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TECHNICAL NOTE

No. 1386

WIND-TUNNEL INVESTIGATION OF DROOPED AILERONS ON A 16-PERCENT-THICK LOW-DRAG AIRFOIL

By Ralph W. Holtzclaw and Jules B. Dods, Jr.

Ames Aeronautical Laboratory
Moffett Field, Calif.

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WIND-TUNNEL INVESTIGATION OF DROOPED AILERONS ON A 16-PERCENT-THICK LOW-DRAG AIRFOIL

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SUMMARY

A wind-tunnel investigation was conducted to determine the practicability of the drooped-aileron-type lateral-control device on NACA low-drag airfoils. Section aerodynamic characteristics of an NACA 66(215)-216(a = 0.6) airfoil with an aileron of normal profile and with an aileron of straight-sided profile with a modified nose shape are presented for various aileron locations, hinge centers, and aerodynamic balances.

Basic data consisting of contours of control location for maximum section lift coefficient and for minimum profile drag coefficient for various control deflections are also presented for use as an aid in aileron and flap design.

Extensive computations were made of the lateral-control characteristics of three hypothetical airplanes of widely different sizes. The results of these computations indicate that the drooped aileron can be applied successfully to airplanes of spans ranging from 45 to 141 feet. Further, the adverse yaw due to full aileron deflection does not appear to be so great as to produce excessive angles of sideslip (rudder locked), or so great as to render the rudder incapable of trimming the airplane to zero sideslip.

The profile of the drooped aileron is critical as evidenced by the nonlinear hinge-moment characteristics of the normal-profile aileron.

INTRODUCTION

The National Advisory Committee for Aeronautics has for some time been conducting research in an effort to develop suitable lateral-control devices which permit the use of full-span flaps. The need for such research is readily understood in the light of the present design trends toward

higher wing loadings with the attendant high landing speeds. One lateral-control device for use with full-span flaps is the drooped aileron which, in effect, merely utilizes the outboard portion of a full-span flap to obtain lateral control. The operation of the drooped ailerons is, from the pilot's point of view, no more complicated than the operation of normal flaps. The mechanism which extends the flaps also places the aileron in their drooped position. The ailerons are then deflected differentially to provide lateral control.

Some of the problems of lateral control introduced by the use of high lift devices have been summarized in reference 1. It was noted therein that the ratio of induced yawing to rolling moment increases adversely in direct proportion to the lift coefficient. Furthermore, the effect of a given yawing moment on the rolling control is usually greater with flaps in use because of the increased dihedral effect of the flap. Thus it was concluded to be almost necessary to use some device for lateral control that causes large changes of profile drag resulting in a favorable component of yawing moment, or to resort to partial-span flaps to reduce the induced yawing moments.

In the past, it did not appear that drooped ailerons on conventional airfoil sections would adequately solve these problems. However, a preliminary examination of slotted flaps on low-drag airfoils indicated drag characteristics superior to those for conventional sections. It appeared that if a suitable ratio between up- and down-aileron deflections were used so as to remain within the region of favorable drag characteristics, the effectiveness of the drooped aileron would be adequate and the adverse yaw would not be too severe. It remained to determine if the hinge-moment characteristics could be made to provide satisfactory control forces. Therefore, the present investigation was undertaken to determine if the obstacles could be overcome with a slotted-type aileron on a low-drag airfoil.

Two 0.25-chord ailerons were tested, one of normal profile, and one of straight-sided profile with a modified nose shape. Various amounts of aerodynamic balance and several drooped positions were investigated. The results were applied to the estimation of lateral-control characteristics of three hypothetical airplanes of widely different sizes.

COEFFICIENTS, SYMBOLS, AND CORRECTIONS

The coefficients and symbols used in the presentation and application of results are as follows:

c_l	section lift coefficient
Δc_l	increment of section lift coefficient due to aileron deflection
c_{d_o}	section profile drag coefficient
c_m	section pitching-moment coefficient about quarter chord of section
c_{n_a}	aileron section normal-force coefficient (based on total aileron chord)
c_{c_a}	aileron section chord-force coefficient (based on total aileron chord)
c_{h_a}	aileron section hinge-moment coefficient (based on total aileron chord)
c	airfoil chord including flap, feet
M.A.C.	mean aerodynamic chord, feet
b	wing span, feet
V	velocity, feet per second
S	wing area, square feet
α_o	angle of attack for infinite aspect ratio, degrees
δ_a	aileron deflection, measured relative to the airfoil chord line (positive when down), degrees
pb/2V	helix angle generated by wing tip in roll, radians
φ	angle of bank, degrees
β	angle of sideslip (positive when right wing is forward), degrees

ψ angle of yaw (positive when left wing is forward), degrees

t time, seconds

θ fraction of control-wheel travel

F aileron wheel force, pounds

In addition, the following symbols are employed:

$c_{l_\alpha} = (\partial c_l/\partial \alpha_o)_{\delta_a = 0^\circ}$ (measured through $\delta_a = 0^\circ$)

$c_{l_\delta} = (\partial c_l/\partial \delta_a)_{\alpha_o = 0^\circ}$ (measured through $\alpha_o = 0^\circ$)

$c_{h_\alpha} = (\partial c_{h_a}/\partial \alpha_o)_{\delta_a = 0^\circ}$ (measured through $\alpha_o = 0^\circ$)

$c_{h_\delta} = (\partial c_{h_a}/\partial \delta_a)_{\alpha_o = 0^\circ}$ (measured through $\delta_a = 0^\circ$)

$c_{h_{c_l}} = (\partial c_{h_a}/\partial c_l)_{\delta_a = 0^\circ}$ (measured through $c_l = 0$)

It should be noted that the aileron section normal-force chord-force, and hinge-moment coefficients were based on the total aileron chord rather than the usual chord aft of the hinge line.

The section lift, profile drag, and pitching-moment coefficients have been corrected for tunnel-wall effects by the method of reference 2. A comparison of force-test results with pressure-distribution measurements of section lift and pitching-moment coefficients indicated negligible end-plate effect on these coefficients. The end-plate effect on the profile-drag coefficients was determined by a comparison of measurements of the loss of momentum in the wing wake with the force-test measurements. All the drag results have been corrected for this effect.

It should be noted that no corrections have been applied to the hinge-moment coefficients for the effects of the tunnel walls. This was done because of the uncertain effects of the hinge-line locations and the large aileron deflections used on the absolute values of the corrections. However, approximate values of $\Delta c_{h_{c_l}}$ computed for the various hinge locations by the method of reference 3 are given in the following table to indicate the order of magnitude of the corrections:

Hinge location	$\Delta C_{h_{c_l}}$
A, C, D, E	0.0021
B	.0044
R, V	.0024
S, W	.0029
T, X, U	.0037

No corrections have been applied to the measured two-dimensional hinge moments for their application to the three-dimensional lateral-control calculations.

MODEL AND APPARATUS

The model was constructed of laminated mahogany to the NACA 66(215)-216(a = 0.6) profile of 4-feet chord.[1] The airfoil ordinates are given in table I. A 0.25-chord aileron of the normal wing profile and a 0.25-chord aileron of straight-sided profile with a modified nose shape were tested (fig. 1). The aileron ordinates are given in tables II and III, respectively. The normal-profile aileron and the slot shape (fig. 2) used for this investigation were identical to the flap and slot A of reference 4.

[1]This was the same model as that used for the tests of references 4 and 5. However, the designation has been changed to conform with the new NACA system of airfoil designation.

The model is shown mounted vertically in the Ames 7- by 10-foot tunnel No. 1 in figure 3. Turntables, 6 feet in diameter, were attached rigidly to the model and mounted flush with the tunnel floor and ceiling.

Each aileron was equipped with a single row of pressure orifices built into the upper and lower surfaces at the midspan station. The orifice locations are listed in table IV.

Provisions were made for mechanically changing the normal and chordwise location of the aileron as well as the aileron deflection. (The limits of the model aileron deflecting apparatus were -17° and 50°.) This permitted the testing of the aileron in practically every position required to simulate the movement about any given hinge location.

TESTS AND PROCEDURE

The tests were conducted at a dynamic pressure of 50 pounds per square foot, corresponding to a Reynolds number of approximately 5,100,000 and a Mach number of 0.19.

Certain undesirable characteristics were discovered for an aileron of normal profile. As these characteristics were attributable to the nose shape and profile, a straight-sided aileron with an altered nose shape was tested. This aileron will be referred to as the straight-sided aileron throughout the report.

The basic lift and drag data used for choosing the aileron hinge locations to be tested for the straight-sided aileron are presented in figures 4 and 5. Figure 4 presents contours of aileron location for maximum section lift coefficient and figure 5 presents contours of aileron location for minimum profile drag coefficient. The reference point for these contours was taken as the intersection of the airfoil chord line and the aileron nose with the aileron in its retracted position (station 0.7532 chord on the chord line). Similar data for the normal-profile aileron have previously been presented in figures 3 and 5 of reference 4.

A summary of the hinge positions tested listing the flight condition for which they were selected is presented

in tables V and VI for the normal-profile and the straight-sided ailerons, respectively.

Lift, drag, and pitching-moment measurements, as well as pressure-distribution measurements over the ailerons, were made throughout the useful angle-of-attack range for constant aileron deflections. Hinge-moment, normal-force, and chord-force coefficients were obtained by mechanically integrating plots of the normal and chordwise pressure distribution over the ailerons. The results of the tests with deflected ailerons are presented in the form of section lift, drag, pitching-moment and aileron hinge-moment coefficients as a function of the aileron deflection. Also included are the aileron section normal- and chord-force coefficients for use in the structural design of drooped ailerons.

The data for deflected ailerons are presented for corrected angles of attack of -4°, 0°, 4°, 8°, and 12°. It should be noted that the experimental data were obtained for a constant aileron deflection as a function of the uncorrected angle of attack before the final cross-plotting against aileron deflection. The symbols are, therefore, not the exact test points on the final cross plots but have been used to identify the data.

RESULTS AND DISCUSSION

Normal-Profile Aileron

The effects of the slotted ailerons (undeflected) on the section aerodynamic characteristics of the NACA 66(215)-216 (a = 0.6) airfoil are shown in figure 6. As shown by this figure, the effect of the undeflected normal-profile slotted aileron was to increase the drag of the aileron at low and intermediate lift coefficients, to decrease the slope of the lift curve slightly, and to cause a slight decrease of the maximum lift coefficient. There was also a small change of the pitching-moment characteristics.

The section aerodynamic characteristics obtained for hinge positions A to E (table V) for the normal-profile aileron are presented in figures 7 to 11. A reversal of

slope in the variation of aileron hinge-moment coefficient with deflection for hinge position A is indicated in figure 7. The reversal, which would contribute to a nonlinear variation of control force with control deflection on an airplane, occurs at an aileron deflection of approximately -10° for angles of attack above 0°. It was in an effort to eliminate this reversal that a modified aileron was designed and tested. Computations are presented later in this report to illustrate further the undesirable characteristics of the normal-profile control.

The effectiveness of the aileron was greatly reduced when it was positioned for minimum drag rather than maximum lift as shown by hinge positions D and E (figs. 10 and 11). Consequently, no further consideration was given such locations.

Application of the results of the tests of the normal-profile aileron with hinge locations A, B, and C to specific airplane configurations are presented and discussed later in this report.

Straight-Sided-Profile Aileron

Because of the deficiencies indicated for the normal-profile aileron, another aileron was designed and tested. This aileron had a modified nose shape, altered to eliminate the hinge-moment coefficient reversal exhibited by the normal-profile control. In an effort to provide a value of C_{h_δ} numerically smaller than that of the normal-profile aileron, the profile was made straight-sided. (See table III.)

As shown by figure 6, the effect of the straight-sided aileron on the airfoil characteristics as compared with the normal-profile aileron was to increase the drag slightly at low and intermediate lift coefficients, decrease the lift-curve slope slightly, and decrease the pitching moment. During the course of the investigation it was necessary to shorten the curtain to permit the testing of the straight-sided aileron as a slotted aileron with reduced balance. (See table VI.) In general, the effect on the aerodynamic characteristics of shortening the curtain was to magnify the effects observed by changing the normal profile to

straight-sided. It should be noted that discontinuity in the lift curves often encountered with low-drag airfoils at low Reynolds numbers was much more noticeable with the straight-sided aileron than with the normal-profile aileron (fig. 6).

Comparison of the data of figures 4 and 5 for the straight-sided aileron with figures 3 and 5 in reference 4 for the normal-profile aileron indicates that there is little effect upon the maximum lift and minimum drag due to changing the aileron profile; furthermore, there is only a small change in the aileron locations for optimum lift and drag. There is some variation in the shape of the contours, however, this may be partly due to variations in the size of the area surveyed and to the frequency of the survey points.

The section aerodynamic characteristics obtained for hinge positions R to X (table VI) for the straight-sided-profile aileron are presented in figures 12 to 18. It should be noted that the straight-sided aileron exhibits the same hinge-moment reversal (figs. 12, 13, and 14) as that of the normal-profile aileron (fig. 7) but to a lesser degree. A comparison of the hinge-moment and effectiveness parameters for the straight-sided aileron with various amounts of balance (hinge positions R, S, and T) with those for the normal-profile aileron with 43.35-percent balance (hinge position A) is shown in table VII. It should be noted that the straight-sided aileron gave the desired reduction in c_{h_δ} but at the expense of a considerable loss in aileron effectiveness c_{l_δ}. The values of c_{h_δ} for the straight-sided aileron with 42.05-percent balance was -0.0013 with a c_{l_δ} of 0.037 as compared to a c_{h_δ} of -0.0030 and a c_{l_δ} of 0.045 for the normal-profile aileron with 43.35-percent balance. However, undue significance should not be attached to these values since they are valid only for small aileron-deflection and angle-of-attack ranges.

In order to determine if the ailerons tested would meet the requirements for a satisfactory lateral-control device, an estimate was made of the lateral-control characteristics of three hypothetical airplanes assuming a full-span-flap installation incorporating drooped ailerons. The estimated characteristics were then compared with the characteristics

required of a satisfactory lateral control device. Aileron hinge positions suitable for use in the high-speed flight condition and for the landing approach were chosen for investigation. For the high-speed condition with the normal-profile aileron, hinge position A (the only applicable position investigated) was chosen. Because of the low value of c_{h_δ} and the higher value of c_{l_δ}, hinge position R was chosen for the straight-sided aileron for this condition. To keep the mechanism relatively simple, it was desired to investigate a position such that the aileron and hinge could be positioned by a single mechanism for the landing approach. To keep the balance unchanged, hinge position C was therefore used for the normal-profile aileron and hinge position V was used for the straight-sided aileron. For comparison, a double-hinge arrangement was also investigated for the approach condition (hinge position B for positive deflections of the normal-profile aileron with hinge position A for negative deflections, and hinge position U for positive deflections of the straight-sided aileron with hinge position R for negative deflections).

Estimation of the Characteristics of Airplanes with Drooped-Aileron Installations

The airplanes chosen for analysis are types, widely varying in size, which might profitably use a full-span-flap installation. Their assumed characteristics are given in table VIII. Airplane A is a large, four engine, long-range bomber; airplane B is a large, two-engine, patrol bomber; and airplane C is a carrier-based, single-engine, scout bomber,

Computations have been made for rudder-locked rolls for each of the three airplanes for the high-speed flight condition and for the landing approach with the flaps extended. The section lift and profile-drag coefficients were first converted to rolling- and yawing-moment coefficients by the method of references 6, 7, and 8. These values were then used for the calculation of $pb/2V$ and the angles of bank, sideslip, and yaw as a function of time by the method of references 9 and 10.

(The results of these calculations are later referred to as the time histories of the roll.) These results are directly comparable with those of reference 5 for spoiler-type controls.

Assumptions.- In estimating the characteristics of the airplanes with drooped-aileron installations, the following assumptions have been made:

1. Slotted ailerons of 25-percent total chord have been assumed for all three airplanes.

2. Rigid wings have been assumed throughout the calculations.

3. No allowance has been made in the calculations for Mach number effects.

4. The values of $pb/2V$ computed for the landing approach have been assumed applicable to the landing condition.

5. The variation of aileron deflection with control-wheel displacement shown in figure 19 has been assumed.

6. For the landing approach the ailerons have been assumed to be drooped sufficiently to give an increment of section lift coefficient of 0.8. (This amounts to a deflection of about 16° for all three airplanes.) The estimated reduction in landing speeds (mph) due to drooping the ailerons and the landing approach speeds of the three airplanes used in the calculations are shown in the following table:

Airplane	Reduction in landing speed due to drooped ailerons, mph	Landing approach speed, mph
A	7.4	98
B	5.4	105
C	3.8	86

Greater reductions could be obtained with increased aileron droop. However, some rolling effectiveness would be sacrificed if the droop were increased to such a point that the resulting aileron deflection exceeds 40°. Also, experiments have indicated a deterioration in stalling characteristics and lateral stability near and at the stall of airplanes with full-span flaps when the wing was too heavily loaded at the tip. For these reasons, more conservative deflections were used.

Calculated Characteristics.- Roll time histories were computed for each of the three airplanes equipped with the normal-profile and straight-sided ailerons for the high-speed flight condition and for the landing approach. Typical time histories (assuming instantaneous control deflection) are presented in figure 20 for airplane A equipped with the straight-sided aileron for the high-speed and approach conditions. The variation of maximum $pb/2V$ and wheel force with control travel for each of the three airplanes is shown in figure 21 for the normal-profile aileron and in figure 22 for the straight-sided aileron.

Control effectiveness requirements.- For a satisfactory lateral-control device, the variation of rolling acceleration with time immediately following an abrupt control deflection should always be in the correct direction. Inspection of the roll time histories indicated that all three airplanes met this requirement with either the normal-profile or straight-sided ailerons as evidenced by the positive gradient of the variation of $pb/2V$ with time.

At any speed, the maximum rolling velocity obtained by abrupt deflection of the lateral control with the rudder locked in its trim position should vary smoothly with and be approximately proportional to the control deflection. As shown by figures 21 and 22, this requirement is also satisfied by all three airplanes with either aileron.

The lateral control should be of sufficient power to produce a wing-tip helix angle $pb/2V$ equal to or greater than 0.09 for airplanes such as fighters, dive bombers, and torpedo bombers, and 0.07 for horizontal bombers, cargo, transport and primary training airplanes in the high-speed flight condition with the rudder locked in its trim position. The required values of $pb/2V$ are somewhat lower for speeds in excess of 300 miles per hour. The lateral control should

also be capable of producing a $pb/2V$ of 0.07 for all airplanes in the landing condition with the rudder locked in its trim position. As shown by figures 21 and 22, airplane C fails to achieve the required $pb/2V$ of 0.09 with either aileron, reaching a value of only 0.068 with the normal-profile aileron and 0.074 with the straight-sided aileron. This airplane has unusually short-span ailerons - only 29 percent of the wing span. To meet this requirement the aileron span would have to be increased to approximately 35 percent of the wing span. The $pb/2V$ for airplane A was also slightly low for the approach condition (0.067 compared with the required 0.07) with the straight-sided aileron. Airplane B reaches rather high values of $pb/2V$ in the approach condition because of a slight roll instability for this flight condition.

For all airplanes the product of the rolling velocity and the wing span should be at least 10 feet per second for the landing condition when the airplane is rolled with abrupt full aileron deflection with the rudder locked in its trim position. The product of the rolling velocity and the wing span is shown in the following table for each of the three airplanes:

Airplane	Product of rolling velocity and wing span	
	Normal-profile aileron	Straight-sided aileron
A	23.3	19.4
B	35.7	29.2
C	18.7	15.9

As shown by the above table all three airplanes satisfy this requirement with either aileron.

For horizontal bombers, cargo, and transport airplanes the ratio $pb/2V$ per 100° of wheel throw should be at least 0.05 up to 70 percent of the maximum indicated level flight speed in the high-speed flight configuration with the rudder

locked in its trim position. An inspection of figures 19, 21, and 22 indicates that both airplanes A and B satisfy this requirement with the straight-sided aileron but that airplane B is marginal with the normal-profile aileron. (Airplane C is not affected by this requirement.)

Control-force requirements.- The variation of lateral-control force with stick or wheel deflection in the rolling maneuvers previously discussed should be a smooth curve with sufficient gradient to provide satisfactory control-centering characteristics. As shown by figure 21 the variation of control force with wheel deflection is unsatisfactory with airplanes A and B with the normal-profile aileron. As shown by figure 22, the variation is satisfactory for all three airplanes with the straight-sided aileron. The control forces appear to be great enough to provide satisfactory control-centering characteristics for airplanes A and B with this aileron, but airplane C might be deficient in this respect unless special care is exercised to keep the control friction small. However, it is obviously quite difficult to make an accurate prediction of this characteristic.

With the rudder locked in its trim position, it should be possible to obtain the required values of $pb/2V$ without demanding forces of the pilot in excess of 80 pounds for wheel-type controls and 30 pounds for stick-type controls. As shown by figure 21 neither airplanes A nor B satisfy this requirement with the normal-profile aileron. As shown by figure 22 the control forces are within the specified limit for airplanes A and C with the straight-sided aileron, but the forces are still high for airplane B. It should be noted that the control force for a $pb/2V$ of 0.07 for airplane B was reduced from a value of 165 pounds with the normal-profile aileron to 92 pounds with the straight-sided aileron. The low angle of attack required for the high-speed flight condition and resulting large hinge moments (fig. 12) of the up-aileron contribute to the high control forces of this airplane. The control forces for airplane B could probably be reduced sufficiently by a slight adjustment of the aileron balance.

From the foregoing discussion it has been demonstrated that from the standpoint of lateral control the straight-sided drooped aileron can be used successfully on three airplanes widely varying in size.

Other requirements.- Other requirements, such as the maximum allowable reduction of roll velocity due to wing twist, and so forth, are considered to be beyond the scope of this discussion.

A common criticism of drooped ailerons has been that the adverse yaw as a result of full aileron deflection would be too great in low-speed flight. However, an inspection of the computed roll time histories indicated that the yaw due to full aileron deflection with the rudder locked did not result in excessive angles of sideslip for any of the airplanes. In addition, an investigation of the rudder power available indicated that the rudder would be capable of trimming out the adverse yaw.

Application to light airplanes.- One application of drooped ailerons, not previously considered in this report, is to the comparatively small airplane flying at speeds not much in excess of 200 miles per hour, such as a personal or a small executive-type airplane. For such an installation, large hinge-moment coefficients may be tolerated, in which case one hinge-location could be used for positive aileron deflections with an alternate hinge location for negative deflections; the control would droop about the hinge center for positive deflections and would then rotate about that same axis for lateral control. A further step could be taken in this type of installation by using large-span drooped ailerons with no other flaps. The merit of drooped ailerons in such installations would probably not be due so much to the reduced landing speed possible (the increment would be quite small for very low wing loadings) as to the possibility of increasing the wing loading without an increase in landing speed.

Comparison with spoilers.- Another method of achieving lateral control which retains the advantages of full-span flaps is the spoiler type of control. The maximum rate of roll obtained by spoiler control for the three exemplary airplanes is compared with that obtained from the drooped-aileron control in the high-speed and in the approach condition in figures 23 and 24, respectively. For each of the airplanes a higher rate of roll is reached with spoiler control than with the drooped aileron. The spoiler control, however, requires that "feeler" ailerons or some other artificial method be used to provide the pilot with the proper control

forces. The computations presented for the spoiler control were taken from figure 23 of reference 5.

Drooped ailerons on thin wings.- All the data presented in this report were obtained from tests of a 16-percent-thick airfoil at low Mach numbers. Preliminary design considerations of drooped ailerons on thin wings for use on very high-speed airplanes indicate that many compromises in the optimum aerodynamic arrangement must be made because of the extreme thinness of the aft portion of the airfoil.

CONCLUSIONS

The results of the wind-tunnel investigation to determine the practicability of the drooped-aileron type of lateral-control device on low-drag airfoils indicated the following:

1. Drooped ailerons can be applied to airplanes as a satisfactory lateral-control device, as shown by calculations of the lateral-control characteristics of three airplanes of spans ranging from 45 feet to 141 feet.

2. The adverse yaw due to full aileron deflection would not be so great as to produce excessive angles of sideslip (rudder locked), or so great as to render the rudder incapable of trimming the airplane to zero sideslip.

3. The profile of the drooped aileron of the type tested is critical as evidenced by the nonlinear hinge-moment characteristics of the normal-profile aileron.

4. The effectiveness of the drooped aileron is seriously reduced when the aileron is positioned for minimum drag rather than maximum lift.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., July 1947.

