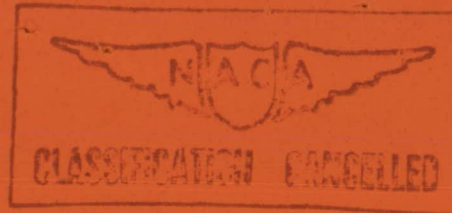


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PRELIMINARY CORRELATION OF THE EFFECTS OF
BEVELED TRAILING EDGES ON THE HINGE-MOMENT CHARACTERISTICS
OF CONTROL SURFACES

By Paul E. Purser and Clarence L. Gillis

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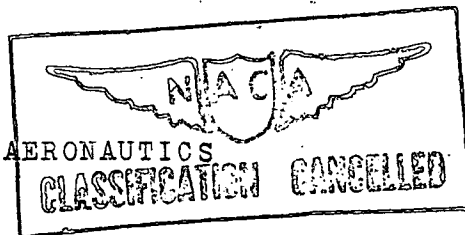
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS



CONFIDENTIAL BULLETIN

PRELIMINARY CORRELATION OF THE EFFECTS OF
BEVELED TRAILING EDGES ON THE HINGE-MOMENT CHARACTERISTICS
OF CONTROL SURFACES

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SUMMARY

A study of available data from various tests of beveled control surfaces has been made in an attempt to develop a rational method for predicting the effects of beveled trailing edges on the hinge-moment characteristics of control surfaces in both two- and three-dimensional flow.

The results of the study indicated that the change in the included angle at the control-surface trailing edge formed a convenient basis on which a correlation could be made of the effects of various profile modifications on hinge-moment characteristics. It is believed that the formulas developed will allow reasonably accurate predictions of the hinge-moment characteristics of sealed beveled control surfaces if the characteristics of the original control surfaces are known. The presence of a gap at the control-surface hinge increased the effect of beveled trailing edges on the hinge-moment characteristics at small control-surface deflections but the available data were insufficient to allow as complete a correlation as was possible for sealed controls.

INTRODUCTION

As the size and the speed of modern airplanes have increased, the problem of obtaining adequate control with reasonable control forces has become increasingly difficult and, in an attempt to solve this problem, the NACA has engaged in several programs of control-surface research. The purpose of the present paper is to correlate the hinge-moment data obtained in various investigations of beveled

control surfaces (references 1 to 4 and some unpublished data from Ames Aeronautical Laboratory). The correlation was made in order to develop a rational method for predicting the effects of beveled trailing edges on the hinge-moment characteristics of control surfaces in both two- and three-dimensional flow.

Throughout this paper, the beveled portion of the aileron is referred to as the "bevel" and the "true-contour" control surface has the same ordinates as the trailing-edge portion of the basic airfoil section.

SYMBOLS

C_L	lift coefficient
c_l	section lift coefficient
C_{L_1}	average lift coefficient over control-surface span
C_h	hinge-moment coefficient
c_h	section hinge-moment coefficient
α	angle of attack, degrees
δ	control-surface deflection relative to airfoil, degrees
ϕ	trailing-edge angle - that is, included angle between upper and lower surfaces at trailing edge of control surface, degrees
c	airfoil chord
c_f	control-surface chord rearward of hinge line
c_b	bevel chord - that is, chord of beveled portion of control surface
b	airfoil span
y_i	distance from plane of symmetry to inboard end of aileron
y_o	distance from plane of symmetry to outboard end of aileron

b_f control-surface span

R_b bevel radius - that is, radius of juncture between
bevel and control surface

A aspect ratio

λ ratio of tip to root chord

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

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

$$C_{L_1\alpha} = \left(\frac{\partial C_{L_1}}{\partial \alpha} \right)_\delta$$

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

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

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

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

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

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

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

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

$\Delta\phi$ increment of trailing-edge angle using angle of true-contour control surface as a base

$\Delta c_{h\alpha}$
 $\Delta c_{h\alpha}$ } increments of slopes of hinge-moment curves for test conditions using data for true-contour control surface as a base
 $\Delta c_{h\delta}$
 $\Delta c_{h\delta}$

$\Delta' c_{h\alpha}$
 $\Delta' c_{h\delta}$ } increments of slopes of hinge-moment curves corrected to section characteristics based on theoretical values of $c_{l\alpha}$ and $c_{l\delta}$

$\Delta'' c_{h\alpha}$
 $\Delta'' c_{h\delta}$ } increments of slopes of hinge-moment curves corrected to section characteristics based on theoretical values of $c_{l\alpha}$ (0.109) and $c_{l\delta}$ (0.072) and corrected to $c_f = 0.30c$

Subscripts:

exp values obtained from tests of airfoil and true-contour control surface

t theoretical values for thin airfoil (reference 5)

AVAILABLE DATA AND DISCUSSION

The characteristics of the models used in the correlation were obtained from references 1 to 4 and some unpublished data from Ames Aeronautical Laboratory and are summarized in table I. The geometric characteristics of the models covered the following ranges:

- 1.-Airfoil section: conventional and low-drag with maximum thicknesses from 9 to 16 percent of the airfoil chord
2. Aspect ratio: approximately 5.5 and infinity
3. Taper ratio: approximately 0.5 and 0.6

4. Ratio of control chord to airfoil chord: from 0.155 to 0.300
5. Bevel chord: from 10 to 34 percent of the control chord and some flat and bulged surfaces
6. Trailing-edge angle: from 9.0° to 42.8°

The slopes of the hinge-moment curves given in table I were measured in the usual way at an angle of attack of 0° and with the control neutral. The slopes are applicable over ranges of α and δ of approximately $\pm 5^\circ$ and $\pm 10^\circ$, respectively, depending on various factors such as bevel chord and bevel radius that will be discussed later in this report.

