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RÉSUMÉ OF DATA FOR INTERNALLY BALANCED AILERONS

By F. M. Rogallo and John G. Lowry

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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RÉSUMÉ OF DATA FOR INTERNALLY BALANCED AILERONS

By F. M. Rogallo and John G. Lowry

SUMMARY

The available test results of internally balanced ailerons have been correlated and summarized herein. Although several variables have yet to be investigated, the results presented will be useful in the preliminary design of internally balanced ailerons and in the determination of the most promising modifications to unsatisfactory ailerons.

INTRODUCTION

In conjunction with the investigation being conducted by the NACA of various types of balancing device for ailerons, a considerable amount of development work has been done on internal balances. These balancing devices, enclosed within the wings or fuselage, are essentially a piston, a diaphram, or bellows attached to the aileron directly or through a linkage. The device is vented at the surface of the airplane at two locations that have a pressure difference which, when applied across the movable portion of the balancing device, will tend to counteract the hinge moment of the unbalanced aileron.

Enclosed or internal balances are of two general types. In the most commonly investigated type, the balancing surface is attached rigidly or linked to the aileron in such a manner that its angular or linear travel is directly proportional to the aileron deflection; the vents are so located that the balance-actuating pressure varies with aileron deflection and with angle of attack in approximately the same manner as does the hinge moment of the unbalanced aileron. In the other type of internal balance, the variation of balancing moment with aileron deflection is obtained by varying the mechanical advantage of the balance relative to the aileron in the same manner as the hinge moment varies; the actuating pressure is essentially

proportional to the free-stream dynamic pressure and is independent of aileron deflection.

The purpose of the present paper is to describe the rigidly attached or constant-leverage type of internal balance and to summarize briefly its characteristics on wings of various plan forms. The data used in preparing this résumé include wind-tunnel investigations made by the NACA and in England and flight tests of two airplanes tested by the NACA, one of which was a modern high-speed airplane. The data were obtained from references 1 to 7, from previously circulated restricted data obtained for the Army Air Forces, Materiel Command, and from unpublished British and NACA data. All the available finite-span data were included in the study and some section data were included to show the effects of variables not covered by the finite-span data.

No mention of rolling effectiveness is made in this résumé because the balanced aileron has the same effectiveness as the plain unbalanced aileron. The addition of the balance neither increases nor decreases the effectiveness of the aileron in producing rolling moments.

PARAMETERS AND SYMBOLS

The parameters and symbols used in the presentation of the data are:

C_h aileron hinge-moment coefficient $(H/q\bar{c}_a{}^2 b_a)$

H hinge moment of aileron about hinge axis; positive when moment tends to move aileron trailing edge downward

c_a aileron chord, that is, distance from hinge axis to trailing edge

$\bar{c}_a$ root-mean-square of aileron chord

b_a aileron span

c airfoil chord

c_b balance chord, that is, distance from hinge axis to center of seal

t twice nose radius of unbalanced aileron

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

ΔC_{h_δ} C_{h_δ} of balanced aileron - C_{h_δ} of unbalanced aileron

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

ΔC_{h_α} C_{h_α} of balanced aileron - C_{h_α} of unbalanced aileron

α angle of attack of airfoil

δ deflection of aileron; positive when trailing edge is deflected downward

q free-stream dynamic pressure $(\frac{1}{2}\rho V^2)$

P resultant pressure coefficient $\left(\frac{p_l - p_u}{q}\right)$

p_u static pressure at point on upper surface of airfoil

p_l static pressure at corresponding point on lower surface of airfoil

$P_\delta = \left(\frac{\partial P}{\partial \delta}\right)_\alpha$

S_a area of aileron behind hinge axis

S_L area of leak across seal

S_V area of vent

BALANCE REQUIRED

In the quantitative analysis of the amount of balance required, data obtained for the following geometric conditions were studied:

(1) The balance arrangements were similar to those shown in figure 1.

(2) The seal on the balancing surface was complete; that is, there was no leakage across the seal.

(3) The cover plates extended as far rearward as practicable.

(4) The cover plates were of airfoil contour.

The effects of deviations from these conditions will be discussed later.

The important dimensions and parameters of the available three-dimensional data (references 1 to 3 and unpublished British and NACA data) are given in table I with the plan forms of the test wings. The tabulated values of C_{h_α} and C_{h_δ} are the slopes for small aileron deflections, about $\pm 5^\circ$, at lift coefficients corresponding to the cruising or high-speed conditions. The variation of C_{h_δ} with balance chord in percentage of aileron chord is given in figure 2. From these data, it appears that to reduce C_{h_δ} to zero required a balance chord between 45 and 57 percent of the aileron chord, depending on the geometry of the arrangement. The range of balance percentage indicated for any other value of C_{h_δ} is equally large. In order to determine more closely the effects of the internal balance upon the hinge-moment characteristics, incremental slopes ΔC_{h_δ} and ΔC_{h_α} calculated from the values of table I were plotted as functions of the area moment of the balance and of the aileron chord. Functions that were found to represent the available data reasonably well (figs. 3 and 4) were

$$\Delta C_{h_\delta} = 0.36B_1 \tag{1}$$

and

$$\Delta C_{h_\alpha} = 0.024B_2 \tag{2}$$

where

$$B_1 = \frac{c_b^2 - \frac{t^2}{4}}{c_a^2} (c_a/c)^{1.4} \tag{3}$$

and

$$B_2 = \frac{c_b^2 - \frac{t^2}{4}}{c_a^2} (c_a/c) \tag{4}$$

When C_{h_δ} for a particular installation is not known, an approximate value may be determined from the curve of figure 5. The data of figure 5 are from tests of both conventional and low-drag airfoils. The available data did not appear to justify construction of a corresponding curve for C_{h_α}. The quantity C_{h_α}, however, is very important and, for low-drag wings in particular, must be taken into account in the computation of control forces.

The aileron-deflection range over which the values of C_{h_δ} and ΔC_{h_δ} were relatively constant was in general 20° or 25°, as determined from wind-tunnel tests at relatively low scale. (See table I.) Outside this range, the value of C_{h_δ} increased negatively because the pressure difference at the vents failed to increase linearly. At full scale, the linear range of C_{h_δ} and ΔC_{h_δ} is expected to be larger than the range observed in the wind tunnel.

VENT LOCATION

Variation of the chordwise location of the vents (fig. 1) has a large effect on the ΔC_{h_α} and ΔC_{h_δ} of a sealed internal balance with given aileron and balance chords. When the vents are moved forward from the hinge line, ΔC_{h_α} increases and ΔC_{h_δ} decreases, as is discussed in detail in reference 4. The relative effectiveness as indicated by balancing $P_\delta/P_{\delta_{max}}$ of a balance with three locations of the cover-plate trailing edges is taken from unpublished British data and is shown in figure

6 with a curve of the external $P_\delta/P_{\delta_{max}}$. Values of $P_\delta/P_{\delta_{max}}$ for two of the arrangements were computed by direct proportion from the hinge-moment data for all three arrangements. The balancing-pressure data observed and calculated are in agreement with the external-pressure data. In balance arrangements of the type shown in figure 1, on conventional airfoils the variation of balancing pressure with aileron deflection appears to be about two-thirds the variation of the peak pressure $P_{\delta_{max}}$.

