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INVESTIGATIONS OF A PLANE LIP JET FROM A NARROW SLIT

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ABSTRACT

A lip jet occurs when a jet leaving a nozzle has a solid boundary on one side parallel to its axis. This report presents results on the physical properties and the possible impact of nozzles on the lip jet. The nozzle had a width of 0.2 mm and an aspect ratio 350. As the lip length was increased from 0 to 100 mm, the jet width near the end of the lip also increased but the jet maximum velocity and profile symmetry decreased. When channel length, distance from the nozzle reservoir to the exit, was changed from 1 to 10 mm the velocity profile remained 'bullet shaped" and there was no significant changes to the jet properties. When a 10° transition slope was introduced between reservoir and the channel, the jet velocity profile was slightly flatter than the previous 1 mm channel nozzle. The slope also increased the air entrainment and downstream velocities were higher but it did not change the jet growth. Varying the trailing edge angle of the nozzle from 90° to 30° did not affect the jet development.

INTRODUCTION

Lip jets are used in industrial application to convert high pressure air to low pressure high volume flow. The nozzle used in these applications have a width less than 1 mm and an aspect ratio greater than 300. A free jet is generated by a nozzle without an obstruction after the nozzle slit. A lip jet is generated by a nozzle with an extended lip on one side of the nozzle slit (Figure 1). A lip jet has properties similar to a wall jet with the difference that the wall jet has an infinite longitudinal extent. A wall jet occurs when a jet similar to the ambient fluid impinges on a surface or flows parallel to a solid body.

The mean velocity profiles for the extent of the lip can be calculated using the theoretical analysis of a wall jet spreading over a plane surface for two dimensional flow by Glauert (1956). The critical Reynolds number for a wall jet determined by Chun and Schwarz (1967) would also apply to the lip jet. The entrainment of ambient fluid into the lip jet was described by Winant and Browand (1974) and Bajura and Catalano (1975). Winant and Browand (1974) observed the turbulent mixing layer between two parallel streams at different velocities exhibited vortex pairing for moderate Reynolds numbers. Bajura and Catalano (1975) qualitatively and quantitatively investigated five transition stages of a two dimensional wall jet.

Ho and Hsiao examined the evolution of coherent structures in a lip jet and a free jet using a wind tunnel with a nozzle height of 25.4 mm and an aspect ratio of 24:1. The effect of the distance from the lip nozzle slit on the velocity profile was compared with the relative distance from the free jet for the length of the 50.8 mm and 254 mm lips.

The purpose of the this current study is to investigate the flow development of a lip jet after leaving the lip. The effect of modifying the nozzle configuration was studied by varying the length of the lip, the distance from the reservoir to the nozzle exit as well as the angle of trailing edge of the lip.

EXPERIMENTAL CONDITIONS

Experiments were carried out by using compressed air as a source of supply for free jets. The two dimension nozzle (Figure 1) was supplied with compressed air into the reservoir. The air flows from the reservoir through the channel and out of the nozzle exit. The channel width d is set by the shim. The nozzle has a modular design so that the distance from the reservoir, length of lip and trailing edge angle could be readily altered without the need to have separate nozzles. The nozzle aspect ratio was varied from 140 to 1400 by replacing a 0.5 mm stainless steel shim with a 0.05 mm shim between the top and base sections. A 0.2 shim was used for this current study. The length of the lip L can be varied from 0 to 100 mm by sliding the top section and shim along the base. The channel lengths were also varied from 1, 2.5, 5 and 10 mm. The 1 mm channel nozzle was compared with a nozzle that had a 10° transitional slope between the reservoir and channel (Figure 1). The effect of the trailing edge angle was investigated for two angles of 30° and 90 °.

