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# Influence of Confinement Geometry on Mixing Characteristics of Co-Axial Swirling Jets

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## INTRODUCTION

Swirl is imparted either to the fuel jet or to the air jet or both in combustion chambers, furnaces to achieve enhanced mixing between the two streams. The swirl induced recirculation zones, observed in furnaces, combustion chambers are responsible for flame stabilization. Mixing of these co-axial swirling jets is governed by geometrical as well as fluid dynamical parameters. Literature reveals that the effects of dynamical parameters such as swirl, turbulence level etc. on the flow development and mixing of co-axial jets have been investigated by many researchers [2,6,8,9]. Singh[6] has obtained a swirl combination (outer=-45°, and inner = 30°) to give better mixing and uniform flow in a shorter length for a suddenly expanding confinement. He has used a diametral expansion of 2.0 and length of confinement as 1.5 m.

Investigations on the effect of geometrical parameters on flow development for co-axial swirling jets is limited. Dixon et al. [1] have investigated the effect of quarl angle and its lengh on mixing and development of swirling co-axial jets. Flow from the quarl exhausted into the atmosphere. Habib [10] investigated the effect of two expansion shapes on the jet mixing with annular swirling jet.

He has used a sudden expansion and a quarl with half quarl angle of 35° at the jet exit plane. The flow exhausted into a long duct. Singh et al. [5] have investigated the effect of blockage shapes at the exit of the test section length for a weak swirling outer jet. They [7] have also investigated the effect of length reduction on the flow development and mixing for contra-swirling jets. Mahallawy and Hassan [3] have studied the effect of test section length on the concentration distribution with swirling annular jet. Choi et al. [11] have conducted measurements for nonswirling jets exhausting into variable area duct.

In the present paper, the results of a systematic study undertaken to analyse the effect of expansion shape and ratio of the confinement for fixed contra swirling jets have been reported. The swirl combination (Outer = -45° and Inner = 30°)has been selected based on Singh [6]. Further, jets were exhausted into a sudden expansion of expansion ratio (1.5,2.0 and 3.0),quarl with constant angle and a quarl with variable angle. The later two shapes were connected to a confinement duct of expansion ratio of 2.0.

## TEST FACILITY

The experimental apparatus used in the present investigation is shown in Fig. 1.

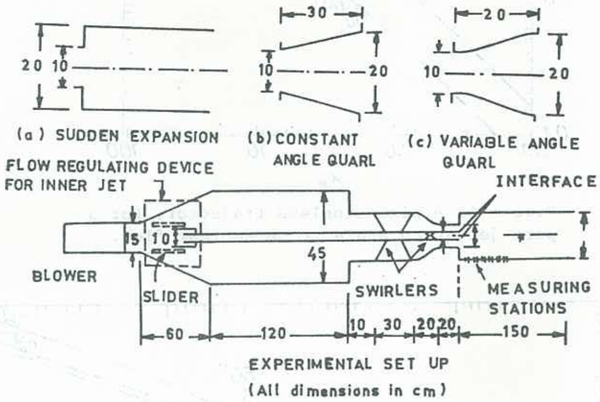


FIG. 1 : EXPERIMENTAL FACILITY

The main components of the rig were an air supply unit,settling chamber, swirlers, annular and central jet, flow regulating device and the confinement. The important features of the experimental facility are -

| | |
|---|---|
| Central jet or Round jet | 39 mm(ID) and 42 mm(OD). Fully developed turbulent velocity profile at the jet exit plane in the absence of swirler. |
| Annular or outer jet | 42 mm (ID) and 100 mm (OD), Flat Velocity profile in the absence of the swirler. |
| Swirlers | Vane Swirlers. |
| Test Section | Confinement expansion shape: Jet exhausting in (I) a constant angle quarl (19°) (II) A variable angle quarl, (III) A sudden expansion (Fig. 1). These expansions were exhausted into a confinement of 2.0 and length equal to 1.5 m. |
| | Confinement expansion: Three confinement geometries with diametral expansion ratios of 1.5, 2.0 and 3.0 for fixed length of 1.5 m. |

Cold air was used as the medium for both the jets and the experiments were conducted for a fixed velocity ratio of 1.6 between outer and inner jets.

Velocity traverses were carried out using a calibrated three hole probe in radial direction at various axial stations along the test section. Wall pressures were measured by the static pressure taps fitted on the test section wall.

## RESULTS

**Mean Velocity Field:**

Figure 2 shows velocity distribution for sudden expansion ratio of 2.0. The axial velocity at the jet exit plane ($x/d_o=0.0$) increases from the centre towards the interface, the peak being close to the interface.

