EFFECTS OF DIFFERENT MEAN VELOCITY RATIOS ON DYNAMICS CHARACTERISTICS OF A COAXIAL JET

by

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The flow field of a coaxial jet configuration having inner and outer diameter ratio $D_i/D_o = 0.33$ is studied for four values of the velocity ratios and $m = U_i/U_o = 5.17$, 1.13, 0.77, and 0.54. The profiles of the mean axial velocity, of the axial turbulence intensities, and of the shear stress are described for the initial and fully zones. The obtained results show the inner potential core length of the coaxial jet strongly depends on the velocity ratio while the outer potential core for jets having velocity ratios greater than unity seems to be insensitive to the velocity ratio. As expected, the inner jet core length is seen to decrease with decreasing velocity ratio; jets with velocity less than unity develop faster than those with m greater than unity and the Reynolds stress show a zero-crossing in the near-region.

Key words: *coaxial jets, turbulent developing flows, experiment*

Introduction

Coaxial jets are widely used in industrial applications as an effective way of mixing two different fluid streams, especially in chemical engineering systems and combustion devices. A coaxial jet is made when a fluid stream with velocity U_o, issuing from an outer annulus of diameter D_o, is added into a round jet flow with velocity U_i, and (inner) nozzle diameter D_i ($D_i < D_o$).

The existence of two (inner and outer) shear layer regions was evidenced by Ko and co-workers [1-3] in coaxial jets. They also noticed the formation of two potential cores, corresponding to each of these regions. In their case ($U_o < U_i$ and U_o relatively small) the outer stream acts mainly as a co-flowing velocity which does not modify substantially the inner jet dynamics. Champagne and Wygnanski [4] used a hot-wire anemometer in their investigation of coaxial turbulent jets. The noise from cold subsonic coaxial jets has been examined by Williams *et al.* [5]. Djeridane [6] analysed the effect of superimposing a small co-flow into a round jet and concluded that for co-flowing velocities smaller than 10% of the jet velocity the co-flow has only a minor influence on the spatial jet evolution.

Nevertheless, the study of the aerodynamic behaviour of coaxial jets is of great interest from both a scientific and a practical point of view. Indeed, the characterization and, possibly, the control of the mixing between the streams of coaxial jet configuration is a primary design feature in many industrial applications, as, for instance, in the design of new-generation industrial burners. Therefore, research activities aimed at an increased understanding of the relative influence of the various parameters on the near-field development are in any case highly needed from a technological point of view. Furthermore, the rapidly increasing capabilities of computational fluid dynamics (CFD) originated the need for high-quality and extensive experimental data referred to flow configurations that may be used as test cases for the validation of numerical codes with different degrees of sophistication.

In the present work, in order to obtain a better definition and, possibly a deeper physical understanding of the flow field of a coaxial jet configuration, swirl, and confinement or reacting are not involved into the flow. The issues from profiled nozzles to discharge freely into still ambient air. For fixed upstream conditions, the velocity ratio between the inner and outer streams is varied in a wide range. In contrast to the majority of the previous investigations, that involved inner jet Reynolds numbers greater and comparable values for the annular Reynolds numbers, lower values of Reynolds numbers for both jets are used thus expanding the available data range to cover the lack of data in double concentric jets of low Reynolds numbers. Also the studies of coaxial jets at low annular Reynolds numbers are important not only to help to understand the detailed phenomena and mechanism of the interaction of the recirculation bubble and flushing jet, but also important to applications of the non-premixed type of burners.

In this study, firstly, the experimental setup and the applied optical instrumentation are descripted. Then, the flow characteristics dynamics, in the initial region and fully merging region, of coaxial jet flows are presented.

Experimental setup

The tests where carried out at the laboratory of Complexe de Recherche Interprofessionnel Aerothermochimie. Coaxial jet is a double jet made up of a simple round jet central (diameter D_i = 6 mm and exit velocity U_i) surrounded by an annular jet (diameter D_o = 18 mm and exit velocity U_o) as shown in fig. 1. The coaxial jet is directed vertically downward, the vertical jet flow discharges in still ambient air and the exit pipe is mounted on a two axis displacement table driven by a personal computer. The stream wise direction is the x-axis and the radial direction is the r-axis. The Reynolds number Re is defined as: $\mathrm{Re}_i = \rho U_i D_i/\mu$, where ρ = 1.14 kg/m^3 is the air density, $\mu = 1.86 \cdot 10^{-5}$ Ns/m^2 is the dynamic viscosity. Table 1 summarizes the central and annular air flow characteristics.