Correlation Procedure

The increments of the slopes of the hinge-moment curves $\Delta C_{h\alpha}$, $\Delta c_{h\alpha}$, $\Delta C_{h\delta}$, and $\Delta c_{h\delta}$ for the sealed control surfaces were first corrected to conditions for theoretical values of $c_{l\alpha}$ and $c_{l\delta}$ (reference 5) by means of the following relationships:

$$\Delta' c_{h\alpha} = \Delta C_{h\alpha} \frac{(c_{l\alpha})_t}{(C_{L1\alpha})_{\text{exp}}} \quad \text{or} \quad \Delta c_{h\alpha} \frac{(c_{l\alpha})_t}{(c_{l\alpha})_{\text{exp}}} \quad (1)$$

$$\Delta' c_{h\delta} = \Delta C_{h\delta} \frac{(c_{l\delta})_t}{(C_{L1\delta})_{\text{exp}}} \quad \text{or} \quad \Delta c_{h\delta} \frac{(c_{l\delta})_t}{(c_{l\delta})_{\text{exp}}} \quad (2)$$

For finite aspect ratio, $(C_{L1\alpha})_{\text{exp}}$ is the product of $(C_{L\alpha})_{\text{exp}}$ and the ratio of the average slope of the lift curve over the control span to the slope of the lift curve of the wing, as determined from span load distributions in references 6 and 7. For aileron tests, $C_{L1\delta}$ was not easily determined and therefore $(c_{l\delta})_t / (C_{L1\delta})_{\text{exp}}$ was replaced

by $(c_{l\alpha})_t / (c_{L1\alpha})_{\text{exp}}$ in equation (2). For infinite aspect ratio, the values of $(c_{l\alpha})_{\text{exp}}$ and $(c_{l\delta})_{\text{exp}}$ were obtained directly from the test results. The values of $\Delta'c_{h\alpha}$ and $\Delta'c_{h\delta}$ obtained by use of equations (1) and (2) were plotted against $\Delta\phi$ because preliminary work had indicated that this angle formed a convenient basis for correlation. From the plots of $\Delta'c_{h\alpha}$ and $\Delta'c_{h\delta}$ and from cross plots on logarithmic paper, it was found that $\Delta'c_{h\alpha}$ varied inversely as the first power of the control chord and that $\Delta'c_{h\delta}$ varied as the four-tenths power of the control chord.

In order to indicate how well the data may be brought into agreement, the values of $\Delta'c_{h\alpha}$ and $\Delta'c_{h\delta}$ were corrected to $c_f/c = 0.30$ by means of the following relationships:

$$\Delta''c_{h\alpha} = \Delta'c_{h\alpha} \left(\frac{c_f/c}{0.30} \right)$$

$$\Delta''c_{h\delta} = \Delta'c_{h\delta} \left(\frac{0.30}{c_f/c} \right)^{0.4}$$

and the results are presented in figure 1.

Application of Results

Aids to application.— In order to simplify the application of the results of this study, the variations with control-surface chord of the increments in the slopes of the hinge-moment curves $\Delta'c_{h\alpha}$ and $\Delta'c_{h\delta}$ available from various increments of trailing-edge angle $\Delta\phi$ are given in figure 2. Interpolation between the curves of figure 2 should be relatively easy because $\Delta'c_{h\alpha}$ and $\Delta'c_{h\delta}$ vary directly with $\Delta\phi$.

An additional aid in the application of the results to aileron design is presented in figure 3 in the form of plots of the ratio of the average slope of the lift curve

over the aileron span to the slope of the lift curve of the wing for various aileron-wing combinations. These curves are presented only for an aspect ratio of 6.0 but an inspection of several span-lift-distribution curves indicated that the effect of aspect ratio on the ratio of lift-curve slopes was negligible.

General procedure.- In applying the results of this study to the design of beveled sealed ailerons, the following items should be known:

1. Geometric characteristics of wing and aileron
2. Slope of lift curve for wing of finite aspect ratio with original aileron
3. Hinge-moment characteristics of original aileron

The procedure for applying the data is then:

1. Determine $\Delta'c_{h\alpha}$ and $\Delta'c_{h\delta}$ from figure 2 for any given value of $\Delta\phi$
2. Determine $\left(\frac{C_{L1\alpha}}{C_{L\alpha}}\right)_{exp}$ from figure 3 and known
3. Determine $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ by means of the following relationships:

$$\Delta C_{h\alpha} = \Delta'c_{h\alpha} \frac{\left(\frac{C_{L1\alpha}}{C_{L\alpha}}\right)_{exp}}{(cl_{\alpha})_t} \quad (3)$$

$$\Delta C_{h\delta} = \Delta'c_{h\delta} \frac{\left(\frac{C_{L1a}}{C_{L\alpha}}\right)_{exp}}{(cl_{\alpha})_t} \quad (4)$$

4. The desired value of $\Delta\phi$ may then be determined by simple proportion because $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ vary directly with $\Delta\phi$

In the design of control surfaces other than ailerons, the procedure is the same as for ailerons except that in equation (4) $\left(\frac{C_{L1\alpha}}{C_{L\alpha}}\right)_{exp} / (cl_{\alpha})_t$ should be replaced by

$(C_{L\delta})_{exp} / (c_{l\delta})_t$. The value of $(c_{l\delta})_t$ may be determined from the appropriate value of $(\alpha_\delta)_t$ (reference 5) and from the value of $(c_{l\alpha})_t$ of 0.109.

Determination of optimum chord for a beveled aileron.- The results of calculations to determine the aileron chord and the trailing-edge angle required to obtain desired values of $C_{h\alpha}$ and $C_{h\delta}$ are shown in figure 4. The calculations were made for the aileron of airfoil D of table I by use of equations (3) and (4) and the estimated values of $C_{h\alpha}$ and $C_{h\delta}$ for the wide-chord plain ailerons.