LEAKAGE ACROSS SEAL

Many installations of the internal balance allow some leakage through the seal for drainage, around the hinges, around the control rods, or for some other reason. Small leaks across the seal were found to cause marked changes in the characteristics of the aileron. Investigations of wings A and D were made by the NACA to determine the effect of leaks (table II). In the investigation of wing A, the vent area was varied and, in the investigation of wing D, the leak area was varied. The investigation of wing G in England (table II) included an investigation of the effects of varying both the vent area and the leak area. Because the magnitude of the leakage effect on ΔC_{h_δ} was thought to be proportional to $(\Delta C_{h_\delta})_{no\ leak}$, the percentage of $(\Delta C_{h_\delta})_{no\ leak}$ available with the leak was plotted as a function of the ratio of leak area to vent area in figure 7. The data of figure 7 indicate that a leak area of one-tenth the vent area reduces ΔC_{h_δ} by about 18 percent and a leak area equal to the vent area decreases ΔC_{h_δ} by about 70 percent. Because the effect of small leaks is relatively large, such leaks must be taken into account in the design of balanced ailerons. Because leaks other than grommets or similar devices may be of unknown magnitude, the balance seal should be made as complete as possible and all leaks should be made of known size.

In addition to reducing the value of ΔC_{h_δ}, leaks generally reduce the aileron-deflection range over which the hinge moment varies linearly and reduce the effectiveness of the aileron for a given deflection.

When elimination of leaks is impracticable, their effect may be reduced to some extent by moving the cover-plate trailing edge forward to enlarge the gap. If this method is used, the balance required to give the same ΔC_{h_δ} will be larger than for a completely sealed balance with small vents near the hinge axis.

CONTOUR MODIFICATIONS AT VENTS

The previous discussion was based on the results of tests of internal balances with vents near the hinge line and cover plates of airfoil contour. Some data are available that show the effect of altering the airfoil contour ahead of the vents when the vents are near the hinge line. It is believed that similar effects will be found at other vent locations.

Intentional or accidental variation of the contour of the trailing edge of the cover plates will change the characteristics of the balanced aileron. The effect of cover-plate misalinement on the values of ΔC_{h_δ} and ΔC_{h_α} is shown in figures 8 and 9. The values of ΔC_{h_δ} increase positively as the cover plates are bent outward until the deviation from airfoil contour is about 0.004c when the values begin to decrease. From these data, movement of the cover-plate trailing edge would appear to be a good way to vary the C_{h_α} and the C_{h_δ} of an internally balanced aileron. A close inspection of the effects at large deflections (fig. 10) shows that, even though C_{h_δ} is less at small deflections, the balance is effective over a much smaller deflection range and may give higher control forces at large deflections with cover plates bent outward than with cover plates of airfoil contour. The comparative curves of figure 10 are for a model with cover plates of airfoil contour and with cover plates having a relatively large deviation from airfoil contour. The adverse effect of the bent cover plates on the hinge-moment characteristics decreases as the cover plates approach their normal positions. It is believed, therefore, that the small variations of cover-plate contour caused by manufacturing irregularities should not change the shape of the curves appreciably but should give the expected variation in ΔC_{h_α} and ΔC_{h_δ}.

The data for figures 8 to 10 are mostly two-dimensional data (reference 5) inasmuch as there are few data available on the effect of cover-plate misalinement in three-dimensional flow. The same qualitative effect is expected with three-dimensional flow, but the magnitude of the changes may be somewhat different.

FLIGHT TESTS

The results of flight tests of internally balanced ailerons within the level-flight speed range (references 6 and 7) showed that light and effective aileron control was obtained without undesirable shaking. The pilots were very favorably impressed by the characteristics of these ailerons. The reduction in stick force as predicted from the data presented in the present paper agrees very well with the results from the flight tests of the light low-speed airplane of reference 6 for which the flight Reynolds number is of the same order of magnitude as that of the wind-tunnel tests. The flight tests of a high-speed modern fighter airplane (reference 7) showed considerably less decrease in stick forces than would be estimated. This discrepancy could have been due to the large change in scale, velocity, or turbulence or to differences in details of construction including accidental leaks around the control mechanism.

CONCLUDING REMARKS

Results of a comprehensive systematic study of internal balances are not available. The effects of many possible geometric variations and of the aerodynamic variables - Reynolds number, Mach number, and turbulence - are as yet unknown. The present study, which is utilizing test data now available, will be of value, however, in the initial design of internally balanced ailerons and in the modification of such ailerons wherever modification is found necessary.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Rogallo, F. M., and Lowry, John G.: Wind-Tunnel Investigation of a Plain Aileron and a Balanced Aileron on a Tapered Wing with Full-Span Duplex Flaps. NACA A.R.R., July 1942.

2. Rogallo, F. M., and Lowry, John G.: Wind-Tunnel Development of Ailerons for the Curtiss XP-60 Airplane. NACA A.C.R., Sept. 1942.

3. Harris, Thomas A., and Purser, Paul E.: Wind-Tunnel Investigation of Plain Ailerons for a Wing with a Full-Span Flap Consisting of an Inboard Fowler and an Outboard Retractable Split Flap. NACA A.C.R., March 1941.

4. Sears, Richard I.: Wind-Tunnel Investigation of Control-Surface Characteristics. IX - Some Analytical Considerations and Experimental Test Results for an Internally Balanced Flap. NACA A.R.R., July 1942.

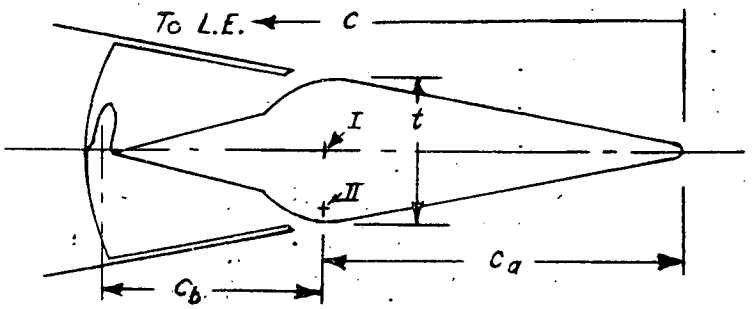
5. Hoggard, H. Page, Jr.: Wing-Tunnel Investigation of Control-Surface Characteristics. XII - Various Cover-Plate Alinements on the NACA 0015 Airfoil with a 30-Percent-Chord Flap and Large Sealed Internal Balance. NACA A.R.R., Jan. 1943.

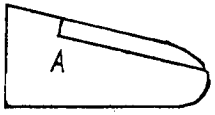
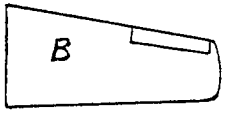
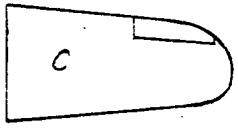
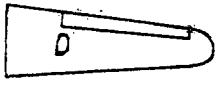
6. Williams, W. C., and Kleckner, H. F.: A Flight Investigation of Internally Balanced Sealed Ailerons. NACA A.R.R., Dec. 1941.

