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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS

XII - VARIOUS COVER-PLATE ALINEMENTS ON THE NACA 0015 AIRFOIL WITH A 30-PERCENT-CHORD FLAP AND LARGE SEALED INTERNAL BALANCE

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NACA

WASHINGTON

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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS

XII - VARIOUS COVER-PLATE ALINEMENTS ON THE NACA 0015 AIRFOIL WITH A 30-PERCENT-CHORD FLAP AND LARGE SEALED INTERNAL BALANCE

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SUMMARY

Force-test measurements in two-dimensional flow have been made in the NACA 4- by 6-foot vertical tunnel to determine the aerodynamic effects of changing the alinement of the cover plates on a sealed internally balanced flap. An NACA 0015 airfoil was utilized for the tests. The chord of the straight-contour flap was 30 percent of the airfoil chord and the balance was 50 percent of the flap chord.

Manufacturing imperfections in the alinement of the cover plates with the airfoil contour, if large, may have serious effects on resultant hinge moment of a flap with a sealed internal balance. With the cover plates bent out from the airfoil contour a rudder would show a tendency to lock in a sideslip, and an elevator to overbalance when used in the landing attitude. In general, bending the cover plates in or out increased the negative slope of the curves of flap hinge moment against angle of attack and against flap deflection.

The slope of the lift curve for the airfoil remained practically unchanged when the cover plates were bent in or out. The lift effectiveness of the flap was decreased by bending the plates out only through the range where flap deflection and angle of attack were of like sign. Bending the plates in did not affect the lift effectiveness but reduced the lift obtainable for the arrangements tested.

The increment of minimum profile drag caused by bending the plates out was appreciable and was larger when the bend location was near the trailing edge of the cover plate.

Bending the cover plates in appeared to have no appreciable effect on the minimum profile drag coefficient.

INTRODUCTION

The NACA has instituted an extensive investigation of the aerodynamic characteristics of various flap arrangements in an effort to determine the types best suited for control surfaces and to supply experimental data for design purposes. The results of this investigation that relate to the present report are given in references 1 and 2.

Difficulties have been experienced by manufacturers in making cover plates for flaps conform exactly to the airfoil contour. The tests reported herein were made to determine the effect, particularly on the flap hinge moments, of various misalinements of the cover plates. The model used was an NACA 0015 airfoil with a 0.30c straight-contour flap having a $0.50c_f$ sealed internal balance. The wide cover plates, discussed in reference 1, were used. The plates were bent for misalinement at two chordwise bend locations to find the effect on the aerodynamic characteristics for different chordwise lengths of misalined cover plates.

APPARATUS AND MODEL

The tests were made in the NACA 4- by 6-foot vertical tunnel (reference 3). The test section of this tunnel has been converted from the original open, circular, 5-foot-diameter jet to a closed, rectangular, 4- by 6-foot throat for force tests of models in two-dimensional flow. A three-component balance system has been installed in the tunnel in order that force-test measurements of lift, drag, and pitching moment may be made. The hinge moment of the flap was measured with a special torque-rod unit built into the model.

The 2-foot-chord by 4-foot-span model was made of laminated mahogany to a modified NACA 0015 contour. (See table I.) The modified airfoil was of NACA 0015 contour forward of the 0.70c station and had a straight contour from the 0.70c station to the trailing edge, which has the same thickness as that of the unmodified NACA 0015 airfoil.

The flap nose balance has the sharp-nose profile tested in reference 1. The model was cut at the 0.50c station and the space from this cut to the flap nose was fitted with a tail block. This tail block was designed to leave a gap of 0.005c at the flap nose. For the tests, however, the gap was closed by a rubber seal attached as shown in figure 1. The rubber seal was attached to the ends of the sharp-nose balance and to the end plates of the model to prevent any air leakage. Care was taken to keep the rubber seal slack enough to prevent interference with the flap hinge-moment readings at all flap deflections.

The 1/16-inch steel cover plates were rolled to approximate the airfoil contour and were made to cover seven-eighths of the distance measured along a line parallel to the chord line from the rear outer edge of the tail block to the flap hinge axis (fig. 1). The distance from the trailing edge of the plates to the flap hinge axis was 0.018c.

Because of the shape of the sharp-nose balance the distance from the trailing edge of the cover plate normal to the sharp-nose balance varies with flap deflection (fig. 2 of reference 1). The distance from the trailing edge of the cover plate normal to the sharp-nose balance is referred to in this paper as the "vent width." The change in vent width from the value of 0.0052c (for the cover plate on the airfoil contour) when the plates were bent in or out (from the airfoil contour) will be referred to as Δv or "change in vent width." The values of vent width were measured when the flap was not deflected.

The cover plates were bent, both inward and outward, at two chordwise points along the airfoil. The first bend was at about the 0.50c station. The amount of bend used gave changes in vent width Δv of −0.0026c, 0.0052c, and 0.0078c which gave vent widths of 0.0026c, 0.0104c, and 0.0130c, respectively, at the trailing edge of the cover plates (fig. 1). The second bend location was at the 0.63c station. It was thought advisable to use small increments of bend in order that the data could be faired more accurately. The values of vent-width change used for this bend location were −0.0026c, −0.0013c, 0.0013c, 0.0026c, 0.0052c, and 0.0078c which gave vent widths of 0.0026c, 0.0039c, 0.0065c, 0.0078c, 0.0104c, and 0.0130c, respectively (fig. 1).

The flap deflections tested were restricted by the shape of the sharp-nose balance which would touch the trailing edge of the cover plates when the flap was deflected. When the cover plates were bent in, the largest flap deflection possible was in some cases only 10°.

TESTS

The NACA 0015 airfoil model with a 0.30c straight-contour flap having a $0.50c_f$ sharp-nose balance was tested with wide cover plates to form an internally balanced flap. The model, when mounted in the tunnel, completely spanned the test section. With this type of test installation, two-dimensional flow is approximated and the section characteristics of the airfoil and flap may be determined. The model was attached to the balance frame by torque tubes that extended through the sides of the tunnel. The angle of attack was set from outside the tunnel by rotating the torque tubes with an electric drive. Flap deflections were set inside the tunnel by templets and were held by a friction clamp on the torque rod that was used in measuring the hinge moments.

The tests were made at a dynamic pressure of 15 pounds per square foot, which corresponds to an air velocity of about 76 miles per hour at standard sea-level conditions. The effective Reynolds number of the tests was approximately 2,760,000. (Effective Reynolds number = test Reynolds number × turbulence factor. The turbulence factor for the 4- by 6-foot vertical tunnel is 1.93.)

The tests were made at flap deflections of 0°, 5°, and 10°, and of 15° when it was possible to reach 15° without contact between cover plate and flap nose. The values of lift, drag, pitching moment, and flap hinge moment were read for all tests throughout the angle-of-attack range (at 2° increments) from negative stall to positive stall. When either stall incidence was approached, the increment in angle of attack was reduced to 1°.

RESULTS

The coefficients and the symbols used in this paper are defined as follows:

c_l airfoil section lift coefficient (l/qc)

L-511

c_{d_o} airfoil section profile-drag coefficient (d_o/qc)

c_m airfoil section pitching-moment coefficient (m/qc^2)

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

where

l airfoil section lift

d_o airfoil section profile drag

m airfoil section pitching moment about quarter-chord point of airfoil

h flap section hinge moment

c chord of basic airfoil with flap neutral

c_f flap chord

q dynamic pressure

and

Δv change in vent width

α_o angle of attack for airfoil of infinite aspect ratio

δ_f flap deflection with respect to airfoil

also

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

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

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

The subscripts outside the parentheses indicate the factors held constant during the measurement of the parameters.

Precision

The accuracy of the data is indicated by the deviation from zero of lift and moment coefficients at an angle of attack of 0° with the flap neutral. The maximum error in effective angle of attack at zero lift appears to be about ±0.2°. Flap deflections were set to an accuracy of ±0.2°. Tunnel corrections, experimentally determined in the 4- by 6-foot vertical tunnel, were applied only to lift. The hinge moments are probably slightly higher than would be obtained in free air and, consequently, the values presented are considered conservative. The increments of drag should be reasonably independent of tunnel effect, although the absolute value is subject to an unknown correction.

Presentation of Data

The aerodynamic section characteristics of the NACA 0015 airfoil with a 0.30c straight contour flap having a $0.50c_f$ internal balance are taken from reference 1 in figure 2. The aerodynamic section characteristics of the airfoil with the cover plates bent either inward or outward varying amounts are given in figures 3 through 11.

The flap hinge-moment parameters are given as a function of change in vent width in figure 12. The increment of minimum profile-drag coefficient is presented as a function of change in vent width for both bend locations in figure 13.

The aerodynamic section parameters of the NACA 0015 airfoil with the various internal balance vent widths are summarized in table II.

DISCUSSION

Lift

The slope of the lift curve $\left(\frac{dc_l}{d\alpha_0}\right)_{\delta_f}$ (table II) for the airfoil with cover plates bent in or out different amounts from either of the two bend locations remained virtually unchanged. The angle of attack at which the airfoil stalled appeared to remain about the same (approximately ±16°) for all positions of the cover plates (figs. 2 to 11).

