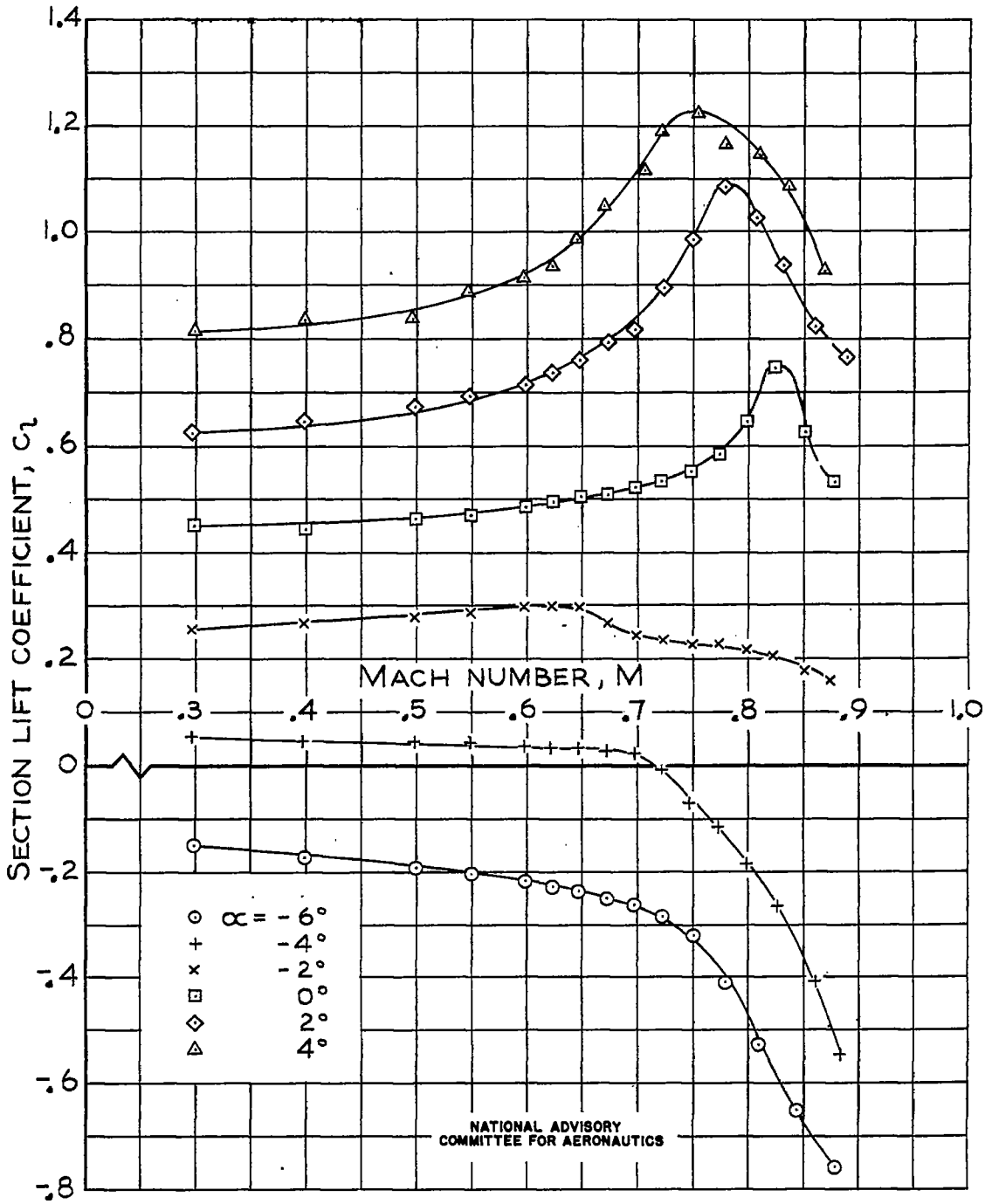

(b) $\delta_f = 10.5°$

FIGURE 3.- CONCLUDED. NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

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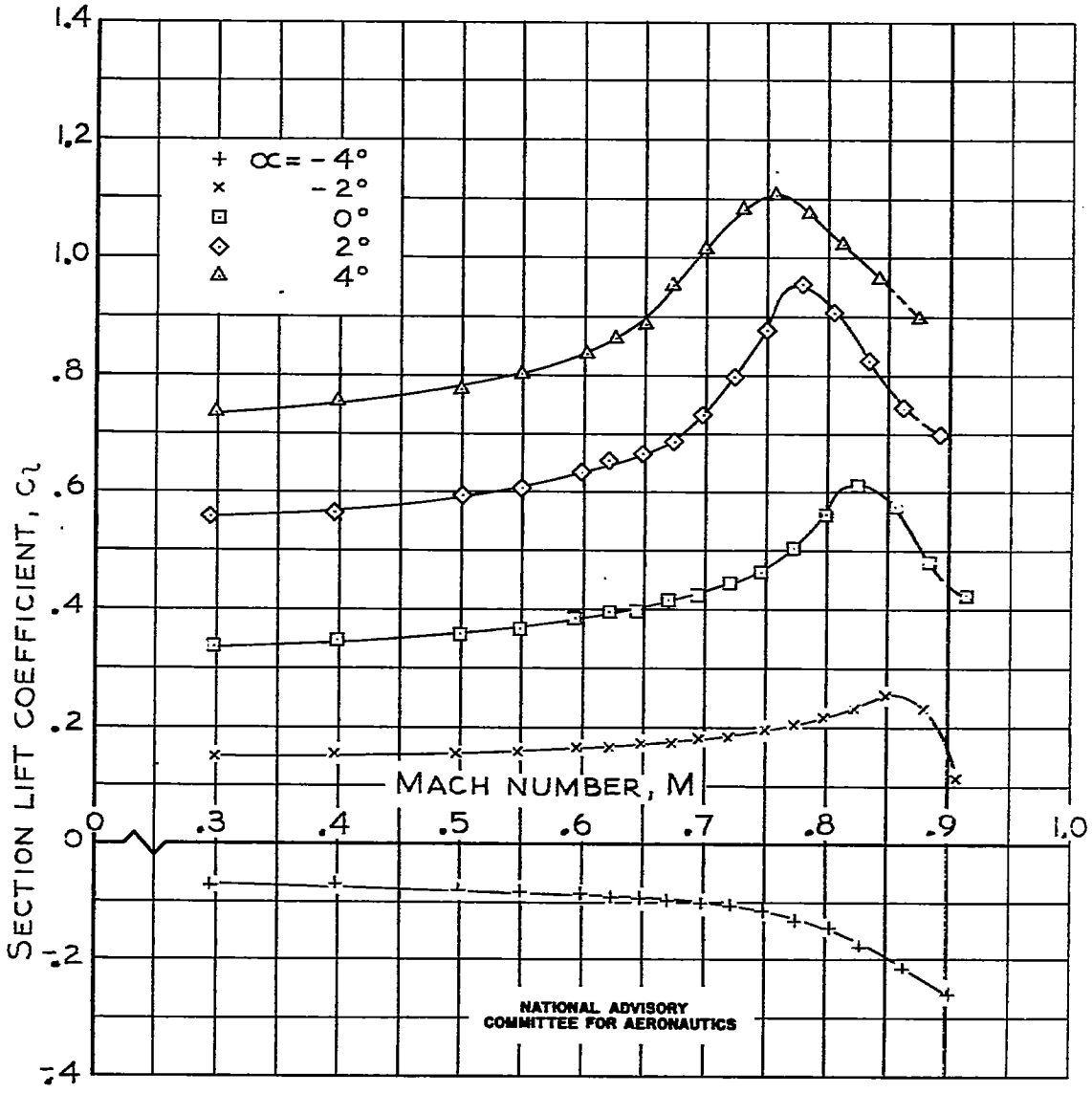

(a) $\delta_f = 4.9°$

FIGURE 4.- THE VARIATION OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

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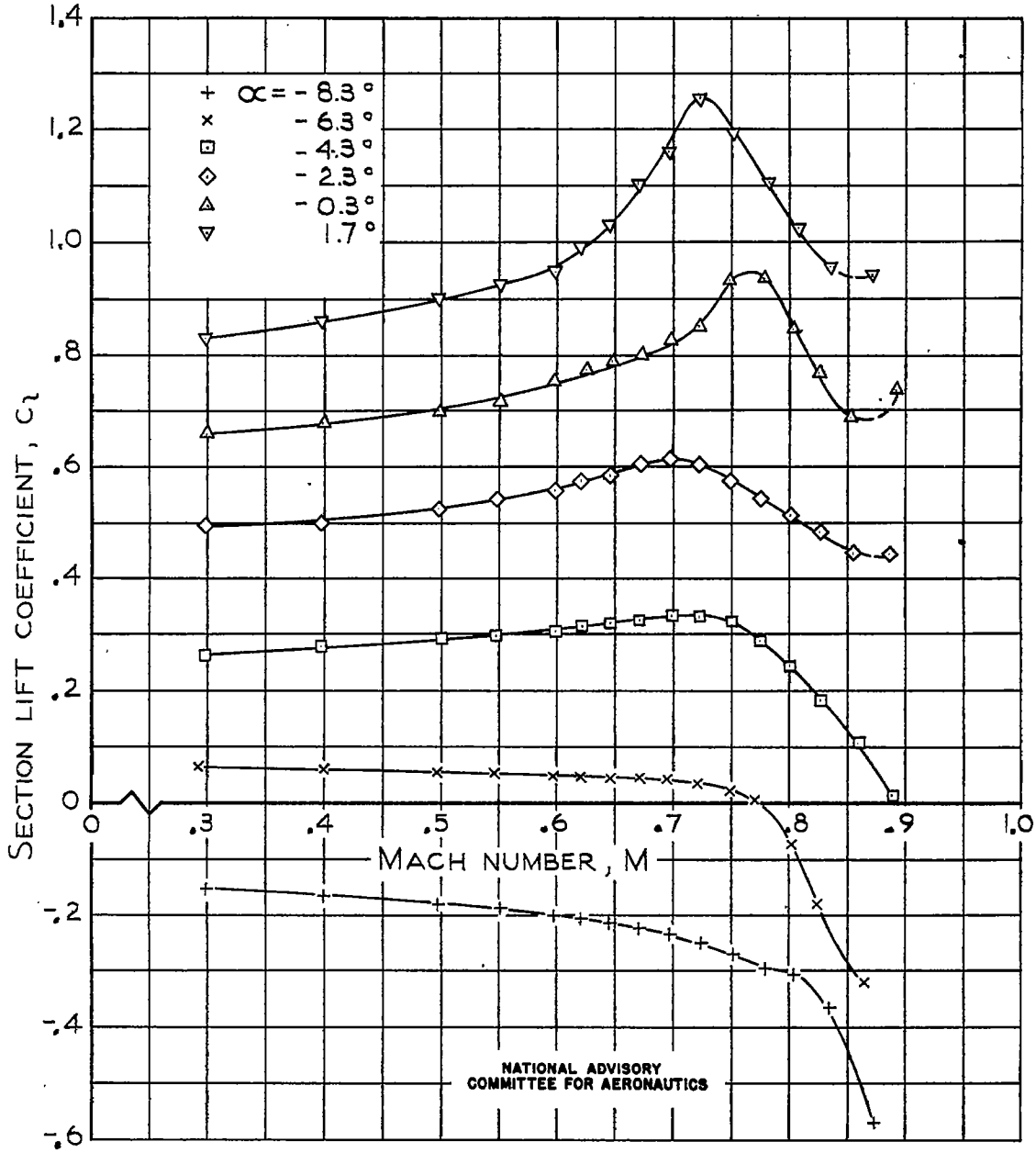

