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EXPERIMENTAL MEASUREMENTS AND COMPUTATIONAL PREDICTIONS OF THE INTERNAL FLOW FIELD IN A PRESSURE SWIRL ATOMIZER

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ABSTRACT
The results of LDA measurements within the swirl chamber of a large scale pressure swirl atomizer are presented. Three outlet geometries, conical, curved and square are considered. Axial and tangential velocity components are measured, and the radial component is determined using mass continuity.The measurements confirm CFD predictions of Gortler wall vortices and central recirculation zones.

INTRODUCTION

The experimental part of the work was prompted by the need for experimental data suitable for CFD model validation for pressure swirl atomizers. As far as can be ascertained the only data available on the internal flow are those from the work of De Keukelare [1] and from the LDA measurements of Horvay and Leuckel [2,3]. In particular the latter measurements lacked the density of measurement points for confirmation of peculiarities in the internal flow pattern suggested by CFD predictions.

The computational work was run in parallel using the same geometric and flow conditions with the two sets of results being brought together at the conclusion of the work. At the same time the experimental data were compared with previous computational work undertaken by Chinn and Yule [4] and Yule and Chinn [5].

EXPERIMENTAL APPARATUS.

The atomizer

The atomizer was constructed from Perspex in modular form so that the number of inlet ports, length of swirl chamber and outlet geometry could be changed independently. For the purposes of this paper, as shown in Fig [1], the length was kept constant and two inlets were used, with three outlet configurations. The working fluid was supplied to the atomizer from a holding tank by means of a centrifugal pump via a flowmeter .

A bypass valve was installed at the outlet of the pump so that it could be run at its optimum performance.
The working fluid was fed into a plenum chamber immediately above the atomizer body so that any swirl and entrained air could be removed. The flow rate was 0.436l/s the mean inlet velocity was 1.65m/s and Re =21000

LDA system

The experimental measurements were taken by means of a DANTEC single component LDA system used in 10 deg off-axis backscatter mode with 3000 validated samples being obtained at each measurement position, the optics being rotated 90 deg about the optical axis to obtain the mean and fluctuating U (axial) and W (tangential) components. The measuring volume effective length was approximately 0.2mm. The radial spacing of data points was between 0.8 and 1.8 mm depending on the geometrical position along the atomizer.

The transmitting and receiving optics were mounted on a XYZ traversing system with a positional resolution of 0.1mm. Measurements were made across one vertical plane through the centre line. Separate checks were made for axisymmetry. All measurement positions were corrected for the displacement effects caused by refraction of the laser beams.

EXPERIMENTAL RESULTS

The data were first high pass filtered to remove noise caused by light scattering from the atomizer walls and from the air core/liquid interface. Then, for each set of U and W data, the mean and rms were plotted. The V component was computed from the U velocity gradient by means of the mass continuity equation i.e.:

$$\frac{\partial U}{\partial x}+\left(\frac{1}{r}\cdot\frac{\partial rV}{\partial y}\right)+\frac{\partial W}{\partial q}=0$$, and assuming W is axisymetric then, $$V=\frac{1}{r}\int r\frac{\partial U}{\partial x}dr$$

The U data in Fig [2] are shown as iso-contours and they indicate Gortler type vortices appearing in the near wall region. These vortices were predicted in earlier work by Chinn and Yule [4]. The vectors and streamlines in the U-V plane, in Fig [4,5], clearly show the central recirculation zones for the three atomizers.

Fig [3] shows, as an example, the mean velocity measurements for the conical nozzle atomizer. In all atomizer cases the mean $\overline{W}$ component $\left(\overline{W} = W / U_{inlet}\right)$ shows an increase in magnitude from the wall to a value near unity, this agrees with what is expected for a free vortex with a wall boundary layer. Outside the boundary layer $\overline{W}$ follows the (1/r) proportionality for a free vortex. $\overline{W}$ reduces when approaching near the air core and this indicates the vorticity-containing regions of the centre of the free vortex. The change in the $\overline{W}$ profile, in Fig [3], is quite complex, i.e. the profiles for $6mm \leq x \leq 13mm$. It is seen that the $\overline{W}$ profile is almost flat near the exit of the convergence. The $\overline{U}$ profiles in Fig [3] have their highest values in the vorticity-containing region near the air-core. Smaller negative values in the free-vortex region show that there is a recirculation zone here. The $\overline{V}$ values are much smaller than those for $\overline{U}$ and $\overline{W}$. In general, the positive $\overline{V}$ near the air core is expected due to the expansion of the core as the flow proceeds to the outlet. The negative values at x=32mm appear to be due to a small standing wave on the air-core. Geometrical restrictions have prevented making measurements in the outlets of the atomizers.