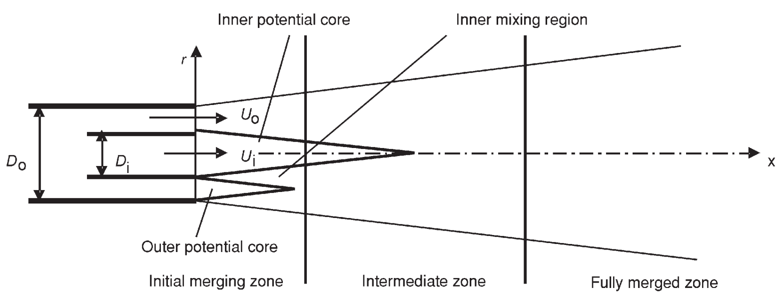

Figure 1. Flow field of a coaxial jet configuration

In order to validate such models, reliable measurement data are necessary. In the last decade efforts where made to develop non-instrusive techniques for measurement of velocity profiles of the flows. In the last laser-Doppler anemometry (LDA) is a reliable method for accurate velocity measurements of the flows. An extension of LDA for measurement the size together with their velocity at defined locations in the flow field is phase-Doppler anemometry (PDA). From the measured data, velocity, also Reynolds and turbulence intensities, can be readily extracted from the measurement data for the flow.

Table 1. Central and annular air flows characteristics, included exit velocity, Reynolds number and velocity ratio *m*

	U_i [m/s]	Re_i	U_o [m/s]	$m = U_i/U_o$
Flow I	32.34	11893	6.25	5.17
Flow II	12.36	4545	10.95	1.13
Flow III	7.72	2839	10.02	0.77
Flow IV	8.07	2968	14.95	0.54

Table 2. Optical parameter of the PDA system

Transmitting lens	6000 mm
Receiving lens	310 mm
Beam separation	50 mm
Wavelength of green laser beam	514.5 nm
Wavelength of blue laser beam	488 nm
Number of frange	22
Scattering angle	30
Sizing range mask C	258 μm

A two-component laser phase-Doppler system (Dantec) was used. The beam emitted from an argon laser is divided into beams of wavelengths λ_1 = 514.5 nm and λ_2 = 488 nm for two-component velocity measurements. The optical system is composed of a Bragg cell unit creating a 40 MHz frequency shift in order to avoid directional ambiguity, transmitting and receiving optics, photomultiplier (PM), and a numeric oscilloscope was used for on-line control of the Doppler signals and the optimisation and tuning of the electronics. For the different experiments, a 600 mm transmitting lens and a 310 mm receiving lens where used. The configuration data of the PDA are listed in tab. 2. The receiving optics are placed 30° to the forward scatter direction, to minimize the contribution of reflected light. Doppler bursts are processed by the Dantec 58N81 phase-Doppler signal processor. The experimental flow configuration is shown in fig. 2.

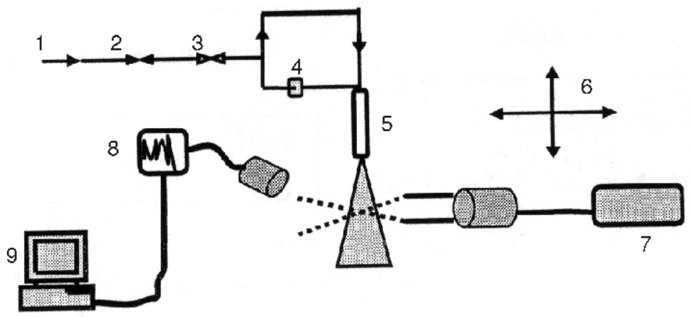

Figure 2. Experimental setup

1 – air, 2 – flowmeter, 3 – colsonic, 4 – tracers generator, 5 – nozzle, 6 – displacement system for tube, 7 – PDA, 8 – signal processor, 9 – computer

The measurement data for each detected and validated particle are arrival and transit times, two velocity components and diameter. The statistical evaluation is performed by Dantec's software BSA-flows [7], which provides mean values, turbulence intensities and Reynolds stress.