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TABLE I.- NACA 66(215)-216 (a =0.6) AIRFOIL
[Stations and ordinates in percent of the airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.371	1.242	.629	-1.112
.607	1.501	.893	-1.319
1.091	1.886	1.409	-1.608
2.317	2.615	2.683	-2.127
4.794	3.701	5.206	-2.869
7.284	4.563	7.716	-3.441
9.781	5.308	10.219	-3.934
14.788	6.500	15.212	-4.702
19.806	7.428	20.194	-5.290
24.832	8.155	25.168	-5.741
29.862	8.708	30.138	-6.080
34.897	9.098	35.103	-6.312
39.936	9.356	40.064	-6.462
44.978	9.471	45.022	-6.523
50.023	9.431	49.977	-6.483
55.073	9.224	54.927	-6.336
60.141	8.800	59.859	-6.048
65.191	8.084	64.809	-5.574
70.198	7.068	69.802	-4.866
75.181	5.889	74.819	-4.037
80.148	4.585	79.852	-3.107
85.106	3.265	84.894	-2.177
90.061	1.937	89.939	-1.235
95.021	.762	94.979	- .432
100	0	100	0

Leading-edge radius: 1.575 Trailing-edge radius: 0.0625 Slope of radius through leading edge: 0.110

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TABLE II.- ORDINATES FOR THE 0.25-CHORD NORMAL-PROFILE SLOTTED AILERON ON THE NACA 66(215)-216(a = 0.6) AIRFOIL

[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
75.000	-1.875	-
75.521	.042	-3.062
76.042	.895	-3.437
77.083	1.937	-3.604
78.125	2.646	-3.417
79.167	3.125	-3.229
80.208	3.458	-3.042
81.250	3.646	-2.854
82.292	3.687	-2.646
83.333	3.625	-2.437
84.375	3.437	-2.250
85.417	3.208	-2.062
87.500	2.646	-1.667
89.583	2.083	-1.292
91.667	1.542	-.917
93.750	1.062	-.583
95.833	.604	-.333
97.917	.271	-.167
100	-	-
Trailing-edge radius = 0.0625		

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TABLE III.- ORDINATES FOR THE 0.25-CHORD STRAIGHT-SIDED SLOTTED AILERON ON THE NACA 66(215)-216(a = 0.6) AIRFOIL

[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
75.000	-0.937	—
75.521	.417	-2.271
76.042	1.021	-2.646
77.083	2.000	2.875
78.125	2.687	2.937
79.167	3.187	2.937
80.208	3.500	2.896
81.250	3.687	2.792
82.292	3.750	2.667
83.333	3.667	2.500
84.375	3.479	2.354
[a]85.417	3.250	2.208
Trailing-edge radius = 0.0625		

[a]Straight lines from station 85.417 tangent to trailing-edge radius.

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TABLE IV.- PRESSURE-ORIFICE LOCATIONS IN THE AILERONS ON THE NACA 66(215)-216 (a = 0.6) AIRFOIL

[1]Station, percent airfoil chord	Location
75.00	Leading-edge
75.31	Upper and lower surfaces
75.63	do.
76.25	do.
77.51	do.
78.76	do.
80.01	do.
82.52	do.
85.03	do.
87.53	do.
90.04	do.
92.54	do.
95.05	do.
97.56	do.
98.81	do.

[1]Flap retracted.

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TABLE V.- SUMMARY OF THE HINGE POSITIONS TESTED FOR THE NORMAL-PROFILE AILERON

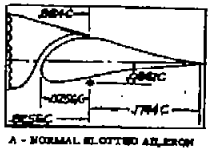
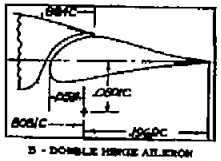
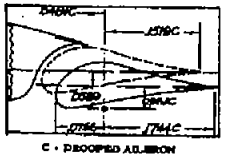
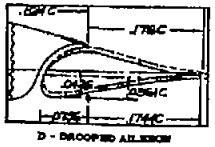
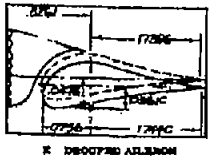
Hinge Position	Percent Balance	Flight Condition for which Selected	Desired Characteristics	Data Presented in Figure	Remarks
 A - NORMAL SLOTTED AILERON	43.35	High-speed	Good effectiveness. Low hinge moments.	7	Reversal in variation of hinge-moment coefficient with aileron deflection.
 B - DOUBLE HINGE AILERON	26.98	Landing (use for positive deflections)	Good lift increment in drooped position plus good effectiveness when deflected from drooped position.	8	High hinge moments.
 C - DROOPED AILERON	43.35	Landing (positioned for maximum lift at 40° deflection)	do.	9	Extremely small hinge moments.
 D - DROOPED AILERON	43.35	Take-off and landing (positioned for minimum drag with 10° deflection)	Low drag and good lift increment at 10° droop plus good effectiveness when deflected from drooped position.	10	Poor effectiveness and extremely small hinge moments.
 E - DROOPED AILERON	43.35	Take-off and landing (positioned for minimum drag with 20° deflection)	Low drag and good lift increment at 20° droop plus good effectiveness when deflected from drooped position.	11	Poor effectiveness and extremely small hinge moments.

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TABLE VI. - SUMMARY OF THE HINGE POSITIONS TESTED FOR THE STRAIGHT-SIDED AILERON

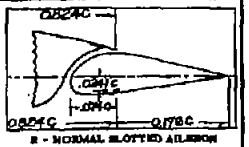
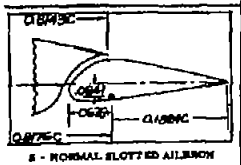
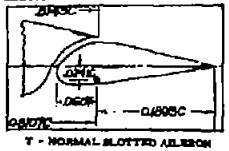
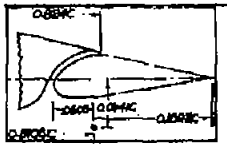
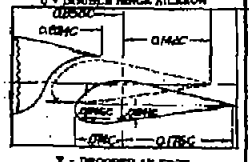
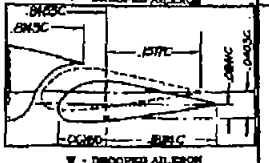
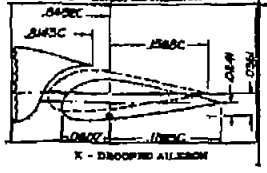
Hinge Position	Percent Balance	Flight Condition for Which Selected	Desired Characteristics	Data Presented in Figure	Remarks
 R - NORMAL SLOTTED AILERON	42.05	High-speed	Good effectiveness. Low hinge moments.	12	Tendency toward overbalance; however, it is less severe than that for hinge position A for normal profile aileron.
 S - NORMAL SLOTTED AILERON	37.05	High-speed	do.	13	Effectiveness less than hinge position R.
 T - NORMAL SLOTTED AILERON	32.05	High-speed	do.	14	Effectiveness less than hinge position R but greater than S.
 U - DOUBLE HINGE AILERON	32.14	Landing (use for positive deflections)	Good lift increment in drooped position plus good effectiveness when deflected from drooped position.	15	Good effectiveness with moderate hinge moments.
 V - DROOPED AILERON	42.05	Landing (with same balance as position R)(positioned for maximum lift for 45° deflection)	do.	16	Low hinge moments with tendency toward overbalance.
 W - DROOPED AILERON	37.05	Landing (with same balance as position S)(positioned for maximum lift at 40° deflection)	do.	17	Effectiveness greater than for hinge position V.
 X - DROOPED AILERON	32.05	Landing (with same balance as position T)(positioned for maximum lift at 40° deflection)	do.	18	Effectiveness better than either hinge position V or W.

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TABLE VII.- SUMMARY OF PARAMETERS FOR THE NORMAL PROFILE AND THE STRAIGHT-SIDED-PROFILE AILERONS

Parameter	Normal profile aileron	Straight-sided profile aileron		
Hinge position	A	R	S	T
Percent balance	43.35	42.05	37.05	32.05
c_{l_δ}	.045	.037	.030	.030
c_{l_α}	.093	.093	.093	.093
c_{h_δ}	-.0030	-.0013	-.0018	-.0023
c_{h_α}	-.0026	.0014	.0011	.0011

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TABLE VIII.- ASSUMED AIRPLANE CHARACTERISTICS

ITEM	Airplane		
	A	B	C
Type airplane	Heavy bomber 4-engine	Large 2-engine patrol bomber	Carrier-based scout bomber
Wing loading, pounds per square foot	61.3	45	39.2
Aspect ratio	11.65	10	5.4
Taper ratio	0.436	0.5	0.5
Wing area, square feet	1714	1000	375
Wing span, feet	141	100	45
Inboard flap span, percent span	60	60	67
Aileron span, percent span	37	36	29
Aileron area, total for one aileron, square feet	60.4	35.8	10.85
Wheel diameter, inches	14	14	12
Wheel throw, degrees	164	164	135
K_X Radius of gyration about X-axis, feet	21.45	14.5	5.54
K_Z Radius of gyration about Z-axis, feet	26.4	18	9.13

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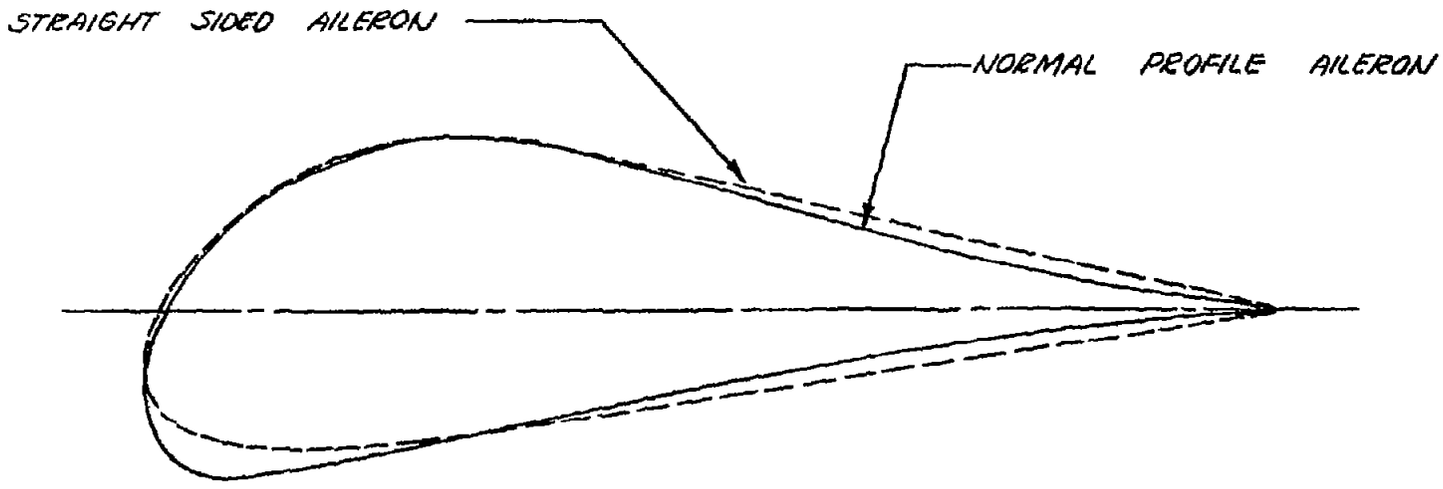

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FIGURE 1.- A COMPARISON OF THE CONTOURS OF THE NORMAL PROFILE AND THE STRAIGHT SIDED AILERONS TESTED ON THE NACA 66(215)-216 (a=0.6) AIRFOIL

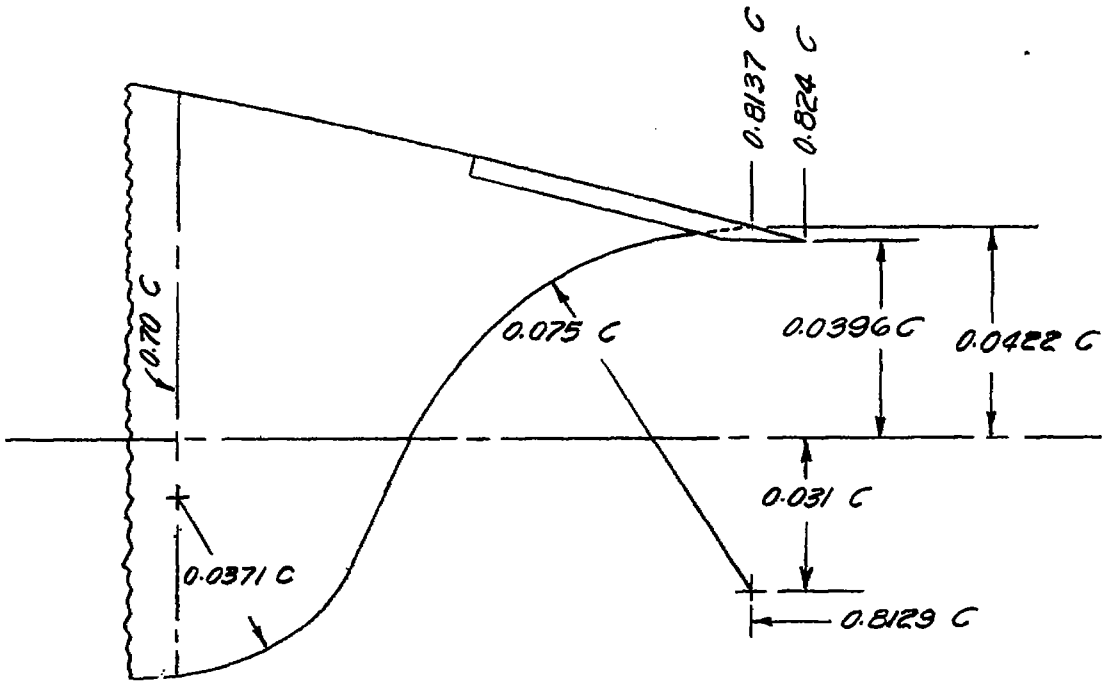

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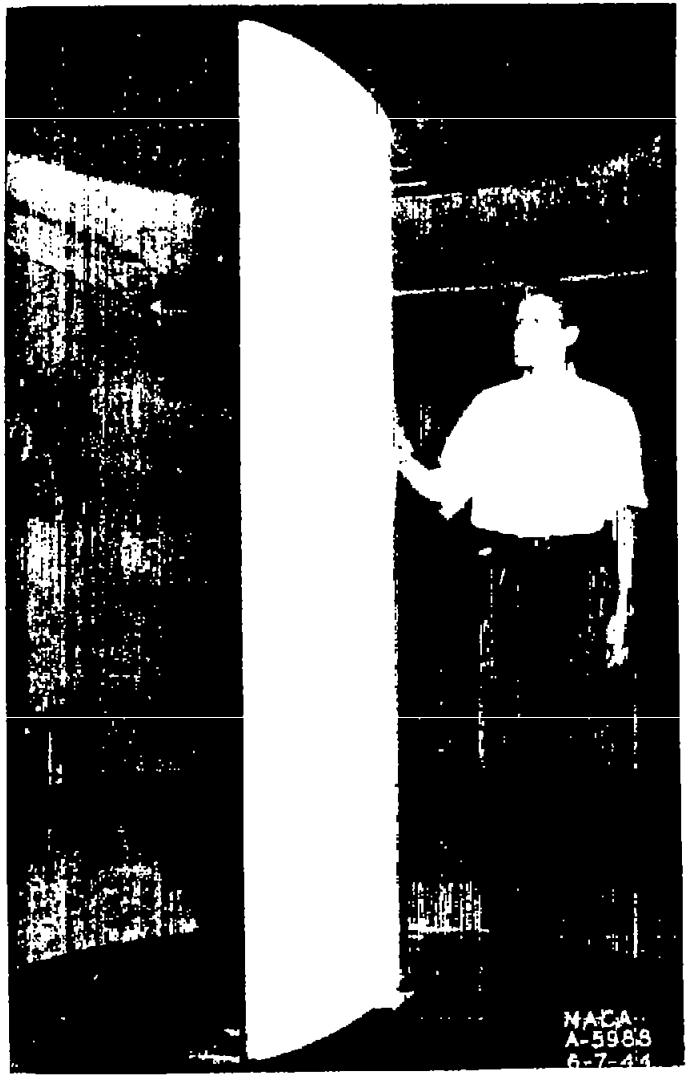
FIGURE 2.- DETAILS OF THE WING SLOT OF THE NACA 66(215)-216 (a=0.6) AIRFOIL.



(a) Front view.

(b) Rear view.

Figure 3.- NACA 66(215)-216(a-0.6) airfoil mounted in the 7- by 10-foot wind tunnel.

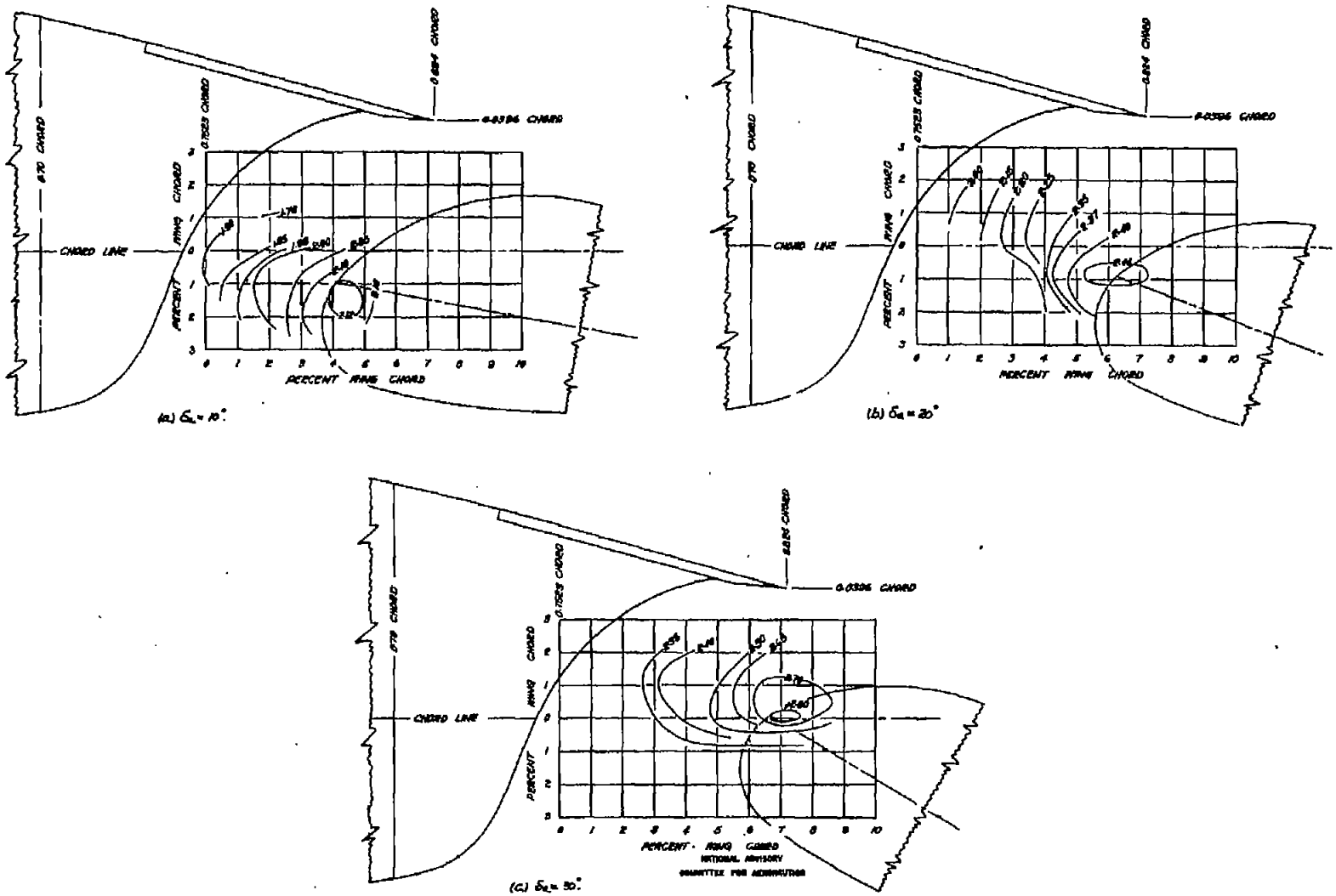


FIGURE 4.- CONTOURS OF AILERON LOCATION FOR MAXIMUM SECTION LIFT COEFFICIENT FOR THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD STRAIGHT-SIDED AILERON.

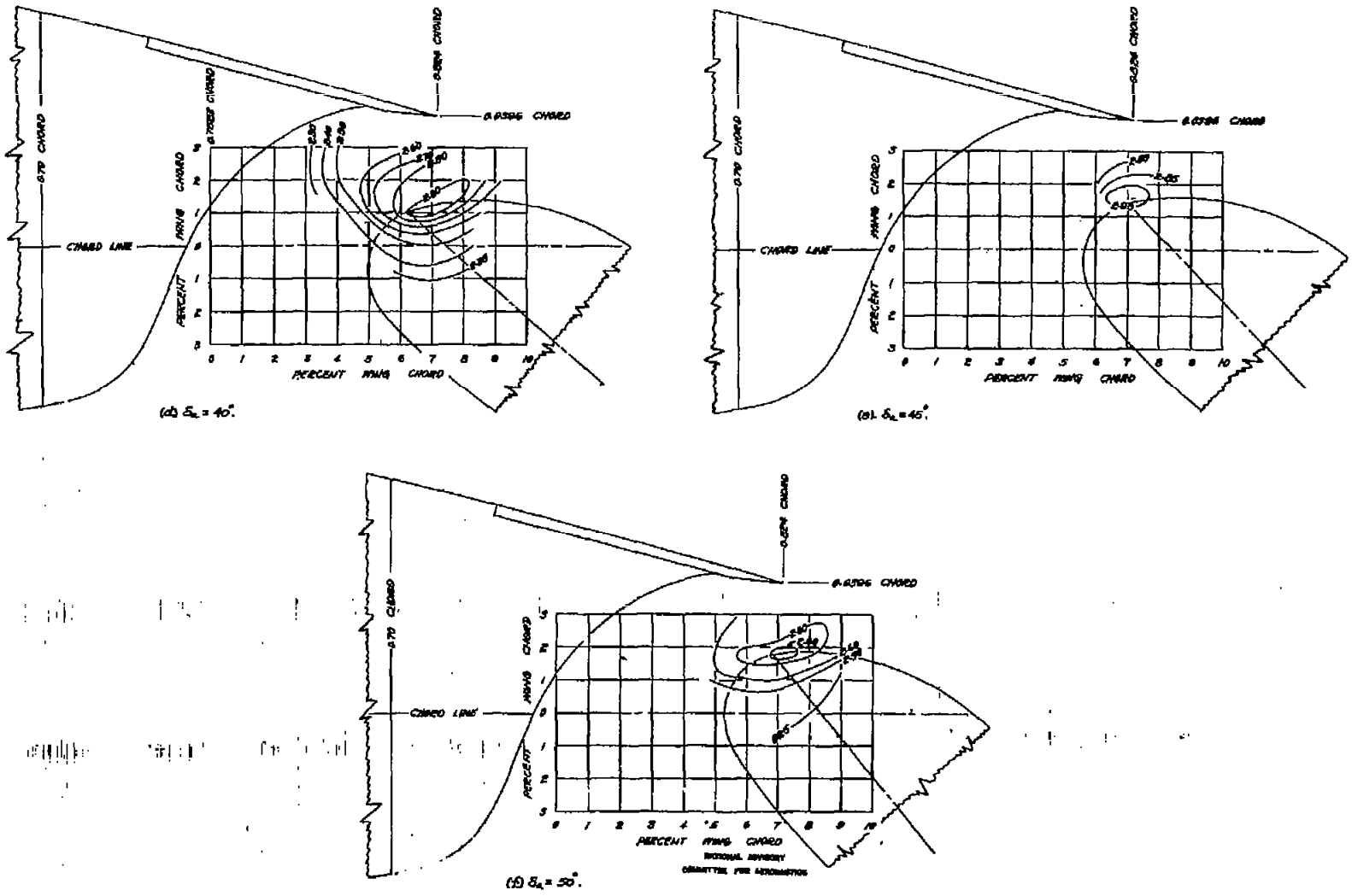


FIGURE 4.- CONCLUDED.