From the curves of figure 4 it is evident that, if an aileron of the usual size is fitted with a bevel to reduce $C_{h\delta}$ to zero or to a small negative value, $C_{h\alpha}$ will have a large positive value. This condition has an adverse effect on the stick forces encountered during rolling. For beveled ailerons the adverse effect is not so great as would be indicated by the value of $C_{h\alpha}$ at $\delta = 0^\circ$ because the effect of the bevel on $C_{h\alpha}$ tends to disappear at large values of δ . As shown in figure 2, the effect of the bevel on $C_{h\delta}$ becomes greater and the effect on $C_{h\alpha}$ becomes smaller as the aileron chord is increased. Figure 4 indicates that, in order to reduce both $C_{h\alpha}$ and $C_{h\delta}$ to zero, it would be necessary to use aileron chords and trailing-edge angles outside the range covered by the available data. When the characteristics of an aileron are changed, however, the stick-free stability of the airplane may be considerably affected. Before the final design of an aileron is selected, therefore, the stability characteristics should be investigated. An alternative arrangement is a narrow-chord aileron with a beveled trailing edge in combination with some other type of aerodynamic balance, such as a sealed internal balance vented at the hinge line. The bevel will cause a large reduction in $C_{h\alpha}$ and a small reduction in $C_{h\delta}$; whereas the sealed internal balance vented at the hinge line will cause a large reduction in $C_{h\delta}$ and a small reduction in

$C_{h\alpha}$. With such a combination, the hinge-moment parameters probably could be adjusted to any desired value.

Specific applications.- An opportunity for checking the validity of the method was afforded when the effect of a beveled trailing edge on the hinge-moment characteristics of a Frise aileron was investigated. By the methods herein presented it was found that $C_{h\delta}$ near zero deflection would be reduced to zero by a bevel with $\phi = 25^\circ$ or $\Delta\phi = 7^\circ$, $c_b = 0.30c_f$, and $R_b = 0.20c$. The changes in the initial hinge-moment coefficients at zero deflection were determined from $\Delta C_{h\alpha}$ and the difference between the angle of attack for zero lift and the angle of attack under consideration. It was assumed that the bevel, being symmetrically distributed about the mean line, would not appreciably affect the hinge moment at zero lift. The additional change in hinge-moment coefficient at each aileron deflection was a product of $\Delta C_{h\delta}$ and the deflection under consideration. The resultant increments were then added to the original hinge-moment coefficients shown in figure-5(a) and new curves were drawn through these points.

The computed hinge-moment characteristics were thought to be satisfactory and the aileron was accordingly modified and tested in the NACA full-scale tunnel. A comparison of the computed and the test hinge-moment characteristics of the beveled aileron is given in figure 5(b). The principal discrepancies between the computed and the test values occur at large deflections or high angles of attack because, in the computations, $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ were assumed to be independent of aileron deflection and angle of attack. As shown by the coefficient values at $\delta = -20^\circ$, the bevel evidently tended to delay the usual separation over the Frise nose in addition to reducing the slope of the hinge-moment curve. This result was probably peculiar to this particular installation and should not be expected to occur on other installations because of the limited deflection range over which the present methods are thought to be applicable.

Additional Factors in Design of Beveled Trailing Edges

The effects of the gap at the control-surface hinge, the bevel chord, the bevel radius, and trimming tabs have not been considered in the foregoing analysis because of the small amount of available data. It is felt, however, that these factors deserve some mention although the scarcity of data makes any definite conclusions subject to revision.

Effect of gap at control-surface hinge.- The available data on the effects of the gap at the control-surface hinge on the hinge-moment characteristics of beveled controls are presented in references 2 to 4. The principal conclusion that can be drawn from the data is that the gap has little effect on $C_{h\alpha}$ but has considerable effect on $C_{h\delta}$. The effect of the gap on $C_{h\delta}$ increases as the trailing-edge angle increases and as the chord of the control surface decreases. The data indicate that the effect of the gap occurs principally at small deflections of the control surface and that little effect occurs for deflections of the order of $\pm 15^\circ$. It can also be noted from the data of references 3 and 4 that the presence of a gap reduces the control effectiveness more on beveled than on true-contour control surfaces.

No correlation of the data on unsealed controls could be made because the irregularity of the curves through zero deflection left slope measurements open to question and because a large part of the unsealed-gap data were obtained with variations of other factors, such as bevel radius and bevel chord, and separation of the various effects is difficult. An attempt will be made to extend the correlation to include unsealed control surfaces when sufficient data become available.

Effect of bevel chord.- From a study of the available data it appears that the bevel chord has little effect on the hinge-moment characteristics at small deflections but that an increase in bevel chord tends to increase the deflection range over which $C_{h\delta}$ is relatively small. Probably the best procedure at present is to use a bevel chord about 30 percent of the control chord.

Effect of bevel radius.- The data of reference 3 indicate that leaving the corner of the bevel sharp tends

to have the same effect as opening a gap at the control hinge; that is, $C_{h\delta}$ tends to become more positive for small deflections and to remain unaffected for deflections of the order of $\pm 15^\circ$.

Effect of trimming tabs.- The results of tests of trimming tabs on a beveled aileron (reference 4) indicate that inset tabs of about the same chord as the bevel have small and unsymmetrical effects on the aileron hinge-moment characteristics. More recent tests (as yet unpublished) have indicated that a small attached tab or an inset tab having a chord about 50 percent larger than the bevel chord would be more satisfactory. It should be noted that the presence of an attached tab or an unsealed inset tab will appreciably alter the aileron hinge-moment characteristics. Unless both right- and left-hand ailerons undergo the same modifications, the system will have unsymmetrical stick-force characteristics for right and left rolls. A marked stick-force asymmetry was noticed in flight tests of an airplane equipped with beveled ailerons having an unsealed inset trimming tab on only one aileron.

Effect of Beveled Trailing Edges on Drag and Effectiveness

Although no attempt has been made in the present paper to correlate the effects of beveled trailing edges on airfoil drag or on the airfoil and control-surface effectiveness, it is felt that these effects should be mentioned.