Results and discussion

Figure 3 shows the variation along the axis of the mean axial velocity U/U_i, of the longitudinal rms fluctuations u'/U_i and the Reynolds stress tensor $u'v'/U_i^2$. This figure presents the

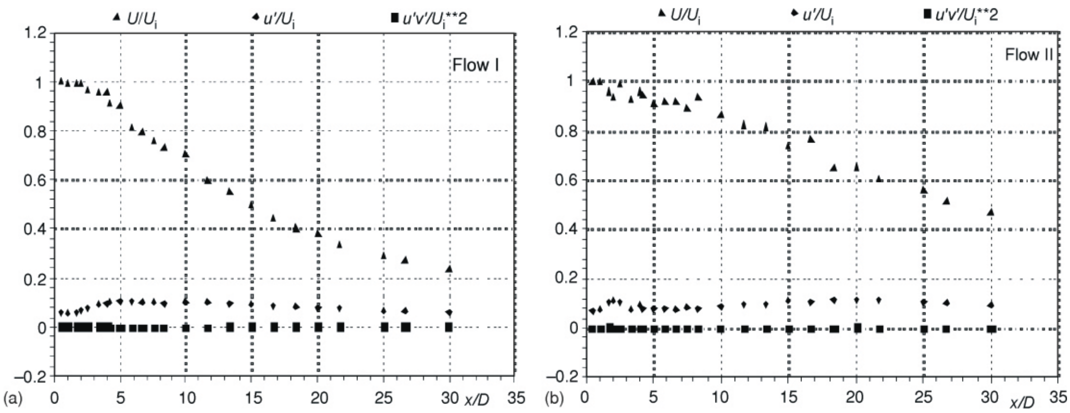

Figure 3. Variation of U/U_i, u'/U_i, and $u'v'/U_i$2 along the axis (m = 5.17; m = 1.13)**

results of the coaxial jets with two different central jet velocity ratios ($m > 1$). Flow I, the jet exit velocities corresponding to $m = 5.17$ where, $U_i = 32.34$ m/s and $U_o = 6.25$ m/s which correspond to Reynolds numbers $Re_i = 11899$. Flow II, the jet exit velocities corresponding to $m = 1.13$ where, $U_i = 12.36$ m/s and $U_o = 10.95$ m/s which correspond to Reynolds numbers $Re_i = 4545$.

Regarding the lengths of the inner potential core for flow I and flow II, this figure reveals that the inner potential cores are of about $4D_i$ and $2D_i$, respectively. The extent of the potential core is defined as the distance from the orifice (or exit plane of the nozzle) to the point of intersection of the constant, issuing velocity in the jet axis and the curve of the hyperbolic decrease of the centreline velocity. The decrease of the length of the inner potential core as the velocity ratio decrease by means of reducing the central jet velocity for a constant annular jet velocity.

The axial profiles of U/U_o, u'/U_o, and $u'v'/U_o^2$ are presented in fig. 4. This figure presents the results of the coaxial jets with two different central jet velocity ratios ($m < 1$). Flow III, the jet exit velocities corresponding to $m = 0.77$ where, $U_i = 7.72$ m/s and $U_o = 10.02$ m/s which correspond to Reynolds numbers $Re_i = 2839$. Flow IV, the jet exit velocities corresponding to

