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APPROXIMATE RELATIONS FOR HINGE-MOMENT PARAMETERS OF CONTROL SURFACES ON SWEPT WINGS AT LOW MACH NUMBERS

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SUMMARY

An approximate method of accounting for the effects of sweep has been applied to previously determined equations for the hinge-moment parameters of control surfaces on unswept wings. The method accounts for the effects of sweep on the section parameters and makes use of the approximation that, regardless of the sweep angle, the relation between the average induced angle of attack and the lift coefficient is the same as that for an unswept elliptic wing. Lifting-surface-theory corrections for the induced-camber effect are considered in an approximate manner. No attempt was made to account for subsonic compressibility effects, although a brief discussion of such effects is included.

A few comparisons of calculated and experimental results for the hinge-moment parameters of various arrangements of control surfaces on wings having different sweep angles indicate that the predicted effects of sweep and control-surface span are reasonably reliable. As in the case of methods developed previously for unswept wings, the accuracy of specific determinations depends on the accuracy with which the section parameters can be evaluated. The accuracy of the proposed method in applications to swept wings appears to be of about the same order as the accuracy of previous methods in applications to unswept wings. The proposed method, therefore, is considered suitable for use in preliminary design or for making estimates of the effects of minor modifications.

INTRODUCTION

Because of the extremely large hinge-moment variations that are known to accompany changes in wing profile shape or in surface conditions, any practical method for predicting control-surface hinge moments must be so formulated that arbitrary section characteristics can be readily accounted for. Of the various wing theories that have been proposed so far, the lifting-line theory provides the only convenient means by which equations for the hinge-moment parameters of finite-span wings can be written in terms of section characteristics. The simplified concepts involved in lifting-line theory have been shown by an analysis applicable to ailerons on unswept wings (reference 1) to result in appreciable errors. Suitable corrections have been obtained, however, by means of lifting-surface theory; and as a result, design procedures applicable to unswept wings have been established. (See references 2 and 3.) The procedures used in these references for evaluating the hinge-moment parameters involve the use of lifting-line-theory equations with an additive correction for the effects of induced camber, as determined by a series of specific lifting-surface solutions. The advantage of relations expressed in terms of section characteristics is thereby retained.

The procedures used for evaluating the hinge-moment parameters of unswept wings must be carefully inspected in order to determine the degree of their applicability to swept wings. Such consideration is necessary since the lifting-line theory, which has provided the basis for the method, is not directly applicable to swept wings. In a strict sense, determinations of the hinge moments of control surfaces on swept wings can be obtained only through direct lifting-surface solutions in which viscosity effects, as manifested in the section characteristics, cannot be easily accounted for. A method of modifying the lifting-line theory, in order to account approximately for the effects of sweep, was proposed in reference 4 and was therein applied to the determination of the stability derivatives. The same concepts are applied in the present paper to the hinge-moment parameters. Simple equations in terms of section characteristics are obtained. A few comparisons are made between calculated and experimental results.

SYMBOLS

c_l	section lift coefficient $\left(\frac{\text{Airfoil lift per unit span}}{qc}\right)$
c_h	section hinge-moment coefficient $\left(\frac{\text{Hinge moment per unit span}}{2qm}\right)$
C_L	lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$
C_h	hinge-moment coefficient $\left(\frac{\text{Hinge moment}}{2qM}\right)$
m	for two-dimensional wing, moment about hinge line of area back of hinge line per unit span of control surface
M	for finite-span wing, moment about hinge line of control-surface area back of hinge line
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$
ρ	mass density, slugs per cubic foot
V	free-stream velocity

c	wing chord measured parallel to plane of symmetry
c'	wing chord measured perpendicular to wing quarter-chord line
c_f'	control-surface chord back of hinge line measured perpendicular to wing quarter-chord line
c_b'	control-surface-balance chord measured perpendicular to wing quarter-chord line
S	wing area
b	wing span measured perpendicular to plane of symmetry
y_i	distance from plane of symmetry to inboard end of control surface
y_o	distance from plane of symmetry to outboard end of control surface
A	aspect ratio $\left(\frac{b^2}{S}\right)$
λ	taper ratio; ratio of tip chord to root chord
ϕ	trailing-edge angle
Λ	angle of sweep of wing quarter-chord line, degrees
Λ_h	angle of sweep of control-surface hinge line, degrees
α	angle of attack measured in plane of symmetry
δ	control-surface deflection measured in plane perpendicular to hinge line
δ_o	effective control-surface deflection measured parallel to plane of symmetry
B_2	factor for evaluating induced camber corrections, given as $F/(c_e/c)^2$ in reference 3
ΔC_{h_α}, ΔC_{h_δ}	incremental corrections for induced-camber effect
K_α	correction factor, applicable to ΔC_{h_α}, for effects of control-surface span
K_δ	correction factor, applicable to ΔC_{h_δ}, for effects of control-surface span

