Experimental Investigation of an Axisymmetric Jet in a Coflowing Airstream

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Theme

AN experimental investigation of the flow development of an axisymmetric jet exhausting into a moving airstream has been made. The flowfield of the axisymmetric jet was examined at locations varying from approximately zero to eight diameters downstream of the orifice. Of primary concern at each downstream location was the mapping of the one point statistical properties of the flow, including mean velocity, turbulent intensity, and intermittency. Autocorrelations and power spectral density curves were determined for the fluctuating velocity field at various distances from the jet's centerline for different downstream locations. A laser-Doppler velocimeter,[1-4] using a phase locked-loop processor, was used to make the desired velocity field measurements. To determine the intermittency profiles and velocity-concentration correlations, a laser light scattering technique[5-7] was employed.

Contents

Many investigators[8-28] have reported results of measurements in the near field of a turbulent jet for both the freely expanding case and the flowfield with a secondary, coflowing stream. The experimental results obtained from this investigation are compared to previous findings by several researchers in the back-up paper.

The flow system consists of a jet, whose compressed air is marked with dioctyl phthalate (DOP), mounted inside the test section of a low-turbulence level subsonic wind tunnel. With the parallel secondary flow in the wind tunnel being kept at a constant speed of 3.20 m/sec, the ratio of the exit plane velocity of the jet to the velocity of the tunnel (λ_j) is 5.1 : 1. The jet itself has a contraction ratio of 14 to 1 over a length of 15.9 cm., a Reynolds number of 22,600, and an exit diameter of 2.14 cm.

Longitudinal mean velocity profiles are shown for five downstream locations ($x/D = 0, 2, 4, 6, 8$) in Fig. 1 (x is downstream from exit plane and D is diameter of jet). In this figure, the local excess mean velocity, $U - U_{FS}$ is normalized by the excess centerline velocity $U_{max} - U_{FS}$, and is plotted against the nondimensional radius, $(r-r_m)/b(x)$ where r_m is the half velocity width and $b(x)$ is the mixing layer width. At the exit plane, the mean velocity profile has the "flat top" typical of an ideal jet. Here $b(x)$ is the radial distance between the locations where the $U = 0.80\ U_{max}$ and $U = 0.20\ U_{max}$. The mixing layer width was defined in this manner because of the confidence in determining those positions in the flowfield. The V velocity component was also measured and found to be several orders of magnitude smaller than the U component.

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Index categories: Jets, Wakes, Viscid-Inviscid Flow Interaction.

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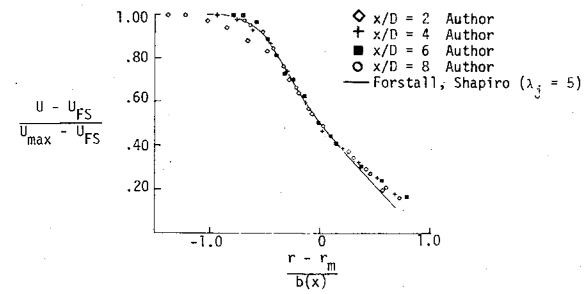

Fig. 1 Similarity plots of mean velocity profiles.

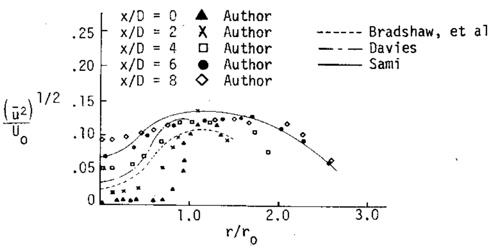

Fig. 2 Turbulent intensity profiles at five downstream locations.

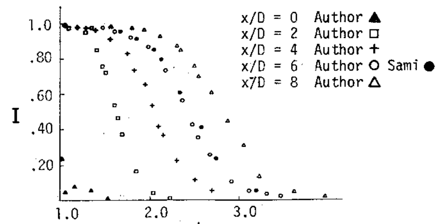

Fig. 3 Intermittency profiles at five downstream locations.

