SOME COMMENTS ON THE STRUCTURE OF THE TURBULENT COFLOWING JET[1]

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ABSTRACT

Experiments recently carried out by the authors on a family of axisymmetric coflowing turbulent jets with different nozzle to free-stream velocity ratios are described. Special care was taken to ensure top-hat velocity profiles at the nozzle exit so as to reduce the number of parameters associated with the initial conditions. This results in a collapse of the data without the need to introduce different effective origins for the streamwise co-ordinate. The mean flow behaviour is compared to self-preserving asymptotic forms. An analysis was carried out to see if the mean flow, Reynolds stress distributions and spectra are consistent with an inviscid "double-roller" vortex structure for the representative large scale energy-containing motions. Results show support for such a model.

INTRODUCTION

This paper presents some experimental results and observations from a study of an axisymmetric turbulent jet issuing into a parallel moving airstream. The particular flow of interest consists of a turbulent jet issuing into a slow moving, constant velocity (U_1), outer flow of infinite extent (as opposed to the flow of a jet in a finite duct, or the flow of coaxial jets). Here this flow case will be referred to as a "coflowing jet". The apparatus used is shown in figure 1.

This flow case is of interest for several reasons. One is that it is postulated that in this flow, at a sufficient distance from the nozzle, the jet should "forget" its initial conditions and therefore only be determined by the nett momentum excess (or the momentum radius, θ which is invariant with streamwise distance in the absence of external pressure-gradients) and local conditions (eg. the local jet radius, Δ, and local velocity excess, $U_o = U_{CL} - U_1$, where U_{CL} is the velocity on the jet centre-line and U_1 is the velocity of the external stream) . If this is true, then measurements from different coflowing jets should collapse when scaled with these parameters. It further suggests the possibility of a self-preserving flow at large distances from the nozzle. This possibility is supported by analysis (see Townsend(1976)) which suggests that the flow may be asymptotically self-preserving in the limit of vanishingly small local velocity excess where the local velocity excess should scale as $(x/\theta)^{-2/3}$.

In this paper the possibility of self-preservation for this flow case is discussed. In order to investigate the role of coherent structures in jets and their contributions to the mean and turbulence quantities a "double-roller" vortex model similar to that proposed by Townsend(1976) is investigated and found to be consistent with experimental data. The essence of this investigation is to assume that coherent structures of some kind exist in turbulent jets. It is further assumed that these structures are distributed randomly in both the streamwise and azimuthal directions. In the radial direction the structures are allowed to jitter about a mean radial position with a Gaussian probability distribution. The objective is to see if some sort of double-roller coherent structure in a jet can explain the shapes of the mean velocity profile, the stress profiles and the spectra.

RESULTS AND DISCUSSION

Some of the results from this study are shown in the following figures. The behaviour of the local velocity excess is shown in figures 2. and 3. It may be seen that the behaviour of λ ($\lambda = (U_{CL} - U_1)/U_1$, where U_{CL} is the velocity on the center-line at the x position of interest, and U_1 is the external veloc-

[1] A more complete version of this paper (Nickels & Perry 1995) will appear shortly.