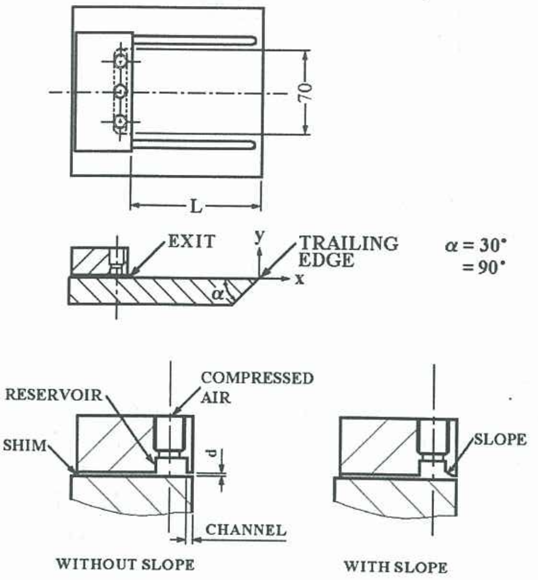

Figure 1: Nozzle Configuration

The mean velocity profiles were measured using a single 5 mm hot-wire probe operated in a constant temperature mode. The position of the hot wire probe was controlled by a computerised x-y traverse system. The hot-wire probe was calibrated using a pitot tube in a free jet. The hot-wire signals were digitised using a 12 bit A to D converter and stored on a computer for processing.

RESULTS AND DISCUSSION

The effect of lip length on jet development

The lip length L from the nozzle exit to the lip trailing edge was increased from 0 to 100 mm. The channel length was 5 mm, the trailing edge angle a was 90°, and the nozzle was supplied with 50 l/min of compressed air.

The mean velocity profiles at x/d = 5 (Figure 2) indicates the profiles become more skewed as L/d increases from 0 to 500. The mean velocity U was normalised by the maximum mean velocity U_{max} and distance in the y-direction was normalised by profile width b. The width of the jet was assumed to be the distance between the y locations either side of U_{max} where U/ U_{max} was equal to 0.1.

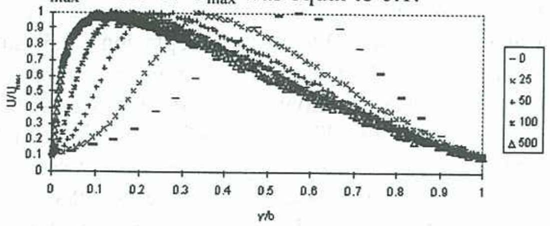

Figure 2: Lip jet mean velocity profiles at x/d = 5

The mean velocity profiles were more symmetrical as x/d increased to 25 (Figure 3) with the exception of L/d = 500. At L/d = 500 the jet had developed a boundary layer profile which resulted in a skewed velocity profile up to x/d = 250.

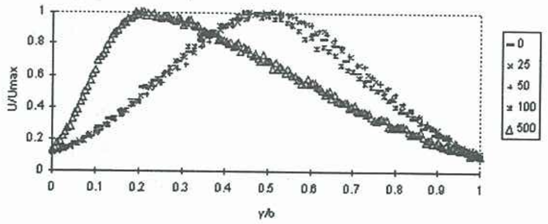

Figure 3: Lip jet mean velocity profiles at x/d = 25

The influence of x/d on U_{max} decreases as L/d increases (Figure 4). For L/d = 0, U_{max} decreased from 68 m/s at x/d = 5 to 32 m/s at x/d = 25 and was 9 m/s at x/d = 250. For L/d = 500 U_{max} was 9.5 m/s at x/d = 5 and only dropped to 6.7 m/s at x/d = 250.

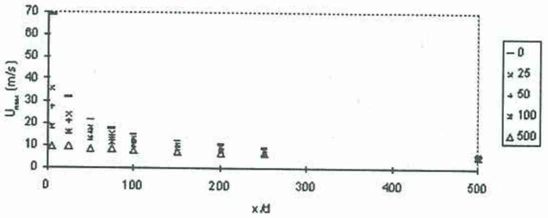

Figure 4: Effect L/d on U_{max}

The growth of the jet from the trailing edge was less symmetrical about the jet centreline as the lip length increased (Figure 5). The boundary of the jet was assumed to be at the y location where U/ U_{max} was equal to 0.1.

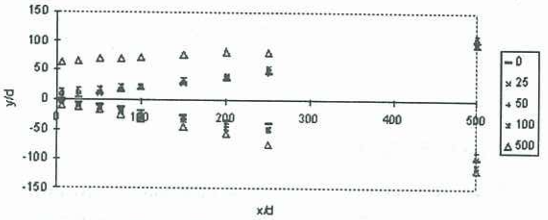

Figure 5: The effect of L/d on jet growth rate.

Effect of nozzle channel on jet performance

The channel length from the reservoir to the nozzle exit was increased from 1 to 2.5, 5 and 10 mm. The nozzle width d was 0.2 mm, the trailing edge angle a was 90°, the lip length was 0 and the nozzle was supplied with 50 l/min of compressed air.

