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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS OF PLAIN AND BALANCED FLAPS ON AN NACA 0009 ELLIPTICAL SEMISPAN WING

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SUMMARY

A series of force tests have been made in the Langley 4- by 6-foot vertical tunnel on an NACA 0009 elliptical semispan wing equipped with a flap either 50 percent of the wing area or 30 percent of the wing area. The 30-percent-area flap was tested as a plain flap and with 35-percent-flap-chord and 50-percent-flap-chord elliptical-nose overhangs.

Results of the investigation indicated that the lift-curve slope increased at large angles of attack for small flap deflections. This tendency was found to be characteristic of wings of low aspect ratio. The effects of the gap and aerodynamic balance on the lift-curve slope were small and inconsistent. The hinge-moment characteristics obtained in the present investigation indicated that, although the effect of the gap was small, the rate of change of hinge-moment coefficient with angle of attack increased positively and the rate of change of hinge-moment coefficient with flap deflection increased negatively when the gap was sealed.

Calculated lift-curve slopes, modified by the Jones edge-velocity correction, were higher than measured values except for one case calculated from extrapolated section data. Calculated values of hinge-moment parameters were always considerably more negative than measured values when determined from lifting-line-theory solutions and

modified by the Jones edge-velocity correction. Application of a streamline-curvature correction, derived for elliptical wings, brought the calculated values of the variation of hinge-moment coefficient with angle of attack into good agreement with measured values. At the present time, however, no streamline-curvature correction is available for the variation of hinge-moment coefficient with flap deflection.

INTRODUCTION

The problem of correlating section and finite-span control-surface data is being extensively investigated by the NACA. Results of correlations indicate that close agreement between experiment and theory concerning the lift-curve slope has been obtained by the application of the Jones edge-velocity correction (reference 1) to the Prandtl lifting-line theory.

Predictions of hinge-moment parameters from section data by means of lifting-line theory, however, are considerably in error; the effect of aspect ratio is not fully accounted for by the lifting-line method of calculation. From previous investigations (references 2 and 3), a streamline-curvature correction was derived by lifting-surface-theory calculations for wings of elliptical plan form. This correction brought the calculated values of the slopes of the curves of hinge-moment coefficients against angle of attack into closer agreement with experimental results. At present, however, no streamline-curvature correction is available for the variation of hinge-moment coefficient with flap deflection.

The Jones edge-velocity correction to lift in reference 1 was derived for elliptical wings of any aspect ratio and the hinge-moment corrections of reference 3 were derived for elliptical wings of aspect ratios 3 and 6.

In order to make a direct comparison of the measured lift and hinge-moment parameters with those calculated from section data for a model in three-dimensional flow, tests were made of an NACA 0009 elliptical semispan wing. A similar investigation has been reported in reference 4 and other investigations are now in progress on models having different configurations.

SYMBOLS

The results are given in the form of standard NACA coefficients of forces and moments. The coefficients and symbols used are defined as follows:

C_L lift coefficient (L/qS)

C_m pitching-moment coefficient (M/qSc')

C_h flap hinge-moment coefficient $(H/q\bar{c}_f{}^2 b_f)$

C_D drag coefficient (D/qS)

c_h flap section hinge-moment coefficient $(h/qc_f{}^2)$

c_l section lift coefficient (l/qc)

where

L twice lift of semispan model

D twice drag of semispan model

H twice flap hinge moment of semispan model

M twice pitching moment of semispan model about quarter-chord point of mean aerodynamic chord (28.90-percent point of root chord)

h flap section hinge moment

l section lift

q dynamic pressure $(\rho V^2/2)$

S twice area of semispan model

b twice span of semispan model

b_f twice flap span of semispan model

$\bar{c}_f$ root-mean-square chord of flap

c_f section flap chord

ρ mass density of air

V velocity

c' mean aerodynamic chord (M.A.C.) $\left(\frac{2}{S}\int_0^{\frac{b}{2}} c^2\, db\right)$

and

c chord of airfoil with flap neutral

c_b chord of overhang

α angle of attack of semispan model

α_o angle of attack of airfoil of infinite aspect ratio

δ flap deflection relative to airfoil; positive when trailing edge is deflected down

A aspect ratio (b^2/S)

$$C_{L_\alpha} = \left(\frac{\partial C_L}{\partial \alpha}\right)_\delta$$

$$\alpha_\delta = \left(\frac{\partial \alpha}{\partial \delta}\right)_{C_L} \text{ or } \left(\frac{\partial \alpha_o}{\partial \delta}\right)_{c_l}$$

$$C_{h_\alpha} = \left(\frac{\partial C_h}{\partial \alpha}\right)_\delta$$

$$C_{h_\delta} = \left(\frac{\partial C_h}{\partial \delta}\right)_\alpha$$

$$c_{h_\alpha} = \left(\frac{\partial c_h}{\partial \alpha_o}\right)_\delta$$

$$c_{h_\delta} = \left(\frac{\partial c_h}{\partial \delta}\right)_{\alpha_o}$$

$$c_{l_\alpha} = \left(\frac{\partial c_l}{\partial \alpha_o}\right)_\delta$$

The subscripts outside the parentheses indicate the factors held constant in determining the parameters.

APPARATUS, MODEL, AND TESTS

All tests were made in the Langley 4- by 6-foot vertical tunnel (reference 5) modified as described in reference 6. The elliptical semispan surface (figs. 1 and 2) was constructed of laminated mahogany and conformed to the NACA 0009 profile (table I). In the present investigation, two sizes of flaps were tested. The larger one had an area 50 percent of the wing area (0.50 area) and had a flap chord 50 percent of the wing chord throughout the span. This flap was tested as a plain flap (radius overhang). Since the wing was elliptical, the smaller flap could not feasibly be made a constant percentage of the airfoil chord throughout the span. This flap was therefore made 30 percent of the wing area (0.30 area) and was tested as a plain flap and with elliptical-nose overhangs of 35 percent ($0.35c_f$) and 50 percent ($0.50c_f$) of the flap chord. Ordinates for the elliptical overhangs are given in table II.

The trailing-edge angle of the model measures 11.1° whereas the theoretical trailing-edge angle measures 11.6° for the NACA 0009 airfoil.

The wing was installed as a reflection-plane model (reference 7) by mounting the model with its root section adjacent to one of the tunnel walls. This system is therefore analogous to mounting a 6-foot-span wing in an 8- by 6-foot tunnel. The model was supported entirely by the balance frame so that all forces and moments acting on the model could be measured. The gap between the tunnel wall and the root section was about 1/16 inch.

The greater part of the flap hinge moment (transmitted through a torque tube) was measured by applying weights at a known lever arm outside the tunnel; the final increment was measured with a calibrated dial attached to a long flexible torque rod.

Flap deflections were set with an electric control-surface position indicator.

Each model configuration was tested with the gap open and with the gap sealed (figs. 1 and 2). The seal was made of impregnated fabric. The model was generally tested throughout an angle-of-attack range of about ±20° and throughout a flap range of 0° to 30°.

A dynamic pressure of 13 pounds per square foot, which corresponds to an airspeed of 71 miles per hour at standard sea-level conditions, was maintained for all tests. The test Reynolds number was 1.43×10^6 based on a mean aerodynamic chord of 25.81 inches. The effective Reynolds number (for maximum lift coefficients) was approximately 2.76×10^6 based on a turbulence factor of 1.93 for this tunnel.

All data have been corrected for tare effects caused by fittings extending beyond the airfoil contour. No correction was made for leakage around the model support. The following tunnel-wall corrections were added to the data:

$$\Delta\alpha = 2.184C_{L_T} - 0.41C_{L_f} \text{ (for 0.30-area flap)}$$

$$\Delta C_h = KC_{L_T} \text{ (for 0.30-area flap)}$$

$$\Delta\alpha = 2.184C_{L_T} \text{ (for 0.50-area flap)}$$

$$\Delta C_h = 0.0146C_{L_T} \text{ (for 0.50-area flap)}$$

$$\Delta C_L = -0.024C_{L_T} \text{ (for both flaps)}$$

$$\Delta C_D = 0.031C_{L_T}^2 \text{ (for both flaps)}$$

$$\Delta C_m = 0.0078C_{L_T} \text{ (for both flaps)}$$

where C_{L_T} is the total uncorrected lift coefficient, C_{L_f} the uncorrected lift coefficient due to flap deflection, and K a constant depending on the chord of the overhang used. Values of K are as follows:

Overhang	K
Radius	0.0145
$0.35c_f$	.0113
$.50c_f$	.0080

For methods of calculating corrections for reflection-plane models, see reference 7.

PRESENTATION OF DATA

The aerodynamic characteristics of the model tested are presented in figures 3 to 7. Symbols with flags denote check points. In some cases, severe oscillations that followed a sudden stall prevented the continuation of the test throughout the proposed angle-of-attack range. Severe oscillation also occurred in testing the flap with overhangs so that only part of the flap range was tested.

Section hinge-moment parameters c_{h_α} and c_{h_δ} and the lift-effectiveness parameter α_δ for plain flaps on the NACA 0009 airfoil are plotted in figures 8 and 9, respectively, as functions of the ratio of flap chord to airfoil chord.

DISCUSSION

Lift

The lift curves of figures 3 to 6 are linear over a small angle-of-attack range with a general tendency existing for C_{L_α} to increase at large angles of attack for small flap deflections. This tendency is characteristic of wings of low aspect ratios and may vary in degree with the wing plan form. Reference 12 clearly shows the increase in the lift-curve slope at high angles of attack for wings of low aspect ratios. The lift curves generally become nonlinear with large flap deflections. Sealing the gap generally increased C_{L_α} but the effect of the aerodynamic balance on C_{L_α} is inconsistent (table III). Comparison of results indicates that C_{L_α} changes only slightly with the configurations tested.

Figures 3 to 6 also indicate that the increment of lift due to flap deflection is maintained to 15° deflection for both wings throughout most of the angle-of-attack range, after which the increment generally becomes smaller with increase in deflection. For the 0.50-area flap, increments of lift due to large flap deflections at high negative angles of attack are considerably larger than those at high positive angles of attack. For the smaller flap (radius overhang), however, the increments are only slightly larger at high negative angles of attack than at high positive angles. At large positive angles of attack and flap deflections, both flaps give about the same maximum lift increments.

Table III shows that sealing the gap generally increased the effectiveness α_δ. For the smaller flap (0.30 area) with gap sealed, α_δ decreased slightly with increase in aerodynamic balance. When the gap remained open, however, the effectiveness increased with overhang.

Hinge Moment

In two-dimensional flow the hinge-moment curves for plain flaps on the NACA 0009 airfoil exhibit linearity throughout a large angle-of-attack and flap-deflection range, gap sealed and open. Figures 3 to 6 illustrate that the hinge-moment data of the present elliptical wing (plain flap) show less linearity than section data. The hinge-moment curves of the rectangular semispan wing presented in reference 4 were found to possess even less linearity than the hinge-moment data of the present model.

With the $0.50c_f$ overhang, overbalance occurs throughout most of the angle-of-attack range with large deflections. Sealing the gap generally lessens the tendency to overbalance. Figure 7 contains the hinge-moment parameters as affected by overhang for the 0.30-area flap. Although the effect of the gap may be considered small, the indications are that Ch_α increases positively and Ch_δ increases negatively when the gap is sealed.

Drag and Pitching Moment

The drag and pitching-moment characteristics are shown in figures 3 to 6. The drag coefficients are not to be considered absolute because of an unknown tunnel correction.

COMPARISON WITH DATA IN TWO-DIMENSIONAL FLOW

A collection of section data for plain flaps (references 6, 8 to 11, and unpublished data), obtained from the Langley 4- by 6-foot vertical tunnel, was used in preparing the hinge-moment-parameter chart shown in figure 8. Part of the data in figure 8 were not corrected for tunnel-wall effects when originally reported (reference 8). The data as presented in figure 8, however, now include a streamline-curvature tunnel correction discussed in reference 8 and derived by methods similar to those used in reference 7. The parameters were measured over a small angle-of-attack range and over a small flap-deflection range. (Reference 3 explains the significance of measuring the hinge-moment parameters in this manner in order to compute finite-span data). Since any difference between the sealed-gap and open-gap data was difficult to ascertain and since the data appeared slightly erratic, a mean curve was established through the points for c_{h_α} and c_{h_δ}. The same section hinge-moment parameters were therefore used in calculating the finite-span characteristics for the model with sealed gap and open gap. The data available for the hinge-moment characteristics of the flaps with overhangs for the NACA 0009 airfoil section in two-dimensional flow were insufficient to justify an attempt to calculate the characteristics for the finite-span model with flaps having overhang balance. The section data values for c_{l_α} and α_δ were obtained from references 6, 8 to 11, and unpublished data. As presented herein, the curve of α_δ plotted against c_f/c (fig. 9) has been corrected for jet-boundary effects.

The lift and hinge-moment parameters were calculated for the finite-span model from two-dimensional data by the methods suggested in references 1 and 3. A complete list of the measured and calculated lift and hinge-moment parameters for the elliptical semispan wing is shown in table III.

In all cases the value of C_{L_α}, calculated according to lifting-line theory and modified by the Jones edge-velocity correction, was larger than the measured value, with the exception of one case for which the section data was obtained by extrapolation. It seems that the present edge-velocity correction is not sufficient and that an additional correction is required.

Measured and calculated values of α_δ were in better agreement for the 0.50-area flap than for the 0.30-area flap. The calculated values were obtained from lifting-line-theory solutions.

Table III indicates that the values of the hinge-moment parameters, calculated on the basis of the lifting-line theory and modified by the Jones edge-velocity correction, are considerably more negative than the measured values. (In order to compute C_{h_δ} for the 0.30-area flap it was necessary to extrapolate the span-load-distribution data of reference 13 for a wing of aspect ratio equal to 3.) Application of the streamline-curvature correction, derived for the particular model under investigation according to references 2 and 3, brought the calculated values of C_{h_α} into good agreement with measured values. As yet, no aspect-ratio correction has been determined for C_{h_δ}.

CONCLUSIONS

From data obtained in tests conducted of an NACA 0009 elliptical semispan wing having a flap of either 50 percent of the wing area or 30 percent of the wing area, a comparison of measured lift and hinge-moment characteristics was made with the characteristics calculated from section data for a similar airfoil. The following conclusions were drawn from the investigation:

1. The slope of the lift curve generally increased at large angles of attack for small flap deflections. This tendency was characteristic of wings of low aspect ratios. The effects of the gap and aerodynamic balance on the lift-curve slope were small and inconsistent.

2. Although the increments of flap lift at negative angles of attack due to deflection of the larger flap were greater than those due to deflection of the smaller flap, the increments obtained with the larger flap decreased more rapidly at positive angles of attack. At large positive angles of attack and flap deflections, both flaps gave about the same maximum lift increment.

3. Sealing the gap generally increased the effectiveness α_δ whereas an elliptical overhang balance tended to decrease the effectiveness with gap sealed and increase it with gap open. The effect of the gap was nevertheless small.

4. Although the effect of the gap was not large, the indications were that the rate of change of hinge-moment coefficient with angle of attack increased positively and the rate of change of hinge-moment coefficient with flap deflection increased negatively when the gap was sealed.

5. Calculated lift-curve slopes were always higher than measured slopes, except for one value that was calculated from extrapolated section data. Since the lift-curve slopes (calculated according to lifting-line theory and modified by the Jones edge-velocity correction) are higher than measured values, an additional correction appears necessary.

6. A comparison of the calculated and measured hinge-moment parameters indicated that the calculated values were considerably more negative when calculated on the basis of lifting-line-theory solutions and modified by the Jones edge-velocity correction. The calculated values of the variation of the hinge-moment coefficient with angle of attack, however, very nearly approached the measured values when altered by a streamline-curvature correction that was derived from lifting-surface theory for the particular model under investigation.