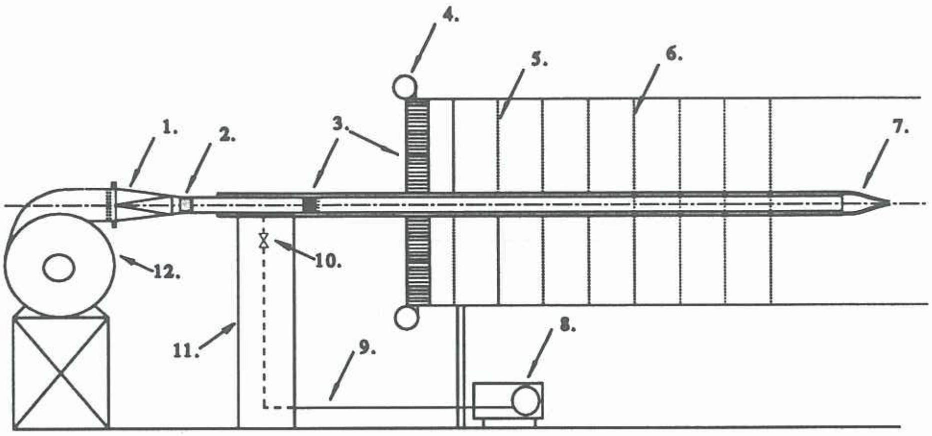

Figure 1: Layout of jet apparatus: 1. Transition piece, 2. Rubber membrane coupling, 3. Honeycomb, 4. Bell-mouth, 5. Screen with hole, 6. Screen passing through jet, 7. Nozzle, 8. Vacuum pump, 9. Suction line, 10. Needle valve, 11. Aerofoil support, 12. Centrifugal fan

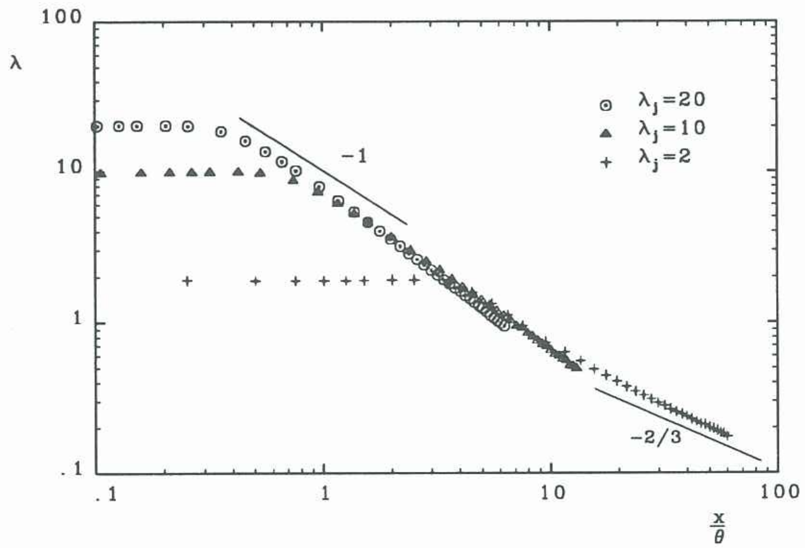

Figure 2: Decay of centre-line mean velocity excess on log scale, showing power-law asymptotes for self-preserving flows

ity). The behaviour appears to evolve from a -1-law behaviour near the nozzle (but beyond the potential core) to a -2/3-law behaviour at large x/θ. The -1-law behaviour is similar to that found for a jet exhausting into still air and as already mentioned the -2/3 law is the behaviour expected asymptotically for an axisymmetric jet (or wake) as the velocity excess becomes small. Also all three cases seem to collapse beyond the potential core without any shift of origin suggesting that the momentum thickness is indeed the correct length scale for non-dimensionalising the data. It would seem then that for simple top-hat profiles the downstream behaviour is independent of the actual velocity excess at the nozzle and only depends on the momentum imparted to the flow initially.

The structure used in the model mentioned is shown in figure 4. This eddy is randomly arranged both in the streamwise and azimuthal positions and jittered about a mean radial position. The contributions to the mean velocity, stresses and spectra are then calculated for an ensemble of randomly placed eddies by assuming that the individual eddies are uncorrelated with each other and hence the contribution to the mean quantities of an ensemble of such eddies can be found by summing the contributions from each eddy. The results are shown in figures 5. and 6. The agreement for the stresses and mean velocity are quite good for this particular structure. Perhaps more interesting is the behaviour of the Reynolds shear stress correlation coefficient spectra shown in figure 7. This quantity was calculated after the shape of the eddy had been modified to give good agreement for the stresses and mean velocity with no further adjustments to the model. The agreement is surprisingly