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

α_δ effective change in section angle of attack per unit change in control-surface deflection; for infinite-span wing, $\alpha_\delta = \dfrac{\left(\dfrac{\partial c_l}{\partial \delta}\right)_\alpha}{\left(\dfrac{\partial c_l}{\partial \alpha}\right)_\delta}$

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

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

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

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

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

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

The subscripts outside the parentheses of the foregoing partial derivatives indicate the factors held constant for evaluation of the derivatives. The foregoing derivatives apply only to the ranges of small angles of attack and deflections for which the characteristics are linear.

Subscript $\Lambda = 0^\circ$, when used with any of the foregoing derivatives, indicates that the derivative is evaluated for zero sweep.

DEVELOPMENT OF METHOD

Section Characteristics

The lift-curve slope of a thin infinite-span wing has been shown (reference 5) to be modified by sweep, according to the relation

$$c_{l_\alpha} = \left(c_{l_\alpha}\right)_{\Lambda=0^\circ} \cos \Lambda \tag{1}$$

where the angle of attack is measured in the plane of symmetry. According to the usual convention the control-surface deflection δ is measured in a plane perpendicular to the control hinge line. For small deflections the effective deflection measured in the plane of symmetry δ_o is therefore related to the deflection δ as follows:

$$\delta_o = \delta \cos \Lambda \tag{2}$$

and the effectiveness parameter in terms of the deflection δ can be expressed as

$$\alpha_\delta = \left(\alpha_\delta\right)_{\Lambda=0^\circ} \cos \Lambda \tag{3}$$

The control-surface hinge-moment coefficient, as defined herein, is based on the area moment of the control surface about the hinge line. For unswept and swept wings with control surfaces having the same chord in the stream direction, the area moment per unit span decreases as the cosine of the sweep angle. This effect on the hinge-moment coefficient is canceled, however, since the distance from the hinge line to the center of pressure of the aerodynamic load carried by the control surface is also decreased as the cosine of the sweep angle. For the same chordwise load distribution, the hinge-moment coefficient, therefore, is proportional to the aerodynamic load, regardless of the sweep angle; and consequently, from equation (1)

$$c_{h_\alpha} = \left(c_{h_\alpha}\right)_{\Lambda=0^\circ} \cos \Lambda \tag{4}$$

and, similarly, from equations (1) and (3)

$$c_{h_\delta} = \left(c_{h_\delta}\right)_{\Lambda=0^\circ} \cos^2 \Lambda \tag{5}$$

The relations just given could not be expected to be very reliable for application in equations for the characteristics of a finite-span tapered swept wing, since the control-surface hinge line then would not be parallel to the sweep reference line. As a first approximation, the effect of taper might be considered to be manifested only by a change in the effective deflection of the control surface. If, for a tapered wing, the sweep angle of the hinge line is designated by the symbol Λ_h, then the relation between the deflections δ_o and δ is given by

$$\delta_o = \delta \cos \Lambda_h$$

rather than by equation (2). Equations (3) and (5) therefore can be rewritten as

$$\alpha_\delta = \left(\alpha_\delta\right)_{\Lambda=0^\circ} \cos \Lambda_h \tag{6}$$

and

$$c_{h_\delta} = \left(c_{h_\delta}\right)_{\Lambda=0^\circ} \cos \Lambda \cos \Lambda_h \tag{7}$$

whereas equations (1) and (4) remain the same. The section parameters, in all instances, should correspond to the profile and chord ratio in planes perpendicular to the quarter-chord line of the finite-span wing. This approach can be considered to represent only an artificial means of accounting approximately for taper, since a tapered infinite-span wing cannot, in fact, exist.