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TABLE I

ORDINATES FOR NACA 0009 AIRFOIL

[All dimensions in percent airfoil chord]

Station	Ordinates	
	Upper	Lower
0	0	0
1.25	1.42	-1.42
2.5	1.96	-1.96
5.0	2.67	-2.67
7.5	3.15	-3.15
10	3.51	-3.51
15	4.01	-4.01
20	4.30	-4.30
25	4.46	-4.46
30	4.50	-4.50
40	4.35	-4.35
50	3.97	-3.97
60	3.42	-3.42
70	2.75	-2.75
80	1.97	-1.97
90	1.09	-1.09
95	.61	-.61
100	(.10)	(-.10)
100	0	0
L. E. radius: 0.89		

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TABLE II

ELLIPTICAL-OVERHANG PROFILE

[All dimensions in percent flap chord]

$0.35c_f$ overhang		$0.50c_f$ overhang	
Station	Ordinate	Station	Ordinate
0	0	0	0
.03	.48	.04	.48
.15	.96	.20	.96
.37	1.44	.43	1.44
.64	1.93	.84	1.93
.99	2.41	1.27	2.41
1.43	2.89	1.91	2.89
2.64	3.85	3.42	3.85
4.26	4.81	5.53	4.81
6.37	5.78	8.27	5.78
9.20	6.74	11.85	6.74
13.06	7.70	16.74	7.70
19.22	8.67	24.18	8.67
28.50	9.16	32.05	9.16
35.00	8.93	50.00	8.93

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TABLE III

PARAMETER VALUES FOR ELLIPTICAL WING WITH TWO SIZES OF FLAPS

$\frac{c_b}{c_f}$	Gap	Balance nose shape	C_{L_α} Measured	C_{L_α} Calculated (a)	α_δ Measured	α_δ Calculated	C_{h_α} Measured	C_{h_α} Calculated (a)	C_{h_α} Calculated (b)	C_{h_δ} Measured	C_{h_δ} Calculated (a)
0.50-area flap											
----	0.005c	Plain	0.050	[c]0.055	-0.74	[c]-0.76	-0.0042	[c]-0.0059	[c]-0.0039	-0.0078	[c]-0.0106
----	Sealed	Plain	.052	.057	-.75	-.78	-.0036	-.0059	-.0038	-.0080	-.0105
0.30-area flap											
----	0.005c	Plain	0.053	0.055	-0.55	-0.52	-0.0028	-0.0038	-0.0022	-0.0077	-0.0109
----	Sealed	Plain	.052	.057	-.63	-.55	-.0024	-.0039	-.0022	-.0079	-.0112
0.35	0.005c	Elliptical	.051	.052	-.60	------	-.0011	------	------	-.0056	--------
.35	Sealed	Elliptical	.054	.055	-.61	------	-.0010	------	------	-.0062	--------
.50	0.005c	Elliptical	.053	[c].052	-.60	------	.0007	------	------	-.0022	--------
.50	Sealed	Elliptical	.054	.057	-.60	------	.0007	------	------	-.0033	--------

[a]Computed from section data with edge-velocity correction (reference 1).

[b]Computed from section data with edge-velocity correction (reference 1) and with streamline-curvature correction (reference 3).

[c]Computed from extrapolated results of two-dimensional data.

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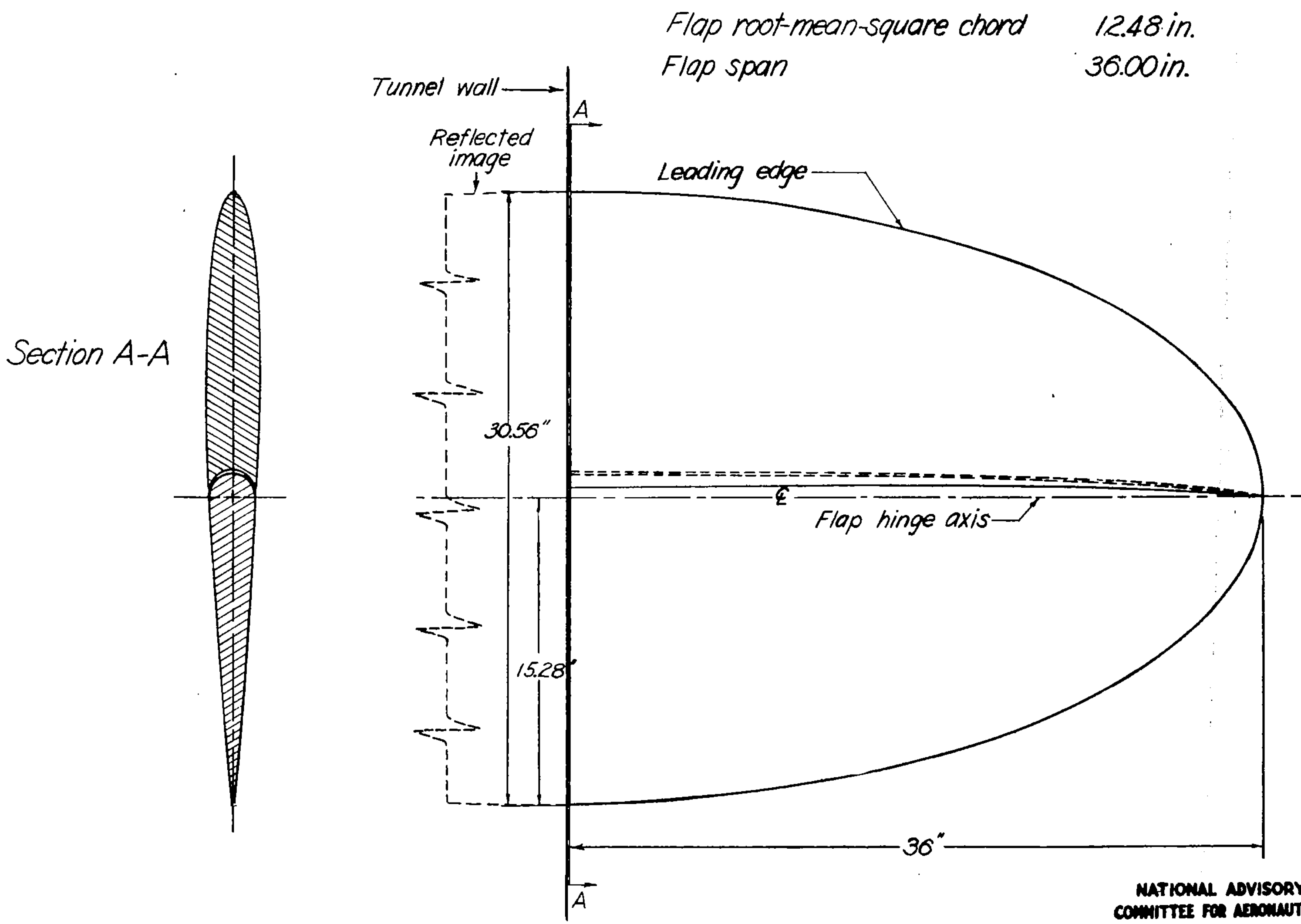

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Figure 1.- Details of elliptical semispan wing having a 0.50-area flap with plain overhang. The gap at the flap nose is open and 0.005c in width or sealed with impregnated fabric. NACA 0009 section; A=3; area=6 square feet.

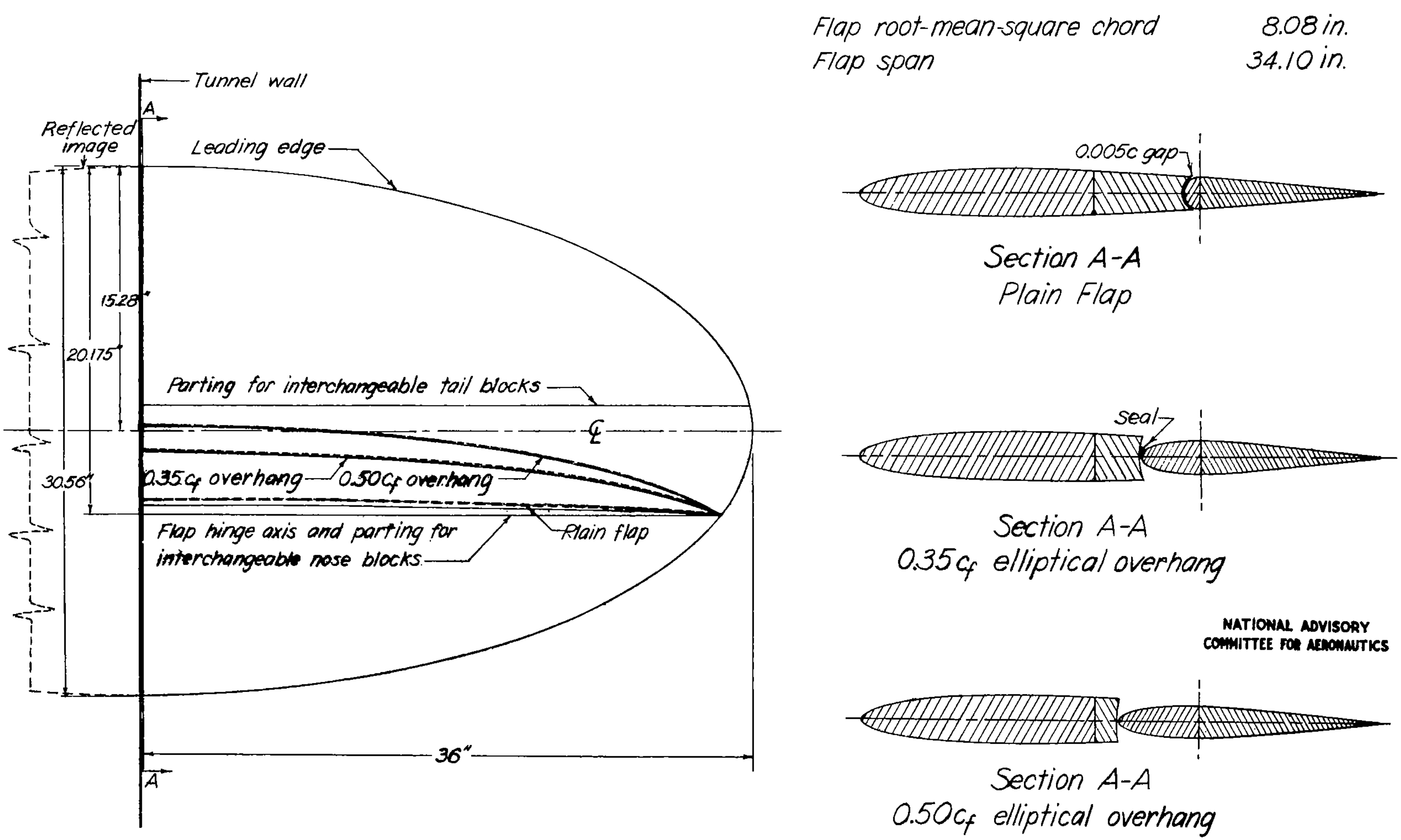
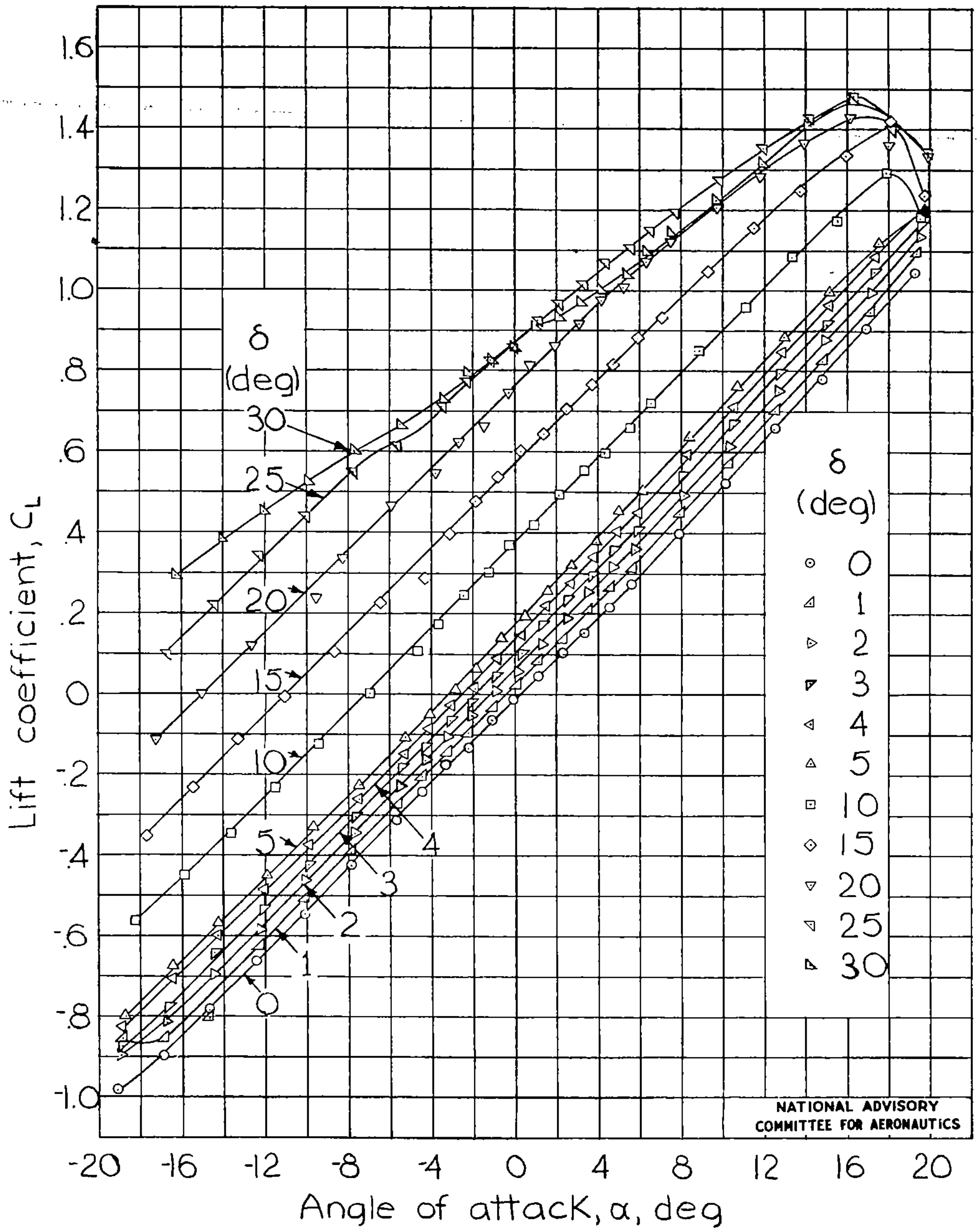
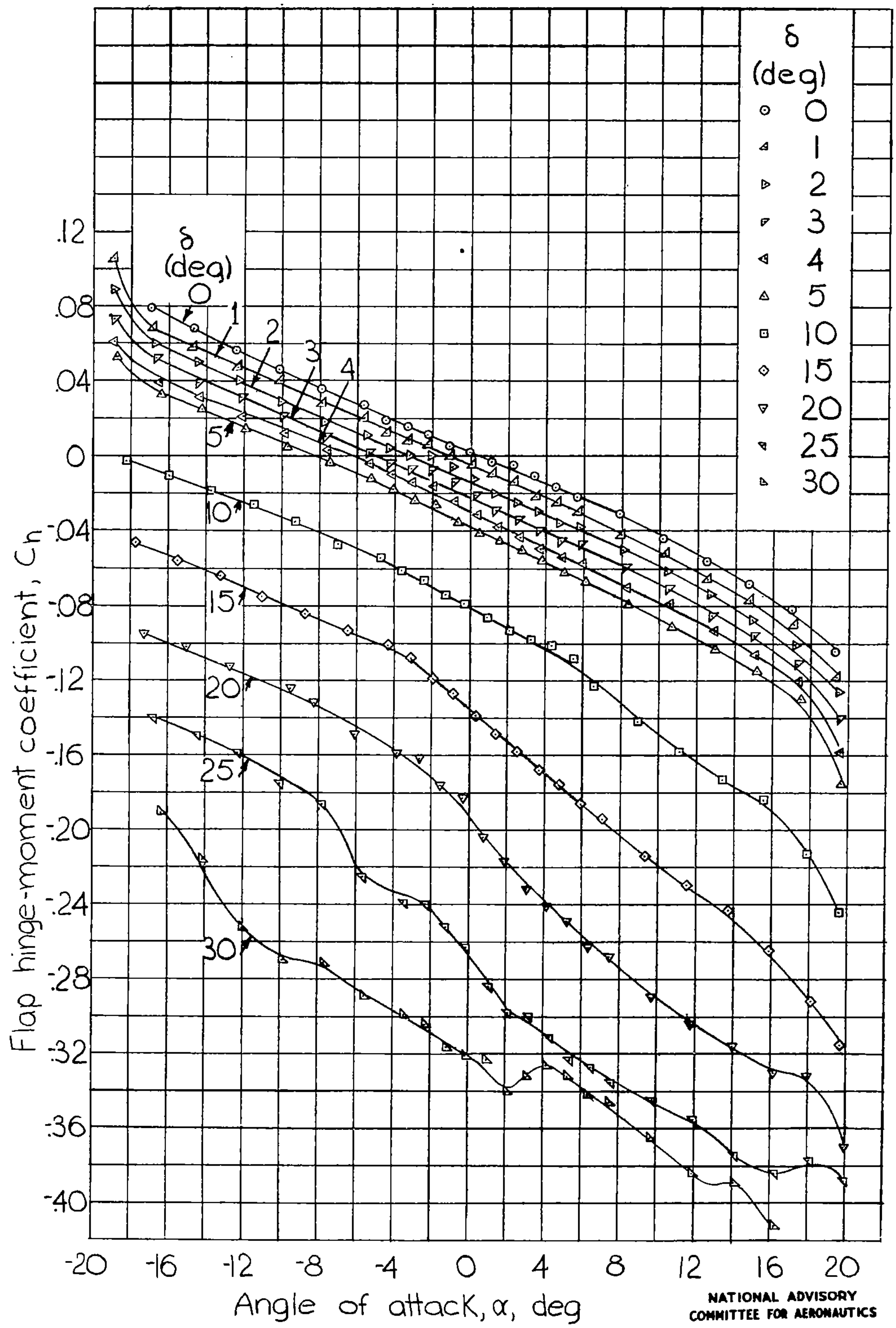


Figure 2.- Details of elliptical semispan wing having a 0.30 wing-area flap with plain overhang and with elliptical-nose overhangs of 35 and 50 percent of flap chord. The gap at the flap nose is open and 0.005c in width or sealed with impregnated fabric. NACA 0009 section; A=3; area=6 square feet.



