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INTERACTION BETWEEN TWO OPPOSING TURBULENT ROUND JETS

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ABSTRACT

Two jets are placed opposed to each other and their interaction process is studied in water using particle image velocimetry (PIV). A fully developed pipe flow exists at the exit. Averaged in time the radial jet will go in the direction perpendicular to the direction of the jets. However, the instantaneous velocity field of the radial jet for both angles is highly unstable. A comparison between the two angles and a single jet is also conducted. The results are compared to the laboratory experiment that simulates a personal ventilation system with two opposing jets supplying fresh air to the occupant.

INTRODUCTION

Many studies have been done at different personal ventilation systems, with all different advantages. Personal ventilation systems with air directed towards the side of the head was advantageous in draft sensation and dry-eye discomfort [1] [2].
As a complement to personal ventilation research conducted at Syracuse University [1], the following research project represents a study on the effects of opposing submerged jets. Although there has been a great deal of research on the advanced aspects of PIV, one of the most basic flow dynamics has gone relatively unstudied. Many studies have been carried out on a single jet (e.g., Pope [3]). However, the interaction between two opposing jets has not been studied [4] in detail to the authors' knowledge. One recent paper deal with an interaction between planar jet (2D). The reaction of two impinging jets is of key importance in understanding the implications of larger research projects and future designs of personal ventilation systems [5].

EXPERIMENTAL SETUP

This experiment in basic configuration compliments the applied research on personal ventilation system. Two round jets with a 9 mm inner diameter d are placed in a water tank (1.80m $\times$ 0.58m $\times$ 0.85m) with the jet exits 23 cm apart from each other (figure 1). The experiment was conducted in water in order to accurately map and analyze the data without the interference inherent in an atmospheric environment. The velocity of the jet exits are approximately 1.03 m/s, ($Re_d \approx 9233$). The angle of inclination can also be varied, and are set to 0 degree (directly impinged) and 10 degree offset (arbitrarily). The exit profile is a fully developed pipe flow. For the PIV setup the laser sheet (NewWave Gemini) is parallel to the bottom of the tank. The camera (8 bit, 1280 $\times$1024 pixels) is mounted under the tank facing the jets and perpendicular to the PIV laser sheet. The jets were controlled by 2 pumps (5W) powered by the adjustable power supply. The pumps were in the same tank, so that the water and the particles are circulating in the tank. The Dantec PIV system with software package Dynamic Studio was used.

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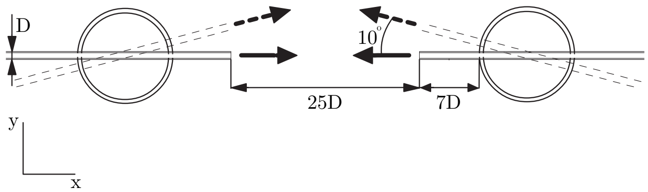


FIGURE 1: SCHEMATIC UPPER VIEW OF SETUP, PARALLEL TO PIV LASER SHEET (OUT OF SCALE).

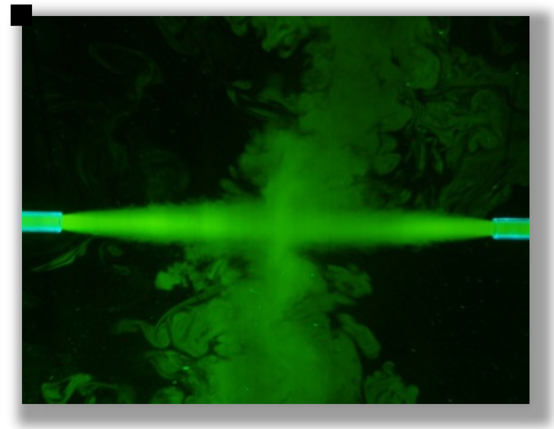


FIGURE 2: FLOW PATTERN OF OPPOSING JETS.

FIGURE 3: IMPINGING JETS.