Near the air-core boundary several small vortices or waves can be detected and these seem to correspond to the same axial position as standing waves on the air-core/liquid interface which can be clearly seen in high speed videos taken of the atomizers. It is believed that the small vortices are a result of fluid recirculation due to these waves. As seen in Fig [4], immediately before the commencement of the exit orifice the air-core increases in radius and this has the effect, especially in the cases of the angled and curved outlets, of compressing and distorting the U velocity contours.

In the main body of the swirl chamber the rms levels, not shown here due to space constraints, are similar for all three geometries averaging 10% of the mean U velocity. As the flow approaches the exit orifice the average level of fluctuations rises in the case of the curved and conical outlets, this is probably due to the reduction in cross sectional area. It is hypothesised that the velocity fluctuations are mainly a result of movement of the recirculation zones, possibly via precessing of the free vortex, rather than true turbulence.

If one looks at the U streamlines in Fig [5], at first appearance the curved and conical outlets look very different from the square outlet however on closer examination the streamline patterns in the case of the square outlet are quite similar but are more stretched in the axial direction.

Figure [6], from Yule and Chinn [5], shows a computed velocity field for a similar (although not identical) atomizer geometry to that of the conical convergence atomizer used here. The time-stepped predictions show that the flow reversal in the main “free vortex” body of the flow is intermittent. At the stage shown in Fig [6], the streamline pattern is qualitatively similar to the measurements shown in Fig [5].

CONCLUSIONS

A detailed series of LDA measurements has been made of the internal flows of pressure swirl atomizers with three nozzle geometries. The basic swirl chamber flows were in accordance with previous CFD predictions. Principle features include concentration of the through-flow either near the wall or near the air core, strong reduction of the tangential velocity component in the rotational flow near the air core, due to deviation from a free vortex, Gortler vortices near the wall and recirculation in the main body of the swirl chamber flow. Both standing and travelling waves were visible on the air core.

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[5] **Yule A.J. and Chinn J.J**. *The Internal Flow and Exit Conditions of Pressure Swirl Atomizers,* Internal Report, Dept. Mech. Eng. UMIST, submitted to Atomisation and Sprays, Oct. 1998