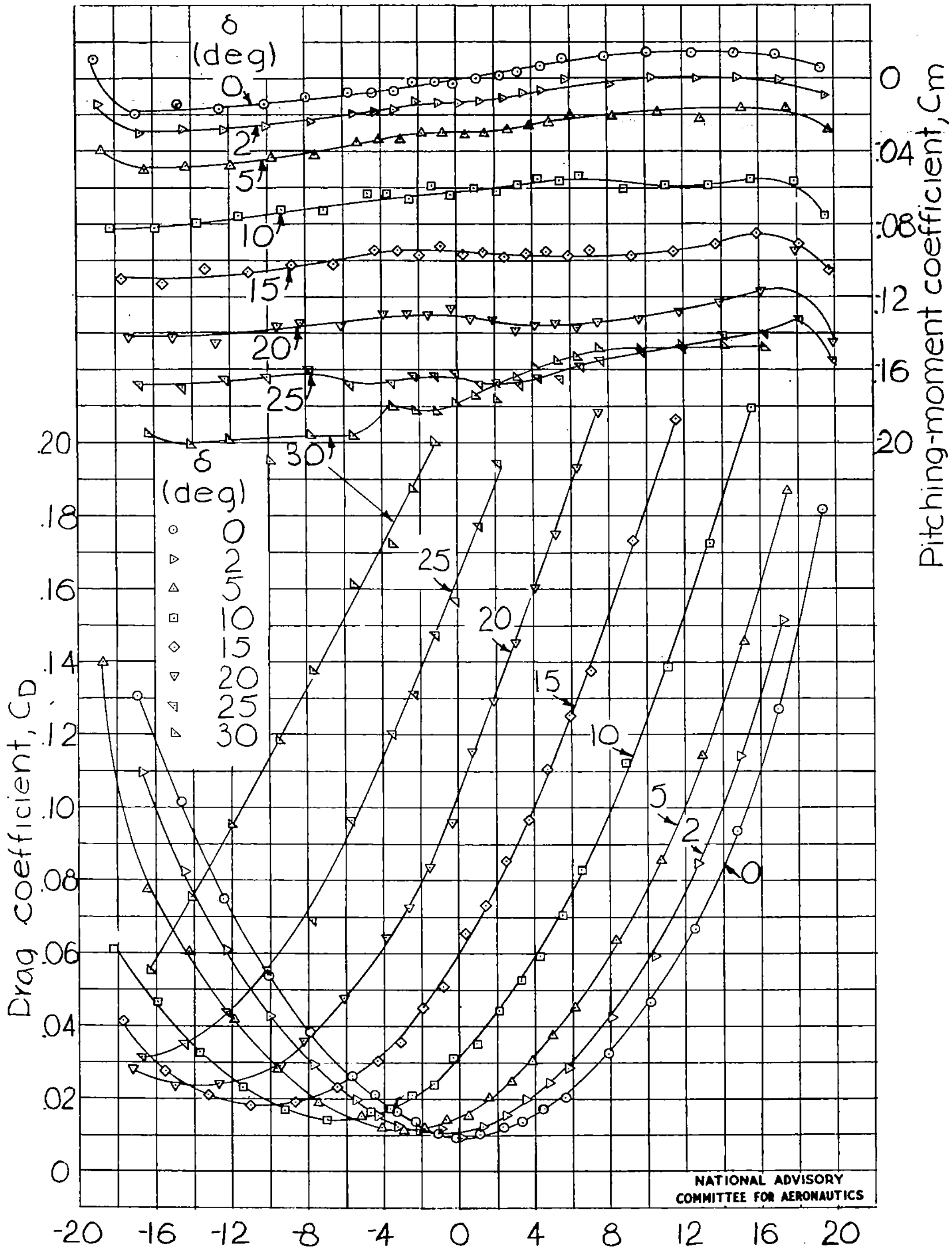
(a) 0.005c gap.

Figure 3.- Aerodynamic characteristics of an elliptical semispan wing. 0.50 wing-area plain flap; A = 3.



(a) Continued. Plain flap; 0.005c gap.

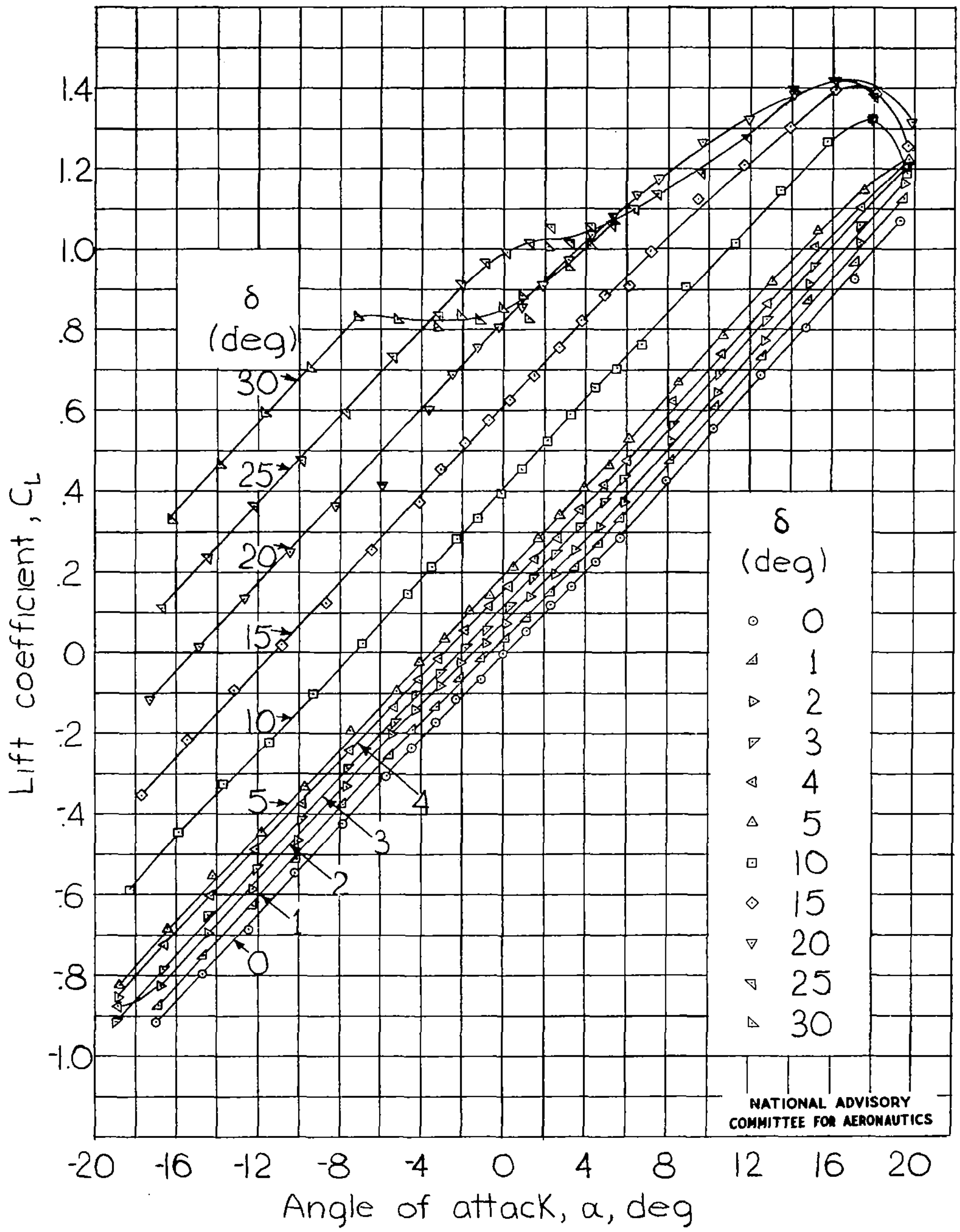
Figure 3.-Continued.



Angle of attack, α, deg

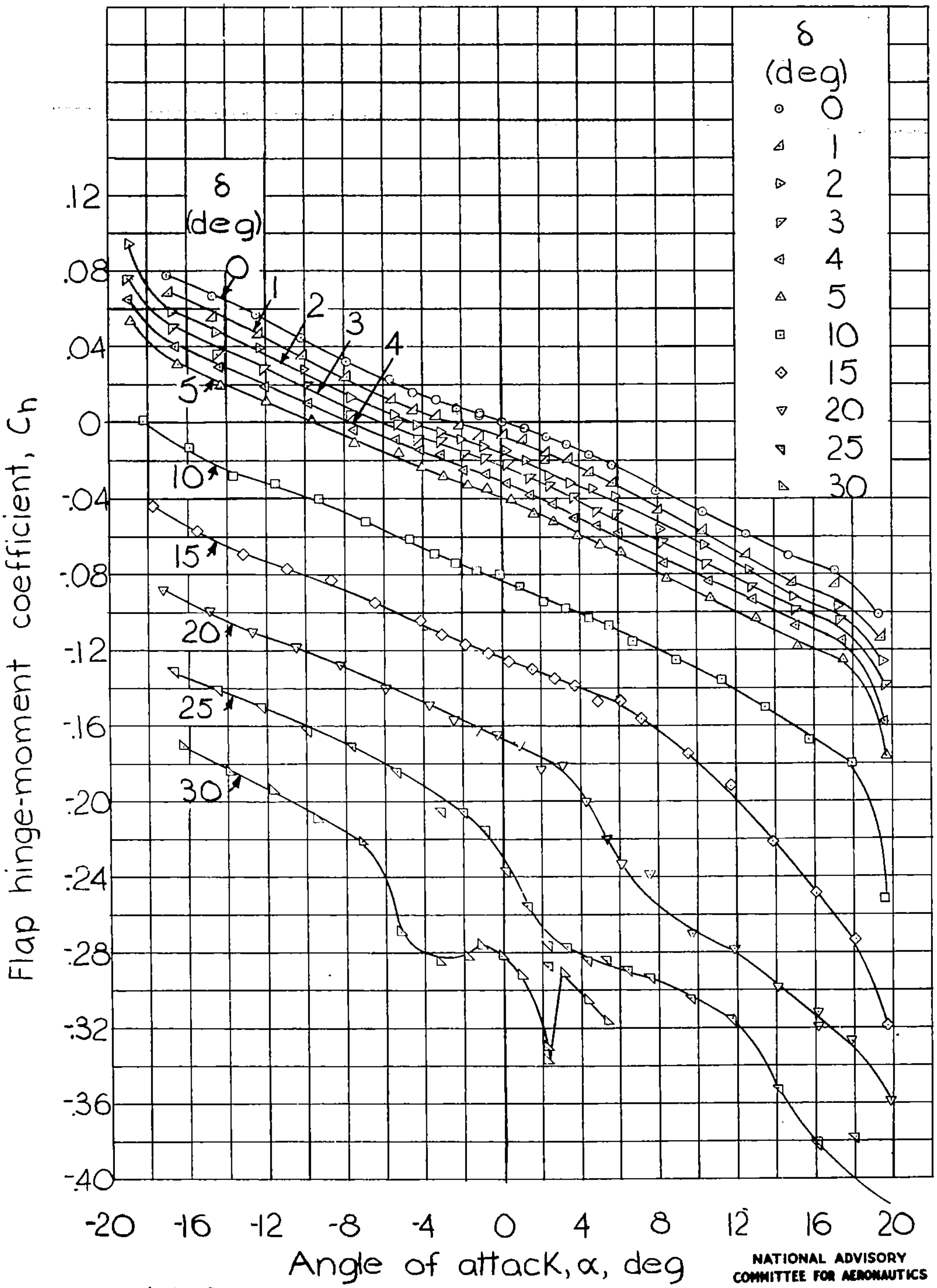
(a) Concluded. Plain flap; 0.005c gap.

Figure 3 - Continued.



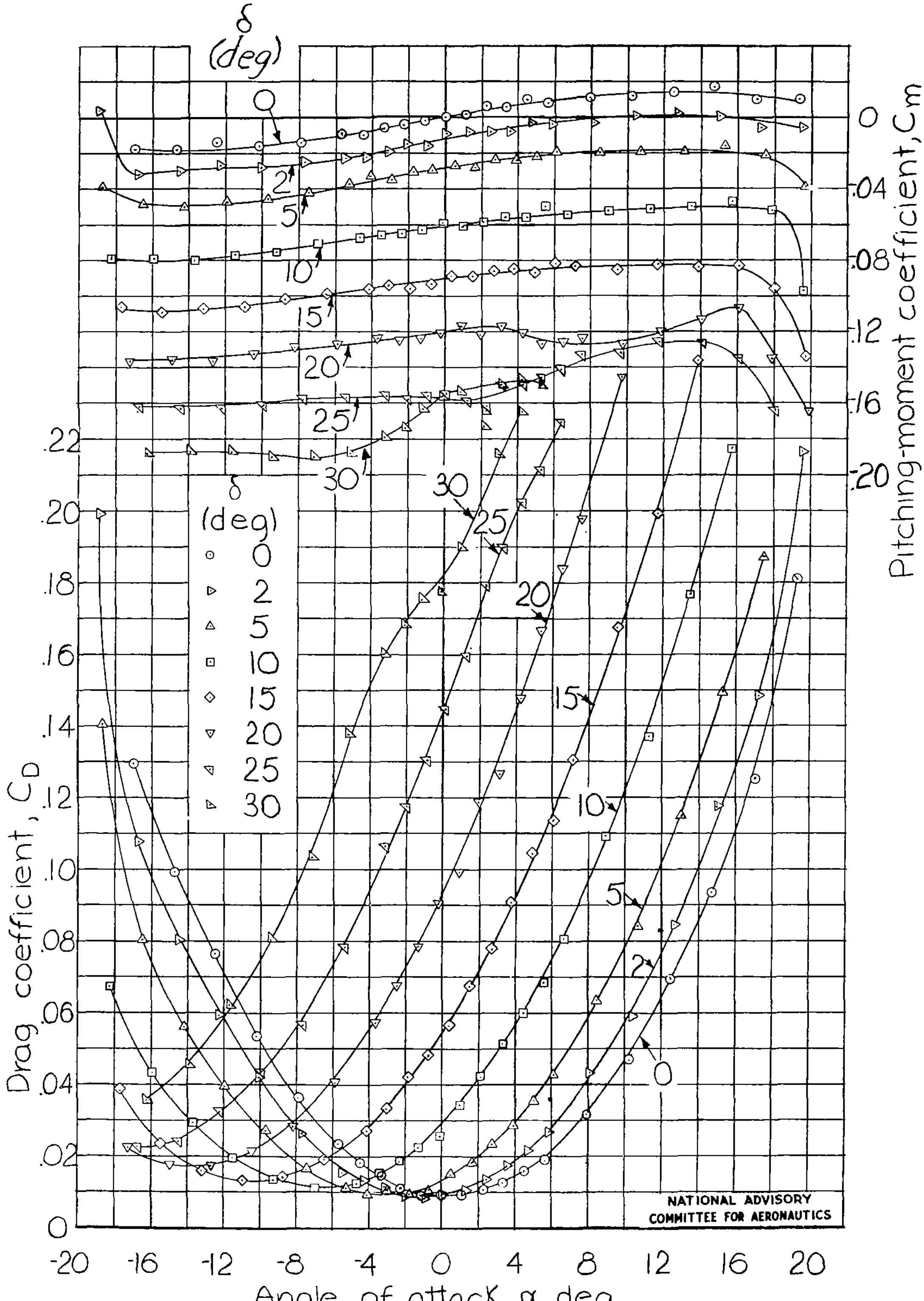
(b) Sealed gap; plain flap.

