NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1506

AN APPLICATION OF FALKNER'S SURFACE-LOADING METHOD TO PREDICTIONS OF HINGE-MOMENT PARAMETERS FOR SWEPT-BACK WINGS

By Arthur L. Jones and Loma Sluder

Ames Aeronautical Laboratory
Moffett Field, Calif.

Washington
February 1948

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 1506

AN APPLICATION OF FALKNER'S SURFACE-LOADING METHOD TO PREDICTIONS OF HINGE-MOMENT PARAMETERS FOR SWEPT-BACK WINGS

By Arthur L. Jones and Loma Sluder

SUMMARY

Application of the Falkner lifting-surface-theory method to the prediction of hinge-moment and, incidentally, lift parameters for swept-back plan forms has been made in an attempt to develop an analogue to the existing lifting-surface-theory procedure for prediction of these parameters on unswept plan forms. For the two specific swept-back plan forms investigated the hinge-moment predictions based on the Falkner method were not in good agreement with experimental values. The discrepancies between the predicted and the experimental results probably are due to the effects of fluid viscosity which were not included in the Falkner method as applied herein.

INTRODUCTION

Previous to the publication of reference 1 it was general practice to predict control-surface hinge-moment parameters for finite-span wings by use of lifting-line theory. Lifting-line theory yields an induced angle of attack which can be applied to modify the section hinge-moment parameters by an effective reduction of the chord load at all sections of the wing. Lifting-surface-theory methods have been introduced recently (references 1 and 2) in the prediction of finite-span hinge-moment parameters in an attempt to include the effects of chord load redistribution as well as chord load reduction. This redistribution of the chord loading that occurs on a finite-span wing has been found to have an appreciable effect on the hinge-moment parameters.

One successful attempt to evaluate the chord load redistribution for unswept elliptical plan forms and to apply the generalized results to other unswept plan forms has been made in reference 2 for a practical range of aspect ratios. This attempt has produced a greatly improved procedure for hinge-moment-parameter prediction for unswept wings. The lifting-surface-theory methods that produced the results of reference 2, the Cohen method (reference 3) and its mechanical counterpart the electromagnetic analogy method, have not been applied as yet to the prediction of surface loadings and subsequent hinge-moment corrections for swept plan forms. The time required to obtain one resultant loading and a lack of rapid convergence of results to a satisfactory solution very probably have been the factors that have prevented the successful application of these methods to the swept plan form case.

Another method for predicting surface loadings is the Falkner application of lifting-surface theory (reference 4) which can be applied as readily to swept as to unswept plan forms. This method has been applied in this investigation to obtain the flat-plate pressure distributions for use in predicting the angle-of-attack hinge-moment parameters. A basic part of the development of this theory, the use of a finite number of terms in a series expansion for expressing the chordwise and spanwise load distributions, apparently has rendered the method impractical for predicting directly the chordwise load distribution on a flapped surface. By use of a simplifying approximation, however, predictions were also made of the parameters for control deflection.

The network of horseshoe vortices used in the Falkner method to represent the vorticity distribution might conceivably restrict the method to producing good values for averaged or integrated parameters such as the finite-span lift-curve slope without yielding accurate distributions of the load over the lifting surface. If such inaccuracies in the predicted load distribution existed they could easily invalidate Falkner's lifting surface solution for use in the prediction of hinge-moment parameters. Consequently an effort has been made to check this possibility by using the Cohen method to determine the induced velocities of the Falkner loading predicted for a swept plan form. These induced velocities were checked against the boundary values required if the stream is to flow along the flat plate at an angle of attack.

The suitability of the loadings calculated by the Falkner method for predicting hinge-moment parameters was measured by a comparison of the predicted and experimental results for two 35° swept-back wings and two unswept wings of aspect ratios 3 and 4.5.

In the process of determining these hinge-moment predictions based on the calculated surface loadings, it was convenient to predict the lift parameters also. No emphasis was placed on this phase of the investigation, however, since the lift parameters for swept and unswept wings have been investigated previously.

