NASA TECHNICAL NOTE

NASA TN D-8060

NASA TN D-8060

2. 4/4

SIMPLIFIED LIFTING-SURFACE THEORY FOR FLAPS ON WINGS OF LOW AND MODERATE ASPECT RATIOS

Bradford H. Wick

Ames Research Center
Moffett Field, Calif. 94035

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1975

1. Report No.
NASA TN D-8060

2. Government Accession No.

3. Recipier

4. Title and Subtitle
SIMPLIFIED LIFTING-SURFACE THEORY FOR FLAPS ON WINGS OF LOW AND MODERATE ASPECT RATIOS

5. Report Date
September 1975

6. Performing Organization Code

7. Author(s)
Bradford H. Wick

8. Performing Organization Report No.
A-6108

9. Performing Organization Name and Address
NASA–Ames Research Center
Moffett Field, California 94035

10. Work Unit No.
505-06-31

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Note

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A modification of the simplified lifting-surface theory presented in NACA Report 1071 (ref. 1) for wings with deflected flaps is presented and evaluated. The modification is simple and straightforward in application, and is shown to overcome the deficiency in the theory that results in an underestimation of flap lift effectiveness for wings that have low or moderate aspect ratios.

17. Key Words (Suggested by Author(s))
Aerodynamics
Wings
Flaps

18. Distribution Statement
Unlimited

STAR Category – 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	10	$3.25

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NOTATION

The notation used in this report is the same as that of reference 1, with the following additions and modifications.

x_δ	distance behind leading edge of center of flap lift in two-dimensional flow, ft
Λ_δ	sweep angle of constant-percent-chord line corresponding to value of x_δ/c, deg
$\left(\frac{d\alpha}{d\delta}\right)_o$	two-dimensional lift-effectiveness parameter $(c_{\ell_\delta}/c_{\ell_\alpha})$

SIMPLIFIED LIFTING-SURFACE THEORY FOR FLAPS ON WINGS OF LOW AND MODERATE ASPECT RATIOS

Bradford H. Wick

Ames Research Center

SUMMARY

A modification of the simplified lifting-surface theory (ref. 1) for wings with deflected flaps is presented and evaluated. The modification is simple and straightforward in application, and is shown to overcome the deficiency in the theory that results in an underestimation of flap lift effectiveness for wings that have low to moderate aspect ratios.

INTRODUCTION

NACA Report 1071 (ref. 1) presents a simplified lifting-surface theory for determining the symmetric span-load distribution and lift coefficient that would result from the deflection of a trailing-edge flap on a wing of arbitrary plan form in subsonic flow. The theory was shown to provide a rapid and reasonably accurate means of calculating flap lift effectiveness for a range of wing plan forms. It was found, however, that the accuracy of the theory (as judged by comparisons with experiment) was a function of wing aspect ratio. For wings of moderate aspect ratio, calculated values of flap lift effectiveness were generally below the corresponding measured values by about 10 percent; and, for wings with smaller aspect ratios, the calculated values were low by as much as 20 percent. These results indicate a systematic deficiency in the theory. It was noted in reference 1 that the deficiency was probably the result of the assumption in the theory that the ratio of lift-per-unit-flap-deflection to the lift-per-unit angle-of-attack was independent of wing aspect ratio. Evidence was cited that suggested that the assumption was reasonably acceptable for all but very low aspect ratio wings. It appears from the results of the comparisons of experiment and theory presented in reference 1, however, that the range of applicability of the assumption is more limited than originally anticipated.

Means of overcoming this theoretical deficiency were examined. The effort resulted in a modification of the theory that is simple, straightforward in application, and that appears to improve the accuracy of predicted flap effectiveness for wings with low to moderate aspect ratios. The modified theory is presented and evaluated herein.

DEVELOPMENT OF THE MODIFIED THEORY

The theory of reference 1 is based on the simplified lifting-surface theory previously developed for unflapped wings (ref. 2). In the simplified lifting-surface theory, the lifting surface, in incompressible flow, is replaced by a lifting vortex at the quarter-chord line and seven control points are located along the three-quarter-chord line. The boundary condition specified for determining the vortex strength distribution is that there be no flow through the lifting surface at any of the control points. Thus, the slope induced in the flow at each control point is equated to the effective wing angle of attack at that point.