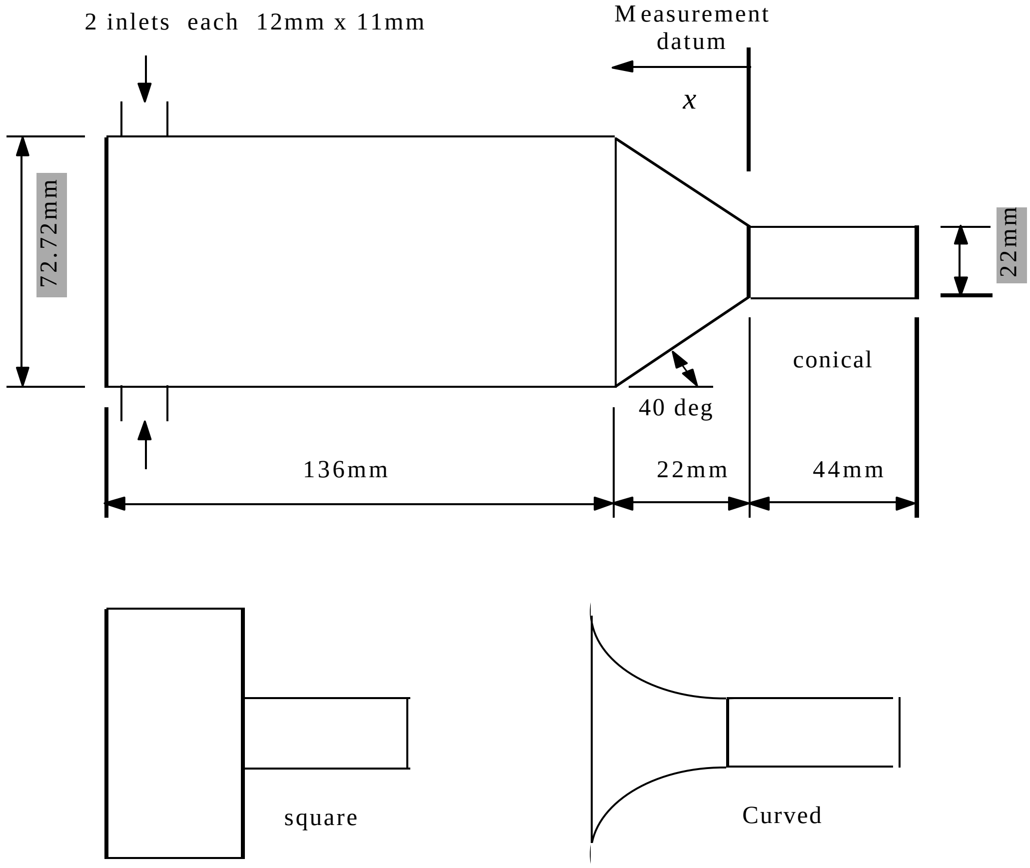

Fig [1] Experimental Atomiser Details

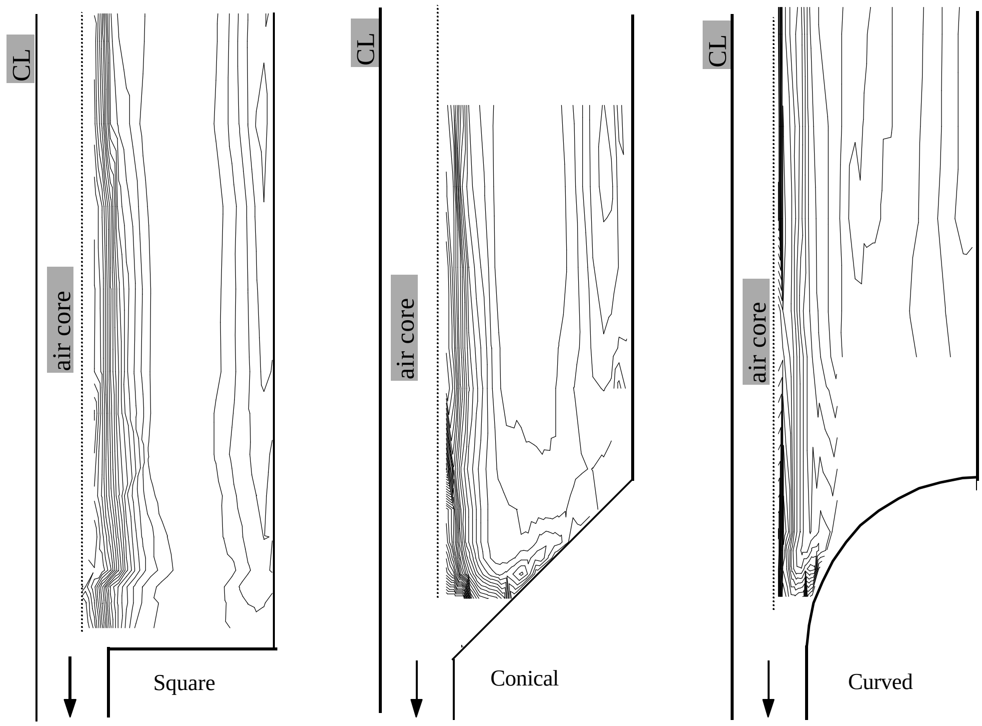

Fig 2. U Iso-contours

