THE UNIVERSITY OF ADELAIDE
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STRUCTURES AND TURBULENCE CHARACTERISTICS IN A PRECESSING JET FLOW

submitted by

Gerald Manfred Schneider

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SUMMARY

The precessing jet (PJ) flow phenomenon can occur as a natural fluid mechanical instability in a 'fluidic' nozzle. In that nozzle an axisymmetric jet passes through a large abrupt expansion into a cylindrical chamber of suitable length. When the dimensions of the chamber are appropriate, the jet attaches asymmetrically to the inside wall, is deflected at the chamber exit, leaves at an angle relative to the geometric axis and precesses about that axis. The jet precesses with a characteristic frequency which is a function of the chamber length and diameter and of the flowrate. If, in addition, a lip is placed at the exit of the chamber, the exit angle of the jet can be increased to 45° or more. The exit angle, the jet diameter and the frequency of precession all fluctuate wildly about the characteristic values from cycle to cycle. To simplify the collection of phase-averaged experimental data and so to allow the effect of precession on the external flow field to be investigated, it is necessary to have control of the characteristic variables. This is not possible with the 'fluidic nozzle' described above.

The present thesis reports on a fundamental investigation of a precessing jet flow which is analogous to that which emanates from the fluidic nozzle. A 'mechanical nozzle' is used to generate a well defined PJ flow. A circular jet is located on, and inclined relative to, an axis about which the nozzle is mechanically rotated. In this mechanical analogue of the fluidic nozzle flow field, the precessional frequency can be varied independently of the exit velocity. Thus, unlike the fluidic nozzle, the precessional Strouhal number is decoupled from the Reynolds number ($Re = u_e \cdot d_e / \nu$).
Nathan (1988) proposed that the key parameters which control the flow in a fluidic nozzle of a fixed length to diameter ratio could be characterised by a non-dimensional Strouhal number of precession, $St_p = f_p \cdot d_e/u_e$, where $f_p$ is the frequency of precession, $d_e$ is the exit diameter and $u_e$ the exit velocity of the jet. The exit angle was recognised as a significant parameter in the PJ flow. One exit angle only, $\alpha_e = 45^\circ$, is examined in depth in the present thesis. For this particular angle the influence of the precessional Strouhal number and of the Reynolds number on the flow field are each explored systematically and independently. For the fully turbulent flows investigated here the Reynolds number has negligible effect on the structure of the flow.

Qualitative images of the changes which occur in the flow field as the Strouhal number is varied, based on conditional smoke pulses and on a laser sheet visualisation technique, are reported for a precessing jet of air issuing into air. For a precessing water jet issuing into water, the field is imaged by use of laser induced fluorescence (LIF). Quantitative velocity and pressure data obtained from hot-wire anemometry, from a high frequency response pitot–type ‘Cobra’ pressure probe and from a three dimensional Laser Doppler Anemometer system are reported. Mean velocity, static pressure and turbulence intensities in both the time–averaged and the phase–averaged domains in all three dimensions are documented and related to the flow visualisations. Reynolds stresses are presented in the phase–averaged domain only where the phase–averaging is tied to the frequency of precession. In addition, frequency spectra and the skewness and flatness have been obtained from the time–averaged velocity data.
Large differences have been identified in the character of a precessing jet flow as the precessional Strouhal number is varied. Using the Strouhal number definition for the precessing jet flow examined by Nathan (1988), as described above, a 'low' Strouhal number regime has been found to occur below \( St_p = 5 \times 10^{-3} \) and a 'high' Strouhal number regime has been identified above \( St_p = 9 \times 10^{-3} \), although the transition between these regimes appears to be gradual.

The flow field identified here as the low Strouhal number regime displays characteristics which are almost identical to those of a simple turbulent jet. Each vortex structure follows a straight line path from its origin, resulting in an overall flow which is described well by a projected Archimedian spiral of low curvature. Negligible asymmetry is found in the pressure gradients.

The flow in the high Strouhal number regime is dramatically different. A low pressure region and a recirculation zone are established in the near field and the path of the jet is changed significantly. The jet spirals out from the nozzle around the recirculating flow zone. The streamlines of the jet are curved, both radially towards the spinning axis, and tangentially in the direction opposite from that of the precession. Meanwhile flow is drawn toward the recirculation zone from the region which is not instantaneously occupied by the jet. The path of the 'individual' vortex structures in the jet, which appear to be very similar to vortex puffs, assumes a helical (spiral) shape whose radial extent seems to asymptote to a well defined radius within the near field examined here. The jet velocity decays much more rapidly and Reynolds stresses are much higher than in a simple turbulent jet. In the flow field downstream from the recirculation zone the flow
becomes axisymmetric in the mean. The vortex puff structures cannot be found when phase-averaging at the frequency of precession and the frequency spectra in this flow region do not carry any obvious information from which the frequency of precession, or any other dominant frequency, can be identified.

The thesis is the first fundamental work on precessing jet flows and will build an important basis for further research. To perform this work a novel experimental methodology has been developed and refined. Through this it has been established that the Strouhal number of precession is the dominant parameter in a precessing jet, while the Reynolds number has been shown to have only a second order effect on the flow. The fundamental parameters which remain to be investigated are the exit angle, the shape of the exiting jet and the significance of 'jitter' in the frequency. Each of these parameters has been found to influence the behaviour of the fluidic precessing jet and an improved understanding will facilitate the optimisation of these flows for the practical applications. Use of the mechanical nozzle concept and measurement methods has been shown to contribute to a greater understanding of precessing jet flows.