PRECESSION IN AXISYMMETRIC CONFINED JETS

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ABSTRACT

Particle streak flow visualisation of axisymmetric configurations of fully confined jet flows has revealed significant periods of time in which the jet precesses asymmetrically about the axis. The experimental configurations studied include large sudden expansions and an axisymmetric nozzle within a circular duct with net forward or net reverse flow. The precession frequency for the present experiments has been determined directly by counting cycles from the flow visualisation. Consideration of the idealised configuration of a point source of momentum confined within a duct identifies a frequency parameter (Strouhal number) which is found to be nearly constant for all the flow conditions in which precession was found. Asymmetry and precession of the instantaneous jet results in mixing characteristics which are different from those seen in axisymmetric flow. This observation suggests that any model in which the flow is constrained to be axisymmetric will be of limited relevance.

INTRODUCTION

Confined jet flows have wide application in systems such as mixing vessels, furnaces and ejectors. Many of these applications are axisymmetric with the jet issuing along the axis. The flow around the jet often contains recirculation zones which are integrally related to the mixing between the jet and surrounding fluid. In furnaces the recirculation of hot combustion products can have a significant influence on flame stability, emissions and reaction processes. Understanding the nature of the recirculation is important in understanding the mixing process.

The present research describes the precession which has been observed in a confined jet flow. Precession of an asymmetric jet flow within an axi-symmetric nozzle and cavity of a specific length to diameter ratio has been studied previously by the present authors (Nathan 1988, Luxton and Nathan 1989, Hill et al 1992). Hallett and Gunther (1984) and Dellenback et al (1988) have observed a precession for sudden expansions with an inlet flow having initial swirl. It is shown in the present paper that precession also occurs in simple fully confined jet flows without the presence of initial swirl and it is suggested that the phenomenon may have wider significance.

EXPERIMENTAL TECHNIQUE

Particle trace flow visualisation has been undertaken using 0.6mm neutral density polystyrene beads in water. Three variations of axisymmetric confined jet flows have been examined as shown in figure 1: (1) pipe flow into a blind ended tube (reverse outflow), (2) pipe flow along the axis of a long tube (forward outflow) and (3) a large sudden expansion into a long tube . The diameter ratio of the expansion has been varied from 2.75 to 14. Tests have been conducted over a range of jet Reynolds numbers from 3,200 to 56,000.

OBSERVATIONS

A static view of flow through a large sudden expansion into a long duct is shown in figure 1(3). The exposure is of sufficient duration to identify particle paths. Dynamic observation of the flow reveals that the instantaneous asymmetric flow field precesses intermittently around the duct axis. A similar flow is observed for confined jets with no co-flow for both reverse, figure 1(1), and forward outlets, figure 1(2). It should be emphasised that the flow precession only occurs intermittently, switching between the precession shown and a flow field which is more like an axial jet surrounded by large scale random turbulence.