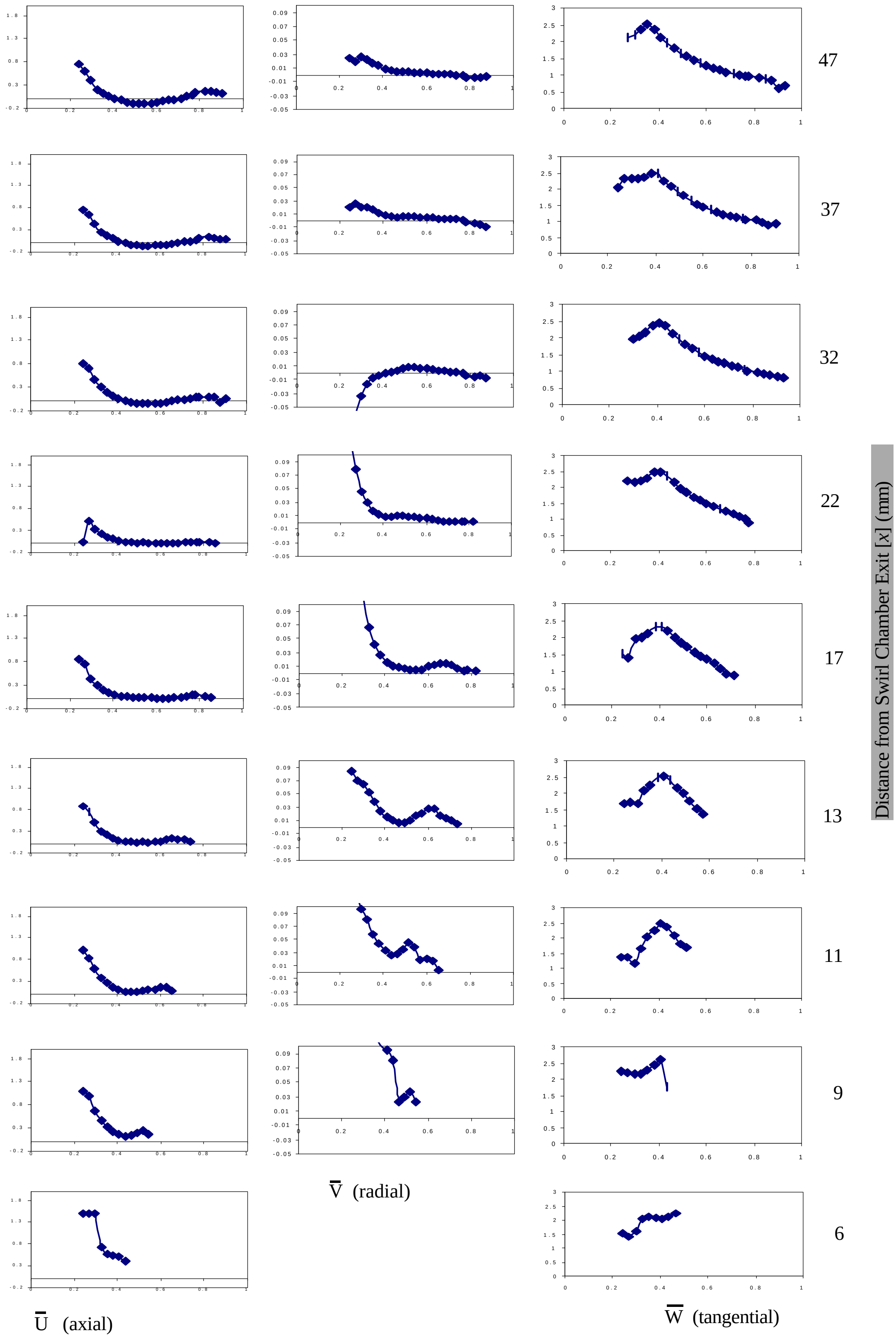

Fig 3 Conical Convergence Atomizer

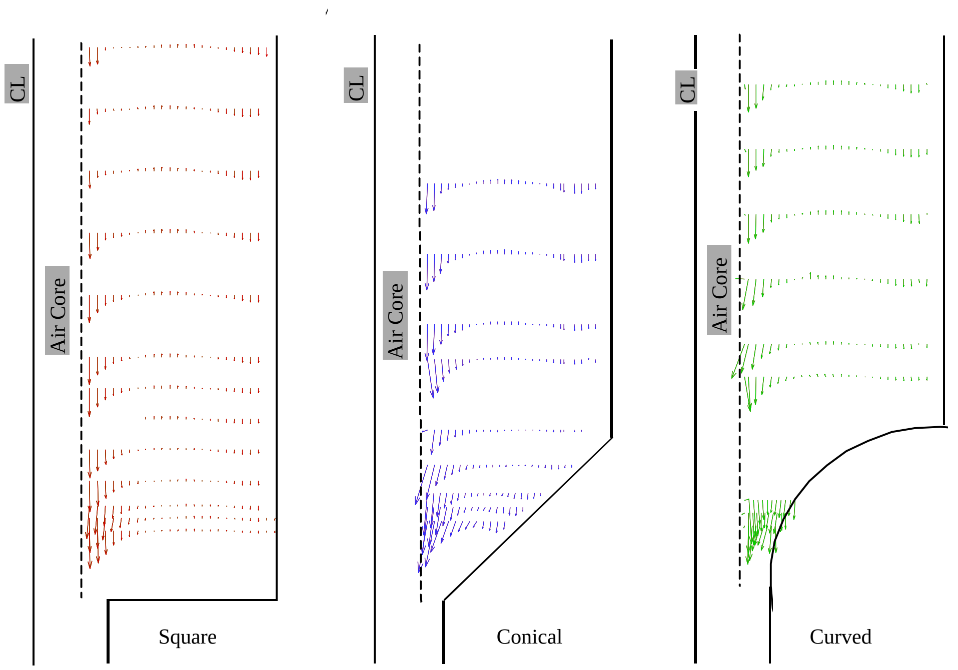

Fig 4 UV vectors