Finite-Span Characteristics

Lifting-line-theory equations.– Glauert (reference 6) has shown that according to the assumptions of lifting-line theory, the parameters $\left(\frac{\partial C_h}{\partial C_L}\right)_\delta$, α_δ, and $\left(\frac{\partial C_h}{\partial \delta}\right)_{C_L}$ are independent of aspect ratio. By equating section and finite-span parameters, therefore, the following lifting-line-theory equations can be derived (see reference 7):

$$C_{h_\alpha} = \frac{C_{L_\alpha}}{c_{l_\alpha}} c_{h_\alpha} \tag{8}$$

and

$$C_{h_\delta} = c_{h_\delta} - \alpha_\delta c_{h_\alpha}\left(1 - \frac{C_{L_\alpha}}{c_{l_\alpha}}\right) \tag{9}$$

Since equations (8) and (9) are in terms of aerodynamic, rather than geometric parameters, they should apply with about the same accuracy to swept or unswept wings. In order to relate the finite-span parameters to the wing plan form, however, appropriate relations for the various aerodynamic parameters included in equations (8) and (9) must be used. The effects of sweep on the parameters c_{l_α}, α_δ, c_{h_α}, and c_{h_δ} have already been given, equations (1), (6), (4), and (7), respectively. A modified-lifting-line-theory equation for the remaining parameter C_{L_α} can be obtained from the approximation, used in reference 4, that, regardless of the sweep angle, the relation between the average induced angle of attack and the wing lift coefficient is the same as that for an unswept elliptic wing. By application of this approximation and by accounting for the effect of sweep on the section lift-curve slope, there is obtained

$$C_L = \left(\alpha - \frac{C_L}{\pi A}\right)\left(c_{l_\alpha}\right)_{\Lambda=0^\circ} \cos \Lambda$$

where α is in radians and, therefore, to a first approximation

$$C_{L_\alpha} = \frac{A\left(c_{l_\alpha}\right)_{\Lambda=0^\circ} \cos \Lambda}{A + 2 \cos \Lambda}$$

Substitution of this equation and equations (1), (6), (4), and (7) in equations (8) and (9) leads to the following modified-lifting-line-theory equations for the hinge-moment parameters of swept wings:

$$C_{h_\alpha} = \frac{A \cos \Lambda}{A + 2 \cos \Lambda}\left(c_{h_\alpha}\right)_{\Lambda=0^\circ} \tag{10}$$

and

$$C_{h_\delta} = \cos \Lambda \cos \Lambda_h\left[\left(c_{h_\delta}\right)_{\Lambda=0^\circ} - \left(\alpha_\delta\right)_{\Lambda=0^\circ}\left(c_{h_\alpha}\right)_{\Lambda=0^\circ} \frac{2 \cos \Lambda}{A + 2 \cos \Lambda}\right] \tag{11}$$

These equations are subject to the usual limitations of lifting-line theory as well as to the inaccuracies of the simplified method of accounting for the effects of sweep.

Hinge-moment parameters given by equations (10) and (11) might be expected to apply only to full-span control surfaces, since the basic relations (equations (8) and (9)) were derived for full-span control surfaces. Experience has indicated, however, that for usual arrangements of partial-span control surfaces results obtained from equations (8) and (9) are almost identical with results obtained from the more cumbersome equations, given in reference 1, which account for the actual control-surface span. It is expected, therefore, that equations (10) and (11) also should be suitable for partial-span control surfaces. Corrections for the induced-camber effect should, however, be applied to equations (10) and (11), as discussed in the following paragraphs.

Lifting-surface corrections.- No attempt has been made herein to evaluate accurately the lifting-surface correction, resulting from the induced camber, to the hinge moments of controls on swept wings. Since the proposed method is considered to be suitable only for rough approximations, any attempt to obtain precise values of the induced-camber effect would be unwarranted. The assumptions are made, therefore, that the correction for induced camber can be applied as an additive increment to the modified-lifting-line-theory equations already presented and that the effects of sweep on the corrections are proportional to the effects of sweep on the section hinge-moment parameters. The assumption regarding the effect of sweep is logical if the induced camber in planes parallel to the plane of symmetry is, for a given aspect ratio and for given wing or control-surface lift coefficients, independent of the angle of sweep.