Figure 3 .- Continued.



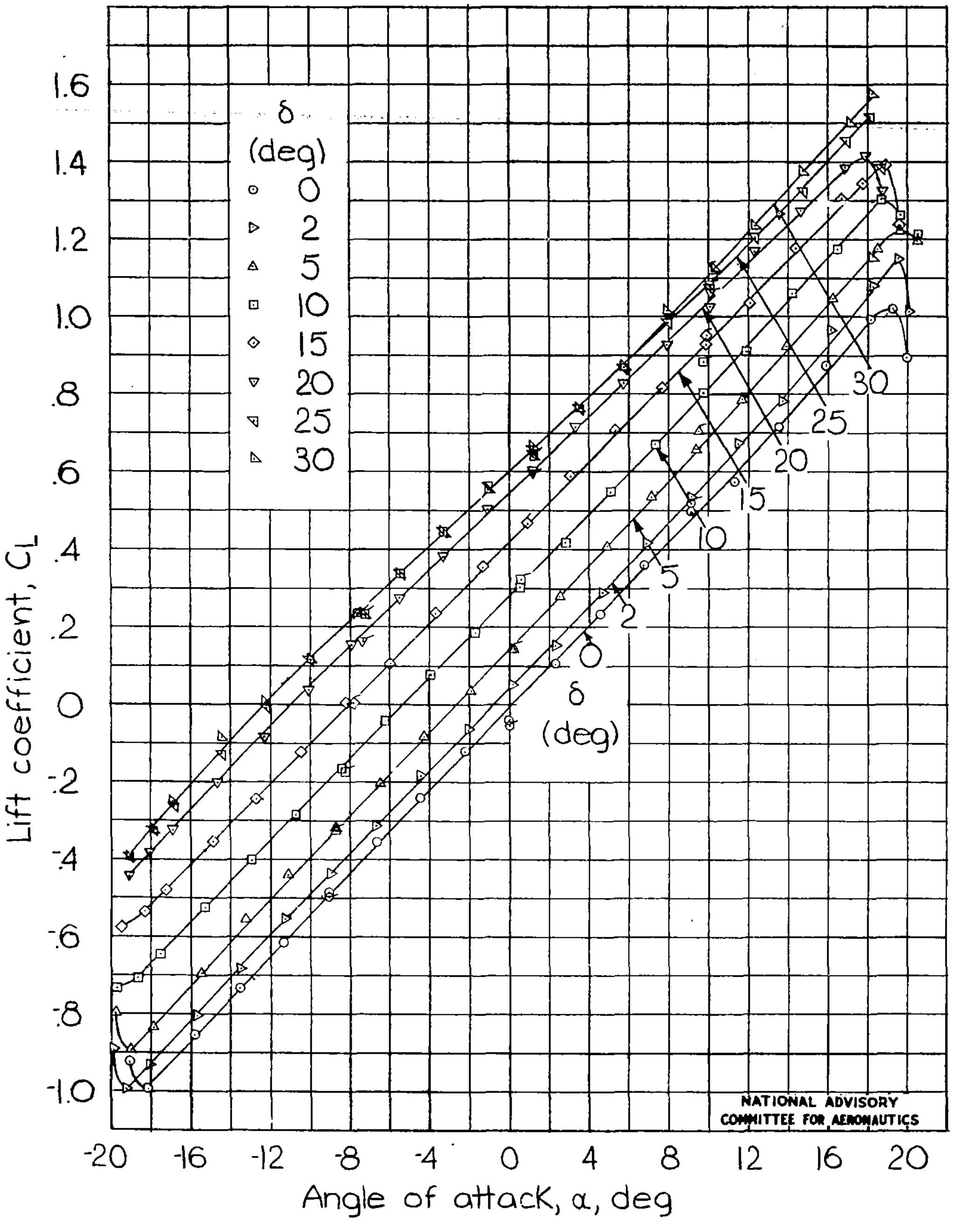
(b) Continued. Plain flap; sealed gap.

Figure 3 .- Continued.



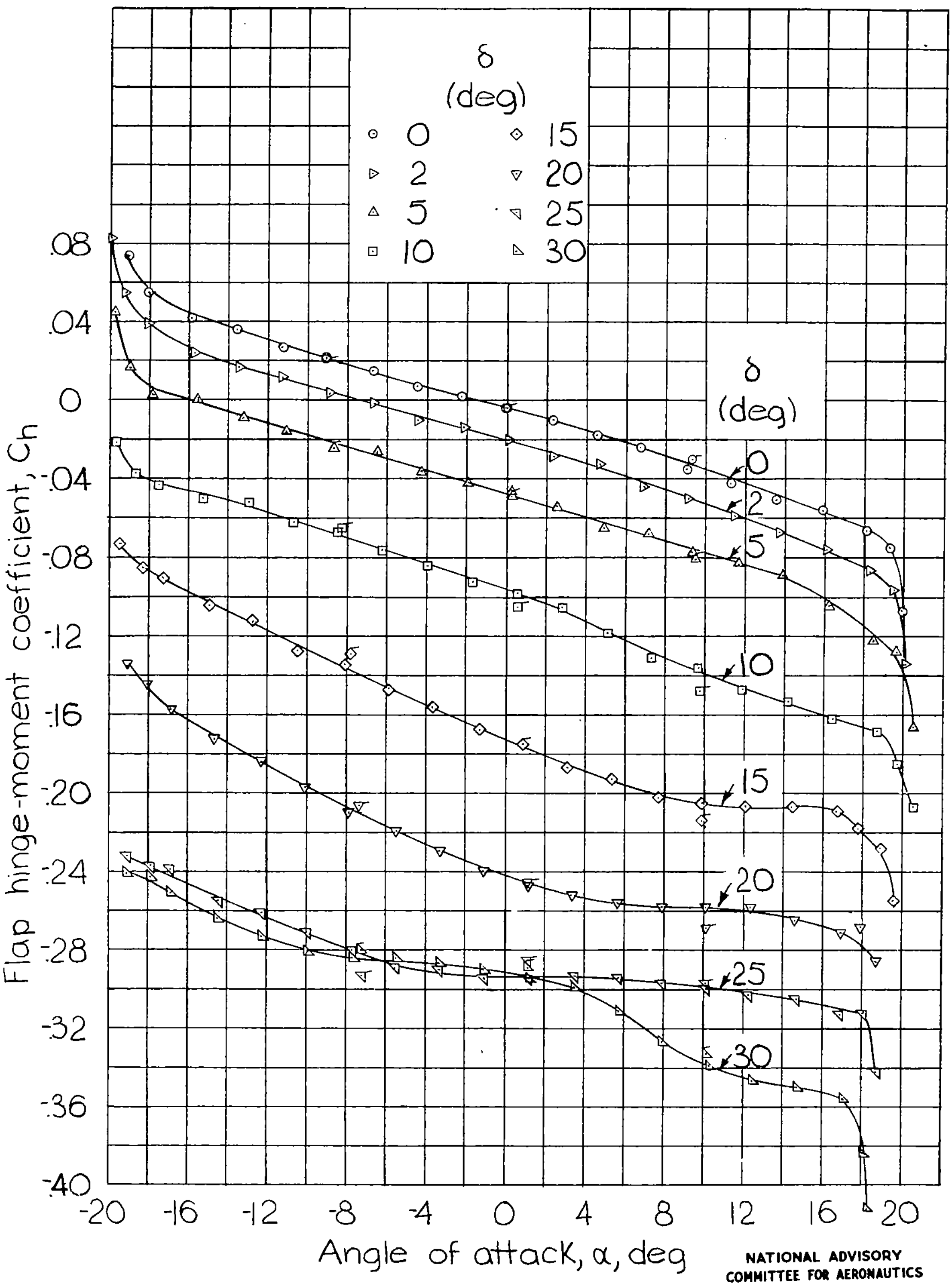
(b) Concluded. Plain flap; sealed gap.

Figure 3. Concluded.



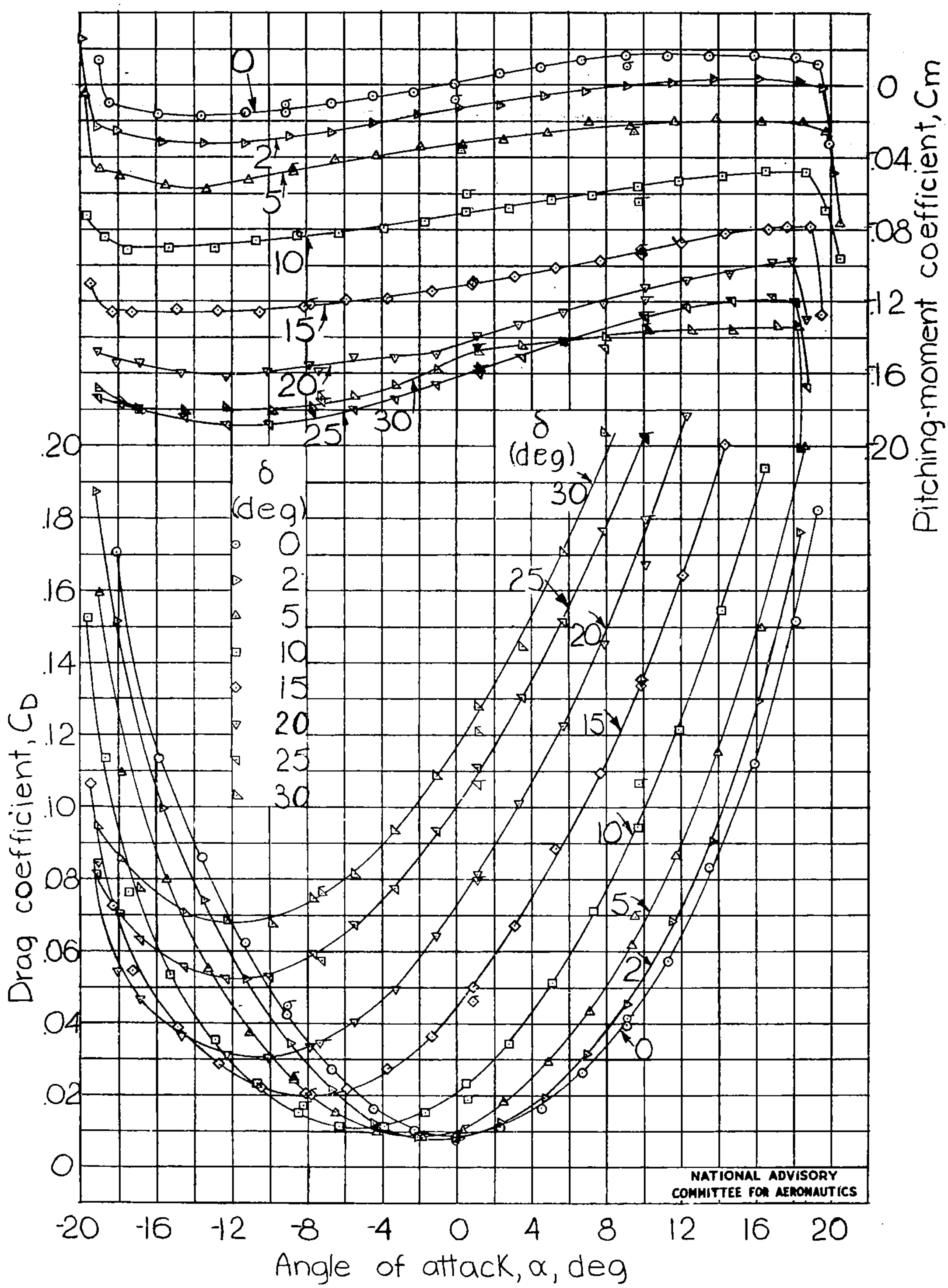
(a) 0.005c gap.

Figure 4.- Aerodynamic characteristics of an elliptical semispan wing. 0.30 wing-area plain flap; A = 3.



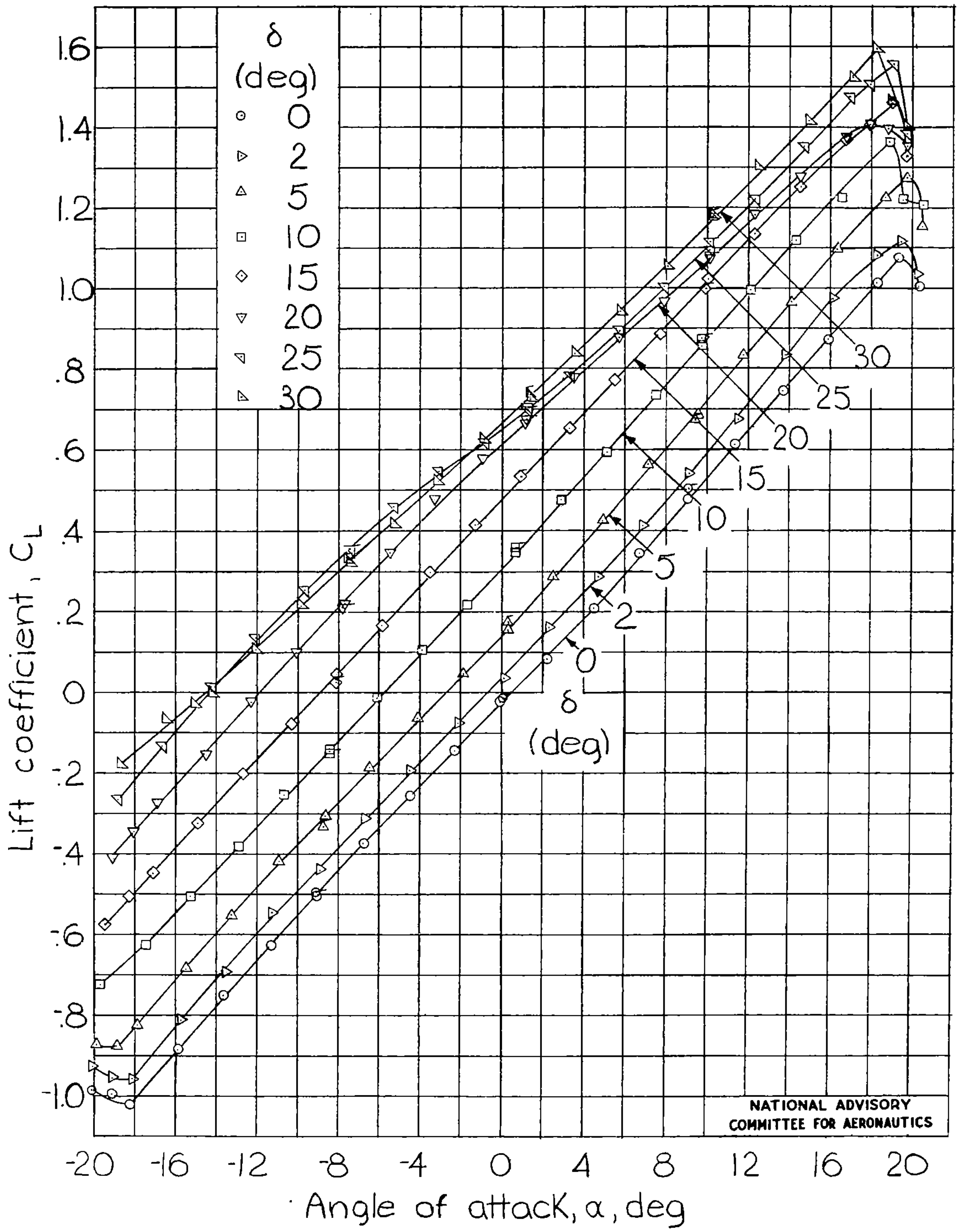
(a) Continued. Plain flap; 0.005c gap.

Figure 4.- Continued.