(b) $\delta_f = 10.2°$

FIGURE 4.- CONCLUDED. NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

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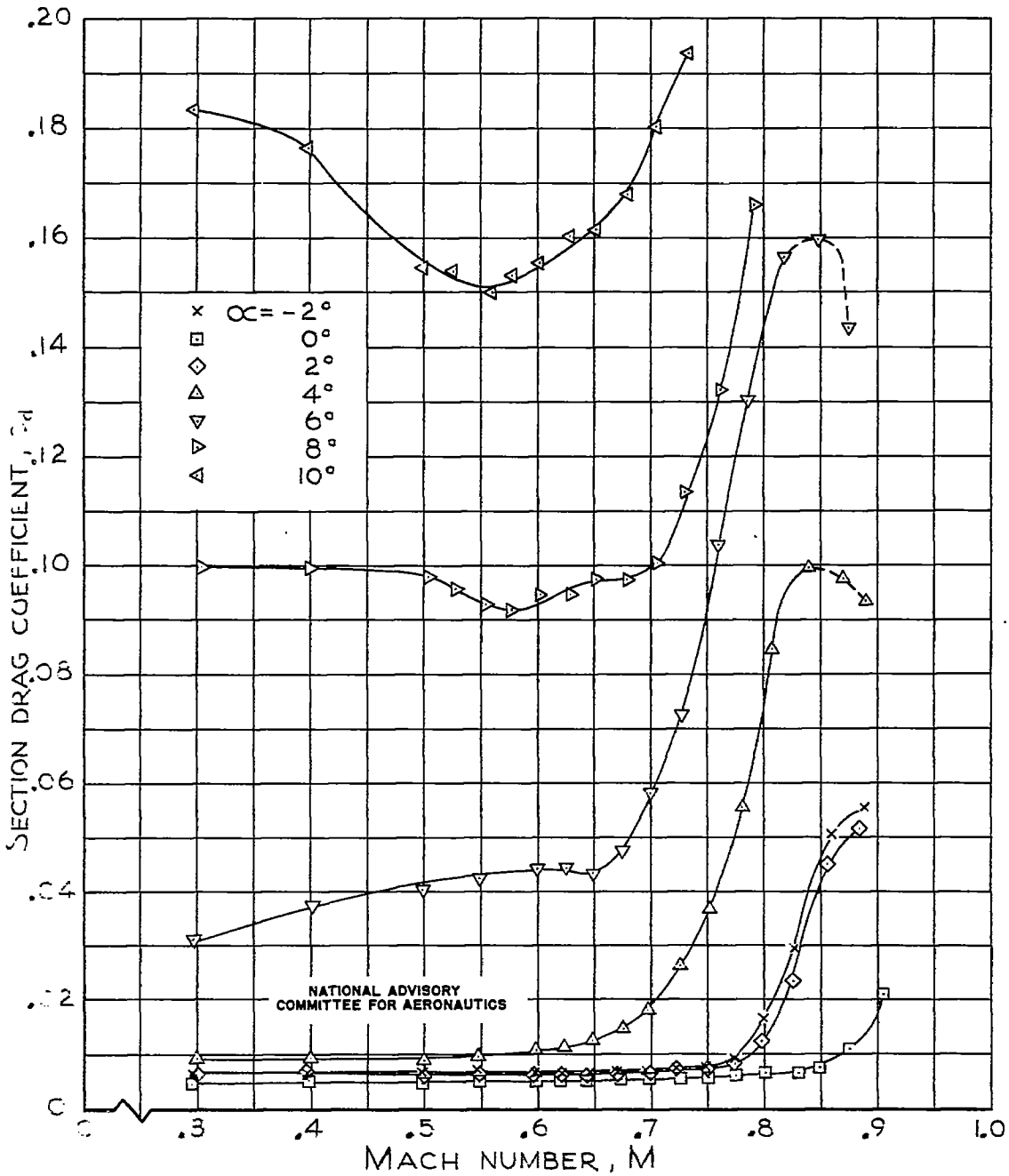

FIGURE 5.-THE VARIATION OF SECTION DRAG COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL.

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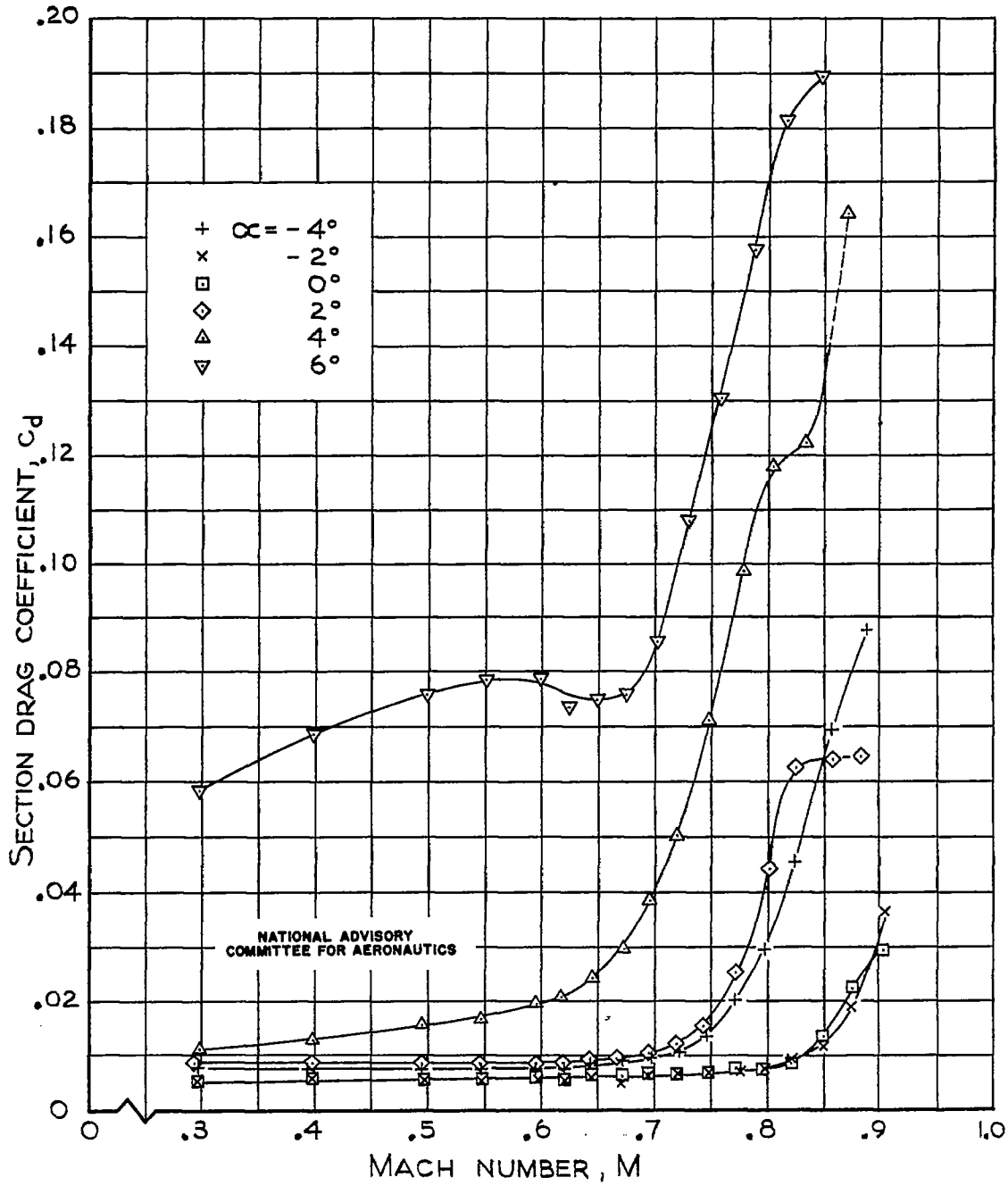

(a) $\delta_f = 5.5°$

FIGURE 6.- THE VARIATION OF SECTION DRAG COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

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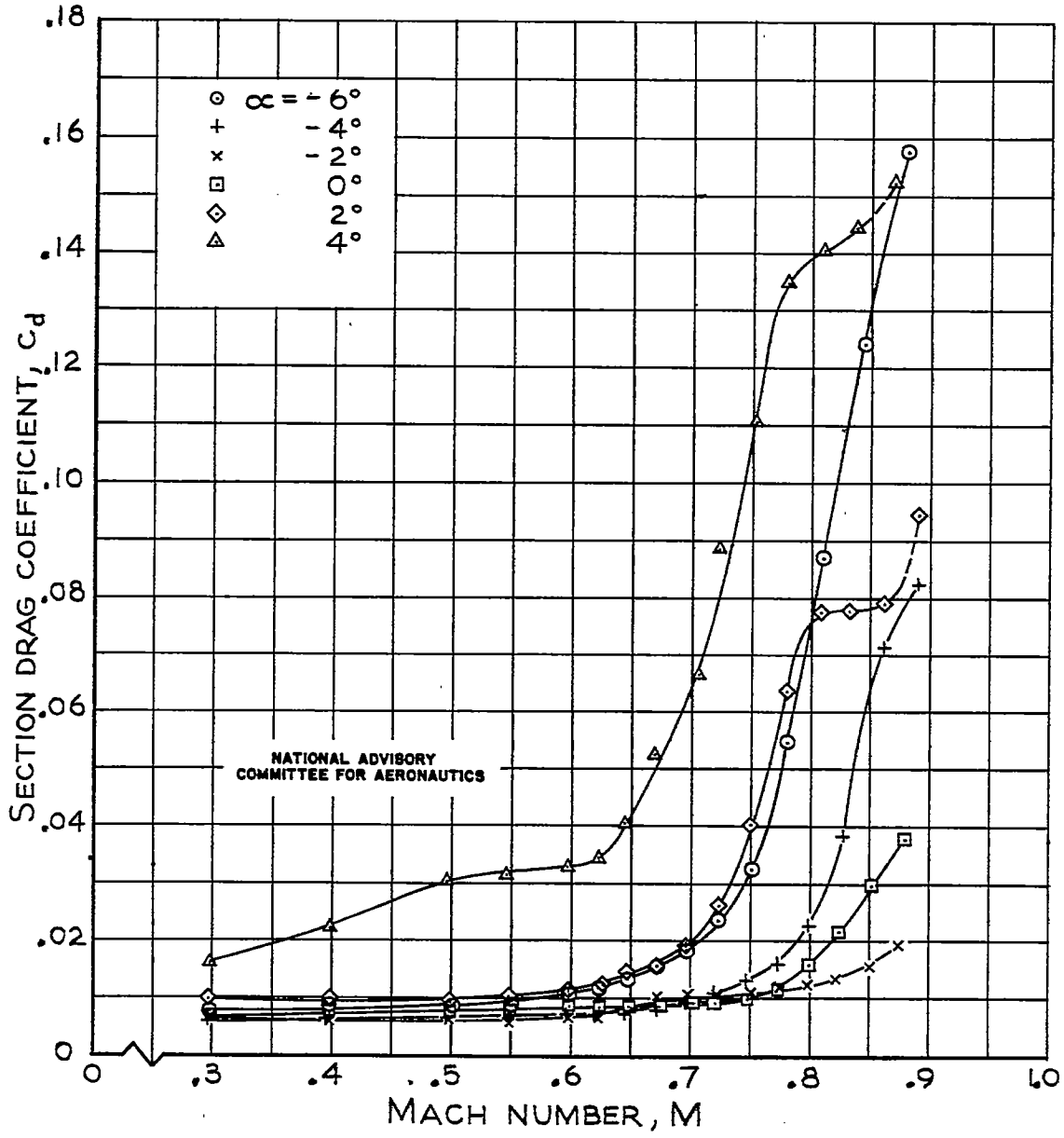