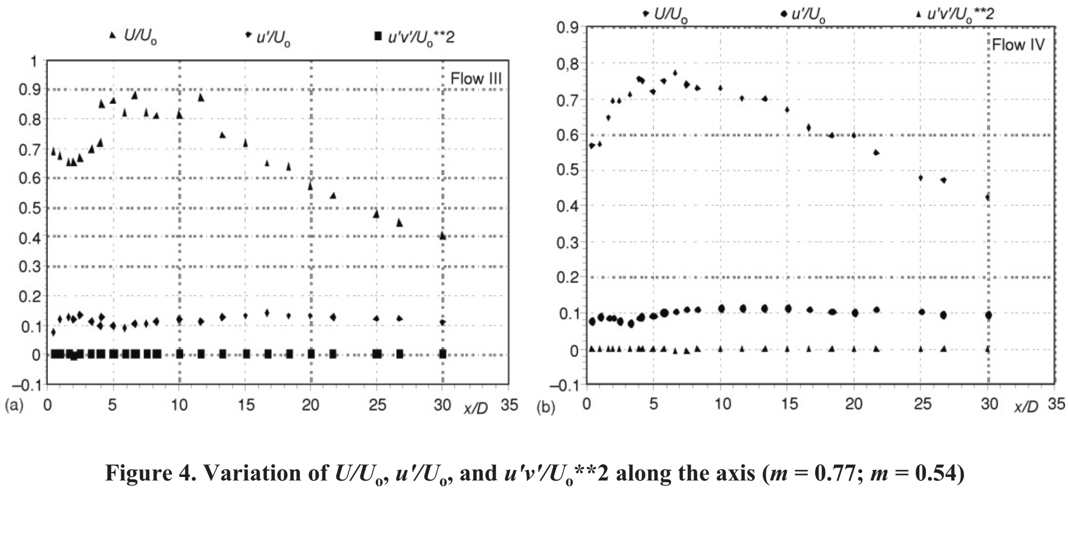

Figure 4. Variation of U/U_o, u'/U_o, and $u'v'/U_o$2 along the axis (m = 0.77; m = 0.54)**

$m = 0.54$ where, $U_i = 8{,}07$ m/s and $U_o = 14{,}95$ m/s which correspond to Reynolds numbers $Re_i =$ 2968. The decreased of the length of the inner potential core as the velocity ratio decrease by means of augmenting the annular jet velocity for a constant central jet velocity. The length of the inner core is a function of the velocity ratio and the approximate relationship $xp_i/D_i = 6{,}2$ U_i/U_o, a result is excellent agreement with Warda *et al*. [8-10].

In order to obtain a better definition and, possibly a deeper physical understanding of the flow field of a coaxial jet, not only the radial profiles of the longitudinal mean velocities are need to be displayed but also the corresponding profiles of turbulence intensities should be considered. Some of the radial profiles of both mean velocity and turbulence intensity that are measured at various axial stations are presented.

The radial profiles U, u', and $u'v'$ at several stream wise locations are shown in figs. 5 to 10. In these figures each set of profiles is divided into two groups, corresponding to the near-exit region and fully merged zones.

