Because of the complex wake structure, it was not possible to determine the vortex shedding frequency when the airfoil is pitch oscillated. Since a mirror image flow behavior (between pitch up and pitch down) must take place, the shedding of the valley region vortex is likely to be associated with the seepage of fluid at the start of pitch down.

At low reduced frequency ($K = 0.75$), the flow behavior is quite similar to the moderate reduced frequency case discussed earlier. The only difference is that the bound vortex is located downstream of the trailing edge at the tip region. Thus, the bound vortex (line) is aligned with the sawtooth trailing edge in this case. A slightly different vortex system results at high reduced frequency ($K = 2.25$). In this case, a single connected bound vortex is not formed as was the case for the lower reduced frequencies. As was the case for the other reduced frequencies, the vortical motion first forms in the valley region and then spreads to the tip region. However, the vortex does not reach the tip before the oscillation completes the pitch-up phase. This situation is shown in Fig. 3. When the airfoil begins to pitch down (i.e., moving towards $-\alpha$), the vortex at the valley region is shed immediately, whereas a sort of disturbance remains over the tip region of the extension until $\alpha \approx -0.3$ deg.

Figure 4 shows the results when the oscillation amplitude is increased to $\Delta\alpha = \pm 4$ deg. Two bound vortices are formed in this case, a primary vortex near the sawtooth trailing edge and a secondary vortex on the main airfoil section. The primary bound vortex is shed immediately when the airfoil begins to pitch down (i.e., moving towards $-\alpha$). However, the secondary bound vortex remains over the airfoil and continues to disturb dye streaks for a short time duration.

Summary

The flow behavior near the trailing edge of an oscillating airfoil was investigated using dye flow visualization. With the sawtooth trailing-edge configuration, a seepage of fluid during a change in pitch direction resulted in the formation of a circulatory motion at the valley region. This circulatory motion then spread to the tip region. The resulting bound vortex was generally aligned parallel to the sawtooth trailing edge. When the pitch direction was changed, the vortex over the valley region was shed immediately, whereas the vortex over the tip region remained over the airfoil for a short time duration. The resulting shed vortex structure (during the oscillation peaks) was quite complex and three dimensional. These results provide insight concerning the bound and shed vortex structure due to trailing-edge modifications.

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Vortex-Wake Characteristics of a Supersonic Transport Wing Planform at Mach 2.5

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Introduction

THE renewed interest in the supersonic transport program has created a need for information on vortex-wake characteristics of airframe components in supersonic flows to address a variety of design and operation issues. However, experimental information of this type is quite sparse even though it has been pointed out in the literature as an important factor in evaluating the environmental impact of a supersonic transport fleet.[1–5] To broaden the existing database and to aid in the development of supersonic vortex-wake models and/or code validation, measured vortex-wake decay and trajectory characteristics of a generic supersonic transport planform in a Mach 2.5 stream are presented.

Experimental Setup

The experiments were performed in Polytechnic University's blowdown tunnel in its Mach 2.5 configuration. A half-wing model with a planform geometry closely following that of the NASA baseline 70–45 deg cranked arrow configuration[6] was tested at an angle of attack of 5 deg. The root chord and span of the half-wing model are 163 and 86 mm, respectively. Detailed information on the experimental setup, facility, and data acquisition is found in Ref. 7. Test results presented herein were carried out at a Reynolds number of 4.04×10^6 based on the mean aerodynamic chord of 95 mm.

Results and Discussion

A panoramic shadowgraph view of the flowfield shows three distinct structures in the vortex wake (Fig. 1). Features 5 and 7 are the wing-tip and leading-edge vortex cores, respectively. Based on data to be presented, feature 6 is a swirling structure as well. The shadowgraph illustrates that the core diameters for both the tip and leading-edge vortices remain virtually unchanged, suggesting that the diffusion effect for the vortices is small and are therefore likely to persist very far downstream. Meanwhile, compared with the vortices, feature 6 has diffused a great deal more within the same visualized area.