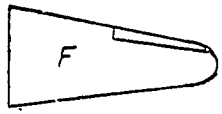
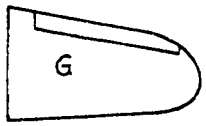
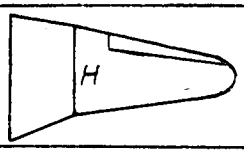
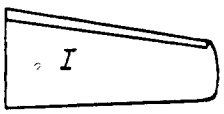
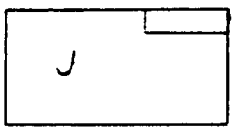
7. Gilruth, R. R.: Flight Tests of Internally Balanced, Sealed Ailerons on the Curtisss XP-60 Airplane. NACA C.B., July 1942.

TABLE I

PLAN FORMS, DIMENSIONS, AND PARAMETERS FOR TEST WINGS



Wing plan form	Symbol	Airfoil series	c_a/c	c_b/c_a	t/c_a	Type of test	Hinge-axis location	C_{h_δ} (a)	C_{h_α}	$\frac{c_b^2-\frac{t^2}{4}}{c_a^2}\left(\frac{c_a}{c}\right)^{1.4}$	$\frac{c_b^2-\frac{t^2}{4}}{c_a^2}\left(\frac{c_a}{c}\right)$	Reference
	○	NACA 66	0.20	0.163 .45 .505 .57	0.325	Semispan	II	-0.0078 -.0009 .0008 .0038	-0.0018 ------- -.0011 0	0 .0186 .0242 .0316	0 .0352 .0457 .0597	Unpublished
	△	NACA 230	0.155	0.110 .333 .415	0.220	Semispan	I	-0.0070 -.0040 -.0028	-0.0013 -.0009 -.0009	0 .0073 .0118	0 .0153 .0248	1
	□	NACA 66	0.20	0.37 .42 .52	0.400	Complete model	I	-0.0046 -.0029 .0013	-0.0026 -.0044 -.0068	0.0103 .0145 .0244	0.0194 .0273 .0461	Unpublished
	▽	NACA 65	0.229	0.558	0.305	Semispan	I	0.0009	-0.0017	0.0366	0.0660	Unpublished

	◇	NACA 66	0.175 .175 .162 .149	0.205 .438 .563 .588	0.410	Semispan	I	-0.0080 -.0032 0 .0030	-0.0051 -.0048 -.0039 -.0043	0 .0132 .0214 .0302	0 .0262 .0445 .0643	2
	◹	NACA 66	0.162	0.563	0.410	Semispan	I	-0.0001	-0.0042	0.0214	0.0445	2
	◸		0.18	0.198 .445 .544 .678	0.395	Semispan	I	-0.0056 -.0004 .0020 .0068	-0.0005 .0005 ------- -------	0 .0145 .0234 .0383	0 .0286 .0462 .0757	Unpublished British
	◿	NACA 66	0.17	0.360	0.400	Complete model	I	-0.0022	-0.0011	0.0075	0.0152	Unpublished
	◺	NACA 230	0.08	0.153 .300 .559	0.306	Semispan	II	-0.0052 -.0048 -.0013	0 0 .0005	0 .0020 .0084	0 .0053 .0232	Unpublished
	▷	NACA 230	0.15	0.136 .354 .375	0.272	Semispan	I II I	-0.0072 -.0048 -.0039	-0.0029 -.0029 -.0029	0 .0075 .0086	0 .0160 .0183	3

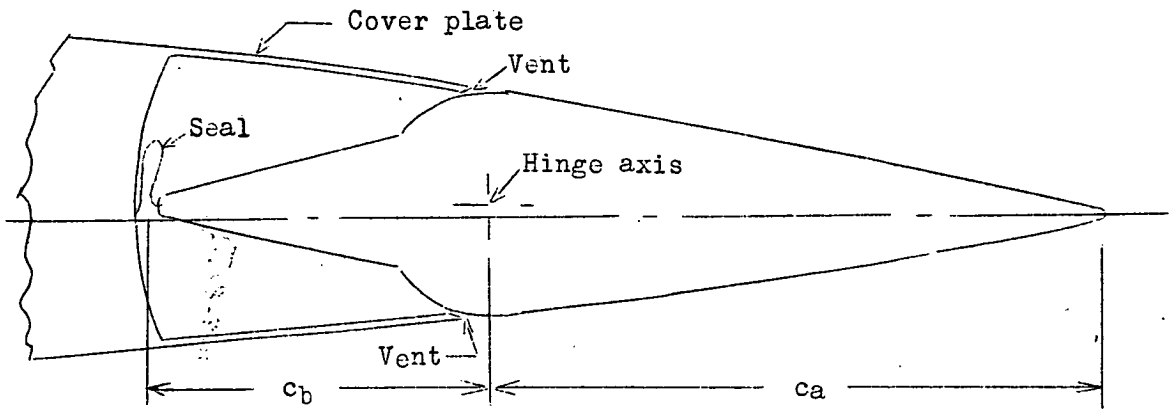
[a] Values for slope between about ±5° deflection.

