NACA TN 2335

NACA TN 2335

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2335

A PLAN-FORM PARAMETER FOR CORRELATING CERTAIN AERODYNAMIC CHARACTERISTICS OF SWEPT WINGS

By Franklin W. Diederich

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
April 1951

18

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2335

A PLAN-FORM PARAMETER FOR CORRELATING CERTAIN AERODYNAMIC CHARACTERISTICS OF SWEPT WINGS

By Franklin W. Diederich

SUMMARY

On the basis of approximate expressions for the lift-curve slope and the coefficient of damping in roll of swept wings at subsonic speeds, the finite-span effects on these aerodynamic characteristics are shown to be functions primarily of a plan-form parameter, which is the aspect ratio divided by the cosine of the sweep angle and by the ratio of the section lift-curve slope to 2π. The use of this parameter in presenting concisely and in correlating certain aerodynamic characteristics and the limitations attendant upon such use are discussed.

INTRODUCTION

The conventionally defined geometric aspect ratio has long been recognized as a very convenient means for correlating, interpreting, and analyzing certain aerodynamic parameters of unswept wings. Specifically, aerodynamic parameters which depend primarily on the over-all level of pressures on the wing surface rather than on the distribution of these pressures depend more on the geometric aspect ratio than on any other geometric parameter. For swept wings the significance of the aspect ratio is not obvious. In fact, neither the geometric aspect ratio nor any other known parameter associated with the geometry of the plan form serves to correlate aerodynamic parameters for swept wings as readily as does the geometric aspect ratio for unswept wings.

In this paper approximate expressions are derived for the lift-curve slope and for the coefficient of damping in roll of swept wings in compressible subsonic flow. On the basis of these expressions, a plan-form parameter is defined which is a function of the aspect ratio, the sweep, and the section lift-curve slope. As is shown in this paper, this parameter aids in the correlation and interpretation of certain aerodynamic properties for swept wings in a manner similar to that of the aspect ratio for unswept wings.

SYMBOLS

A	aspect ratio $\left(\frac{b^2}{S}\right)$
b	span (wing tip to wing tip)
C_{D_i}	wing induced-drag coefficient
c_{l_α}	lift-curve slope of section perpendicular to leading edge or quarter-chord line at a Mach number equal to $M \cos \Lambda$, per radian
C_L	wing lift coefficient
C_{L_α}	wing lift-curve slope, per radian
C_{l_p}	coefficient of damping in roll
F	plan-form parameter $\left(\frac{A}{\eta \cos \Lambda}\right)$
M	free-stream Mach number
S	wing area
η	section-lift efficiency factor $\left(\frac{c_{l_\alpha}}{2\pi}\right)$
Λ	angle of sweep
λ	taper ratio $\left(\frac{\text{Tip chord}}{\text{Root chord}}\right)$

ANALYSIS

Lift-Curve Slope

Incompressible flow.- According to lifting-line theory, the lift-curve slope of an elliptic unswept wing is given exactly and that of most other unswept wings, approximately by the relation

$$C_{L_\alpha} = \frac{A}{A + 2\eta} c_{l_\alpha} \tag{1}$$

where the section-lift efficiency factor η is defined by

$$\eta \equiv \frac{c_{l_\alpha}}{2\pi} \tag{2}$$

The lift on a section perpendicular to the leading edge of an infinite swept wing, according to the effective-velocity-component concept (reference 1), is the same as that of a section of an infinite unswept wing which has the same chord and section as those perpendicular to the leading edge of the swept wing, which is exposed to a free-stream velocity equal to the component of the free-stream velocity perpendicular to the leading edge of the swept wing, and which is at an angle of attack equal to that of the swept wing relative to this component. As a result of this concept, the lift-curve slope of a section of an infinite swept wing parallel to the free-stream velocity is

$$\left(c_{l_\alpha}\right)_{\text{Swept}} = c_{l_\alpha} \cos \Lambda \tag{3}$$

so that

$$\lim_{A \to \infty} C_{L_\alpha} = c_{l_\alpha} \cos \Lambda \tag{4}$$

where c_{l_α} is the lift-curve slope of the section perpendicular to some swept reference line, such as the quarter-chord line, and where α is measured in planes parallel to the plane of symmetry.