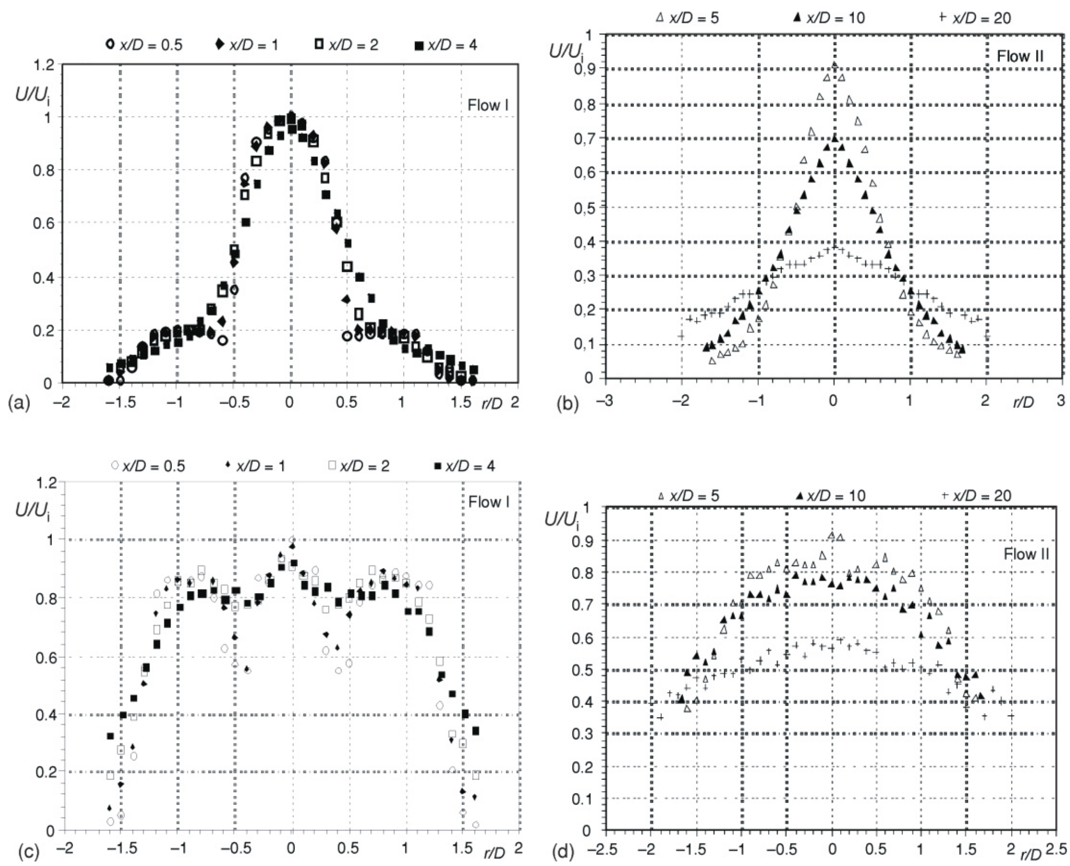

Figure 5. Radial profiles of the axial mean velocity U/U_i at various x/D_i ($m = 5.17$; $m = 1.13$)

Figure 5 shows the radial profiles of the mean axial velocity, U/U_i for flow I and flow II. This figure revealed that the rate of decay along the centreline is increased as the velocity ratio is increased. Comparing the centreline velocity in the fully merged region, fig. 5(b) and fig. 5(d), for flow I and flow II, it can be seen that the centreline velocity is larger in case of flow I than that of flow II.

The radial distributions of the axial turbulence intensity and corresponding the Reynolds stress tensor to the velocity ratios $m = 5.17$ and $m = 1.13$ are shown in figs. 6 and 7. It can be seen the two potential cores. Also, there appear two other regions of higher turbulence levels, namely the inner and outer mixing regions. As the axial distance increased the turbulence level inside the inner mixing region decreased. Regarding the radial distribution of the turbulence intensity at several streamwise location within the fully merged region of the velocity ratios $m = 5.17$ and $m = 1.13$, these are developed and became similar to those of a single jet.