Theoretical corrections to C_{h_α} for full-span and outboard control surfaces and to C_{h_δ} for full-span control surfaces have been evaluated for unswept wings in references 2 and 3, respectively. A method of obtaining corrections to C_{h_δ} for outboard control surfaces has been derived empirically from results of an unpublished experimental investigation of the effects of control-surface span made with an unswept wing of aspect ratio 6.23. The test results were used to evaluate the ratio of the required correction for an outboard control surface to the required correction for a full-span control surface.

The corrections for induced-camber effect are given in a simplified form, applicable to swept or unswept wings, in figure 1. Corrections for a specific control surface are obtained by multiplying the quantities $\frac{\Delta C_{h_\alpha}}{c_{l_\alpha} B_2 K_\alpha}$ and $\frac{\Delta C_{h_\delta}}{c_{l_\delta} B_2 K_\delta}$ by appropriate values of the factors given in the denominators. The section lift-curve slopes for the airfoil and control surface c_{l_α} and c_{l_δ} are, according to equations (1) and (6),

$$c_{l_\alpha} = \left(c_{l_\alpha}\right)_{\Lambda=0^\circ} \cos \Lambda$$

and

$$c_{l_\delta} = \left(c_{l_\delta}\right)_{\Lambda=0^\circ} \cos \Lambda \cos \Lambda_h$$

The factor B_2, which is given as $\frac{F}{(c_e/c)^2}$ in reference 3, accounts for effects of control-surface and balance chord ratios and can be evaluated from figure 1. The curves given for B_2 are directly applicable to exposed-overhang balances. Experience has indicated that appropriate values of B_2 for internally balanced control surfaces can be approximated by assuming the internal-balance chord to be equivalent to about eight-tenths of the same exposed-overhang-balance chord. The factors K_α and K_δ, which account for the control-surface span, are also given in figure 1. For outboard control surfaces that extend approximately to the wing tips, values of K_α and K_δ are obtained from figure 1 at the value of $\frac{y_i}{b/2}$ corresponding to the spanwise location of the inboard end of the control surface. For inboard control surfaces that extend from the plane of symmetry to an arbitrary spanwise station the values of K_α and K_δ must be less than 1.0, since the induced camber at a given station decreases as the distance of the station from the plane of symmetry decreases. For practical purposes, sufficient accuracy probably can be obtained by assuming that for inboard control surfaces the value of either K_α or K_δ is equal to $\frac{y_o}{b/2}$, where y_o is the distance from the plane of symmetry to the outboard end of the control surface.

Complete equations for the hinge-moment parameters, with the induced-camber effect included, are as follows:

$$C_{h_\alpha} = \frac{A \cos \Lambda}{A + 2 \cos \Lambda} \left(c_{h_\alpha}\right)_{\Lambda=0^\circ} + \Delta C_{h_\alpha}$$

and

$$C_{h_\delta} = \cos \Lambda \cos \Lambda_h \left[\left(c_{h_\delta}\right)_{\Lambda=0^\circ} - \left(\alpha_\delta\right)_{\Lambda=0^\circ}\left(c_{h_\alpha}\right)_{\Lambda=0^\circ} \frac{2 \cos \Lambda}{A + 2 \cos \Lambda}\right] + \Delta C_{h_\delta}$$

<u>Mach number effects</u>.- The Prandtl-Glauert correction for Mach number effects has been applied by British investigators to the lifting-line-theory

equations for the hinge-moment parameters of control surfaces on unswept finite-span wings. Similar principles could be applied to the equations presented herein for swept wings; but because of the approximate nature of the equations presented and because of limitations of the Prandtl-Glauert factor, such an application is considered to be unwarranted. In general, it is found in practice that the changes in boundary-layer characteristics, which accompany changes in Mach number, may be at least as important with regard to hinge moments as the so-called first-order Mach number effects on the surface pressures, which are accounted for by the Prandtl-Glauert correction. The over-all effect of Mach number on hinge moments, therefore, is frequently found to be considerably different from that which is indicated through application of the Prandtl-Glauert factor. Test results generally have indicated small effects of subcritical variations in Mach number on the hinge-moment parameters of control surfaces having trailing-edge angles of about 12° or less. For such control surfaces, estimates made by the proposed procedures, which neglect Mach number effects, should be reasonably reliable over the greater part of the subcritical Mach number range.