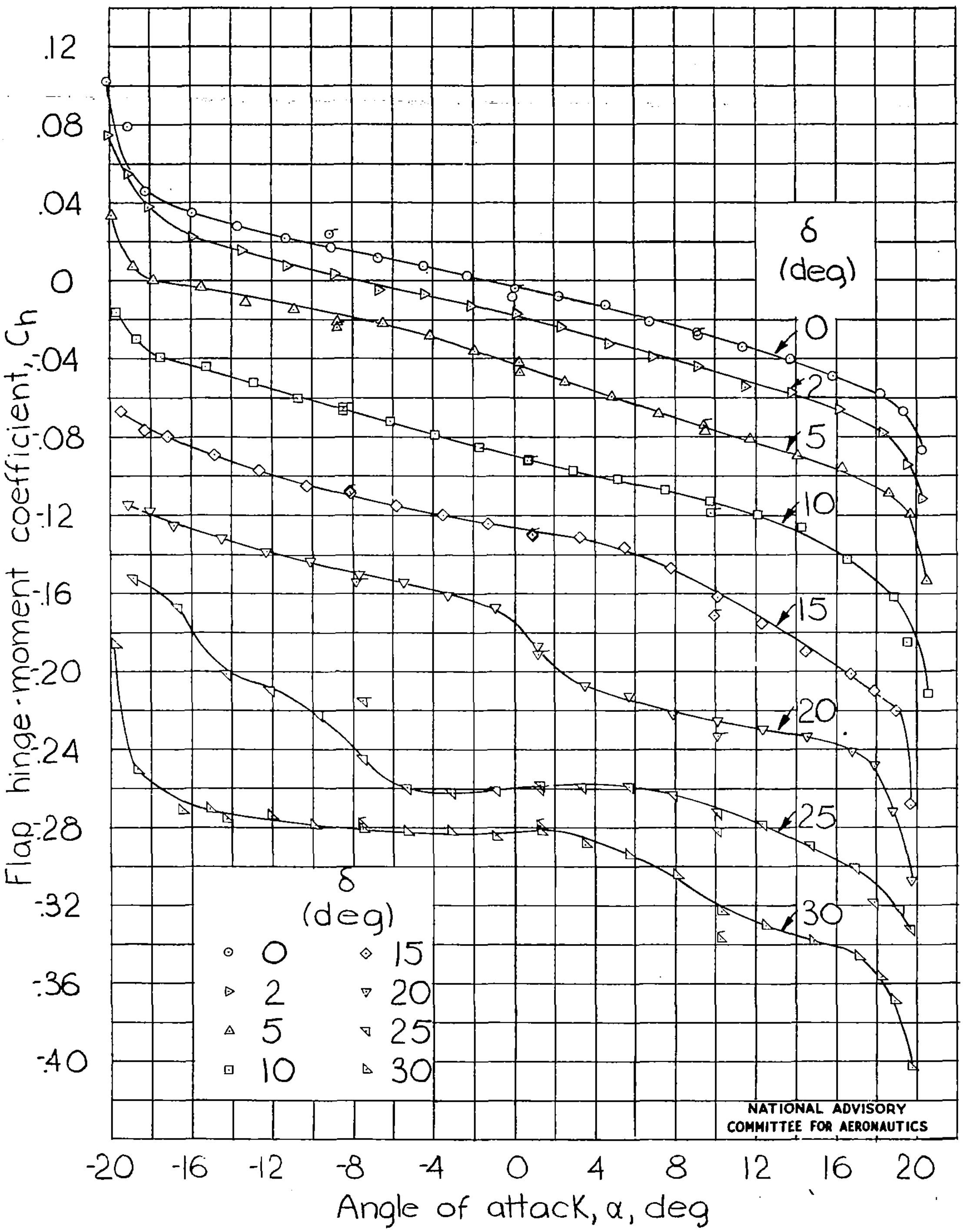
(a) Concluded. Plain flap; 0.005c gap.

Figure 4.- Continued.



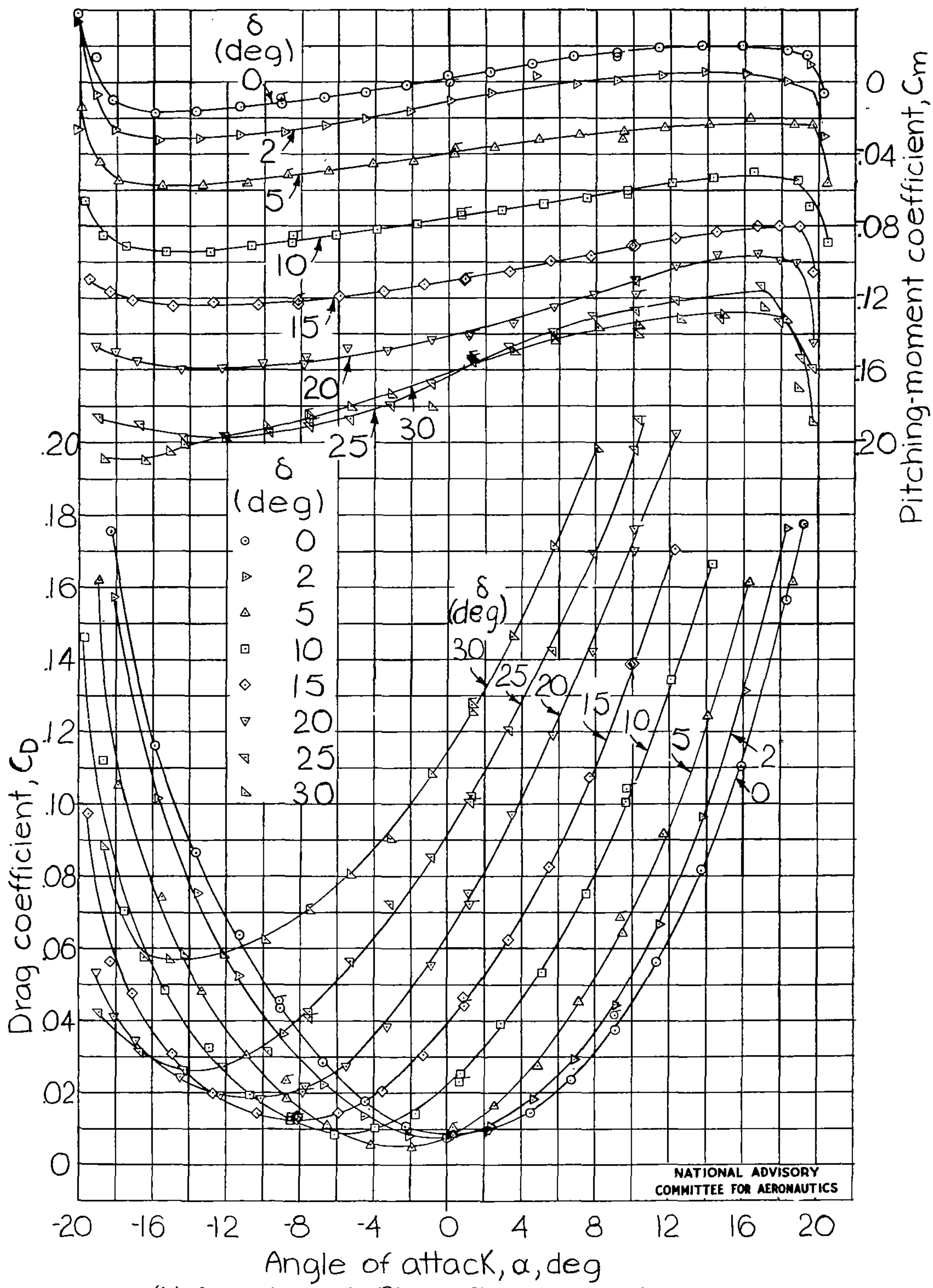
(b) Sealed gap; plain flap.

Figure 4.- Continued.



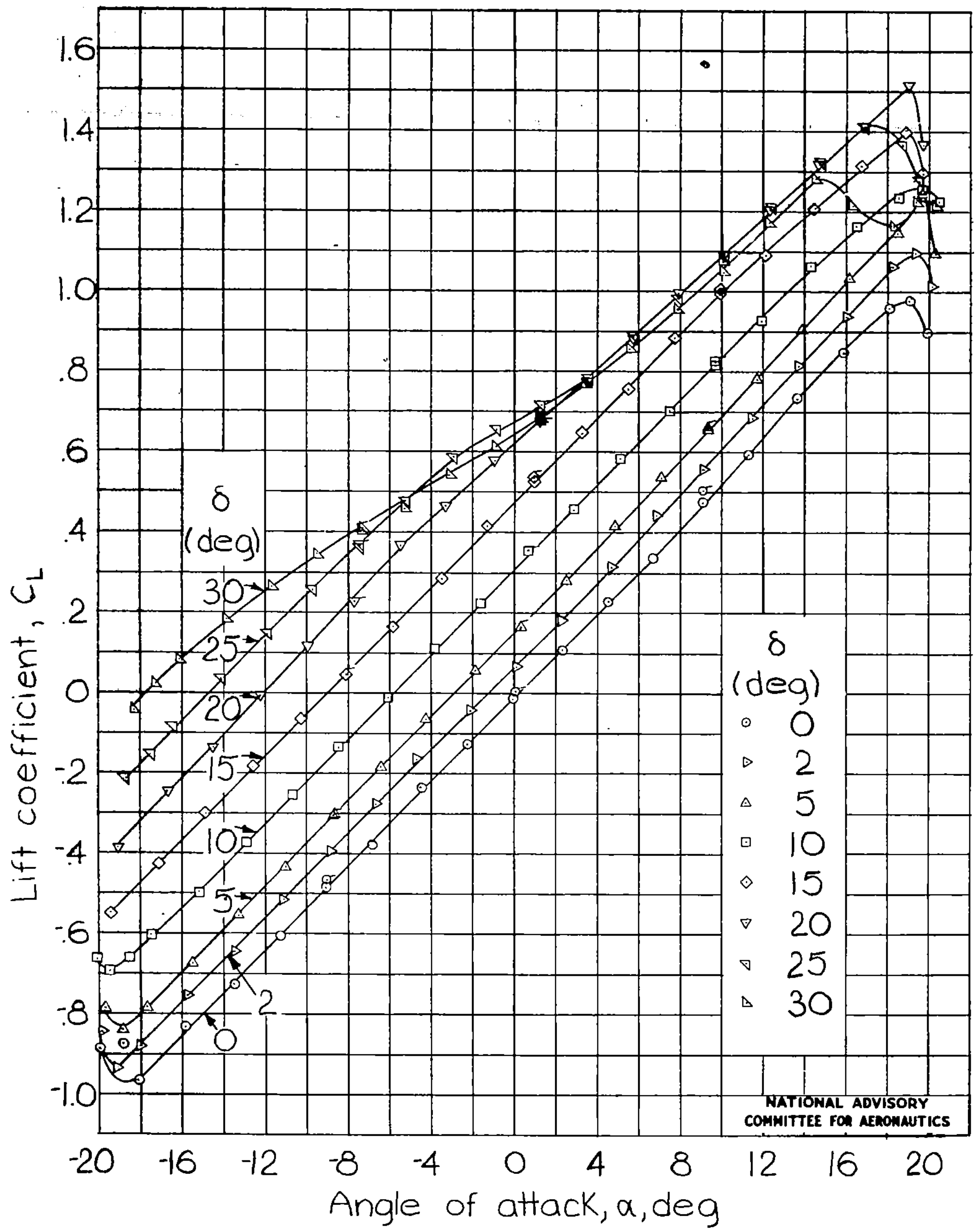
(b) Continued. Plain flap; sealed gap.

Figure 4.- Continued.



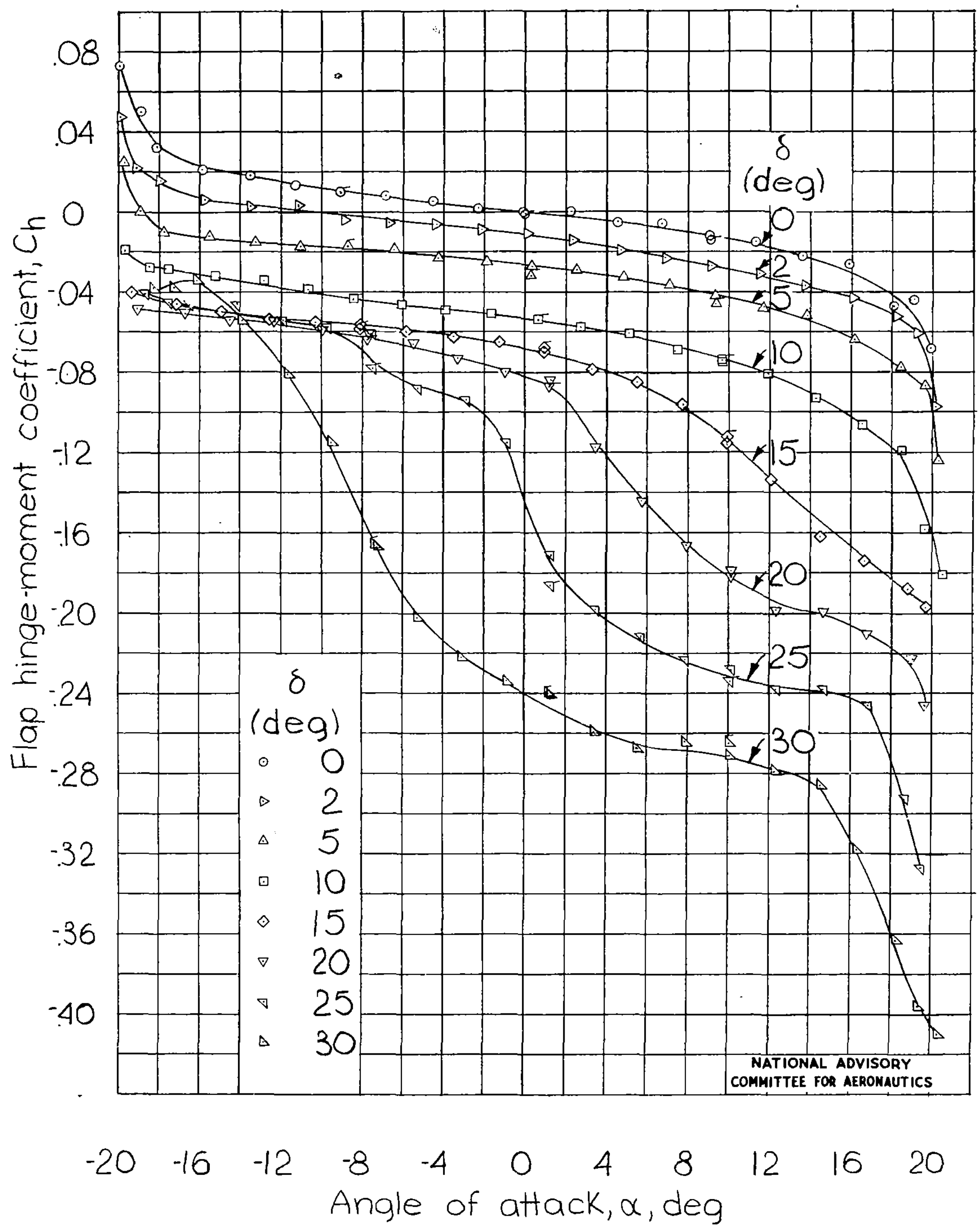
(b) Concluded. Plain flap; sealed gap.

Figure 4.- Concluded.