SYMBOLS AND COEFFICIENTS

α	geometric angle of attack of lifting surface measured in the plane of symmetry, degrees (unless otherwise specified)
α_i	induced angle of attack, degrees (unless otherwise specified)
δ	control deflection angle measured in a plane perpendicular to the hinge line, degrees (unless otherwise specified)
C_L	lift coefficient $\left(\frac{\text{lift}}{qS}\right)$
c_l	section lift coefficient $\left(\frac{\text{section lift}}{qc}\right)$
C_h	hinge-moment coefficient $\left(\frac{\text{hinge moment}}{q\ b_e\ \overline{c_e}^2}\right)$
c_h	section hinge-moment coefficient $\left(\frac{\text{section hinge moment}}{q\ c_e^2}\right)$
c	chord of the lifting surface measured parallel to plane of symmetry
c_e	chord of control surface
$\overline{c_e}$	root-mean-square chord of elevator
x/c	distance along the chord measured from the local leading edge as a fraction of the chord
b'	semispan of the lifting surface
$y/(b/2)$	distance measured perpendicular to the plane of symmetry divided by the semispan
b_e	span of control surface
S	area of wing
q	free-stream dynamic pressure
C_{L_α}	variation of lift coefficient with angle of attack $(\partial C_L/\partial\alpha)$
c_{l_α}	variation of section lift coefficient with angle of attack $(\partial c_l/\partial\alpha)$

C_{h_α}	variation of hinge-moment coefficient with angle of attack $(\partial C_h/\partial\alpha)$
c_{h_α}	variation of section hinge-moment coefficient with angle of attack $(\partial c_h/\partial\alpha)$
C_{h_δ}	variation of hinge-moment coefficient with angle of control deflection $(\partial C_h/\partial\alpha)$
c_{h_δ}	variation of section hinge-moment coefficient with angle of control deflection $(\partial c_h/\partial\delta)$
α_δ	control effectiveness parameter $\left\|(c_{l_\delta}/c_{l_\alpha})\right\|$
w	vertical component of induced velocity
Γ	circulation strength
Γ_{max}	maximum circulation strength
$\frac{w\ b/2}{\Gamma_{max}}$	nondimensional value of the vertical induced velocity
A	aspect ratio
Λ	angle of sweep in degrees

subscripts

c_l	at a constant section lift coefficient
C_L	at a constant lift coefficient
δ	at a constant control deflection angle
S.C.	an increment due to "streamline curvature" effects
L.S.	predicted using lifting-surface-theory methods

APPLICATION OF THEORIES TO DETERMINATION OF FINITE-SPAN HINGE-MOMENT PARAMETERS FROM SECTION DATA

An understanding of the procedure used herein for applying the Falkner lifting-surface-theory method to the prediction of hinge-moment corrections can be greatly facilitated by a short discussion of the fundamental lifting-surface theory. Most of these ideas have appeared previously in other publications. The diversity of the analytical operations required by the Falkner and Cohen[1] methods, however, warrants the following comparison of the two methods with regard to hinge-moment prediction applications.

General Prodecures for Loading and Hinge-Moment Determinations

The lifting-surface-theory methods of references 3, 4, and 5 are intended to provide surface loadings that satisfy the boundary conditions of no flow through the wing for a finite-span thin airfoil. These theoretical solutions generally are obtained using the limiting case of a thin airfoil (such as the mean camber line to obtain the basic loading, or the chord line to obtain the additional loading) for the boundary conditions. To predict C_{h_α} the chord line at an angle of attack is established as the basic boundary condition and for an untwisted wing of finite span the chord lines form a flat plate. The prediction for C_{h_δ} can be obtained by using the mean camber line with control deflected as the basic boundary condition.

Since the usual procedure in the prediction of C_{h_α} and C_{h_δ} is to modify the section data corresponding to the airfoil profile of the wing by accounting for three-dimensional effects, it is apparent that for a given plan form the difference between the strip-theory loading and a lifting-surface theory loading is needed for the hinge-moment corrections. This difference in loadings is generally regarded (references 1 and 2) as having two components: one that can be considered as due to an average induced angle of attack α_i and another that can be considered as due to the variation of the induced angle of attack (produced by the variation of the vertical induced velocities) along the chord. The latter component has been called the streamline curvature effect (references 1 and 2). The consideration of the induced load as having two components was evolved with the application of the Cohen method to the prediction of finite-span hinge moments.

[1]The electromagnetic-analogy method (reference 5) is based on the same analytical development as the Cohen semigraphical method reported in reference 3. For the purpose of this analysis then, the two methods can be considered to be the same and reference will be made only to the Cohen method.