Drag.- It is natural that questions should arise concerning the effect of thickened and beveled trailing edges on the airfoil drag coefficient. The data in references 1 and 2, which were obtained under conditions of low scale, low velocity, and high turbulence, indicate that bevels caused increases from 0 to 0.0014 in the minimum profile-drag coefficient. The data in references 3 and 4, which were obtained at low scale and high turbulence, showed negligible increases in minimum drag. Unpublished data from tests at higher scale and low turbulence showed that the bevel on airfoil E (table I) caused an increase of about 0.0002 in the minimum profile-drag coefficient. Wake surveys made during flight tests of an airplane equipped with an unsealed beveled aileron having a trailing-edge angle of 26° and similar to the 31° beveled aileron of

airfoil D (table I) disclosed no measurable effects of the bevel on the drag coefficient and later tests (unpublished) of an intermediate section of the wing and ailerons in the NACA two-dimensional low-turbulence pressure tunnel indicated that the bevel increased the minimum profile-drag coefficient by 0.0001 to 0.0002.

Airfoil and control-surface effectiveness.— The data in references 1 to 4 indicate that thickening and beveling the control-surface trailing edge reduces the slope of the airfoil lift curve and also the lift effectiveness of the control surface. For ailerons the reduction in the slope of the lift curve should reduce the coefficient of damping in roll; the loss in available rate of roll should therefore be less than that indicated by considering only the change in available static rolling-moment coefficient. The maximum aileron deflection generally can be sufficiently increased to counteract the loss in control associated with the use of bevels. For tail surfaces, unlike ailerons, the question of airplane longitudinal or directional stability must also be considered. The loss in control effectiveness may again be counteracted by larger deflections but the decreased slope of the airfoil lift curve would necessitate a larger tail area or a larger aspect ratio to maintain the same degree of airplane stability.

CONCLUDING REMARKS

The amount of data concerning beveled trailing edges available at present is considered too small to justify any definite conclusions. It is believed, however, that use of the method developed and presented herein will lead to reasonably accurate estimates of the effects of beveled trailing edges on the hinge-moment characteristics of sealed control surfaces. The available data were insufficient, however, to extend the correlation to include unsealed control surfaces.

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Langley Field, Va.

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TABLE I

CHARACTERISTICS OF MODELS CONSIDERED IN CORRELATION

Airfoil section	Designation	Symbol	Aspect ratio, A	Ratio of tip to root chord, λ	Control type	Control location	Control span, $b_f/b/2$	Control chord, c_f/c	Bevel chord, c_b/c_f	Bevel radius, R_b/c	T.-E. angle, ϕ , deg	c_{la} CL_a	c_{ha} Ch_a	c_{ls}	c_{hs} Ch_s	Reference
NACA 0009	A	⊙	∞	-----	Plain sealed	-----	-----	0.300	$\left\{ \begin{array}{l} 0 \\ \text{Bulged} \end{array} \right.$	$\left\{ \begin{array}{l} \text{-----} \\ \text{-----} \end{array} \right.$	$\left\{ \begin{array}{l} 11.6 \\ 18.0 \\ 25.2 \\ 29.2 \\ 35.0 \\ 42.8 \end{array} \right.$	$\left\{ \begin{array}{l} 0.098 \\ .095 \\ .092 \\ .091 \\ .090 \\ .088 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0065 \\ -.0048 \\ -.0024 \\ -.0012 \\ .0011 \\ .0028 \end{array} \right.$	$\left\{ \begin{array}{l} 0.056 \\ .048 \\ .052 \\ .051 \\ .049 \\ .044 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0120 \\ -.0100 \\ -.0070 \\ -.0050 \\ -.0030 \\ 0 \end{array} \right.$	1
NACA 0015	B	⊠	∞	-----	Plain sealed	-----	-----	0.300	$\left\{ \begin{array}{l} 0 \\ \text{Flat} \end{array} \right.$	$\left\{ \begin{array}{l} \text{-----} \\ \text{-----} \end{array} \right.$	$\left\{ \begin{array}{l} 19.4 \\ 16.8 \end{array} \right.$	$\left\{ \begin{array}{l} 0.096 \\ .098 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0023 \\ -.0028 \end{array} \right.$	$\left\{ \begin{array}{l} 0.056 \\ .055 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0080 \\ -.0089 \end{array} \right.$	2
NACA 230 series	C	+	5.55	0.60	Plain sealed	0.580b/2 to .985b/2	0.405	0.155	$\left\{ \begin{array}{l} 0 \\ .34 \\ .20 \\ .20 \end{array} \right.$	$\left\{ \begin{array}{l} \text{-----} \\ 0.100 \\ .200 \\ .200 \end{array} \right.$	$\left\{ \begin{array}{l} 12.6 \\ 27.0 \\ 26.8 \\ 40.2 \end{array} \right.$	$\left\{ \begin{array}{l} 0.075 \\ .072 \\ .072 \\ .070 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0027 \\ \text{-----} \\ .0056 \\ .0084 \end{array} \right.$	$\left\{ \begin{array}{l} \text{-----} \\ \text{-----} \\ \text{-----} \\ \text{-----} \end{array} \right.$	$\left\{ \begin{array}{l} -0.0070 \\ -.0030 \\ -.0034 \\ -.0010 \end{array} \right.$	3
NACA 66,2 series	D	$\left\{ \begin{array}{l} \nabla \\ \Delta \end{array} \right.$	5.66	0.52	Bottom seal (Plain sealed) Top seal (a)	0.270b/2 to .980b/2	0.710	0.200	$\left\{ \begin{array}{l} 0 \\ \text{Flat} \\ .30 \\ .20 \end{array} \right.$	$\left\{ \begin{array}{l} \text{-----} \\ \text{-----} \\ 0.200 \\ .200 \end{array} \right.$	$\left\{ \begin{array}{l} 14.0 \\ 17.5 \\ 31.0 \\ 40.0 \end{array} \right.$	$\left\{ \begin{array}{l} 0.073 \\ .071 \\ .068 \\ .067 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0009 \\ .0005 \\ .0076 \\ .0120 \end{array} \right.$	$\left\{ \begin{array}{l} \text{-----} \\ \text{-----} \\ \text{-----} \\ \text{-----} \end{array} \right.$	$\left\{ \begin{array}{l} -0.0076 \\ -.0072 \\ -.0030 \\ -.0007 \end{array} \right.$	4
NACA 66,2-216 a = 0.6	E	◇	∞	-----	Plain sealed (a)	-----	-----	0.200	$\left\{ \begin{array}{l} 0 \\ .20 \\ 0 \\ \text{Flat} \end{array} \right.$	$\left\{ \begin{array}{l} \text{-----} \\ (b) \\ \text{-----} \\ \text{-----} \end{array} \right.$	$\left\{ \begin{array}{l} 9.0 \\ 27.6 \\ 9.0 \\ 21.0 \end{array} \right.$	$\left\{ \begin{array}{l} 0.107 \\ .092 \\ .104 \\ .100 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0064 \\ .0072 \\ -.0032 \\ .0053 \end{array} \right.$	$\left\{ \begin{array}{l} 0.046 \\ .038 \\ .045 \\ .041 \end{array} \right.$	$\left\{ \begin{array}{l} -0.0105 \\ -.0035 \\ -.0034 \\ .0003 \end{array} \right.$	Unpublished