Figure 2 shows the results of a surface oil flow test that was made to help clarify the cause of flow feature 6 in the shadowgraph. The oil accumulation line along the leading edge of the 70-deg section is the outer edge of the leading-edge vortex,[8] whose continuing development over the delta planform is interrupted by the flow at the root chord of the outboard planform. This interaction is believed to be responsible for feature 6 in the vortex wake in Fig. 1. Additional discussion on the surface oil flow results is documented in Ref. 7.

A vertical survey through feature 6 with an uncalibrated five-hole cone probe was made at the $X/C_{\text{tip}} = 2.1$ location (where the tip chord $C_{\text{tip}} = 30$ mm and X is the downstream distance measured from the trailing edge of the wing tip) to determine the nature of the flow.[7] It was found that the structure is a swirling flow rotating in the counterclockwise direction (with respect to an observer in front of the model looking downstream). Meanwhile, based on physical intuition as well as experiments on unswept and delta wings,[8–12] both the wing-tip and the leading-edge vortices are known to be swirling in the clockwise direction. However, the swirling structure

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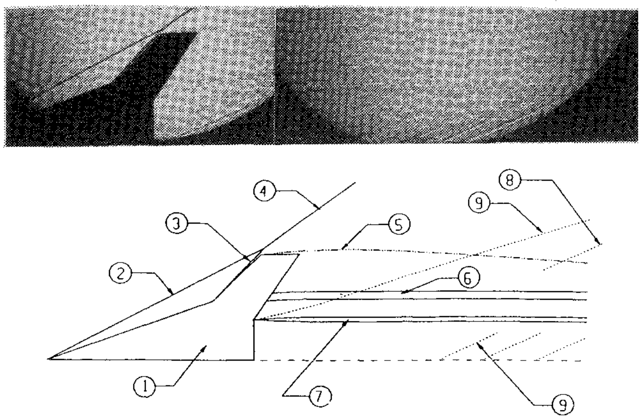

Fig. 1 Shadowgraph of the vortex-wake flow: 1 = half-wing model, 2 = leading-edge shock wave, 3 = shock pattern of the outer panel, 4 = interaction of 2 and 3, 5 = wing tip vortex, 6 = swirling wake-like structure, 7 = leading edge vortex, 8 = shock wave reflecting off window, and 9 = weak disturbances.

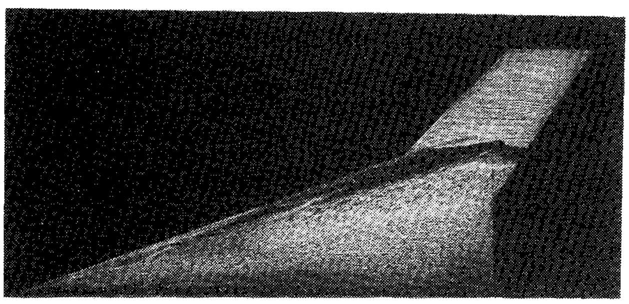

Fig. 2 Surface oil pattern of the model.

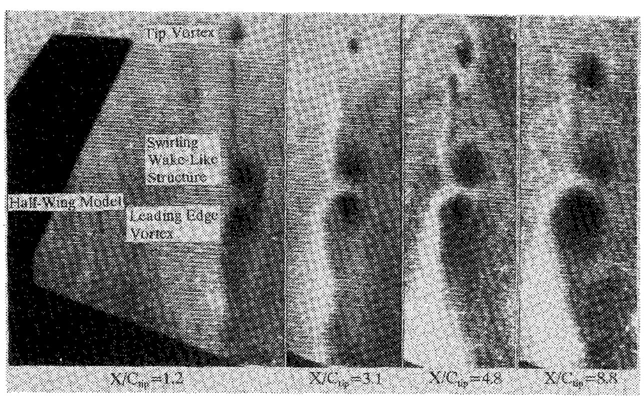

Fig. 3 Vapor screen photographs.

differs in appearance from that of the vortices in that it has a very spotty look when revealed by shadowgraphy and it appears to decay much quicker than the two vortices.