(b) $\delta_f = 10.5°$

FIGURE 6.- CONCLUDED. NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

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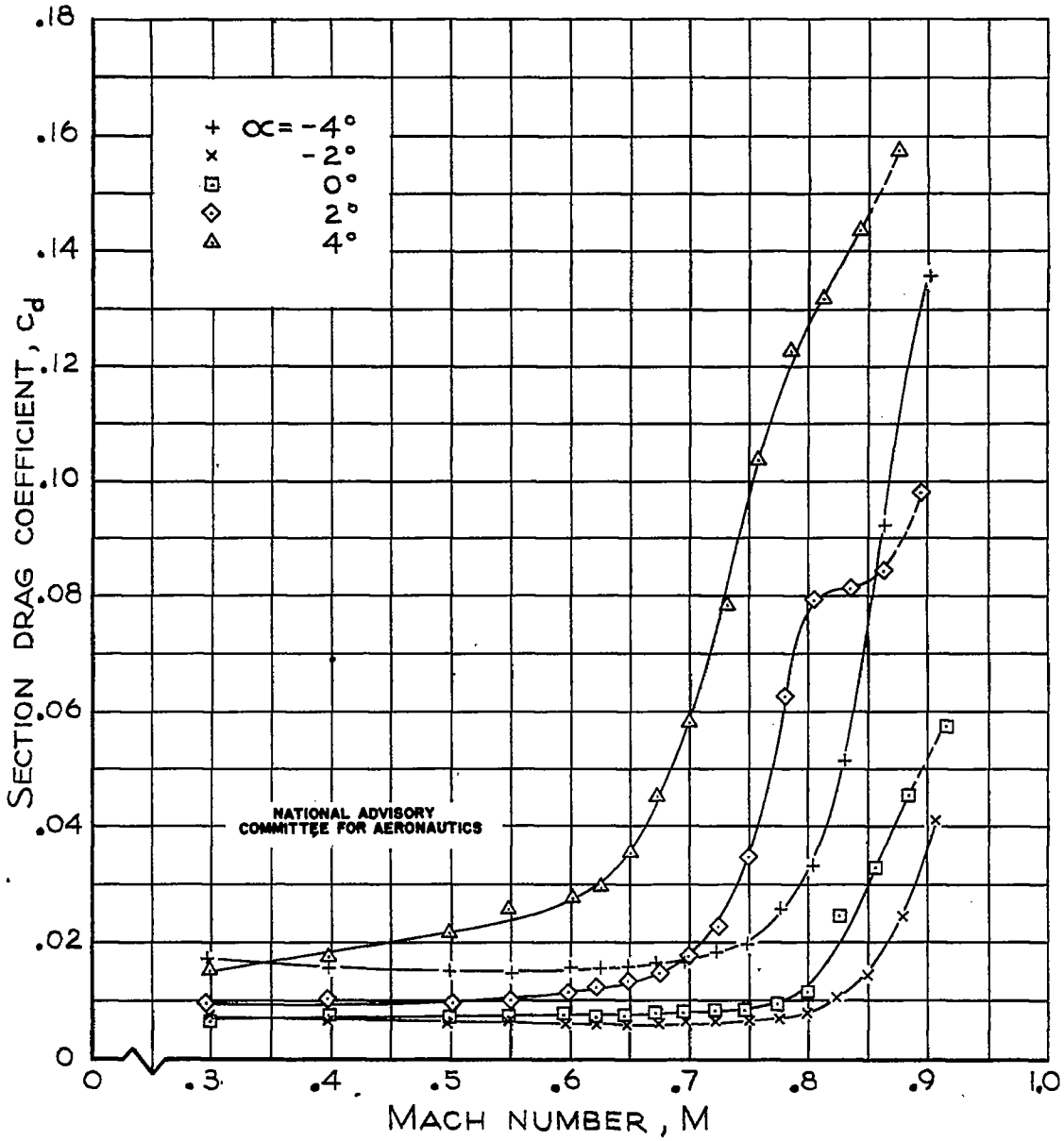

(a) $\delta_f = 4.9°$

FIGURE 7.- THE VARIATION OF SECTION DRAG COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

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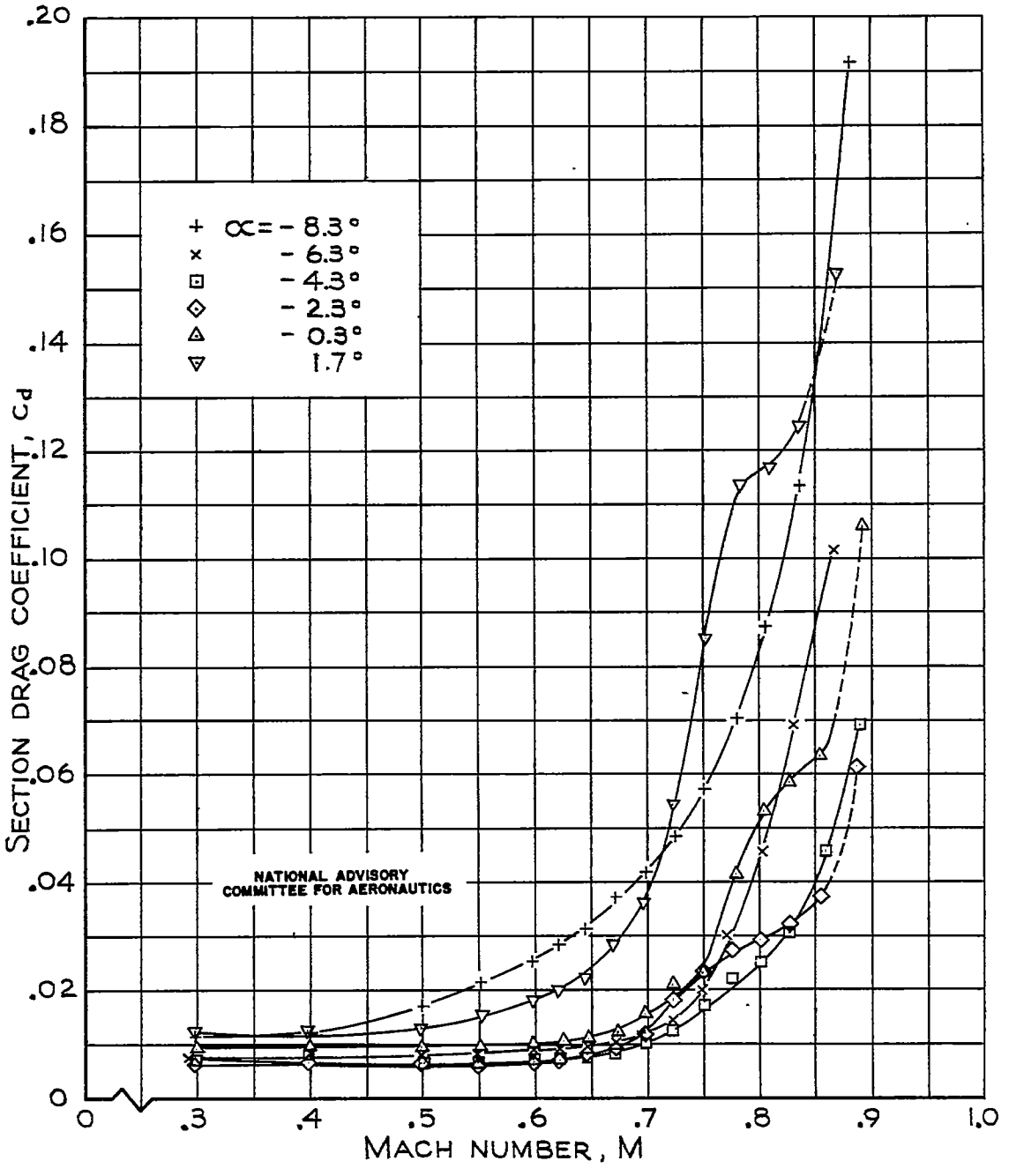