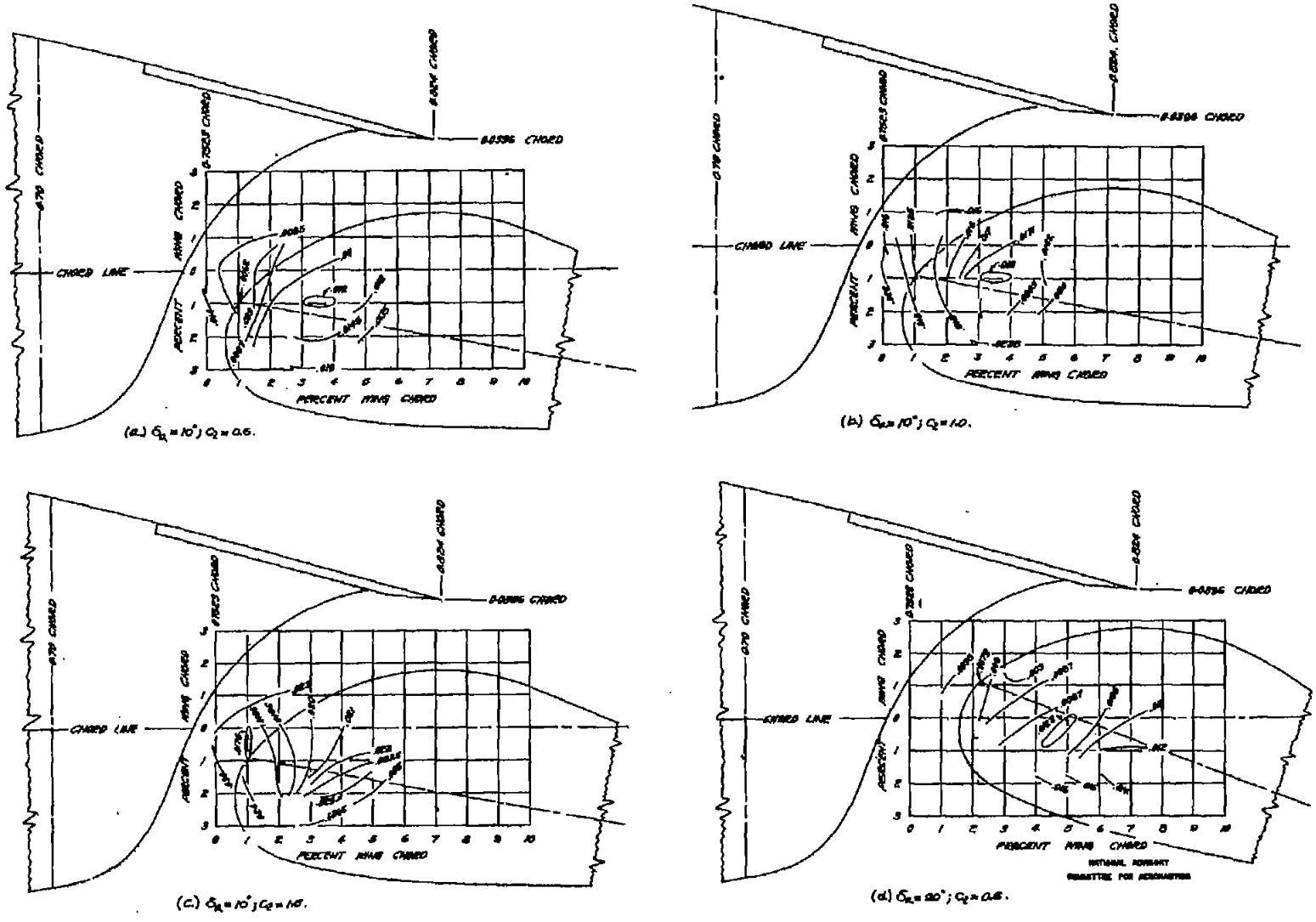
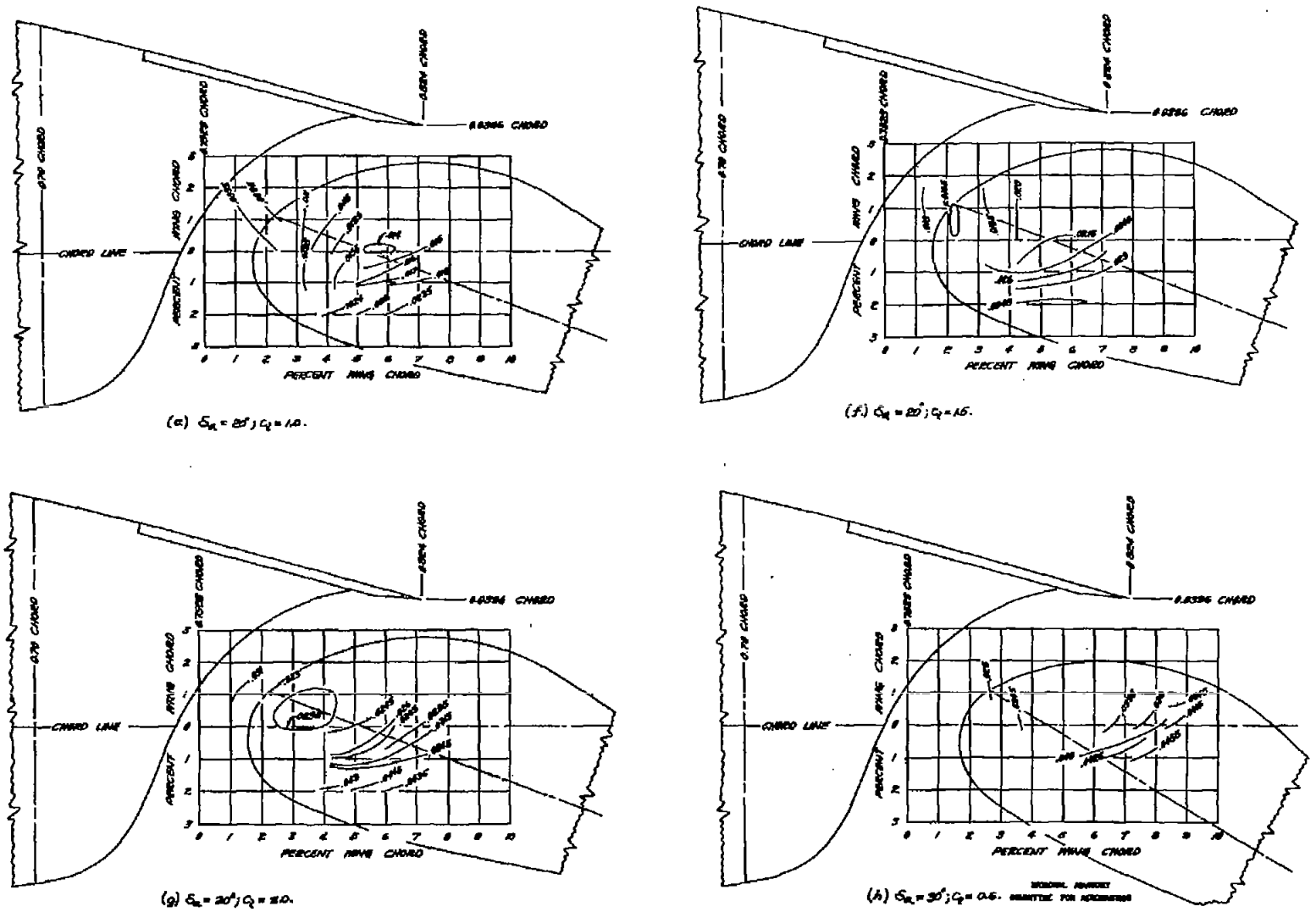


FIGURE 5.- CONTOURS OF AILERON LOCATION FOR MINIMUM PROFILE-DRAG COEFFICIENT FOR THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD STRAIGHT-SIDED AILERON.



(a) $\delta_{fl} = 20°$; $C_L = 1.0$.

(f) $\delta_{fl} = 20°$; $C_L = 1.5$.

(g) $\delta_{fl} = 20°$; $C_L = 2.0$.

(h) $\delta_{fl} = 20°$; $C_L = 0.5$.

FIGURE 5.- CONTINUED.

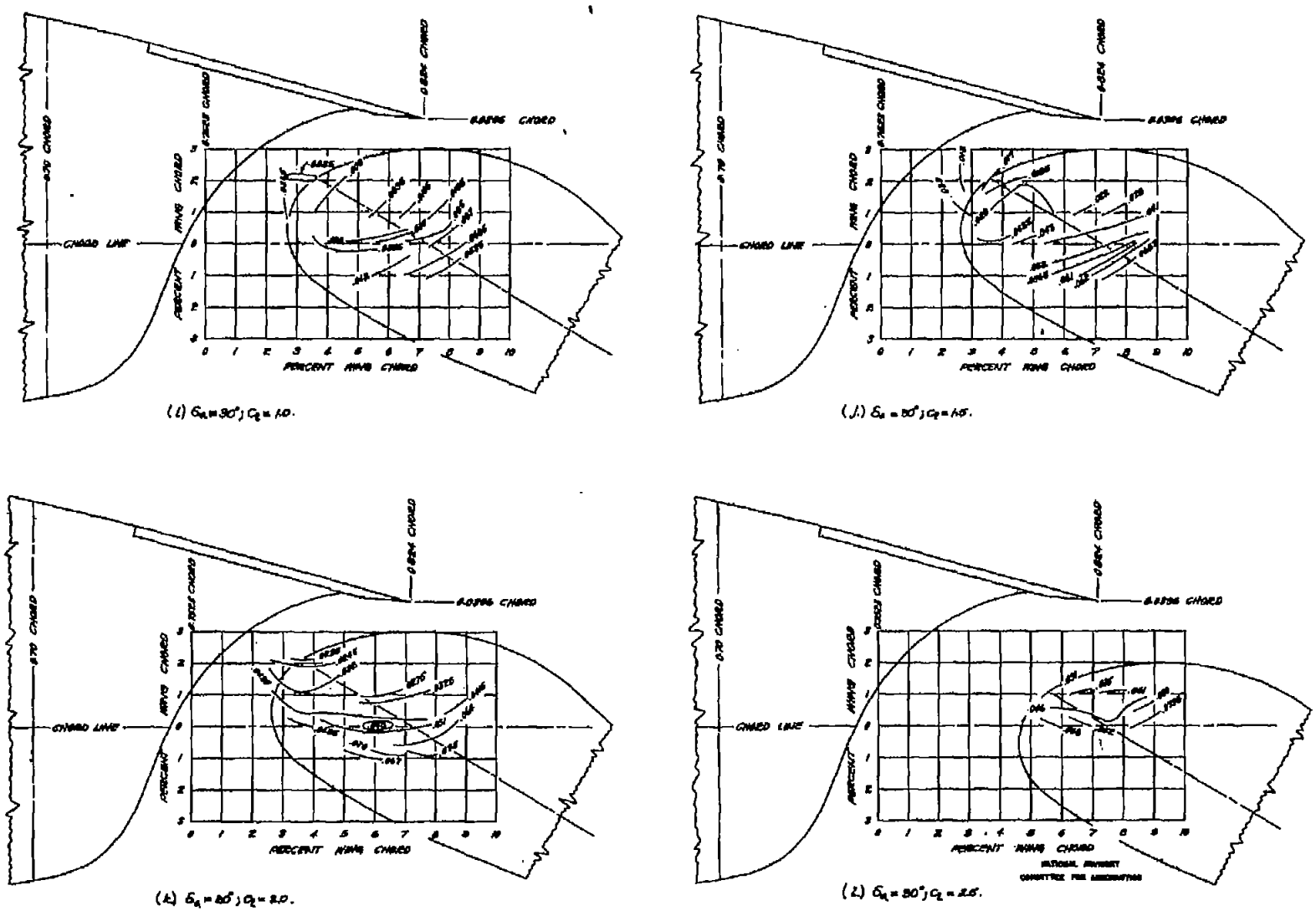


FIGURE 5.- CONCLUDED.

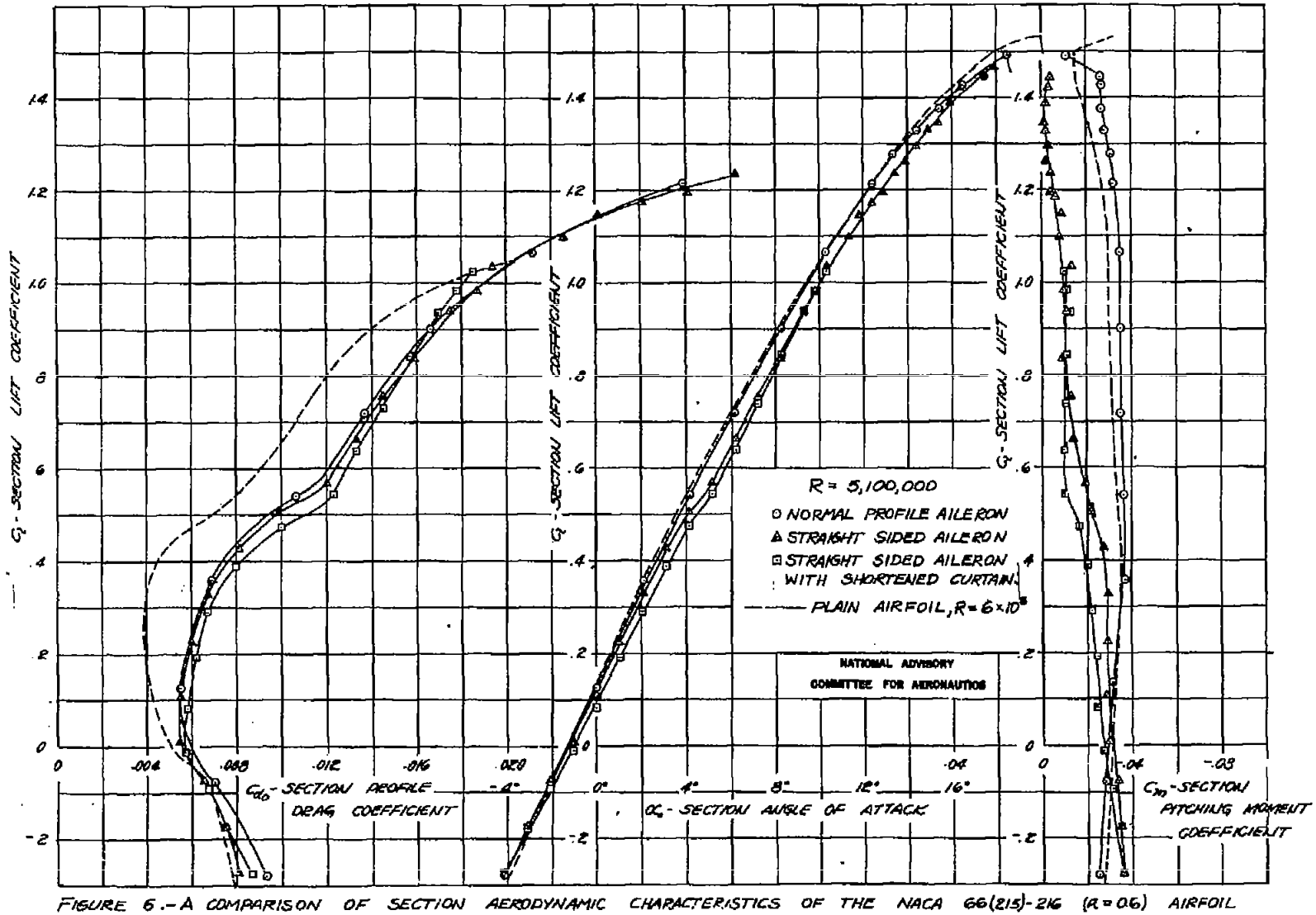
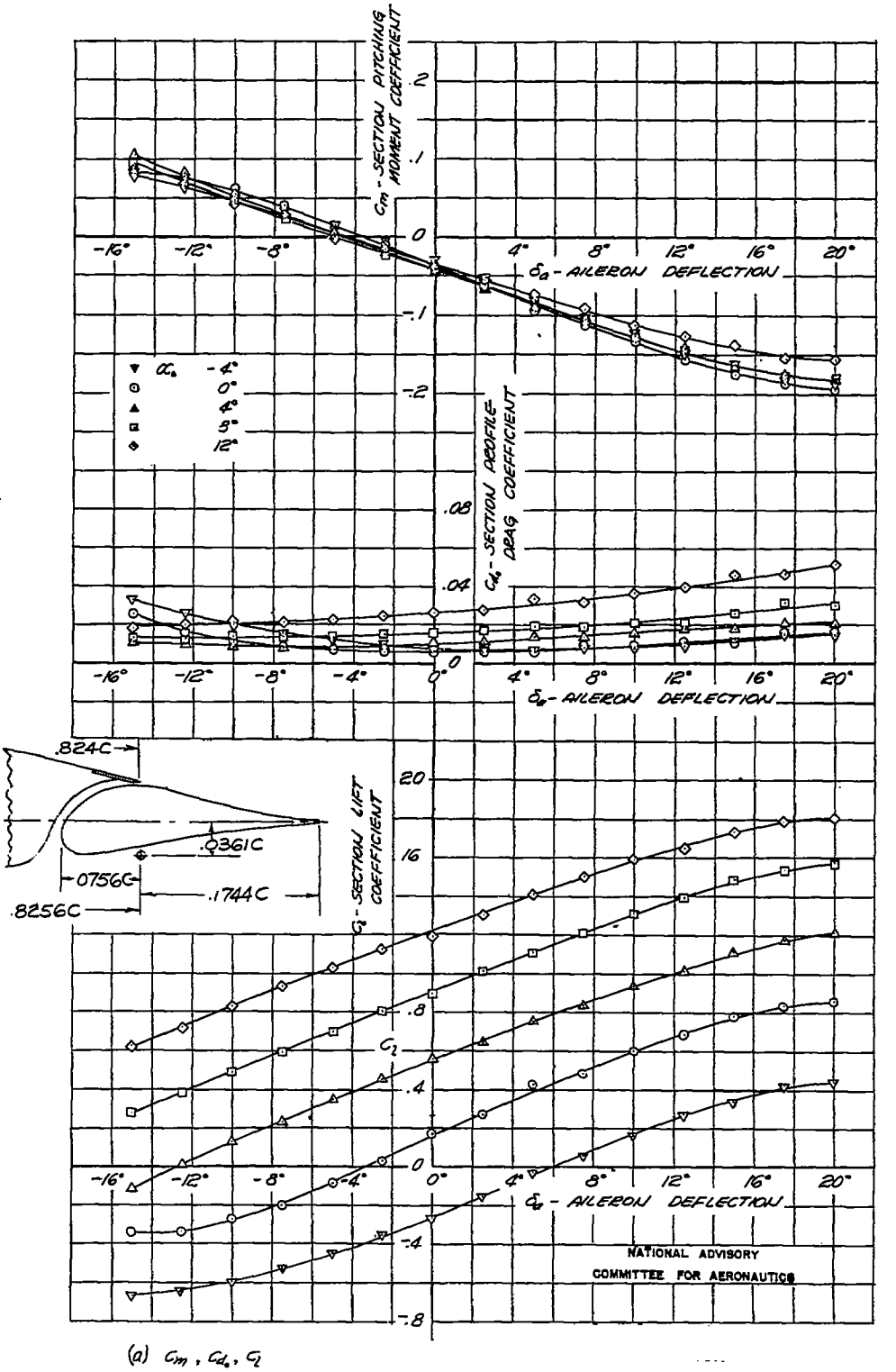
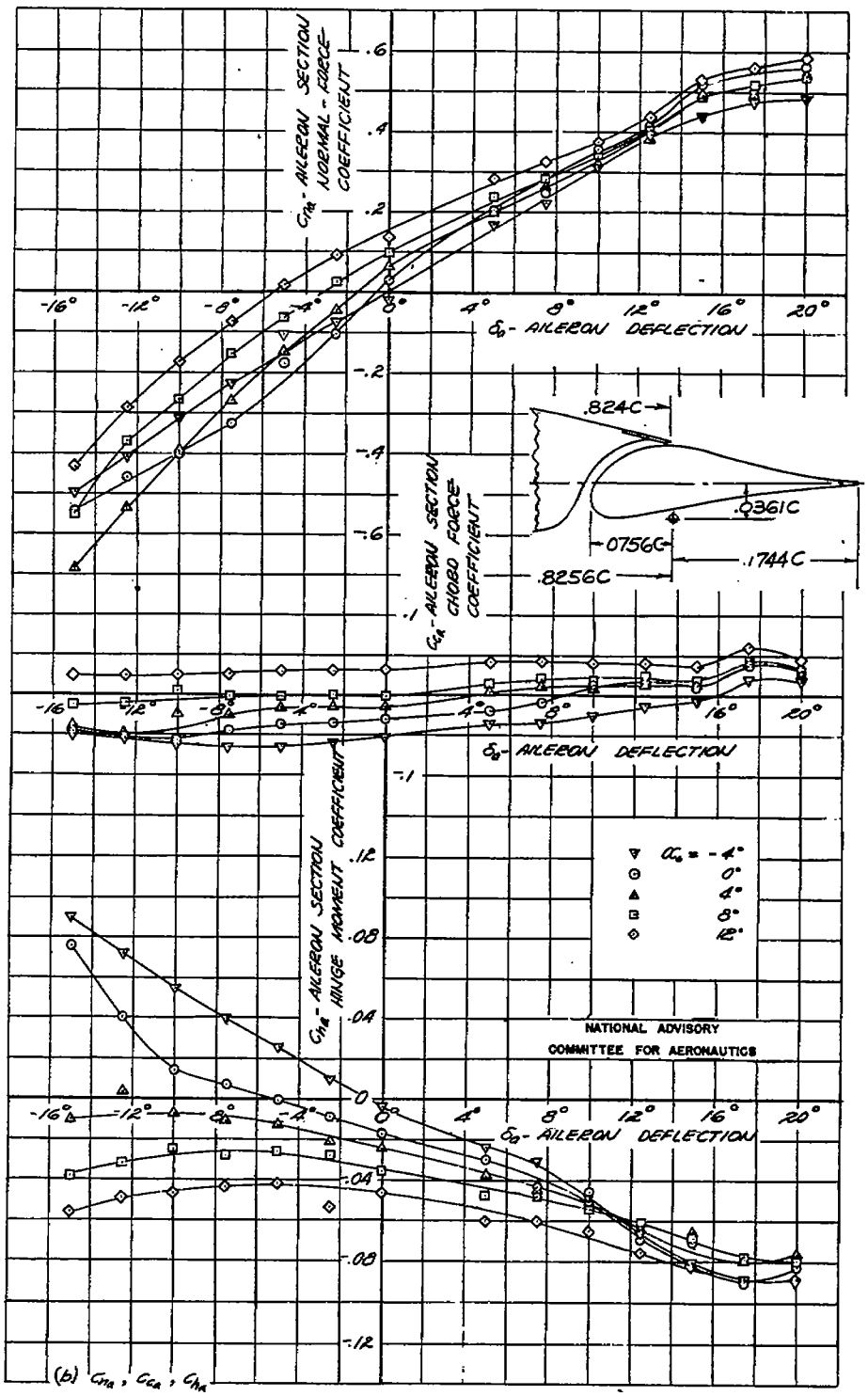


FIGURE 6.- A COMPARISON OF SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a = 0.6) AIRFOIL EQUIPPED WITH SLOTTED AILERONS WITH THE CHARACTERISTICS OF THE PLAIN AIRFOIL.



(a) c_m, c_{d_o}, c_l

FIGURE 7 - SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD NORMAL PROFILE AILERON WITH A 43.35 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION A.



(b) C_{n_a}, C_{c_a}, C_{h_a}

FIGURE 7.- CONCLUDED.