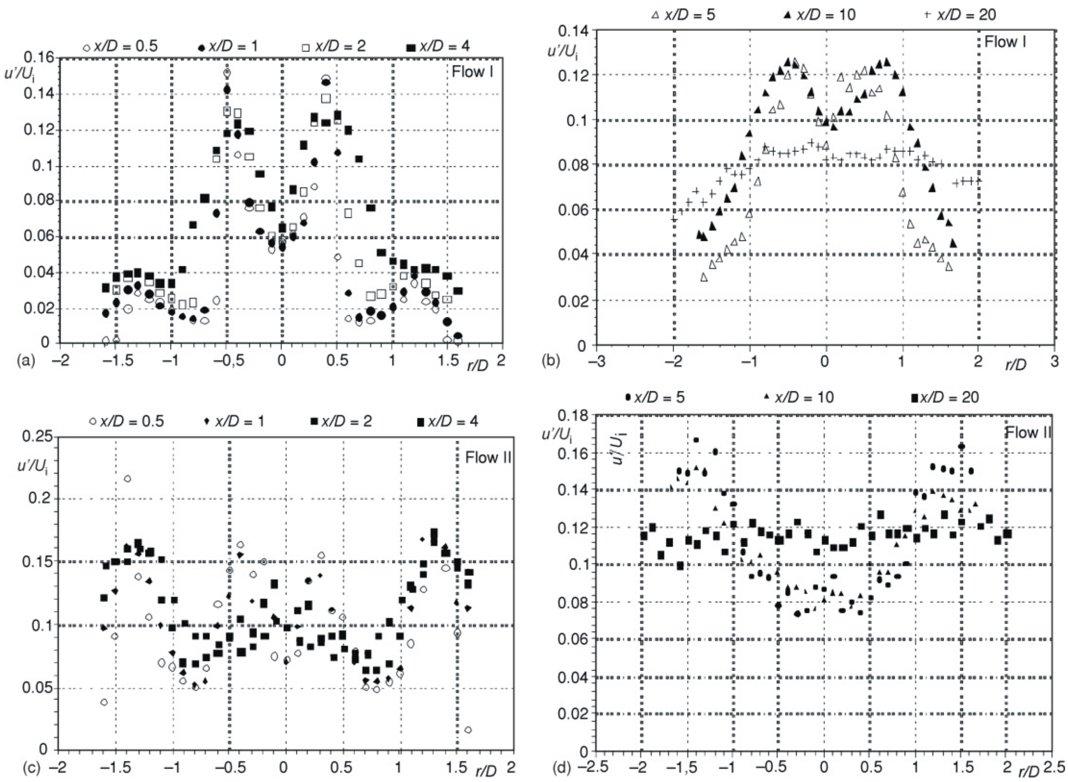

Figure 6. Radial profiles of the axial turbulence intensity u'/U_i at various x/D_i ($m = 5.17$; $m = 1.13$)

The radial profiles U/U_o, u'/U_o, and $u'v'/U_0^2$ at several streamwise locations are shown in fig. 8 to 10. The length of the inner potential core, which $U/U_o = 0.77$ is approximately $4D_i$, decreases for $U/U_o = 0.55$ to slightly above $1.5D_i$, *i. e.*, to a value in good agreement with Buresti *et al.* [11]. In the near-exit region, the axial rms fluctuations for flow III is larger than flow IV. In the very first region, the Reynolds stress profiles show a zero-crossing corresponding to the local maxima of the fluctuations and show one peak on each side of the inner duct wall (a positive one on the inner side and a negative one on the outer side) [12].

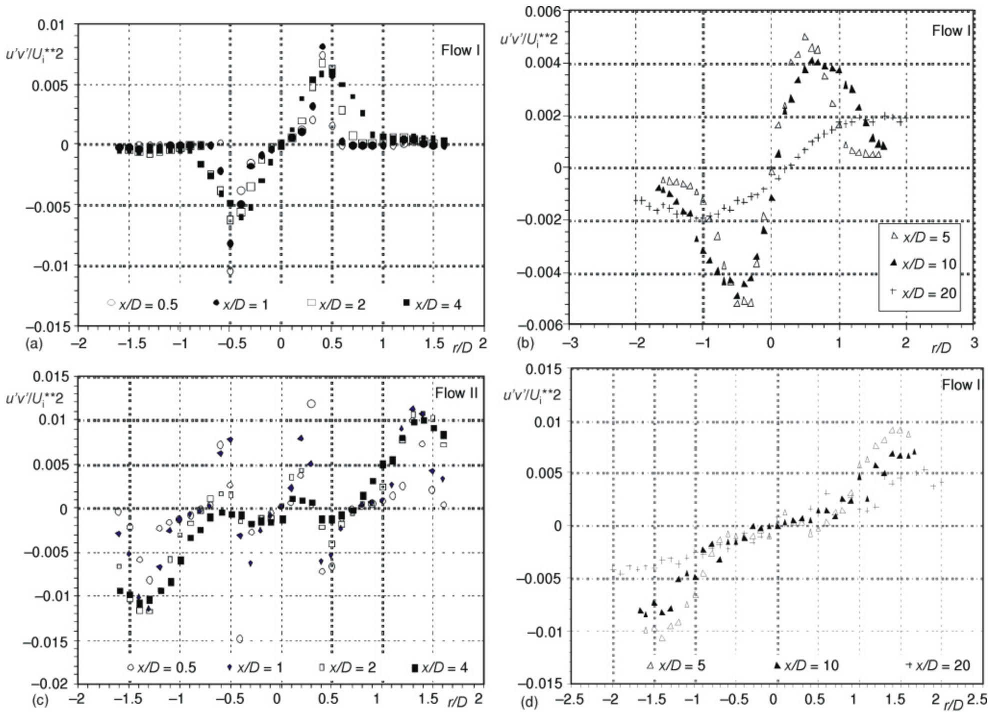

Figure 7. Radial profiles of the Reynolds stress $u'v'/U_i$2 at various x/D_i (m = 5.17; m = 1.13)**