On the basis of reasoning concerning induction effects of swept wings of finite span which takes into account the results of lifting-line theory for unswept wings and the results of the effective-velocity-component concept for infinite swept wings, an approximate expression for the lift-curve slope of swept wings of finite span has been given in reference 2:

$$C_{L_\alpha} = \frac{A}{A + 2\eta \cos \Lambda} c_{l_\alpha} \cos \Lambda \tag{5}$$

This expression indicates that the lift-curve slope of a swept wing depends separately on the aspect ratio and the sweep. However, equation (5) may be rewritten in the form

$$\frac{C_{L_\alpha}}{c_{l_\alpha} \cos \Lambda} = \frac{F}{F + 2} \tag{6}$$

or

$$C_{L_\alpha} = \frac{F}{F + 2} \left(c_{l_\alpha}\right)_{\text{Swept}} \tag{7}$$

where the plan-form parameter F is defined as

$$F \equiv \frac{A}{\eta \cos \Lambda} \tag{8}$$

As indicated by equation (7) the use of the plan-form factor serves to reduce equation (5) to an expression which depends only on the plan-form factor, rather than on the aspect ratio and sweep separately, although the sweep is also contained implicitly in the section lift-curve slope of the swept wing.

By comparing equations (1) and (7) the plan-form parameter is seen to determine the lift-curve slope of swept wings in the same way as does the aspect ratio in the case of unswept wings. For this reason, and because the plan-form parameter reduces to the aspect ratio in the case of unswept wings with a theoretical (incompressible-flow, thin-airfoil) section lift-curve slope of 2π, the plan-form parameter may conveniently be regarded as an equivalent aspect ratio for certain purposes.

Since equation (1) and hence equations (5), (6), and (7) are based on lifting-line theory, they are valid only for wings of moderate and high aspect ratios. At low aspect ratios they yield results that are too high. A modification to equation (1) based on lifting-surface theory for elliptic wings has been introduced in reference 3. With a generalized interpretation of the results of reference 3 for the case of arbitary section lift-curve slope, the wing lift-curve slope of an unswept wing may be written as

$$C_{L_\alpha} = \frac{A}{A\sqrt{1 + \frac{4\eta^2}{A^2}} + 2\eta} c_{l_\alpha} \tag{9}$$

In reference 4 this relation has been modified for swept wings. The expression for the lift-curve slope obtained in this manner gives good results at low-subsonic speeds but does not yield the correct limit for wings of very low aspect ratio as given in reference 5, that is,

$$\lim_{A \to 0} C_{L_\alpha} = \frac{\pi}{2} A \tag{10}$$

or, in terms of the plan-form parameter,

$$\lim_{A \to 0} \frac{C_{L_\alpha}}{c_{l_\alpha} \cos \Lambda} = \frac{1}{4} F$$

However, if in equation (9) the value of the section lift-curve slope that appears both as such and in the factor η is corrected for sweep as in equation (3), equation (9) becomes

$$C_{L_\alpha} = \frac{A}{A\sqrt{1 + \frac{4\eta^2}{(A/\cos \Lambda)^2}} + 2\eta \cos \Lambda} c_{l_\alpha} \cos \Lambda \tag{11}$$

which does go to the correct limits given by equations (4) and (10).

With the plan-form parameter defined by equation (8), equation (11) may be rewritten either as

$$C_{L_\alpha} = \frac{F}{F\sqrt{1 + \frac{4}{F^2}} + 2} \left(c_{l_\alpha}\right)_{\text{Swept}} \tag{12}$$

analogous to equation (9) or as

$$\frac{C_{L_\alpha}}{c_{l_\alpha} \cos \Lambda} = \frac{F}{F\sqrt{1 + \frac{4}{F^2}} + 2} \tag{13}$$

analogous to equation (6). As in the case of equations (6) and (7), the expressions for the lift-curve slope given by equations (12) and (13) depend on the plan-form parameter F rather than the aspect ratio and the sweep separately. The fact that they serve to reduce the lift-curve slopes of wings with widely varying aspect ratios and angles of sweep to a single function is illustrated by figure 1, which shows the lift-curve-slope ratio $\frac{C_{L_\alpha}}{c_{l_\alpha} \cos \Lambda}$ of a wide variety of plan forms calculated by the method of reference 6 as a function of the plan-form parameter F. Also shown in figure 1 are a few points which correspond to lift-curve slopes measured in some of the wind-tunnel tests mentioned in references 4 and 7; these points are in good agreement with the line defined by equation (13).