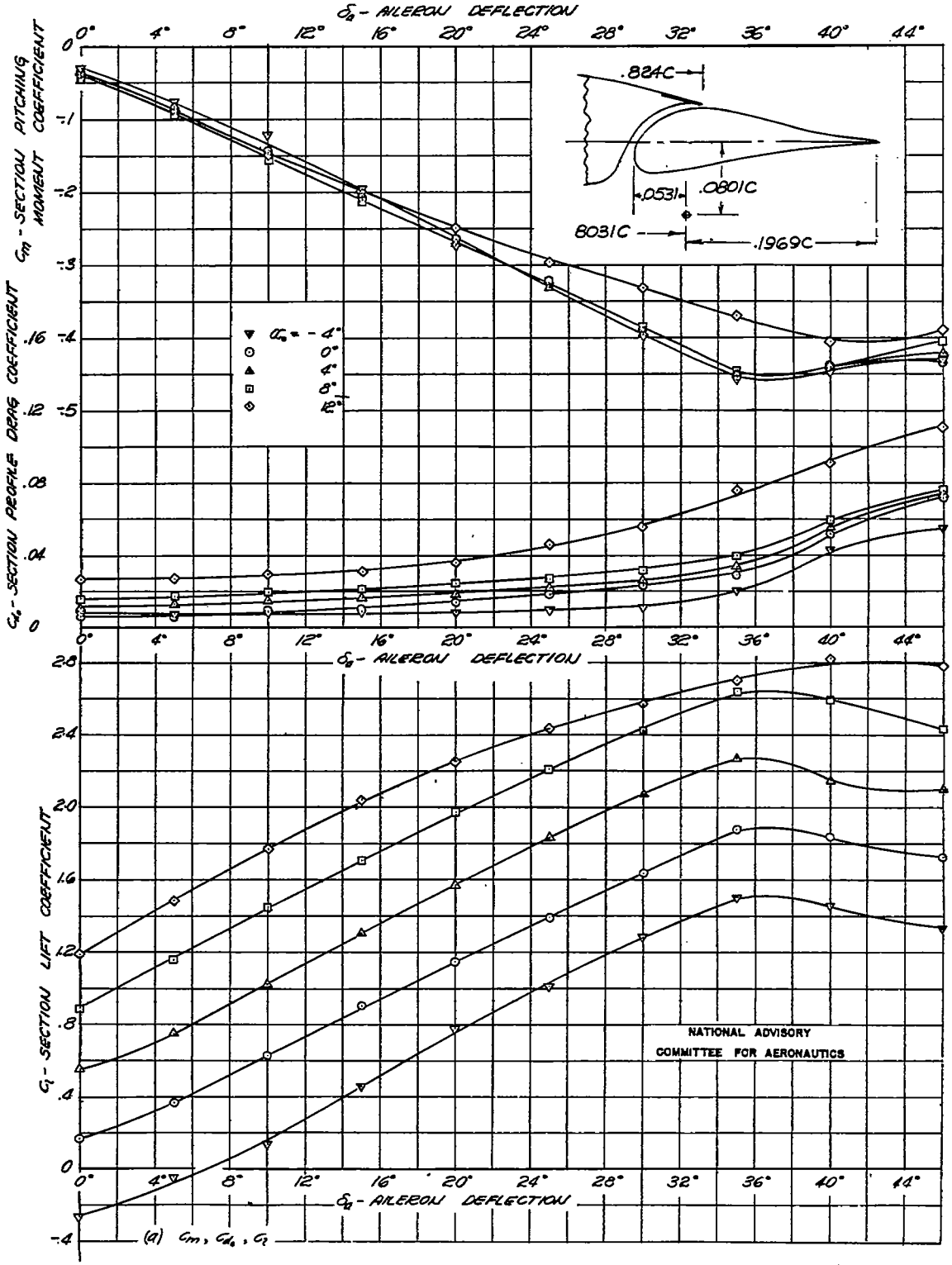
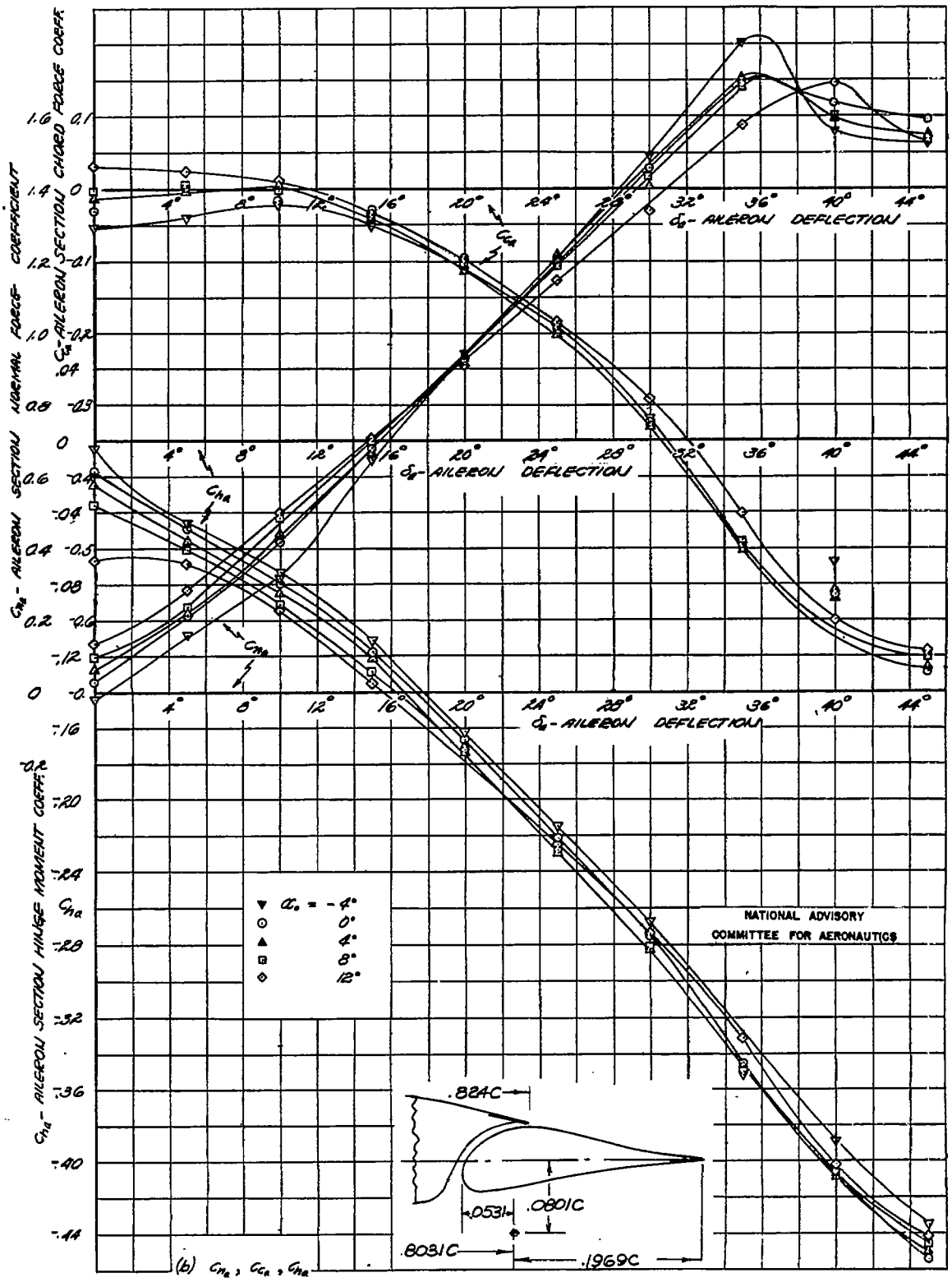
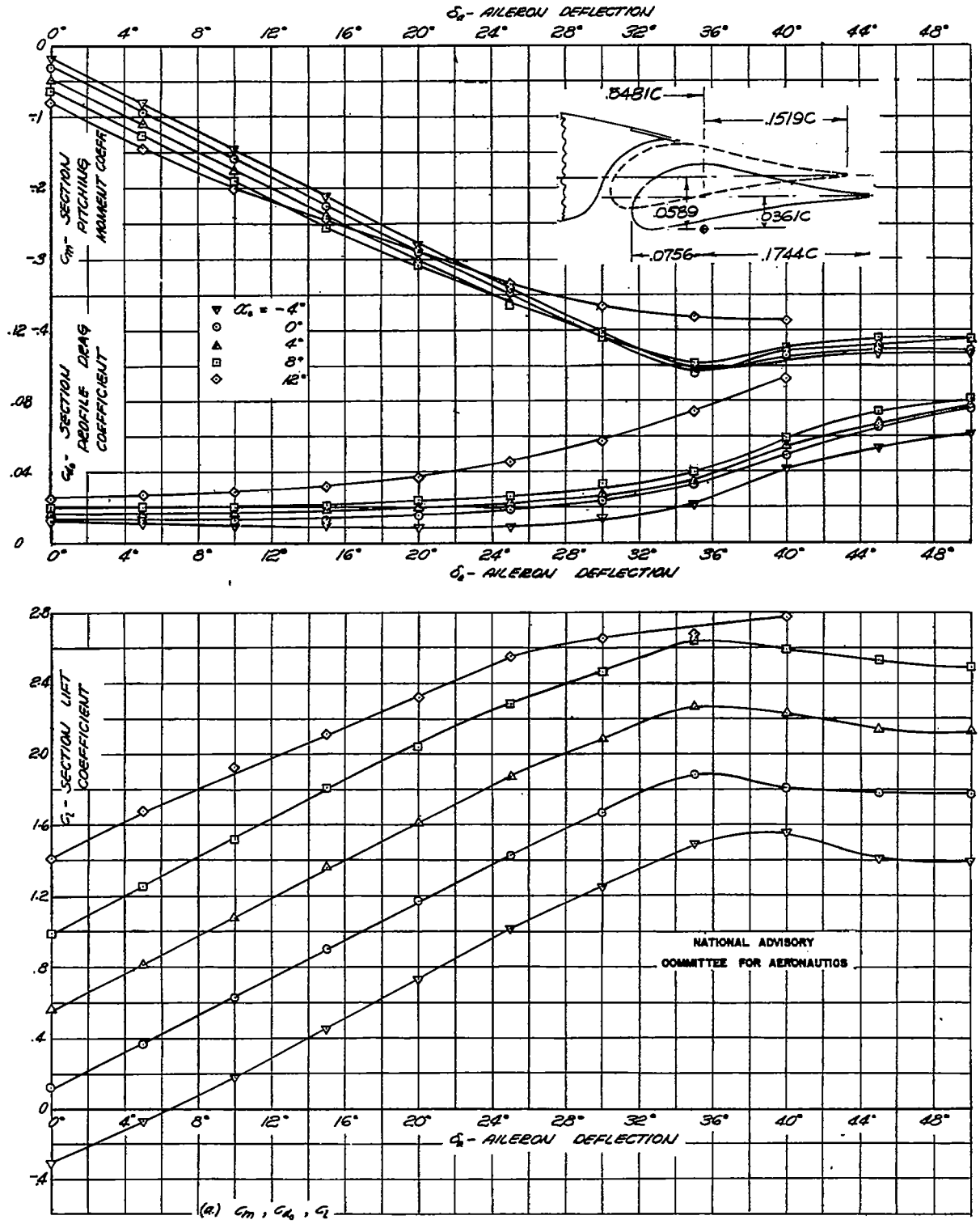


FIGURE 8 .- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=.06) AIRFOIL EQUIPPED WITH THE 0.25-CHORD NORMAL PROFILE AILERON WITH A 26.98 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION B.



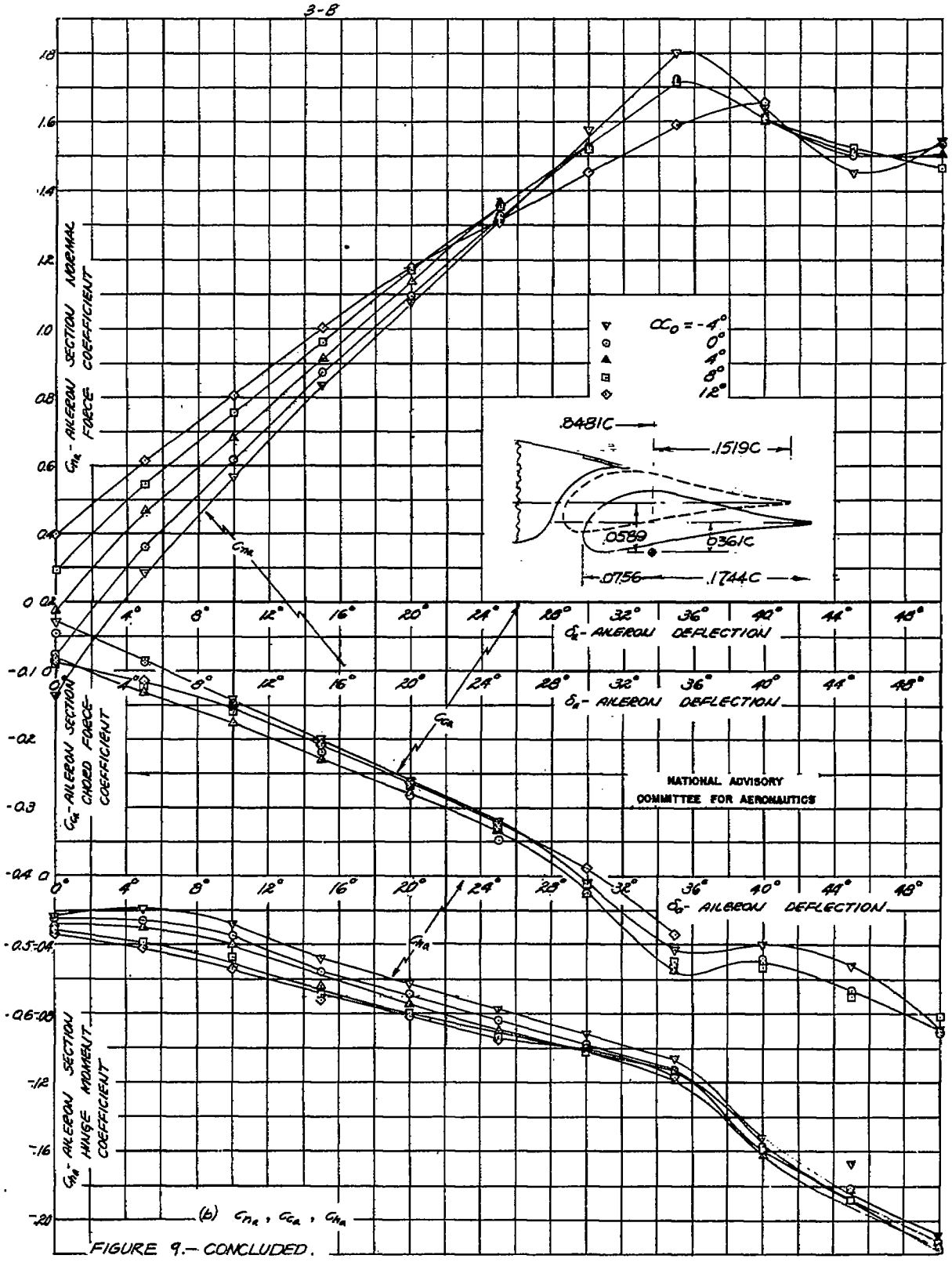
(b) C_{N_a}, C_{c_a}, C_{h_a}

FIGURE 8 - CONCLUDED.



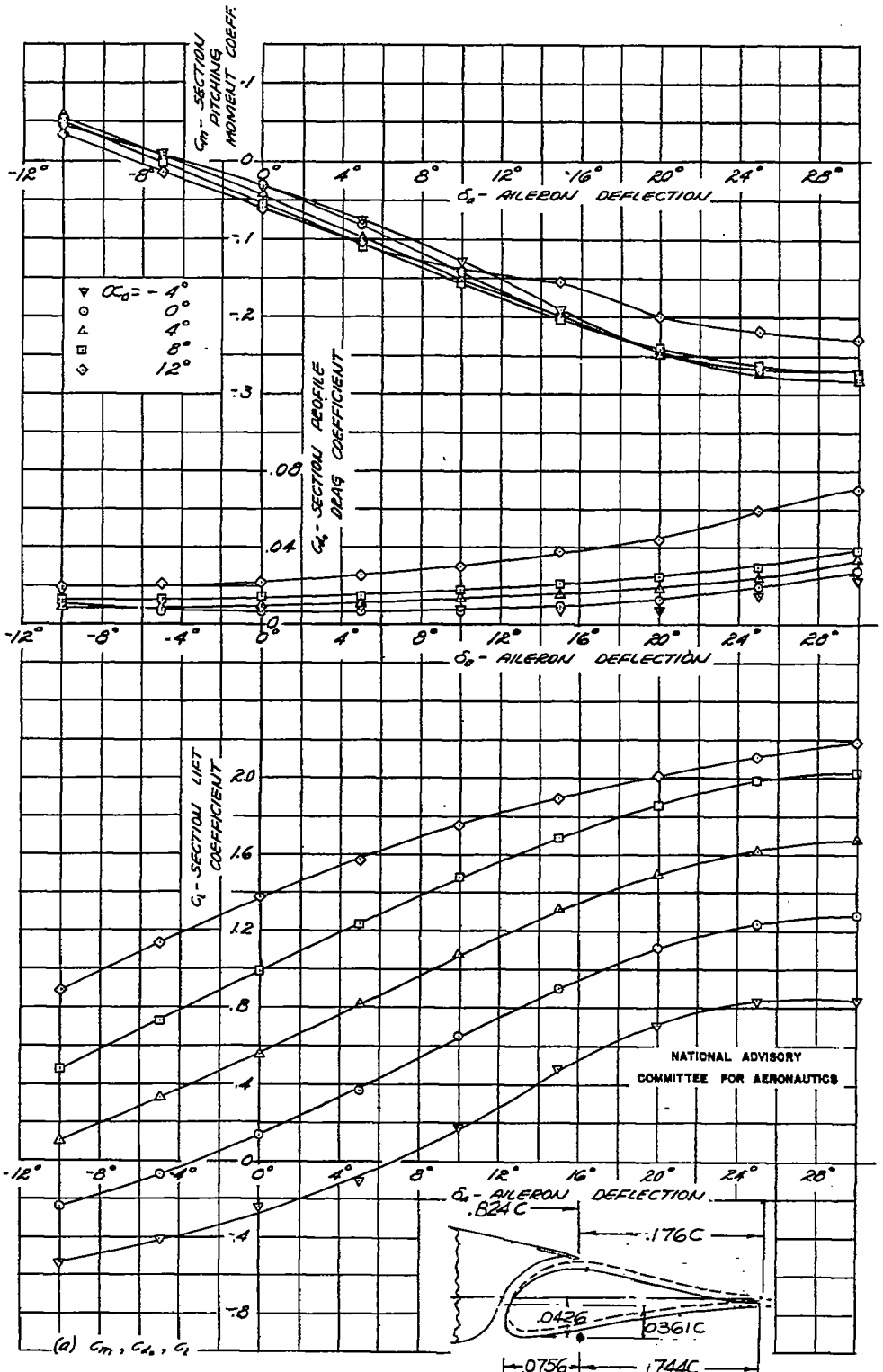
(a) c_m, c_{d_0}, c_l

FIGURE 9.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD NORMAL PROFILE AILERON WITH A 43.35 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION C.



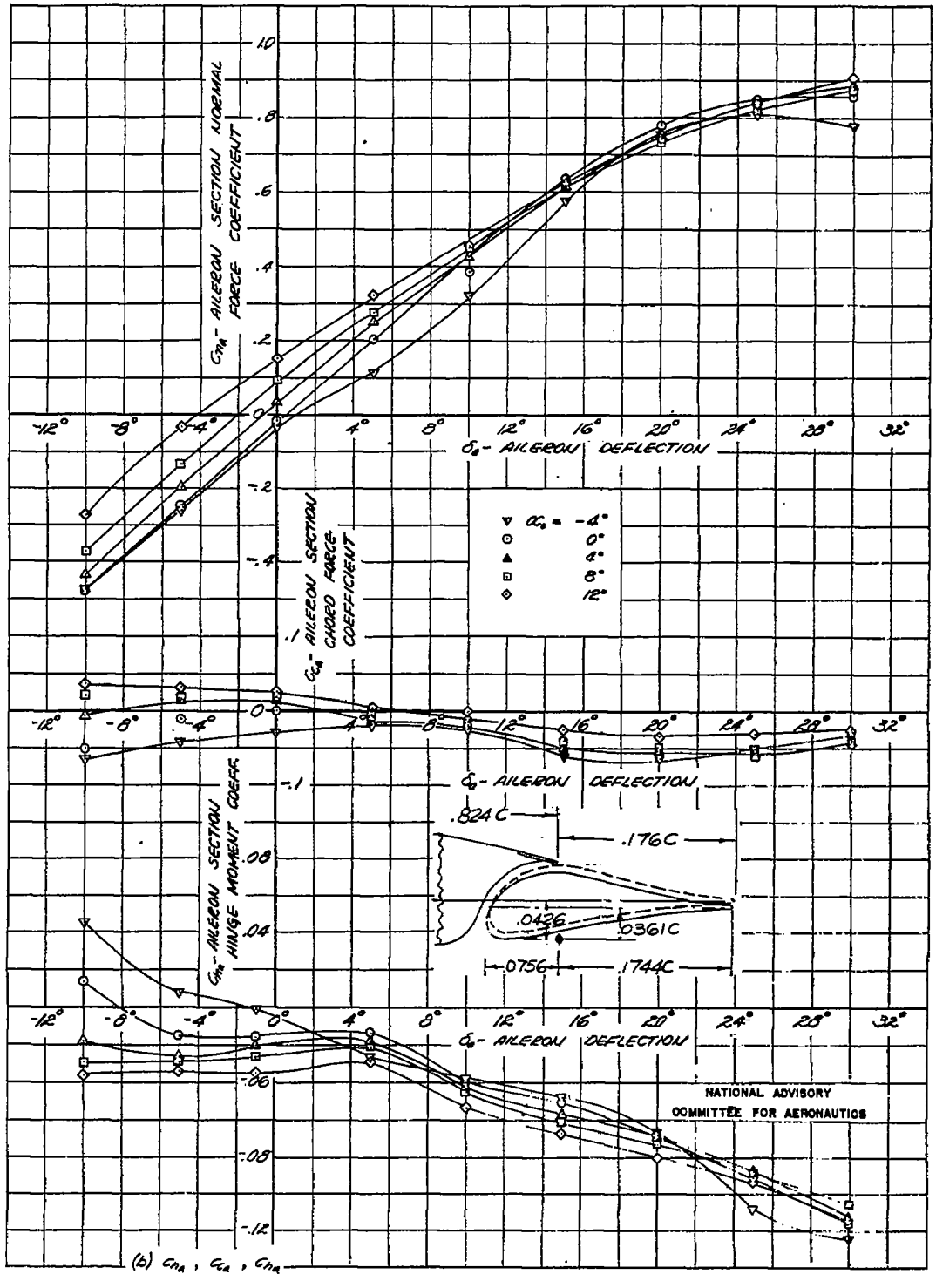
(b) c_{n_a}, c_{c_a}, c_{h_a}

FIGURE 9.- CONCLUDED.



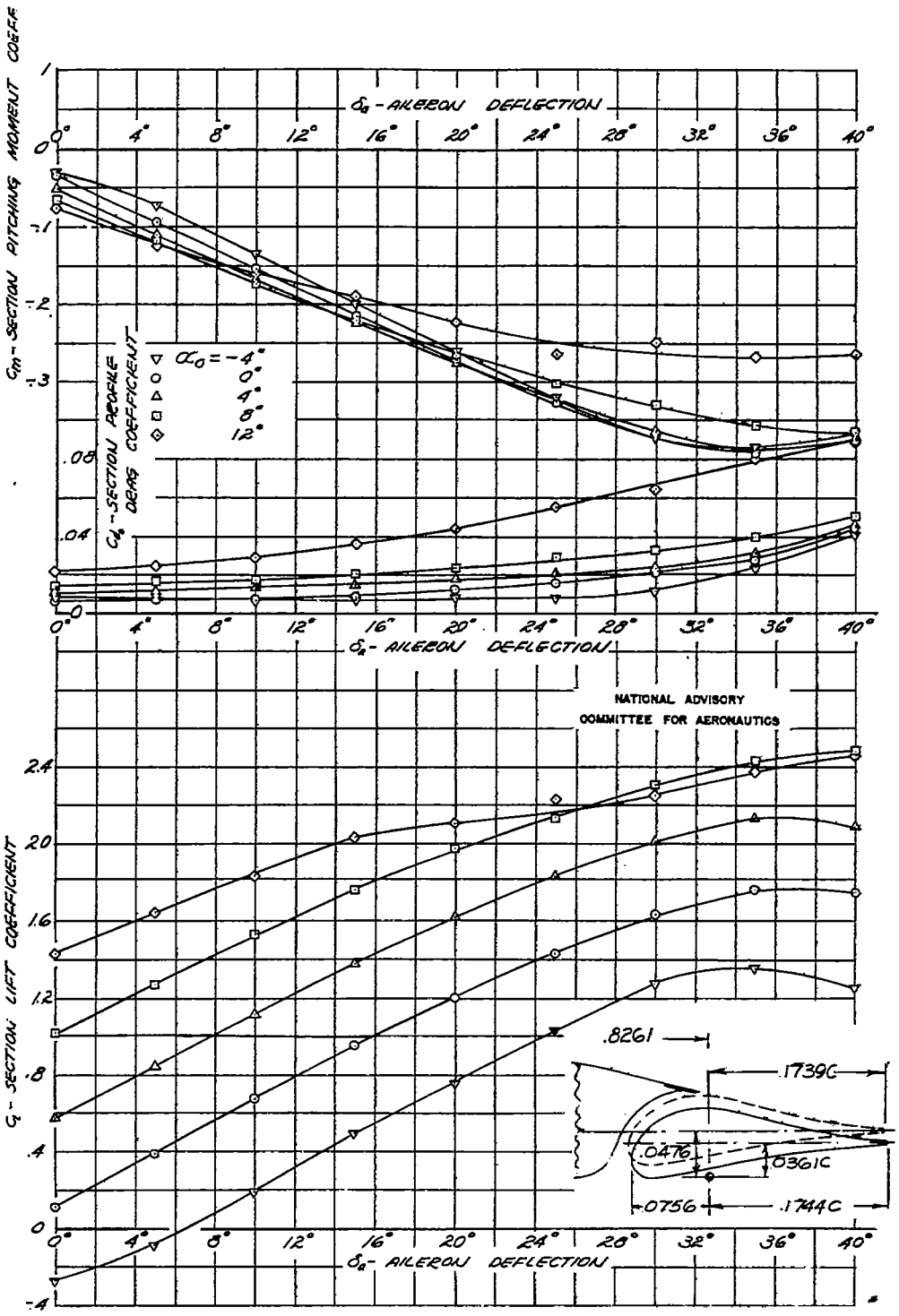
(a) c_m, c_{d_0}, c_l

FIGURE 10.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD NORMAL PROFILE AILERON WITH A 43.35 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION D.