TABLE II

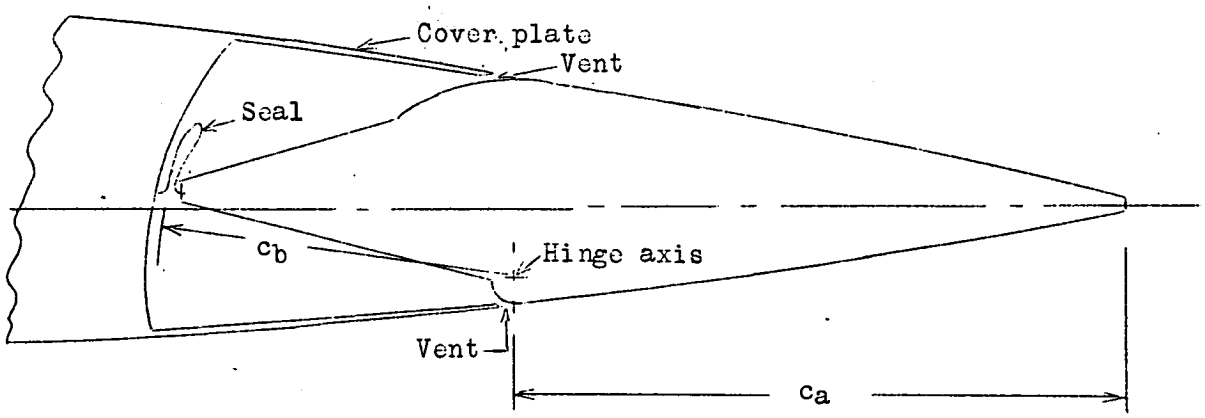
EFFECT OF LEAKS ON AILERON CHARACTERISTICS OF WINGS A, D, AND G

Wing	Symbol	Airfoil series	Type of test	Hinge-axis location	c_a/c	c_b/c_a	S_V/S_a	S_L/S_a	C_{h_δ}	S_L/S_V	Unbalanced C_{h_δ}	$\frac{\Delta C_{h_\delta}}{(\Delta C_{h_\delta})_{\text{no leak}}}$ (percent)
A	○	NACA 66	Semi-span	II	0.20	0.57	0.0173	0	0.0038	0	-0.0078	100
							.0087	.0045	-.0015	.52		54
							.0173	.0045	-.0005	.26		63
D	▽	NACA 65	Semi-span	I	0.229	0.558	0.0145	0	0.0009	0	-0.0084[a]	100
								.0005	0	.03		90
								.0009	-.0006	.06		84
								.0014	-.0010	.10		79
G	◸	----	Semi-span	I	0.18	0.678	0.0236	0	0.0068	0	-0.0056	100
								.0024	.0052	.10		87
								.0099	.0007	.42		51
								.0189	-.0012	.80		36
							0.0394	0	0.0061	0	-0.0056	100
								.0010	.0049	.03		90
								.0024	.0040	.06		82
								.0099	.0010	.25		56
								.0189	-.0010	.48		39
							0.0691	0	0.0055	0	-0.0056	100
								.0024	.0046	.03		92
						0.544	0.0236	0	0.0020	0	-0.0056	100
								.0158	-.0022	.67		45
								.0189	-.0026	.80		39
						0.445	0.0236	0	-0.0004	0	-0.0056	100
								.0020	-.0009	.08		91
								---	---	---		---
								.0197	-.0035	.83		40
							0.0394	0	-0.0007	0	-0.0056	100
								.0020	-.0010	.05		94
								.0099	-.0019	.25		76
								.0197	-.0028	.50		57
							0.0691	0	-0.0009	0	-0.0056	100
								.0020	-.0011	.03		96
								.0099	-.0018	.14		81
								.0197	-.0030	.29		55

[a] Estimated.



(a) Hinge axis on mean line.



(b) Hinge axis offset from mean line.

Figure 1.- Internally balanced ailerons.

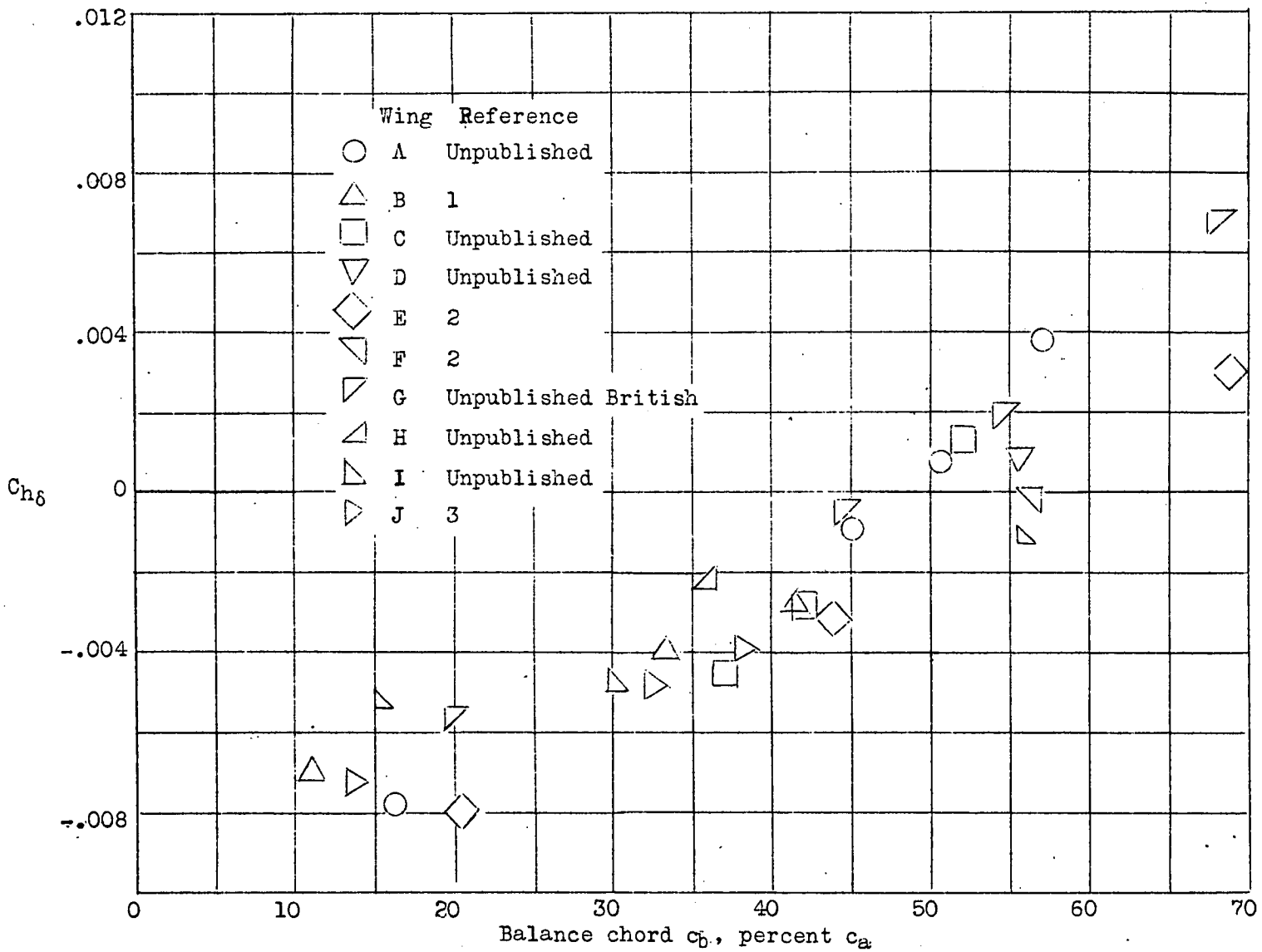


Figure 2.- Variation of hinge-moment-coefficient slope C_{h_δ} with balance chord.