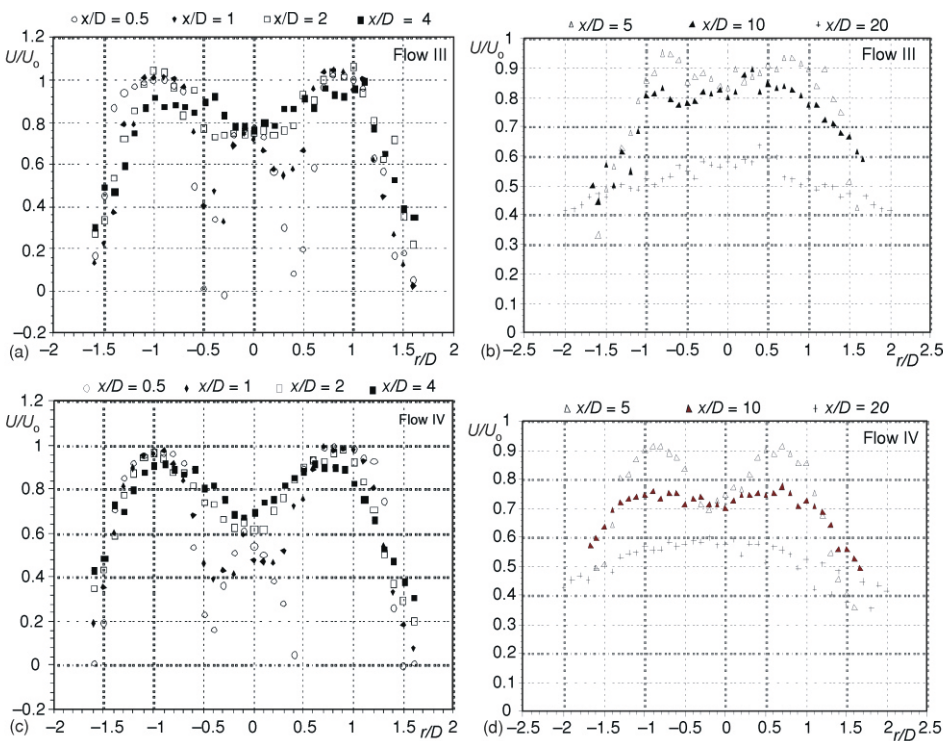

Figure 8. Radial profiles of the axial mean velocity U/U_o at various x/D_i (m = 0.77; m = 0.54)