DISCUSSION

The approximate relations derived for the hinge-moment parameters of control surfaces on swept wings are in terms of the usual two-dimensional parameters of an unswept airfoil, for which the significant section is considered to be in a plane normal to the wing quarter-chord line. The method applies directly to full-span control surfaces and to outboard control surfaces that extend approximately to the wing tips. The method can also be expected to apply with reasonable accuracy to inboard control surfaces.

Comparison with Experiment

Comparisons of experimental and calculated results for wings having 3.6° and 48.6° sweepback of the quarter-chord lines are presented in figure 2. The wing with 3.6° sweepback (zero sweep of the 0.5c line) had an aspect ratio of 6.23, a taper ratio of 0.49, and 0.20c plain sealed control surfaces extending from various spanwise stations to the wing tip. The 48.6° sweptback wing was obtained by rotating the 3.6° sweptback wing about the intersection of the 0.5c line with the plane of symmetry. Tests of the 48.6° sweptback wing were made with tips cut perpendicular to the 0.5c line and with tips cut parallel to the plane of symmetry. In either case the aspect ratio was approximately 3.5. The section parameters of the flapped airfoil (NACA 65_1-012 with straight sides back of the hinge line) were estimated from results of two-dimensional tests of the same airfoil section, but with a different flap chord ratio, to have the following values:

$$\left(c_{l_{\alpha}}\right)_{\Lambda=0^{\circ}} = 0.105$$

$$\left(\alpha_{\delta}\right)_{\Lambda=0^{\circ}} = 0.47$$

$$\left(c_{h_{\alpha}}\right)_{\Lambda=0^{\circ}} = -0.0040$$

and

$$\left(c_{h_{\delta}}\right)_{\Lambda=0^{\circ}} = -0.0117$$

The calculated curves shown in figure 2 indicate smaller negative values of the hinge-moment parameters for the 48.6° sweptback wing than for the 3.6° sweptback wing. The reductions result both from the effect of the larger sweep angle and from the effect of the smaller aspect ratio. For the case of full-span control surfaces on wings of zero sweep, the proposed method reduces essentially to the method of reference 3, which has generally been found to be reliable over a wide range of aspect ratios. The calculated variations of hinge-moment parameters with control-surface span appear from figure 2 to be about as reliable for the 48.6° sweptback wing as for the wing with essentially no sweep. Since good agreement between calculated and experimental results was obtained for the 3.6° sweptback wing, any differences between calculated and experimental results for the 48.6° sweptback wing might logically be considered to result from the inadequacy of the proposed method in accounting accurately for the effects of sweep, at least for the particular configurations tested.

Although the calculated and experimental results are in qualitative agreement, in that smaller negative values of the hinge-moment parameters were obtained as the sweep angle was increased, the experimental reductions in the parameters with increased sweep angle were somewhat smaller than the predicted reductions. The average error of the predicted values for the 48.6° sweptback wing is about 0.0010 when the wing tips were cut parallel to the plane of symmetry and about 0.0005 when the wing tips were cut perpendicular to the 0.5c line. For all the partial-span control surfaces tested, the inboard ends of the control surfaces were cut perpendicular to the hinge line. Some unpublished test results have indicated that the hinge moments of control surfaces on sweptback wings are critically affected by the shape of the inboard end of the control surface. Values smaller in magnitude than those presented in figure 2 have been obtained when the inboard end of the control surface was cut parallel to the plane of symmetry. For such configurations, the errors in the predicted values may be smaller or may actually be opposite in sign to those indicated by figure 2.

As in the case of previous methods developed for unswept wings, the proposed method is based on equations which are in terms of section parameters. The accuracy of specific determinations for finite-span swept wings, therefore, depends on the accuracy with which the section parameters can be evaluated. Comparisons of calculated and experimental values of the hinge-moment parameters, at speeds well below the critical Mach number, for several swept wings and tail surfaces are given in table I. For all models, except those numbered 2 and 5, the section parameters were estimated by means of the empirical procedures outlined in reference 8. Models 2 and 5 had been included in investigations that also comprised tests of unswept wings with the same section and general control-surface arrangements as the swept wings. For these models, the section parameters required to give the experimentally determined values of finite-span parameters of the unswept wings were used in the calculations of the parameters for the swept wings. This procedure was followed in order to obtain the best possible indication of the reliability of the proposed method for predicting the effect of the change from the unswept to the swept configuration.