(b) $\delta_f = 10.2°$

FIGURE 7.-CONCLUDED. NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

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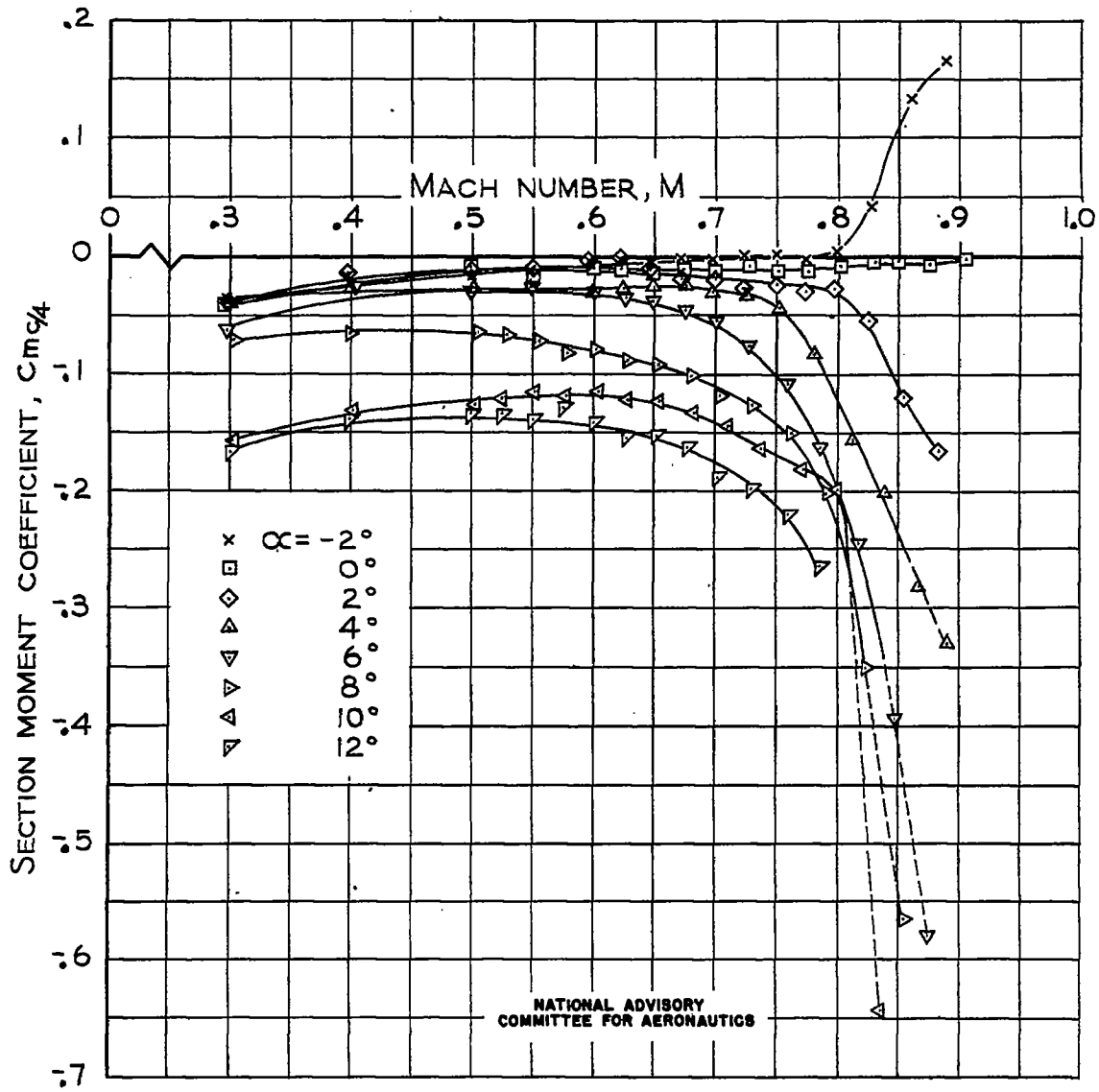

FIGURE 8.- THE VARIATION OF SECTION MOMENT COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFO[redacted]

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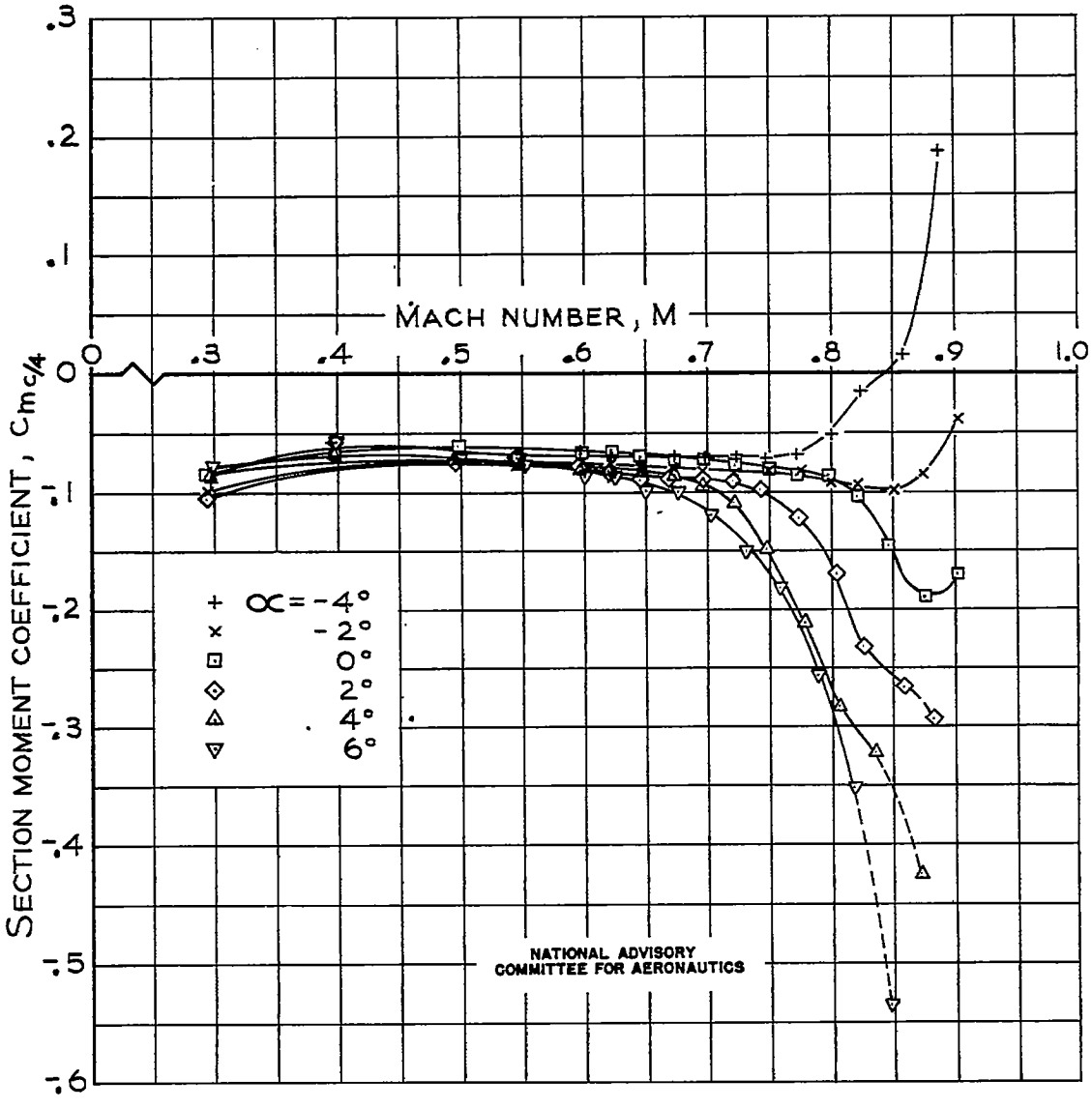

(a) $\delta_f = 5.5°$

FIGURE 9.- THE VARIATION OF SECTION MOMENT COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

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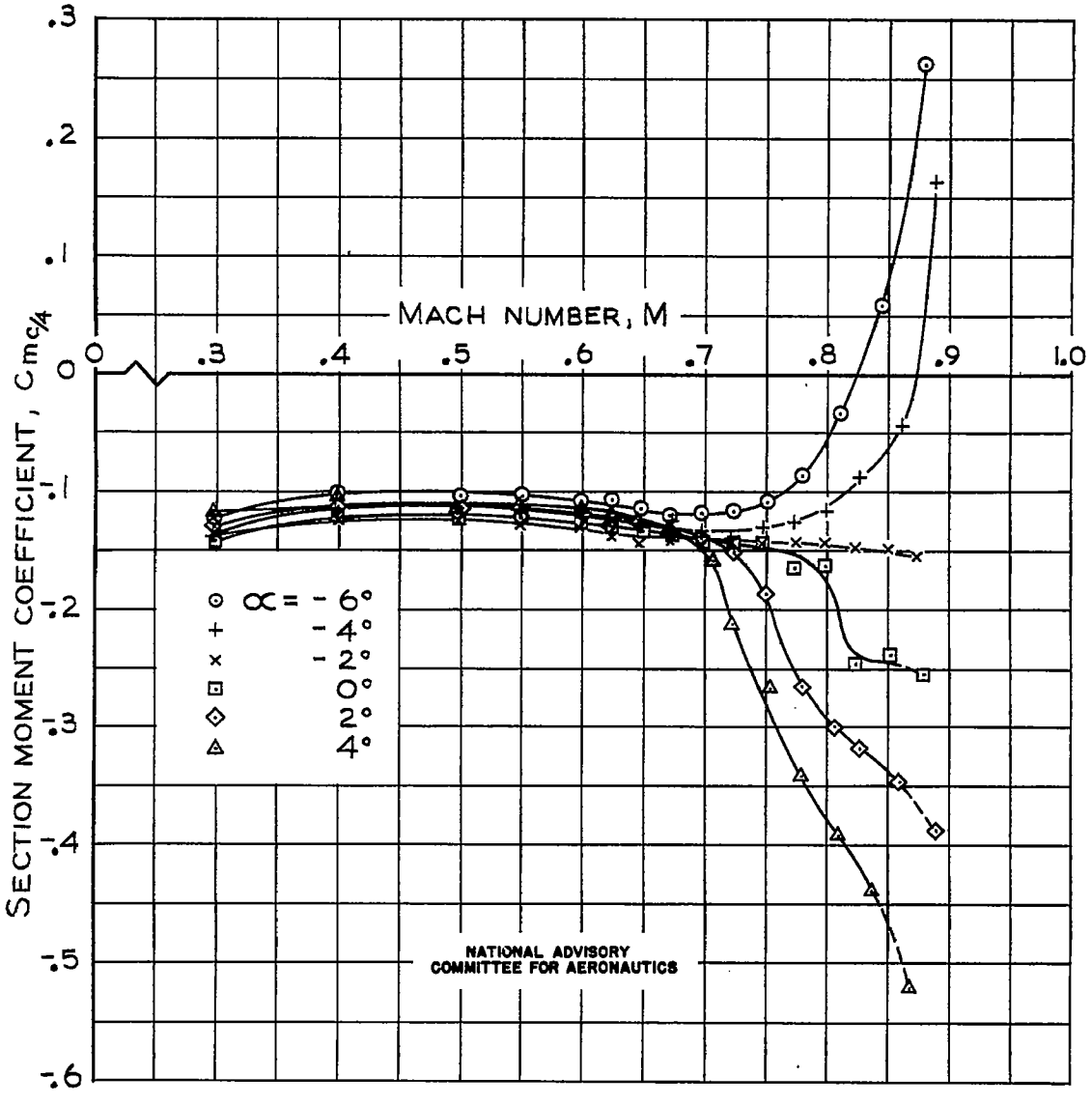

