Engineering Notes

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Modeling Effects on the Prediciton of Aerodynamic Performance of Double-Delta Wing

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Nomenclature

A	= aspect ratio
$b(x)$	= local wing span
$\bar{c}$	= mean aerodynamic chord
C_L	= lift coefficient
C_m	= pitching moment coefficient
C_p	= pressure coefficient
c_r	= wing root chord
FVS	= free vortex sheet
M	= Mach number
x,y,z	= body axis coordinates
α	= angle of attack
ΔC_D	= drag-due-to-lift coefficient

Introduction

MOST of the modern aircraft and missiles designed for supersonic speeds employ highly swept-back and low-aspect ratio wings with sharp or thin edges. Flow separation takes place near the leading and tip edges of such wings at moderate-to-high angles of attack. The separation induces vortex sheets that roll up into strong vortices above the wing surface. These vortices, being regions of low pressure, generate additional lift, which is responsible for the well-known nonlinear aerodynamic characteristics.

For designing high-speed aircraft, a detailed knowledge of separation-induced vortex flow is required to predict the performance under various operating conditions. As the attached flow theories are inadequate for these conditions, the designer presently has to rely on extensive and costly wind-tunnel tests for the required data. Therefore, attempts have been made over the years to develop analytical/numerical methods for predicting the aerodynamic characteristics of such aircraft. They have met with varying degrees of success. A brief summary of some of the more successful methods can be found in the recent work of Reddy.[1]

In studying these highly swept-back wings using analytical/numerical methods, different types of modeling may be employed for effecting economy in computational time or facilitating easier analysis. For example, in the investigation of a straked wing, one can model the flow on the wing with a single vortex on the entire leading edge or two separate vortices, one each on inboard and outboard leading edges. The type of modeling may affect the accuracy of the predicted results. In this work, an investigation is undertaken to determine such an effect on the aerodynamic performance of a double-delta wing. The method employed for the study, the wing analyzed, and the types of modeling are discussed in the next section.

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Method and Type of Modeling

The method employed for this investigation is the free vortex sheet (FVS) method[2,3] developed by Boeing Aircraft Company under a contract with NASA Langley Research Center. The method is based on a three-dimensional inviscid flow model. This is an advanced panel method using quadratic doublet distributions to represent the wing surface, rolled-up vortex sheet, and wake. It is capable of computing forces, moments, and surface pressures. It has been tested[1,4–8] and found to predict aerodynamic results satisfactorily up to moderate angles of attack for various configurations.

An 80/65 deg flat double-delta wing[9] is numerically investigated using the FVS method. It is modeled in three ways: 1) with two separate vortex systems, one on the inboard and the other on the outboard leading edges, as shown in Fig. 1; 2) with a single-vortex system all along the leading edge, as shown in Fig. 2; and 3) with separated flow on the inboard leading edge and attached flow on the outboard leading edge, as shown in Fig. 3. The predicted results are analyzed in the next section.

Results and Discussion

The theoretical results obtained in the three cases are compared with the experimental data[9] for the double-delta wing in Fig. 4. The double-vortex modeling provides better agreement with the data as expected, in terms of longitudinal aero-

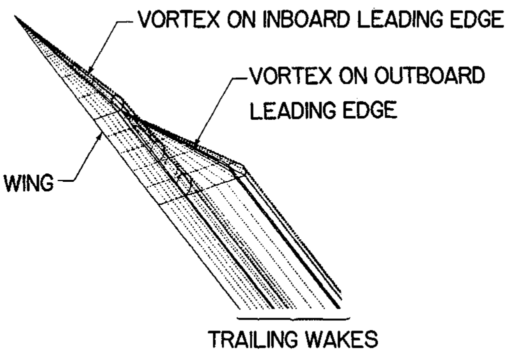

Fig. 1 80-deg/65-deg flat double-delta wing with two separate vortex systems, one along inboard and other along outboard leading edges.

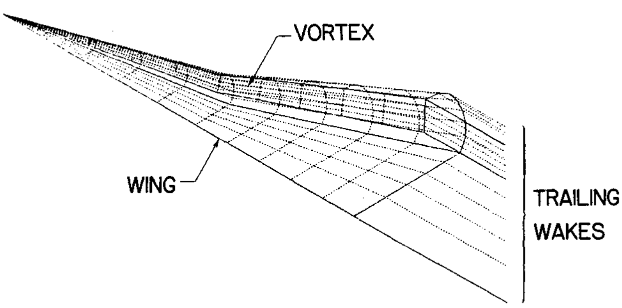

Fig. 2 80-deg/65-deg flat double-delta wing with single vortex system along entire leading edge.