The mean velocity profiles at x/d = 5 (Figure 6) indicates there is no significant change as the channel length increases.

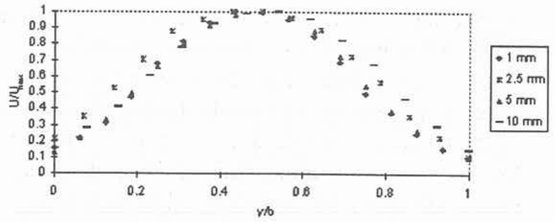

Figure 6: Effect of channel length on the mean velocity profile.

The length of the channel did not significantly affect the decrease in U_{max}, as x/d was increased from 5 to 200 (Figure 7). For a channel length of 5 mm the decrease was initially slow from x/d = 5 to 50 followed by a decrease at a slightly higher rate to x/d = 200 than for the other channels lengths.

U_{max} is initially sensitive to x/d and decreases by 60% at x/d = 25 and 75% at x/d = 50. When x/d is greater than 50 the reduction in U_{max} is less and is almost constant from x/d = 250 to 500. The growth rate of the jet is only slightly affected by the channel length as x/d increases from 5 to 250 (Figure 8). The increase of the volumetric flow rate as x/d increased also appears independent of channel length (not shown).

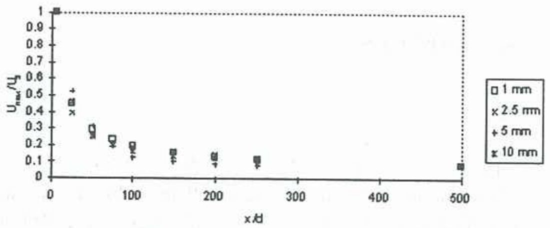

Figure 7: Effect nozzle channel length on U_{max}.

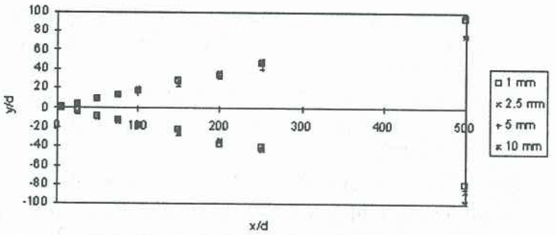

Figure 8: Effect of x/d and nozzle channel lengths on growth rate.

Transition between the Reservoir and Channel

The nozzle parameters of gap width, trailing edge angle, lip length and supply flow rate were kept identical to the previous experiment. Both nozzles had a 1 mm channel length but one had a 10° transitional slope from the reservoir to the channel while the other had a sudden reduction from the reservoir to the channel (Figure 1).

The normalised velocity profile at x/d = 5 (Figure 9) of the jet with the 10° transition is flatter than the "bullet shaped" profile of the other jet.

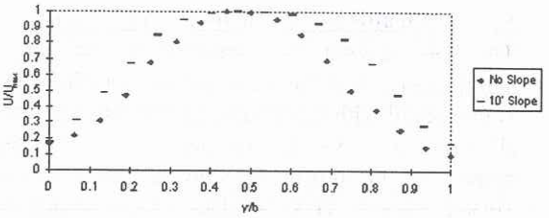

Figure 9: The effect of the transition from the chamber to channel on the velocity profile.

When the nozzle had a 10° transitional slope U_{max} decreases at a slower rate as x/d increases from 5 to 250 (Figure 10). The difference between the two curves reduces as x/d increases from 17% at x/d = 5 to only 3% at x/d = 250.

The growth rate of the jets was not significantly affected by the 10° transitional slope (Figure 11).

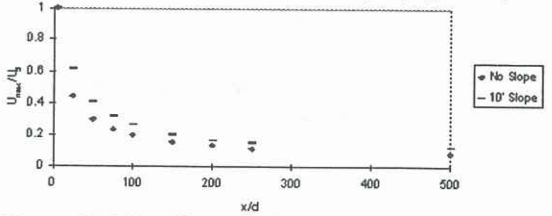

Figure 10: The effect of the chamber transition on U_{max}.

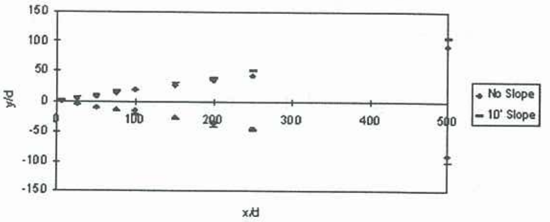

Figure 11: Effect of transition on the jet growth.