These two components of the difference between the strip-theory and lifting-surface-theory loadings yield two separate corrections; the α_i component is applied as a percentage correction to the section data and the streamline curvature component is applied as an additive correction. In view of this analysis C_{h_α} and C_{h_δ} can be written (neglecting the spanwise variations),

$$(C_{h_\alpha})_{L.S.} = c_{h_\alpha} - \frac{\alpha_i}{\alpha} c_{h_\alpha} + (\Delta C_{h_\alpha})_{S.C.}$$

$$(C_{h_\delta})_{L.S.} = c_{h_\delta} - \frac{\alpha_i}{\delta} c_{h_\alpha} + (\Delta C_{h_\delta})_{S.C.}$$

Determination of Hinge-Moment Aspect Ratio Corrections Using the Cohen Method

This method is set up to find the induced velocities for a given or an assumed surface loading. It is desired to find, however, the surface loading for specified boundary conditions. The best approximate loading which can be estimated readily is assumed, therefore, and the induced vertical velocities at a number of points on the lifting surface are calculated. For this analysis the strip-theory loading (two-dimensional chord loadings superimposed on the wing) was considered adequate for a first approximation. If the induced velocities for the assumed loading do not satisfy the boundary conditions it is necessary to determine the proper combination of induced angle-of-attack loading and streamline curvature loading which, when superimposed on the assumed loading, will eliminate the differences between the boundary conditions and the vertical induced velocities. Thus by a process of systematic approximations the load distribution can be adjusted until the induced velocities satisfy the boundary conditions. The nature of the operations prescribed by this method permits its application to discontinuous surfaces and provides a method of predicting C_{h_δ} as well as C_{h_α}.

Determination of Hinge-Moment Aspect-Ratio Corrections Using the Falkner Method

The approach followed in the development of the Falkner method limits the application of the method to some extent but provides a means of obtaining directly the surface loading for a given set of boundary conditions. In this method the spanwise and chordwise load distribution is represented by a double infinite series which in practical application is restricted to a small finite number of terms. To simplify the evaluation of the coefficients in the series, the surface distribution of vorticity is concentrated into a finite number of vortices and the boundary conditions are satisfied at a finite number of points. The number of chordwise terms in the series required to determine the load distribution due to control deflection with sufficient accuracy would extend the computation time excessively; hence the prediction of C_{h_δ} directly by the use of the Falkner method appears to be impractical. A simplifying assumption concerning the components of the control-deflected loading, however, provided the approximate prediction for C_{h_δ} presented in the discussion of the results.

For the predictions of the angle-of-attack parameters the desired difference between the strip-theory loading and the Falkner lifting-surface loading for a given angle of attack is found directly by subtraction. Consequently the difference in loading does not appear in the convenient two-component form. The physical interpretation associated with the two components of the induced load and the equation expressing the finite span parameters as functions of these components are well established. It is desirable, therefore, to resolve the induced load based on the Falkner method calculations into the two components rather than to attempt an analysis using the total induced load as one unit. To separate the induced angle-of-attack effect contained in the second term of equation (1) from the streamline curvature component forming the third term of equation (1) the factor α_i/α must be determined somewhat arbitrarily. It was found that the most suitable arrangement was to determine a factor α_i/C_L based on the Falkner predicted value for C_{L_α} which subsequently could be transformed to α_i/α. Since the lift-curve slope can be expressed in terms of α_i and $(\Delta C_L)_{S.C.}$ in the following manner (neglecting the spanwise integrations)

$$C_{L_\alpha} = \frac{c_{l_\alpha}}{1 + c_{l_\alpha}\left(\frac{\alpha_i}{C_L}\right) + \frac{(\Delta C_L)_{S.C.}}{C_L}} \qquad (3)$$

where $\frac{(\Delta C_L)_{S.C.}}{C_L}$ is composed of all the elemental loads of the chordwise load distribution except the additional type loading element represented by the $\cot \theta/2$ term in Falkner's series, then

$$\frac{\alpha_1}{C_L} = \left[\frac{1}{C_{L_\alpha}} - \frac{1}{c_{l_\alpha}} - \frac{1}{c_{l_\alpha}} \frac{(\Delta C_L)_{S.C.}}{C_L}\right]$$

where C_{L_α} is the Falkner result and $c_{l_\alpha} = 2\pi$.