Compressible subsonic flow.- The lift-curve slopes given by equations (12) and (13) can be corrected for subsonic compressibility effects by means of the three-dimensional Glauert-Prandtl rule. This rule states that the pressures and forces on a thin wing at a low angle of attack in compressible subsonic flow may be calculated by multiplying by $1/\sqrt{1 - M^2}$ the incompressible-flow pressures and forces on a fictitious wing which is obtained from the actual wing by stretching all its coordinates parallel to the free stream by the factor $1/\sqrt{1 - M^2}$ and which is set at the same angle of attack as the actual wing. According to this rule, equation (12) becomes

$$C_{L_\alpha} = \frac{1}{\sqrt{1 - M^2}} \frac{\frac{A\sqrt{1 - M^2}}{\eta \cos \Lambda_e}}{\frac{A\sqrt{1 - M^2}}{\eta \cos \Lambda_e}\sqrt{1 + \frac{4\eta^2 \cos^2 \Lambda_e}{A^2\left(1 - M^2\right)}} + 2} c_{l_\alpha} \cos \Lambda_e \tag{14}$$

where c_{l_α} is the incompressible-flow lift-curve slope of the section of the fictitious wing perpendicular to its leading edge or quarter-chord line, where η is based on this value of c_{l_α}, and where Λ_e is the angle of sweepback of the fictitious swept wing, so that

$$\tan \Lambda_e = \frac{1}{\sqrt{1 - M^2}} \tan \Lambda$$

and hence

$$\cos \Lambda_e = \frac{\sqrt{1 - M^2}}{\sqrt{1 - M^2 \cos^2 \Lambda}} \cos \Lambda \tag{15}$$

By combining the effective-velocity-component concept and the two-dimensional Glauert-Prandtl rule the value

$$\left(c_{l_\alpha}\right)_{\text{Compressible}} = \frac{1}{\sqrt{1 - M^2 \cos^2 \Lambda}} \left(c_{l_\alpha}\right)_{\text{Incompressible}} \tag{16}$$

may be obtained for the lift-curve slope of the section of a swept wing perpendicular to the leading edge or the quarter-chord line. (The same result may be obtained by an application of the three-dimensional Glauert-Prandtl rule, except that $\left(c_{l_\alpha}\right)_{\text{Incompressible}}$ refers to the fictitious rather than the actual wing.) If the values of $\cos \Lambda_e$ and of $\left(c_{l_\alpha}\right)_{\text{Compressible}}$ given by equations (15) and (16) are substituted in equation (14), equation (14) reduces to equation (12). Consequently, equations (12) and (13) are valid for compressible subsonic flow, provided that the section lift-curve slope c_{l_α}, which enters into equations (12) and (13) both directly and through the definitions of η and F, is that of the section of the actual wing perpendicular to its leading edge or quarter-chord line at a Mach number equal to $M \cos \Lambda$. If that value is unavailable, the quantity $\frac{1}{\sqrt{1 - M^2 \cos^2 \Lambda}}$ times the lift-curve slope of the same section in incompressible flow may be used instead.

In figure 1 several points represent lift-curve slopes measured at Mach numbers in the vicinity of 0.7 in the tests mentioned in references 4 and 7. These points are close to the line defined by equation (13) and follow the trend of the points representative of lift-curve slopes which were calculated theoretically or obtained in low-speed tests.

Coefficient of Damping in Roll

The coefficient of damping in roll may be obtained for swept wings of moderate or high aspect ratio in incompressible flow from reference 2, modified for lifting-surface effects in a manner similar to that employed for the lift-curve slope (see also reference 4), and corrected for compressibility effects by means of the three-dimensional Glauert-Prandtl rule. The resulting expression may be written as

$$C_{l_p} = -\frac{K^2}{8}\frac{F}{F\sqrt{1 + \frac{16}{F^2}} + 4}\left(c_{l_\alpha}\right)_{Swept} \tag{17}$$

or

$$-\frac{C_{l_p}}{c_{l_\alpha} \cos \Lambda} = \frac{K^2}{8}\frac{F}{F\sqrt{1 + \frac{16}{F^2}} + 4} \tag{18}$$

where K is the ratio of the ordinate of the effective lateral center of pressure in roll to one-half the semispan and is equal to twice the term $\frac{\bar{y}_{L'p}}{b/2}$ used in references 2 and 4. The factor K varies between about 0.92 and 1.09 as a function primarily of the taper ratio and, to a lesser extent, of the aspect ratio and the angle of sweep. The variation with aspect ratio can be expressed equally well as a variation with the plan-form parameter F or the aspect ratio proper in view of the smallness of the aspect-ratio effect. As F approaches ∞ the factor K approaches $\sqrt{\frac{2}{3}\frac{1 + 3\lambda}{1 + \lambda}}$ for tapered wings or 1 for elliptic wings; as F approaches 0 the factor K approaches 1 for all plan forms.