The values for lift effectiveness $(\partial\alpha_0/\partial\delta_f)_{c_l}$ given in table II were taken at zero lift and show very little change for different cover-plate misalinements. Figures 4, 5, 8, 9, 10, and 11, which are for the plates in the bent-out position, show a decrease in lift effectiveness for flap deflections greater than 10° at positive values of lift coefficient. Since the decrease in the parameter value is, in every case, for the condition with cover plates bent out, the reduction in lift effectiveness may be attributed to the breaking up of the air flow over the flap by the protruding plate, which acts like a spoiler. The loss of lift effectiveness appeared more pronounced when the plates were bent from the 0.63c location, probably because of the greater angle between the airfoil contour and the portion of the plate extending into the air stream.

Flap Hinge Moments

The values of $c_{h_{f_\alpha}}$ (table II) were taken over a small range of angle of attack (±5°) because the curves were linear over only a short range. The values of $c_{h_{f_\delta}}$ (table II) were taken as the average slope between 0° and 10° flap deflection, since the curves were not linear. For a complete picture of the effect of each cover-plate position, all the hinge-moment curves (figs. 2 to 11) must be taken into consideration and too much reliance should not be placed on the values of the slopes measured over a small part of each curve except for stick-free stability calculations.

The value of $c_{h_{f_\alpha}}$ was not changed when the cover plates were bent in at the 0.50c location (fig. 12). With the plates bent in at the 0.63c location $c_{h_{f_\alpha}}$ became slightly less negative in magnitude. When the cover plates were bent out, the value of $c_{h_{f_\alpha}}$ for both bend locations increased in a negative direction as the vent width increased. The slope of the $c_{h_{f_\alpha}}$ curve for the 0.63c bend location was almost twice the slope of the curve for the 0.50c location.

When the cover plates were bent in, the value of $c_{h_{f_\delta}}$ increased in a negative direction for both bend locations (fig. 12). These values for 0.50c bend location increased much more rapidly. With the cover plate bent in at the 0.50c station to give the minimum vent width, 0.0026c, the value of $c_{h_{f_\delta}}$ was approximately −0.0062. The value of $c_{h_{f_\delta}}$ for an unbalanced flap was −0.0089 (reference 2). With the cover plates coincident with the airfoil contour, the 0.50c_f internal balance reduced the value of $c_{h_{f_\delta}}$ to −0.0030 (table II). Thus, the internal balance produced a balancing increment of 0.0059. The balancing increment was reduced to 0.0027, or the difference between −0.0089 and −0.0062, by bending the cover plates in from the 0.50c station.

Bending the cover plates out about the 0.63c bend location had a pronounced effect on the negative value of $c_{h_{f_\delta}}$, which decreased rapidly until a value of −0.0010 was reached with a vent width change of 0.0025c. With additional increases in vent width, the value of $c_{h_{f_\delta}}$ increased rapidly in a negative direction until a value of −0.0106 was reached with the maximum vent width tested. Since the plain straight-contour flap gave a value for $c_{h_{f_\delta}}$ of −0.0089, bending the cover plates out an excessive amount actually causes the internal balance to unbalance or increase the flap hinge moment. The unbalancing effect of bending the cover plates out was caused by the reversal of the pressure differential acting on the enclosed nose of the internal balance. The protruding cover plate had a spoiler action, which reduced the velocity over the upper vent (flap deflected down) and thus increased the pressure in the upper chamber of the ininternal balance. The pressure in the lower chamber would probably remain nearly constant. Because the lower surface vent is in a low velocity region with the flap down, cover plate misalinements should have little effect on the pressure in the lower chamber. Bending the plates out at the 0.50c location had the same though less pronounced effect on $c_{h_{f_\delta}}$ as at the 0.63c location. The effect was smaller probably because the upper plate made a smaller angle with the airfoil surface and therefore acted less like a spoiler.

A comparison of figures 4, 5, 8, 9, and 10 (for the plates in the bent-out position) with figure 2 indicates that bending the plates out tended to give an overbalanced condition when angle of attack and flap deflection are of opposite sign. With the cover plates bent out and angle of attack and flap deflection of like sign, both $c_{h_{f_\alpha}}$ and $c_{h_{f_\delta}}$ become erratic at flap deflections greater than 5°.

The horizontal tail surface in the landing attitude and the vertical tail surface in a sideslip are both in the condition where the angle of attack and flap deflection are in opposition. Bending the cover plates out produces an overbalancing tendency when angle of attack and flap deflection are in opposition. Therefore, bending the cover plates out may cause rudder lock in a sideslip or overbalance in the horizontal tail when the airplane is in the landing attitude.

The values of $c_{h_{f_\alpha}}$ and $c_{h_{f_\delta}}$ obtained with the cover plates coincident with the airfoil contour increased considerably in a negative direction when angle of attack and flap deflection were of like sign (fig. 2). Bending the cover plates in made the values of $c_{h_{f_\alpha}}$ and $c_{h_{f_\delta}}$ nearly independent of the signs of angle of attack and flap deflection (figs. 3, 6, and 7). Bending the cover plates in appears to have less serious effects on the flap hinge-moment characteristics than bending the cover plates out.

Pitching Moment

The slopes of the curves of pitching moment as a function of lift at constant angle of attack and at a constant flap deflection are listed in table II. The aerodynamic center for the lift due to angle of attack was located at approximately the 0.23c station for the airfoil having the cover plates bent to the various positions. The aerodynamic center for the lift due to flap deflection was located at about the 0.41c station for all cover-plate positions except the extreme bent-out position from the 0.63c bend location, for which case the aerodynamic center was located at the 0.448c station.

Drag

Because of the unknown tunnel correction, the values of drag coefficients cannot be considered absolute; the relative values, however, should be practically independent of tunnel effect. The increments of drag coefficient (fig. 13) were determined by deducting the drag coefficient of the airfoil with plain 0.30c flap with sealed gap, flap not deflected, from the drag coefficient of the airfoil with the cover plates bent to the various positions and the flap neutral.

The increments of minimum profile-drag coefficient are plotted against changes in vent width in figure 13. Bending the plates in at either bend location had no measurable effect on the minimum profile drag. Bending the plates out gave an increase in drag which increased rapidly with the larger amounts of bend. The 0.63c bend location gave larger increments of drag for the same vent width than the 0.50c bend location. The larger increments of drag may be attributed to the spoiling of the air flow over the flap by the protruding plate which acts like a spoiler. The spoiler action indicates that the increment of drag produced is a function of the angle between the protruding part of the plate and the airfoil surface and increases as the angle increases.

CONCLUSIONS

The results of the tests indicate the following conclusions:

1. Manufacturing imperfection in the alinement of the cover plates for internally balanced flaps with the airfoil contour, if large, may have serious effects on the resultant hinge moment of a flap with a sealed internal balance.

2. In general, bending the cover plates in or out increased the negative slope of curves of flap hinge moment plotted against angle of attack and against flap deflection.

3. A rudder with internal balance with the cover plates bent out an appreciable amount should have a tendency toward rudder lock in a sideslip. Similarly, an elevator should have a tendency toward overbalance when used in the landing attitude when the cover plates are bent out. Bending the plates in should have no serious effect other than a slight increase in hinge moment.

4. Bending the cover plates in or out had practically no effect on the slope of the lift curve for the airfoil.

5. The lift effectiveness of the flap with flap deflection and angle of attack of like sign was reduced when the cover plates were bent out at either bend location. Bending the plates in did not affect the lift effectiveness.

6. The increment of minimum profile drag due to bending the plates out was appreciable and was larger when the bend location was near the cover-plate trailing edge. Within the experimental accuracy of the tests, bending the cover plates in had no appreciable effect on the minimum profile-drag coefficient.

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REFERENCES

1. Sears, Richard I., and Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Control-Surface Characteristics. XI - Various Large Overhang and Internal-Type Aerodynamic Balances for a Straight-Contour Flap on the NACA 0015 Airfoil. NACA A.R.R., Jan. 1943.

2. Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Control-Surface Characteristics. X - A 30-Percent-Chord Plain Flap with Straight Contour on the NACA 0015 Airfoil. NACA A.R.R., Sept. 1942.

3. Wenzinger, Carl J., and Harris, Thomas A.: The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics. Rep. No. 387, NACA, 1931.