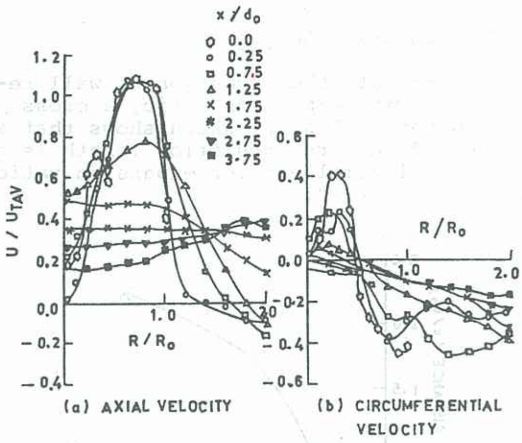


FIG. 2: VELOCITY DISTRIBUTION FOR EXPANSION RATIO 2.0

The increase in velocity being rapid between $R/R_o=0.2$ and $R/R_o=0.3$. The axial velocity profile for the outer jet is similar to a fully developed turbulent profile. At $x/d_o=0.25$, the centre line velocity becomes zero. Rapid changes in velocity profile are seen mainly in the central core near the jet exit plane. At $x/d_o=1.25$, the flow begins to fill up the total cross-section attaining a uniform distribution at $x/d_o=2.25$. Further downstream the flow is wall oriented, an affect which could be attributed to the presence of large component of circumferential velocity close to the wall as seen from Fig. 2b. The circumferential velocity distribution at inlet has the expected form of distribution. The decay of the circumferential velocity in the near jet exit region is rapid in the centre core with a spreading out tendency in the outer core. Beyond $x/d_o=1.25$, the distribution is of the forced vortex type with a decaying trend.

The axial velocity distribution for expansion ratio of 3.0 shown in Fig. 3a depicts a similar profile at the inlet to Fig. 2a. At $x/d_o = 1.25$, the inner jet is completely engulfed by the outer jet. The flow attaches to the wall at $x/d_o=2.25$ and becomes nearly uniform at $x/d_o = 3.25$. The circumferential velocity distribution Fig. 3b is similar to expansion ratio of 2.0 (Fig. 2b) except at the last station where the velocity is uniform instead of forced vortex.

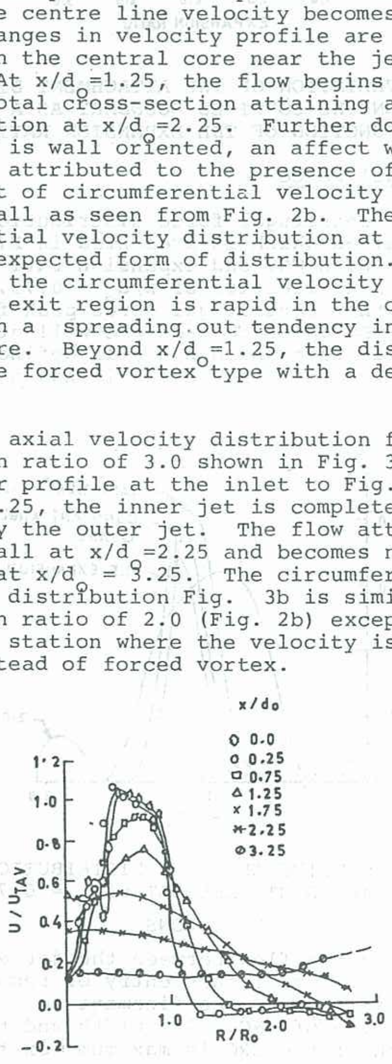


FIG.3a: AXIAL VELOCITY DISTRIBUTION FOR EXPANSION RATIO OF 3.0

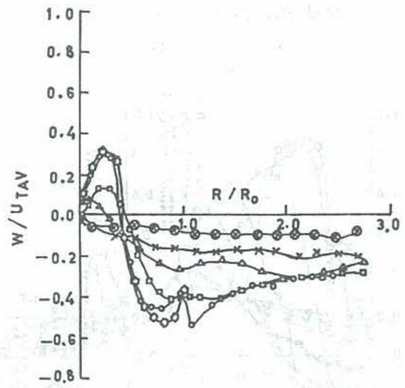


FIG. 3b: CIRCUMFERENTIAL VELOCITY DISTRIBUTION FOR AN EXPANSION RATIO OF 3.0

Figure 4 shows velocity profile at inlet for expansion ratio of 1.5 to be similar to expansion 2.0 and 3.0. However, at $x/d_o=0.25$, negative velocities appear at the centre line. As the fluid flows downstream, central recirculation core (CRC) increases in size. The formation of the CRC could be attributed to the effect of low availability of surrounding stagnant air for entrainment. Formation of the CRC forces the bulk of the flow towards the wall resulting in reduced wall recirculation length. After attachment, of the flow at $x/d_o=1.25$, the flow distributes itself to attain uniformity, limiting the growth of the CRC which disappears only at around $x/d_o=1.75$. Beyond this point, the flow fills the test section at $x/d_o=2.25$ and even at $x/d_o=3.75$, the flow is wall oriented. The circumferential velocity distribution is similar to the other cases at the inlet but in the near jet exit region, the peaks move away from the centre due to formation of CRC.