The aforementioned chordwise locations of the lifting vortex and the control points are based on two-dimensional wing theory. The lifting-vortex location corresponds to the two-dimensional center of lift resulting from a change in wing angle of attack. The choice of the three-quarter-chord line for the control points is based on the assumption of a two-dimensional lift-curve slope of 2π; a procedure is given in reference 2 for adjusting the chordwise location for a value of lift-curve slope other than 2π. (See reference 2 for further discussion of the choice of control-point location.)

In applying the boundary condition to a flapped wing, it was assumed in reference 1 that the flapped wing could be replaced by an unflapped wing having an effective angle of attack at each control point location equal to the product of the local flap angle and the two-dimensional lift-effectiveness parameter $(d\alpha/d\delta)_o$. It followed that the locations of the lifting vortex and the control points were as specified for the unflapped wing.

The modification presented here is based on the assumption that the unflapped wing will provide a better representation of the flapped wing if the chordwise locations of its lifting vortex and control points are based on the two-dimensional theory for flap lift rather than angle-of-attack lift. With this assumption, the local angles of attack of the equivalent unflapped wing are to be taken equal to the local flap angles, and the section lift-curve slope is to be taken equal to c_{ℓ_δ}, the rate of change of lift coefficient with flap deflection. These changes can be readily taken into account in the existing simplified lifting-surface theory.

The modified location of the lifting line is used to define the reference sweep angle (i.e., the effective quarter-chord sweep) to be used in applying the equations and charts of reference 1. The chordwise location of the lifting line is, from two-dimensional flap theory (ref. 3):

$$\frac{x_\delta}{c} = 0.25 + 0.25 \sin\phi \left(\frac{1 - \cos\phi}{\pi - \phi + \sin\phi}\right) \tag{1}$$

where

$$\cos\phi = -\left(1 - 2\frac{c_f}{c}\right)$$

The sweep of this lifting line is given by

$$\frac{\tan\Lambda_\delta}{\beta} = \frac{\tan\Lambda_{0.25c}}{\beta} - \frac{4}{\beta A}\left(\frac{x_\delta}{c} - 0.25\right)\left(\frac{1-\lambda}{1+\lambda}\right) \tag{2}$$

The control-point location for the unflapped-wing equivalent of the flapped wing is determined through use of the procedure developed in reference 2 to account for the effects on wing lift of values of c_{ℓ_α} that differ from the thin airfoil theory value of 2π. As noted in reference 2, simplified lifting-surface theory requires that the local control point be taken as the point behind the lifting line at which the flow is parallel to the wing chord plane. The distance of this point behind the lifting line was shown to be

$$\frac{h}{c} = \frac{c_{\ell_\alpha}}{4\pi} \tag{3}$$

For a value of c_{ℓ_α} of 2π, h/c equals 0.5, which places the control point at the three-quarter chord. Reference 2, in treating other values of c_{ℓ_α}, introduced the parameter κ, the ratio of the selected value of c_{ℓ_α} to the value of 2π. The control-point location is then given by

$$\frac{h}{c} = \kappa(0.5) \tag{4}$$

Thus, if the selected value of c_{ℓ_α} (e.g., an experimental value) is less than 2π, the control point should be located forward of the three-quarter-chord point; if greater, it should be located aft of the three-quarter-chord point.

For the flapped wing, replaced by the assumed equivalent unflapped wing, the control-point location is

$$\frac{h}{c} = \frac{c_{\ell_\delta}}{4\pi}$$

or

$$\frac{h}{c} = \frac{(d\alpha/d\delta)_o \, c_{\ell_\alpha}}{4\pi} \tag{5}$$

For c_{ℓ_α} equal to 2π,

$$\frac{h}{c} = (d\alpha/d\delta)_o \, (0.5) \tag{6}$$

If κ is assigned the value of $(d\alpha/d\delta)_o$, equation (6) becomes identical to equation (4). Thus the equations and charts of references 1 and 2 for unflapped wings are directly applicable to flapped wings on the basis of the theoretical approach proposed herein.

For values of c_{ℓ_α} other than 2π, the control-point location can be expressed as

$$\frac{h}{c} = \frac{(d\alpha/d\delta)_o \, c_{\ell_\alpha}}{2\pi} (0.5) \tag{7}$$

where

$$\kappa = \frac{(d\alpha/d\delta)_o \, c_{\ell_\alpha}}{2\pi} \tag{8}$$

and

$$\left(\frac{d\alpha}{d\delta}\right)_o = 1 - \left(\frac{\phi - \sin\phi}{\pi}\right) \tag{9}$$

An example, using the following values, will serve to illustrate the application of the modified theory.