TABLE I

ORDINATES FOR NACA 0015 AIRFOIL WITH STRAIGHT-CONTOUR FLAP

[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
0	0	0
1.25	2.37	-2.37
2.5	3.27	-3.27
5.0	4.44	-4.44
7.5	5.25	-5.25
10	5.85	-5.85
15	6.68	-6.68
20	7.17	-7.17
25	7.43	-7.43
30	7.50	-7.50
40	7.25	-7.25
50	6.62	-6.62
60	5.70	-5.70
70	4.58	-4.58
80	3.10	-3.10
90	1.63	-1.63
95	.90	-.90
100	(.16)	(-.16)
100	0	0
L.E. radius: 2.48		

TABLE II.- PARAMETER VALUES FOR A 0.30c STRAIGHT-CONTOUR FLAP WITH A $0.50c_f$ SEALED INTERNAL BALANCE ON AN NACA 0015 AIRFOIL WITH THE COVER PLATES BENT AT DIFFERENT LOCATIONS TO GIVE VARIOUS VENT WIDTHS

[The vent width with the airfoil-contour cover plates is 0.0052c]

Figure number	Bend location (percent chord)	Direction of bend	Change in vent width, Δv (fraction of chord)	Parameters					
				$\left(\frac{\partial c_l}{\partial \alpha_0}\right)_{\delta_f}$	$\left(\frac{\partial \alpha_0}{\partial \delta_f}\right)_{c_l}$	$\left(\frac{\partial c_{h_f}}{\partial \alpha_0}\right)_{\delta_f}$	$\left(\frac{\partial c_{h_f}}{\partial \delta_f}\right)_{\alpha_0}$	$\left(\frac{\partial c_m}{\partial c_l}\right)_{\delta_f}$	$\left(\frac{\partial c_m}{\partial c_l}\right)_{\alpha_0}$
2	No bend	No bend	0.0000	0.097	-0.53	-0.0017	-0.0030	0.016	-0.160
3	50	In	-.0026	.100	-.54	-.0017	-.0062	.016	-.156
4	50	Out	.0052	.094	-.53	-.0029	-.0023	.016	-.163
5	50	Out	.0078	.095	-.54	-.0034	-.0042	.015	-.165
6	63	In	-.0026	.097	-.54	-.0013	-.0038	.014	-.155
7	63	In	-.0013	.098	-.54	-.0015	-.0029	.014	-.155
8	63	Out	.0013	.096	-.54	-.0019	-.0011	.017	-.155
9	63	Out	.0026	.097	-.56	-.0035	-.0010	.016	-.154
10	63	Out	.0052	.096	-.54	-.0037	-.0026	.018	-.164
11	63	Out	.0078	.095	-.48	-.0045	-.0106	.015	-.198

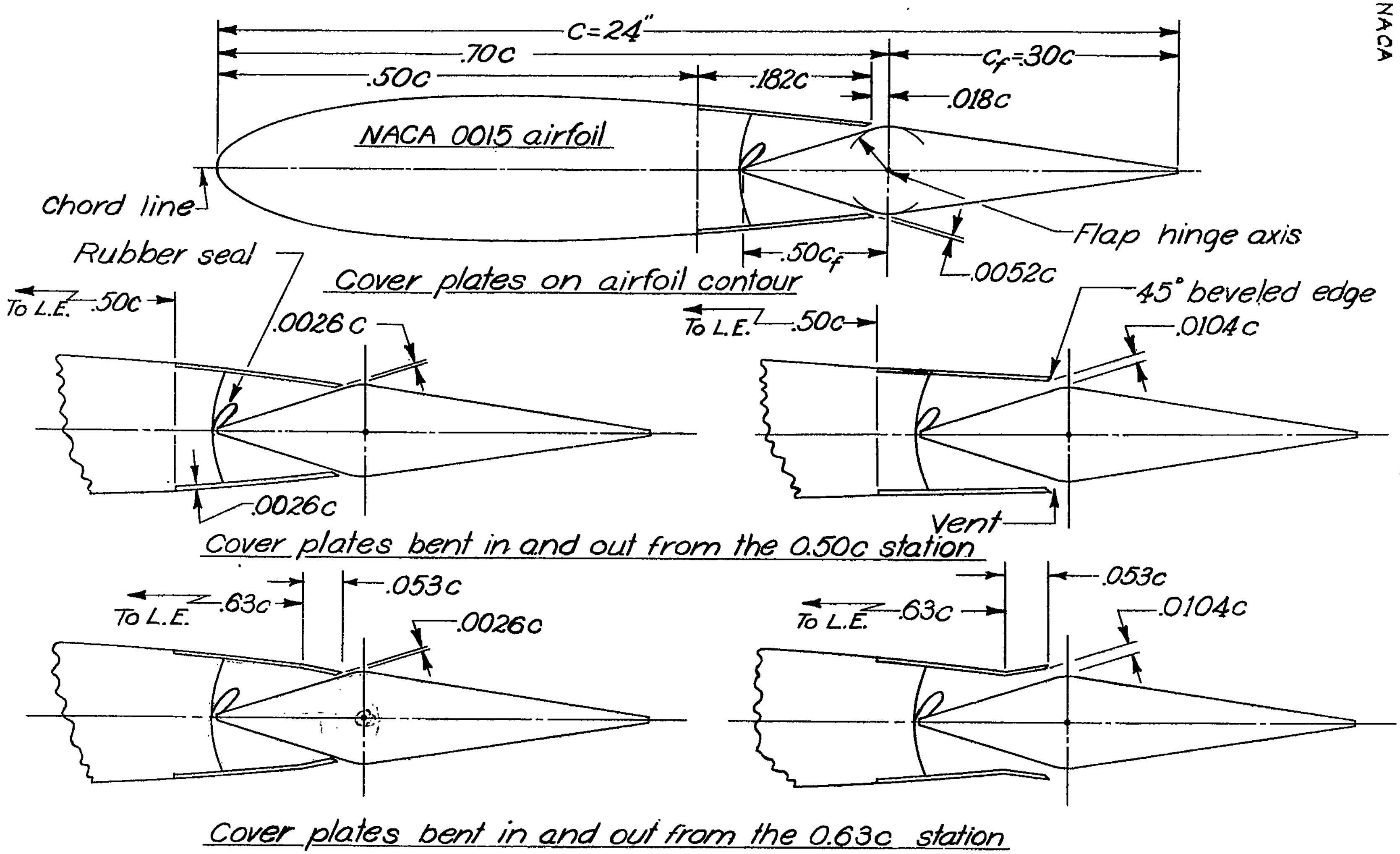

Figure 1.-Two-foot chord NACA 0015 airfoil with a 0.30c straight-contour flap having a 0.50c_f sealed internal balance.

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Fig. 2

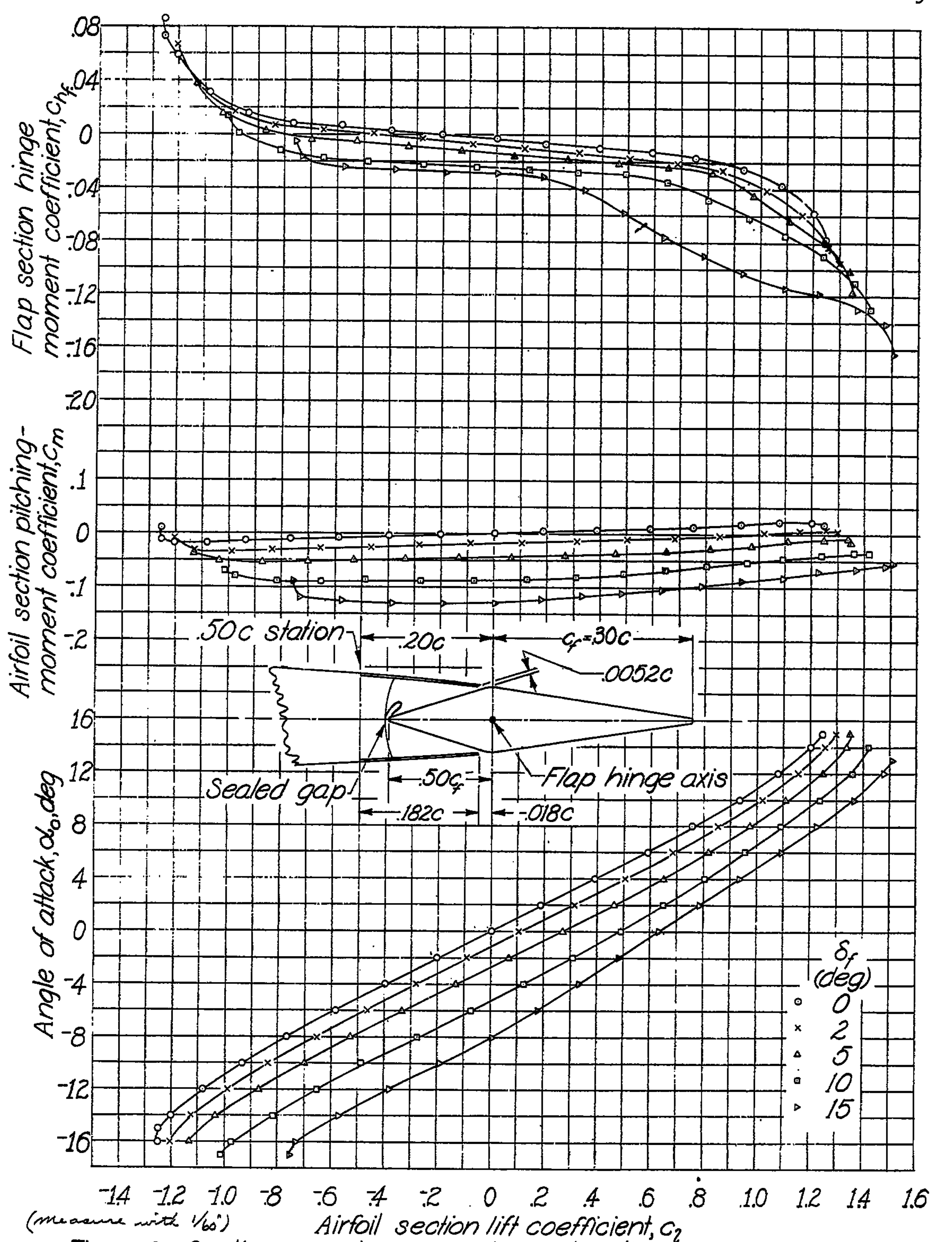


Figure 2 - Section aerodynamic characteristics of an NACA 0015 airfoil Flap, 0.30c straight contour; balance, 0.50c_f internal; gap, sealed; cover plate, on contour; vent width, 0.0052c. (Reference 1.)