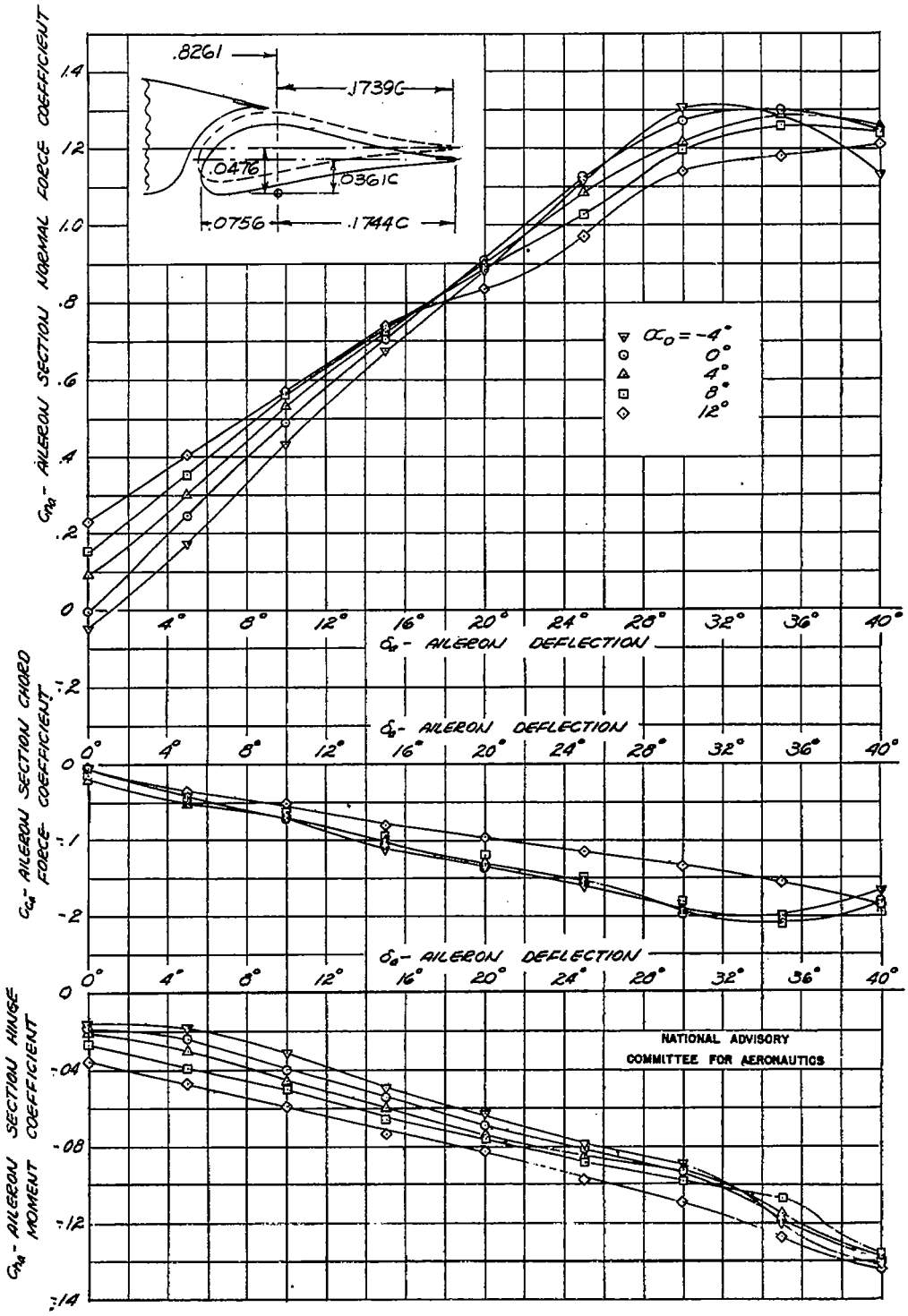
(b) c_{n_a}, c_{a_a}, c_{h_a}

FIGURE 10.- CONCLUDED.



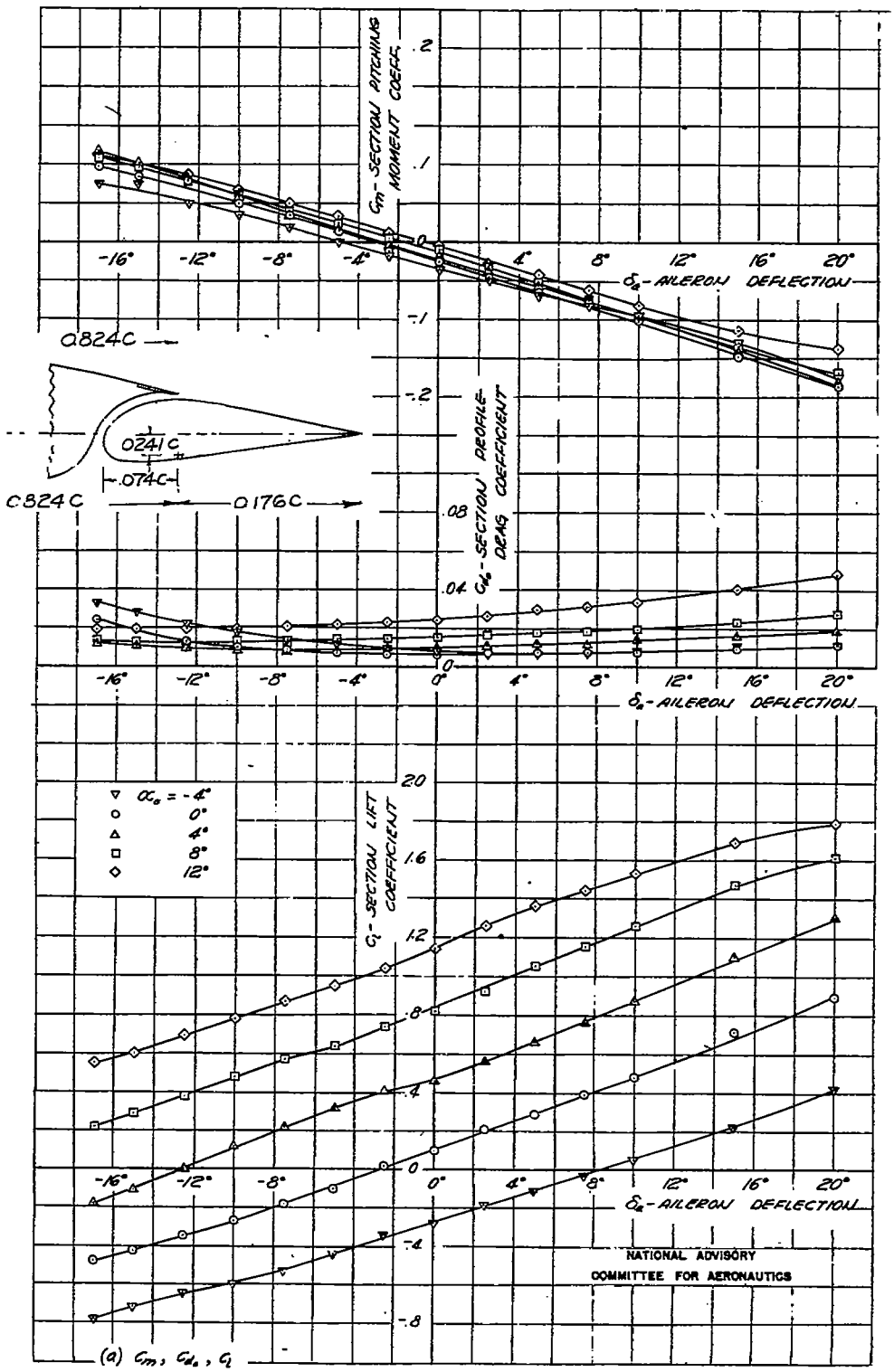
(a) c_m, c_{d_0}, c_l

FIGURE 11 - SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD NORMAL PROFILE AILERON WITH A 43.35 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION E.



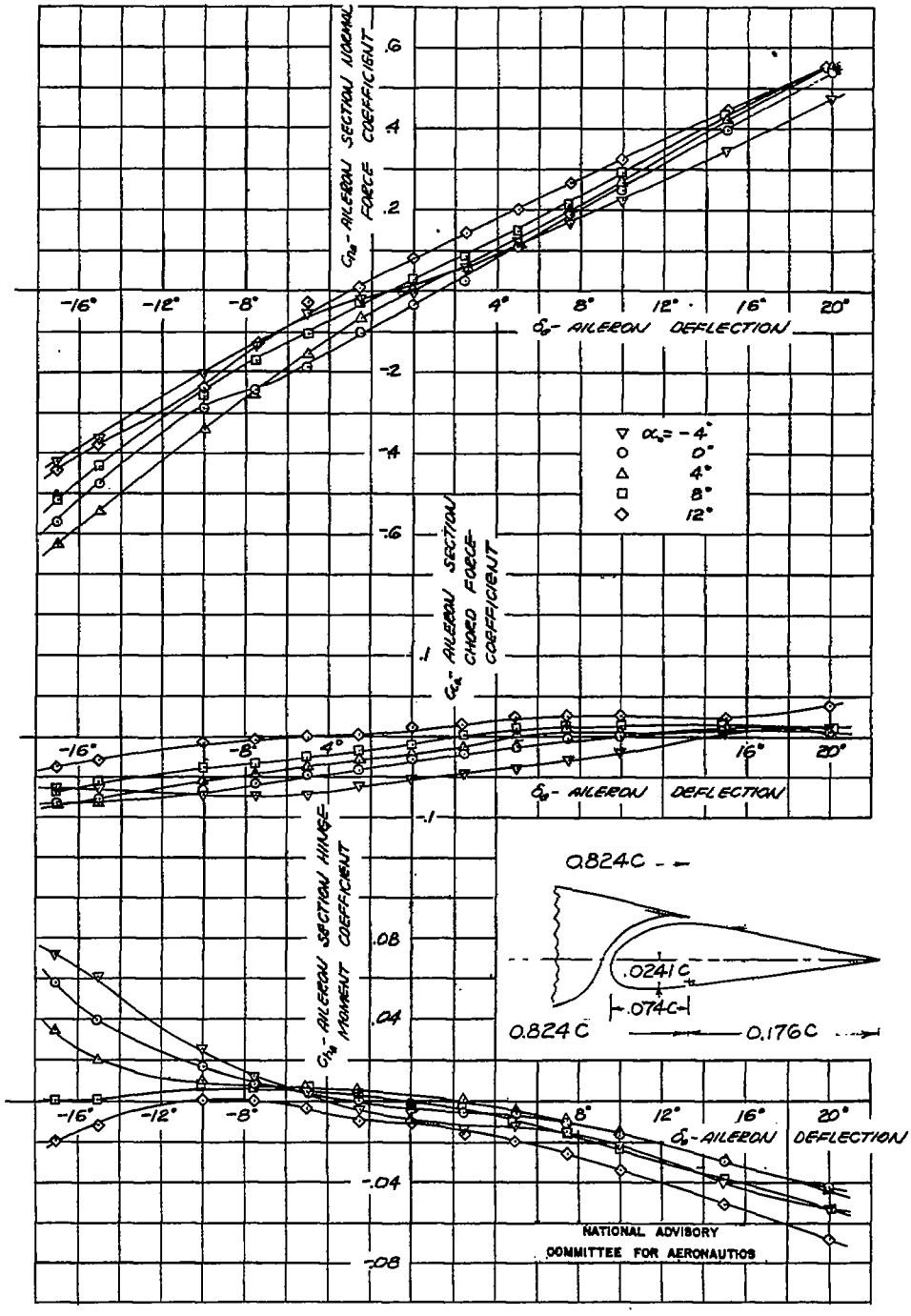
(b) C_{n_a}, C_{c_a}, C_{h_a}

FIGURE 11 .- CONCLUDED.



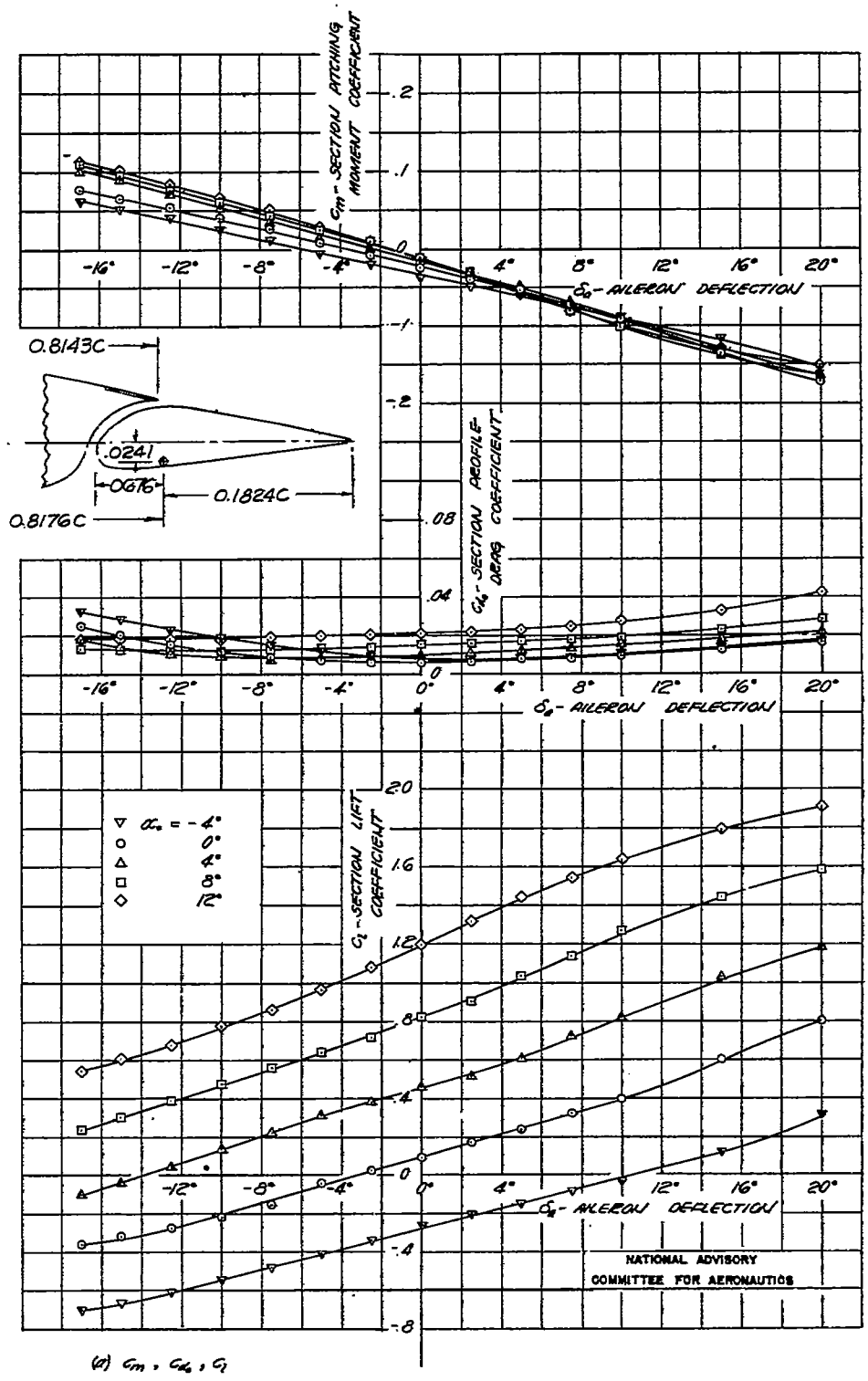
(a) C_m, C_{d_0}, C_l

FIGURE 12.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a = 0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD STRAIGHT SIDED AILERON WITH A 42.05 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION R.



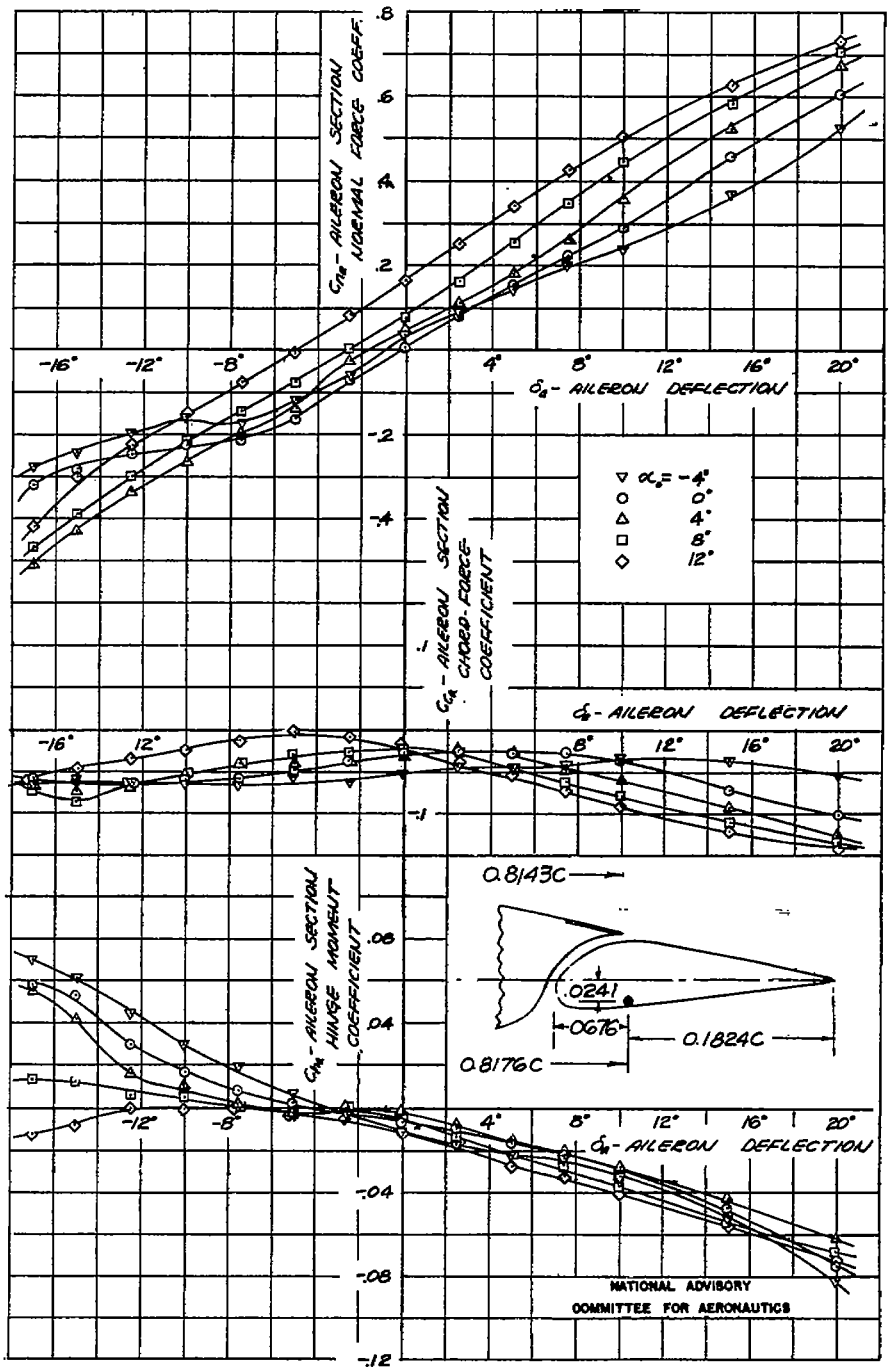
(b) C_{n_a}, C_{c_a}, C_{h_a}

FIGURE 12.- CONCLUDED.



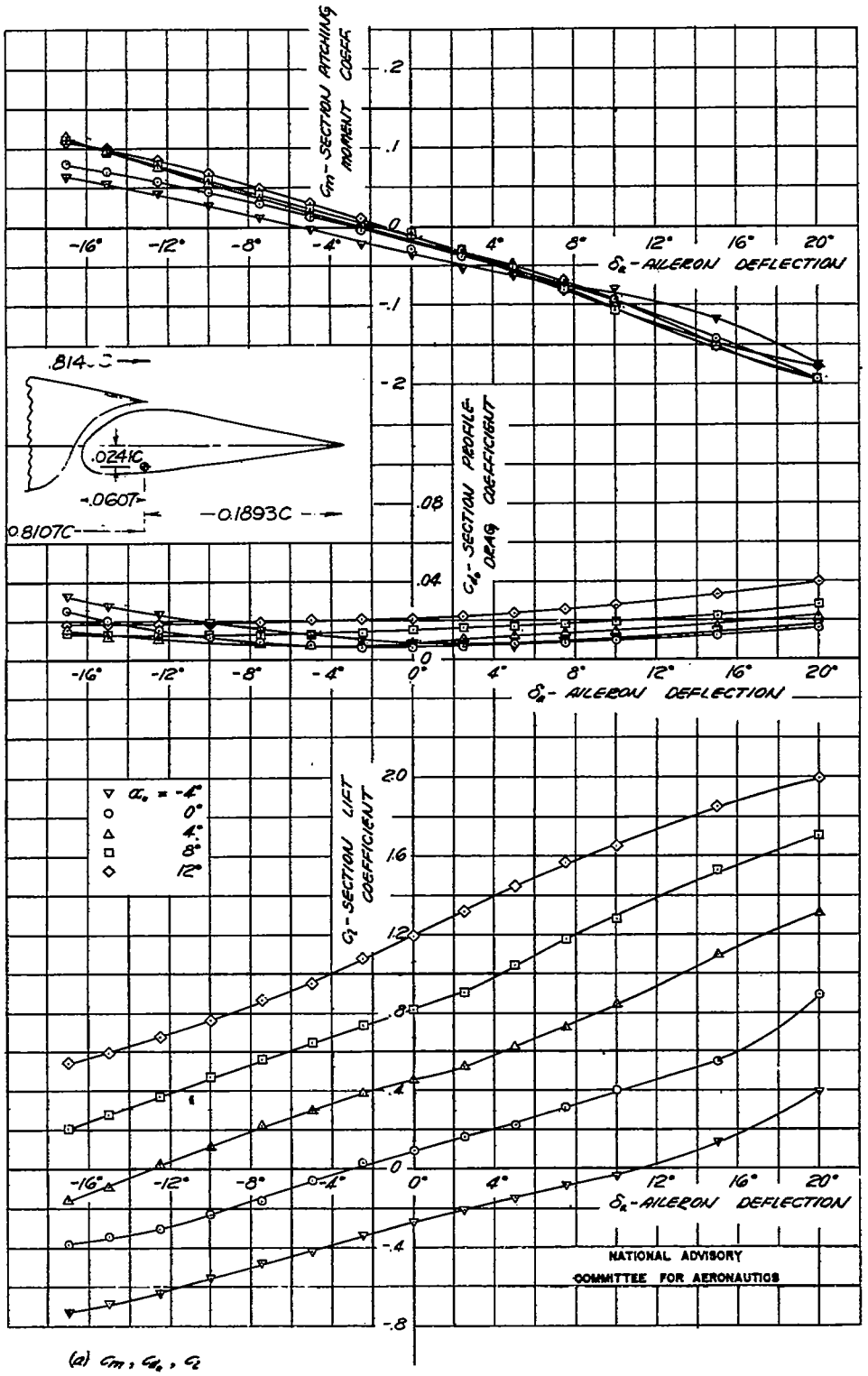
(a) c_m, c_{d_0}, c_l

FIGURE 13.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25 CHORD STRAIGHT SIDED AILERON WITH A 37.05 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION S.



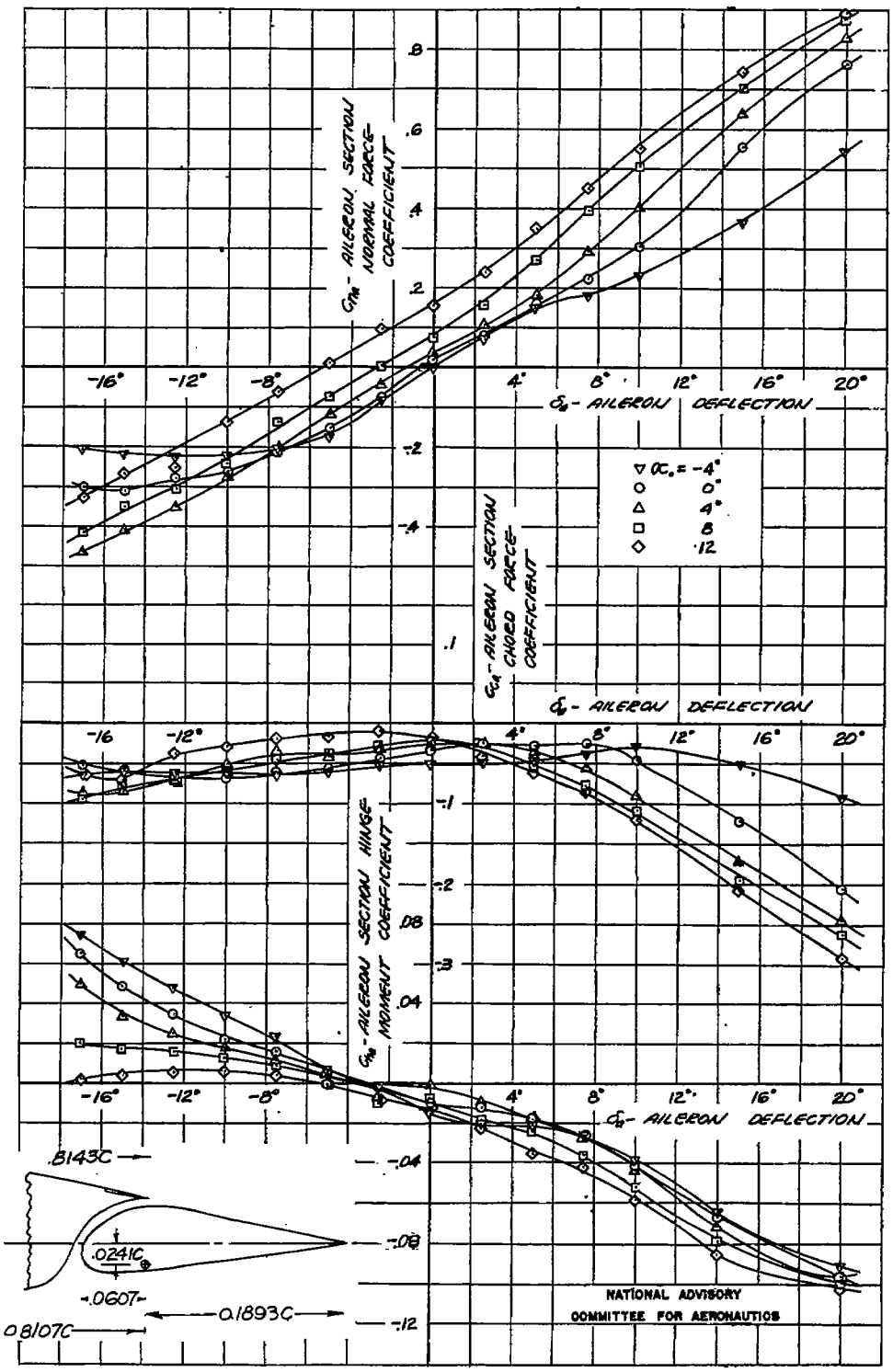
(b) c_{n_a}, c_{c_a}, c_{h_a}

FIGURE 13.—CONCLUDED



(a) c_m, c_{d_0}, c_l

FIGURE 14.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25 CHORD STRAIGHT SIDED AILERON WITH A 32.05 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION T.