^a Sealed internally balanced.^b Not noted on drawing, appeared to be almost zero.

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Fig. 1

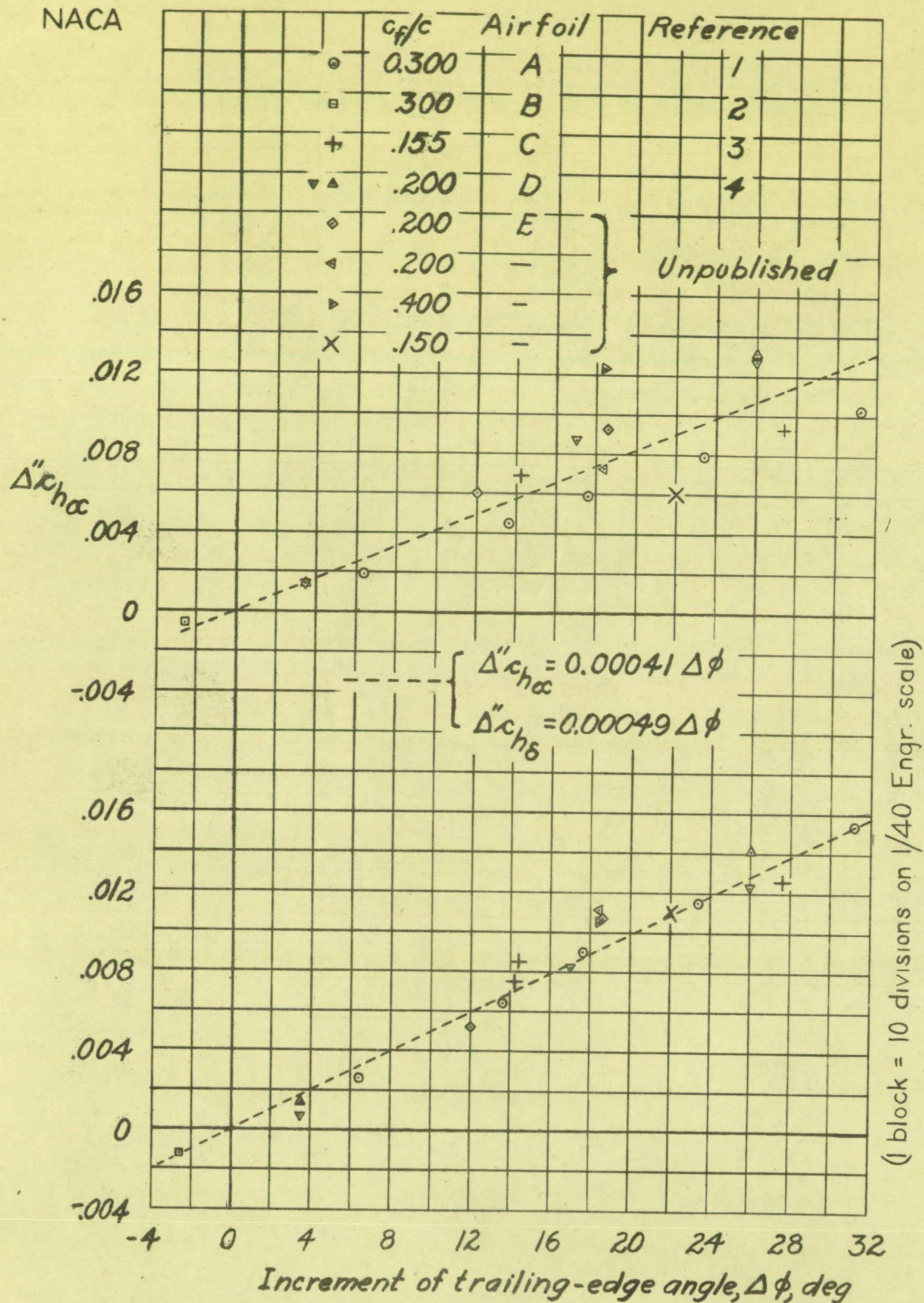


Figure 1.- Variation of the increments of the slopes of the hinge-moment curves with increments in trailing-edge angle. Data corrected to $c_f/c=0.30$, $c_{l\alpha}=0.109$, $c_{l\delta}=0.072$.