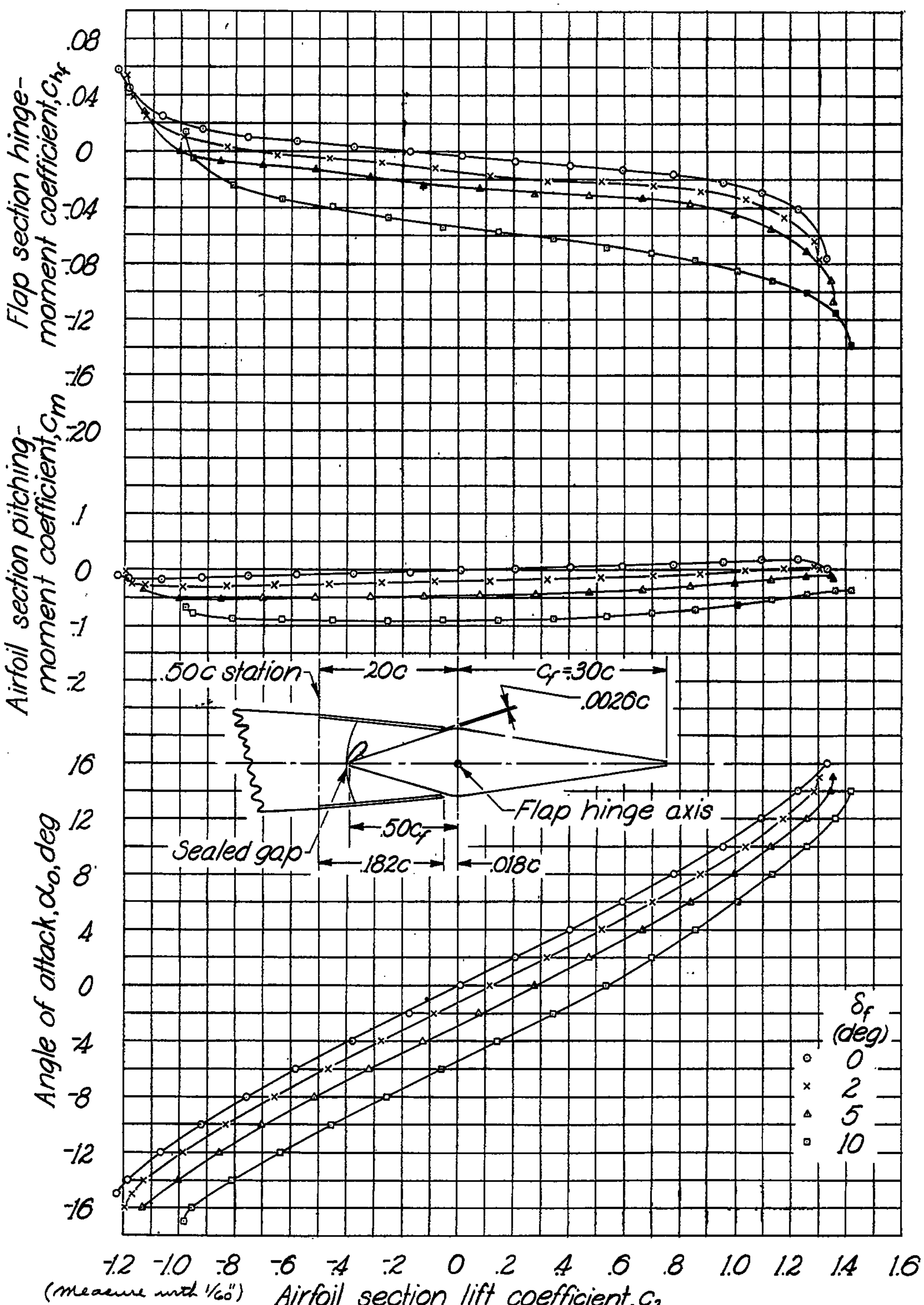


Figure 3 -Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50c_f internal; gap, sealed; cover plate, bent in; bend location, 0.50c; vent width 0.0026c.

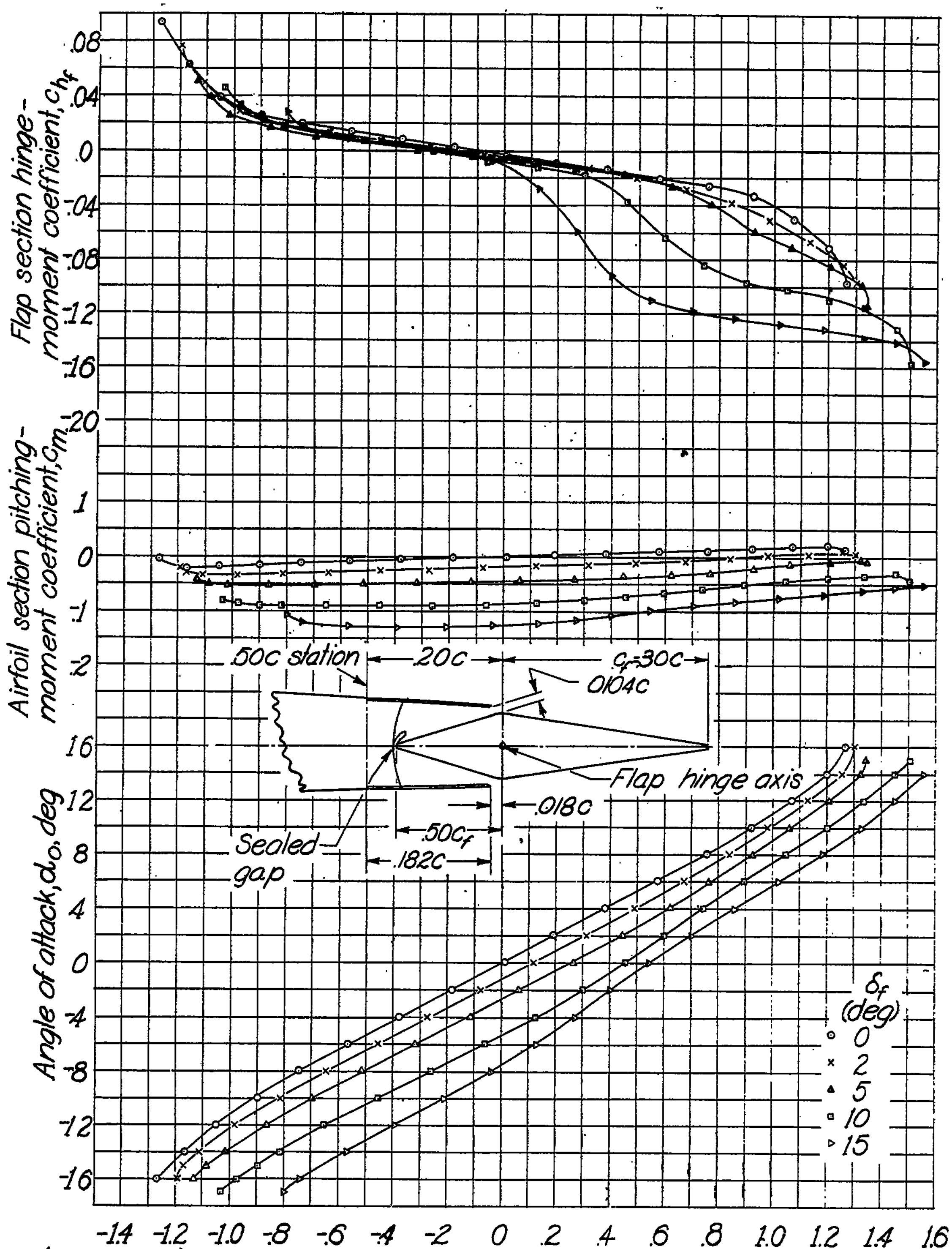


Figure 4.-Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, $0.50c_f$ internal; gap, sealed; cover plate, bent out; bend location, 0.50c; vent width, 0.0104c.

