Aircraft Wing-Tip Vortex Modification

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Introduction

IT is well known that a finite-span lifting wing sheds a trailing vortex sheet which rolls up rapidly downstream of the aircraft to form two, oppositely rotating vortices. A few chord lengths downstream of the wing, almost all the measurable circulation of the vortex system is contained in the tip vortices.[1] These vortices persist for some time after their generation and pose a hazard to other aircraft that penetrate them.[2,3] A number of techniques have been tried to modify and reduce the lift induced vorticity such as the addition of end plates, a body of revolution, a flow through nacelle, or an engine at the wing tip,[4] the use of drooped tips,[5] and downstream injection into the vortex core.[6,7] In this Note, the results of a low speed experimental wind tunnel study of the modification of a wing tip vortex using a tip mounted, upstream facing jet are discussed.

Experimental Setup

The wing-tip vortex alleviation experiments were performed in the MIT Wright Brothers 7 ft x 10 ft closed return subsonic wind tunnel. The tip vortex was produced by a rectangular wing (7.75 in. chord, 31.5 in. span, NACA 0012 airfoil) mounted vertically on the floor of the tunnel with the wing angle of attack fixed at 8°. The jet exhausted forward tangentially to the wing tip from a $\frac{5}{16}$ i.d. tube located at the 37.5% chord location and the flow rate of air to the jet was measured with a Fisher-Porter Flowrator Meter. The vorticity of the vortex was measured by a vorticity meter[1] located seven chord lengths downstream of the wing trailing edge and in line with the wing tip. A moveable smoke generator unit was used to obtain flow visualization photographs of the vortex with and without upstream jet injection.

Experimental Results

Smoke flow visualization photographs (Fig. 1) show substantial enlargement of the vortex with increases in the jet momentum coefficient (essentially a thrust coefficient) $C_J = J/qA$, where J is the jet momentum, q the freestream dynamic pressure and A the wing area. The vortex diameter increases by a factor of two as the momentum coefficient is increased from zero to $C_J = 0.0075$ and by a factor of four for $C_J = 0.140$. Previous investigations[8,9] of isolated upstream facing jets have shown that the jet penetration and plume size are directly correlated by the jet momentum coefficient.

Vorticity meter data are shown in Fig. 2 as a function of the jet momentum coefficient. The maximum observed rpm and the average rpm measured over a 10 sec interval are graphed in Fig. 2. The maximum rpm was obtained from the minimum time between pulses as observed on an oscilloscope display while the average was provided by an electronic counter. The vortex intensity is reduced nearly to zero for a jet momentum coefficient of $C_J = 0.0075$.

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Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interactions; Subsonic and Transonic Flow; Aircraft and Component Wind Tunnel Testing.

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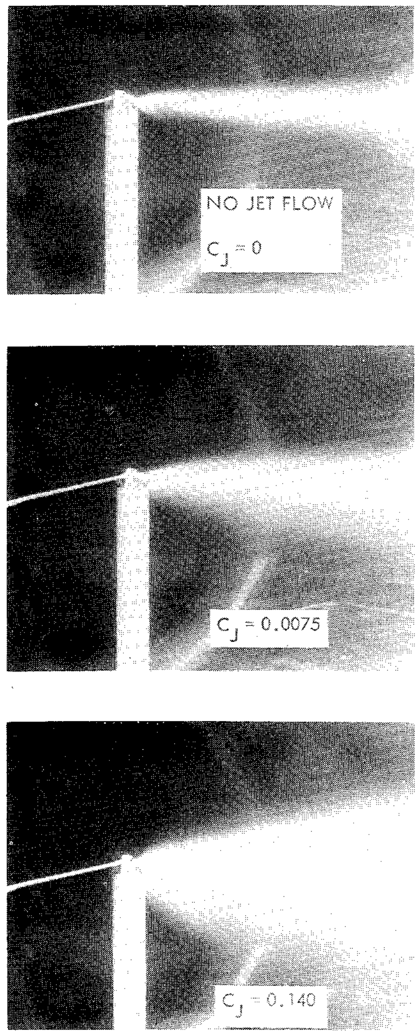

Fig. 1 Smoke injection into vortex.

Discussion of Results

A comparison of the effectiveness of using an upstream and a downstream facing jet to modify the vorticity of the wing tip vortex is made in Fig. 3. Data from the present experiment is compared with that of Kantha[7] et al. and shows that the upstream facing jet is more effective in reducing the vorticity at the same value of the jet momentum coefficient C_J than the downstream facing jet.

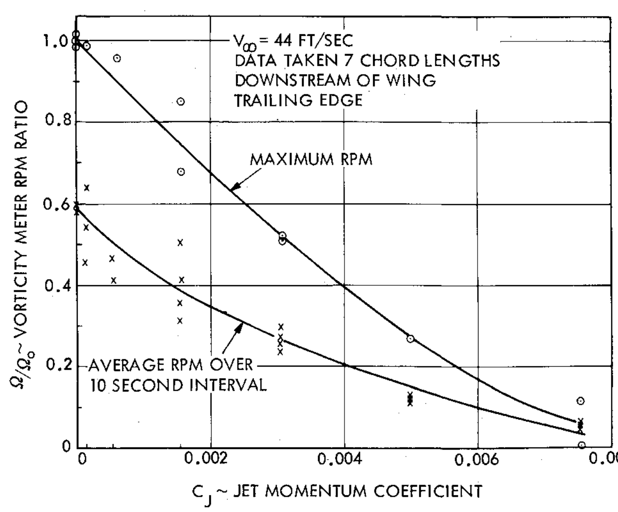

Fig. 2 Effect of forward facing jet on vortex strength.

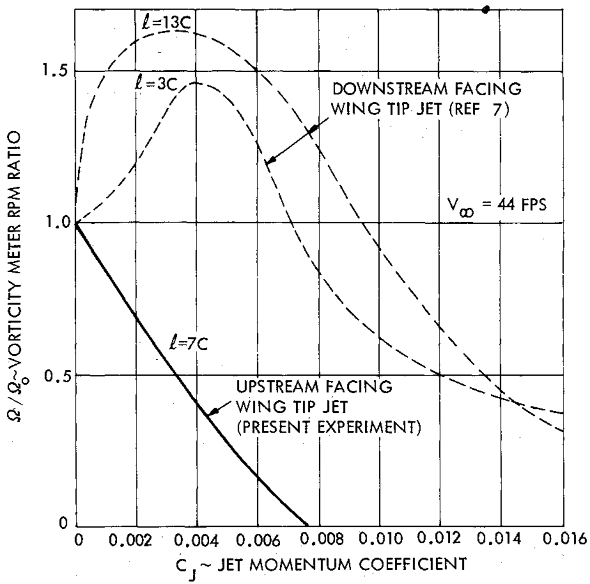

Fig. 3 Comparison of the effectiveness of upstream and downstream facing jets in modifying a wing tip vortex.

The subscale data for forward facing jets shown in Fig. 2 has been scaled (by preserving the value of the jet momentum coefficient) to full scale jet aircraft to determine the jet thrust required to dissipate the wing tip vortex and indicates that complete dissipation of the tip vortex in the near field to the aircraft requires but a few percent of the total installed aircraft thrust.

Much additional work is required to evaluate the use of tip mounted forward facing jets for vortex modification. The effect of the jet on the wing load distribution and performance as well as on the subsequent growth of the vortex in the region far downstream from the aircraft must be ascertained. However, since the forward facing jet interaction is unsteady, the use of a forward facing, tip mounted jet holds promise that instabilities may be introduced into the vortex core which may lead to earlier vortex breakdown.

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