The volumetric flow rate of the jets with and without 10° transition at x/d = 5 (Figure 8) were within 2%. The volumetric flow rate Q was normalised by the volumetric flow rate Q_5 at x/d = 5. The difference increases to 62% as x/d increases to 50 followed by a decrease to 31% at x/d = 200. The jet with the 10° slope had a 45% higher flow rate at x/d = 500.

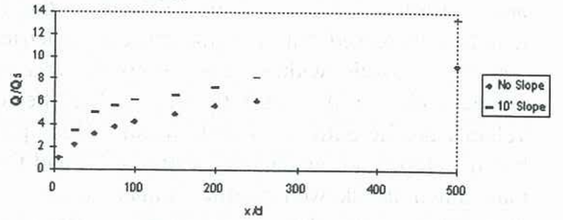

Figure 12: Effect the chamber transition on the Q.

Effect of trailing edge on Jet Performance

The base trailing edge angle α of 30° did not significantly skew the mean velocity profile when it is compared with the results for 90° base at x/d = 5 (Figure 13). The difference between the profiles is caused by 30° profile finishing above U/Umax = 10% at y/b = 1. This was due to the 0.02 mm limit of movement of the x-y traverse table used to measure the profile width of 0.26 mm.

U_{max} decreased at faster rate as x/d increased for the 30° base (figure 14). The 30° base did not improve the entrainment of air and actually reduces it as x/d increases from 75 to 500 (Figure 15).

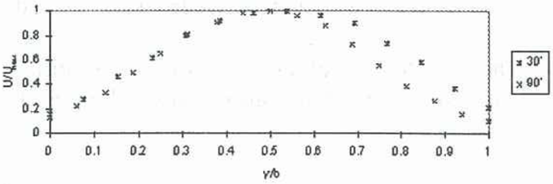

Figure 13: Effect of α on the mean velocity profiles at x/d = 5.

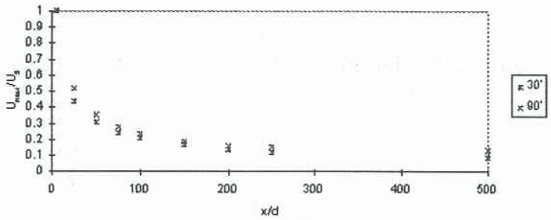

Figure 14: Effect of α on U_{max}.

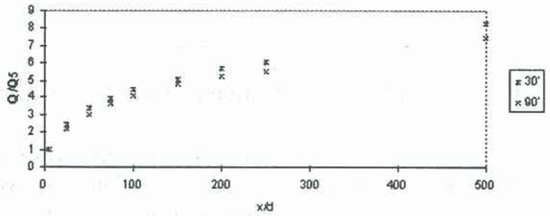

Figure 15: Effect of a on Q

CONCLUSION

The mean velocity profiles of the lip jet near the nozzle trailing edge are more skewed as the lip length is increased but become more symmetrical within 25 nozzle widths. The exception was the nozzle with a L/d = 500 lip that had a skewed velocity profile until 250 nozzle widths. This lip jet had developed a boundary layer on the lip and thus maintained its skewed profile. Umax at x/d = 5 decreases as the lip length was increases but at x/d = 500 all the jets had a similar maximum velocity. The initial jet width at x/d = 5 increases as the lip length increases but the width at x/d = 500 was independent of the lip length.

Increasing the channel length from 1 to 10 mm from the reservoir to the nozzle exit does not have a significant effect on the jet velocity profile, downstream maximum velocity or growth rate.

The 10° transitional slope from the reservoir to the channel flattens the initial velocity profile at x/d = 5 compared with a nozzle that has a sudden reduction from the reservoir to the channel. U_{max} of the nozzle with a 10° slope is higher as x/d increases and the entrainment of air into the expanding jet also increases but it does not affect the jet growth rate. The combined effect of the transitional slope and changing the channel length will be investigated later in the project.

The trailing edge angle does not appear to have a significant effect on the jet development.

This report presents results of preliminary investigations and there are several areas yet to be examined including the following;

-changing the nozzle height.

-spectra of velocity fluctuations to identify any characteristic frequencies.

-turbulence measurements

ACKNOWLEDGEMENT

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