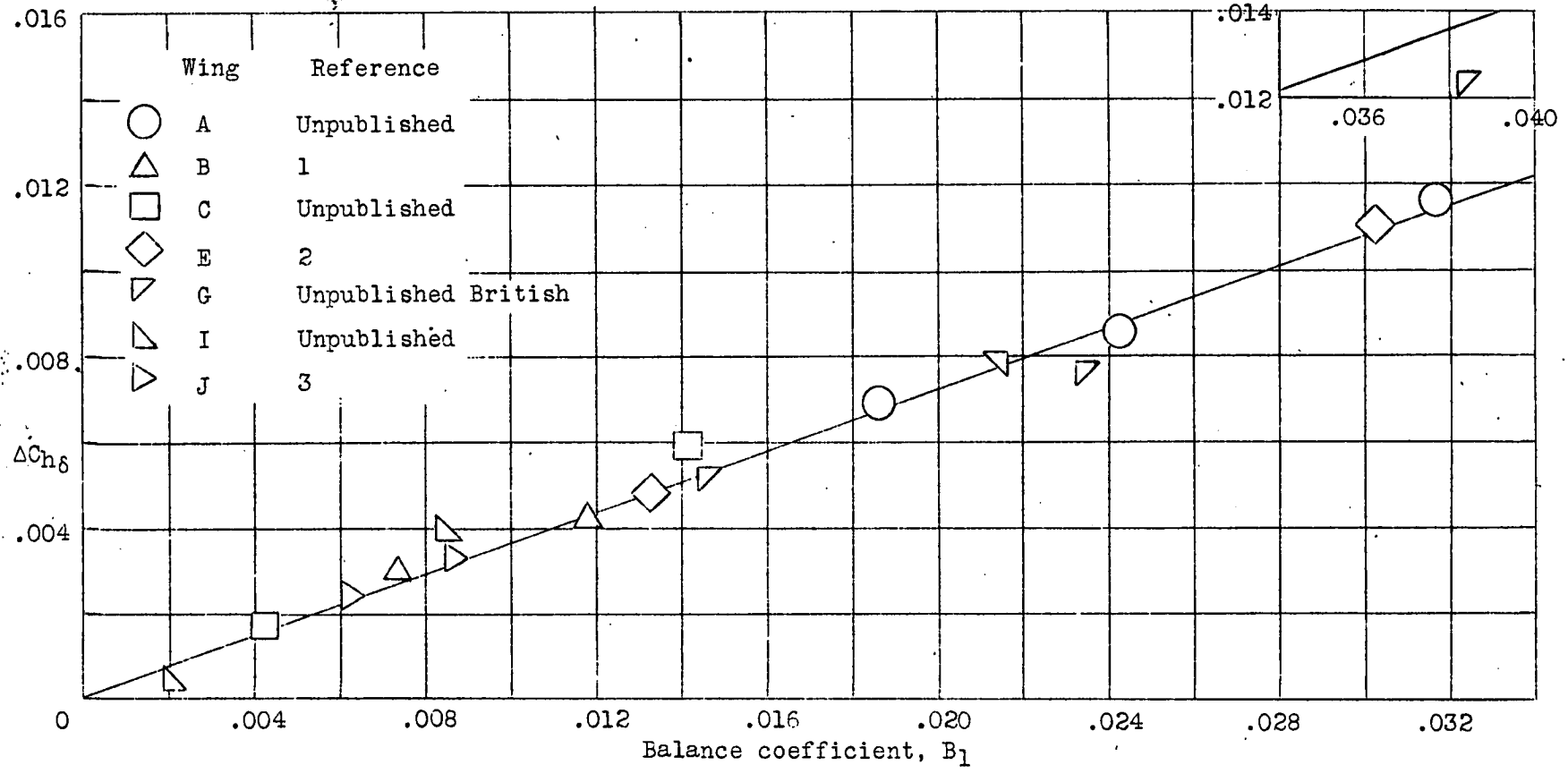


Figure 3.- Variation of incremental hinge-moment-coefficient slope ΔC_{h_δ} with balance coefficient $B_1 = \frac{c_b^2 - t^2/4}{c_a^2}(c_a/c)^{1.4}$.

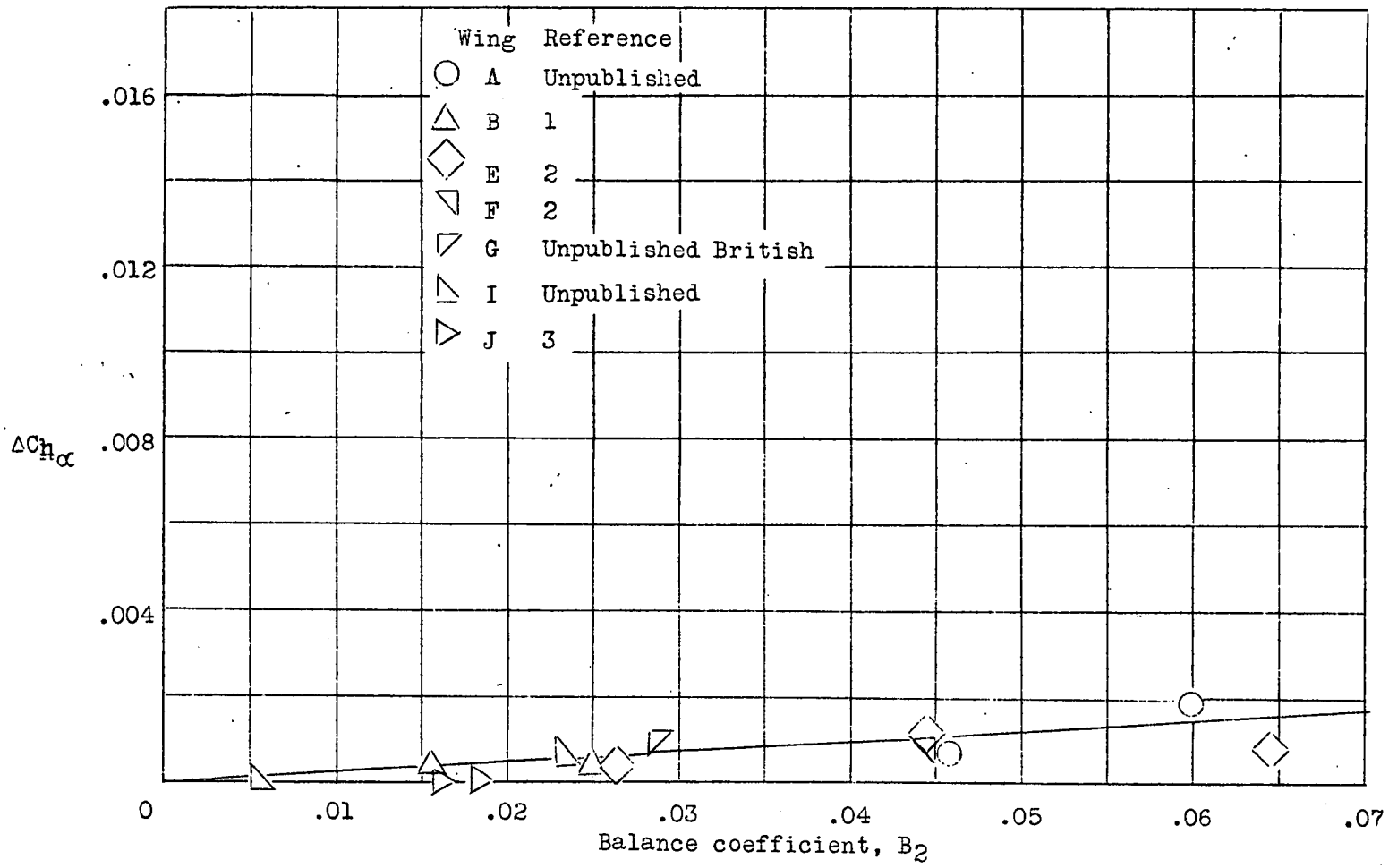


Figure 4.- Variation of incremental hinge-moment-coefficient slope ΔC_{h_α} with balance coefficient $B_2 = \frac{c_b^2 - t^2/4}{c_a^2}(c_a/c)$.