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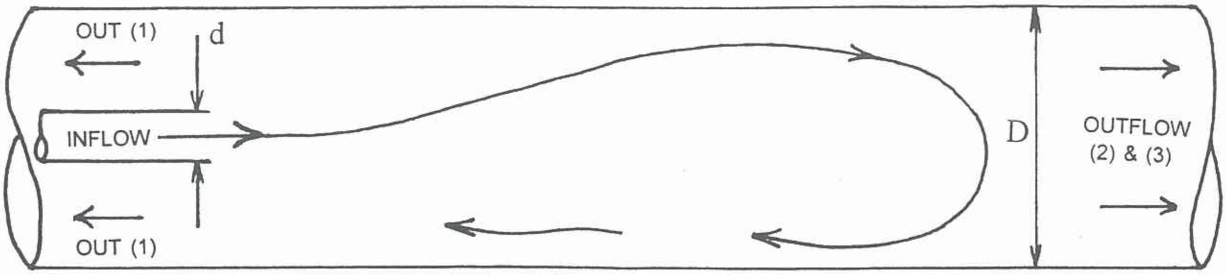
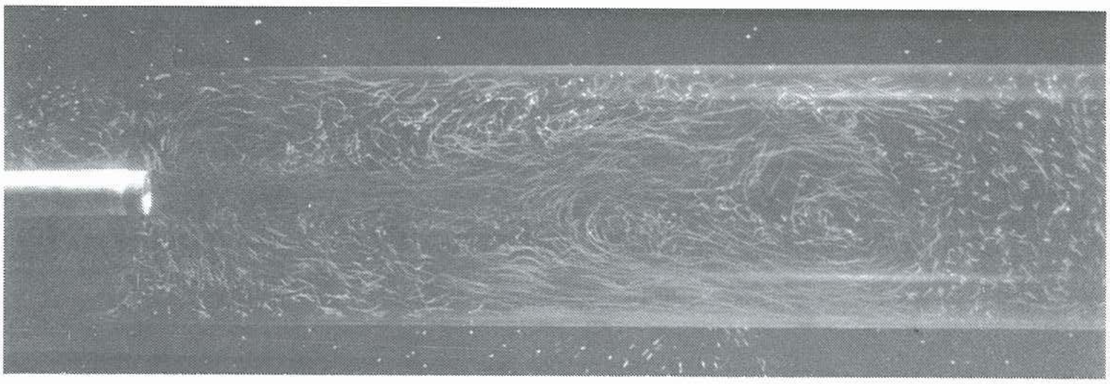
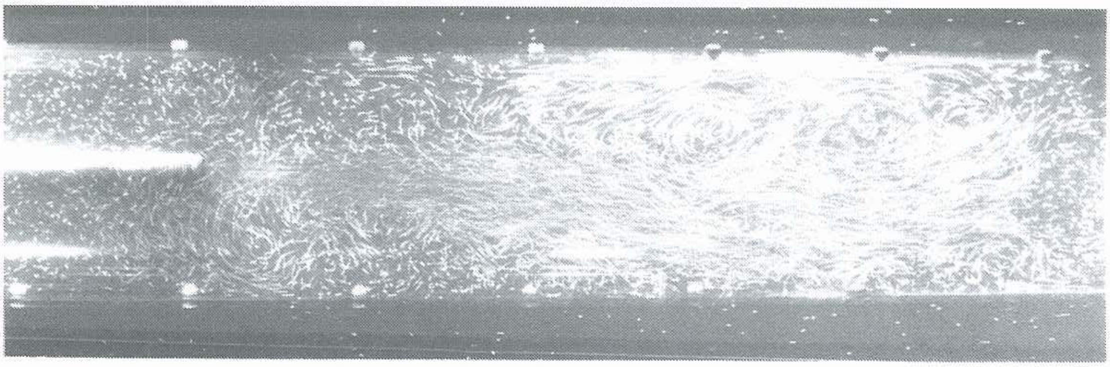
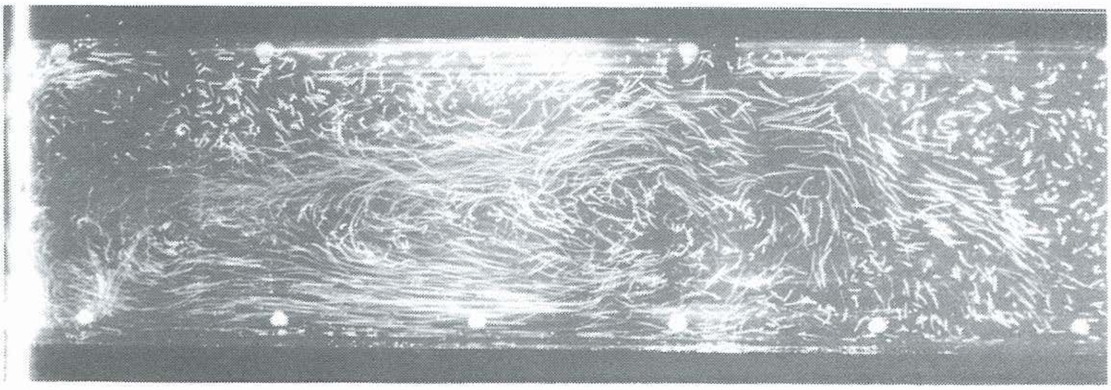




(1) Pipe inflow with reverse outflow. d = 19mm, D = 140mm, Re = 17800. Exposure: 1/4 second, f1.7.



(2) Pipe inflow with forwards outflow. d = 19mm, D = 140mm, Re = 3700. Exposure: 1/2 second, f11.



(3) Smooth contraction inlet to a sudden expansion. d = 16mm, D = 140mm, Re = 8800. Exposure: 1/4 second, f4.

FIGURE 1. CONFINED JET FLOW VISUALISATION

Table 1. Strouhal numbers for different expansion ratios. St(x) = f_p.x / v where x is h,d,D and v = inlet velocity. h is the step height = (D-d)/2. St(eq.1) = Strouhal number as defined by equation 1.