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Fig. 2

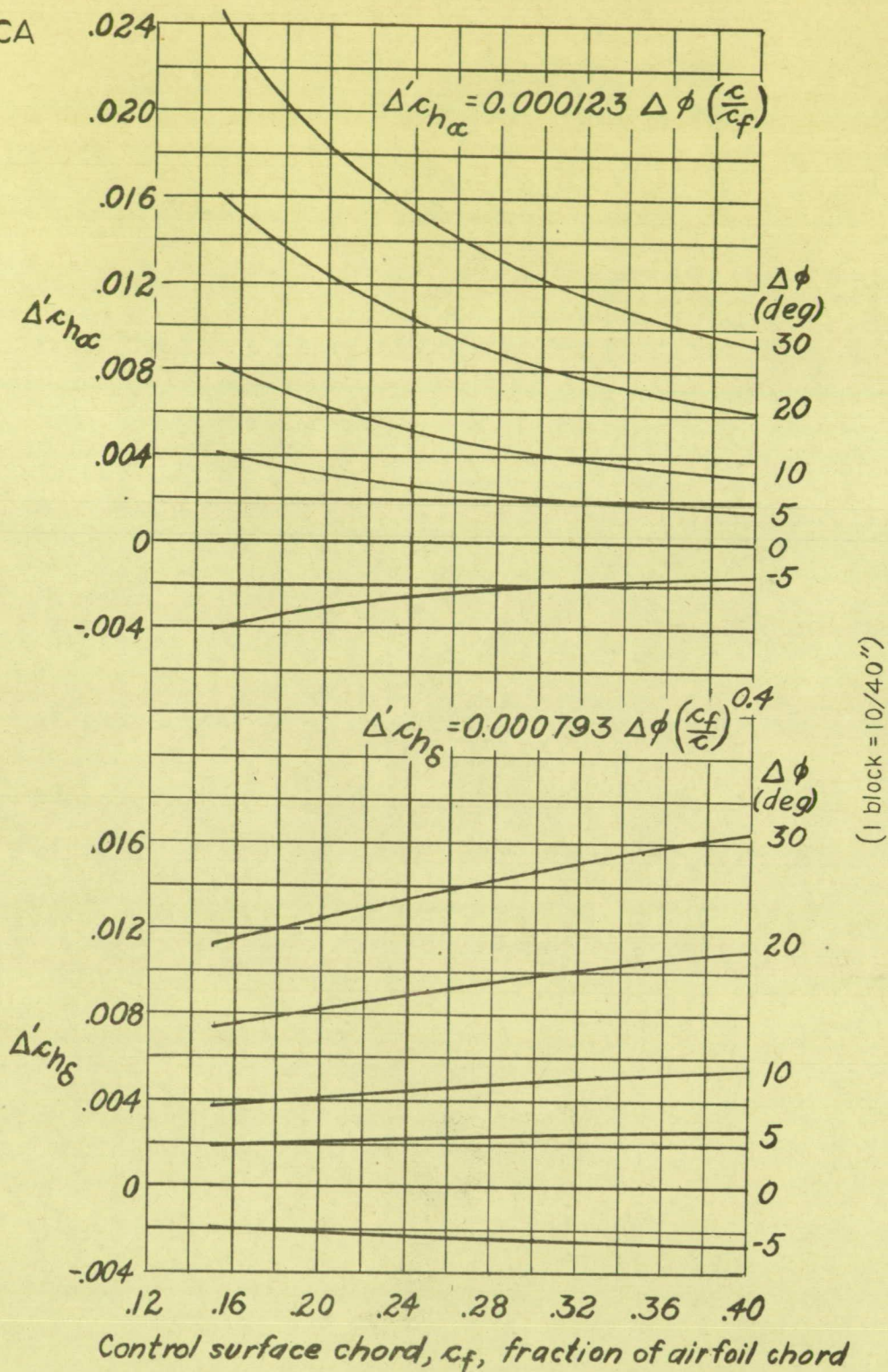


Figure 2:- Variation of the increments of the slopes of the hinge-moment curves with control-surface chord for various increments of trailing-edge angle. Data corrected to $c_{2\alpha} = 0.109$ and $c_{2\delta} = 0.109(\alpha_{\delta})_t$.