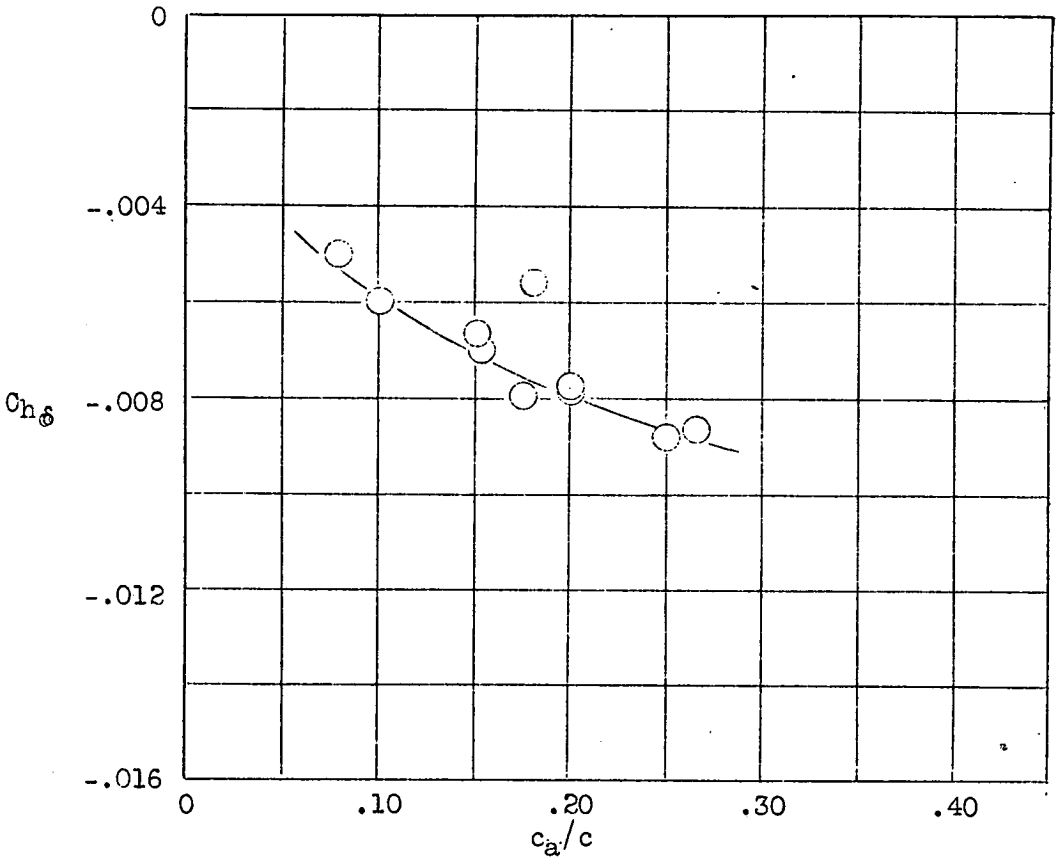


Figure 5.- Variation of hinge-moment-coefficient slope C_{h_δ} with chord ratio c_a/c. Unbalanced ailerons.

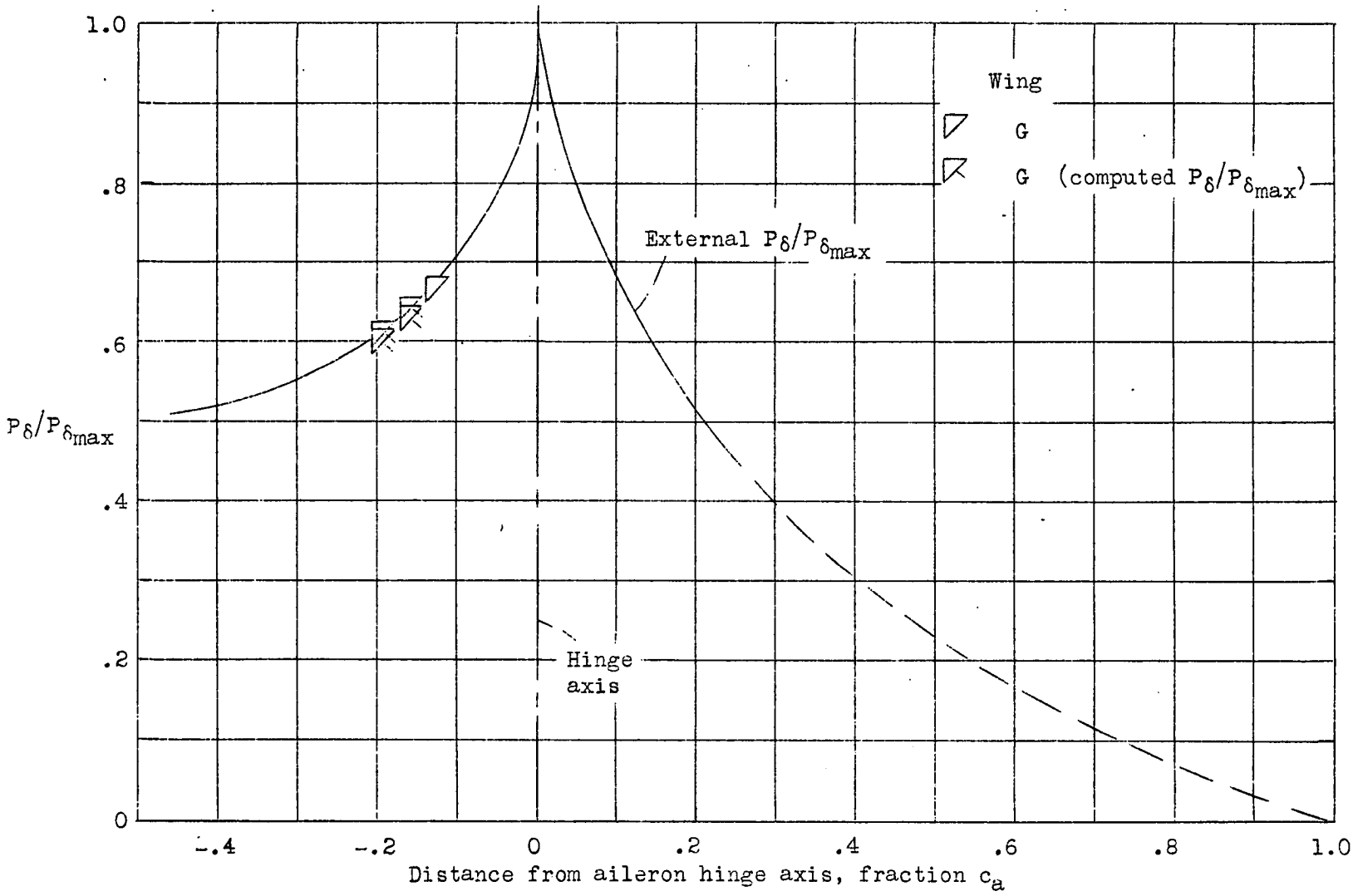


Figure 6.- Variation of balancing $P_\delta/P_{\delta_{max}}$ with location of cover-plate trailing edge. (Unpublished British data)