(b) $\delta_f = 10.5°$

FIGURE 9.- CONCLUDED. NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

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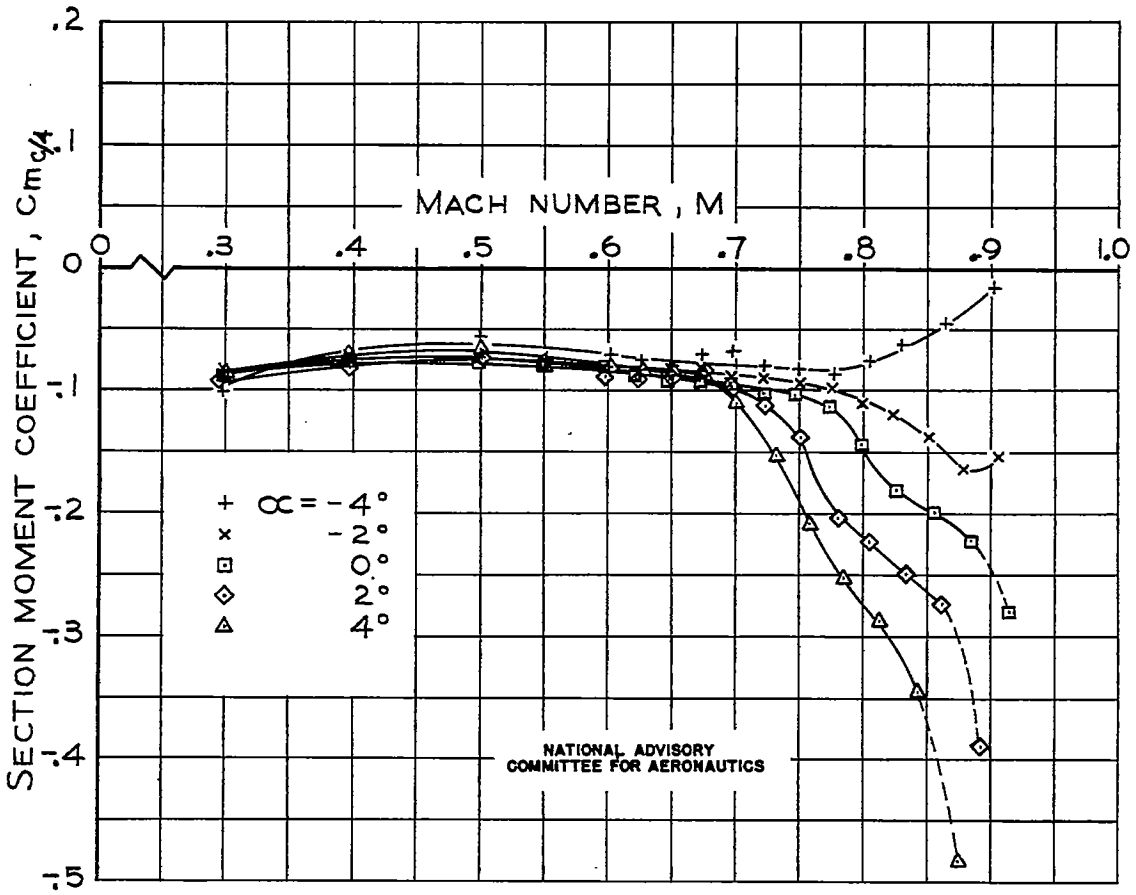

(a) $\delta_f = 4.9°$

FIGURE 10.- THE VARIATION OF SECTION MOMENT COEFFICIENT WITH MACH NUMBER FOR THE NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

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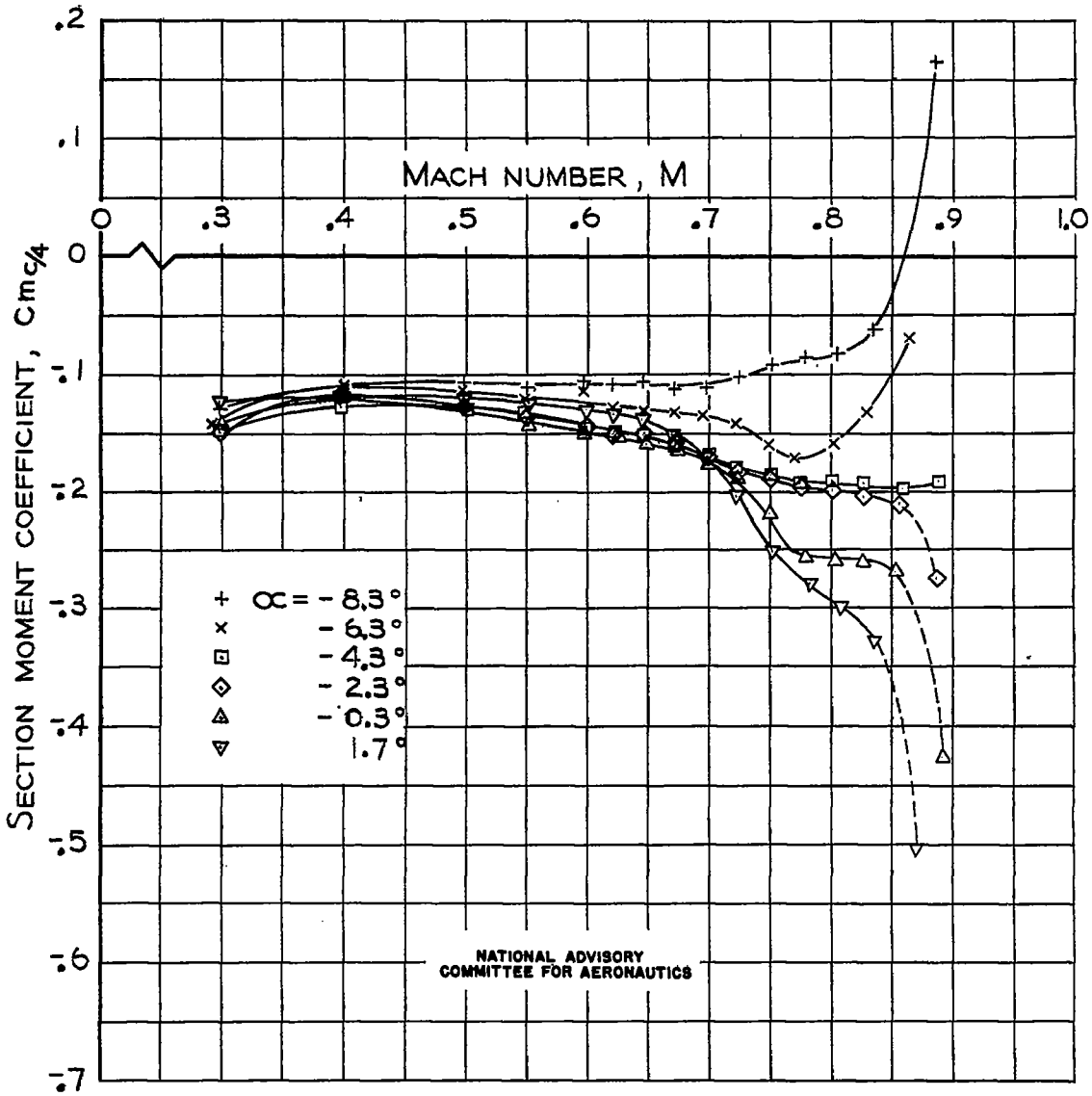

(b) $\delta_f = 10.2°$

FIGURE 10.- CONCLUDED. NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

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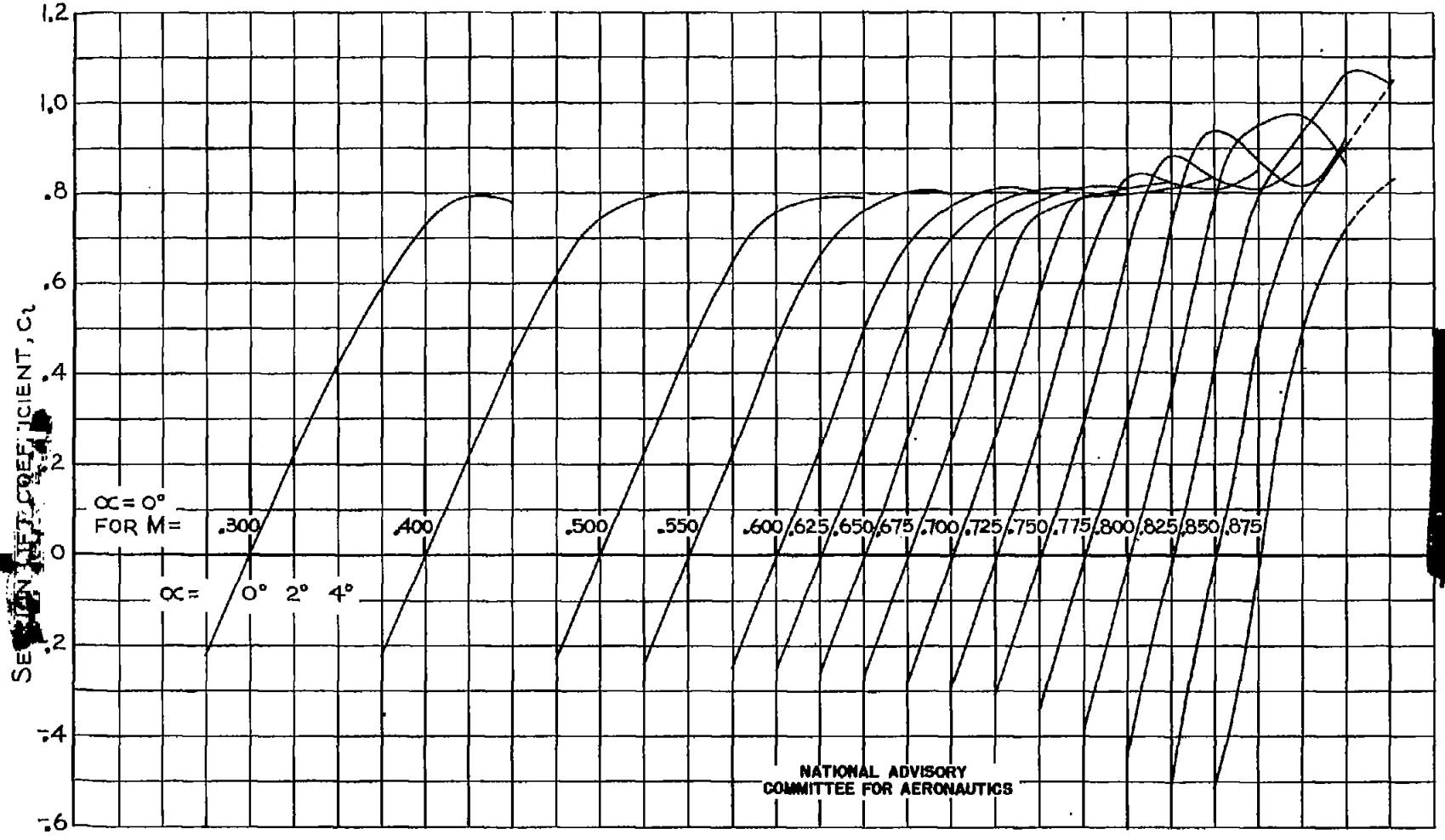

FIGURE 11. - THE VARIATION OF SECTION LIFT COEFFICIENT WITH ANGLE OF ATTACK FOR THE NACA 0006 AIRFOIL.