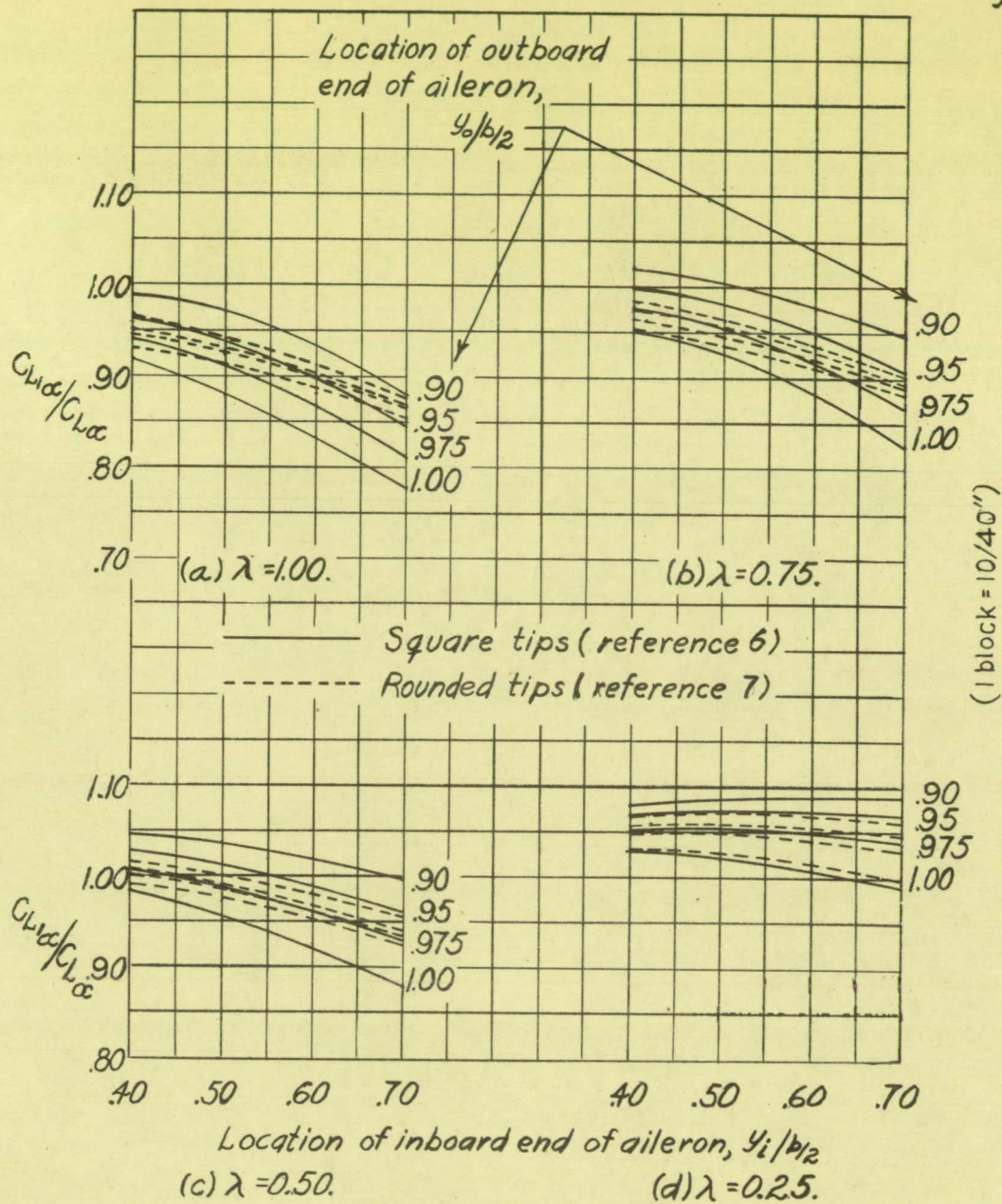


Figure 3 :-Ratio of average slope of lift curve over aileron to slope of lift curve of wing for ailerons of various sizes and locations on wings of various ratios of tip to root chord with square and rounded tips. $A=6.0$.

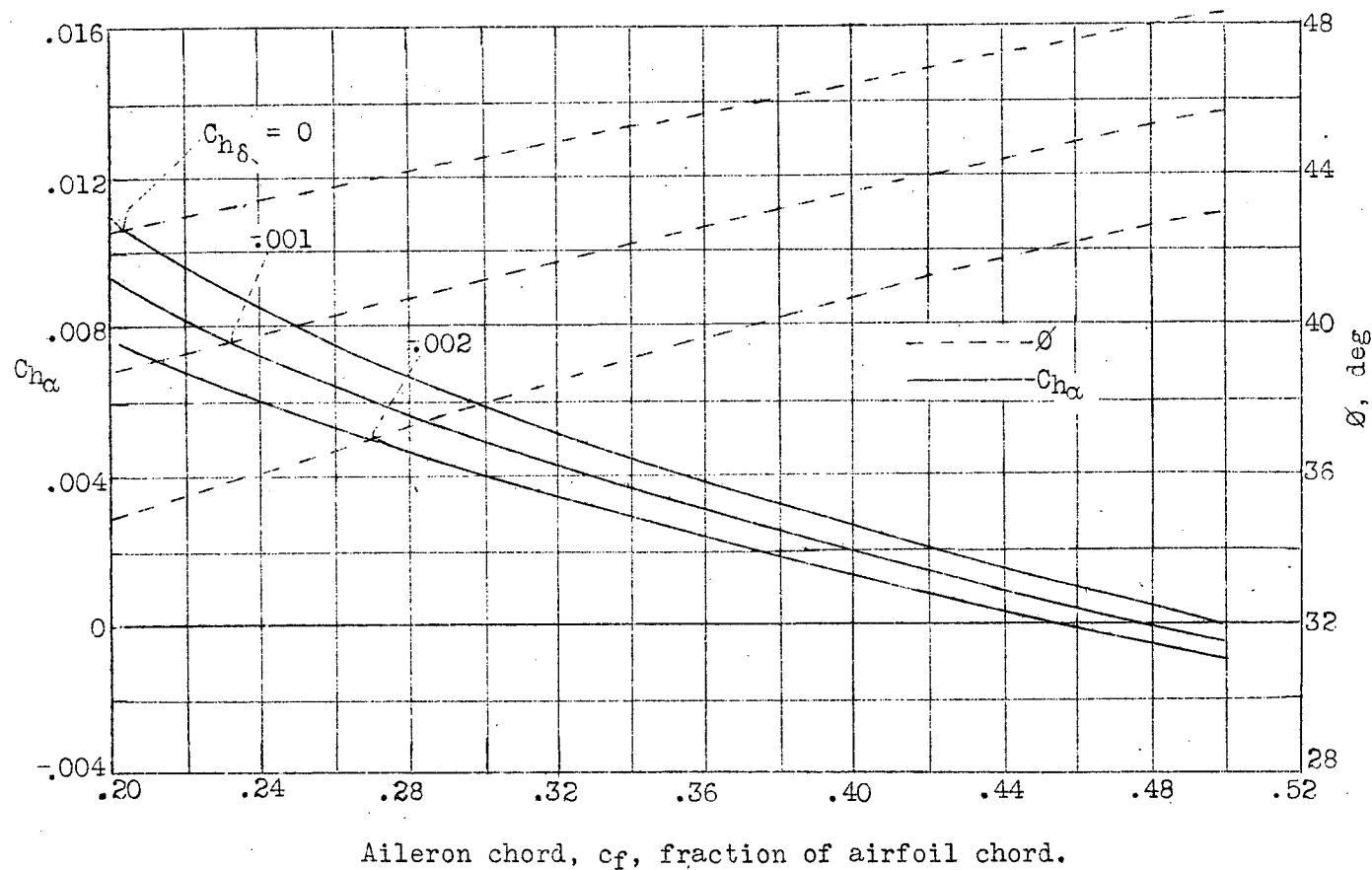


Figure 4.- Effect of aileron chord and trailing-edge angle on the hinge-moment characteristics computed for 0.71 $b/2$ plain sealed ailerons on a tapered wing. A , 5.66; λ , 0.52.