The desired form for α_1 is finally obtained from

$$\frac{\alpha_1}{\alpha} = \frac{\alpha_1}{C_L} C_{L_\alpha}$$

where the C_{L_α} to be used has been adjusted to the proper section c_{l_α} by means of equation (3).

This value of α_1/α is applied in the second term of the hinge-moment equation (1). The third term of equation (1) $\left(\frac{\Delta C_h}{\alpha}\right)_{S.C.}$ can be computed from the loading elements making up the $\Delta C_{L_{S.C.}}$ load plus the integration of the spanwise variation of the the $\cot \theta/2$ load relative to the average $\cot \theta/2$ load. The average $\cot \theta/2$ load corresponds to the α_1/α factor discussed.

DISCUSSION OF THEORETICAL AND EXPERIMENTAL RESULTS

Theoretical Check of Falkner Solution

The possibility that the Falkner method might not provide a sufficiently accurate theoretical solution for the load distribution at fairly large angles of sweep led to a theoretical investigation to check a Falkner solution for a 45° swept-back wing by means of the Cohen semigraphical method. The calculated induced velocities and their locations are given in figure 1 along with the proper boundary value. The boundary condition established by the flat plate at an angle of attack was not precisely satisfied at any of the points investigated. The estimated loads necessary to remove the discrepancies between the induced velocities and the boundary conditions, however, yielded a very small change in hinge-moment coefficient, approximately $\Delta C_{h_\alpha} = 0.0002$.

This result indicates that any sizeable error in the hinge-moment parameter C_{h_α} predicted by the Falkner method would be due to the effects of viscosity rather than the inability of the Falkner method to provide a sufficiently accurate solution for potential flow.

Source of Experimental Results

The experimental two-dimensional and finite-span values of the parameters included in table 1 were obtained from tests of a two-dimensional model, two unswept semispan models, and two swept semi-span models, in the 7- by 10-foot wind tunnels at the Ames Aeronautical Laboratory. The airfoil section was an NACA 64A010 and on the swept plan forms this section was located perpendicular to the quarter-chord line. All the finite-span models had taper ratios of 0.5 and had 30-percent-chord full span, sealed gap elevators with nose radius balances. Both the two-dimensional and three-dimensional tests were made at a Reynolds number of approximately 3.0 by 10^6.

Comparison of Theoretical and Experimental Results

The values of the parameters predicted by the Swanson method and presented in table I were calculated by the operations outlined in reference 2. Included in these operations were a viscosity factor for the streamline curvature load and a compressibility factor. The computations of the values attributed to the Falkner method are based on the Falkner loading solutions for four elliptical plan forms, two swept and two unswept of aspect ratios 3 and 4.5. The sweep angle of 35° was referred to the one-quarter chord line, which was kept straight on these plan forms. The expressions for predicting the aerodynamic parameters considered are given in the discussion of the individual parameters.

The difference in the plan forms used to obtain the predicted and experimental results (respectively, an elliptical and a 0.5 taper ratio plan form) left the possibility that any discrepancies arising between the predicted and experimental results might be due to a greatly increased effect of taper ratio changes on the surface load distribution at appreciable sweepback angles. For unswept wings the application of elliptical plan form results to the prediction of aerodynamic parameters for various types of tapered plan forms has been found to be reasonably accurate as well as practical. The added effects of sweep, however, made it desirable to analyze a 0.5 taper ratio swept-back plan form of aspect ratio 3 and compare the results with the results based on the analysis of the elliptical plan forms. The comparison showed that the difference between the predicted results for the elliptical and 0.5 taper ratio plan forms, given in the following table, was small enough to be of little consequence in this case.

Parameter	Taper ratio 0.5	Elliptical
C_{h_α}	−0.0022	−0.0023
C_{h_δ}	−.0093	−.0093
C_{L_α}	.054	.055
C_{L_δ}	.032	.033
α_δ	.60	.60

The predicted values for the unswept wings are not intended as a comparison between experiment and theory in order to check the validity of the predictions by reference 2. This method has already been established as generally satisfactory by experimental verification on a large number of wings (approximately 30). The unswept wing results are presented to indicate that exclusive of the incidental compressibility and viscosity factors the Falkner method provides essentially the same correction in magnitude and direction that the established method of reference 2 provides. (For profile trailing-edge angles of 14° or less the viscosity factor reduces the streamline curvature correction by less than 10 percent.)