RESULTS

Flow visualization

In order to visualize and obtain a qualitative view of the flow field around the nozzle exit and the impingement region, fluorescent dye illuminated was used. The fluorescent dye was illuminated by an air cooled 300mW Argon ion laser light sheet and a photograph was taken of the flow.

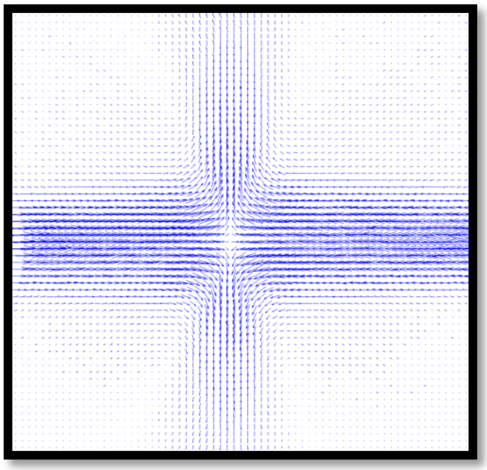
Single jet flow velocity visualization and measurement. A flow visualization was first obtained for a single jet. The flow starts at the exit of the jet and then disperses linearly downstream. A further analysis was applied to the single jet using the PIV to obtain a mean velocity measurement. The core is about $4 \sim 5$ diameters downstream.

Opposing Jets. A (fluorescence) dye flow visualization technique was then applied to the opposing jets case (figure 2). The two opposing jets directly impinged on each other, in this case. The visualization shows the stagnation region in the middle of the nozzle-to-nozzle centerline, and the radial jets generated from the impingement region. To illustrate the basic principle of the impinging jets, a photograph is taken when the jets are not submerged in the water. Despite the density difference, figure 3 gives a more enhanced illustration of the radial water jets in air that emerge during impingement. Fluctuations of the radial jets were also observed; this will further be discussed in the unsteady flow behavior section.

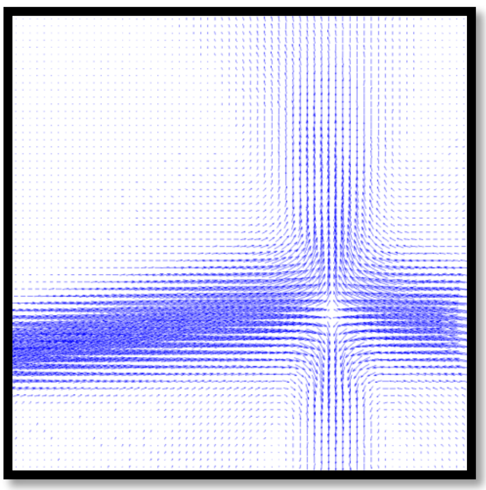
Velocity Measurement

Velocity measurements for both the zero and ten degree angle cases were obtained using the data acquired from the PIV system.

Mean Velocity The mean velocity profile around the impact are shown. A saddle point for both angles as illustrated in figures 4a and 4b, where the velocity is equal to zero (stagnation point). Furthermore, one can see that there is a radial jet emanating from that region in both figures, as deducted from the flow visualization as well. Averaged in time the radial jet will go in the direction with the averaged angle of the two jets (figure 4). Figures 5a and 5b show the mean velocity profile for directly impinging jets (0 degrees) normalized by the jet exit velocity. Here $x/D = 0$ and $x/D = 25$ correspond to the jet exits, respectively. The velocity profile shows that the flow is at its highest velocity at the jet exit and then gradually decays till reaching the impingement region at which the velocity is zero, see figure 7 The radial jets emerging at the stagnation region are symmetric at both sides in this cross section. By doing measurements for different vertical distances from the centerline, an axisymmetric flow is indicated. The mean velocity profile for the 10 degree offset which is also normalized by the jet exit is illustrated in figure 6. The similar results are observed for this case as for the 0 degree case, with the exception that the radial jets are asym-