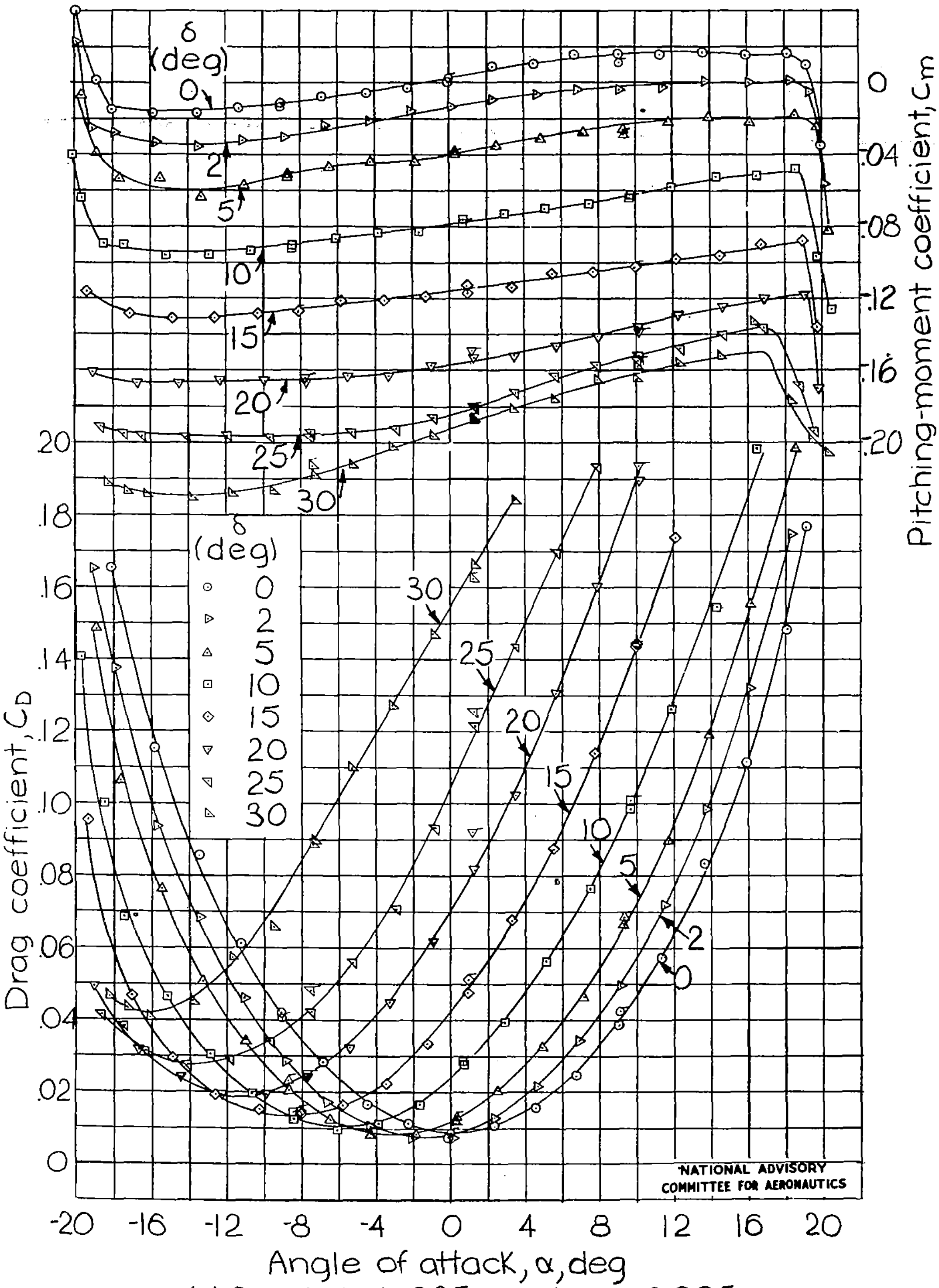
(a) 0.005c gap.

Figure 5.- Aerodynamic characteristics of an elliptical semispan wing. 0.30 wing-area flap with $0.35c_f$ elliptical overhang; A = 3.



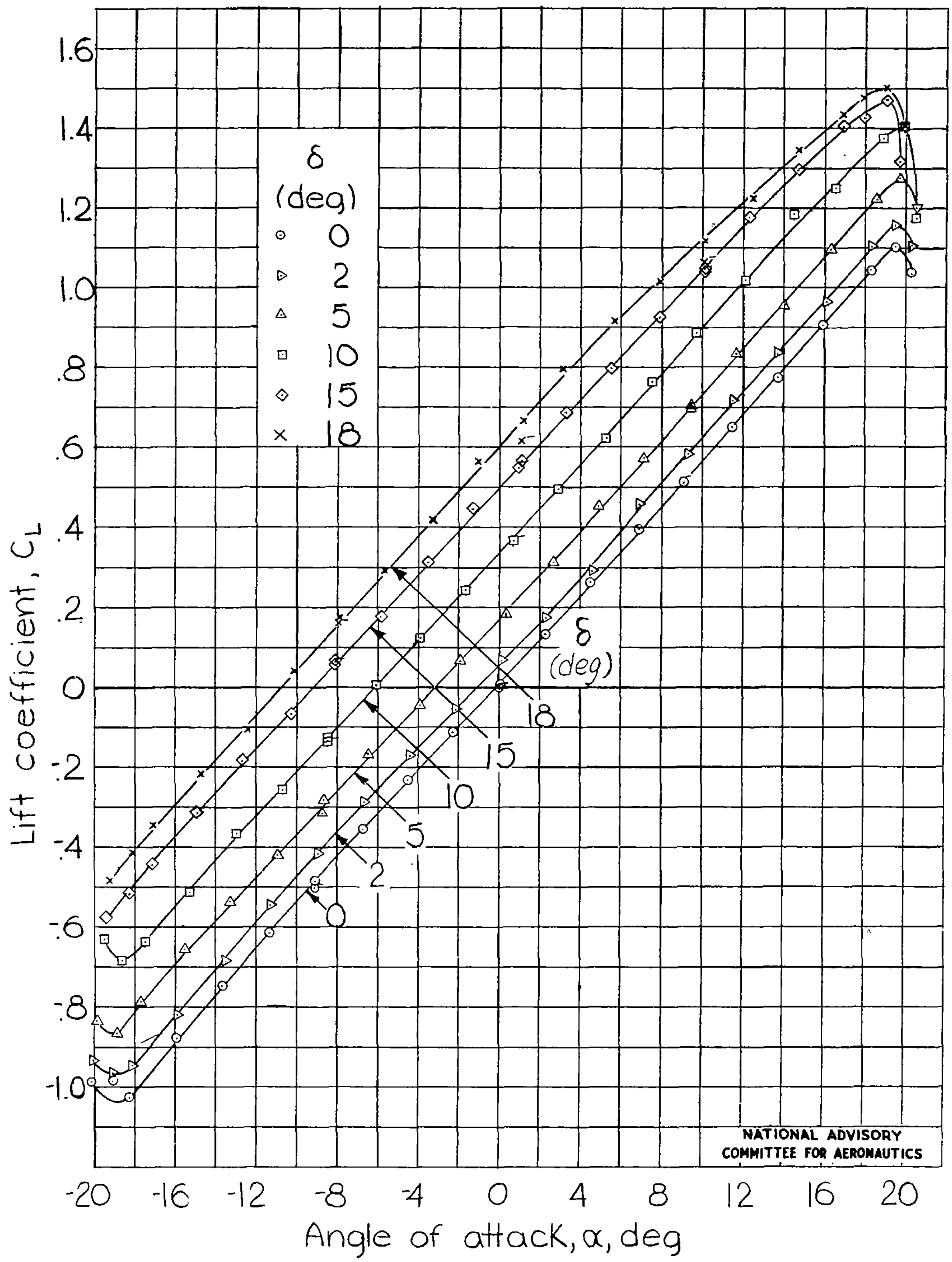
(a) Continued. $0.35c_f$ overhang; 0.005c gap.

Figure 5.- Continued.



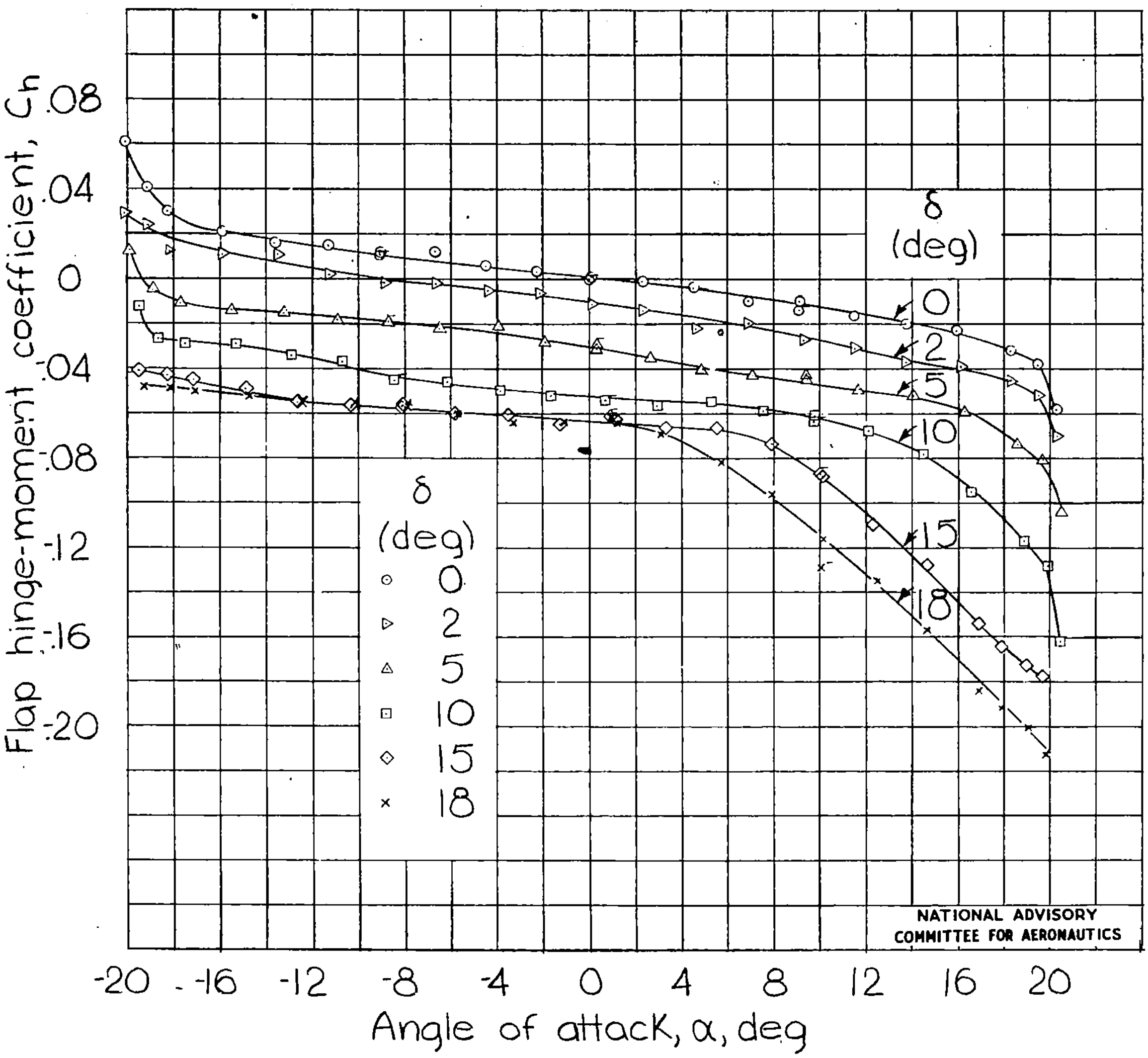
(a) Concluded. 0.35 overhang; 0.005c gap.

Figure 5.- Continued.



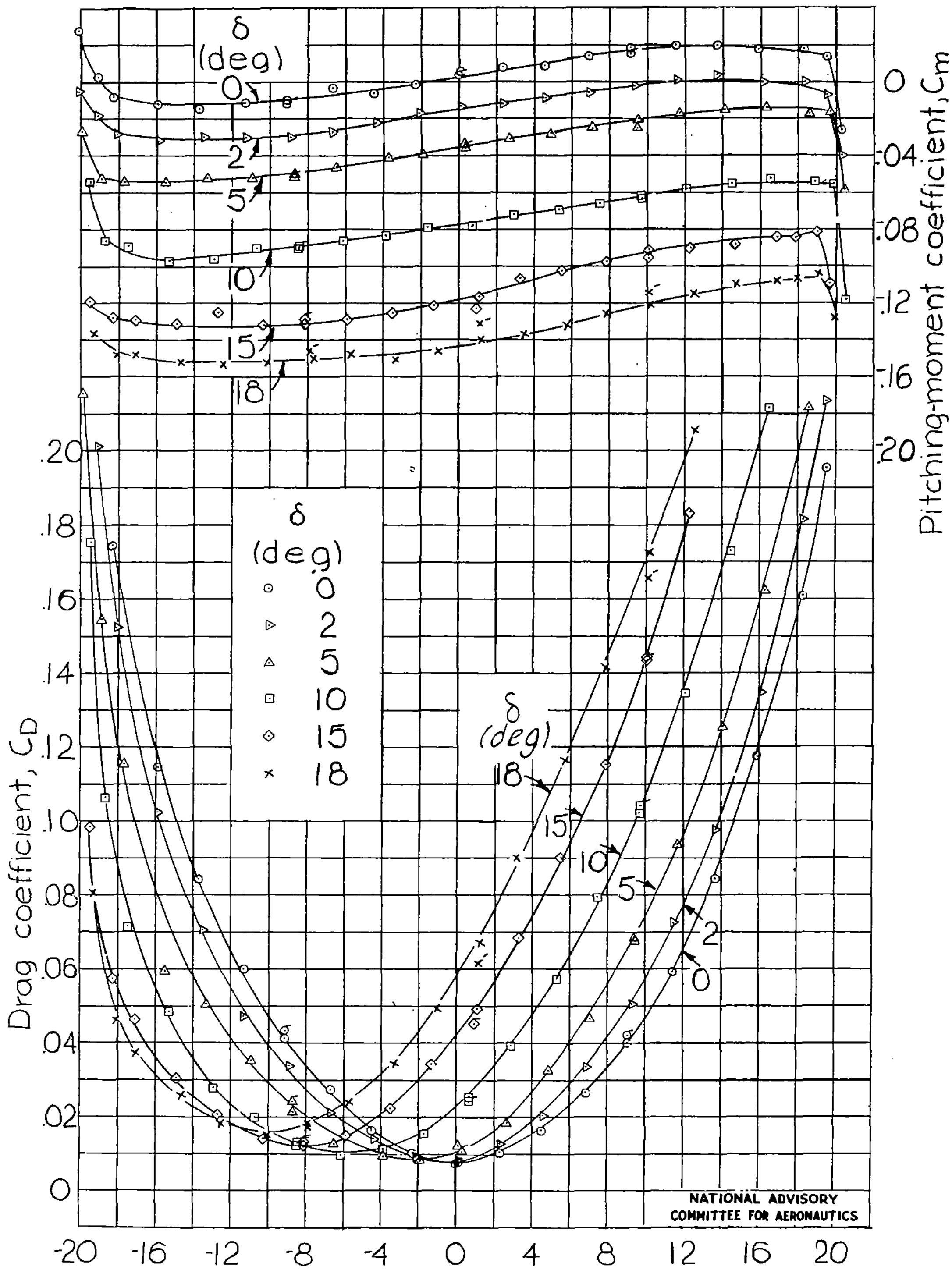
(b) Sealed gap; 0.35c_f overhang.

Figure 5.- Continued.



(b) Continued. $0.35c_f$ overhang; sealed gap.

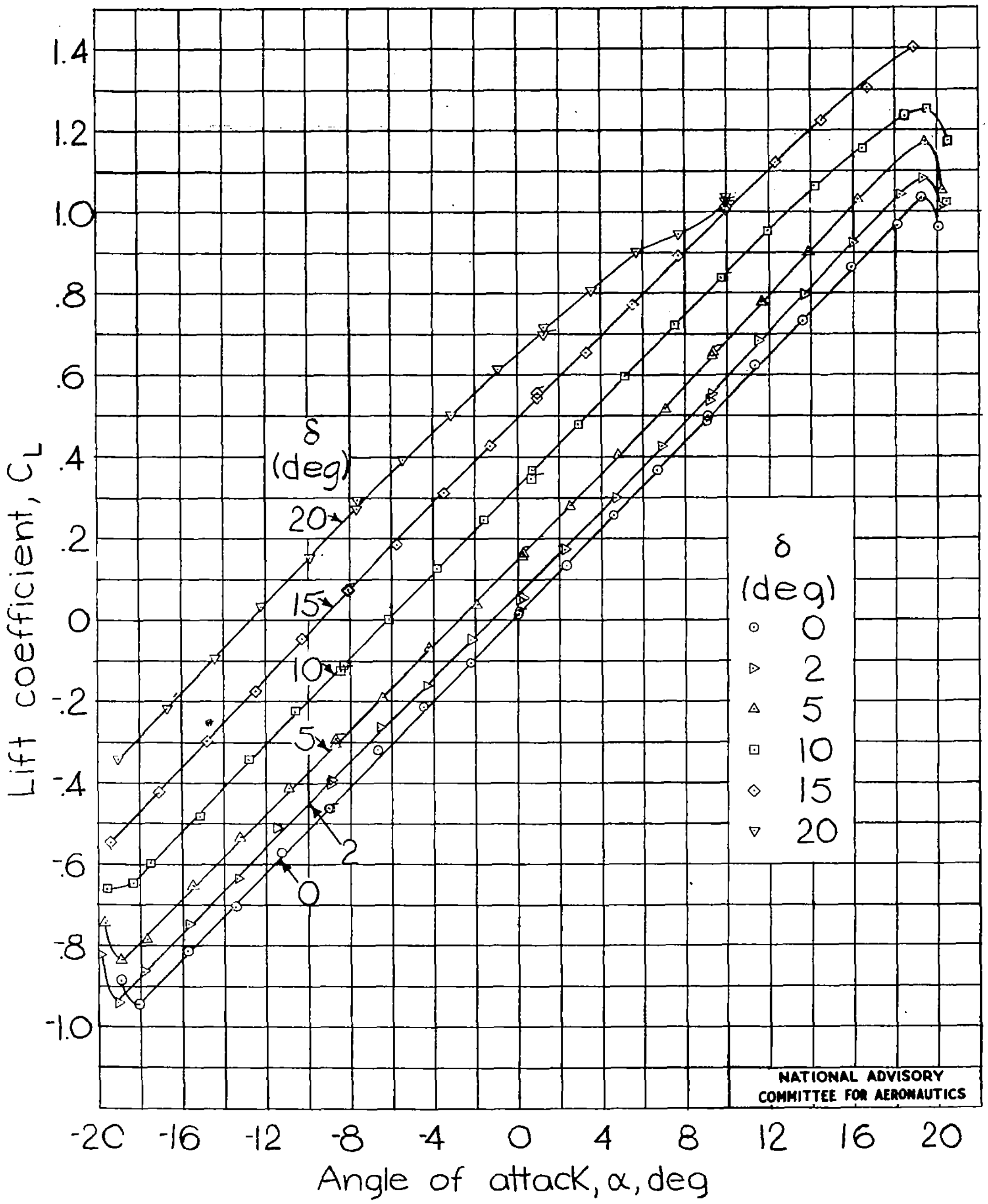
Figure 5.- Continued.