Equations (17) and (18) give values of C_{l_p} which approach the proper limit as F approaches 0 and ∞, that is,

$$\lim_{F \to \infty} C_{l_p} = -\frac{1}{12}\frac{1 + 3\lambda}{1 + \lambda}\left(c_{l_\alpha}\right)_{Swept}$$

and

$$\lim_{F \to 0} C_{l_p} = -\frac{\pi}{32} A$$

or

$$\lim_{F \to 0} \left(-\frac{C_{l_p}}{c_{l_\alpha} \cos \Lambda} \right) = \frac{1}{64} F$$

(See reference 8.)

As in the case of the wing lift-curve slope, the section lift-curve slope c_{l_α} that appears in equations (17) and (18) both directly and through the term η in F is that of the section of the actual wing perpendicular to its leading edge or quarter-chord line at a Mach number equal to $M \cos \Lambda$. Also, as in the case of the wing lift-curve slope, the coefficient of damping in roll and the ratio $-\frac{C_{l_p}}{c_{l_\alpha} \cos \Lambda}$ are functions only of the plan-form parameter F, except for the presence of the term K^2. The plan-form factor can therefore be used to plot the coefficients of damping in roll of a wide variety of plan forms (with a given taper ratio) and a wide range of subsonic Mach numbers on a single line.

Induced Drag

The drag of a wing is usually considered to consist of two parts, the profile drag and the induced drag. At low Mach numbers the profile drag is largely independent of aspect ratio and sweep. The induced drag associated with a given lift distribution depends only on the aspect ratio of the wing; it may be expressed in the form

$$\frac{C_{D_i}}{{C_L}^2} = \frac{1 + \delta}{\pi A} \tag{19}$$

where δ is a positive number, usually small compared with 1, which depends on the deviation of the spanwise lift distribution from an elliptical distribution.

If the lift-curve slopes and coefficients of damping in roll for a variety of plan forms and Mach numbers are plotted in the form of

$\dfrac{C_{L_\alpha}}{c_{l_\alpha} \cos \Lambda}$ and $-\dfrac{C_{l_p}}{c_{l_\alpha} \cos \Lambda}$, respectively, against the plan-form parameter F as suggested by equations (13) and (18), a parallel method of presenting information concerning the induced drag may be of interest. Such a method can be deduced by rearranging the terms of equation (19) to obtain the relation

$$\frac{\dfrac{\left(C_{D_i}\right)_{\alpha=1}}{c_{l_\alpha} \cos \Lambda}}{\left(\dfrac{C_{L_\alpha}}{c_{l_\alpha} \cos \Lambda}\right)^2} = 2\,\frac{1 + \delta}{F} \tag{20}$$

which suggests plotting the function of the induced drag defined by the left side of equation (20) against the plan-form parameter F.

DISCUSSION

Limitations of Plan-Form Parameter F

The wing lift-curve slope and the coefficient of damping in roll, both as fractions of the swept-wing section lift-curve slope, have been shown to depend only on the plan-form parameter F, in both incompressible and compressible subsonic flow, provided that the effects of taper are disregarded. The exact manner in which these fractions vary with the plan-form parameter is immaterial for the purpose of establishing the utility of the plan-form parameter, so that the limitations inherent in equations (13) and (18) are not necessarily limitations of the applicability of the plan-form parameter; nonetheless, a discussion of the limitations of these equations serves to shed some light on the applicability of the parameter F as well.