d/D	d mm	D mm	h (step) mm	Re	Count, n	frequency Hz	St(h) (e-3)	St(d) (e-3)	St(D)	St (eq.1) (e-2)
Configuration (3), Sudden expansion										
0.07	10	140	65	7046	8	0.04	2.91	0.45	1.23	9.90
0.07	10	140	65	56538	107	0.27	2.39	0.37	1.01	8.12
0.11	16	140	62	40738	73	0.21	3.97	1.02	0.69	8.85
0.16	22	140	59	15451	20	0.07	4.20	1.57	0.40	7.16
0.16	22	140	59	31646	29	0.14	4.42	1.65	0.42	7.53
0.17	10	60	25	7046	9	0.18	4.91	1.97	0.42	7.98
0.17	10	60	25	21077	50	0.54	4.93	1.97	0.43	8.01
0.27	16	60	22	4406	3	0.14	8.36	6.08	0.32	9.64
0.27	16	60	22	13169	26	0.33	6.68	4.86	0.26	7.71
0.27	16	60	22	40738	13	1.00	6.65	4.83	0.25	7.67
Configuration (2), Pipe inflow, Forward outflow										
0.14	19	140	61	11136	5	0.06	4.74	1.48	0.60	9.17
0.14	19	140	61	17984	52	0.10	4.89	1.53	0.62	9.46
0.14	19	140	61	34456	15	0.16	4.09	1.28	0.52	7.90
						Average:	4.94	2.48	0.54	8.26
						Std dev:	1.55	1.81	0.21	0.81
						Sdev/ave:	0.31	0.73	0.39	0.10

Previous measurements of similar flows in short ducts has shown that the percentage of time for which precession occurs is a function of Reynolds number (Hill et al 1992). This has also been observed qualitatively here. The minimum Reynolds number for which precession has been observed is 3700, though higher Reynolds numbers are required to generate significant intervals of precession. The minimum expansion ratio for which precession has been observed is D/d = 3.75. Only the smallest expansion ratio of 2.7 failed to produce precession. The precession occurs more consistently for larger expansion ratios and for higher Reynolds numbers.

ANALYSIS

It is well known that a fully developed jet can be modelled as originating from a point source of momentum at the jet's "virtual origin". The inlet flow in the present work may be considered to be a turbulent jet and modelled as a point source of axial momentum M, located on the centre-line of a long axisymmetric duct of diameter D. Experimentally it is observed that the resulting flow precesses with a characteristic frequency f_p. It is postulated that this frequency is determined by the parameters M, D and the fluid properties. That is, if the expansion ratio is large enough for the precession to occur, the frequency is independent of the jet inlet diameter d. This leads to normalisation of the frequency to give a Strouhal number St, defined as

$$St = \frac{f_p \sqrt{\rho}\, D^2}{\sqrt{M}} \quad . \qquad (1)$$

The remaining dimensionless parameter is the Reynolds number,

$$Re = \frac{\sqrt{\rho M}}{\mu} \quad . \qquad (2)$$

Experimental data for the frequency of precession has been assembled and analysed to test the above postulate, as described below.

FREQUENCY MEASUREMENTS

Table 1 shows the frequency of precession for several different conditions. Normalisation of the frequency by various candidate parameters is shown. It can be seen that the postulated dimensionless groups described in equations (1) and (2) lead to a good collapse of the data suggesting that the Strouhal number based on the inlet momentum is the appropriate parameter. It is seen that the Strouhal Number is approximately constant with a magnitude in the range 0.07 to 0.10 over the range of Reynolds numbers examined. The error in measuring the frequency is relatively large due to the small number of cycles counted in some instances.

DISCUSSION

Previous work has noted the presence of oscillations in confined jet flows, but the oscillations have not been investigated in detail. Curtet (1958) studied the two dimensional confined jet with co-flow and observed a large scale oscillation of the whole jet for low or zero co-flow. Barchilon and Curtet (1964) investigated axisymmetric confined jets. They described an oscillation viewed using a planar light sheet which is consistent with the present observations of precession. Interpretation of the observations in terms of the precession of the flow was not considered by Barchilon and Curtet. They did not report sufficient details of the oscillation to allow conclusions to be drawn retrospectively. It can only be supposed that what they saw as a two dimensional flapping in the asymmetric configuration is consistent with a two dimensional cross section through a precession around the circumference. Kaji et al. (1979) and Sallam et al. (1980) have reported a flapping motion when a two dimensional jet is injected into a blind cavity. No note was made of any precession for axisymmetric configurations. This may have been due to the short time scale associated with the high air flow velocity and/or to the limited range of expansion ratios investigated. The 2D flapping appears to be related to the fluidic flip-flop nozzle mechanism described by Viets (1975) and further investigated by Mi et al (1995).

CONCLUSIONS

The precessing phenomenon for confined jets described here is consistent with that previously reported in the Australasian Fluid Mechanics Conference series for the "Precessing Jet Nozzle" (Luxton and Nathan 1989, Hill et al 1992). Observation of the precession in this simple flow geometry has lead to a better basis for determining the frequency scaling which is relevant for the Precessing Jet Nozzle (Hill et al 1995). The present paper demonstrates the existence of the phenomenon in a much wider range of configurations. The shortcoming of attempting to model confined jet flows as axisymmetric flow is apparent.

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