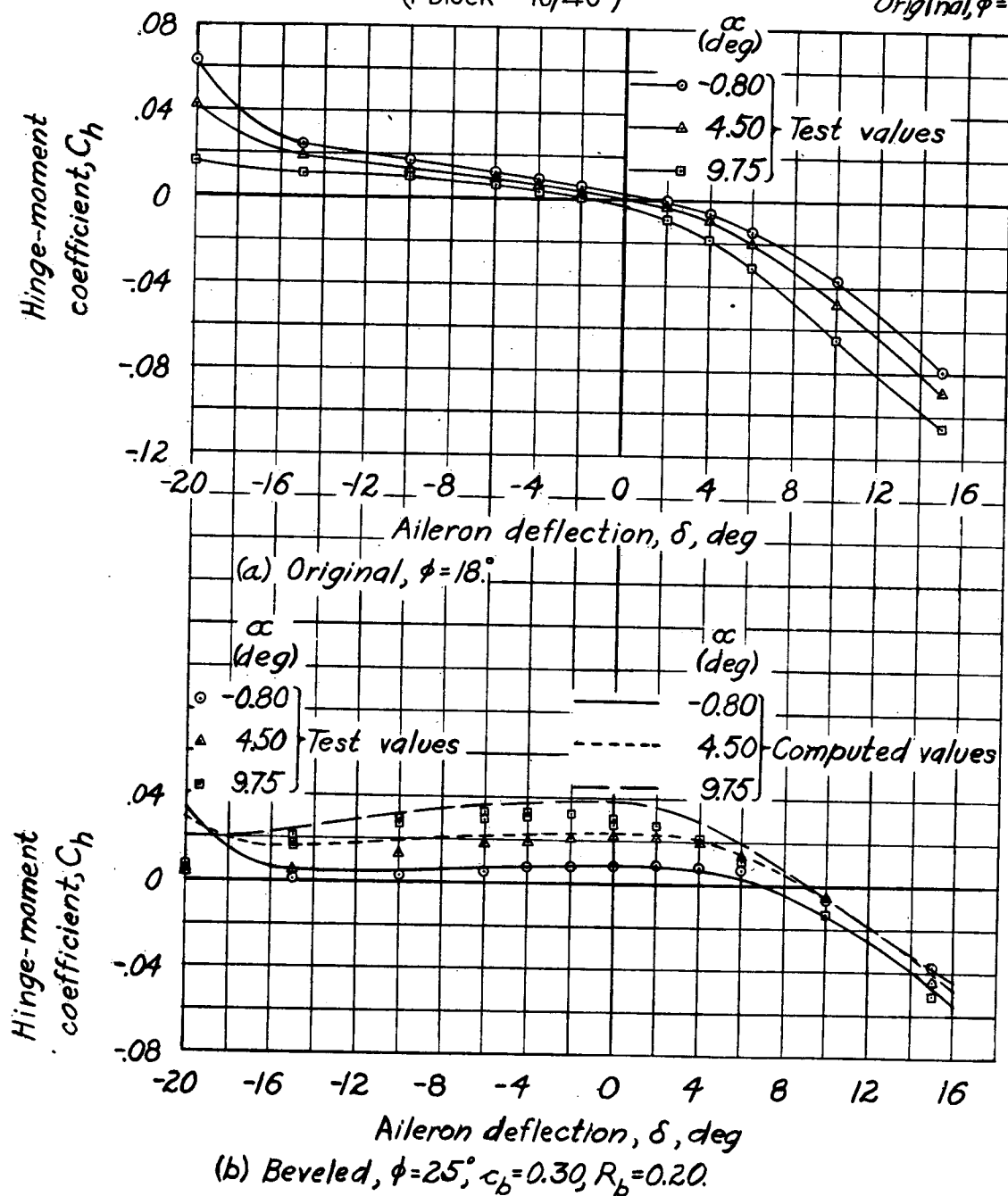
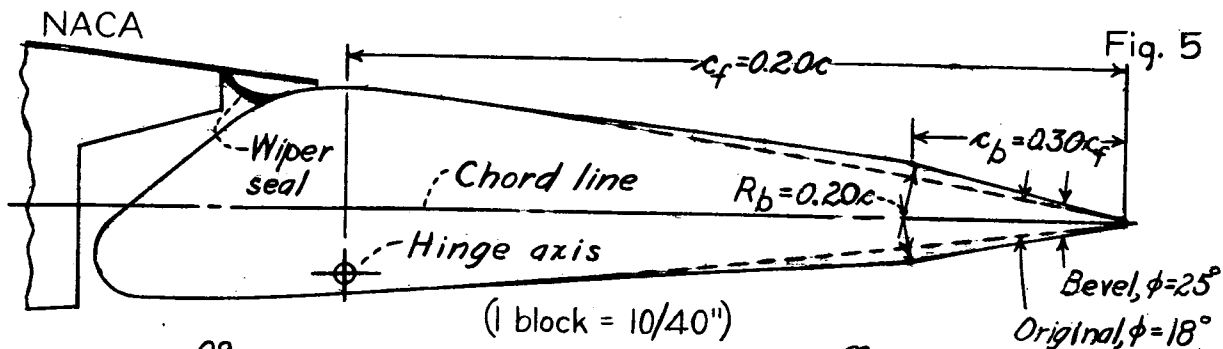


Figure 5.-Computed and test values of hinge-moment coefficients of a Frise aileron on an NACA 230-series wing with rounded tips. $A, 5.35$; $\lambda, 0.70$; $c_f, 0.20c$; location, $0.565\frac{1}{2}$ to $0.930\frac{1}{2}$.