$\underline{C_{h_\alpha}}$.— The expression used to calculate C_{h_α} is equation (1) which has been discussed previously in the section on application of the method to hinge-moment corrections.

The discrepancies between predicted and experimental values for the unswept wings are larger than expected. The utility of these predictions, consequently, could be questioned. It should be noted, however, that for these unswept plan forms the streamline curvature corrections amount to $\Delta C_{h_\alpha} = 0.0018$ and $\Delta C_{h_\alpha} = 0.0011$ for the aspect ratios 3 and 4.5, respectively. The lifting-line-theory predictions which would be equivalent to the lifting-surface-theory predictions minus the streamline curvature corrections would be in error by 2-1/2 to 4 times as much as the lifting-surface-theory predictions. Previous evidence (references 2 and 6) indicate that for applications of the lifting-surface-theory correction errors of 0.0006 and 0.0008 for the predicted values of C_{h_α} are exceptional but not unreasonable.

The discrepancies in the predicted values of C_{h_α} for the swept-back wings, however, are beyond the limits of rationalization by consideration as random cases. The streamline curvature correction for these swept-back wings are $\Delta C_{h_\alpha} = 0.0007$ and $\Delta C_{h_\alpha} = -0.0003$ for the aspect ratios 3 and 4.5, respectively. Thus the lifting-line-theory values would be only slightly improved upon in one case and would be slightly superior in the other. As shown previously the Falkner method gives a sufficiently accurate theoretical load distribution for inviscid flow, hence the deterioration of the lifting-surface-theory predictions in the swept-back cases apparently is due to the increased viscous effects.

$\underline{C_{L_\alpha}}$.- The C_{L_α} values attributed to the Falkner method have been adjusted to the proper section lift-curve slope by means of equation (3). The reliability of the Swanson and Falkner methods for predictions of C_{L_α} for unswept wings has been investigated and discussed previously in references 2 and 4. In both of the present applications to unswept wings the predicted values were slightly high. The predicted values of C_{L_α} for swept wings by the Falkner method were also higher than the experimental values.

$\underline{C_{h_\delta}}$.- The inability of the Falkner method to yield directly surface loading solutions for deflected control surfaces has been discussed previously. Although this restriction prevents an explicit determination of C_{h_δ} by the Falkner method, an expression for C_{h_δ} can be developed involving merely the section c_{h_δ} and a partial evaluation of the induction effects.

The equation for section $(c_{h_\delta})_\alpha$,

$$(c_{h_\delta})_\alpha = (c_{h_\delta})_{c_l} + (\alpha_\delta)_{c_l} (c_{h_\alpha})_\delta$$

indicates that the loading for a control deflection at a constant α can be considered as composed of two constituent parts, a loading corresponding to the variation of the hinge moment with control deflection for a constant c_l, $(c_{h_\delta})_{c_l}$, and a loading corresponding to the variation of hinge moment with angle of attack for a constant control deflection, $(c_{h_\alpha})_\delta$. The induction effects can be determined for only the second term by the Falkner method, but if the induction effects of the first term are considered to be negligible the expression for the finite span C_{h_δ} becomes

$$C_{h_\delta} = (c_{h_\delta})_\alpha + (\alpha_\delta)_{c_l} \, c_{h_\alpha} - (\alpha_\delta)_{C_L} \, (C_{h_\alpha})_{L.S.}$$

This expression was used to determine the predicted values attributed to Falkner that are presented in table I. An excellent check on this expression can be made by substituting experimental results for the terms on the right-hand side of the equation. Thus for the aspect ratio 3 unswept wing

$$C_{h_\delta} = -0.0114 + (-0.602) \; (-0.0057) - (-0.70) \; (-0.0010) = -0.0087$$

and for aspect ratio 4.5 unswept wing

$$C_{h_\delta} = -0.0114 + (-0.602) \; (-0.0057) - (0.68) \; (-0.0020) = -0.0094$$

almost the precise measured values.

For the unswept cases this expression applied to the section data yielded very good predictions of C_{L_δ}. In the swept cases, however, the viscous effects and possibly the neglected induced effects are apparently quite important and the Falkner method does not appear to be applicable even in the approximate form of expression.