The experimental results for the models included in table I show relatively large random deviations from the calculated results. These random deviations are no larger, however, than the deviations that had been noted previously (reference 9) in comparisons of calculated and experimental hinge-moment parameters of controls on unswept tail surfaces. No consistent error in the calculated values is evident from the comparisons shown in table I. Although the experimental results available at the present time are considered to be inadequate for establishing the range of wing plan forms over which the proposed method would be expected to apply with reasonable accuracy, the indications are that for most wing plan forms the method should be suitable for use in preliminary-design estimates or for estimating the effects of minor modifications in plan form or section.

Limitations of the Method

The accuracy of the proposed method for predicting effects of sweep angle, taper ratio, or control-surface span is expected to decrease as the aspect ratio decreases. Although no definite plan-form limitations can yet be established, application of the proposed method to wings of approximately triangular plan form, with aspect ratios of about 3 or less, could not be expected to yield the order of accuracy normally obtained for unswept wings or tail surfaces. The method has not been set up in a manner that is directly applicable to control surfaces having variable chord ratios or section contours along the spans. For most configurations, sufficient accuracy probably can be obtained by using simple average values of the section parameters. Reduced accuracy of predicted finite-span parameters would, of course, be expected to result from increased spanwise variations in control-surface chord ratio or in section contour.

As had been mentioned previously, tests have shown that for sweptback wings the shape of the ends of the control surface may have an important effect on the hinge moments. The proposed method, being based on the assumption of simple potential-flow load distributions, is expected to apply most satisfactorily to arrangements that have the control-surface ends cut parallel to the plane of symmetry. The effects of variables such as the shape of the control-surface ends, the wing-tip shape, or wing cut-outs can be handled most satisfactorily by empirical procedures that can be developed only after a considerable amount of experimental data has been accumulated.

CONCLUDING REMARKS

An approximate method of accounting for the effects of sweep has been applied to previously determined equations for the hinge-moment parameters of control surfaces on unswept wings at low Mach numbers. Comparisons of calculated and experimental results for the hinge-moment parameters of various arrangements of control surfaces on two wing plan forms indicate that the predicted effects of sweep and control-surface span are reasonably reliable. As in the case of methods developed previously for unswept wings, the accuracy of specific determinations depends on the accuracy with which the section parameters can be evaluated. The accuracy of the proposed method in applications to swept wings appears to be of about the same order as the accuracy of previous methods in applications to unswept wings. The proposed method, therefore, is considered suitable for use in preliminary design or for making estimates of the effects of minor modifications in plan form or section.

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National Advisory Committee for Aeronautics
Langley Field, Va., July 28, 1948

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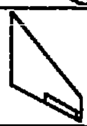
TABLE I.— COMPARISON OF EXPERIMENTAL AND CALCULATED VALUES OF THE CONTROL-SURFACE HINGE-MOMENT PARAMETERS FOR VARIOUS SWEPT WINGS

Model	Configuration	A	λ	Λ (deg)	$\frac{c_f'}{c'}$	ϕ (deg)	$\frac{y_i}{b/2}$	$\frac{y_o}{b/2}$	Section characteristics $\left(c_{h_\alpha}\right)_{\Lambda=0^\circ}$	Section characteristics $\left(c_{h_\delta}\right)_{\Lambda=0^\circ}$	Section characteristics $\left(\alpha_\delta\right)_{\Lambda=0^\circ}$	Section characteristics $\left(c_{l_\alpha}\right)_{\Lambda=0^\circ}$	$\left(C_{h_\alpha}\right)_{exp}$	$\left(C_{h_\alpha}\right)_{cal}$	$\left(C_{h_\delta}\right)_{exp}$	$\left(C_{h_\delta}\right)_{cal}$
1		4.79	0.51	35.4	0.41	14	0.48	1.00	−0.0070	−0.0140	0.61	0.107	−0.0013	−0.0025	−0.0066	−0.0078
2		2.31	.27	56.5	.25	12	.00	.85	−.0050	−.0107	.47	.107	−.0010	−.0006	−.0025	−.0036
3		6.00	.50	35	.20	4.6	.50	.97	−.0080	−.0127	.44	.107	−.0031	−.0044	−.0086	−.0085
4		3.96	.63	40	.20	16	.50	.97	−.0020	−.0082	.44	.107	.0000	.0002	−.0017	−.0045
5		5.60	.50	45	.20	20	.47	.91	.0030	−.0049	.44	.107	.0015	.0009	−.0035	−.0021
6		3.01	.50	48.6	.22	6	.55	.95	−.0075	−.0125	.49	.107	−.0010	−.0019	−.0042	−.0048
7		3.01	.50	48.6	.22	14	.55	.95	−.0034	−.0093	.49	.107	−.0004	−.0001	−.0039	−.0035
8		3.01	.50	48.6	.22	25	.55	.95	.0022	−.0049	.49	.107	.0034	.0025	−.0013	−.0017

