2005 ME Graduate Student Conference
April 9, 2005

3D-DIMENSIONAL FLOW MEASUREMENTS IN SQUARE COAXIAL JETS

Thomas Lagarde
M.S. Candidate

Faculty Advisor: Dr. Dimitris Nikitopoulos

ABSTRACT

Results of a study of the three-dimensional flow emanating from coaxial contoured nozzles with a square cross section are going to be presented and discussed. Two experiments were conducted with the inner to outer jet velocity ratio equal to λ=0.5 and λ=1.5. The Reynolds number of the outer jet based on the hydraulic diameter of the outer nozzle exit was 15,300. A hot-wire anemometry method was used for the measurement of mean-velocity components and Reynolds stresses using an X-probe. A methodology to correct for velocity gradient effects and 3-D turbulence was developed and implemented.

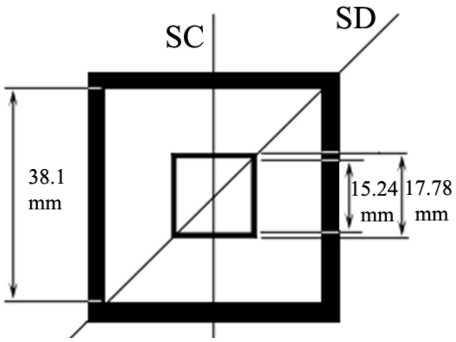

Figure 1: Square coaxial nozzle exit geometries and scan planes for square jets measurements

Many flow measurement techniques are making the assumption that the two wires of the X-probe are located at the same point in space. In reality, the wires are built a small distance $\delta \approx 1mm$ apart from each other to avoid prong interference. As pointed out by Bell and Mehta (1989) [1], a velocity gradient in the direction perpendicular to the plane of measurement can result in errors in the estimation of the velocity components. Post-processors of commercial constant temperature anemometry systems do not take into account the effect of velocity gradient. It is yet possible to apply a correction afterward using the method proposed by Bell and Mehta (1989) [1]. This method is accurate in purely 2-dimensional flows, but results are biased in 3-dimensional flows. This research proposes a technique inspired from Müller (1982) [2] where a gradient correction is added. It is adapted to three-dimensional flows where the mean velocity component $\overline{W}$ in the direction perpendicular to the plane of the wires is null, or approximately so, but where fluctuations w' in the same direction are not negligible. Data reduction is based on Jörgensen's equation in the most generalized form, keeping the terms standing for the sensitivity of the sensor to normal and tangential velocities in and perpendicular to the plane of measurement of the X-probe. The data used are acquired with the X-probe successively orientated at each location of the jet stream in two different orientations: the probe is first positioned so that the two mean velocity components remain in the plane of the sensors, then the probe is rotated around its axis by a 90° angle.

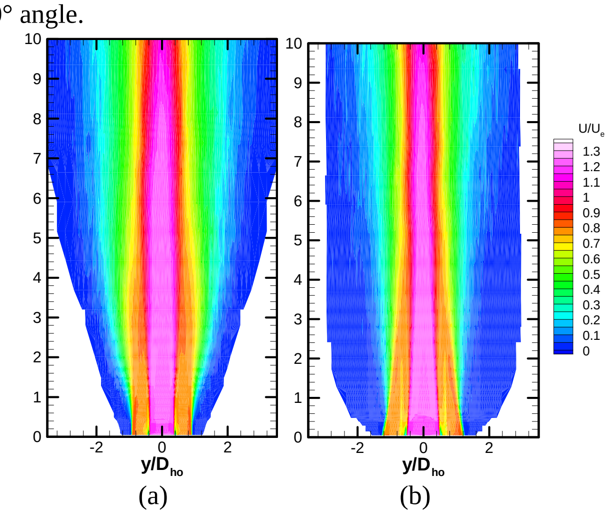

Figure 2: Axial mean velocity evolution for the coaxial jet (a) Side Plane of the square jet, (b) Diagonal Plane of the square jet; all at Re_{hi}=16,000, λ=1.5

This method is then used to examine properties of the square coaxial jets and their shear layers, such as turbulence, shear layer thicknesses, flow entrainment and mean growth rates. The study of Bonnafous *et al.* (2004)

[3], has indicated that mixing is locally enhanced through the use of square nozzles where axis switching was shown to occur for coaxial nozzles as evidenced in Figure 2 from measurements on the side plane (SC) and diagonal plane (SD) as indicated in Figure 1. Because, the measurements were confined on these two planes a full quantitative assessment of the entrainment was not possible. However, the results of Bonnafous *et al.*, which were obtained under the same experimental conditions as the present study, were obtained on planes of symmetry and were therefore unbiased by velocity gradients. Our work provides additional results for eight different vertical planes including SC and SD corrected for velocity gradient effects in order to give a more complete view of the characteristics of the jet flow in three dimensions, and to quantify the overall entrainment as a measure of the mixing. In addition, spectral analysis is carried out to reveal the distribution of discrete modal amplitudes in three dimensions.

ACKNOWLEDGMENTS

This work has been supported through NASA-DART, the Clean Power and Energy Research Consortium of the State of Louisiana and the Board of Regents LEQSF Enhancement Program. The author wishes to thank Dr. Dimitris Nikitopoulos for his valuable advice and ideas.

REFERENCES

1. Müller, U. R. (1982). On the accuracy of turbulent measurements with inclined hot wires. *J. Fluid Mech*., **119**, 155.
2. Bell, J. H. and Mehta, R. D. (1989). Three-dimensional structure of plane mixing layer. *JIAA Rep*.TR-90. Dept. of Aeronautics and Astronautics, Stanford University.
3. Bonnafous, S., Piffaut, V., Choy, W. -H. and Nikitopoulos, D. E. (2004). Local, near-field mixing augmentation using square coaxial jets, Paper GT2004-53985, ASME Turbo Expo 2004, 14-17 June, Vienna, Austria.