The lift-curve slope given by equations (12) and (13) has been derived from incompressible-flow lifting-line results with approximate lifting-surface corrections for elliptic wings together with a rational but approximate correction for sweepback. For tapered wings these equations give results which approach the proper limits as the aspect ratio approaches zero and infinity and which are known to be in good agreement with measured or more accurately calculated results for unswept and sweptback wings with taper ratios from 1:5 to 1:1.5. For sweptforward wings with taper ratio less than 1, for unswept and sweptback wings with taper ratio greater than 1, and, in general, for wings with spanwise lift distributions which differ greatly from an elliptical distribution, equations (12) and (13) cannot be expected to yield accurate values of the lift-curve slope in all cases (although the few points in fig. 1 representative of plan forms which are swept forward follow the pattern set by the other plan forms quite well). This limitation is a reflection of the fact that these equations are, in effect, concerned only with average pressures but imply a more or less elliptical spanwise lift distribution.

Equations (17) and (18) for the coefficient of damping in roll are derived in the same manner as equations (12) and (13) and are, therefore, subject to the same limitations. The coefficient of damping in roll is more sensitive to the spanwise distribution of the pressures and, hence, to the effects of taper, than is the lift-curve slope, as evidenced by the presence of the factor K^2 in equations (17) and (18). Consequently, although the lift-curve slopes of a wide variety of plan forms (within the aforementioned limitations) can be presented as a single line in a plot of $\frac{C_{L_\alpha}}{c_{l_\alpha} \cos \Lambda}$ against the plan-form parameter F, the coefficient of damping in roll plotted in a similar manner may require several lines for different taper ratios.

The foregoing discussion applies directly only to wings in incompressible flow; however, by means of the Glauert-Prandtl correction the results of equations (12), (13), (17), and (18) have been shown to be applicable to subsonic compressible flows as well. The assumptions inherent in the Glauert-Prandtl correction are those of small flow disturbances, that is, small angles of attack, small thicknesses, and, for Mach numbers near 1, low aspect ratios or high angles of sweep. By interpreting the term $\left(1 - M^2\cos^2\Lambda\right)^{-1/2} \left(c_{l_\alpha}\right)_{\text{Incompressible}}$ as being the lift-curve slope of the section perpendicular to the leading edge or quarter chord of the actual wing at a Mach number equal to $M \cos \Lambda$, as implied in equations (12), (13), (17), and (18), and using experimentally obtained values for this lift-curve slope in these equations, the limitations of the Glauert-Prandtl correction can be circumvented to a large extent. This manner of incorporating the section characteristics in the framework of the Glauert-Prandtl correction is equivalent to, but much more general than, method 1 of reference 7, which has been shown in reference 7 to be superior to a strict application of the Glauert-Prandtl correction. Nonetheless, for high angles of attack, for thick wings, and at Mach numbers near 1, the plan-form factor F and the equations for the lift-curve slope and coefficient of damping in roll given in the present paper must be used with caution.

The limitations of the plan-form parameter F in correlating aerodynamic characteristics can then be summarized as follows: The aerodynamic characteristics which may be expected to be amenable to correlation by means of the plan-form parameter are those which depend primarily on the average pressures and to a lesser extent on the spanwise distribution of the pressures. Aerodynamic characteristics which depend on the induced drag can be correlated by means of the plan-form parameter F, but no more satisfactorily than by means of the aspect ratio. The plan forms amenable to treatment by means of the plan-form parameter are those which are unswept or swept back with taper ratios less than 1; for other plan forms correlation of aerodynamic characteristics by means of the plan-form parameter may not be altogether satisfactory. The application of the plan-form parameter F is restricted to subsonic Mach numbers preferably not too near 1.

Applications of Plan-Form Parameter F

As has been shown, the lift-curve slope and the coefficient of damping in roll can, within certain limitations, be expressed as products of functions of the plan-form parameter F and the swept-wing section lift-curve slope $c_{l_\alpha} \cos \Lambda$. Consequently, by using the plan-form parameter F, the lift-curve slopes for a wide range of plan forms and subsonic Mach numbers can be plotted on a single line and the coefficients of damping in roll on a few lines, with taper as a parameter. This possibility of presenting a large amount of information concisely also facilitates the correlation of lift-curve slopes and damping-in-roll coefficients of widely differing plan forms and Mach numbers, as well as the interpolation between measured or calculated values of these aerodynamic characteristics. Similarly, with the correlation of measured or calculated results for these characteristics facilitated in this manner, fewer plan forms need be tested at fewer Mach numbers, or fewer calculations need be made to determine these characteristics for a given range of plan forms and Mach numbers. This statement is not to be construed as implying that, in making systematic tests of, or calculations for, a wide variety of plan forms, the plan-form parameter F need be held constant in different series of these tests or calculations; this procedure is neither necessary nor particularly desirable, inasmuch as the parameter F includes the section lift-curve slope which varies with Mach number, so that a given plan form has a given value of F at only a certain Mach number.