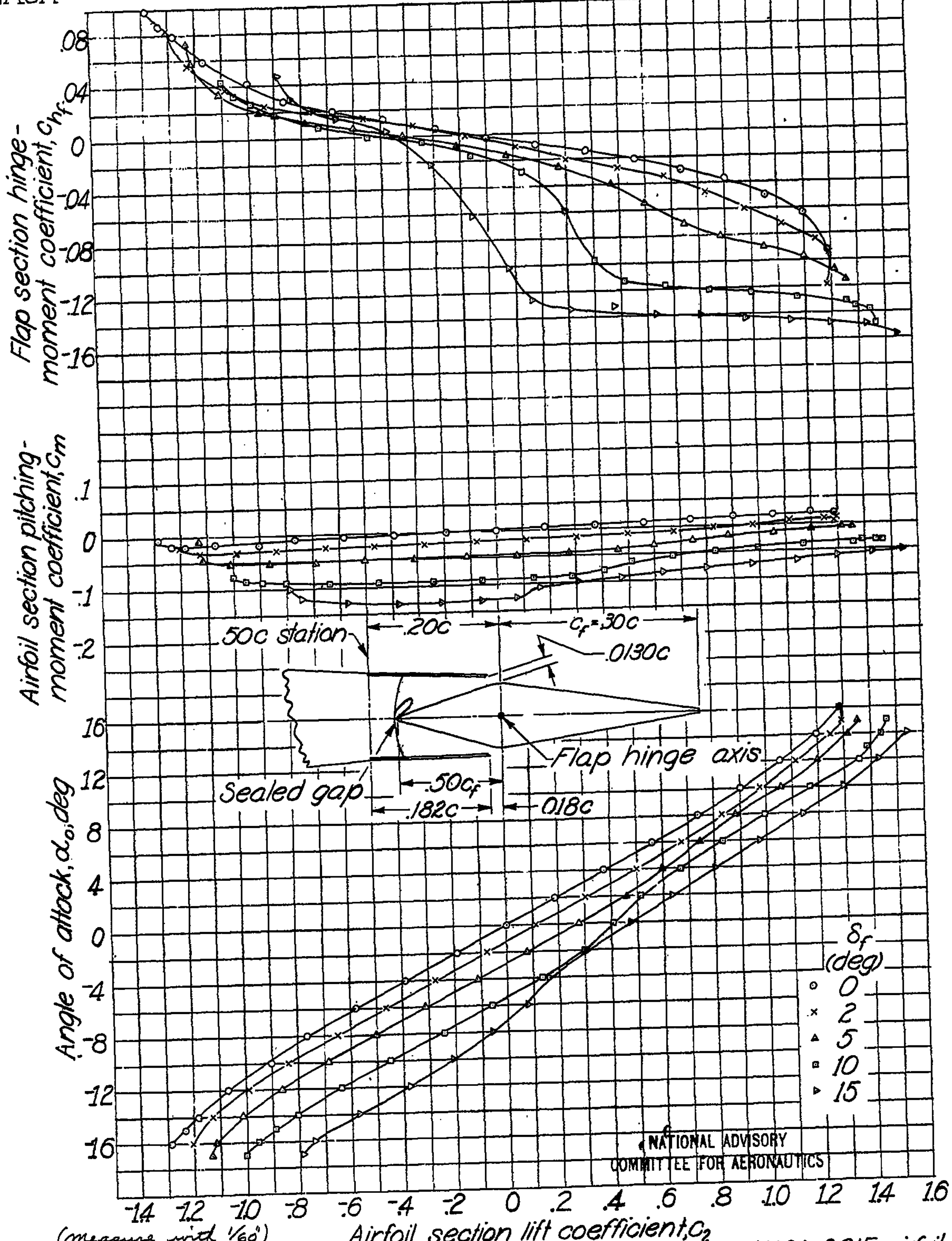
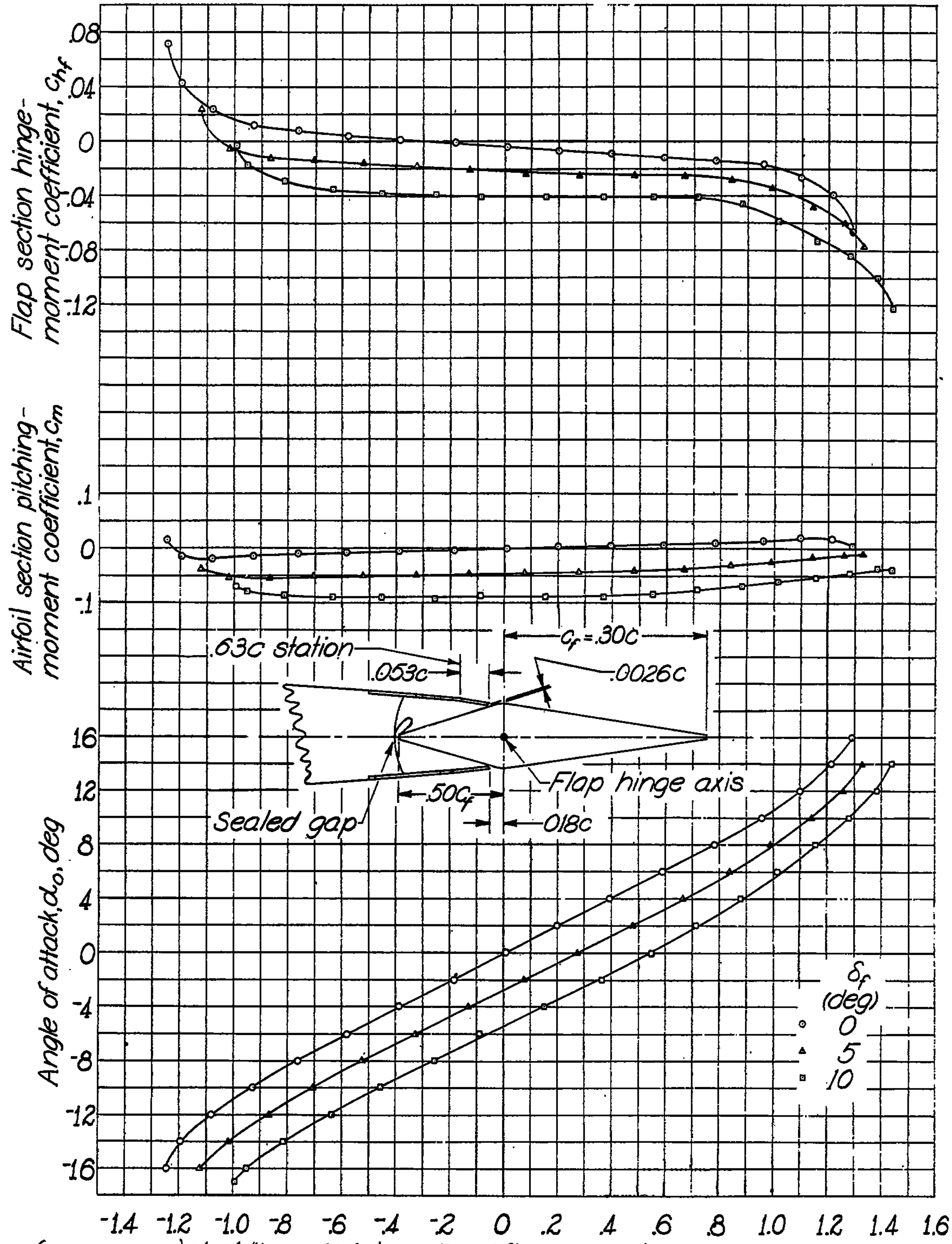


Figure 5 - Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50c_f internal; gap, sealed; cover plate, bent out; bend location, 0.50c; vent width, 0.0130c



(measure with 1/60")

Figure 6 - Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50c_f internal; gap, sealed, cover plate, bent in; bend location, 0.63c; vent width, 0.0026c.