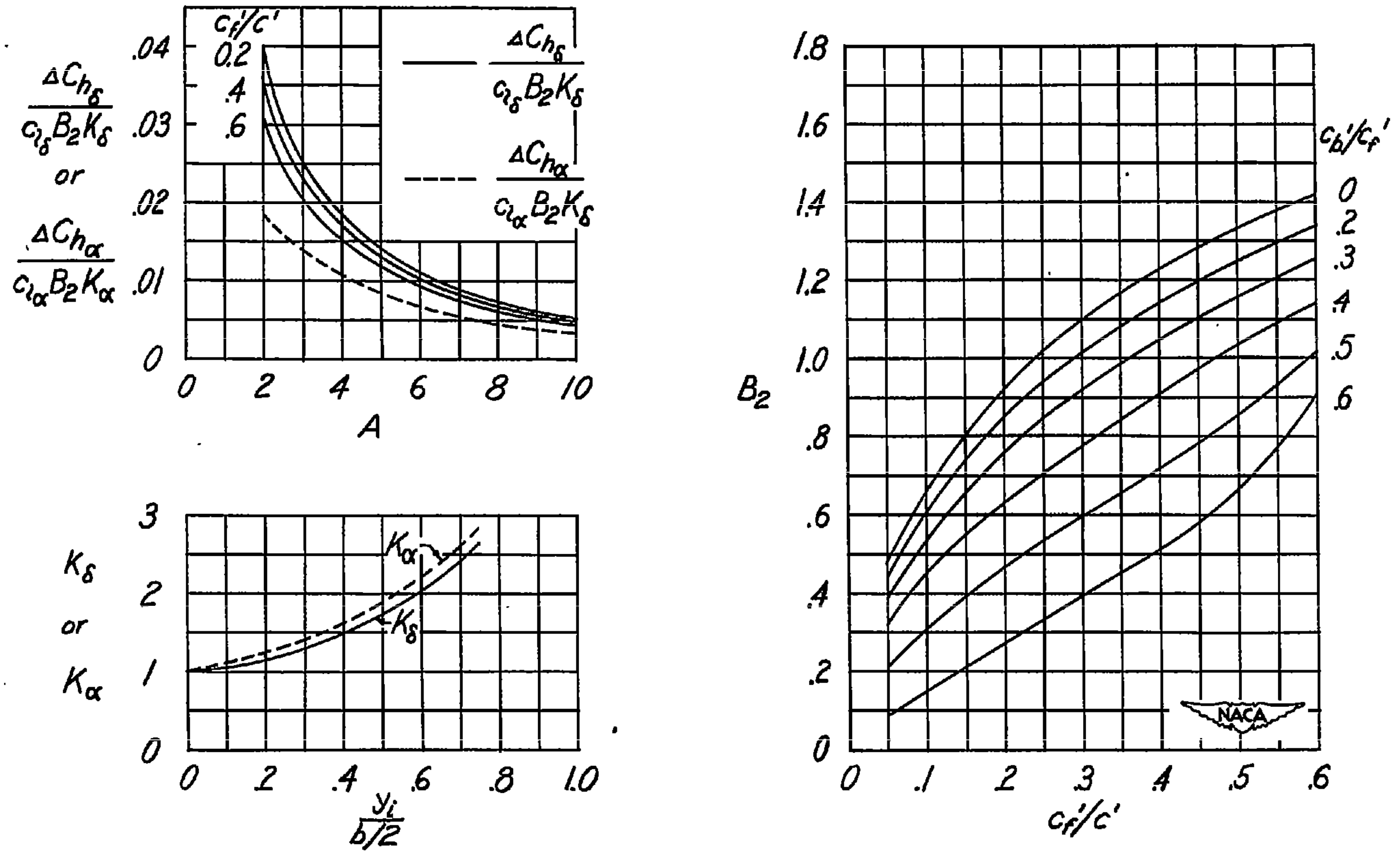


Figure 1.- Chart for evaluating induced-camber corrections to the hinge-moment parameters of finite-span wings.