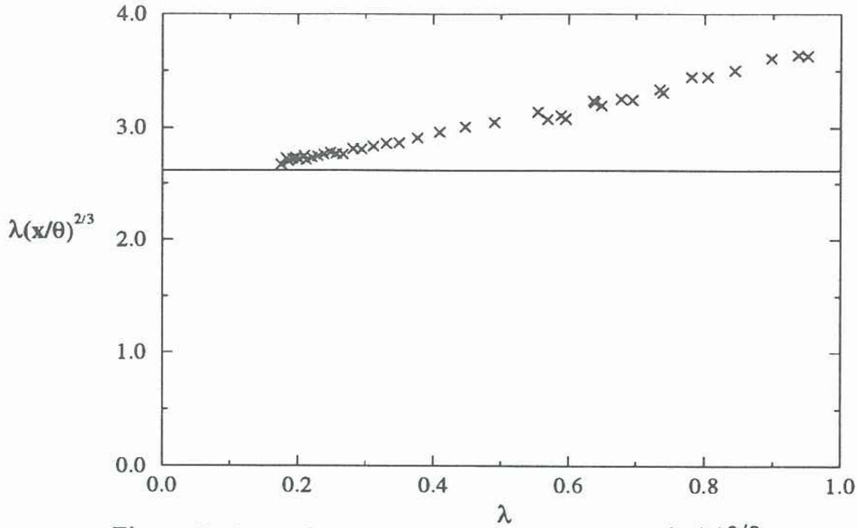

Figure 3: Centre-line velocity excess premultiplied by $(x/\theta)^{2/3}$ versus λ.

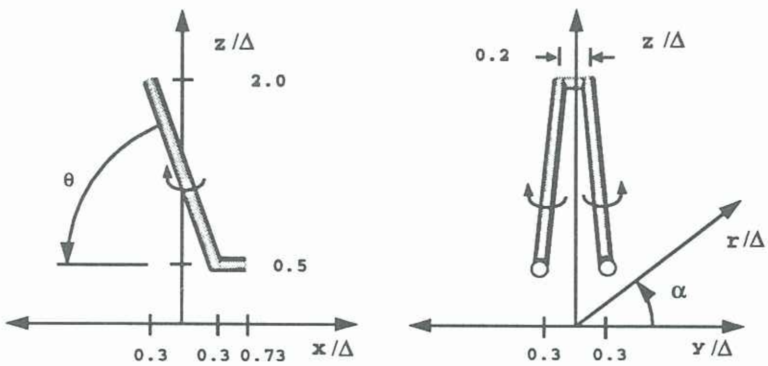

Figure 4: Eddy structure used in model

good and demonstrates an interesting behaviour in that for both the experiment and the model negative values of this quantity occur at high-wavenumbers. Initially this behaviour in the experiment was neglected as it was thought to be due to correlated noise in the experiments, but after the same trend occured in the model this conjecture was checked more closely and it was found that the noise was not large enough to explain the trend. Hence the model has already shown some usefulness in predicting the behaviour of jets.

REFERENCES

Townsend A.(1976). *The structure of turbulent shear flow.* Cambridge University Press.

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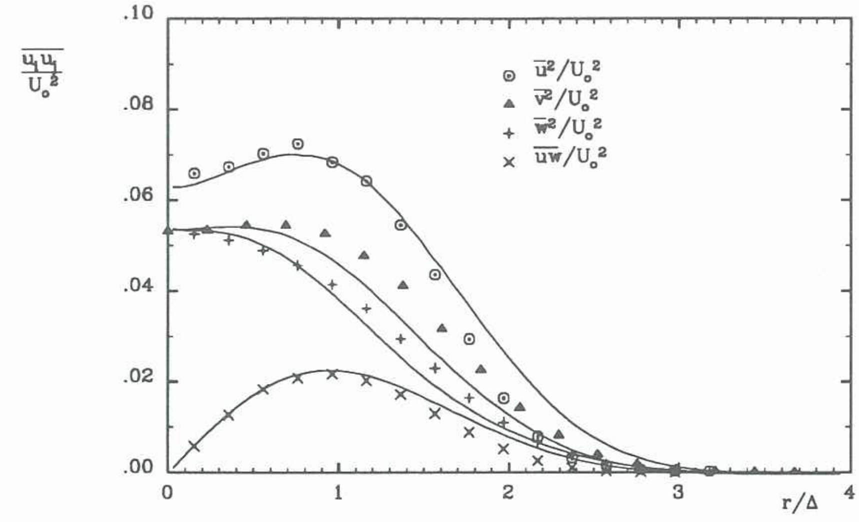