1. aspect ratio, 3
2. sweep of quarter chord, 45°
3. plain flap with sealed gap
   a. flap chord-wing chord ratio, 0.30
   b. flap span-wing span ratio, 1.00

The charts given in figure 5 of reference 1 are used to determine the flap lift effectiveness. In the charts, flap lift effectiveness is presented in the form of the parameter $\beta C_{L_\delta}/\kappa_{av}$, as a function of the ratio of flap span to wing span; for various values of Λ_β, $\beta A/\kappa_{av}$, and λ. (The parameter κ_{av} is used to account for any spanwise variation of κ; for this example, κ is constant.) The effective sweep angle Λ_β for the present example is determined from equations (1) and (2) to be 43.0°. The value of κ is calculated from equation (9), and is equal to 0.66, the value of $(d\alpha/d\delta)_o$ when c_{ℓ_α} is equal to 2π. The resulting value of the aspect-ratio parameter $\beta A/\kappa_{av}$ is 4.55. From the pertinent chart of figure 5 of reference 1, a value of $\beta C_{L_\delta}/\kappa$ of 3.32 is obtained, from which a value of C_{L_δ} of 2.19 is calculated. The unmodified theory gives a value of C_{L_δ} of 1.82, a value that is about 17 percent lower.

DISCUSSION

To evaluate the effectiveness of the present modification of the simplified lifting-surface theory, values of the flap lift effectiveness parameter $d\alpha/d\delta$, calculated by use of the two versions of the theory, will be compared with experimental values, and with values given by lifting-surface theory. As previously noted, the unmodified version of the theory is based on the assumption that $d\alpha/d\delta$ is equal to the two-dimensional value $(d\alpha/d\delta)_o$. Reference 1, in recognition of the limitation of the assumption, states that: “An analysis based on lifting-surface theory indicates that the $d\alpha/d\delta$ of a wing does not vary appreciably with aspect ratio until aspect ratio becomes less than approximately 2; for $A=2$, $d\alpha/d\delta$ increases rapidly with decreasing aspect ratio until at $A=0$, $d\alpha/d\delta=1.0$.” Results presented below suggest that the increase becomes significant at an aspect ratio considerably higher than 2.

Comparisons With Experiment

Experimental and theoretical variations of dα/dδ with aspect ratio are compared in figure 1. The results are for wings that are unswept, have a taper ratio of 0.5, and are equipped with full-span, sealed-gap, plain flaps with a chord equal to 30 percent of the wing chord. The experimental data are from reference 4, and were obtained from wind-tunnel measurements on semi-span models mounted directly on a turntable mounted flush with the tunnel floor; the flaps were deflected to small angles. (These data were also used in reference 1 in the evaluation of the unmodified theory. The data are attractive for this purpose because of the number of wings investigated and the type of flap and flap conditions used; the semi-span mounting arrangement make the data less attractive, however, because of a possible adverse effect on the accuracy of some of the data, as will be discussed.) Also shown in figure 1 is the upper limit of the flap lift effectiveness that is given by the theory presented in reference 5.

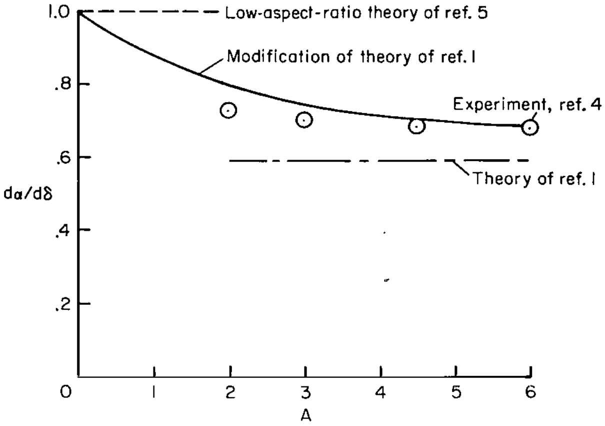

Figure 1.— Comparison of theoretical and experimental values of the flap lift-effectiveness parameter.

Both the modified theory and experiment indicate an increase in dα/dδ with decreasing aspect ratio, even at as high an aspect ratio as 6. Experiment shows a somewhat lower rate; the lower rate could have been the result of the use of a semi-span mounting arrangement that exposed the inboard end of each wing to the tunnel boundary-layer air flow. Even though the modified theory and experiment differ somewhat as to the rate of increase, it seems reasonable to conclude that the experiment shows the modified theory to be an improvement over the unmodified.

