Flow Structures of Coaxial Jet of Mean Velocity Ratio 0.5

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Abstract

THE presence of two trains of coherent structures in the inner and outer mixing regions of homogeneous coaxial jet of mean velocity ratio λ (outer to inner) greater than unity has been established.[1,2] At mean velocity ratio λ of 0.5, both the inner and outer structures were observed to undergo substantial development.

The present investigation was intended to study the development of the two coherent structures and their possible mutual interaction in a coaxial jet of $\lambda = 0.5$. The experimental techniques employed included conditional samplings of both structures and an azimuthal mode expansion scheme on the outer structures.

Contents

The inner and outer jets had an exit diameter D_i of 2.0 cm and D_o of 4.0 cm. The lip thickness of the inner nozzle was 1 mm. The inner and outer exit velocities U_i and U_o were 60 m/s and 30 m/s, giving a mean velocity ratio (U_o/U_i) of 0.5. The jet exit boundary layers of the two nozzles were all laminar.

The first set of conditional sampling measurements was to educe the inner structures, and the triggering microphone was located within the inner mixing region at $x/D_o = 2.5$ and $y/D_o = 0.1$ (Fig. 1).

Pressure traces $p_R(t)$ were recovered along $y/D_o = 0.1$, 0.2, and 0.3, where t is the time delay relative to the triggering instant. They show that a pressure crest and two pressure troughs can be well identified and are found convecting downstream (Fig. 2). Two remarkable features are observed for the pressure crest. First, it is convecting downstream with a very uniform front across the lateral extent of the inner mixing region of $y/D_o \leq 0.3$. In similar studies of coherent structures in a circular jet[3] and in an annular jet,[4] the recovered pressure fronts are not uniform across the mixing region but are bulging towards the downstream direction. The reason for the uniform $p_R(t)$ fronts in Fig. 2 is still unknown. The second remarkable feature is that the recovered pressure crest and troughs convect downstream with constant velocity of about 50 m/s. This value of convection velocity is $0.66(U_i - U_o) + U_o$, agreeing well with the value of 0.6–0.7 for circular jet flow. Besides these two features, the recovered $p_R(t)$ traces show the general trend of changing from high-frequency component dominance to low-frequency component dominance as the recovery location is further downstream.

The second set of conditional sampling measurements was to educe the outer structures, and the trigger microphone was located within the outer mixing region at $x/D_o = 1.5$ and $y/D_o = 0.45$ (Fig. 1). In the outer mixing region, the outer structures are only satisfactorily recovered at axial locations of $1 \leq x/D_o \leq 2$. The quasiperiodicity of the recovered $p_R(t)$ traces occurs at a frequency around 500 Hz. Beyond $x/D_o > 2$, there is obvious decrease in the magnitudes of the recovered $p_R(t)$ traces and in the degree of large-scale organized fluctuations, indicating the decay of the outer structures beyond $x/D_o > 2$. Their convection velocity at $1 \leq x/D_o \leq 2$ is about 21 m/s or 0.7 U_o.

Inside the inner potential cone, the recovered $p_R(t)$ traces at $x/D_o \leq 2$ show undulations at a frequency of the outer structures around 500 Hz, indicating that their effects are also felt there. In the inner mixing region, the influence of the outer structures also is observed. Figure 3 shows the large-scale low-frequency undulations due to the outer structures at $x/D_o \leq 2$. Superimposed on these undulations are high-frequency fluctuations. When compared with the pressure spectra at these locations,[1,2] these fluctuations are due to the initial developing inner structures. In an annular jet (i.e., $U_i = U_o$), in which there is a large-scale wake-induced instability affecting the outer shear layer,[5] the initial vortices are observed to lock onto that instability and eventually develop into a train of induced coherent structures in the outer mixing

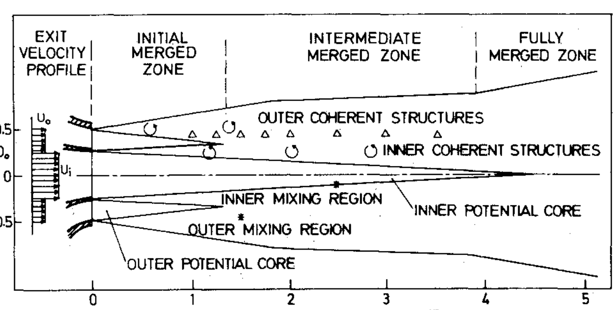

Fig. 1 Schematic diagram of flow regions of coaxial jet (λ = 0.5; *: location of triggering microphones; △: location of fixed microphone in modal analysis).

