Pressure and Velocity Measurements in a Three-Dimensional Wall Jet

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Abstract

ONE of the present designs being investigated for increasing the lifting capabilities of aircraft is termed upper surface blowing. The exhaust gases of the jet engine are directed along the upper surface of the wing and, when attached, are turned by the wing's upper surface and trailing edge flaps. It has been found that a significant increase in lift is realized, but the loading that the structure must endure is greatly increased. Hence, there exists a need for more information about the flowfield for this three-dimensional wall jet.

Several previous reports[1-3] have dealt with the experimental investigation of the near-field region of a three-dimensional wall jet.

The present paper emphasizes two areas. First, the effects on the flowfields of varying the ratio of the velocity at the exit plane of the nozzle to the outer tunnel flow are reported. Second, pressure-velocity correlations are taken and some trends are discussed. Emphasis is placed on comparing the coherence between the fluctuating pressure and velocity fields at various locations in the different flow configurations.

Contents

The arrangement of the confining surfaces, the flap, and the flat plate are shown in Fig. 1. The flow system consists of a jet whose compressed air is marked with dioctyl phthalate mounted inside the test section of a low turbulence level subsonic wind tunnel. Two values of the ratio λ_j of the exit plane velocity of the jet (16.30 m/s) to the velocity of the tunnel flow are chosen; namely, $\lambda_j = 5.1$ and $\lambda_j = 10.88$. The Reynolds number of the jet flow is 22,600 using the nozzle diameter (2.14 cm) as the length scale.

A laser Doppler velocimeter in conjunction with a phase-locked loop processor is used to make the velocity measurements.[1] To determine the static and wall surface pressures, the system developed by Schroeder[4] and Herling[5] is used. The essential items include a 1/2-in. condenser-type microphone and a tape recorder. When cross correlations are made between the fluctuating pressure and velocity fields, both signals are filtered (10-1000 Hz) before being processed in order to achieve a good signal-to-noise ratio.

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Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interactions; Boundary Layers and Convective Heat Transfer—Turbulent.

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Mean Velocity Field

The effects of the velocity ratio λ_j on the decay of the centerline velocity for the three respective mean flowfields are presented in Fig. 2. In Fig. 2 for $\lambda_j = 5.1$ and 10.88, the nondimensionalized centerline velocity is plotted vs $x/2r_0$. In this figure, U_0 is the centerline velocity at the jet exit plane and U_{FS} is the secondary (wind-tunnel) velocity.

Turbulent Intensities

Turbulent intensity is the ratio of the rms turbulent velocity fluctuations to a reference mean velocity. In this investigation, turbulence level is nondimensionalized by excess centerline mean velocity at the exit plane of the nozzle. The turbulent intensities are corrected for ambiguity noise using the method of Morton.[7] In Fig. 3, the turbulent intensity at $y/2r_0$ and $z/2r_0 = 0.5$ is plotted vs downstream location, $x/2r_0$. For both $\lambda_j = 5.1$ and $\lambda_j = 10.88$, the turbulence increases at about the same rate for the unconfined co-flowing jet and the flow over the plate. The magnitude is consistently higher for the plate configuration. In fact, λ_j seems to have very little effect on the experimental data. For the flow over the flap, however, the value of the parameter λ_j is of considerable importance. At the location in the flowfield where the jet is decelerated and widened at the most rapid rate, the turbulence is also amplified greatly, giving a strong indication that the flap serves to quickly break up the potential core.

Pressure-Velocity Correlations

Additional information concerning the turbulence structure of the various flowfields can be gained from measurements of the pressure fluctuations at both the wall and in the turbulent jet, correlating those signals with fluctuating turbulent velocities in the potential core and in the shearing region.

Pressures are measured either at surface ports located on the flap or plate or by a pressure probe in the flow. In either case, the following space-time correlation is measured:

$$R_{pa}(x,\epsilon,t,\tau) = \frac{\overline{p(x,t)u(x+\xi,t+\tau)}}{[\overline{p(x,t)^2}]^{\frac{1}{2}}[\overline{u(x,\xi,t+\tau)^2}]^{\frac{1}{2}}}$$

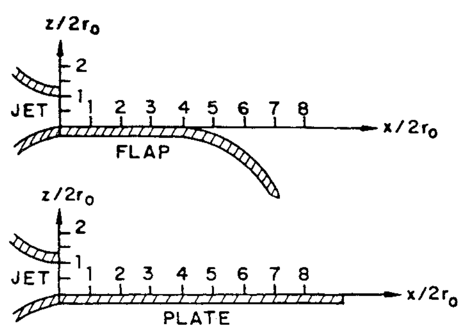

Fig. 1 Jet flap and plate arrangements.