Figure 5: Reynolds stresses from experiment ($x/D = 30$, $\lambda_J = 2$)

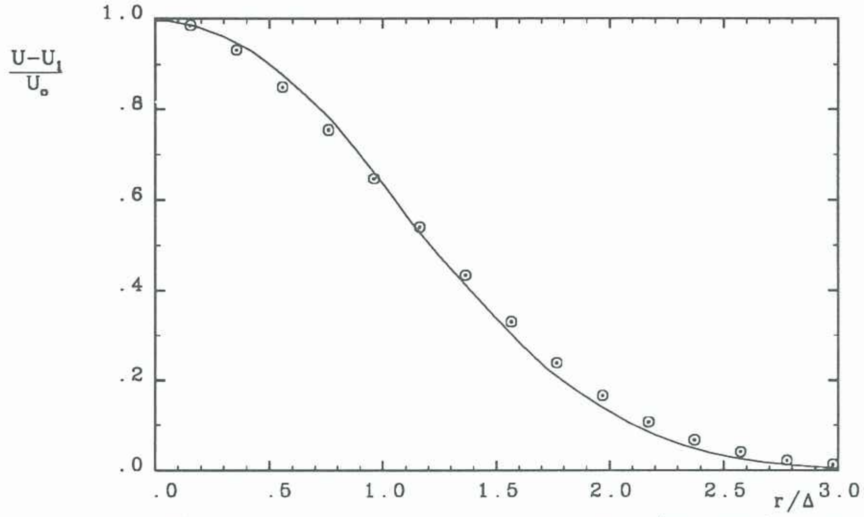

Figure 6: Experimental mean velocity profile($x/D = 30$, $\lambda_J = 2$)

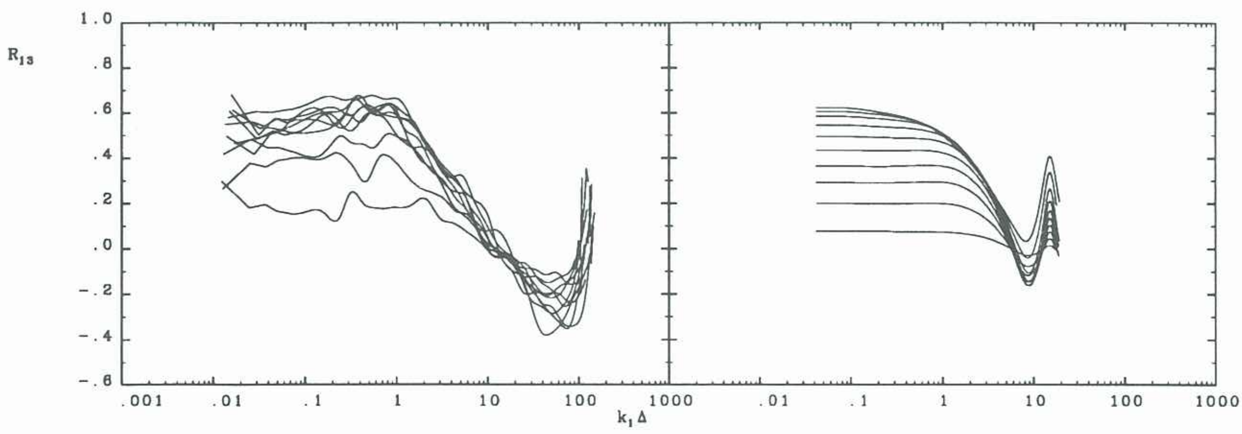

Figure 7: Reynolds shear-stress correlation coeffient spectra, experiment(left), model (right)