Engineering Notes

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Accumulated Span Loadings of an Arrow Wing Having Vortex Flow

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Nomenclature

A	= aspect ratio
a/ℓ	= notch ratio
b	= wing span
C_L	= lift coefficient
C_m	= pitching moment coefficient about $\bar{c}/4$
c	= local wing chord
$\bar{c}$	= mean aerodynamic chord
c_ℓ	= section lift coefficient
c_{ℓ_a}	= accumulated sectional lift coefficient
c_r	= wing root chord
LE	= leading edge
ℓ	= distance between the apex and tip along x-axis
M	= Mach number
TE	= trailing edge
x,y,z	= body axis coordinates
α	= angle of attack
ΔC_p	= difference between upper and lower surface pressure coefficients

Introduction

A WIDE range of modern aircraft designed for supersonic speeds employ highly swept-back and low-aspect-ratio wings with sharp edges. Flow separation occurs near the leading and tip edges of such wings at moderate to high angles of attack. The separation produces vortex sheets that roll up into strong vortices above the upper surfaces of the wings. Because of the low pressure connected with these vortices, additional lift is generated, which is responsible for the well-known nonlinear aerodynamic characteristics.

In this Note, the vortex flow over an arrow wing is theoretically investigated. The sectional lift coefficient and accumulated span loadings, which are important in determining the root bending moment, are calculated. The longitudinal stability variation is also estimated.

Method of Approach

The free-vortex-sheet method,[1,2] a numerical scheme developed by Boeing Aircraft Company under a contract with NASA Langley Research Center, is used in the present study. It is capable of predicting forces, moments, and surface pressures on sharp-edged wings with vortex flow. It is based on a three-dimensional inviscid flow model. It has been tested at NASA-Langley[3-5] and found to predict reasonably well the aerodynamic characteristics of low-aspect-ratio wings with pointed tips in moderate angle-of-attack range.

The free-vortex-sheet method provides spanwise pressures from which the chordwise pressure distributions, illustrated in Fig. 1, are obtained by interpolation. The figure corresponding to an angle of attack of 35 deg is shown here as a sample. Similar figures for other angles of attack are also drawn to obtain the necessary information, but they are not shown here. c_{ℓ_a} is calculated from the following equation by integrating with a planimeter the area under the curves in Fig. 1:

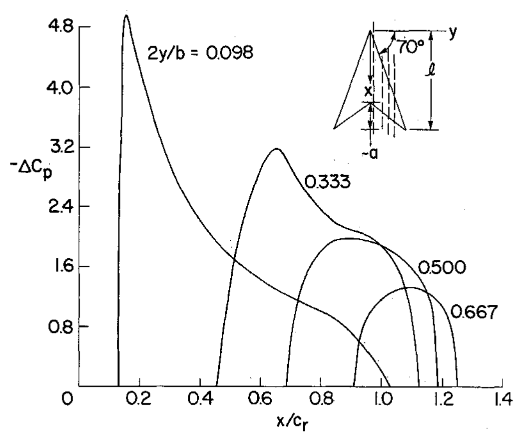

Fig. 1 Chordwise pressure distributions for $A = 2$ arrow wing, $a/\ell = -0.273$, $\alpha = 35$ deg, $M = 0$.

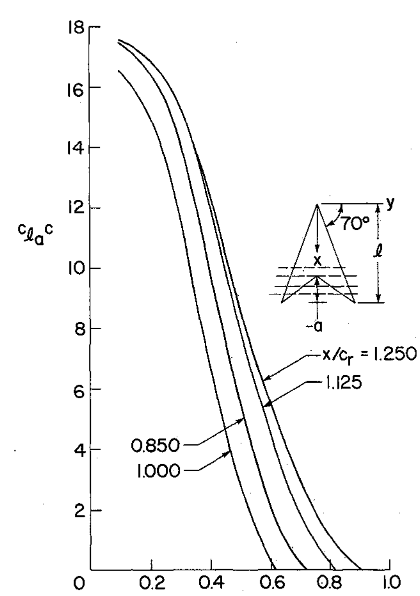

Fig. 2 Accumulated span loadings for $A = 2$ arrow wing, $\alpha = 35$ deg, $a/\ell = -0.273$, $M = 0$.

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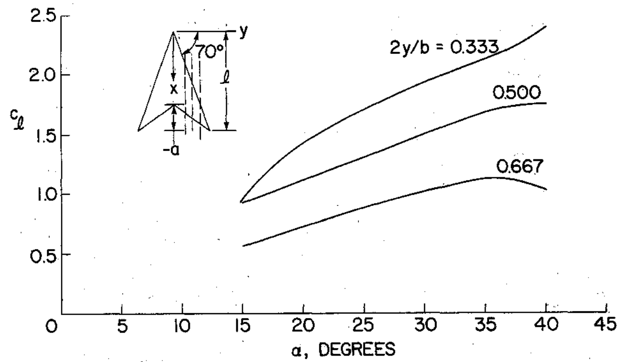

Fig. 3 Variation of sectional lift coefficient with angle of attack for $A = 2$ arrow wing, $a/\ell = -0.273$, $M = 0$.

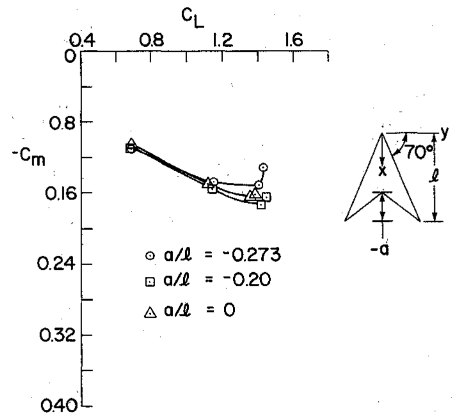

Fig. 4 Theoretical estimates of longitudinal stability variation for arrow wings, $M = 0$.

$$c_{\ell_a} = \frac{1}{c} \int_{x_{LE}}^{x'} - \Delta C_p \, dx$$

where x' is the distance along the plane of symmetry and varies between 0 and ℓ, depending upon the chordwise location at which c_{ℓ_a} is desired. c_ℓ is obtained from the same equation by letting $x' = x_{TE}$.

Results and Discussion

The accumulated span loadings at 35-deg angle of attack for an arrow wing with aspect ratio of 2 and notch ratio of -0.273 are shown in Fig. 2. These loadings are unusual in comparison with attached flow results. The slopes of the curves near the point of maximum local span are also important in that they do not tend to infinity as they do in an attached flow.

Figure 3 depcits the variation of sectional lift coefficient with the angle of attack for an arrow wing at three different spanwise stations. As can be noticed from the figure, the rate of growth of c_ℓ with respect to α increases inboard and decreases outboard at higher values of α. This may partially explain the pitchup tendency of arrow planforms evidenced in Fig. 4, which illustrates the pitching characteristics of wings with different notch ratios.

Conclusions

The accumulated span loadings obtained from the separated flow analysis for an arrow wing are unusual in comparison with attached flow results. Unlike the case of attached flow, the slopes of these loading curves near the point of maximum local span do not tend to infinity. The arrow wings show the pitchup tendency, which can be partially explained by the behavior of the sectional lift coefficient growth rate.

Acknowledgments

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References

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