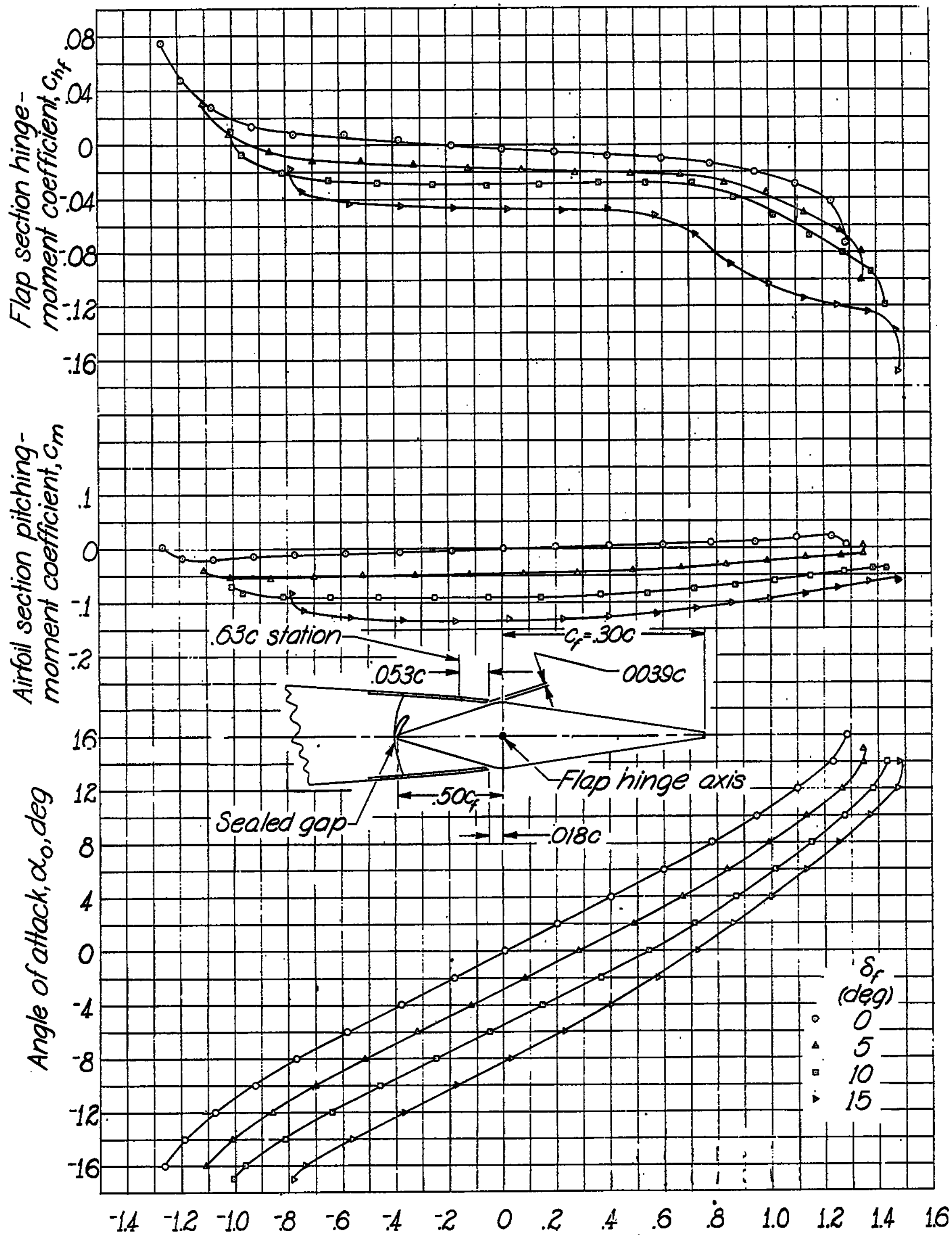


Figure 7.- Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50 c_f internal; gap, sealed; cover plate, bent in; bend location, 0.63c.; vent width, 0.0039c.

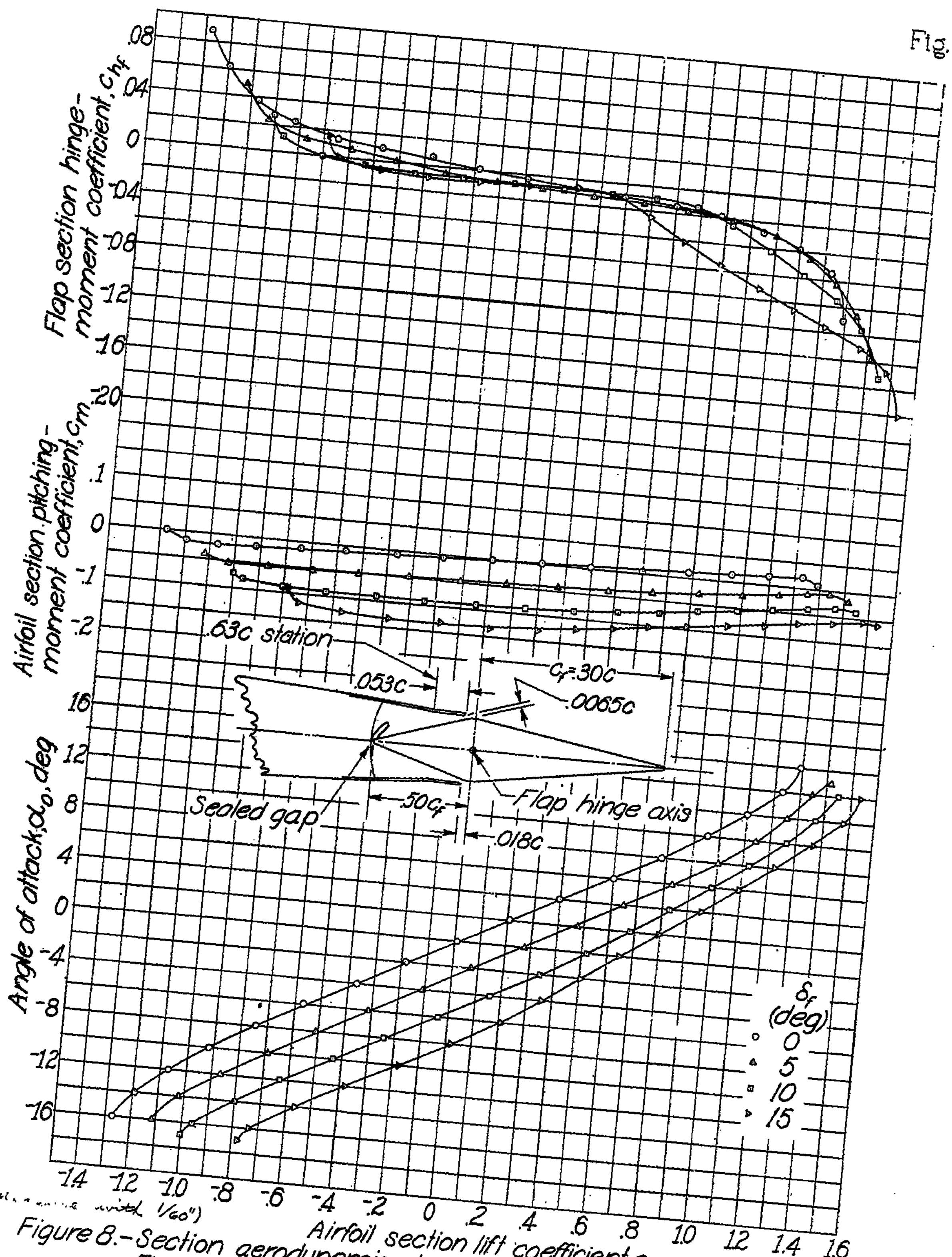


Figure 8.- Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50c_f internal; gap, sealed; cover plate, bent out; bend location, 0.63c; vent width, 0.0065c.

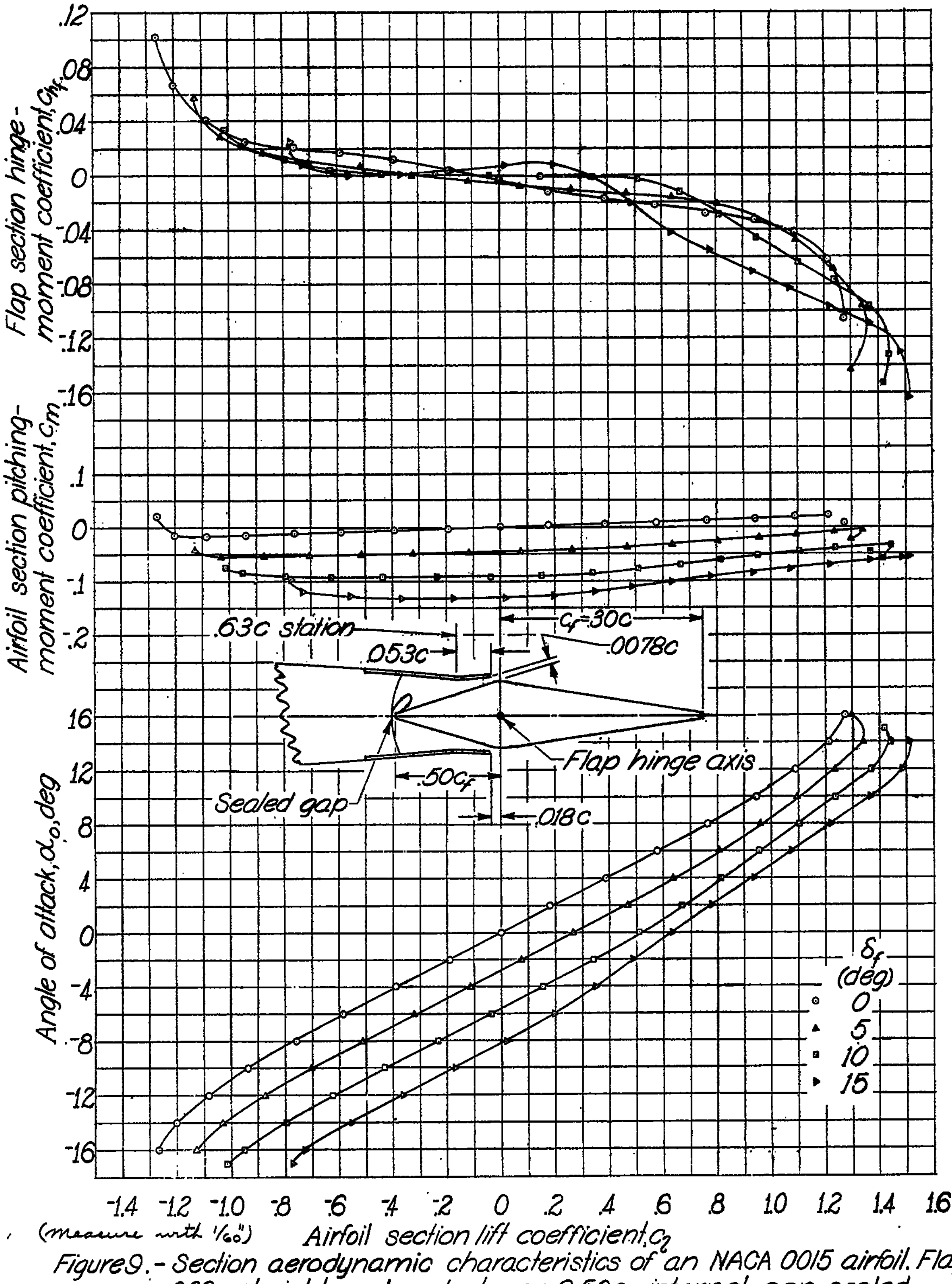


Figure 9. - Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50c_f internal; gap, sealed; cover plate, bent out; bend location, 0.63c; vent width, 0.0078c.