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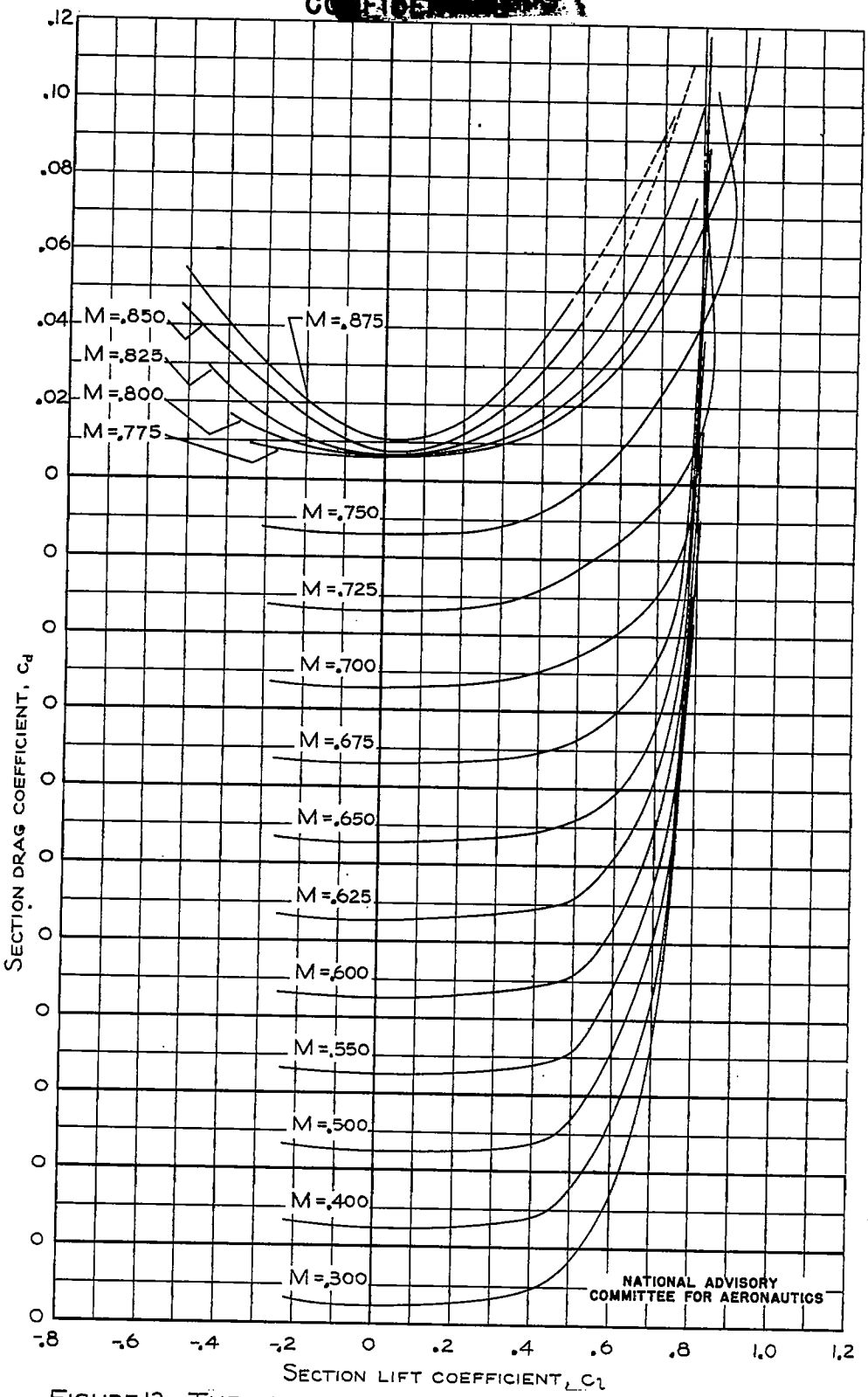

FIGURE 12.- THE VARIATION OF SECTION DRAG COEFFICIENT WITH LIFT COEFFICIENT FOR THE [redacted] 0006 AIRFOIL.

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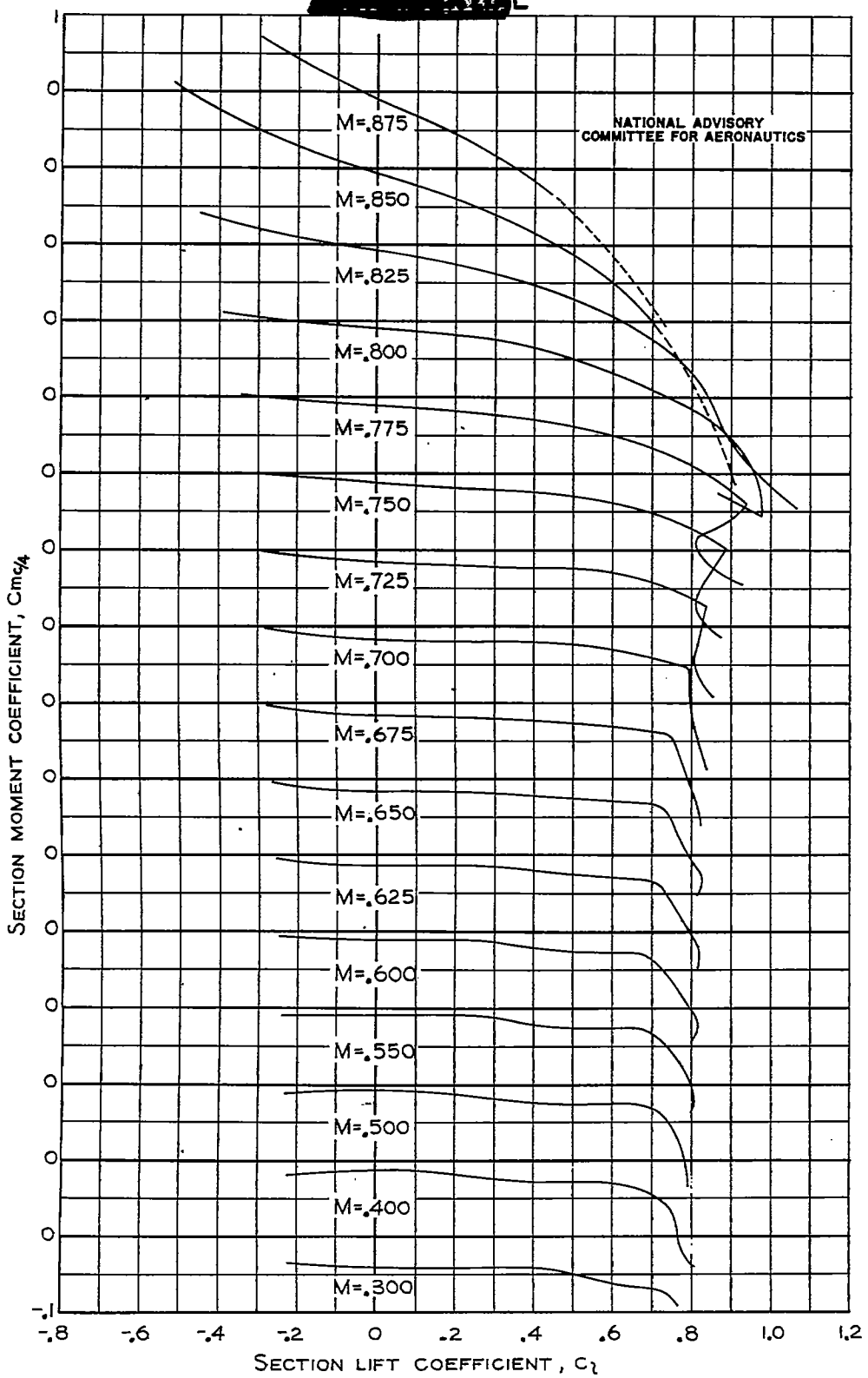

FIGURE 13.- THE VARIATION OF SECTION MOMENT COEFFICIENT WITH LIFT COEFFICIENT FOR [redacted] NACA [redacted] FOIL.

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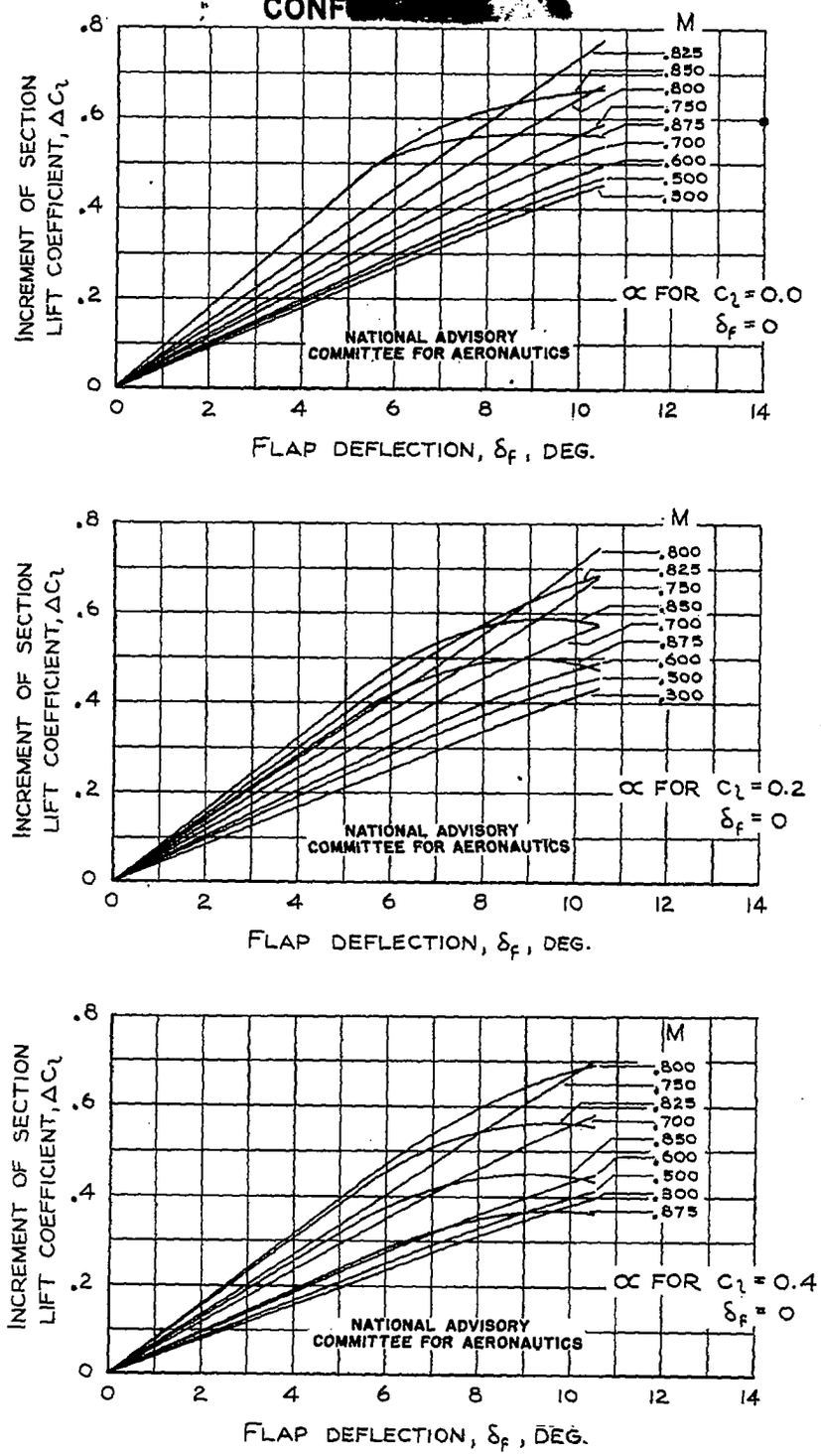