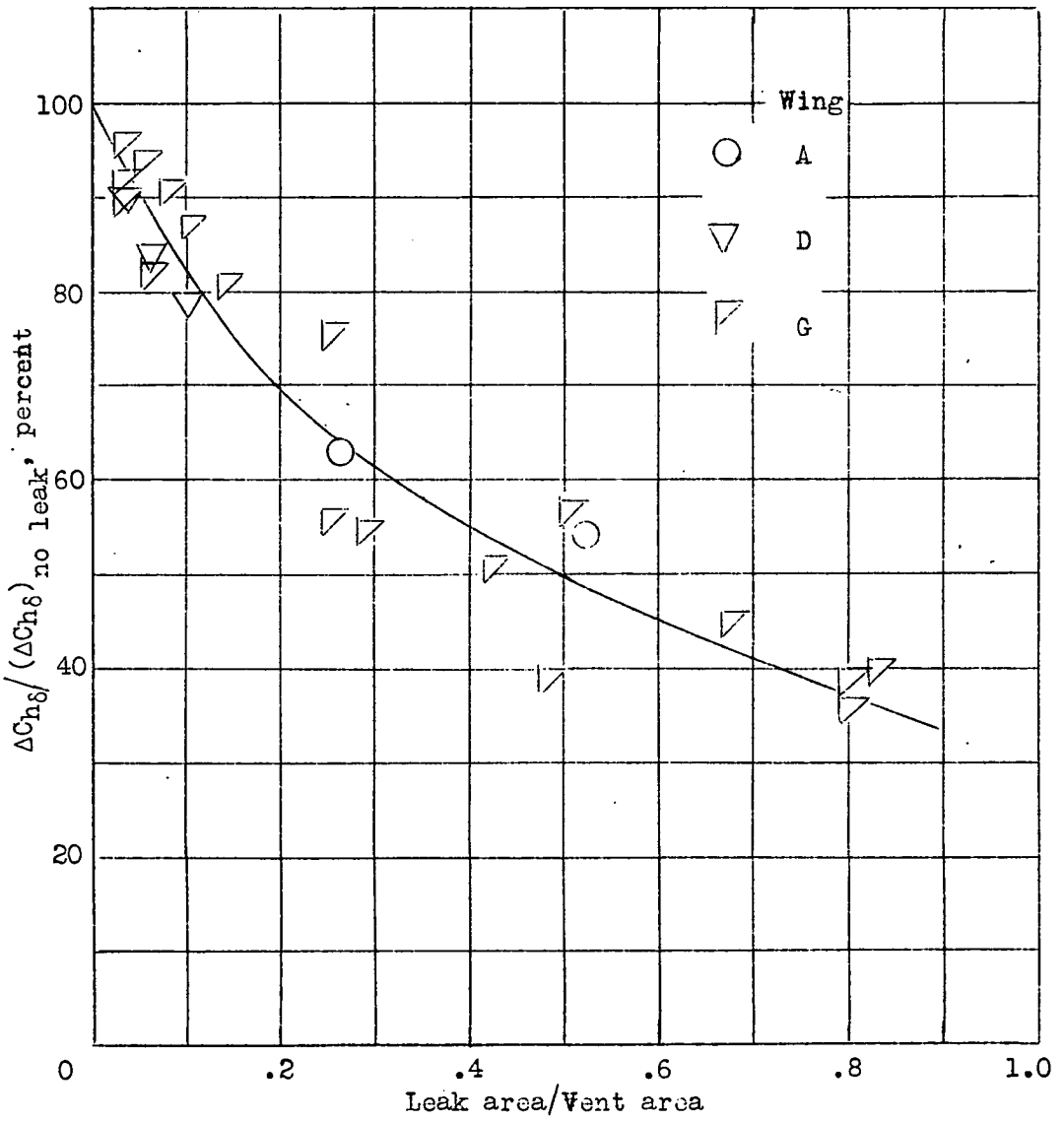


Figure 7.- Variation of incremental hinge-moment-coefficient slope ΔC_{h_δ} with leak area/vent area. (Unpublished data)

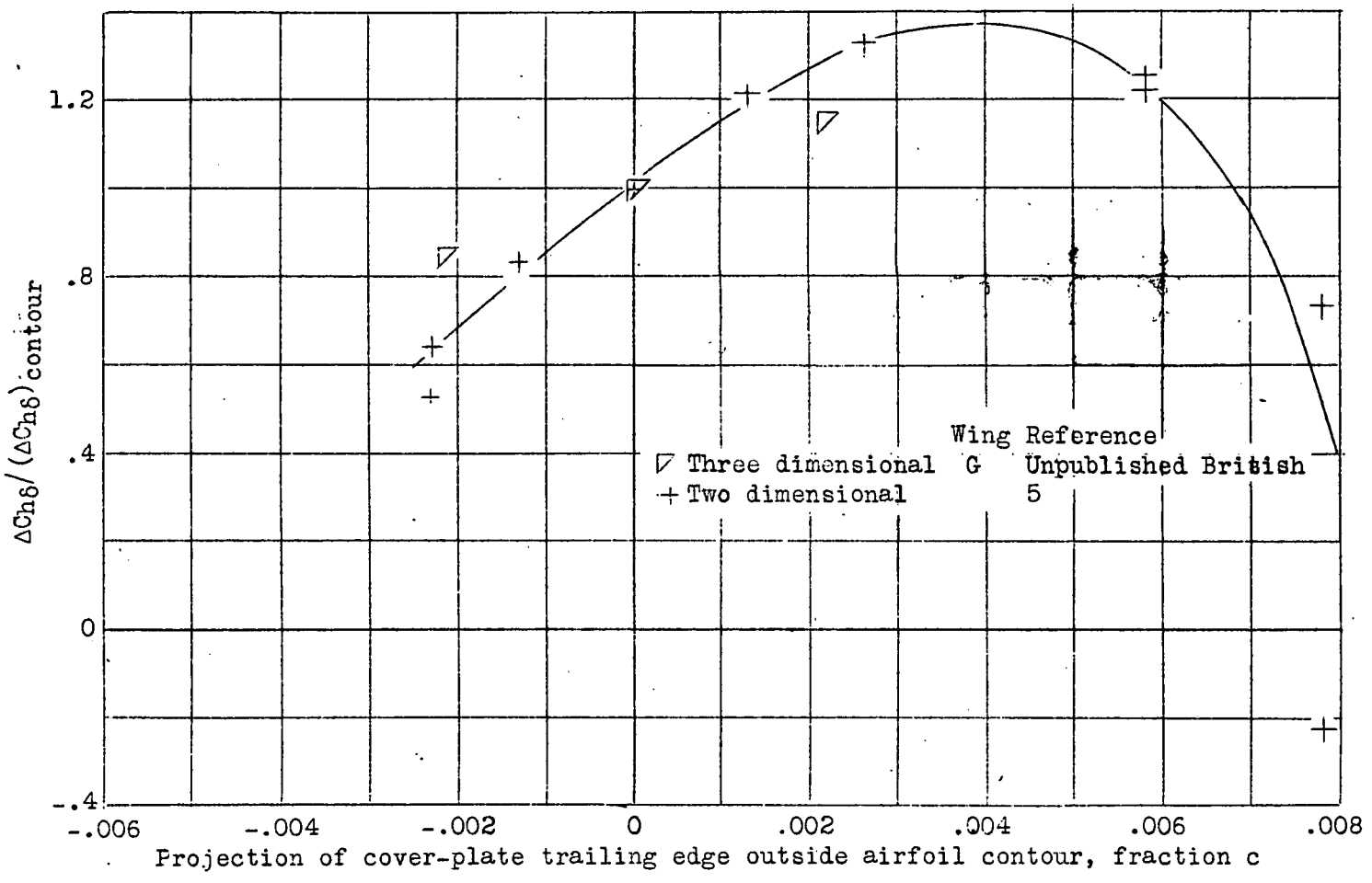


Figure 8.- Variation of incremental hinge-moment-coefficient slope ΔC_{h_δ} with cover-plate misalinement.