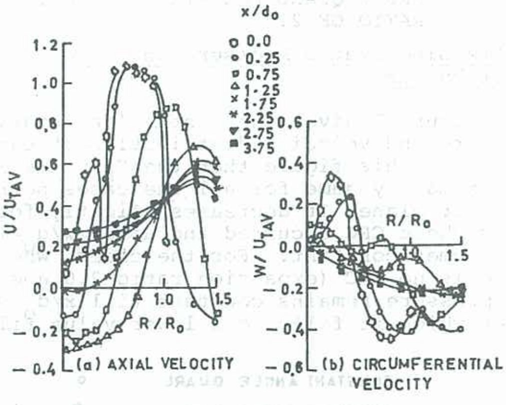


FIG. 4: VELOCITY DISTRIBUTION FOR AN EXPANSION RATIO OF 1.5

The velocity distributions for the two quarls (constant angle and variable angle) are depicted in Figs. 5 and 6. The inlet axial velocity profiles is unaltered in comparison to Fig. 2. A CRC appears at the centre for both the cases as the flow proceeds down-stream in the quarls and the peak velocity of the outer jet shifts towards the wall. Further, there is no recirculation near the wall. The CRC covers a larger portion of the confinement in both axial and radial directions as compared to Fig. 4. For the variable angle quarl, the size of CRC is largest. The CRC disappears at $x/d_o=4.75$ for both the cases. The circumferential velocity trend for both the quarls is identical all along the test Section(see Fig. 4) except in the near jet exit region where it has a double crested shape.

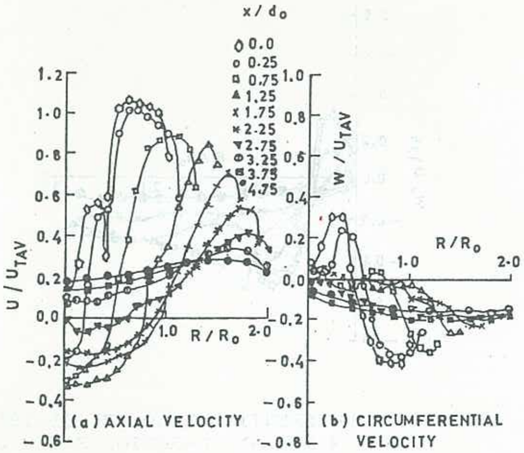


FIG. 5: VELOCITY DISTRIBUTION FOR CONSTANT ANGLE QUARL FOR FIXED EXPANSION RATIO OF 2.0

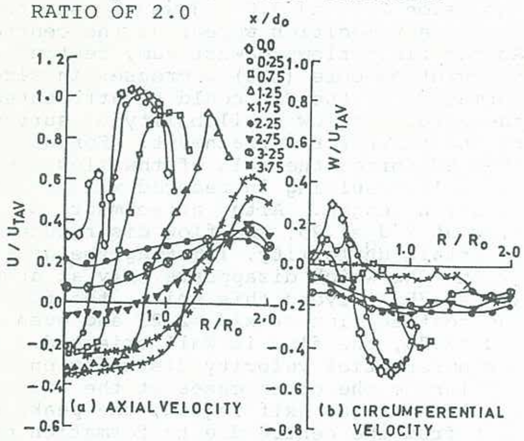


FIG. 6: VELOCITY DISTRIBUTION FOR VARIABLE ANGLE QUARL FOR FIXED EXPANSION RATIO OF 2.0

## Centre Line Static Pressure and Velocity Distribution

Figure 7 gives the centre line static pressure and velocity distribution. It can be seen from this figure that the $C_p$ value is approximately same for all the cases near the jet exit plane. It decreases slightly for the cases where CRC occurred and after $x/d_o$ =1.0, it becomes constant. For the cases, where there is no CRC (expansion ratio 2.0 and 3.0) the pressure remains constant till $x/d_o$ =0.75 after which it falls to a lower value till