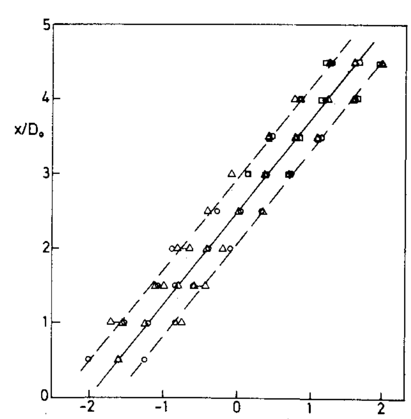

Fig. 2 x-t plot of recovered pressure crest (–) and pressure troughs (---) of inner structures (y/D_o: 0, 0.1; △, 0.2; □, 0.3).

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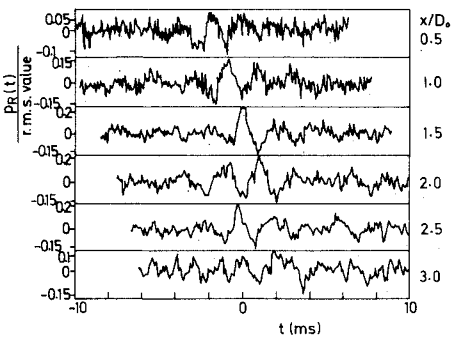

Fig. 3 Recovered pressure traces in inner mixing region, $y/D_o = 0.2$, using outer structures as triggering signal.

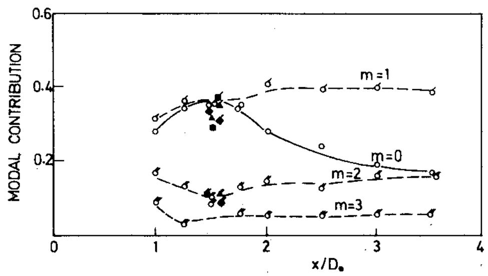

Fig. 4 Axial variation of modal constituents in outer mixing region (0: present study, $\lambda = 0.5$; ■: results of Ref. 11, $\lambda^{-1} = 0.3$; ▲, Ref. 11, $\lambda^{-1} = 0.6$; ◆: circular jet of Ref. 9). Number of apostrophes on symbols denotes different modes.

region. In the present coaxial jet, the magnitude of the high-frequency fluctuations are nearly the same whether they are superimposed on the crests, troughs, or zeros of the low-frequency outer structure induced-pressure undulations (Fig. 3). Thus, there appears to be no locking of the initial inner structures onto the outer structure frequency. In other words, interaction between the inner and outer coherent structures in the coaxial jet is not so strong as that in the annular jet.

Based on the mode expansion procedure of Fuchs et al.,[6] the contributions of different modal constituents to the fluctuating pressure energies in the outer mixing region are shown in Fig. 4. The values of the contributions are taken from the average over a narrow frequency band around the spectral peak in the different modal spectra. As a result, comparison is made at different frequencies corresponding to the structure frequencies at different axial distance. As is evident from results not shown here, the relative strengths of the different modal constituents only vary slightly over the frequency range covered by the spectral peaks. From Fig. 4, most of the energies comes from the first two modes. Between them, the contribution of the axisymmetric mode is always lower than that of the first mode, except around $x/D_o = 1.5$, where the contributions from the two modes are nearly the same. Both the zero and first modes undergo growth within the initial merging zone ($x/D_o < 1.5$). Then the contribution from the first mode remains nearly constant at a value of 40%. For the zero mode, its contribution drops off rapidly after reaching a maximum of 36% at $x/D_o = 1.6$. Beyond $x/D_o > 3$, its contribution becomes less than 20%. The drop of the zero mode begins at a location where the outer potential core ends. Similar breakdown of ring-like structures at the end of the potential core has been observed in studies of circular jet flow.[3] Contributions from higher modes ($m \geq 2$) are much less than those of the first two modes and are always below 20%. In general, they do not vary much with axial distance.

The modal distribution at $x/D_o = 1.5$ is compared with the available results obtained in a circular jet[6] and in coaxial jets of different mean velocity ratios[7] (Fig. 4). For the circular jet, the axisymmetric mode is always more dominant than the first mode. For the coaxial jets of mean velocity ratio less than and greater than unity, the first azimuthal mode is more dominant.

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