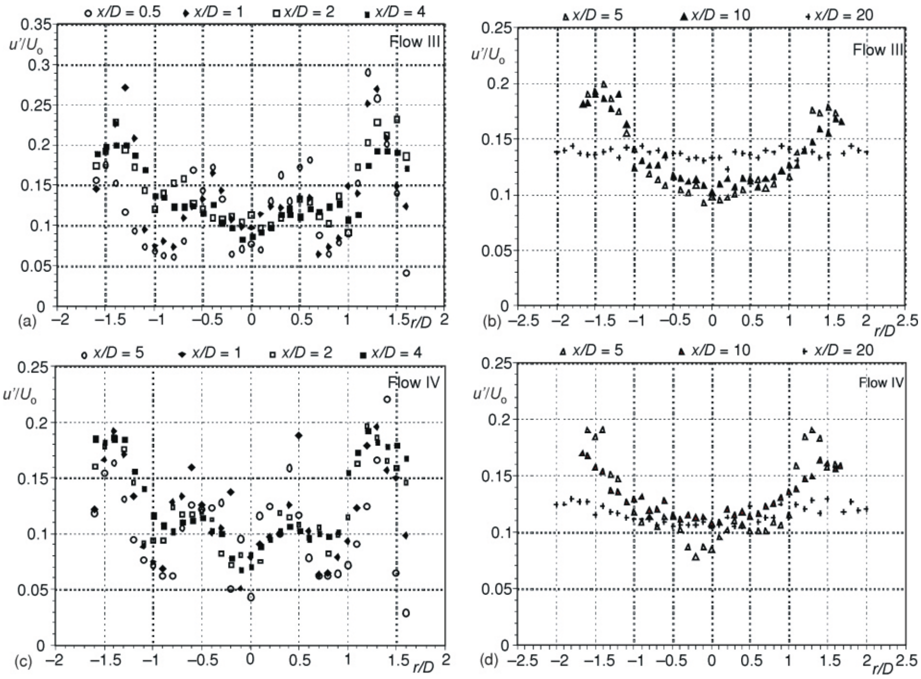

Figure 9. Radial profiles of the axial turbulence intensity u'/U_o at various x/D_i (m = 0.77; m = 0.54)

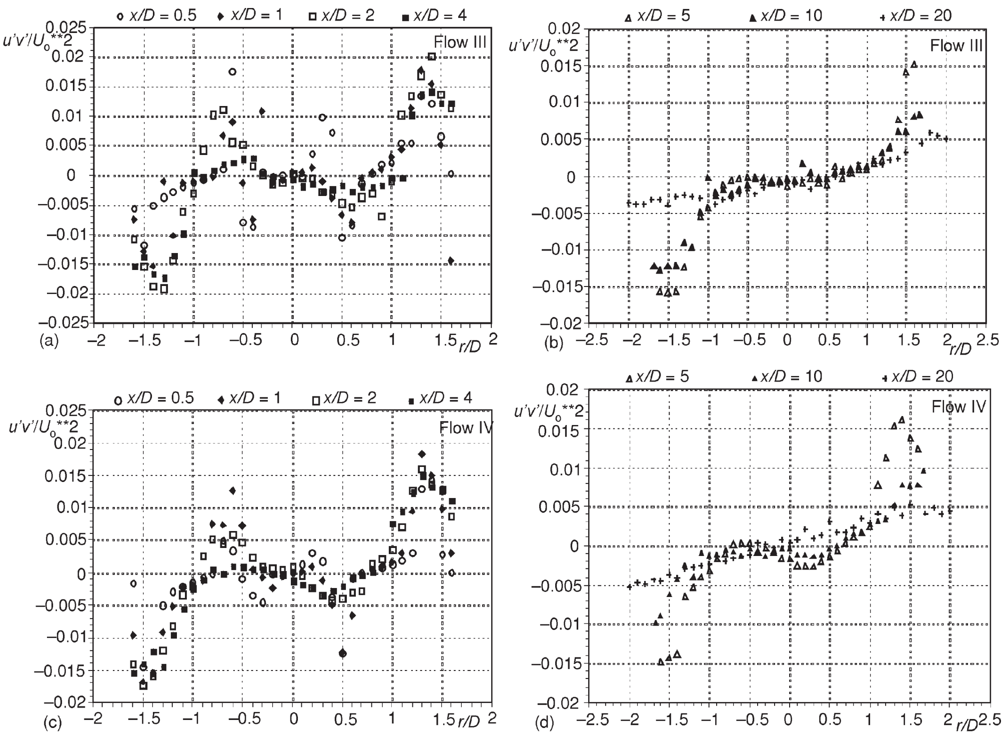

Figure 10. Radial profiles of the Reynolds stress $u'v'/U_o$2 at various x/D_i (m = 0.77; m = 0.54)**

Conclusion

A description was given of the flow field of coaxial jets with different velocity ratios $m = U/U_i$ and diameter ratio D_i/D_o. A simultaneous measurement of size and velocity distributions of continuous of coaxial jet a technique PDA was used, axial and radial velocity components are presented. The inner potential core length of the coaxial jet strongly depends on the velocity ratio while the outer potential core for jets having velocity ratios greater than unity seems to be insensitive to the velocity ratio. Coaxial jets with the velocity ratio less than unity develop faster than that with $m > 1$ and to enhance rapid mixing between the two streams.

The present experimental data refer only to particular geometrical and flow conditions, they should be a contribution to both the description of the process of mixing in axisymmetric coaxial jets and the creation of an adequate experimental data base. The may be used profitably for the validation of CFD codes and, particularly for analyzing the performance of their turbulence models.

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