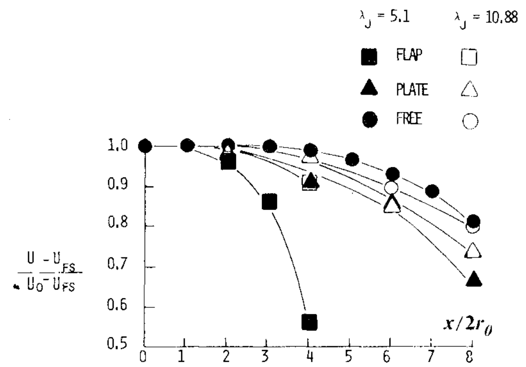

Fig. 2 Decay of centerline mean velocity, $z/2r_0 = 0.5$.

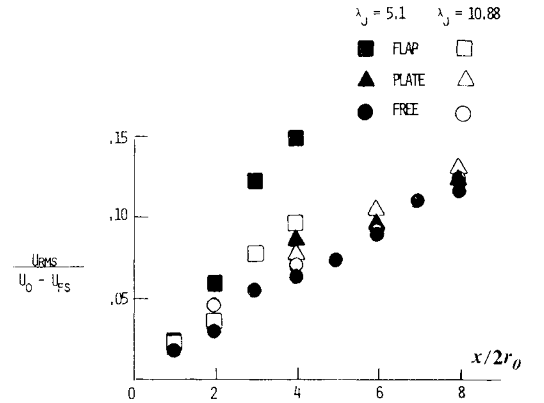

Fig. 3 Growth of turbulent intensity, $U_{rms}/(U_0 - U_{FS})$, at the centerline.

where ξ is the position of the velocity "probe" measured relative to the pressure probe, and p is the static pressure measured at the wall or in the flowfield. Coherence, which is similar to a correlation coefficient but contains no phase information and varies with frequency, is defined as:

$$\delta_{12}{}^2 = |G_{12}|^2/G_{11}G_{22}$$

where G_{11}, G_{22}, are the Fourier transforms of the individual autocorrelation functions, and G_{12} is the Fourier transform of the cross-correlation function.

Cross correlations between fluctuating pressure signals measured at surface ports in the plate and flap and turbulent velocity signals monitored at various locations in the flowfield are determined. These correlations were Fourier transformed to get the spectra and coherence. An example of the data obtained for the jet/plate flowfield is shown in Fig. 4. This figure shows peaks in both the velocity and pressure spectra at the same frequency. It should be noted that the coherence also has a peak at the same frequency.

The value of the velocity ratio λ_j was found to have a significant influence on the mean velocity field. For the case of the flow over the flap, an increasing value of λ_j decreases the effectiveness of the curved wall surface in diminishing the x-directed momentum. Evidence existed that as λ_j approached infinity, the flow would not remain attached. The parameter λ_j influenced the width of the mean velocity profiles as well, especially in the case of the flow over the flap. An increase in λ_j caused a resultant decrease in the mixing width y_m.

Pressure velocity correlations using both the static pressure probe and the surface ports yielded strong evidence[8] that as

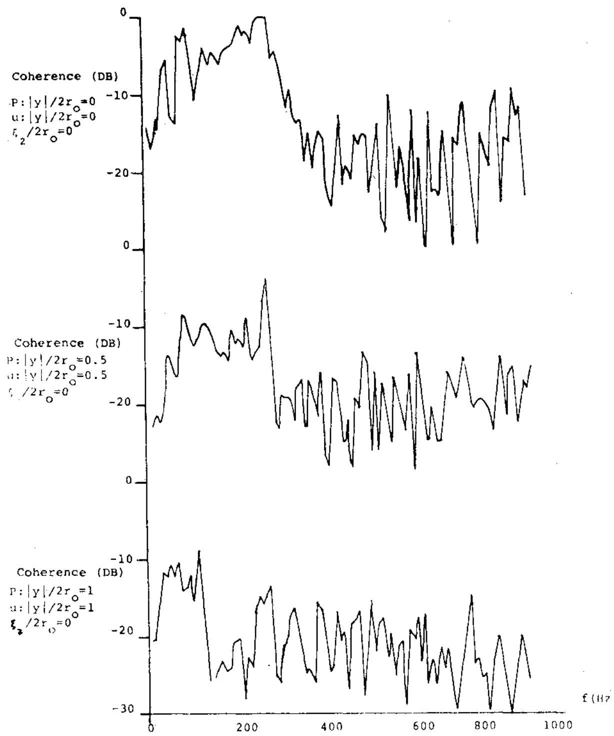

Fig. 4 Wall pressure and velocity coherence, $\xi_1/2r_0 = 0$, $\xi_3/2r_0 = 0.2$. Jet plate ($\lambda_j = 5.1$, DB reference to dynamic pressure/Hz).

the flow progresses downstream and becomes a fully developed turbulent flow, the relationship between the pressure and velocity field diminishes. For the first several diameters downstream from the exit plane where the pressure and velocity spectra peak at approximately 300 Hz, the coherence between the two fluctuating fields is the strongest.

Acknowledgment

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