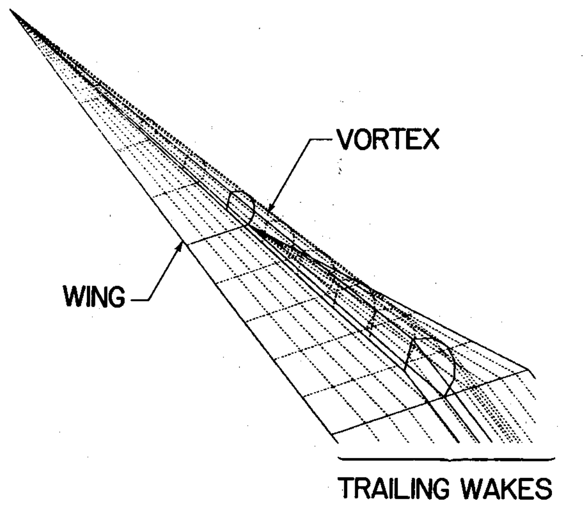

Fig. 3 80-deg/65-deg flat double-delta wing with vortex system along inboard leading edge only.

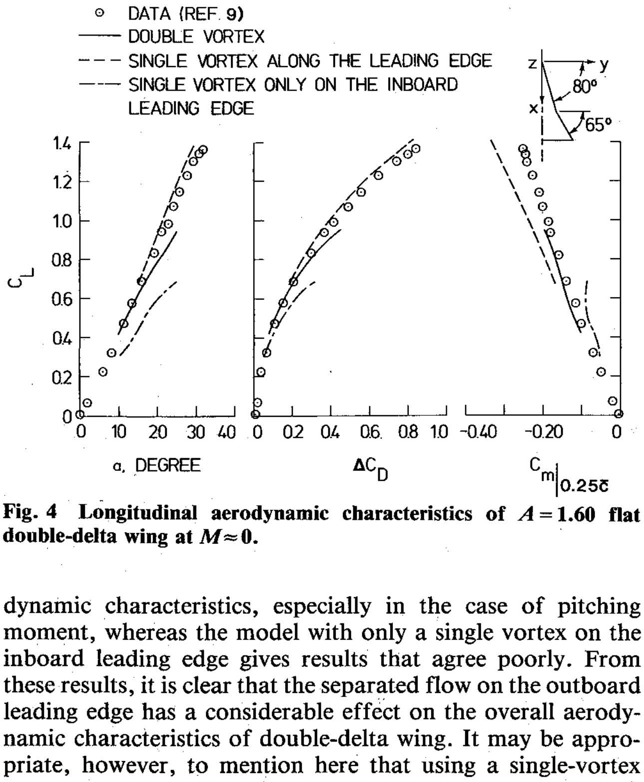

Fig. 4 Longitudinal aerodynamic characteristics of $A = 1.60$ flat double-delta wing at $M \approx 0$.

dynamic characteristics, especially in the case of pitching moment, whereas the model with only a single vortex on the inboard leading edge gives results that agree poorly. From these results, it is clear that the separated flow on the outboard leading edge has a considerable effect on the overall aerodynamic characteristics of double-delta wing. It may be appropriate, however, to mention here that using a single-vortex system all along the entire leading edge may be adequate modeling for the double-delta wing of this study. Moreover, the computational time required for the convergence of the results in the case of a single vortex all along the leading edge is less than that in the case of double-vortex modeling. Of course, the computational time for the model involving a vortex system on the inboard leading edge only is the least and so also is the accuracy of the predicted results.

Figure 5 illustrates the converged vortex sheet shapes for the three types of modeling at two chordwise stations and 15 deg angle of attack. It shows that vortex sheet sizes become bigger as the chordwise distance from the apex increases.

The spanwise pressure distributions at different chordwise stations and an angle of attack of 15 deg for the three cases of modeling studied are shown in Fig. 6. The pressures on the bottom surface are essentially the same in all three cases, whereas upper-surface pressures differ significantly in terms of magnitude and peak locations. The two-vortex system modeling gives two pressure peaks in the aft region of the wing, as expected. In the case of modeling with separated flow on the inboard leading edge and attached flow on the outboard leading edge, the pressure is very high at the outboard leading edge, in accordance with the theory.

