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Technical Notes

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Mean Velocity and Static Pressure Distributions of a Circular Jet

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Nomenclature

d	= diameter of the nozzle
P_s, P_a	= mean static and atmospheric pressure
U_{ec}, U_c	= exit and local centerline mean velocity
ρ	= air density

Introduction

IT is known that negative static pressure exists everywhere in the mixing field except in the potential core immediately adjacent to the nozzle exit where pressure is positive (in the plane jet,[1] round jet,[2] rectangular jet,[3] and square jet[4]). Hussain and Clark[1] explained the existence of negative mean static pressure by the spanwise transverse mean momentum equation. A small decay of centerline mean velocity has been observed in a submerged plane jet,[5] in a submerged pipe jet,[6] and in a free circular jet.[7] Giger et al.[5] explained that secondary currents are developed near the exit of the jet in the form of helical cells. The rotation of these cells is such that high-velocity fluid is transferred toward the boundary surface along the center plane and low-velocity fluid is transferred toward the axis of the jet along the midplane. A significant reduction of the centerline velocity therefore occurs in the range where secondary currents are developed.

Saddle-shape mean velocity profiles are known to exist in asymmetric jets (issued from rectangular,[3] square,[4] and tapered[8] nozzles) and wakes.[9] The profiles appear to move in the downstream direction and seem to disappear beyond the potential core.[5] The profiles apparently are more pronounced in flows from sharp-edged rectangular slots.[10] Trentacoste and Sforza[11] concluded from their experiments that these saddle-shape profiles may exist for circular jets but have been unable to detect them because of their small magnitude. The saddle-shape profile phenomenon may be a result of the superposition of the velocity induced by vortex rings surrounding the jet upon a uniform mean streamwise velocity[12] or a strong pressure-driven secondary flow activity near the exit.[4] Circumferential vortex rings exist in all jet flows, and consequently saddle-shape profiles are observed in the initial region of all jet flowfields.[12]

The aim of the present experiment is to study the axial mean velocity and static pressure in the near field of a circular jet to seek saddle-shape profiles of mean velocity and corresponding profiles of the static pressure.

Experimental Rig and Methodology

The experiment is carried out in an air jet facility consisting of two settling chambers, one fan unit, diffusers, an excitation chamber, and a flow nozzle, as shown in Fig. 1. Air enters the fan unit, through the butterfly valve that controls the air flow. A silencer is fitted at the discharge of the fan to reduce noise generation. Flow from the silencer enters the first settling chamber through a diffuser, where a flow straightener and wire screens are used to straighten the flow as well as to break down large eddies generated at the fan discharge. Next the air passes through the excitation chamber, where two loudspeakers are mounted. The loudspeakers are not used in the current study. Flow then enters the second settling chamber through a nozzle and a second diffuser, where a straightener and wire screens are also used for ensuring axial flow free of large eddies. Finally, air discharges through a circular convergent nozzle (cubic profile) of exit diameter 80 mm (Fig. 1).

In the present experiment, the measurements of axial mean velocity and static pressure are done by the application of pitot-static tube (1.6-mm diam) along with Furnace Control (UK) pressure transducer and Keithly (USA) digital microvoltmeter. The pilot-static tube is traversed with the help of a Mitutoyo (Japan) three-coordinate (x, y, and z) traversing mechanism. The exit centerline of the nozzle in the direction of the flow is taken as the positive x axis, and the transverse distance pointing upward is taken as the positive y axis (Fig. 1). All measurements are done at exit Reynolds number 5.3×10^4. The exit condition is taken 0.5 mm downstream from the nozzle tip.

Uncertainties in the mean velocity, pressure, and Reynolds number are estimated by the single-sample measurement technique[13] (using the uncertainty interval of odds 20:1). It is estimated that the uncertainty of mean velocity is within ±0.431%, pressure within ±1.08%, and Reynolds number within ±0.75%. The lateral turbulent intensities of the jet are estimated to be in the range of 2–14%. The corresponding errors in the measurement of static pressure are found to vary from 0.09 to 2.5%.

Results and Discussion

The centerline mean velocity and corresponding mean static pressure distributions, along with the data of Zaman and Hussain,[14] are presented in Fig. 2 and show that the regular decay of the velocity

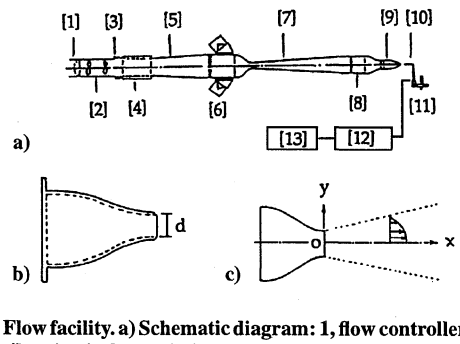

Fig. 1 Flow facility. a) Schematic diagram: 1, flow controller; 2, fan section; 3, vibration isolator; 4, silencer box; 5, diffuser-1; 6, excitation and settling chamber-1; 7, diffuser-2; 8, settling chamber-2; 9, test nozzle; 10, pitot-static tube; 11, traversing mechanism; 12, pressure transducer; and 13, datalogger; b) test nozzle; and c) coordinate system.