FIGURE 14.- THE VARIATION OF INCREMENT OF SECTION LIFT COEFFICIENT WITH FLAP DEFLECTION AT VARIOUS MACH NUMBERS FOR SEVERAL ANGLES OF ATTACK OF THE NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

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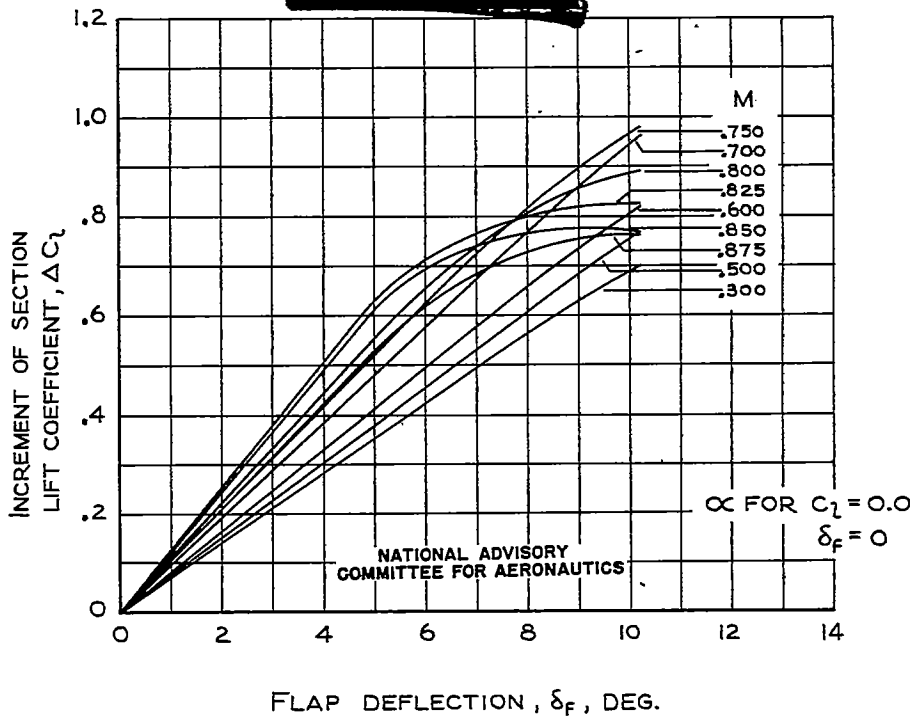

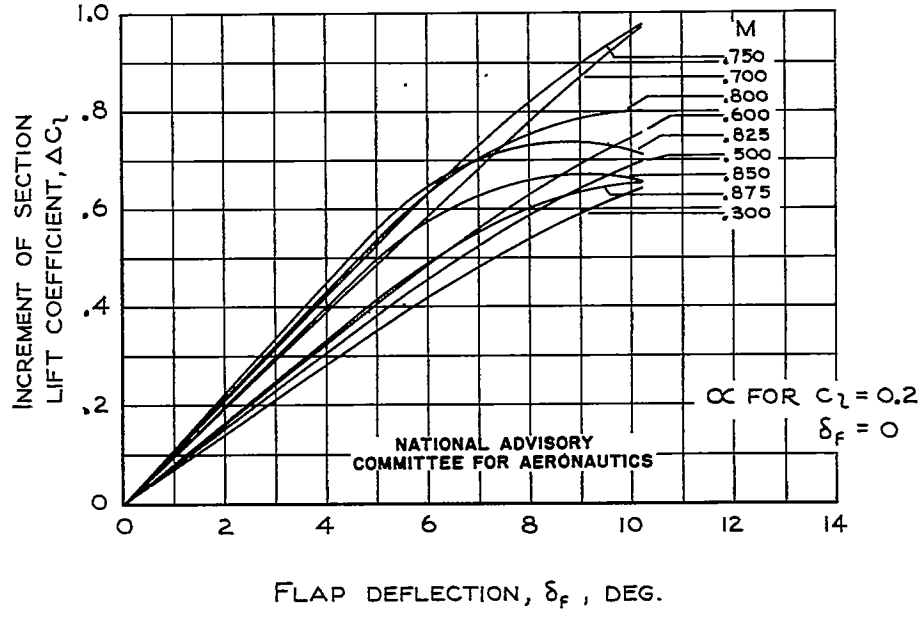

FIGURE 15.- THE VARIATION OF INCREMENT OF SECTION LIFT COEFFICIENT WITH FLAP DEFLECTION AT VARIOUS MACH NUMBERS FOR TWO ANGLES OF ATTACK OF THE NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

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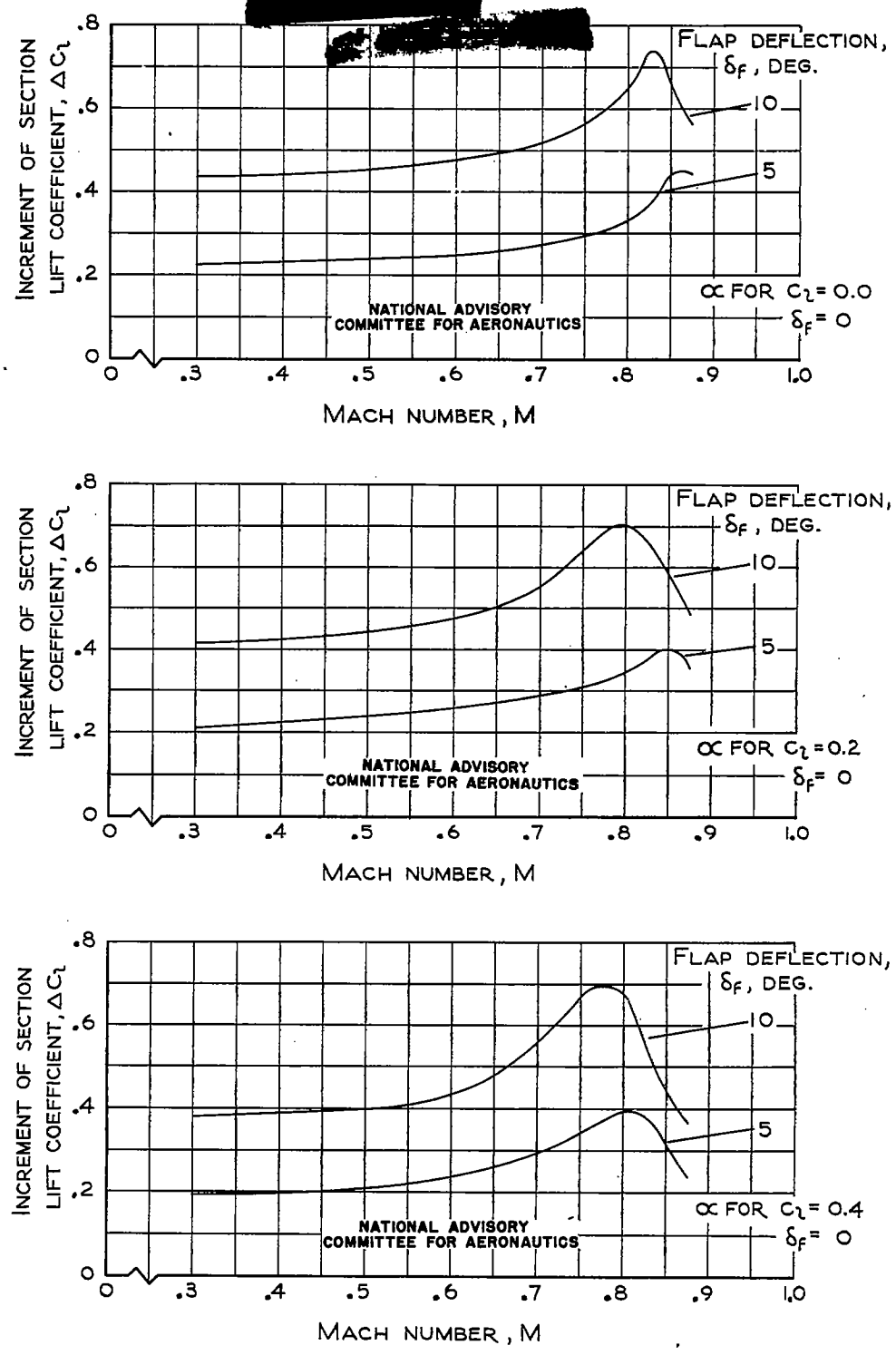
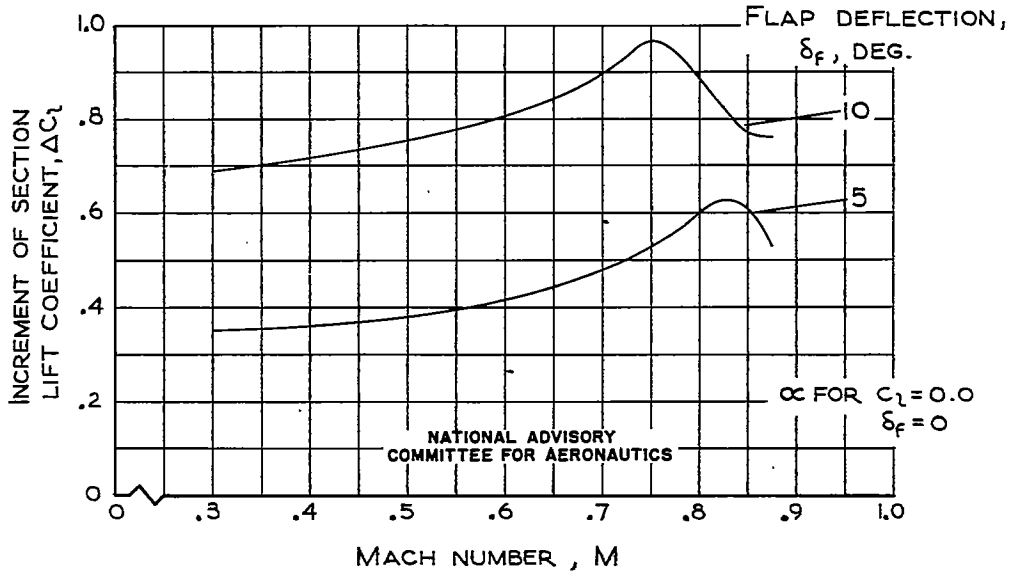


FIGURE 16.- THE VARIATION OF INCREMENT OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR VARIOUS FLAP DEFLECTIONS AND ANGLES OF ATTACK OF THE NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

[redacted]