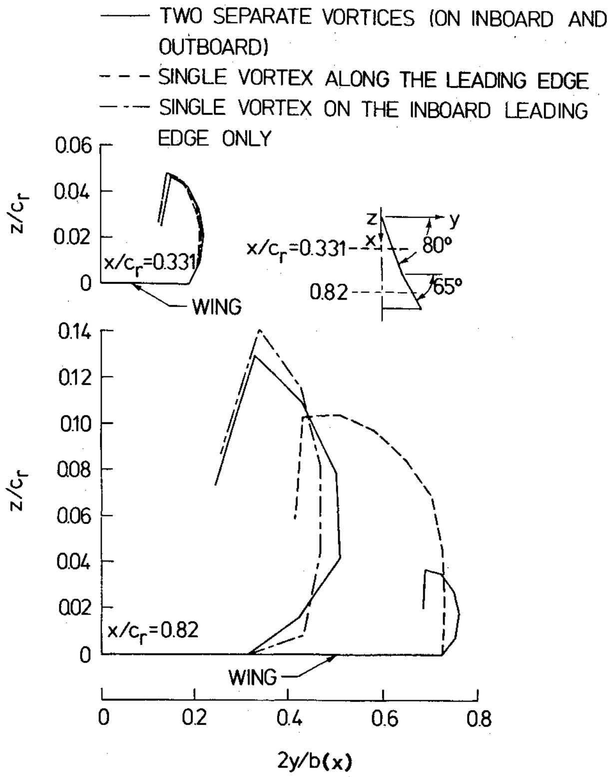

Fig. 5 Converged shapes of vortex systems for three types of modeling of $A = 1.60$ flat double-delta wing at $\alpha = 15$ deg and $M \approx 0$.

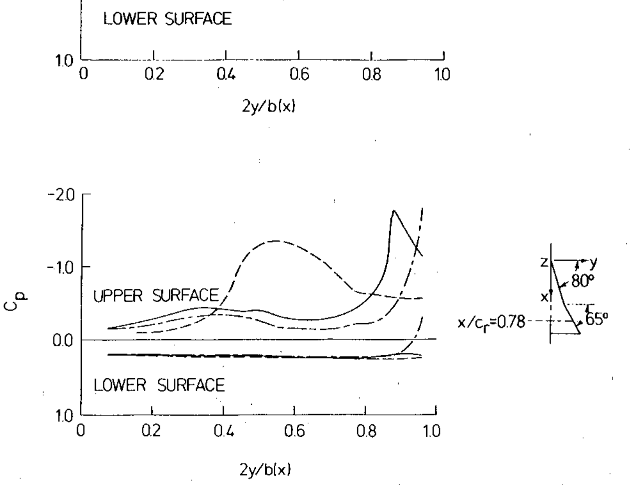

Fig. 6 Effect of vortex system modeling on spanwise pressure distributions for $A = 1.60$ flat double-delta wing at $\alpha = 15$ deg and $M \approx 0$.

Conclusions

An 80-deg/65-deg flat double-delta wing is numerically investigated using the free vortex sheet method. The vortex system on the leading edge is modeled in three ways and the effect of the type of modeling on the aerodynamic performance of the wing is studied. The predicted results are compared with the experimental data.

The modeling that employs two separate vortex systems, one each on inward and outward leading edges, predicts aerodynamic characteristics that are in best agreement with the experimental data as expected, especially in the case of pitching moment. However, the model with a single-vortex representation all along the leading edge is capable of adequately estimating the aerodynamic characteristics for the double-delta wing studied and takes less computational time. The third type of modeling, which involves separated flow on the inboard leading edge and attached flow on the outboard leading edge, provides the results that are in least agreement with the data and, of course, takes the least amount of computational time.

Acknowledgments

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We apologize that this issue was mailed to you late. As you may know, AIAA recently relocated its headquarters staff from New York, N.Y. to Washington, D.C., and this has caused some unavoidable disruption of staff operations. We will be able to make up some of the lost time each month and should be back to our normal schedule, with larger issues, in just a few months. In the meanwhile, we appreciate your patience.