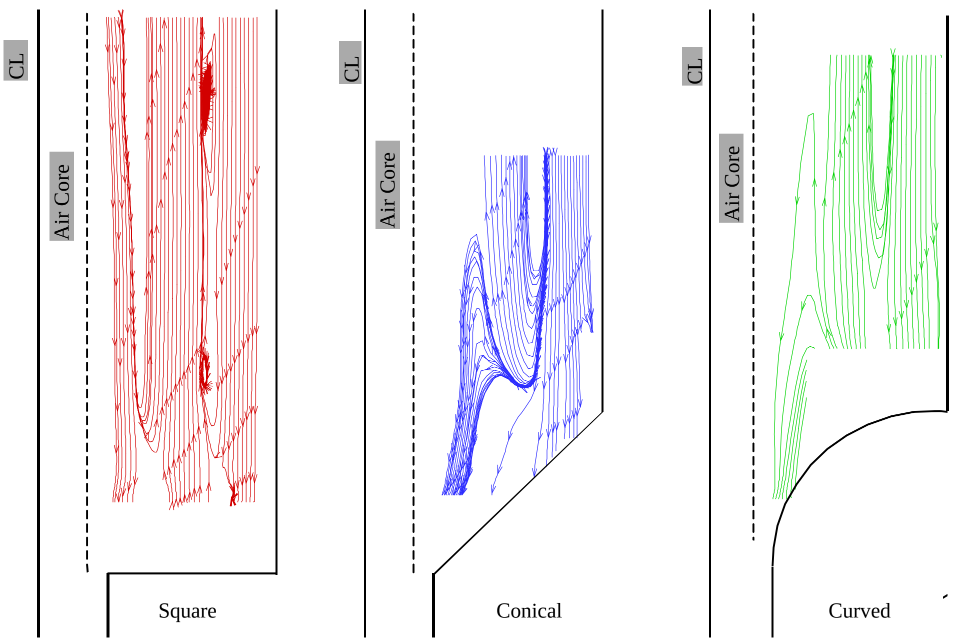

Fig 5 UV Streamlines

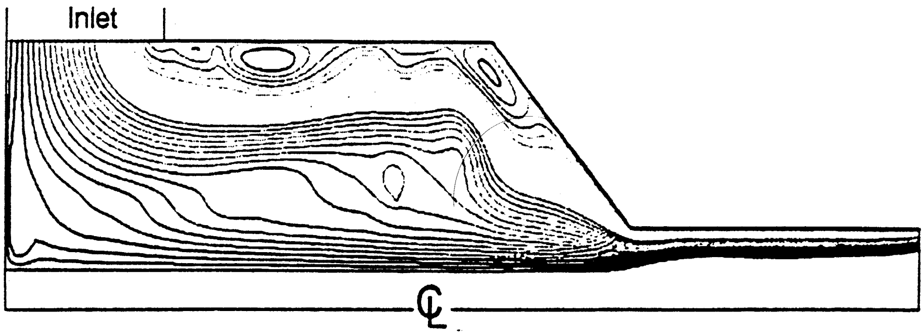

Fig 6 Computed Velocity Field Conical Convergence