The potentialities of the plan-form parameter in analyzing and interpreting the physical phenomena which affect the lift, rolling moment, and associated aerodynamic characteristics have not as yet been explored. Some considerations involved in such an analysis are given herewith. Equations (12) and (17) indicate that the lift-curve slope and the coefficient of damping in roll of a swept wing are products of the swept-wing section lift-curve slope and functions of the plan-form parameter F which give the finite-span reduction to be applied to the swept-wing section lift-curve slope. Consequently, if the sweep and the plan-form parameter F, instead of the sweep and the aspect ratio, are considered as the two pertinent variables which, except for the taper ratio, serve to define any plan form, then the effect of sweep on these aerodynamic characteristics may be considered to be confined to the swept-wing section lift-curve slope, and the finite-span effect is a function only of the plan-form parameter.

This repartition of sweep and of finite-span effects is not entirely arbitrary. According to the effective-velocity-component concept (reference 1), the section characteristics of a swept wing depend on the chord perpendicular to the leading edge, but the finite-span effects depend on the induced downwash, which depends primarily on the spanwise location of the bound and trailing vortices. Therefore, the wings of a series of plan forms obtained by sweeping the wings back in such a manner as to maintain a constant span and constant chord perpendicular to the leading edge or quarter-chord line may be expected to have similar finite-span effects; according to equations (12) and (17) they should have the same lift-curve slopes and the same coefficients of damping in roll at low speeds, except for a factor of $\cos \Lambda$. For a plan form which is swept back in this way the factor $A/\cos \Lambda$ is maintained constant in the sweeping process.

This and several alternative ways of sweeping wings back are illustrated in figure 2. The wings with sheared chords are those in which the chords parallel to the plane of symmetry are constant; wings with rotated chords are those in which the chords perpendicular to the leading edge or quarter-chord line are kept constant. Sheared-span wings are those for which the span is invariant in the sweeping process; rotated-span wings, those for which the span varies as $\cos \Lambda$. The sheared-span - rotated-chord wing is the one mentioned in the previous paragraph; both it and the rotated-span - sheared-chord wing are shown in figure 2 by dotted lines, and the corresponding plan forms scaled up by the factor $\frac{1}{\sqrt{\cos \Lambda}}$ or down by the factor $\sqrt{\cos \Lambda}$ in order to obtain areas equal to those of the unswept wings, by solid lines. Both these wings appear to be more nearly related to the unswept wings than do either the sheared wing, which appears to be of larger span, or the rotated wing, which appears to be of smaller span.

Since both the aerodynamic argument concerning induction effects of swept wings and the corroborating geometric argument are largely intuitive in nature, any attempt at using the plan-form parameter F in the analysis and interpretation of the physical phenomena associated with the lift-curve slope and coefficient of damping in roll should be made with caution.

CONCLUDING REMARKS

On the basis of an approximate expression for the lift-curve slope and the coefficient of damping in roll for swept wings in compressible subsonic flow, the finite-span effects on these aerodynamic characteristics have been shown within certain limitations to be functions primarily of a plan-form parameter

$$F \equiv \frac{A}{\frac{c_{l_\alpha}}{2\pi} \cos \Lambda}$$

where A is the aspect ratio, c_{l_α}, the section lift-curve slope, and Λ, the angle of sweep. The use of this parameter in presenting concisely and in correlating aerodynamic characteristics which depend primarily on the average pressure rather than the spanwise pressure distribution has been discussed.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., February 1, 1951

REFERENCES

1. Jones, Robert T.: Wing Plan Forms for High-Speed Flight. NACA Rep. 863, 1947.

2. Toll, Thomas A., and Queijo, M. J.: Approximate Relations and Charts for Low-Speed Stability Derivatives of Swept Wings. NACA TN 1581, 1948.

3. Helmbold, H. B.: Der unverwundene Ellipsenflügel als tragende Fläche. Jahrb. 1942 der Deutschen Luftfahrtforschung, R. Oldenbourg (Munich), pp. I 111 - I 113.