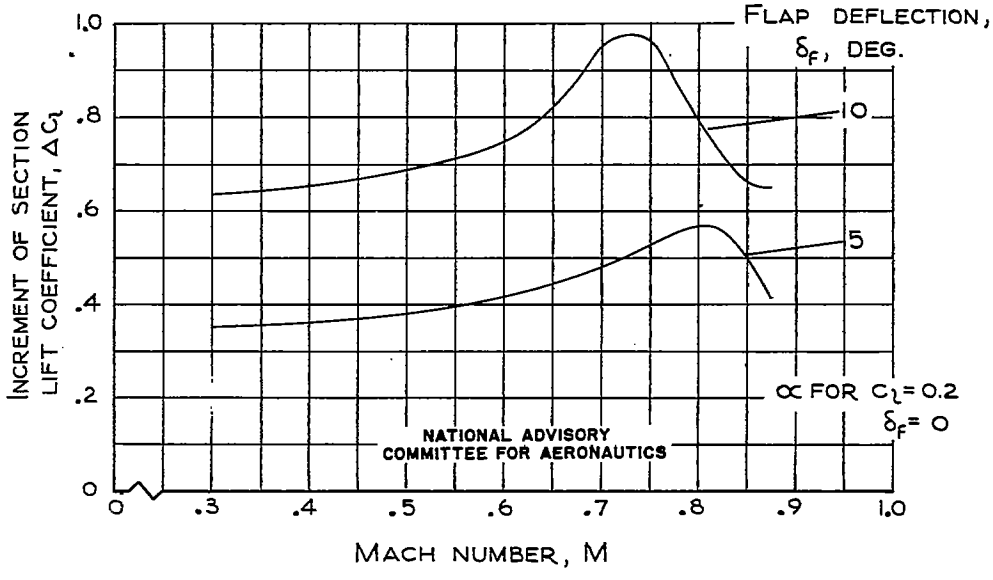


FIGURE 17.- THE VARIATION OF INCREMENT OF SECTION LIFT COEFFICIENT WITH MACH NUMBER FOR VARIOUS FLAP DEFLECTIONS AND ANGLES OF ATTACK OF THE NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

[redacted]

CONFI[redacted]

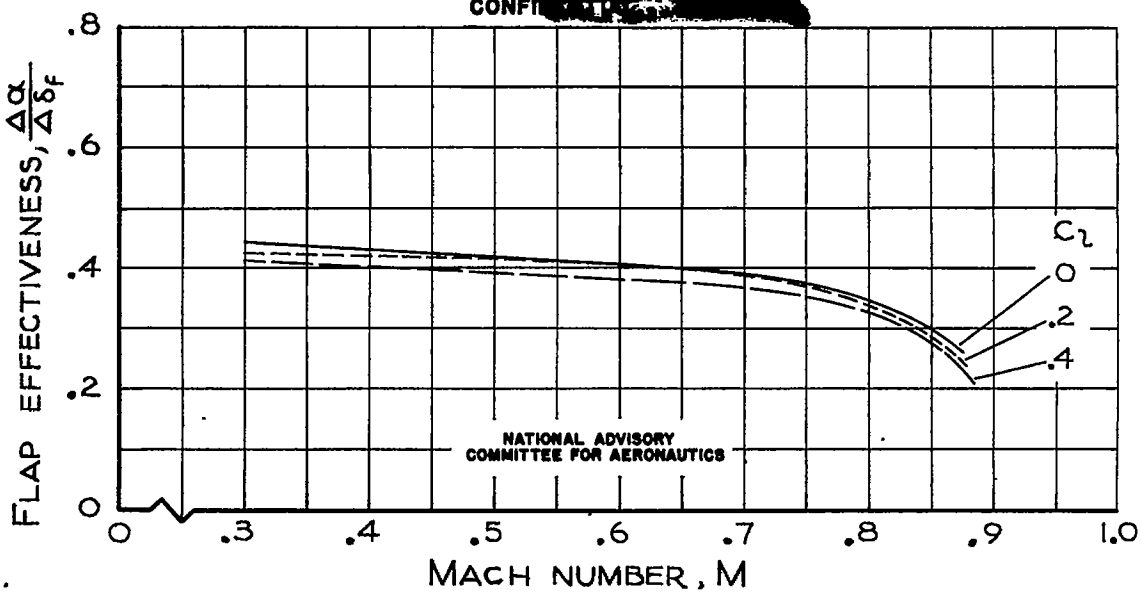


FIGURE 18.- THE VARIATION OF FLAP EFFECTIVENESS WITH MACH NUMBER AT VARIOUS LIFT COEFFICIENTS FOR THE NACA 0006 AIRFOIL WITH 15-PERCENT-CHORD PLAIN FLAP.

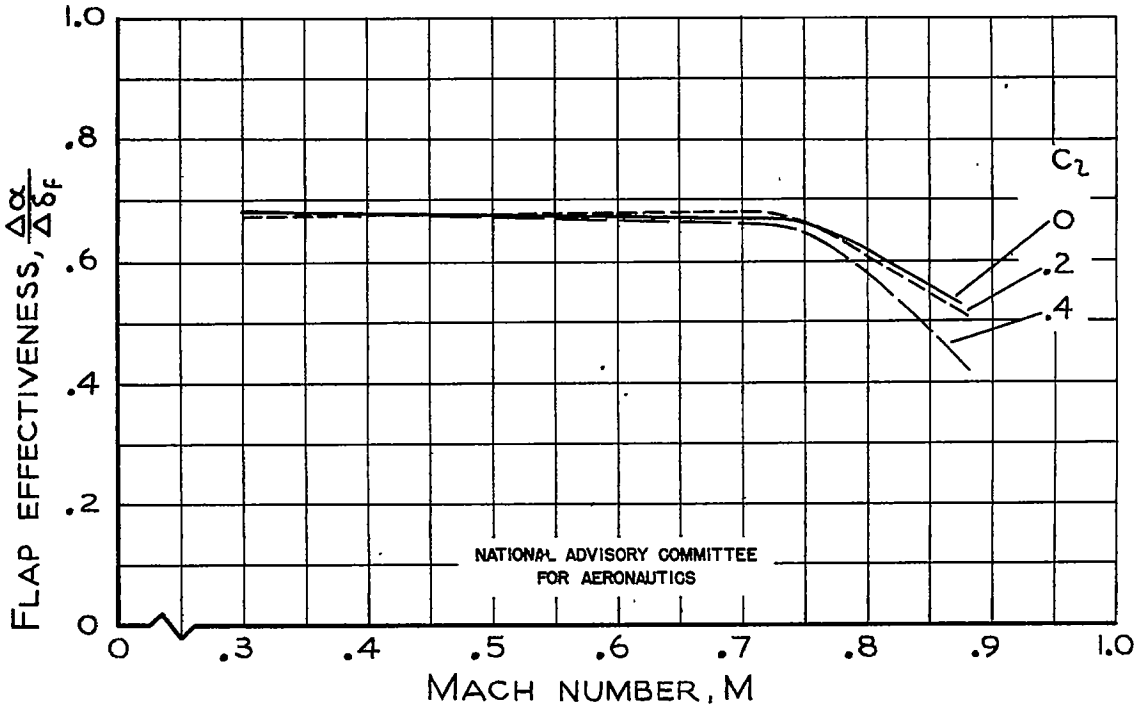


FIGURE 19.- THE VARIATION OF FLAP EFFECTIVENESS WITH MACH NUMBER AT VARIOUS LIFT COEFFICIENTS FOR THE NACA 0006 AIRFOIL WITH 35-PERCENT-CHORD PLAIN FLAP.

CONF[redacted]

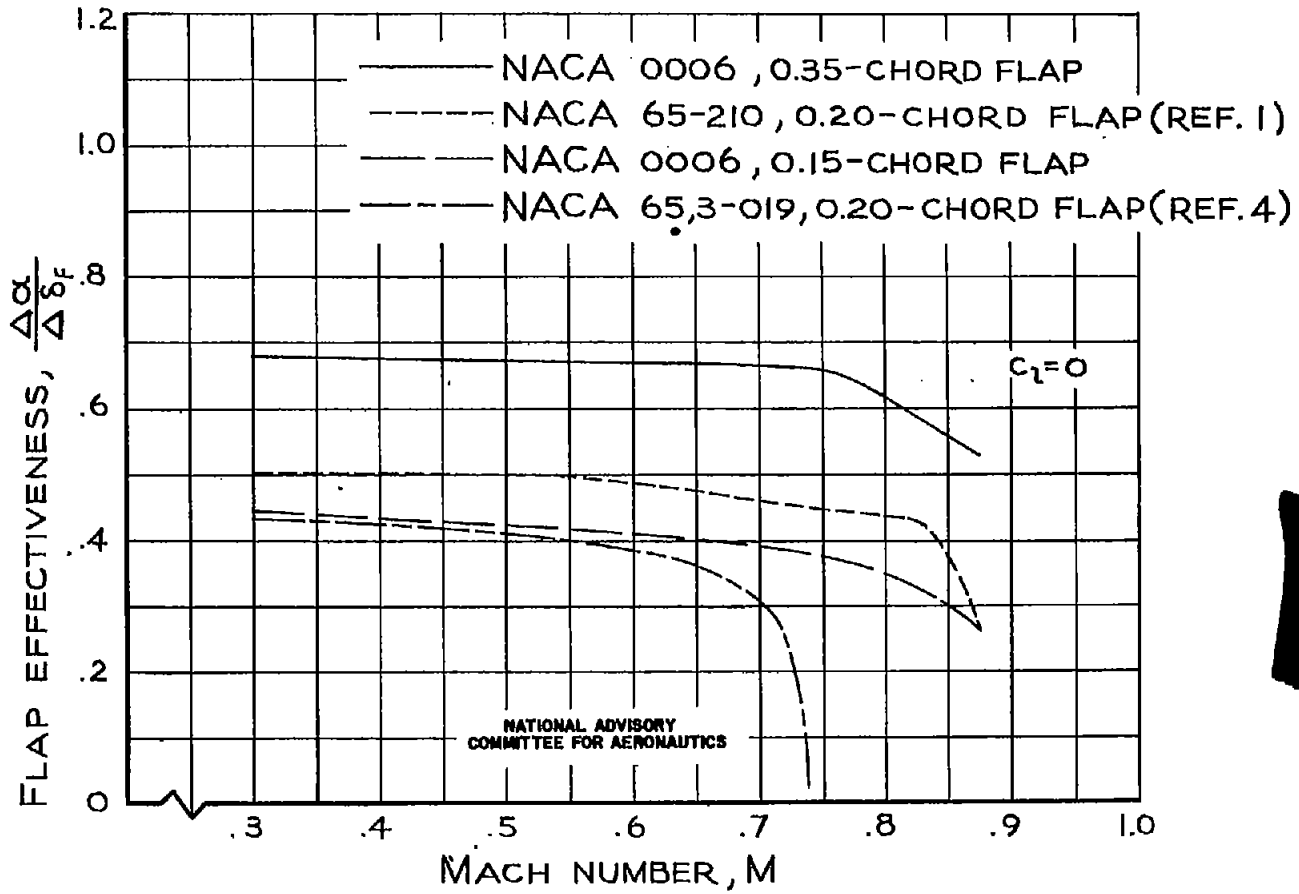


FIGURE 20.- COMPARISON OF THE VARIATION OF FLAP EFFECTIVENESS WITH MACH NUMBER AT ZERO LIFT COEFFICIENT FOR VARIOUS NACA AIRFOILS WITH PLAIN FLAP.