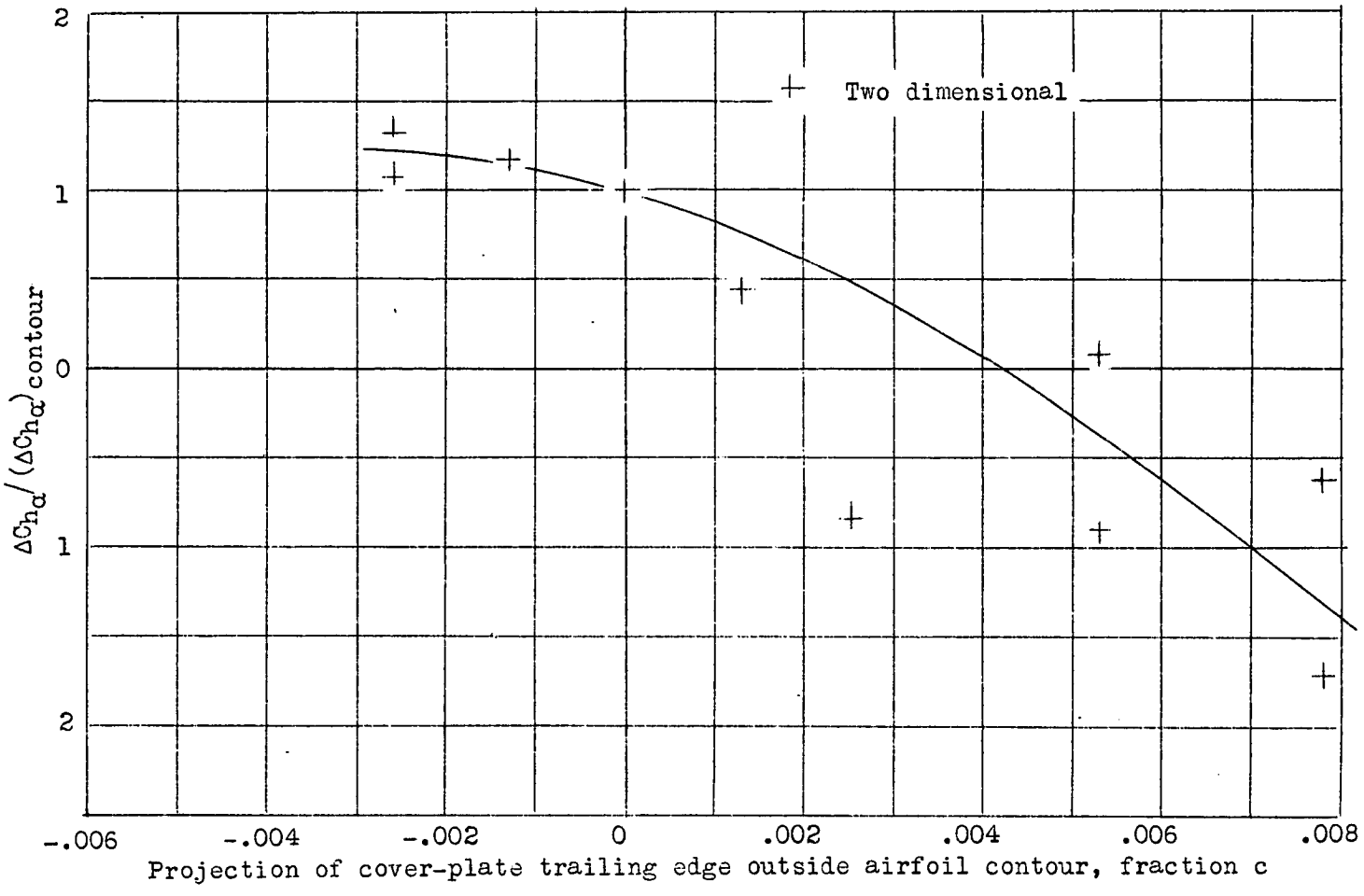


Figure 9.- Variation of incremental hinge-moment-coefficient slope ΔC_{h_α} with cover-plate misalinement. (Data from reference 5.)

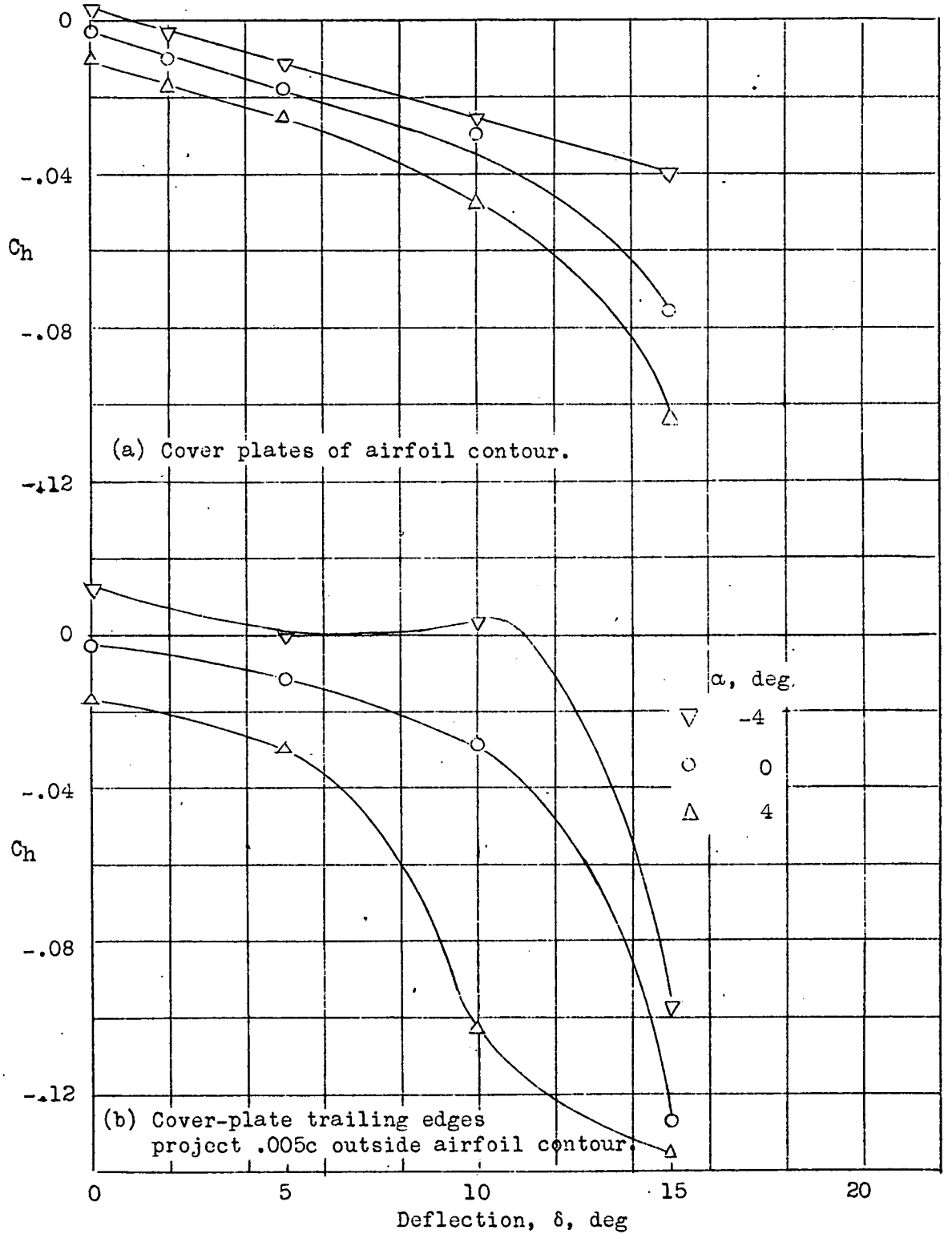


Figure 10.- Hinge-moment characteristics for two cover-plate modifications. (Two-dimensional data from reference 5.)