Turbulent intensity in the longitudinal direction, $[(\overline{u^2})^{1/2}/U_o]$, is presented in Fig. 2 for various downstream locations. In the potential core, the turbulence level is less than 5%. The radial turbulent intensities were also measured and found to be of the same order as $[(\overline{u^2})^{1/2}/U_o]$, and both quantities' profiles are quite similar in shape.

The radial and axial distributions of the intermittency factor I throughout the region investigated are shown in Fig. 3. The rise in intermittency in the region $r/r_o = 1$ to $r/r_o = 1.5$ for the downstream location $x/D = 0$ in Fig. 3 indicates the presence of a vortex sheet at the exit of the jet. The vortex sheet at the lip is caused by the high-velocity jet air exhausting into the slower secondary air.

The profiles for intermittency presented are for the region outside the lip of the jet. Here, the presence of a nonzero value for intermittency indicates that there are smoke particles in the control volume which implies the flow is turbulent there due to the large Schmidt number (4×10^4). The Schmidt number is defined as the ratio of the kinematic viscosity to the coefficient of diffusivity of the DOP smoke particles.

Autocorrelations of the axial velocity fluctuations at the centerline of the jet and at a distance of 1 radius from the cen-

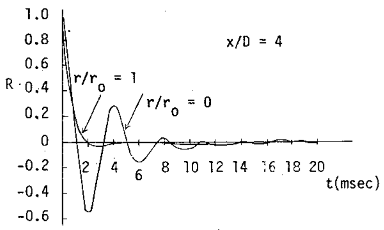

Fig. 4 Longitudinal autocorrelations.

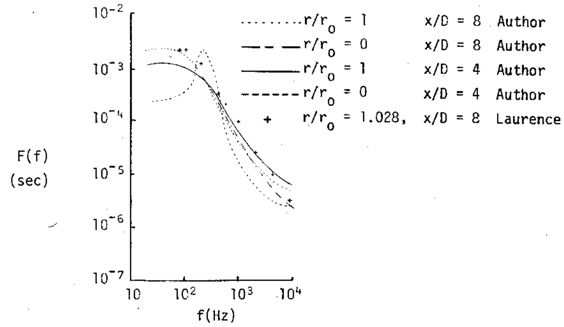

Fig. 5 Spectral density curves.

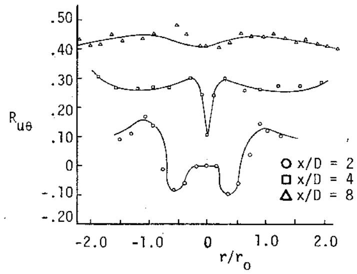

Fig. 6 Concentration-velocity correlations.

ter of the jet for the downstream location, $x/D = 4$, are shown in fig. 4. Notice the dramatic difference in the shapes of the autocorrelation coefficient curves in the potential core ($r/r_0 = 0$) as opposed to outside in the mixing region of the flow ($r/r_0 = 1$).

The spectral density curves are shown for the downstream location of $x/D = 4$ and $x/D = 8$ for two radial locations ($r/r_0 = 0$, $r/r_0 = 1$) in Fig. 5. Comparison is made with data from Laurence.[23] The appearance of the peak for the spectra determined in the potential core ($r/r_0 = 0$) region of the flow is in agreement with Ko and Davies[10] and Bradshaw, et al.[25]

The concentration-velocity correlation coefficient, $R_{u\theta}$, is presented for three downstream locations in Fig. 6. A zero correlation would indicate that the velocity fluctuations are totally independent of the fluctuations in the concentration field. This is the case for $x/D = 2$. Out from the centerline of the jet, $R_{u\theta}$ initially becomes negative and then changes sign and reaches a maximum value at approximately $r/r_0 = 1$. Vortices which would entrain "clean" air from outside the jet and accelerate the entrained fluid particles would give rise to a negative region in the concentration velocity correlation.

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