Vapor-screen visualization using a ruby laser sheet was performed at the $X/C_{tip} = 1.2, 3.1, 4.8$, and 8.8 downstream locations. Figure 3 shows the light sheet photographs (observer in front of the model looking downstream obliquely), in which considerable alteration of the vortex-wake shape may be observed. These photographs provide an alternative viewing perspective to once again confirm that three predominant structures were generated by the wing. Moreover, they show that the outer portions of the vortex-wake system become progressively brighter as the result of continuously entraining the surrounding seeding particles over a broad region.

Pitot pressure measurements with uncertainty of ± 1.86 KPa were made at the $X/C_{tip} = 1.3, 7.8$, and 16.3 downstream locations. The time-averaged pitot pressures normalized by tunnel chamber pressure were used to generate the contour plots in Fig. 4. The results indicate that the wing-tip vortex trajectory alters noticeably while being convected downstream. The leading-edge vortex trajectory on the other hand shows no alteration. The swirling wakelike structure appears to have been upwashed by the neighboring leading-edge

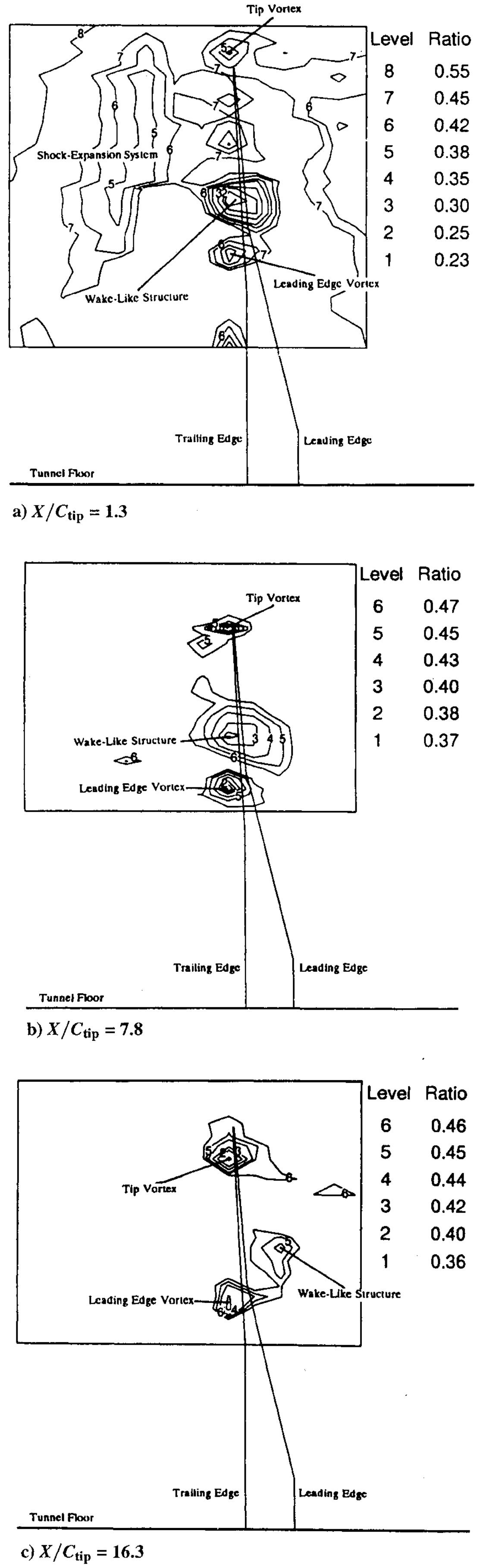

Fig. 4 Pitot pressure contours shown to scale. Boxed region outlines survey limits, and projection of half-wing on the measurement plane is superimposed for reference.