(b) C_{n_a}, C_{c_a}, C_{h_a}

FIGURE 14 - CONCLUDED

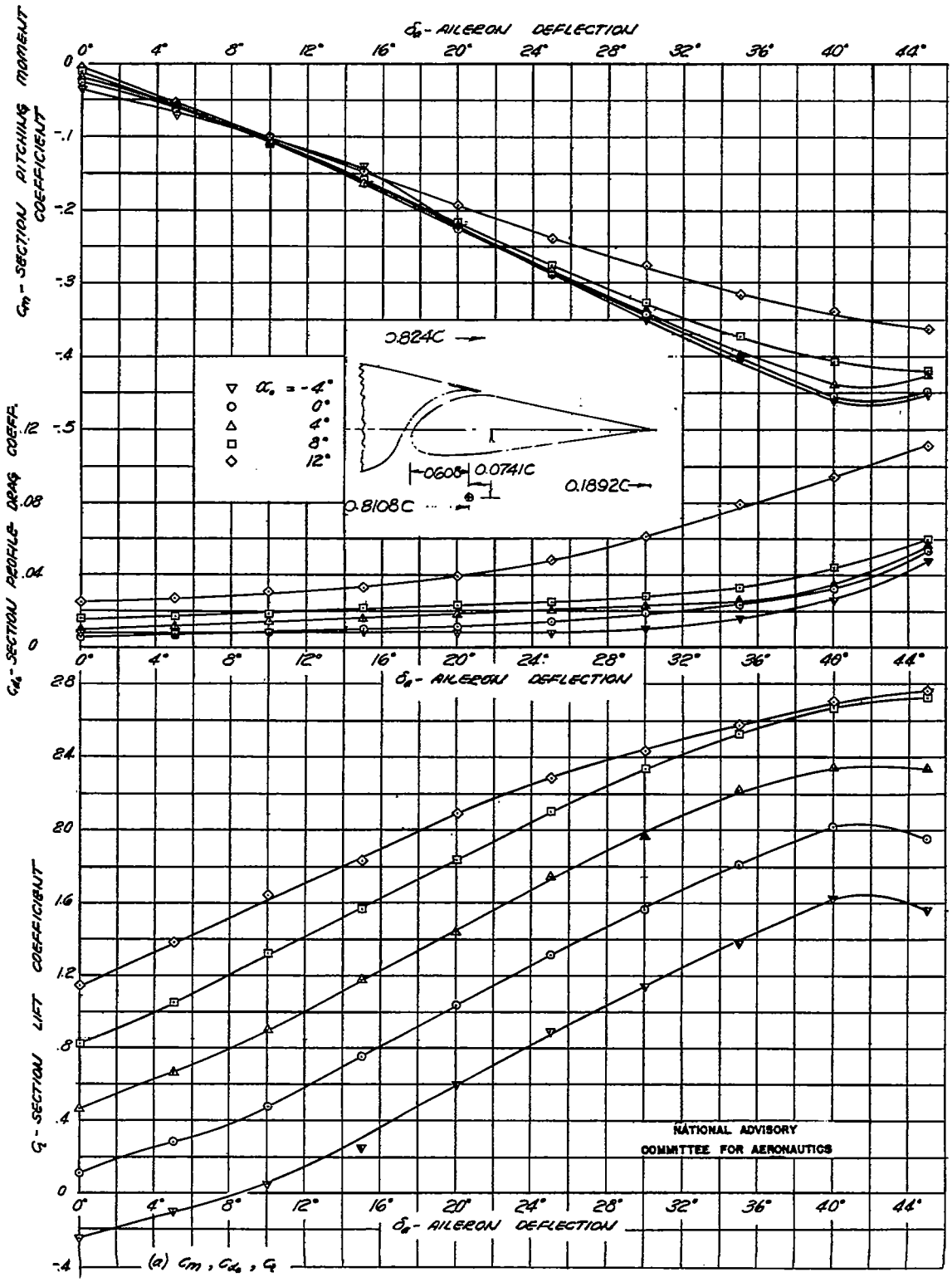
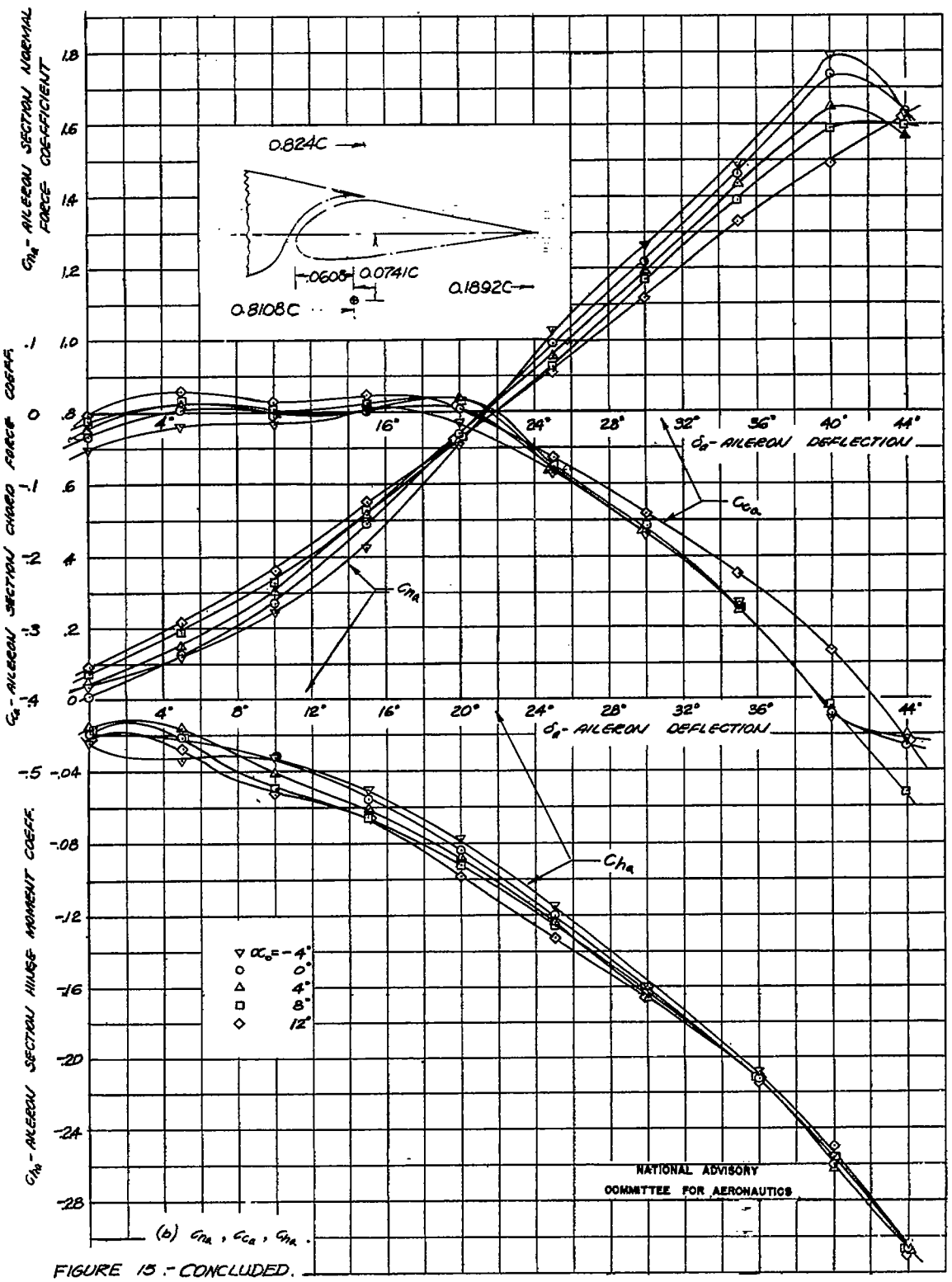


FIGURE 15.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD STRAIGHT SIDED AILERON WITH A 32.14 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION U.



(b) c_{n_a}, c_{c_a}, c_{h_a}.

FIGURE 15.- CONCLUDED.

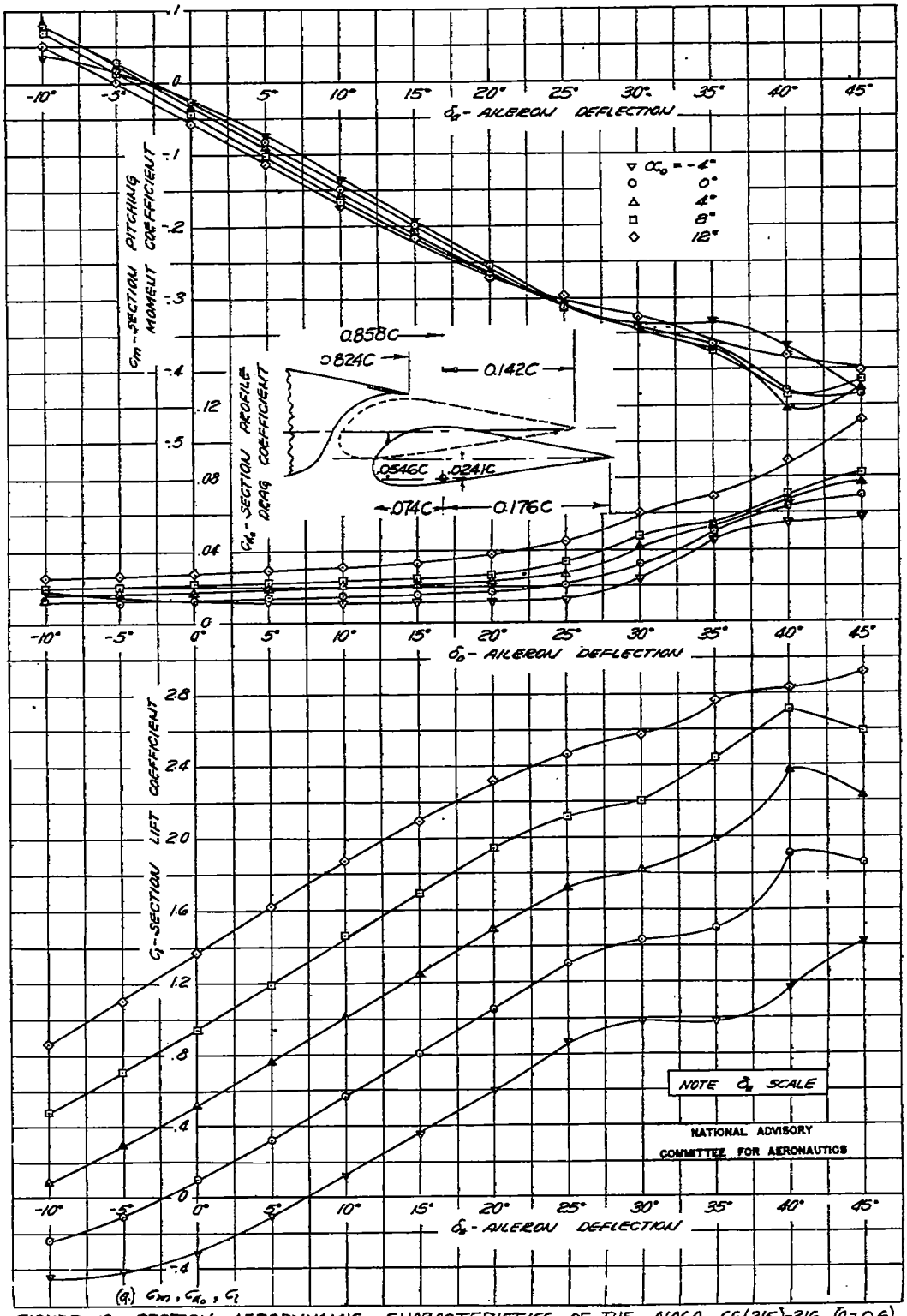
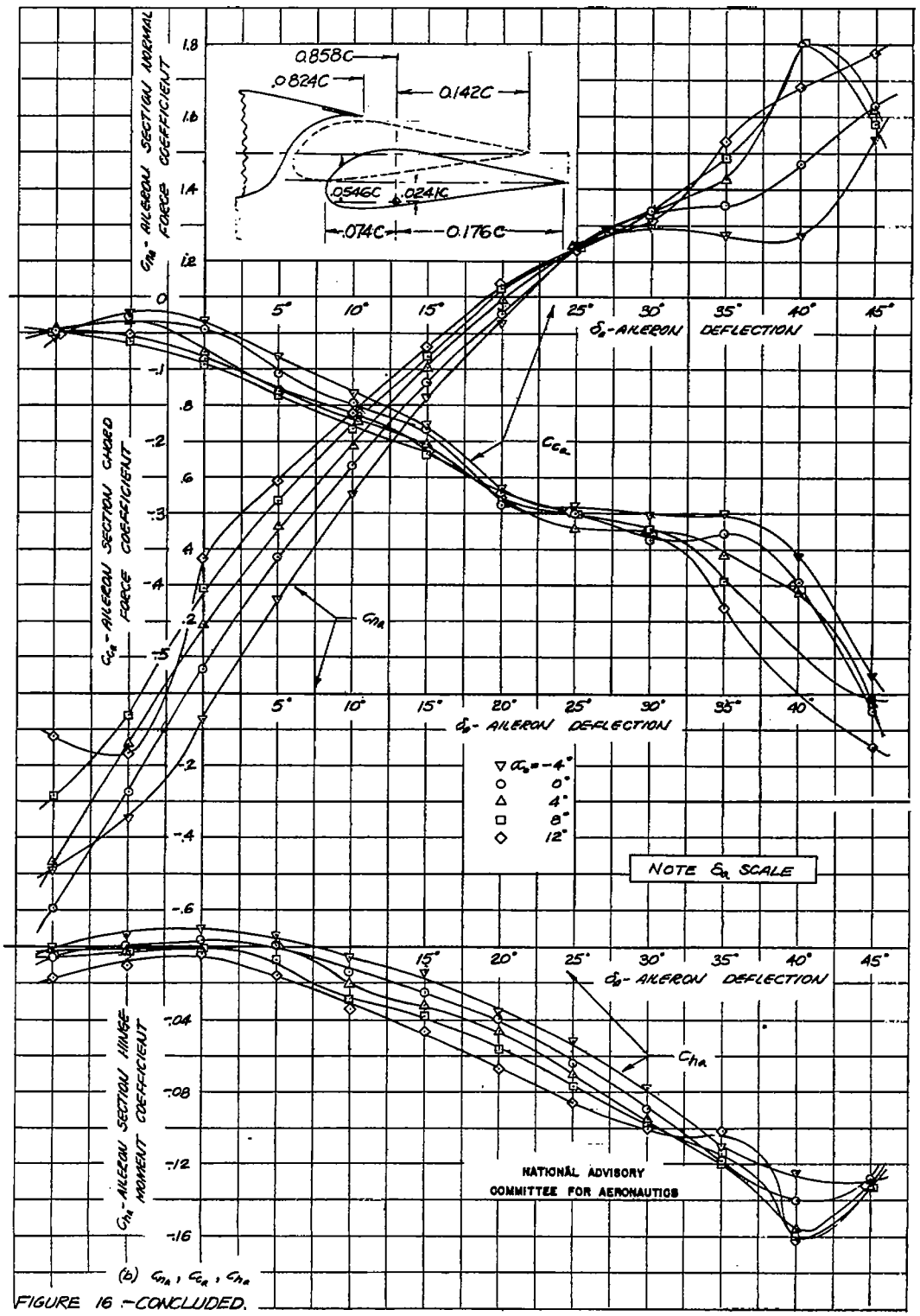
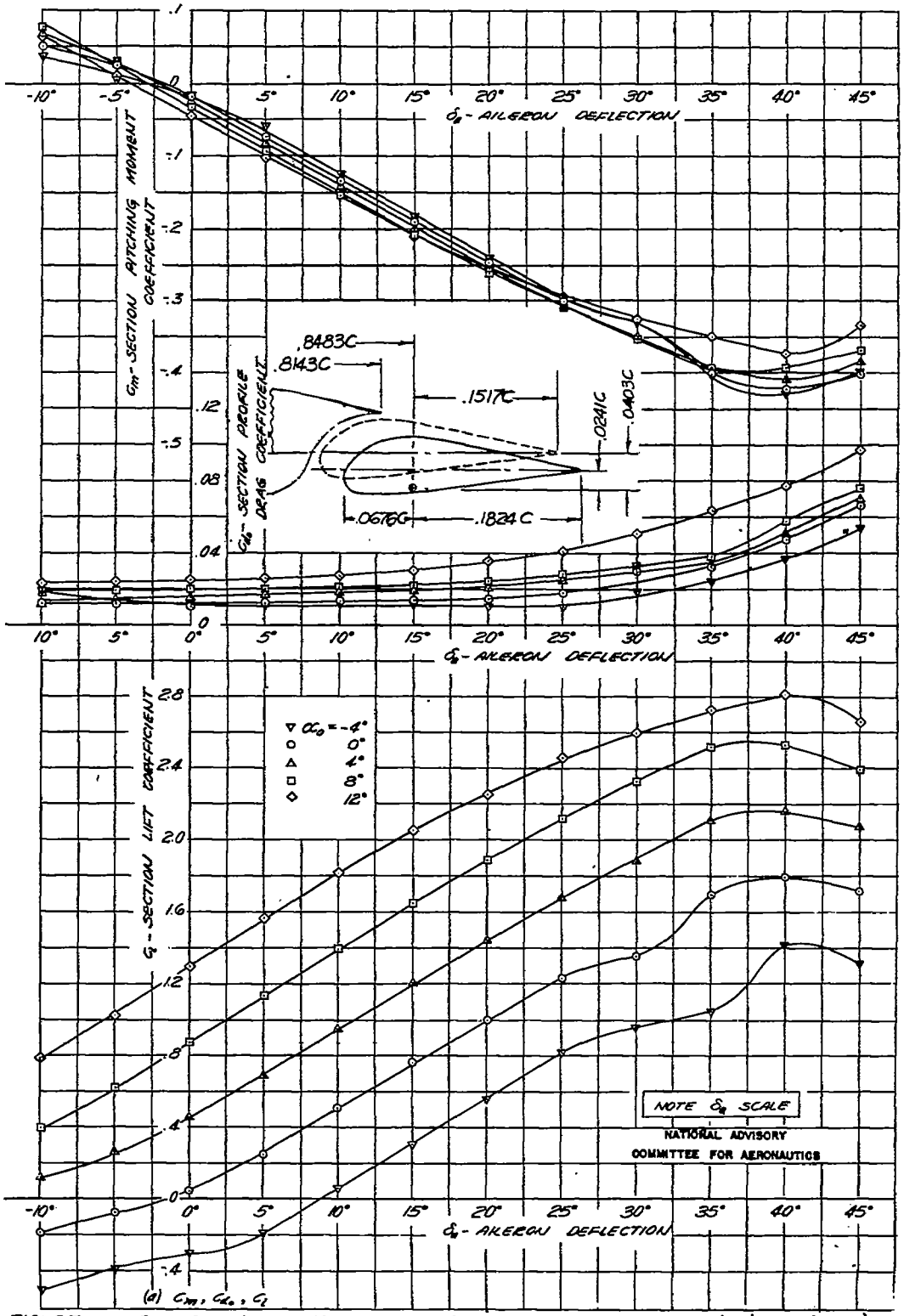


FIGURE 16 - SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL. EQUIPPED WITH THE 0.25-CHORD STRAIGHT SIDED AILERON WITH A 42.05 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION V.



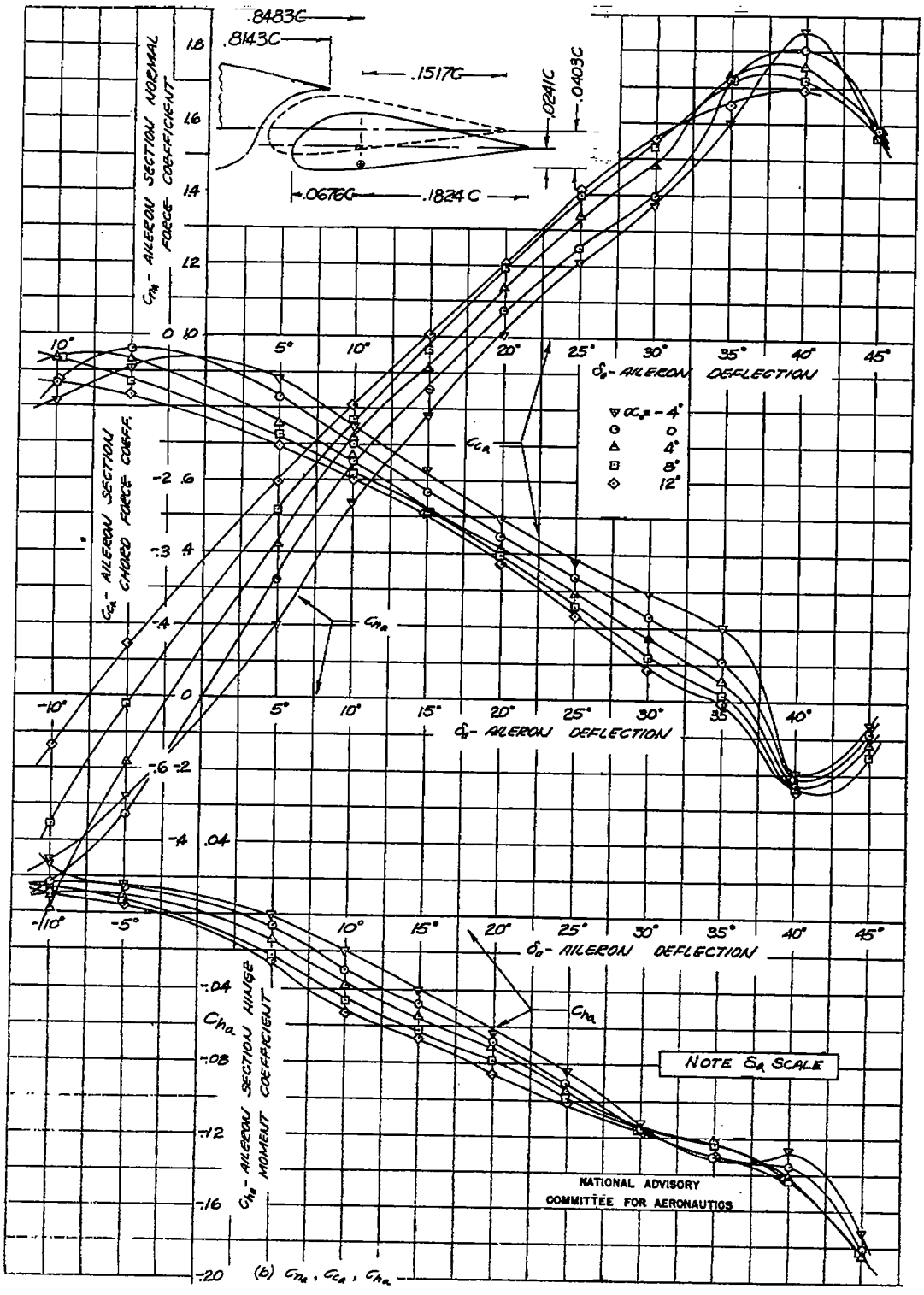
(b) C_{n_a}, C_{c_a}, C_{h_a}

FIGURE 16.—CONCLUDED.



(a) C_m, C_{d_0}, C_l

FIGURE 17.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD STRAIGHT SIDED AILERON WITH A 37.05 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION W.



(b) c_{n_a}, c_{l_a}, c_{h_a}

FIGURE 17.- CONCLUDED.