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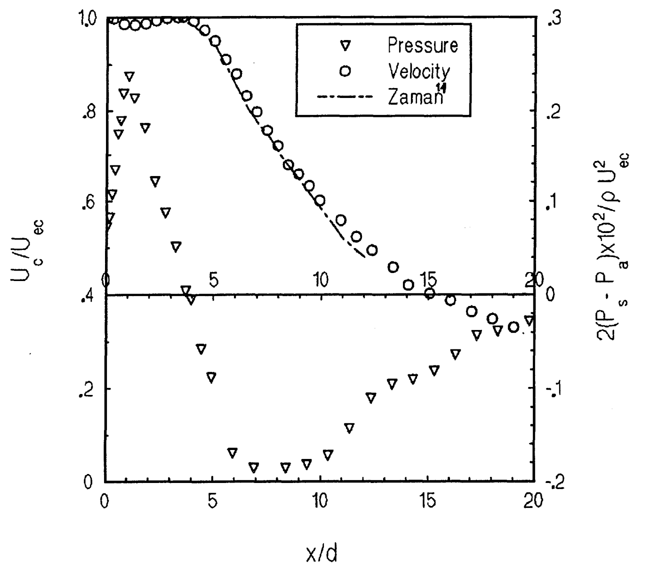

Fig. 2 Mean velocity and static pressure distribution along centerline.

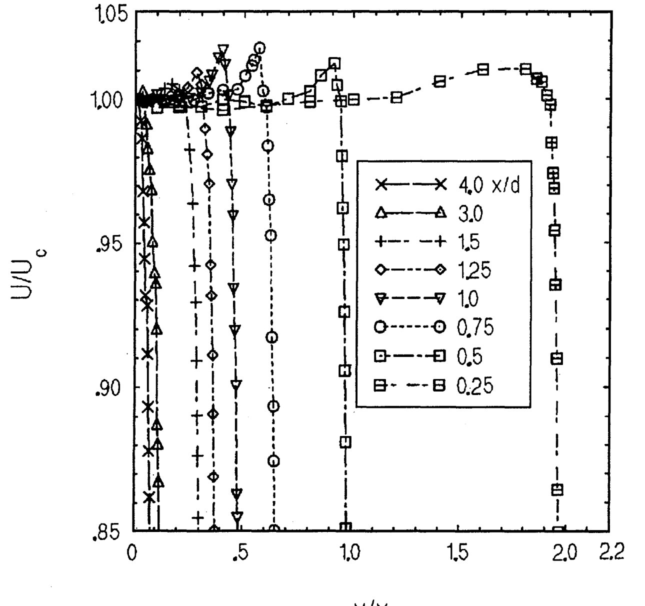

Fig. 3 Streamwise evolution of mean velocity profiles.

starts after $x/d = 4$. From this behavior it can be said that the potential core exists up to $4d$ downstream from the exit. Beyond the potential core, the static pressure is seen to be negative. A small deceleration of the centerline mean velocity (about 1.7% of its exit value at $x/d = 0.75$ downstream) is observed near the exit. From the static pressure distribution curve, it is seen that the centerline positive pressure is maximum at a location $x/d = 0.75$, where the centerline mean velocity is minimum. The similar deceleration of centerline mean velocity near the exit was also observed in a plane submerged jet,[5] in a submerged pipe jet,[6] and in a circular jet.[7]

The streamwise mean velocity profies as presented in Fig. 3 are of saddle shape. The maximum peak velcity of this saddle shape is observed (at $x/d = 0.75$, about 1.75% of its centerline value) in the mixing region, appears to move toward the jet ceterline with the increase of downstream distance, and seems to disappear at the end of the potential core. Similar results are found in the rectangular jet.[3] From the corresponding mean static pressure distribution curve, as shown in Fig. 4, it is seen that the negative minimum pressure occurs at $x/d = 1$, which differs with the location of maximum peak of the saddle-shape mean velocity (at $x/d = 0.75$). This phenomenon was also observed by Quinn and Militzer[4] in a square jet.

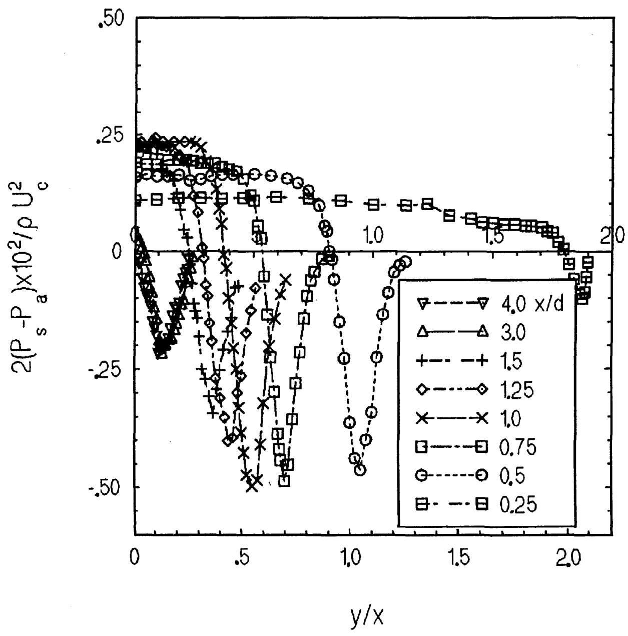

Fig. 4 Streamwise evolution of mean static pressure profiles.

Conclusions

From this experimental investigation in a circular jet, the conclusions are as follows. Small deceleration of centerline mean velocity and corresponding acceleration of static pressure are observed within the potential core close to the exit. The streamwise mean velocity profile showed saddle-shape behavior, which was found to die down beyond the potential core. The corresponding drop of mean static pressure was significant with the saddle-shape mean velocity profile.

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