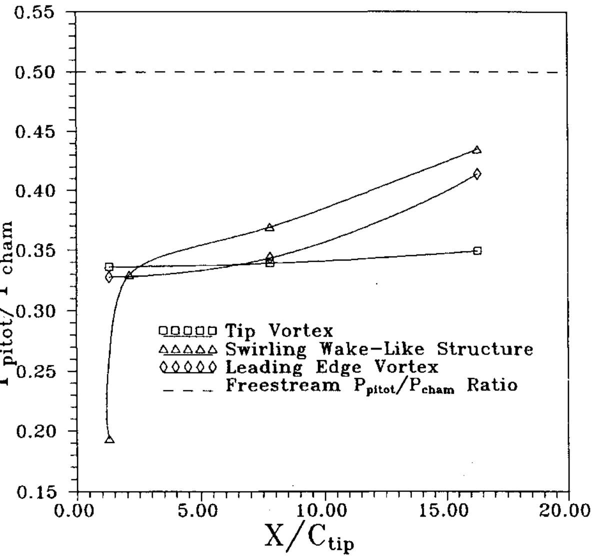

Fig. 5 Minimum pitot pressure characteristics of the three swirling structures in the vortex wake.

vortex, which itself exhibits downwash. Figure 5 summarizes the decay characteristics of the three predominant structures in the vortex wake as extracted from the pitot pressure surveys. The tip vortex and the leading-edge vortex start out at about the same pitot pressure ratio, but the latter starts relaxing towards the freestream value by $X/C_{\text{tip}} = 7.8$. The swirling wakelike structure initially has a very low pitot pressure reading but relaxes rapidly as it convects downstream. The pitot pressure readings of the tip vortex are virtually unchanged over the entire surveyed range of 16.3 tip chords, which suggests that tip vortices act as flow confinement structures that suppress diffusion. This may result in the transport of entrained passive contaminants to larger downstream distances than usual wake processes would suggest. The nature of the diffusion of these vortex flows is of concern for supersonic transport operations and may also affect the stealthiness of supersonic aircraft designs.

A rake of seven common stainless steel sewing needles with 6.35-mm spacing and pointing in the freestream direction was positioned vertically so as to lie in the plane of the three swirling structures. Shadowgraphy was used to record the Mach cones generated by the needles to provide an estimate of the axial Mach number distribution.[7,9] When the needles were placed immediately behind the model, the waves generated in the wakelike structure (feature 6) showed larger wave angles compared with those generated outside the swirling structures.[7] This qualitatively indicates that there is a wakelike axial Mach number profile in feature 6. However, when the needles were placed at the $X/C_{\text{tip}} = 2$ location, all of the waves generated by the needles appear unrefracted, and the wave angles are all essentially equivalent[7] (i.e., wave angles are within 1 deg of each other) to the freestream Mach angle.[7] Therefore, within the resolution of the photographs, the vortex wake appears to be convected downstream at the freestream Mach number very shortly after its generation. With the assumption of constant stagnation temperature in the vortex wake, the axial velocity will then be that of the freestream, suggesting that the condition of the Trefftz plane[13] is met just a short distance downstream. This implies that the application of an incompressible roll-up model[2] could be a viable approach for calculating the vortex-wake evolution from supersonic aircraft, provided that a realistic wing loading on the planform is available to initialize the subsequent vortex-wake computation.

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Dynamic Buckling of Long Thin Elastic Plate Under Rapidly Applied Shear Loading

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Introduction

THIN-WALLED structures are widely used in construction, shipbuilding, aircraft, spacecraft, etc. Many of their elements are, in fact, thin elastic plates. They transmit out-of-plane forces as well as in-plane (membrane) forces to the neighboring elements of the structure. That is why the buckling analysis is very important for their design. It is well known that in the classical theory of stability the loads are considered to be applied statically (i.e., gradually and slowly). But in reality the dynamic loads are predominant (they may be time dependent or time independent). There are three approaches for the analysis of the dynamic stability[1]: equations of motions approach (Budiansky–Roth), total energy-phase plane approach (Hoff–Hsu), and total potential energy approach (Hoff–Simitses). The dynamic stability of plates has been discussed by many authors,[2–5] but they considered mainly the case of compressive loading. Some of them considered also the case of shear loading,[3,5,6] but either the deflections were assumed to be small,[3] or in the case of large deflections only a rectangular plate with small difference between the sides was analyzed,[5] or in the case of a long thin elastic plate the changes in the slope of the nodal lines and in the length of the half-waves with the increase of loading were not taken into account.

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