Angle of attack, α, deg

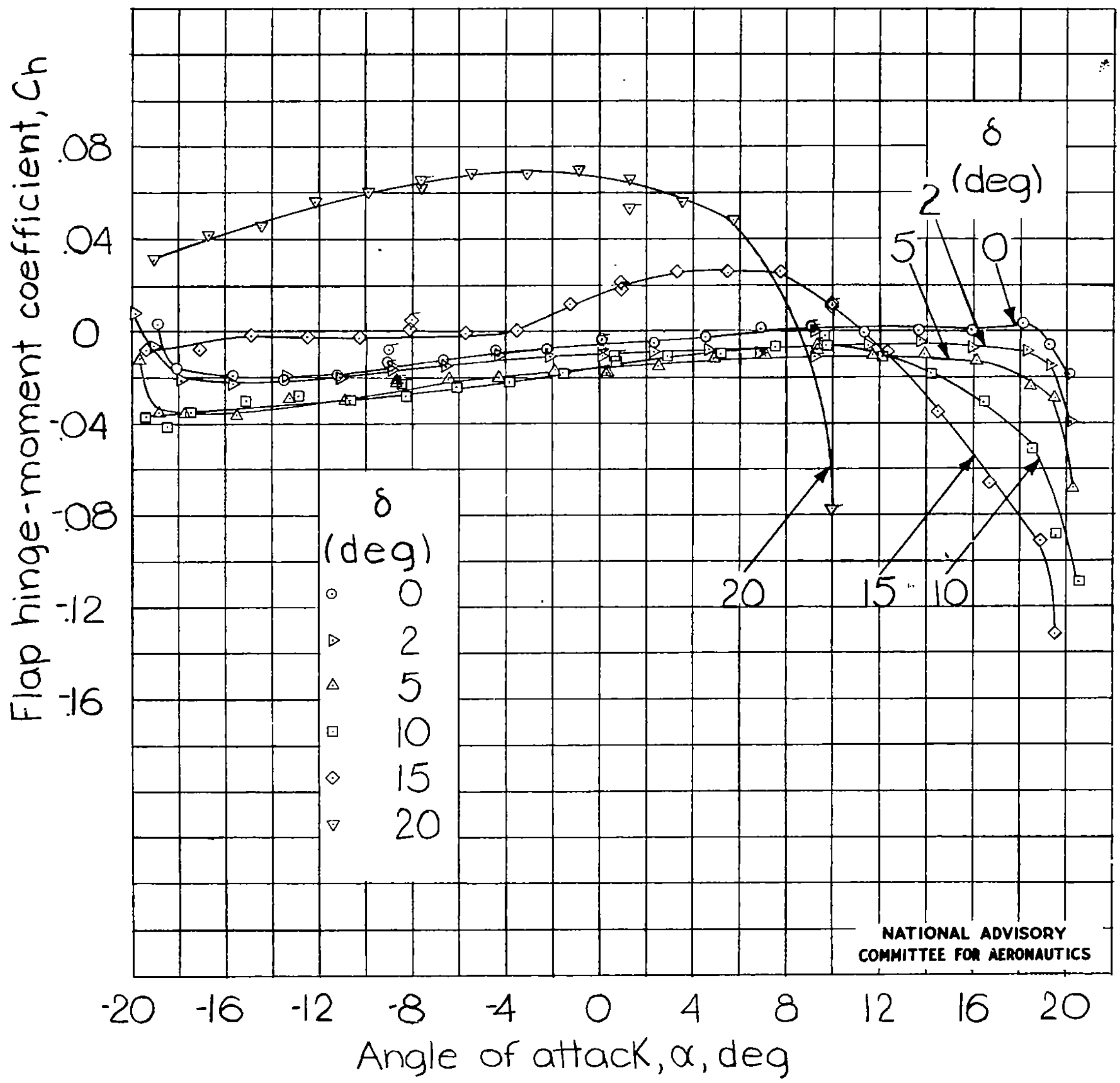
(b) Concluded. 0.35c_f overhang; sealed gap.

Figure 5.- Concluded.



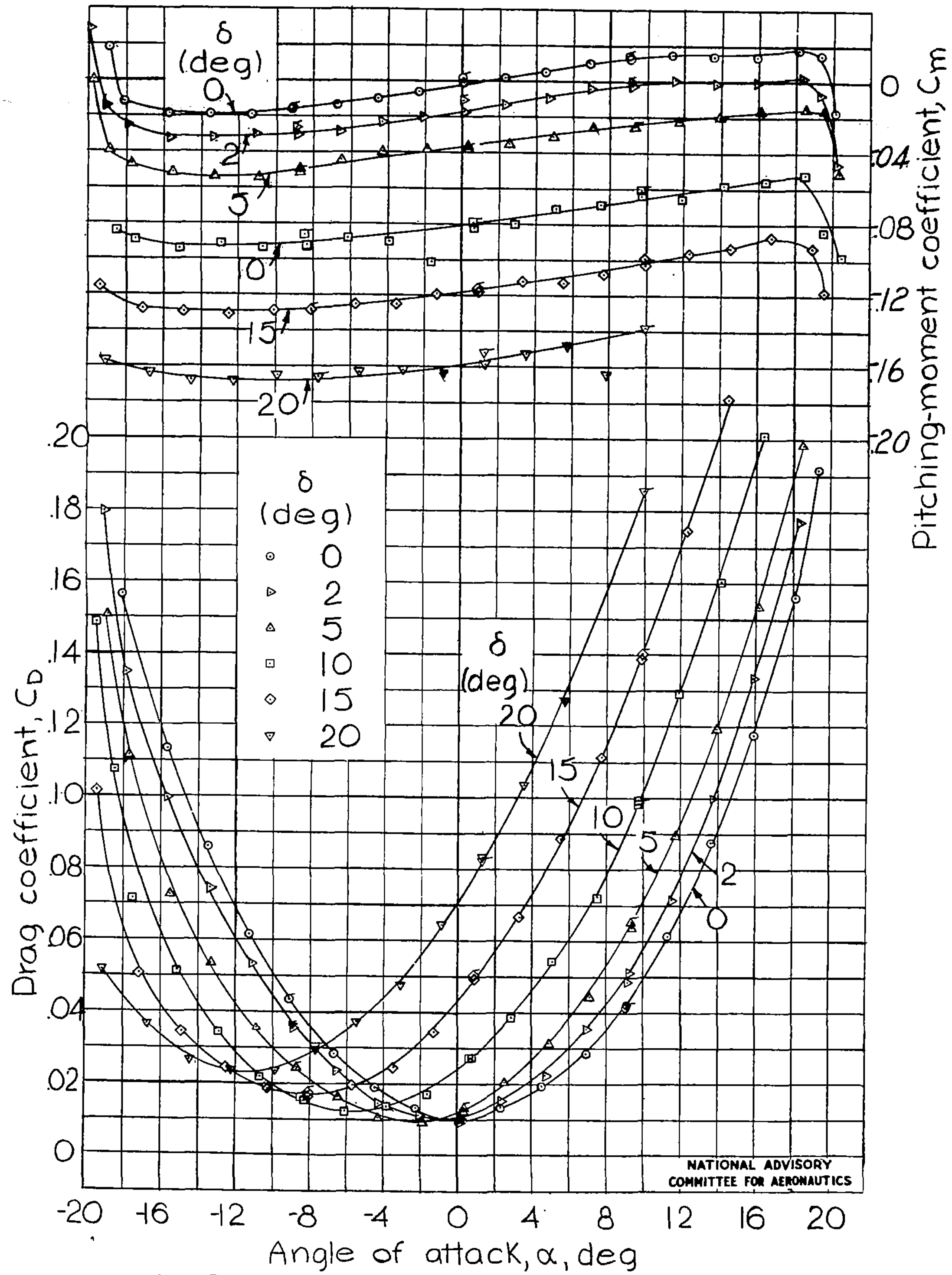
(a) 0.005c gap.

Figure 6.- Aerodynamic characteristics of an elliptical semispan wing. 0.30 wing-area flap with $0.50c_f$ elliptical overhang; A=3.



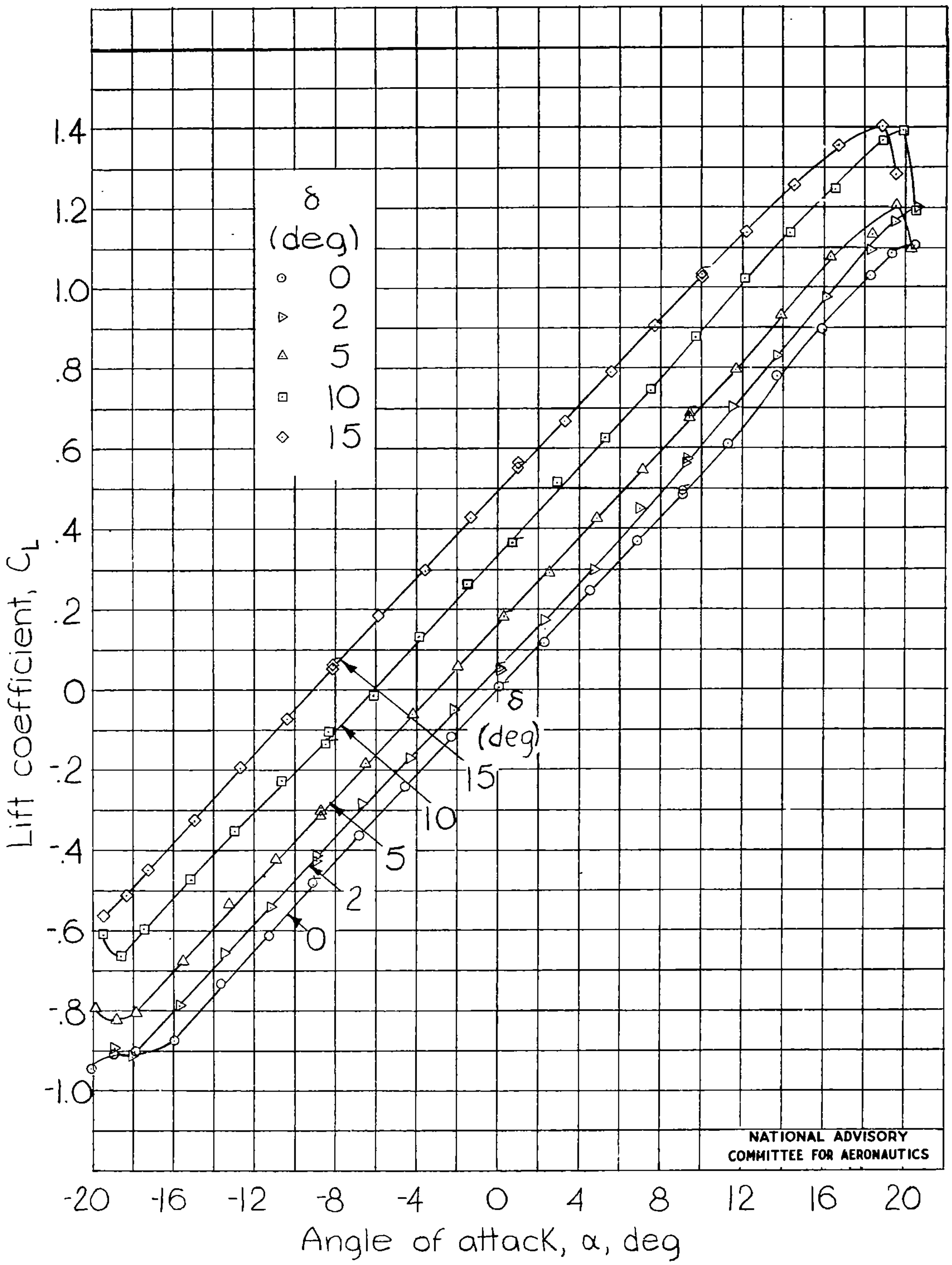
(a) Continued. 0.50 c_f overhang; 0.005c gap.

Figure 6 .- Continued.



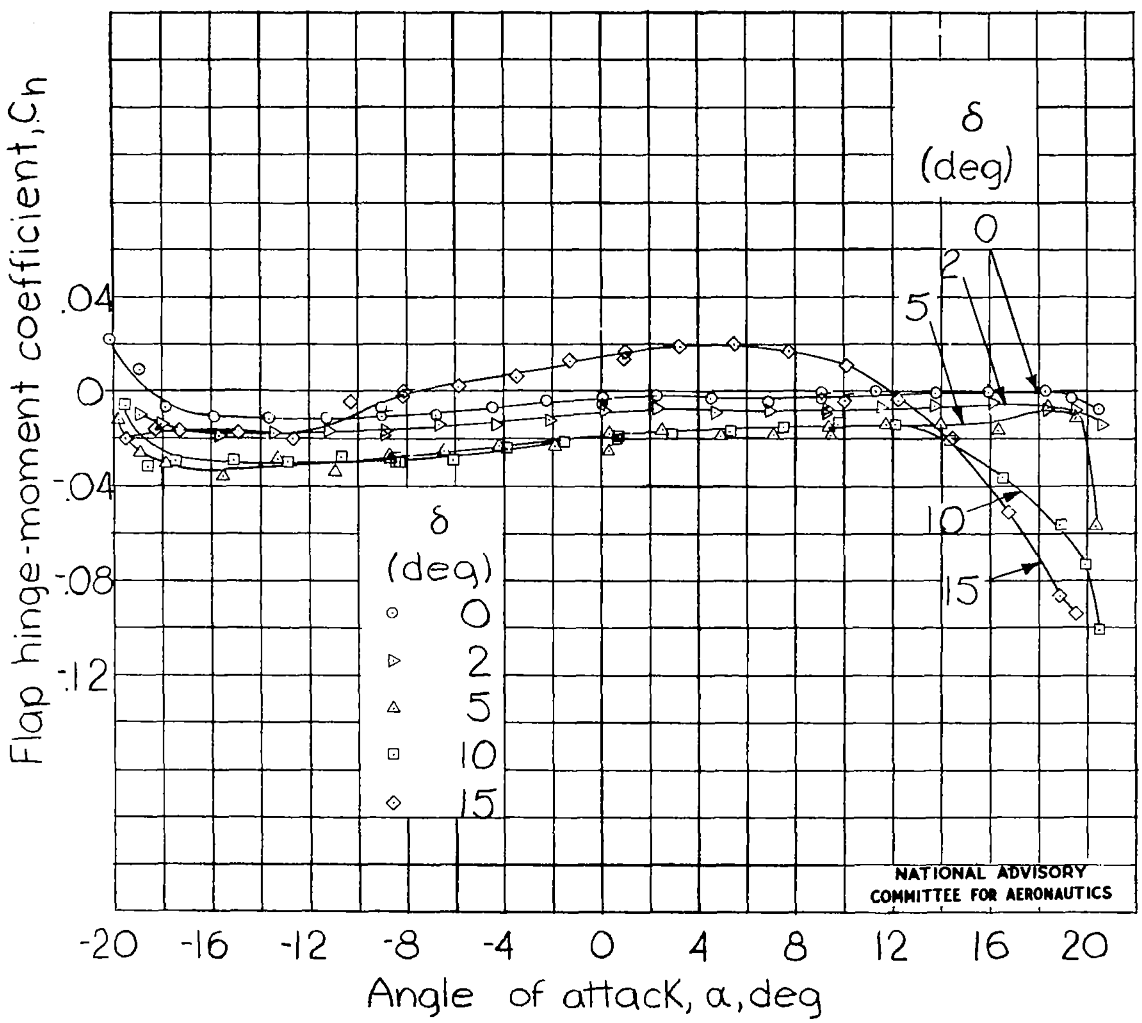
(a) Concluded. 0.50c_f overhang; 0.005c gap.