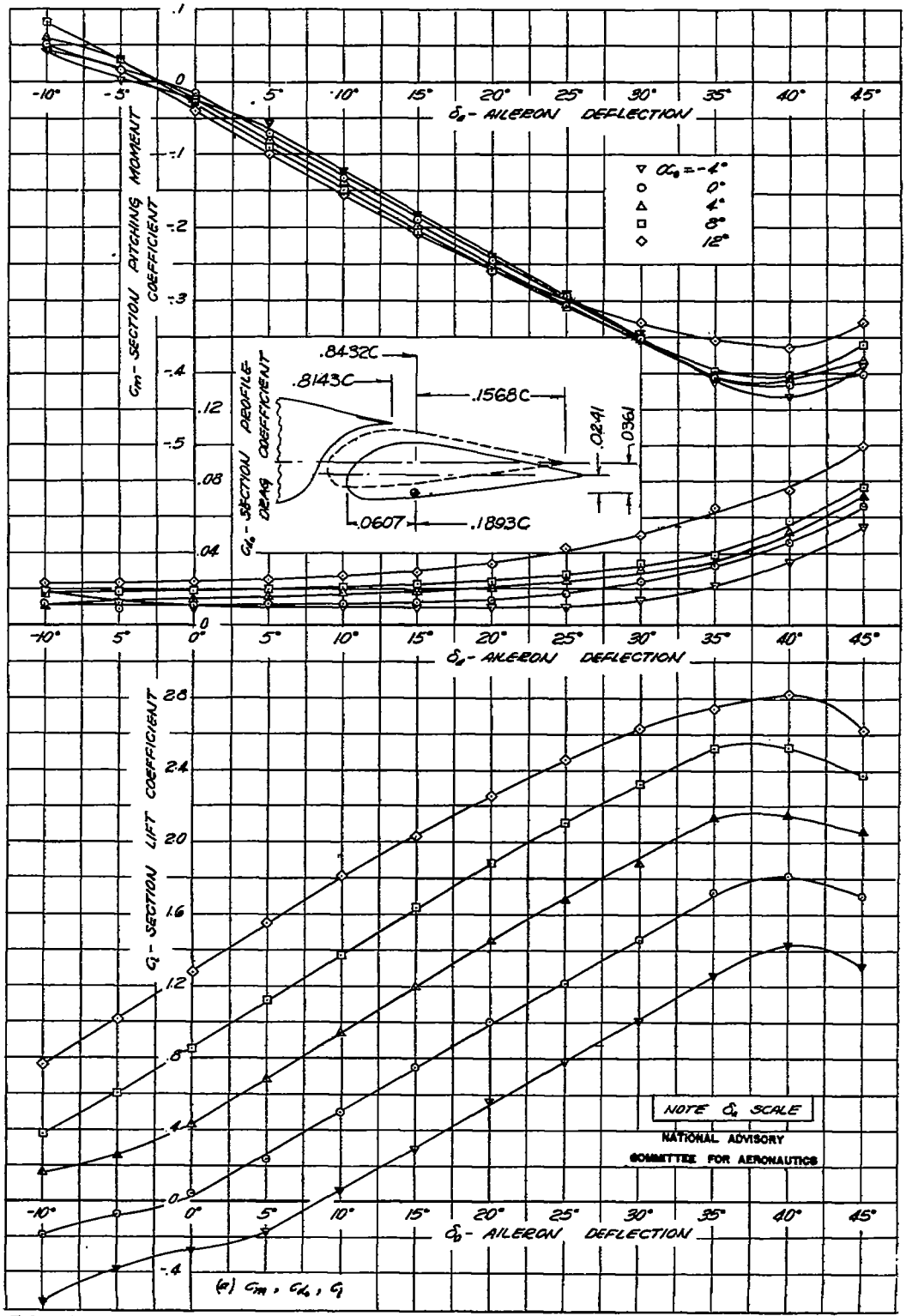
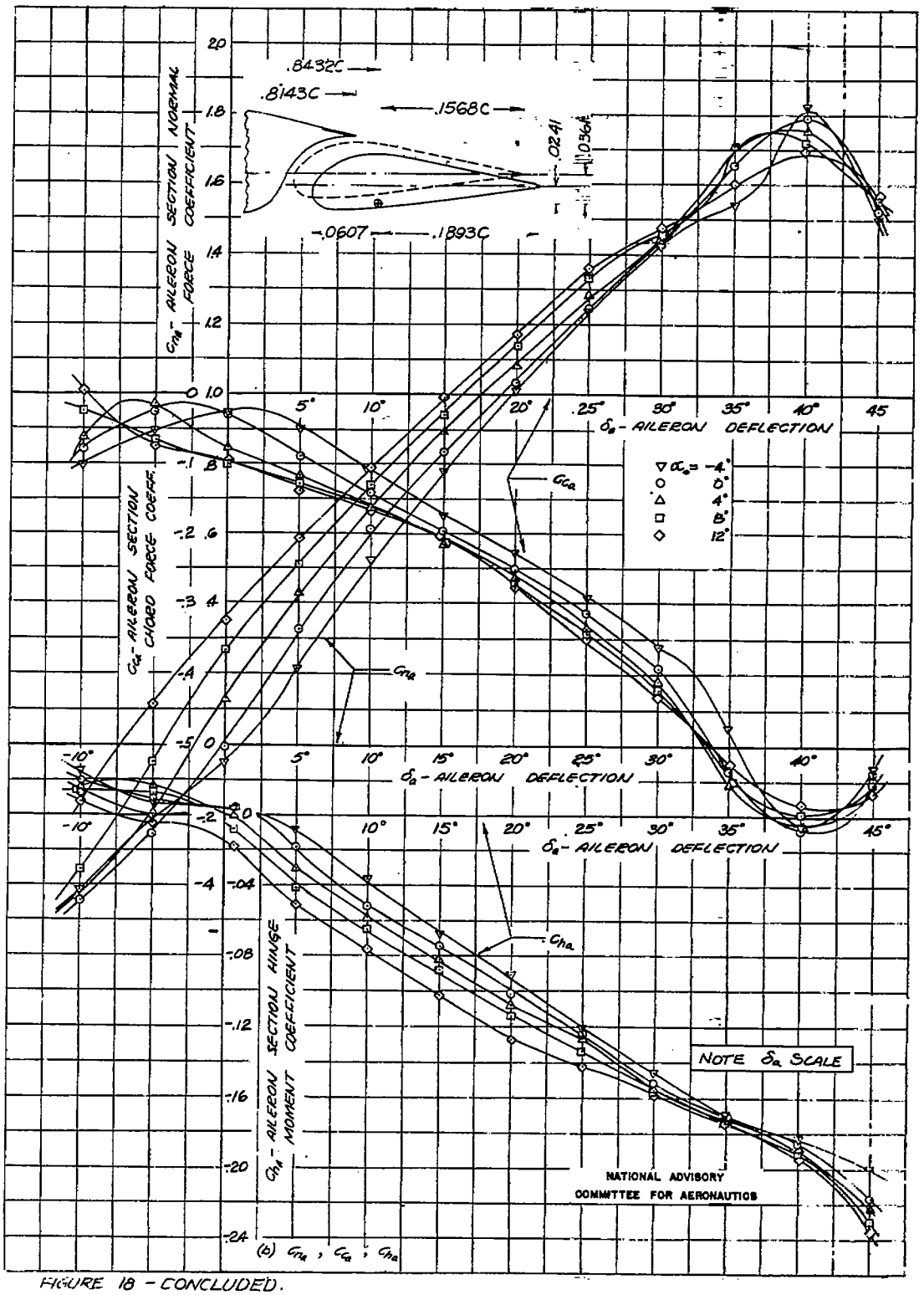


FIGURE 18.- SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66(215)-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD STRAIGHT SIDED AILERON WITH A 32.05 PERCENT AERODYNAMIC BALANCE; HINGE LOCATION X.



(b) C_{n_a}, C_{c_a}, C_{h_a}

FIGURE 18 - CONCLUDED.

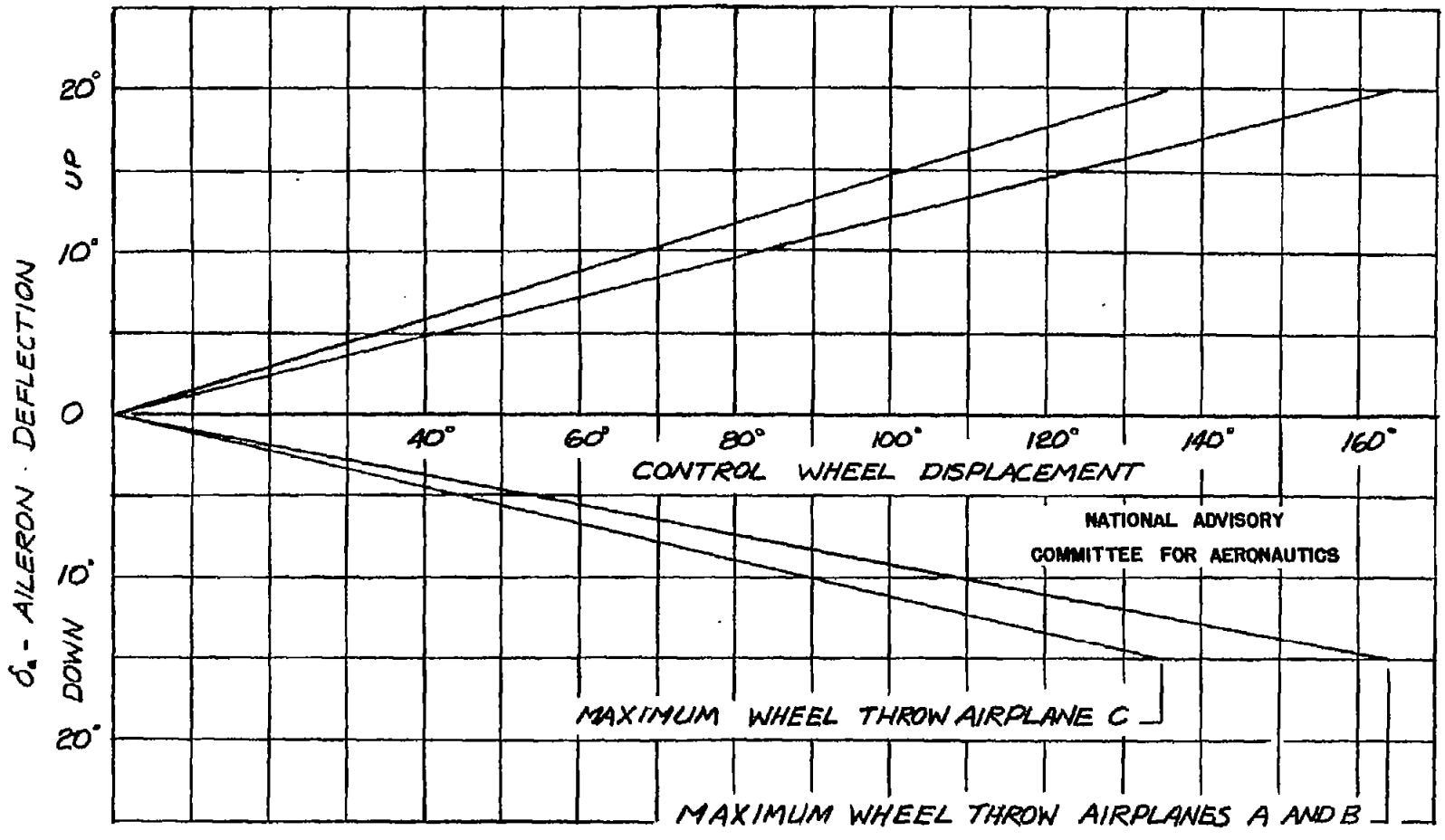
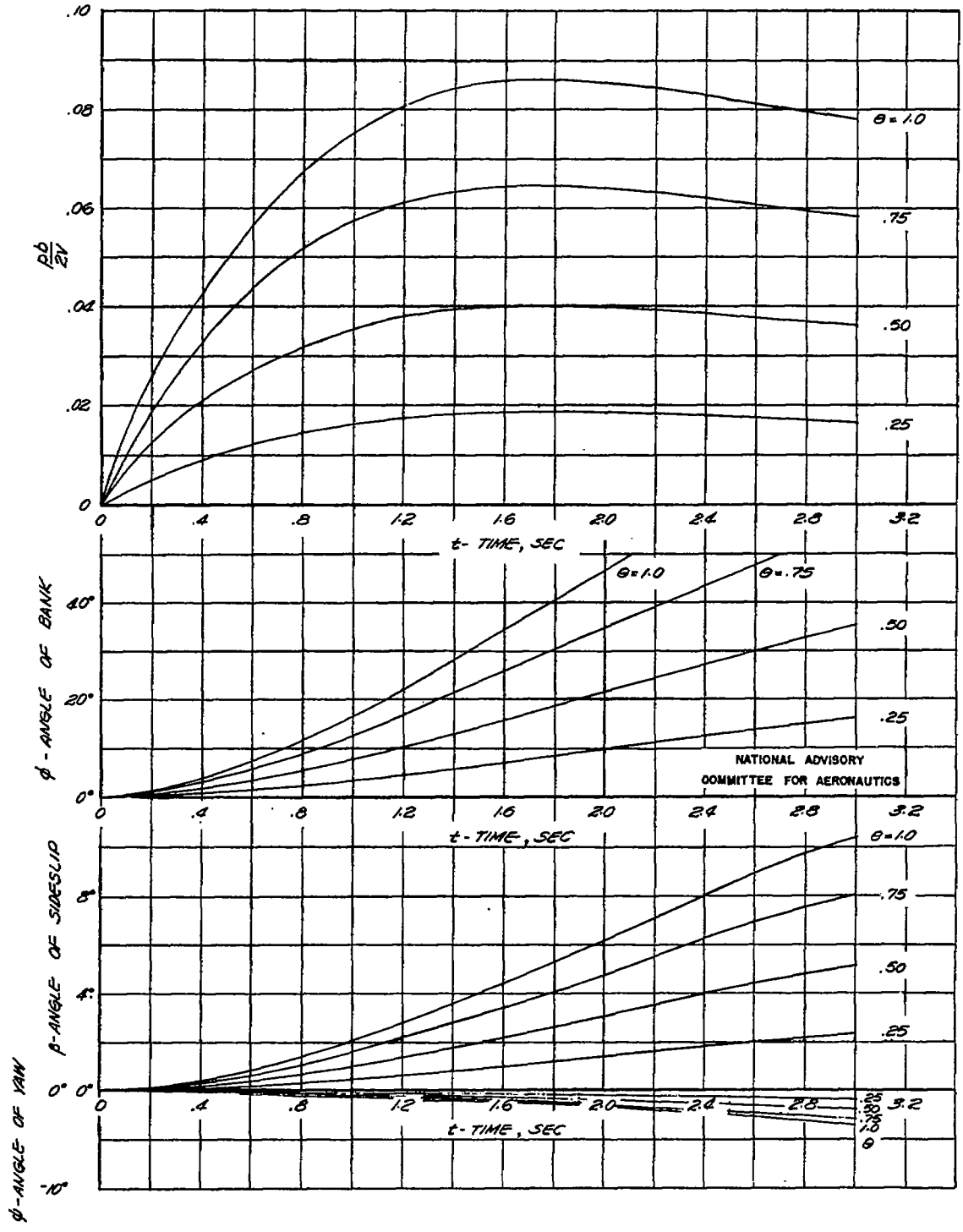
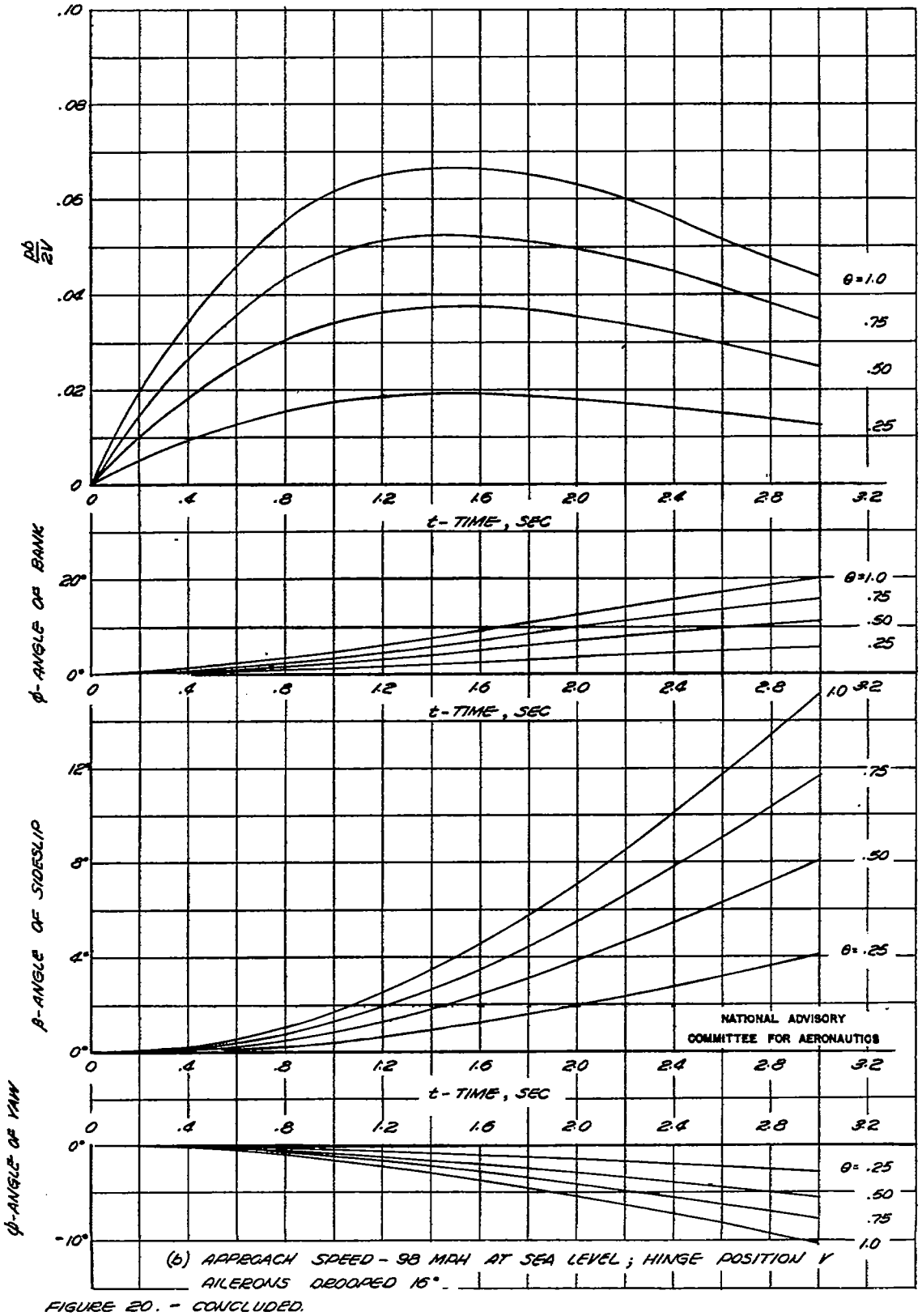


FIGURE 19 .- LINKAGE CHARACTERISTICS OF THE AILERON CONTROL SYSTEMS OF THE EXEMPLARY AIRPLANES.



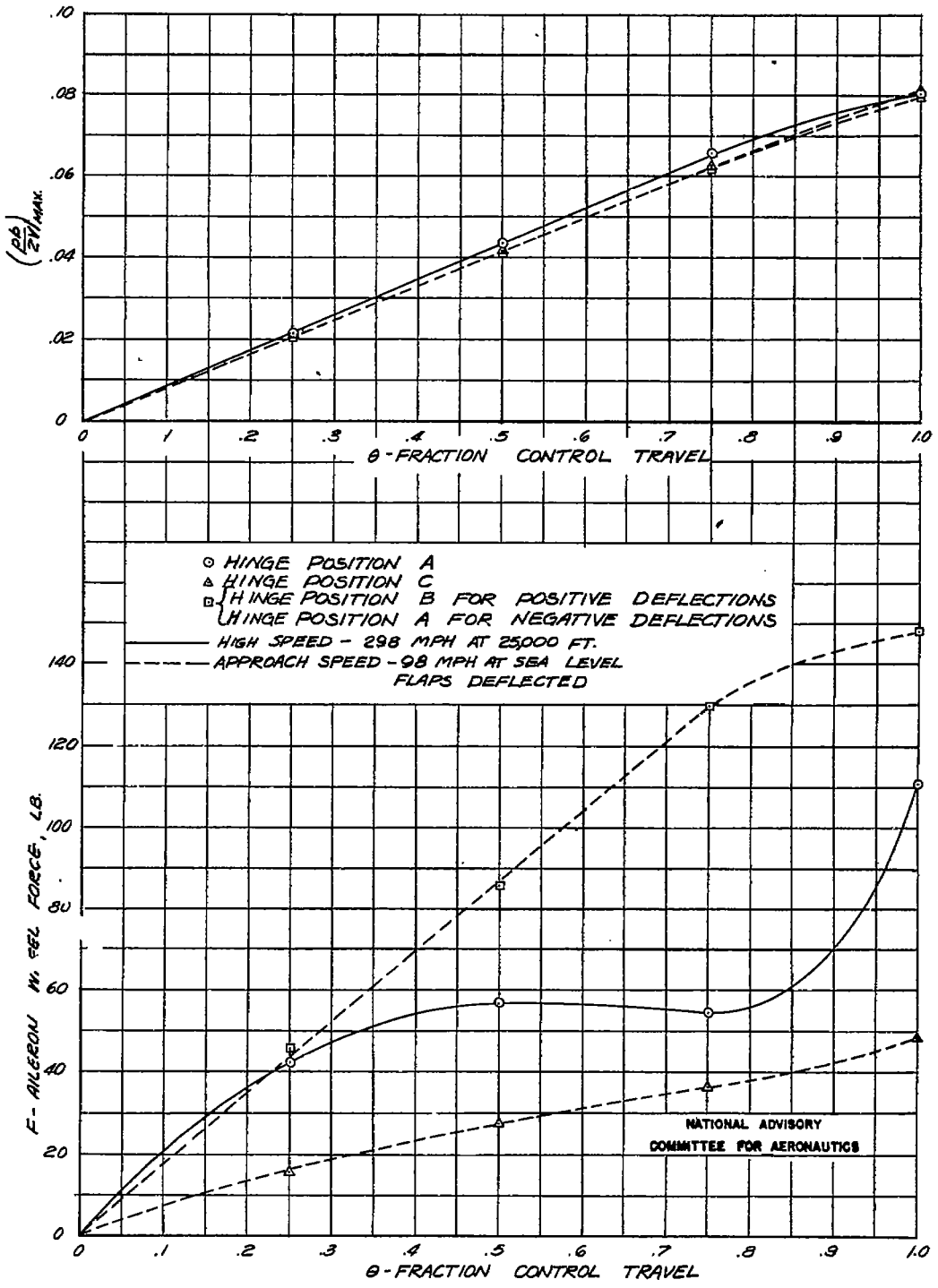
(a) HIGH SPEED - 298 MPH AT 25,000 FT, HINGE POSITION R

FIGURE 20.- ESTIMATED CHARACTERISTICS OF AIRPLANE A EQUIPPED WITH THE STRAIGHT-SIDED AILERON WITH 42.05 PERCENT AERODYNAMIC BALANCE IN ROLLS WITH THE RUDDER LOCKED.



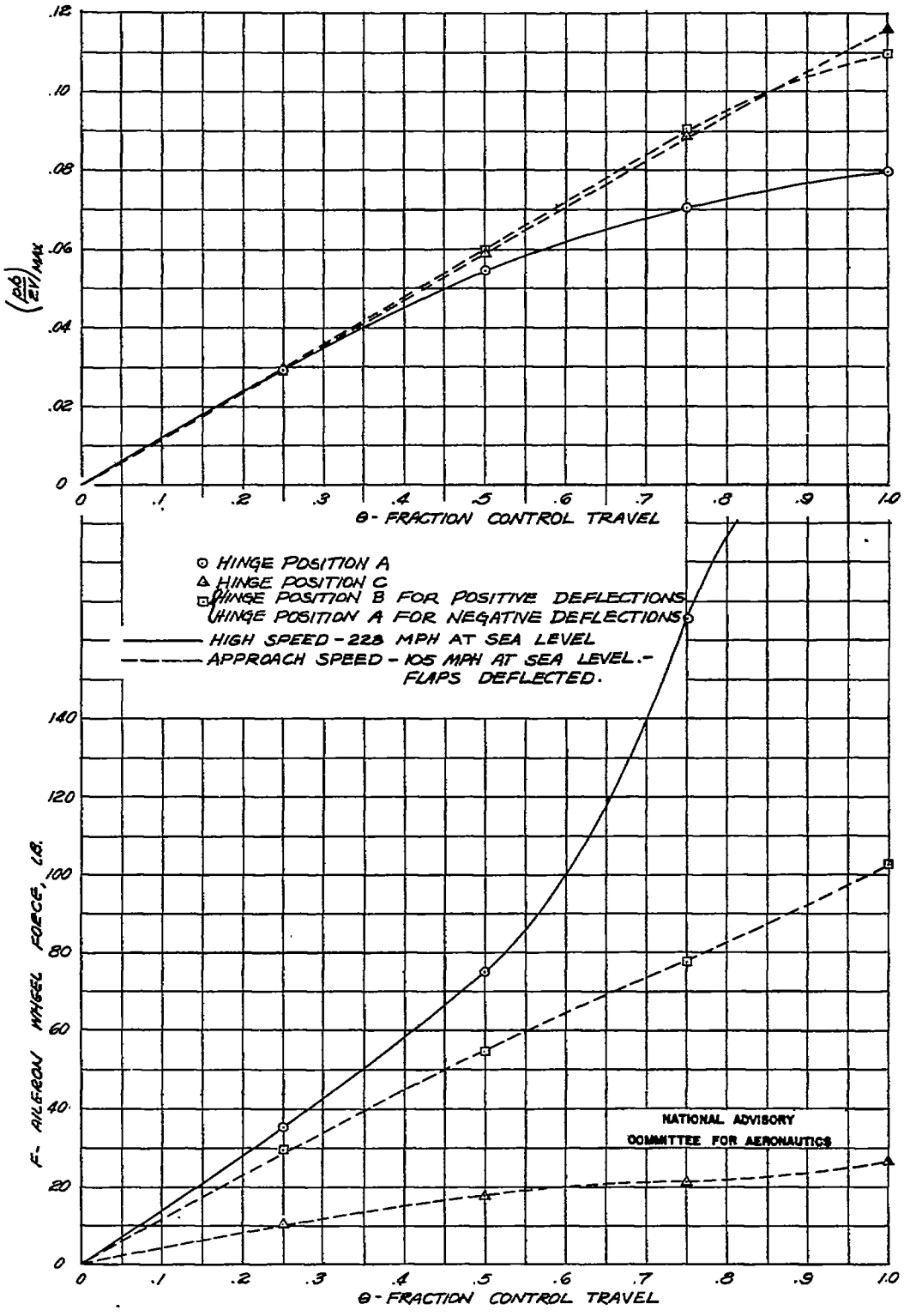
(b) APPROACH SPEED - 98 MPH AT SEA LEVEL; HINGE POSITION V
AILERONS DROOPED 16°.