4. Polhamus, Edward C.: A Simple Method of Estimating the Subsonic Lift and Damping in Roll of Sweptback Wings. NACA TN 1862, 1949.

5. Jones, Robert T.: Properties of Low-Aspect-Ratio Pointed Wings at Speeds below and above the Speed of Sound. NACA Rep. 835, 1946.

6. Weissinger, J.: The Lift Distribution of Swept-Back Wings. NACA TM 1120, 1947.

7. Murray, Harry E.: Comparison with Experiment of Several Methods of Predicting the Lift of Wings in Subsonic Compressible Flow. NACA TN 1739, 1948.

8. Ribner, Herbert S.: The Stability Derivatives of Low-Aspect-Ratio Triangular Wings at Subsonic and Supersonic Speeds. NACA TN 1423, 1947.

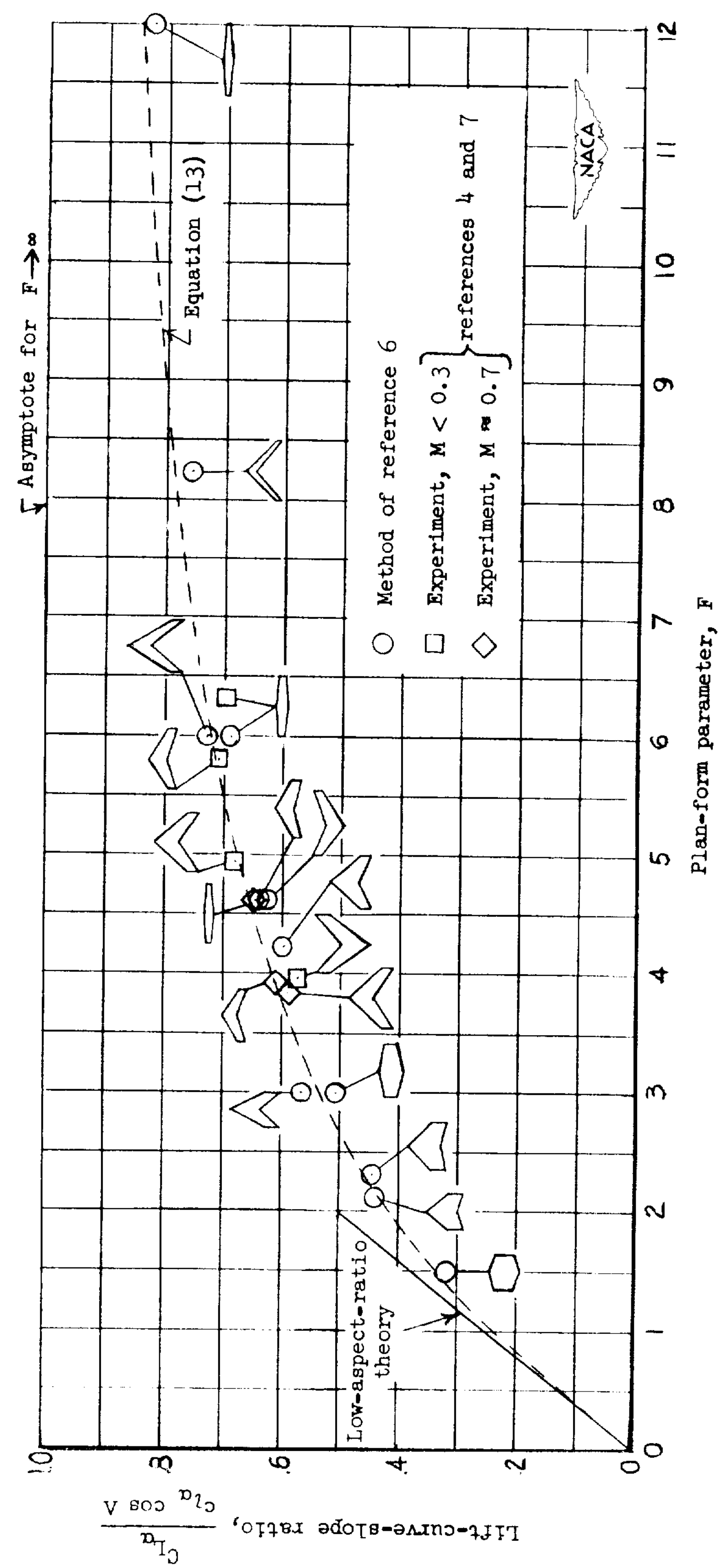
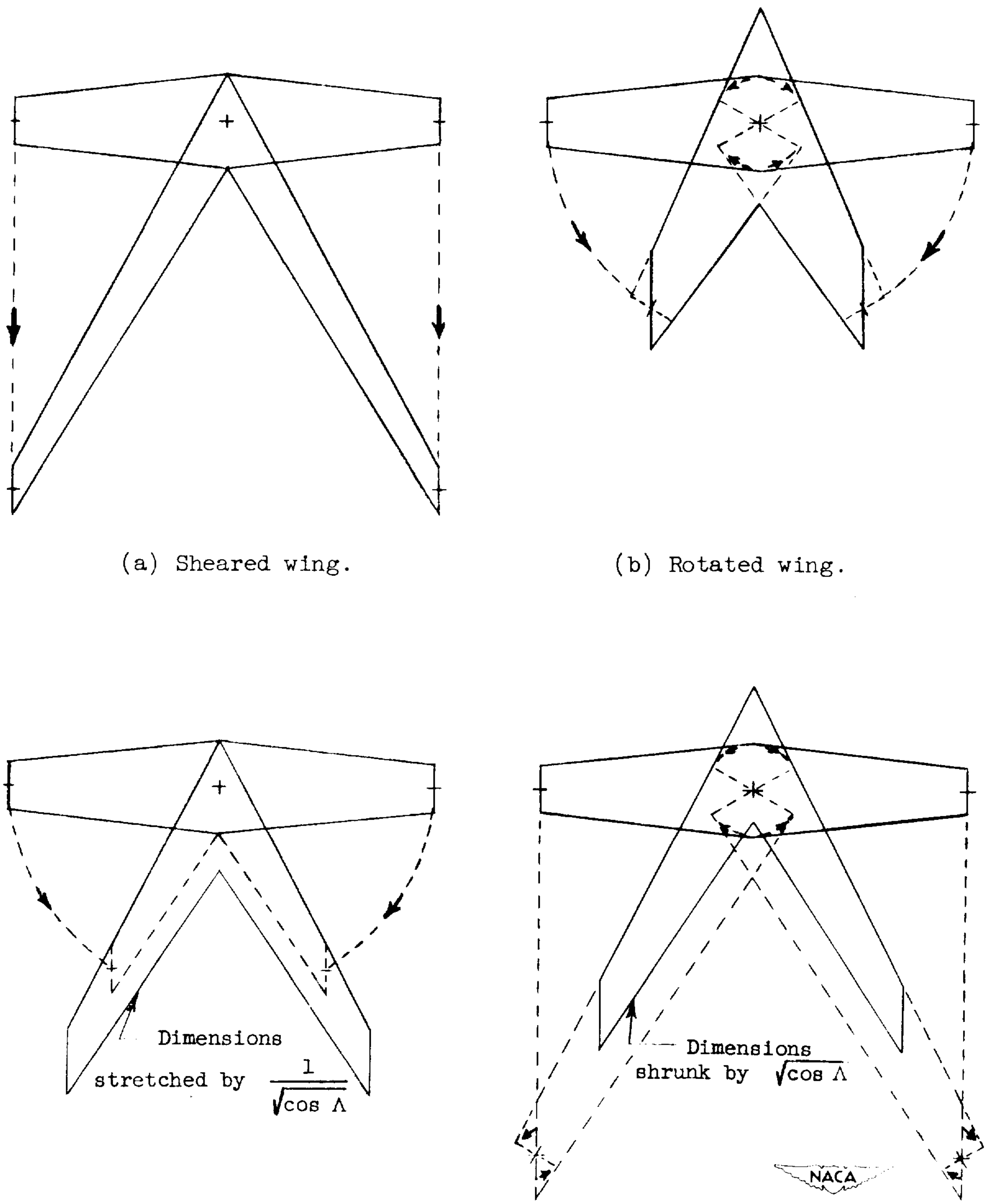


Figure 1.- Variation of lift-curve slope with plan-form parameter.



(a) Sheared wing. (b) Rotated wing.

(c) Rotated span, sheared chord. (d) Sheared span, rotated chord.

Figure 2.- Illustration of several ways of sweeping wings.