Reference 4 also presents experimental data for wings swept at angles of 35° and 45°. Comparisons of experiment and theory for these wings (not shown here) were found to differ from those for the unswept wings. The experimental values of dα/dδ for the swept wings showed essentially no variation with aspect ratio and were about equal to the two-dimensional; thus, they were in agreement with the unmodified theory. The accuracy of the swept wing data appears suspect because of the absence of any indication of an effect of aspect ratio on dα/dδ. This difference with the unswept wing data could have been caused by differences in the effect of the tunnel boundary-layer air flow over the wings.

Comparisons With Lifting-Surface Theory

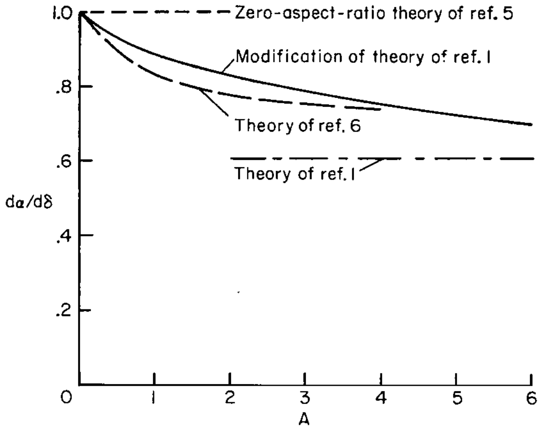

Figure 2.— Comparison of theoretical values of the flap lift-effectiveness parameter.

Figure 2 compares results given by the two versions of the simplified lifting-surface theory with results given by a lifting-surface theory for low-aspect-ratio wings (ref. 6). The results are for wings with unswept trailing edges, a taper ratio of 0.5, and 25 percent chord, full-span, sealed-gap, plain flaps. The modified version of the simplified theory is shown to be in good agreement with the lifting-surface theory of reference 6; both indicate values of $d\alpha/d\delta$, at low and moderate aspect ratios, that are considerably higher than the two-dimensional, the value assumed in the unmodified version of the simplified theory.

CONCLUDING REMARKS

A modification of a simplified lifting-surface theory for wings with deflected flaps has been presented and evaluated. The evaluation was made by comparing values of flap lift-effectiveness calculated by use of two versions of the theory with corresponding experimental values, and with values given by a lifting-surface theory for low-aspect-ratio wings. The modified theory was shown to provide an improvement in accuracy, particularly for wings of low to moderate aspect ratio.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035, May 30, 1975

REFERENCES

1. De Young, John: Theoretical Symmetric Span Loading Due to Flap Deflection for Wings of Arbitrary Plan Form at Subsonic Speeds. NACA Rep. 1071, 1952 (Supersedes NACA TN 2278).

2. De Young, John, and Harper, Charles W.: Theoretical Symmetric Span Loading at Subsonic Speeds for Wings Having Arbitrary Plan Form. NACA Rep. 921, 1948.

3. Glauert, H.: Theoretical Relationships for An Aerofoil with Hinged Flap. Aeronautical Research Committee, Reports & Memorandum, 1095, 1927.

4. Dods, Jules B., Jr.: Estimation of Low-Speed Lift and Hinge-Moment Parameters for Full-Span Trailing-Edge Flaps on Lifting Surfaces with and without Sweepback. NACA TN 2288, 1951.

5. De Young, John: Spanwise Loading for Wings and Control Surfaces of Low Aspect Ratio. NACA TN 2011, 1950.

6. Stone, Howard N.: Aerodynamic Characteristics of Low-Aspect-Ratio Wings with Various Flaps at Subsonic Speeds. Rep. No. AF-743-A-2, Contract No. AF 33(038)-17397, Cornell Aero. Lab., Inc., Jan. 1952.

NASA-Langley, 1975 A-6108

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

SPECIAL FOURTH-CLASS RATE
BOOK

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
451

U.S.MAIL

864 001 C1 U A 750822 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LABORATORY
ATTN: TECHNICAL LIBRARY (SUL)
KIRTLAND AFB NM 87117

POSTMASTER : If Undeliverable (Section 158 Postal Manual) Do Not Return

> *"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*
>
> —NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546