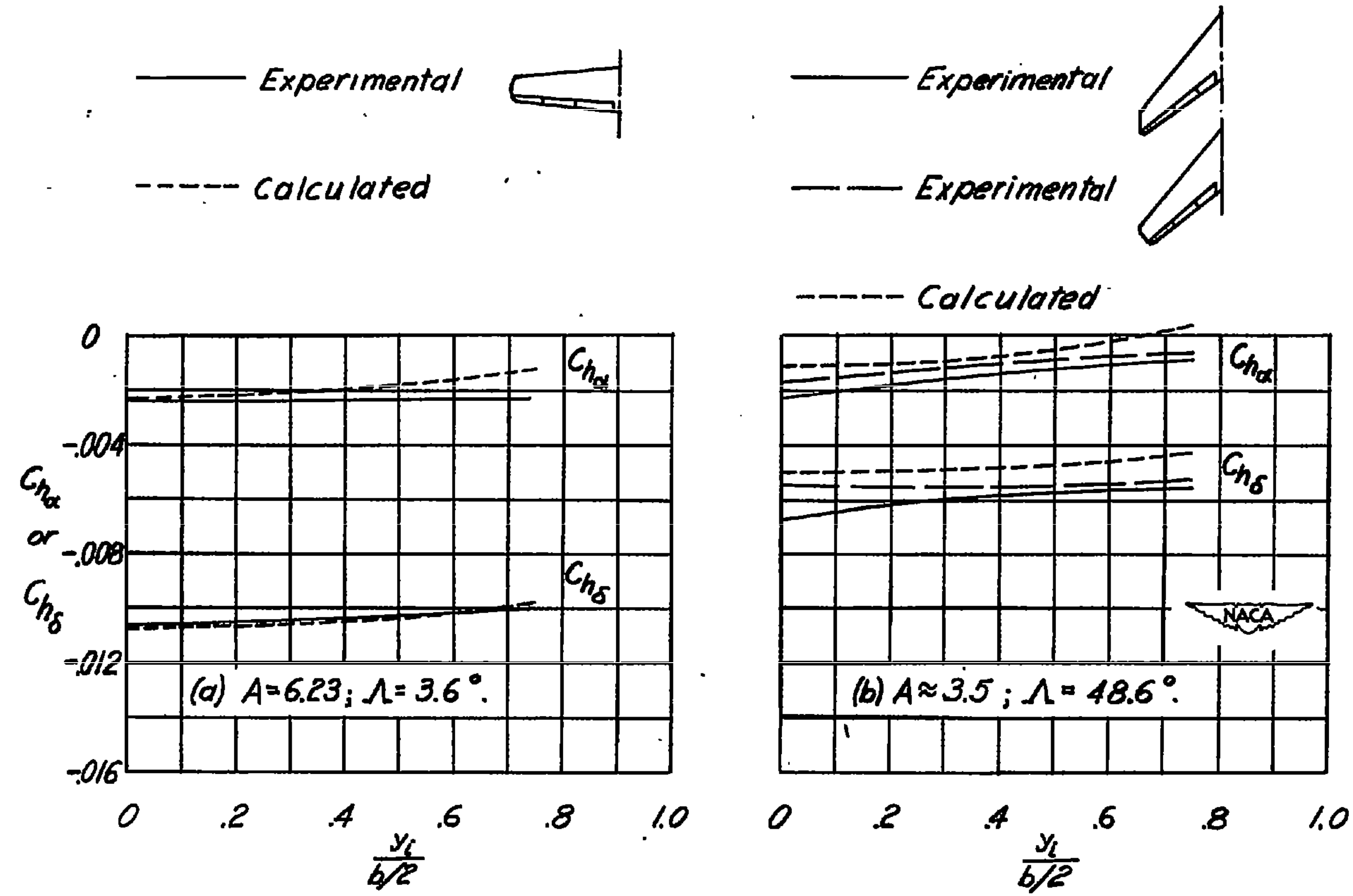


Figure 2.- Comparison of calculated and experimental values of the hinge-moment parameters of plain sealed control surfaces. $C_L = 0$.