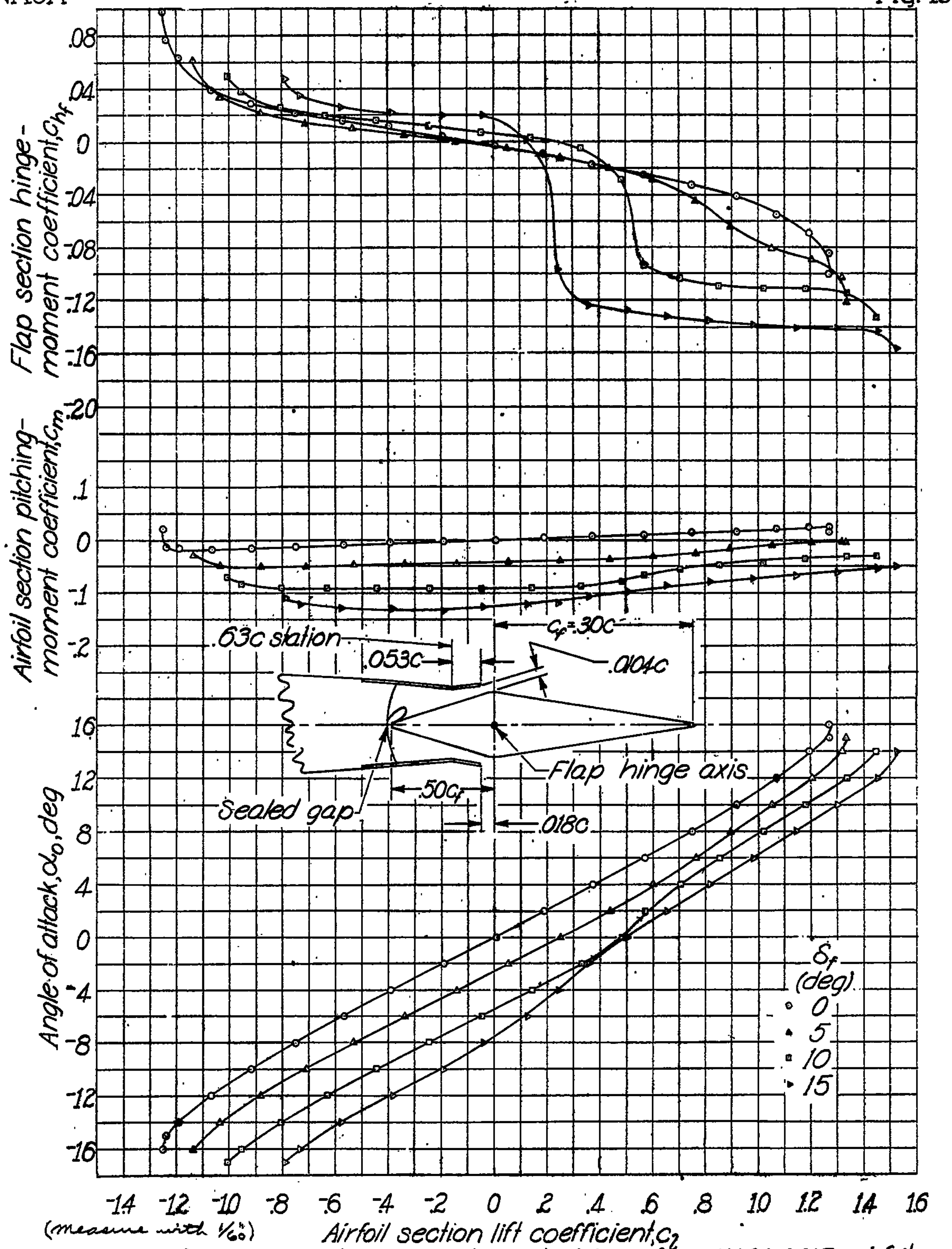


Figure 10.- Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50c_f internal; gap, sealed; cover plate, bent out; bend location, 0.63c; vent width, 0.0104c.

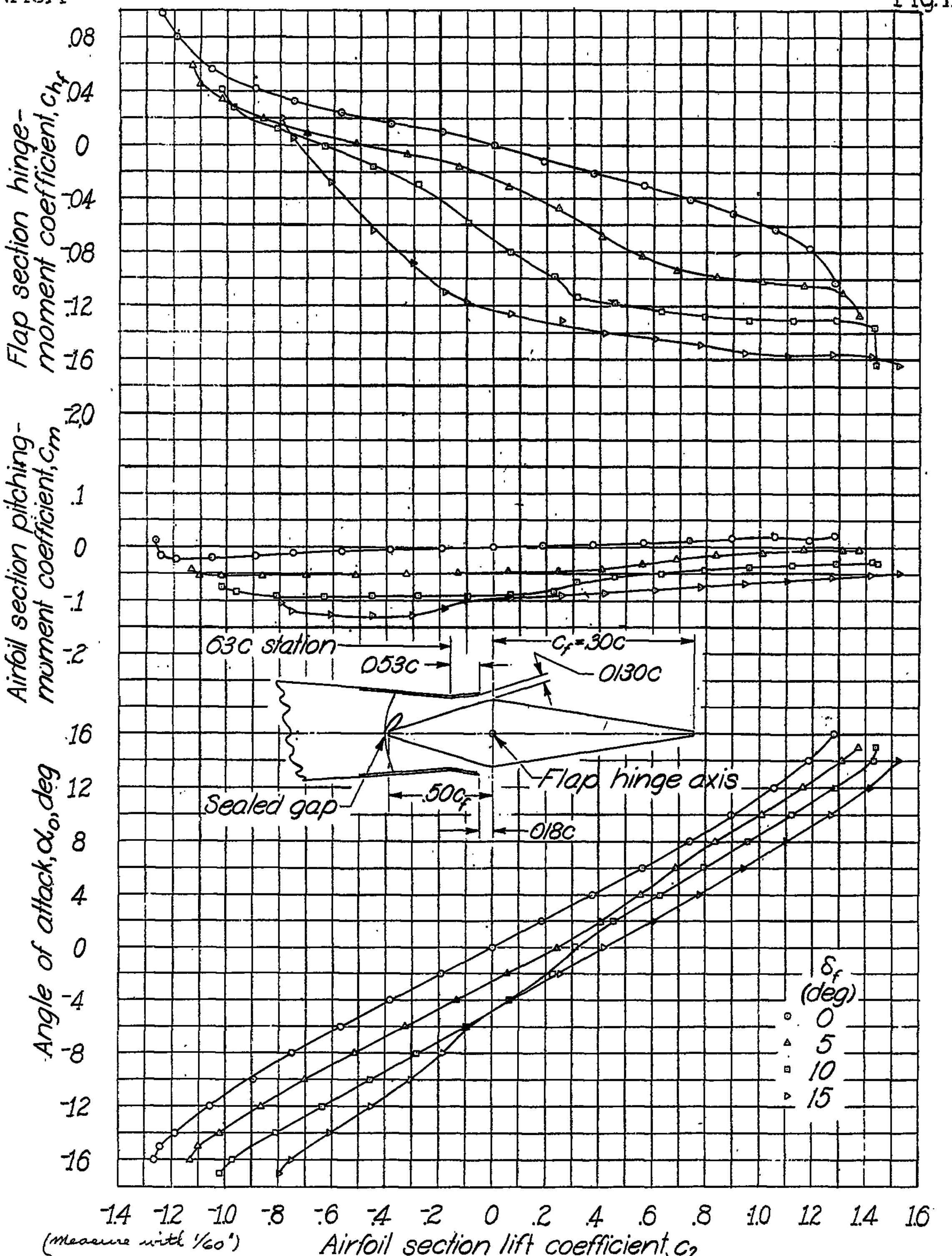


Figure 11-Section aerodynamic characteristics of an NACA 0015 airfoil. Flap, 0.30c straight contour; balance, 0.50 c_f internal; gap, sealed; cover plate, bent out; bend location, 0.63c; vent width, 0.0130c