$\underline{C_{L_\delta}}$.- By using the same division of the loading due to flap deflection that was analyzed for C_{h_δ} and by making the same assumptions concerning the induced effects, a simplified expression for C_{L_δ} can be written

$$C_{L_\delta} = c_{l_\delta}\left(1 - \frac{\alpha_i}{\alpha}\right) - (\alpha_\delta)_{c_l}\left[\frac{(\Delta c_l)_{S.C.}}{\alpha}\right]$$

The values for C_{L_δ} that are attributed to the Falkner method were calculated using this expression. Comparison of the predicted and experimental values for C_{L_δ} leads to conclusions similar to those for C_{h_δ}. The predicted values for the unswept wings are satisfactory and justify the assumptions that were made. The predictions for the swept-back wings, however, are appreciably in error indicating that the neglected induced and viscous effects are important.

CONCLUDING REMARKS

Comparison of the predicted values of C_{h_α} with the experimental values for the two unswept wings indicated that notwithstanding incidental viscosity and compressibility factors the Falkner method provided essentially the same corrections to the lifting-line-theory hinge-moment and lift parameters that was provided by the procedure outlined in TN No. 1175 by Swanson and Crandall. Although neither set of predicted C_{h_α} values for the unswept wings checked the experimental results as well as expected, the predicted lifting-surface-theory values were great improvements over the lifting-line-theory predictions.

The values of C_{h_α} for the swept-back wings predicted by an application of Falkner's lifting-surface theory were in error to such an extent as to be impractical. These values showed no net improvement over the lifting-line-theory values. The other hinge-moment parameter C_{h_δ} estimated by use of the Falkner predicted surface loading was appreciably in error also.

The unreliability of the aerodynamic parameters predicted for the swept-back wings is not directly chargeable to the potential theory surface loadings predicted by the Falkner method for these plan forms. The predicted loading for a 45° swept-back wing was checked and found to satisfy the boundary conditions reasonably well. Thus it is probable that the discrepancies between the predicted and experimental results for the swept-back wings are due to viscous effects which were not included in the Falkner method analysis applied in this investigation.

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

REFERENCES

1. Swanson, Robert S., and Gillis, Clarence L.: Limitations of Lifting-Line Theory for Estimation of Aileron Hinge-Moment Characteristics. NACA CB No. 3L02, 1943.

2. Swanson, Robert S., and Crandall, Stewart M.: Lifting-Surface-Theory Aspect-Ratio Corrections to the Lift and Hinge-Moment Parameters for Full-Span Elevators on Horizontal Tail Surfaces. NACA TN No. 1175, 1947.

3. Cohen, Doris: A Method for Determining the Camber and Twist of a Surface to Support a Given Distribution of Lift. NACA TN No. 855, 1942.

4. Falkner, V.M.: The calculation of Aerodynamic Loading on Surfaces of Any Shape. R. & M. No. 1910, British A.R.C., 1943.

5. Swanson, Robert S., and Crandall, Stewart M.: An Electromagnetic-Analogy Method for Solving Lifting-Surface-Theory Problems. NACA ARR No. L5D23, 1945.

6. Jones, Arthur L., Flanagan, Mildred G., and Sluder, Loma: An Application of Lifting-Surface Theory to the Prediction of Angle-of-Attack Hinge-Moment Parameters for Aspect Ratio 4.5 Wings. NACA TN No. 1420, 1947

TABLE I.- COMPARISON OF PREDICTED AND EXPERIMENTAL VALUES

Parameter	Section	A=3.0			A=4.5		
	Experimental	Reference 2	Applied Falkner method	Experimental	Reference 2	Applied Falkner method	Experimental
Unswept							
C_{h_α}	-0.0057	-0.0017	-0.0016	-0.0010	-0.0029	-0.0028	-0.0020
C_{h_δ}	-.0114	-.0084	-.0089	-.0087	-.0095	-.0097	-.0095
C_{L_α}	.108	.056	.057	.053	.071	.070	.066
C_{L_δ}	.065	.036	.035	.037	.044	.042	.045
α_δ	.602	.640	.610	.700	.625	.600	.680
Swept							
C_{h_α}	-.0057	- -	-.0023	-.0013	- -	-.0039	-.0021
C_{h_δ}	-.0114	- -	-.0093	-.0072	- -	-.0103	-.0069
C_{L_α}	.108	- -	.055	.053	- -	.067	.061
C_{L_δ}	.065	- -	.033	.028	- -	.040	.032
α_δ	.602	- -	.600	.520	- -	.600	.520