FIGURE 20. - CONCLUDED.



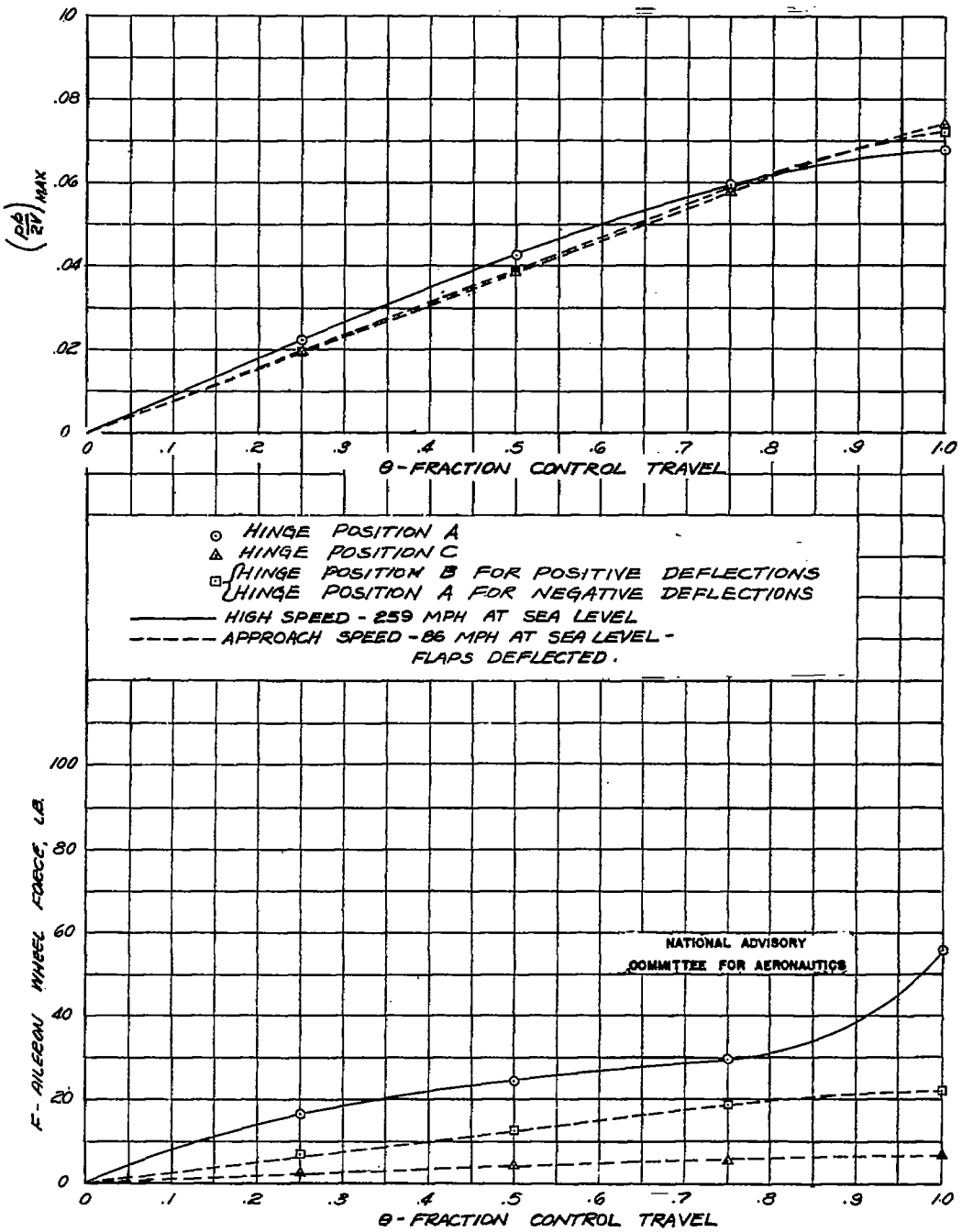
(a). AIRPLANE A.

FIGURE 21 .- VARIATION OF $(pb/2V)_{MAX}$ AND WHEEL FORCE WITH CONTROL TRAVEL IN ROLLS WITH THE RUDDER LOCKED FOR THE EXEMPLARY AIRPLANES EQUIPPED WITH THE 0.25 CHORD NORMAL PROFILE AILERON.



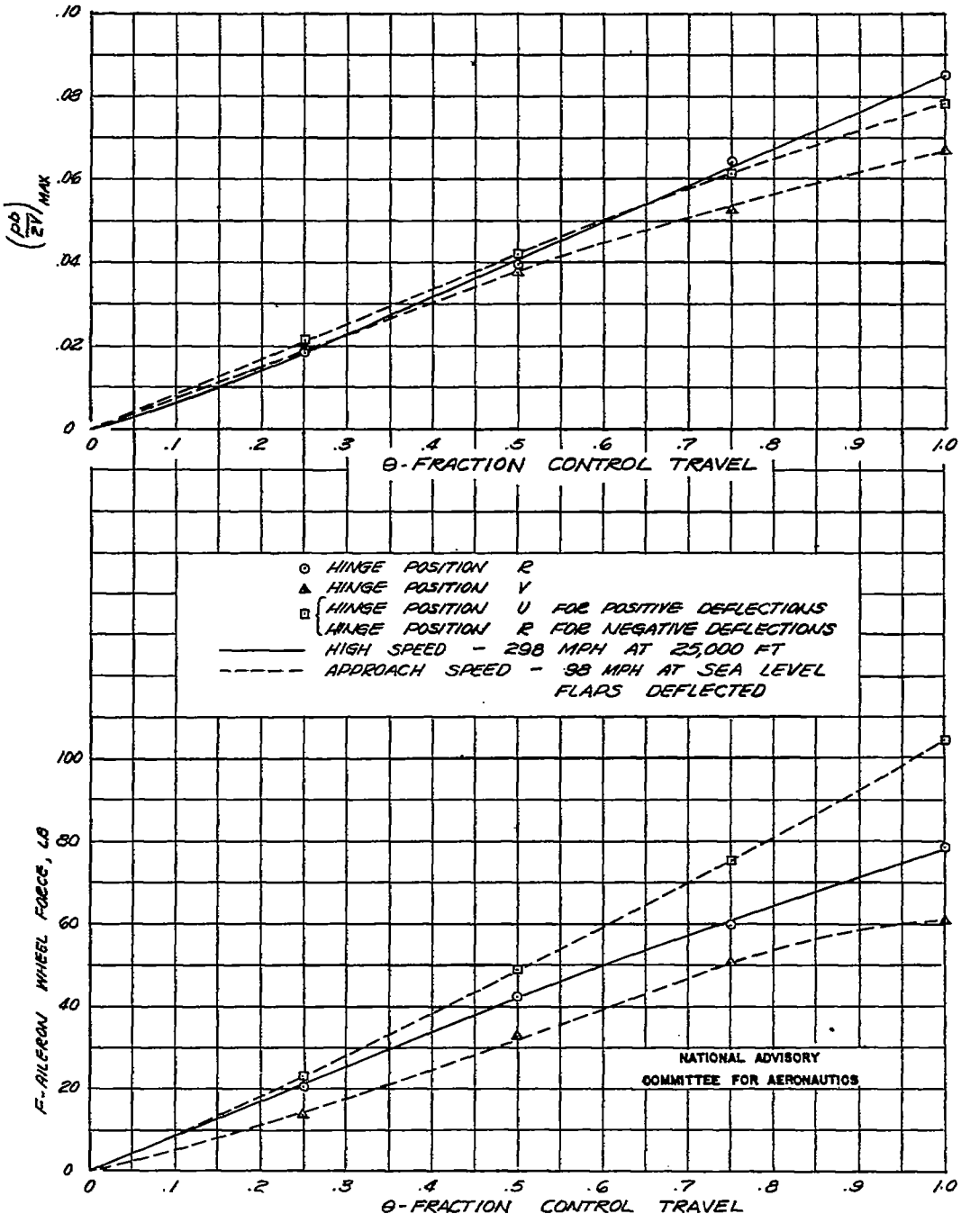
(b). AIRPLANE B.

FIGURE 21 .- CONTINUED.



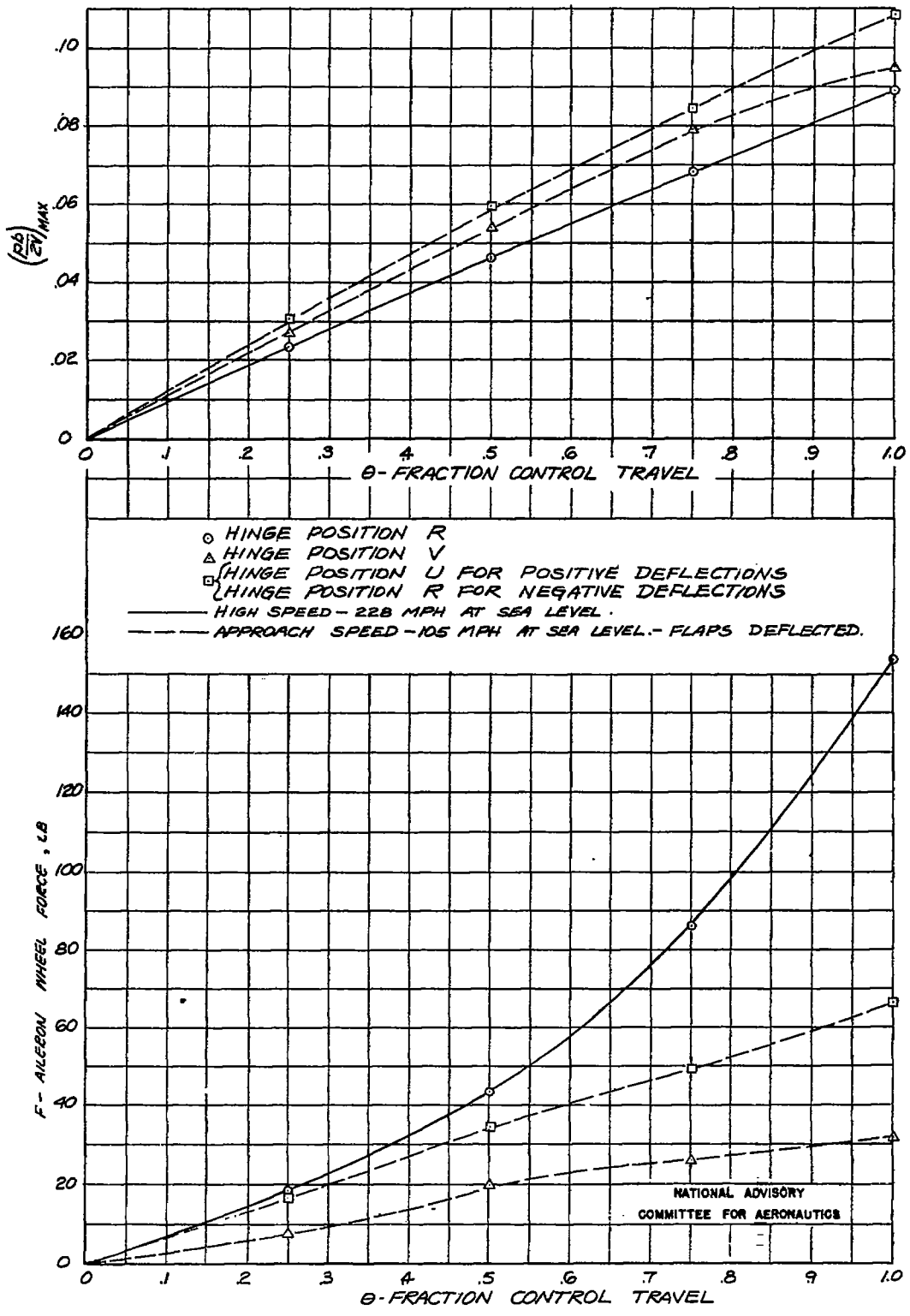
(c). AIRPLANE C.

FIGURE 21 -CONCLUDED.



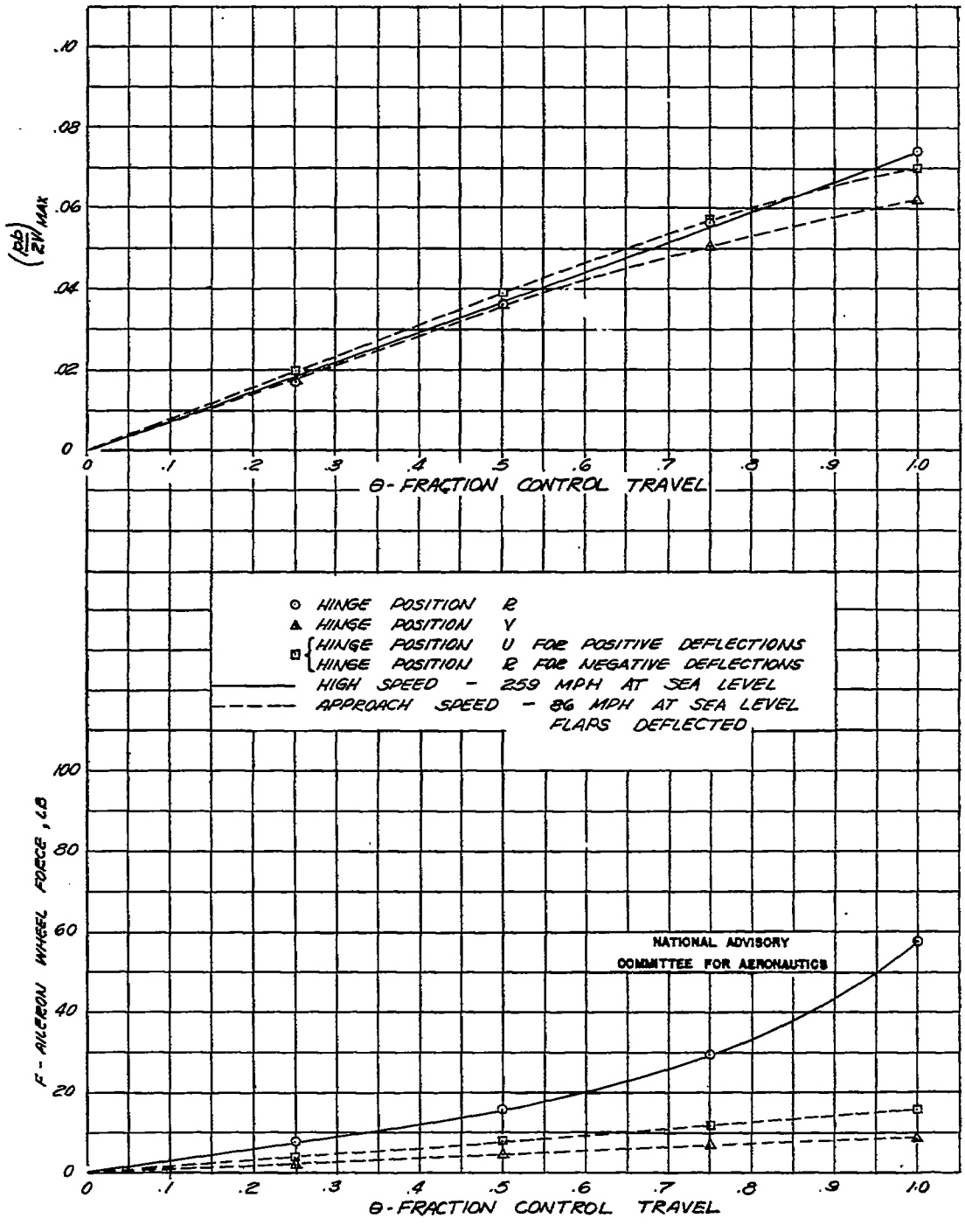
(a). AIRPLANE A.

FIGURE 22.- VARIATION OF $(pb/2V)_{MAX}$ AND WHEEL FORCE WITH CONTROL TRAVEL IN ROLLS WITH THE RUDDER LOCKED FOR THE EXEMPLARY AIRPLANES EQUIPPED WITH THE 0.25 CHORD STRAIGHT SIDED AILERON.



(b). AIRPLANE B.

FIGURE 22 - CONTINUED.



(c) AIRPLANE C.

FIGURE 22.-CONCLUDED.

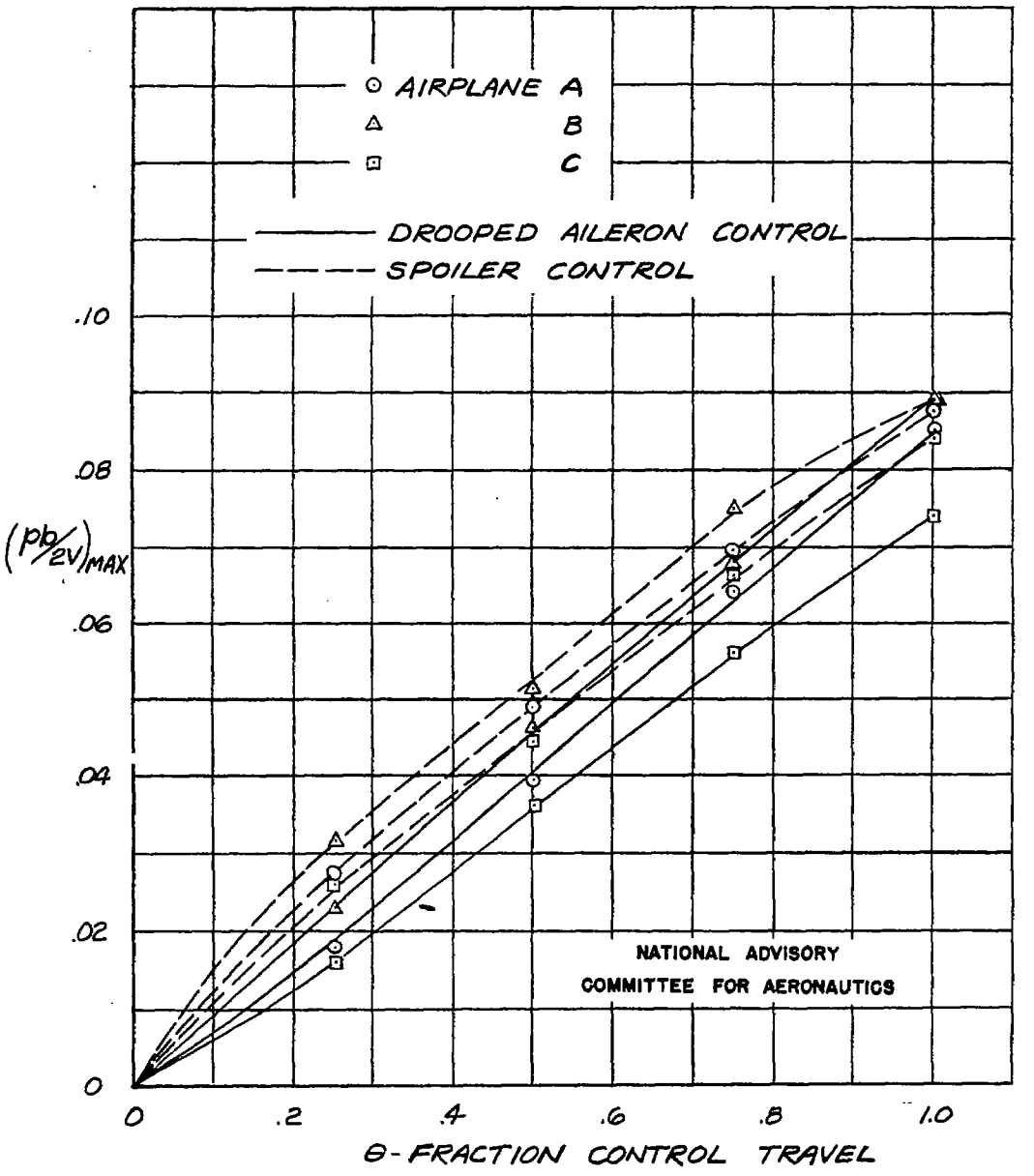


FIGURE 23.- COMPARISON OF THE VARIATION OF $(pb/2V)_{MAX}$ WITH FRACTION CONTROL TRAVEL IN RUDDER LOCKED ROLLS AT HIGH SPEED FOR AIRPLANES A, B, AND C EQUIPPED WITH DROOPED AILERONS AND SPOILER CONTROL.

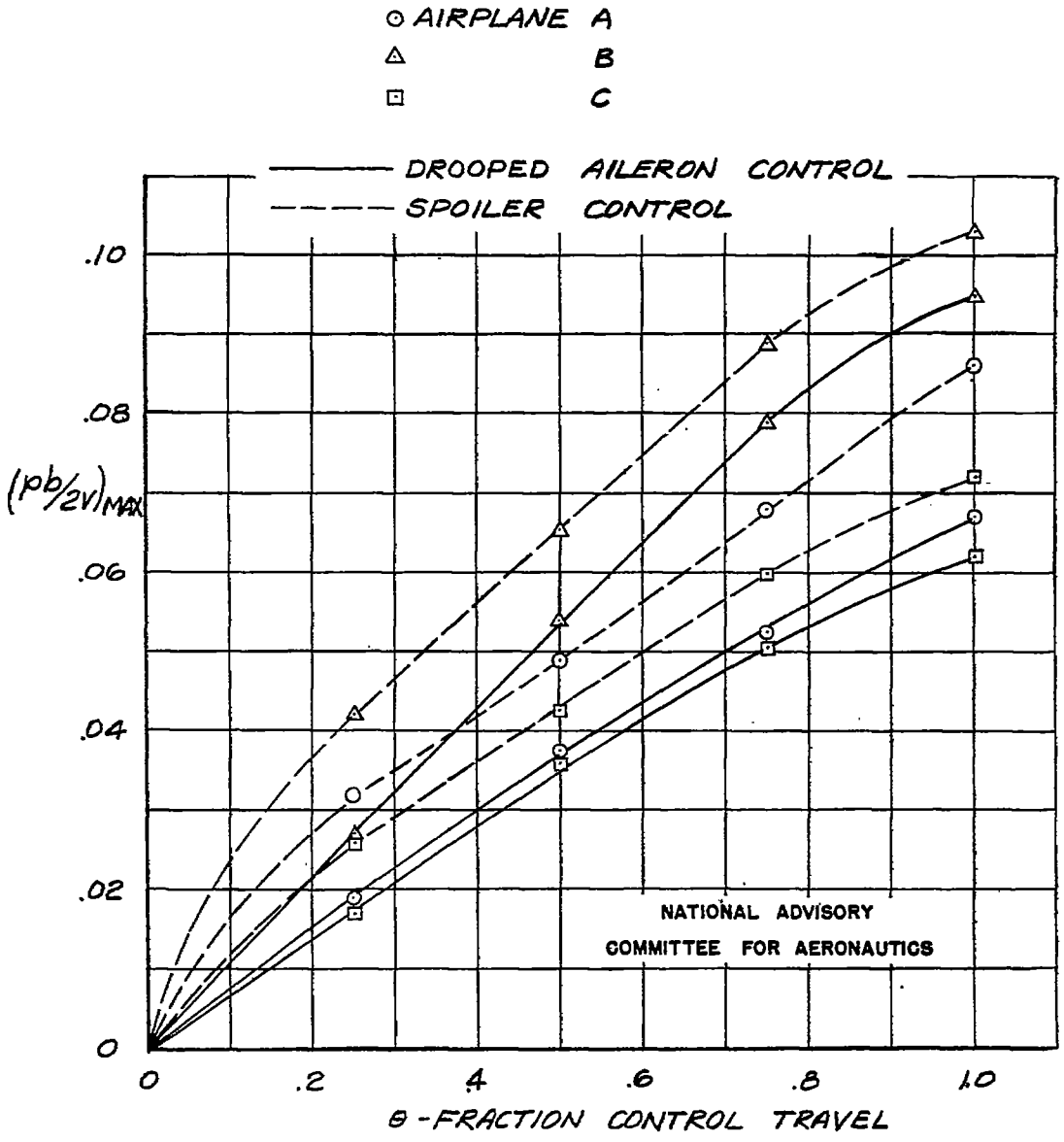


FIGURE 24.- COMPARISON OF THE VARIATION OF $(pb/2V)_{MAX}$ WITH FRACTION CONTROL TRAVEL IN RUDDER LOCKED ROLLS AT THE APPROACH SPEED FOR AIRPLANES A, B, AND C EQUIPPED WITH DROOPED AILERONS AND SPOILER CONTROL.