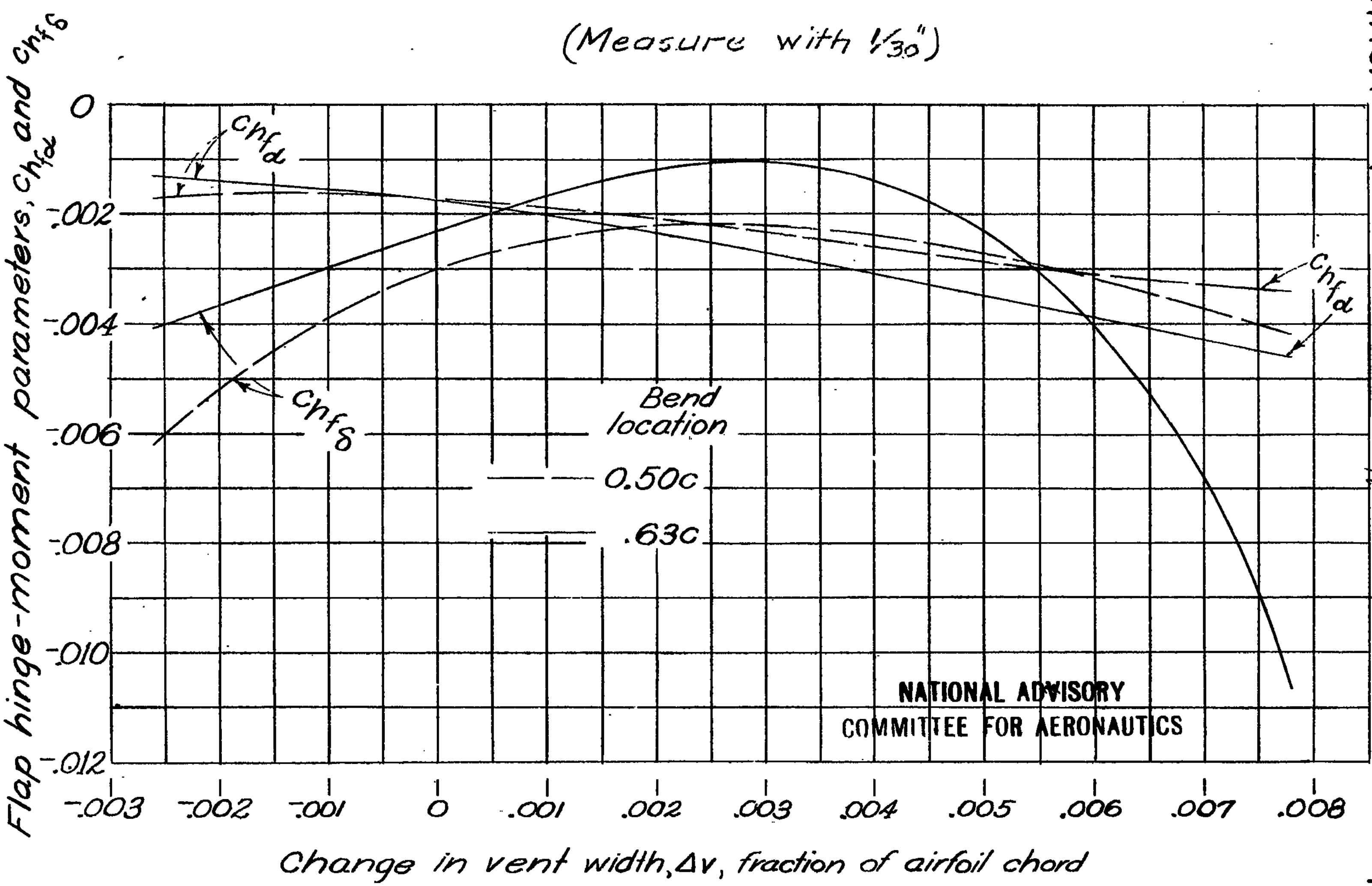


Figure 12.- Variation of the flap hinge-moment parameters with changes in vent width. Cover plates bent at each of two locations. NACA 0015 airfoil with a 0.30c straight-contour flap having a 0.50c_f internal balance.

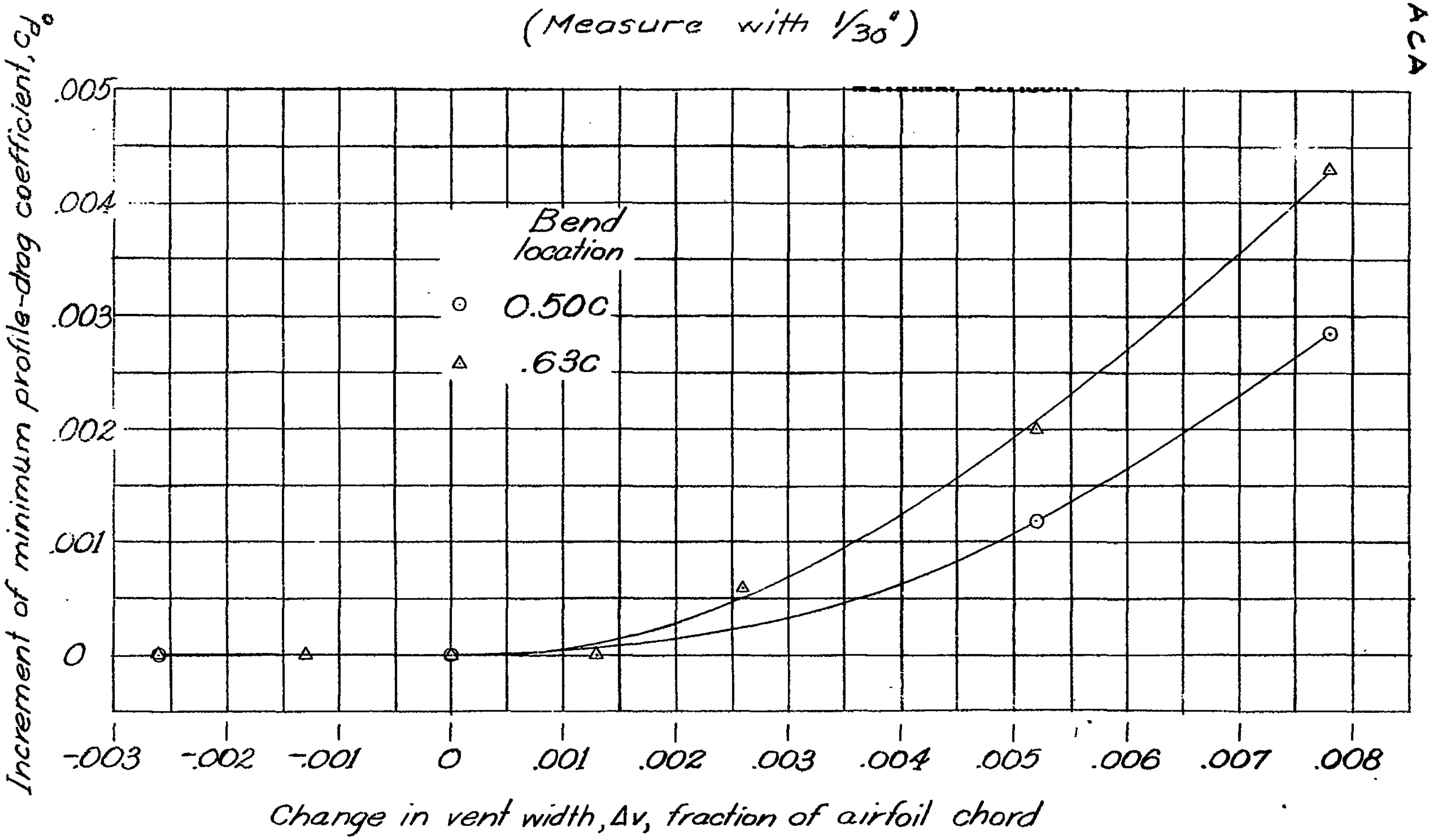


Figure 13.- Variation of the increment of minimum profile-drag coefficient with changes in vent width. Cover plates bent at each of two locations. NACA 0015 airfoil with a 0.30c straight-contour flap having a $0.50c_f$ internal balance.

RESTRICTED

TITLE: Wind-Tunnel Investigation of Control-Surface Characteristics. XII-Various Cover-Plate Alinements on the NACA 0015 Airfoil with a 30-Percent-Chord Flap and *

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ABSTRACT:

Force-test measurements in two-dimensional flow were made to determine the aerodynamic effects of changing the cover-plate alinements on the NACA 0015 airfoil with 30% chord flap and large sealed internal balance. The results indicated that manufacturing imperfections in the alinement of the cover plates with the airfoil contour, if large, may have serious effects on resultant hinge moment of a flap with a sealed internal balance. Bending the cover plates in or out has practically no effect on the slope of the lift curve for the airfoil.

* Large Sealed Internal Balance EO 10501 dd 5 NOV 1953

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