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

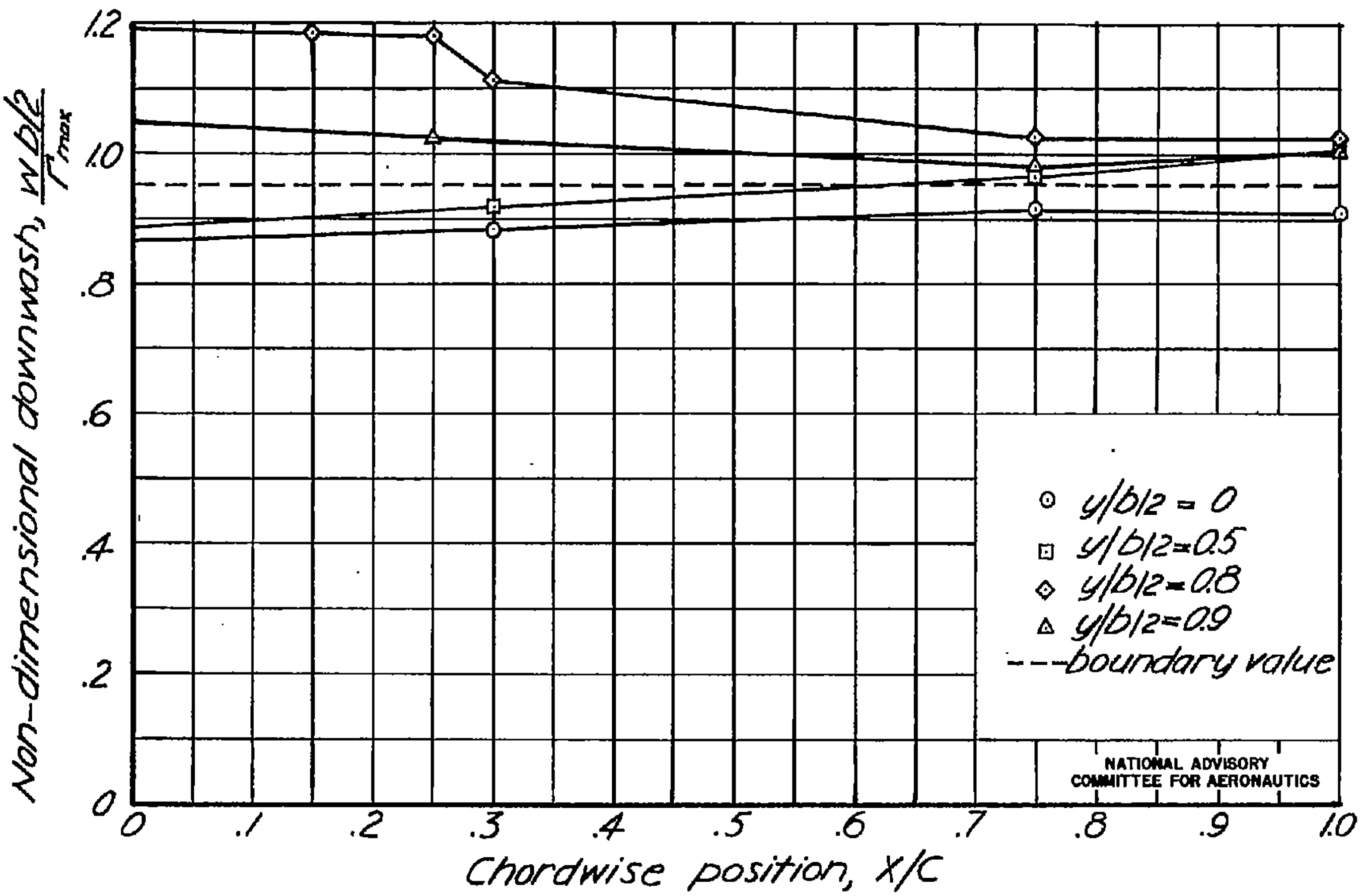

Figure 1.- Induced velocities calculated by the Cohen method for the loading predicted by the Falkner method on a 45° sweptback wing.