Figure 6 .- Continued.



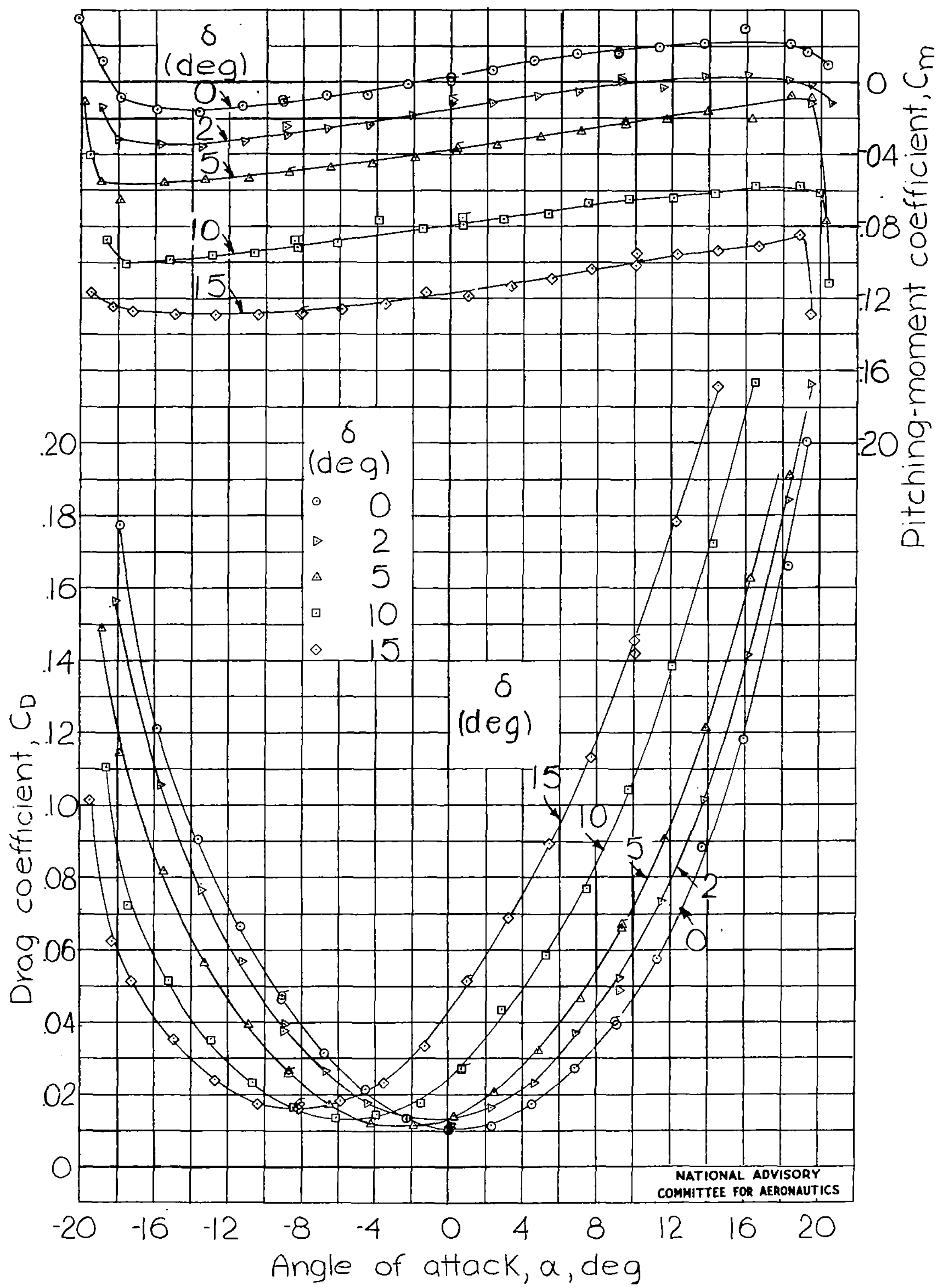
(b) Sealed gap; $0.50c_f$ overhang.

Figure 6.- Continued.



(b) Continued. 0.50c_f overhang; sealed gap.

Figure 6.- Continued.



(b) Concluded. 0.50 c_f overhang; sealed gap.

Figure 6.- Concluded.

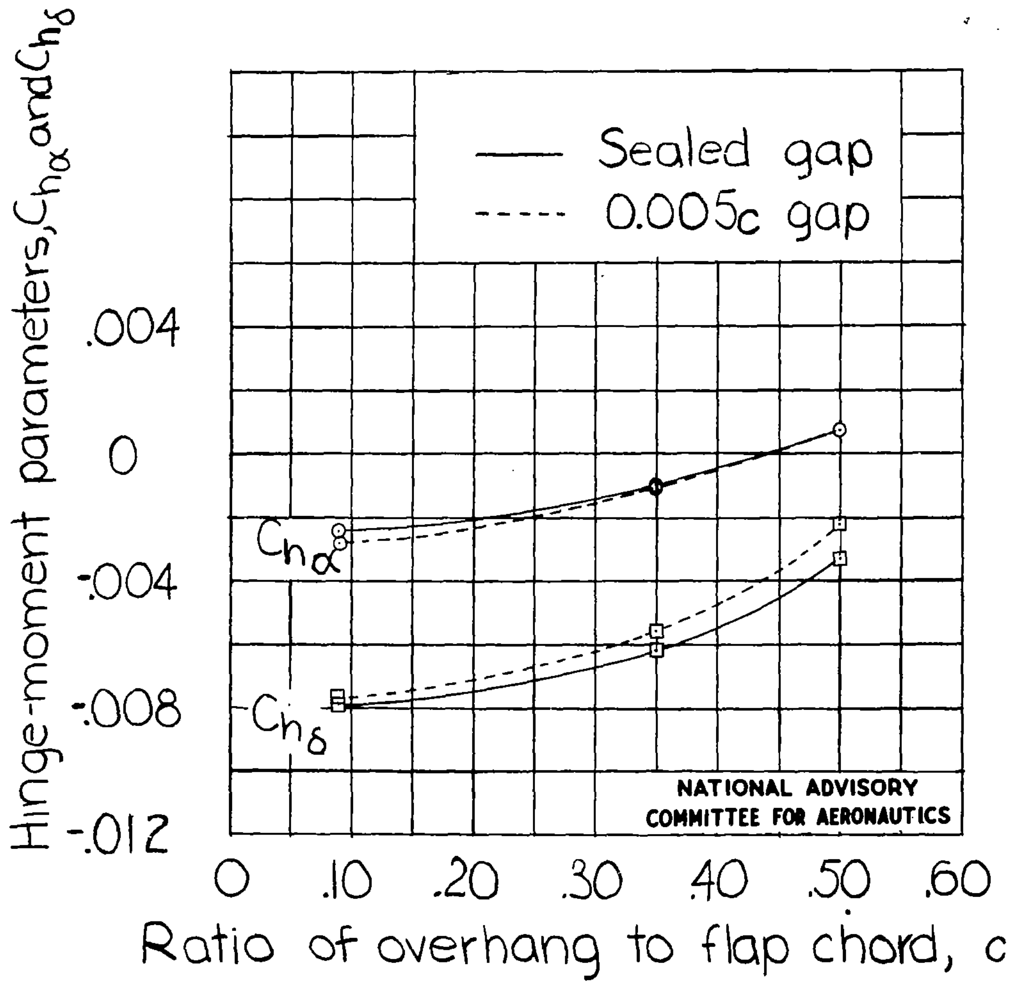


Figure 7.- Variation of flap hinge-moment parameters with chord of elliptical-nose overhang. NACA 0009 elliptical semispan wing; 0.30 wing-area flap; A=3.

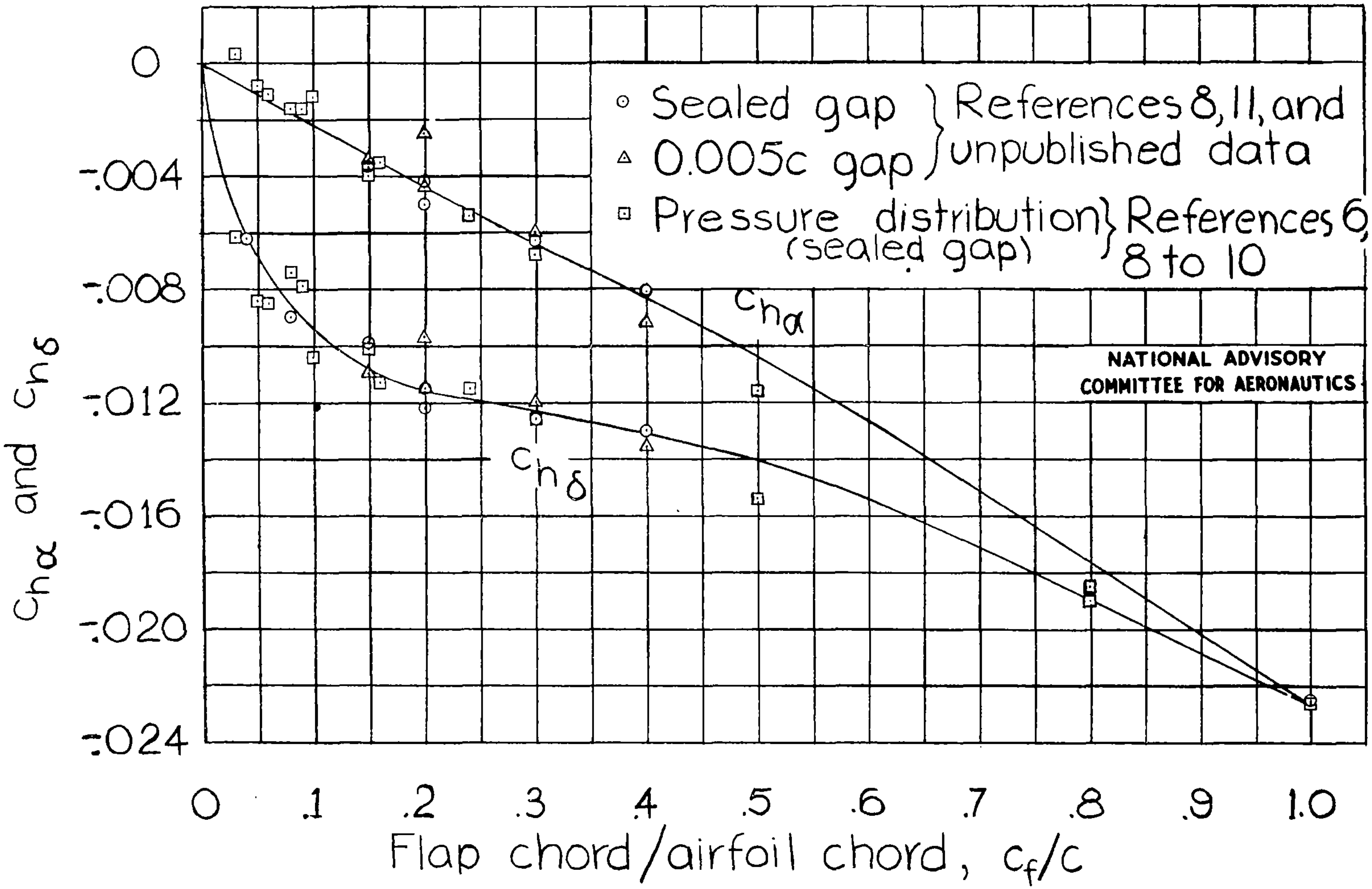


Figure 8.- Variation of flap section hinge-moment parameters with ratio of flap chord to airfoil chord. Plain flaps on NACA 0009 airfoil.

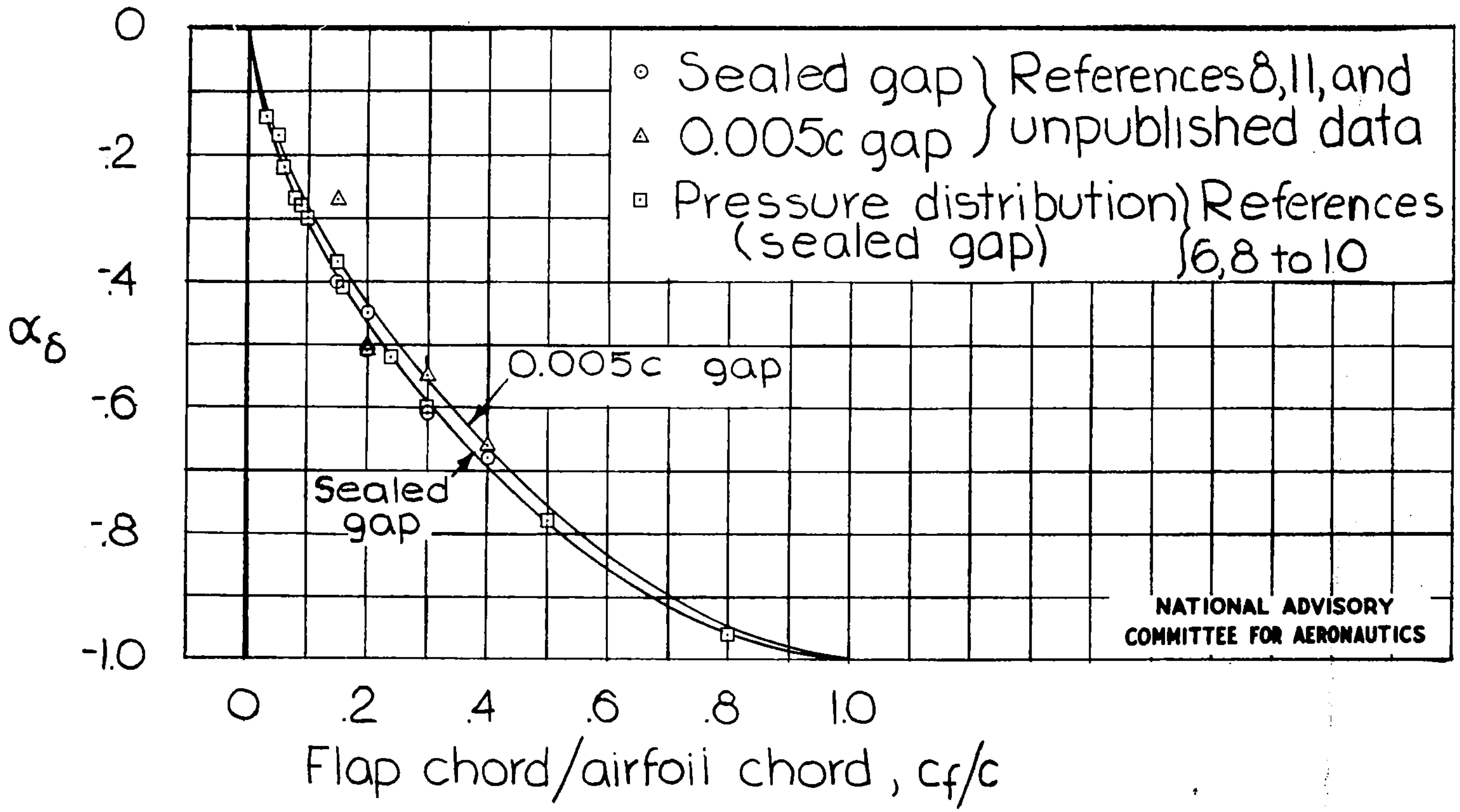


Figure 9.- Variation of lift-effectiveness parameter with ratio of flap chord to airfoil chord. Plain flaps on NACA 0009 airfoil.