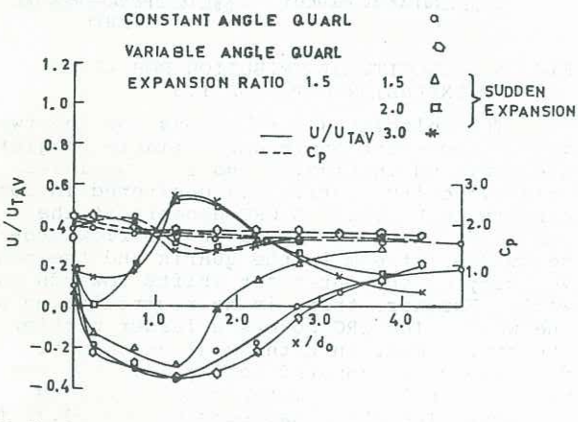


FIG.7: CENTRELINE VELOCITY AND COEFFICIENT OF PRESSURE DISTRIBUTION FOR CONTRA SWIRLING JETS FOR DIFFERENT TEST SECTION SHAPES

$x/d_o$ =1.25. Thereafter it increases and becomes constant beyond $x/d_o$ =1.75. The Centre line velocity plot clearly shows that there is no tendency for recirculation for expansion ratio 3.0. It approaches zero value for expansion ratio 2.0 at $x/d_o$ =0.25. For the other three cases CRC is observed. Further the presence of quarl at the jet exit plane increases the size of the CRC which is maximum for variable angle quarl.

## Wall Recirculation Length

To correlate the formation of wall recirculation with expansion ratio, a cross plot is given in Fig. 8, which shows that the variation of wall recirculation length is non-linear. It is smallest for expansion ratio 1.5.

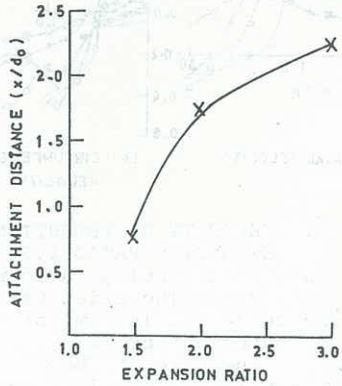


FIG.8 : VARIATION OF THE ATTACHMENT DISTANCE ON THE CONFINED BOUNDARY AS A FUNCTION OF THE EXPANSION RATIO

## Centrifugal Force

The centrifugal force distribution was also obtained which is presented in Fig. 9 for the cases with CRC and expansion ratio 2.0 at a fixed axial location of $x/d_o$ = 0.75. It is observed that centrifugal force peak for the cases of CRC moves towards the wall at an appreciable rate and has a well defined peak where as for the other cases it has a broader peak.

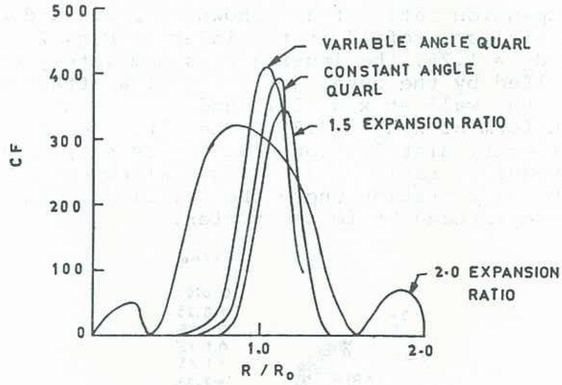


FIG. 9 : CENTRIFUGAL FORCE DISTRIBUTION FOR DIFFERENT CASES AT $x/d_o$ = 0.75

CONCLUSIONS

(1) Guiding the flow between the jet exit plane and confinement duct entry or reducing the expansion of the confinement results in formation of CRC. The width and the length of the CRC is maximum for the variable angle quarl.

(2) Flow is wall oriented for the confinement expansion shapes. Mixing of the flow is better for cases with CRC due to single jet behaviour being observed from the jet exit plane itself. In terms of flow development, expansion ratio 2.0 leads to development much faster than other cases.

(3) The variation of wall recirculation length with expansion ratio is non-linear.

(4) The centrifugal force acting on the flow field had the tendency to pull the flow apart from the centre in those cases where CRC is formed.

(5) The flow behaviour at higher confinement expansion ratios is analogous to unconfined flow conditions.

## NOTATIONS

$C_p$ Coefficient of Pressure $(=(P-P_{AV})/\frac{1}{2}\rho U^2_{TAV})$
CF Centrifugal force (N)
$d_o$ Outer diameter of outer jet
P Static pressure
$P_{AV}$ Average static pressure at inlet
R Radius at the point of measurement
U Velocity component in axial direction (m/s)
$U_{TAV}$ Average total velocity at inlet
W Velocity component in circumferential direction (m/s)
x Axial distance from jet exit plane
$\rho$ Density of fluid (Air)

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