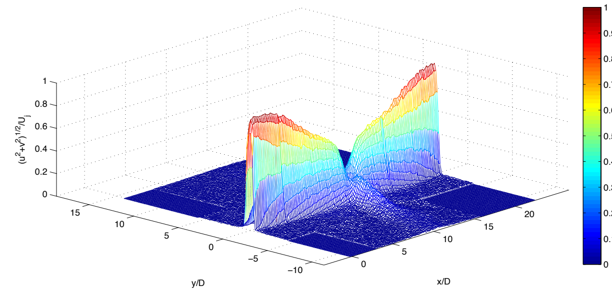


(a) DIRECT OPPOSING JETS

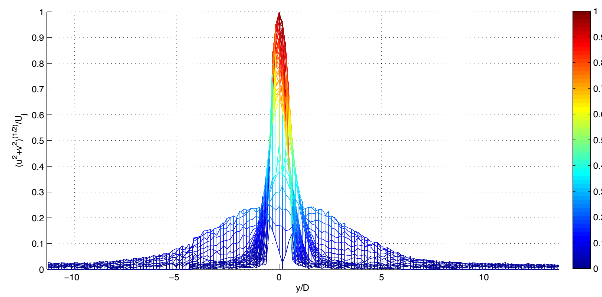


(b) OPPOSING JETS WITH 10 DEGREES ANGLE

FIGURE 4: TIME AVERAGED FLOW OF OPPOSING JETS.



(a)



(b)

FIGURE 5: VARIATION OF VELOCITY MAGNITUDE PROFILE OF DIRECTLY IMPINGING JETS.

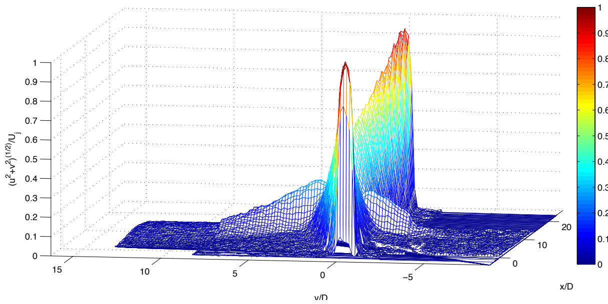
metric. The radial jet which is in the direction of the offset is greater in comparison to the one in the opposite direction. Figure 8 represents the comparison between the single jet centerline velocity decay and the opposing jets at both 0 and 10 degrees[1]. The single jet gradually decays as expected. The radial jet at different position along the centerline is given in figure 9. The core length of the opposing jets remained similar to that of the single jet, which is $4 \sim 5$ diameters downstream from the exit. Furthermore, the two cases for the opposing jets are similar to the single jets decay till $x/D \sim 13$. From here the impinging affects the flow, the rapid decrease of the centerline velocity can be seen in figure 8. It decreases to zero, in the impinging region. The stagnation point for the 0 and 10 degree angle cases is actually at the same point ($x/D \sim 15$), however, due to a slight change in the jet origin for the 10 degree experiment, it seems as though the stagnation points are different.

Instantaneous Velocity and unsteady flow behavior

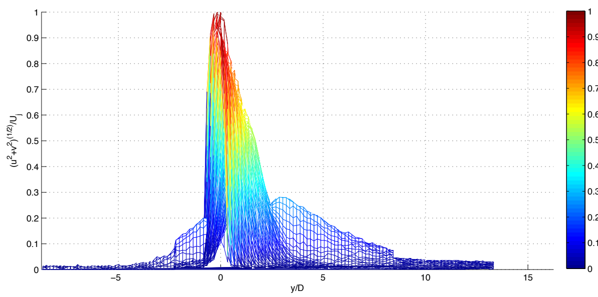
During the analysis of the PIV data, an interesting instantaneous effect was noted. As mentioned above, the radial jet will go in the direction perpendicular to the direction of the jets when averaged in time, but instantaneously, it fluctuates around this position as shown in figure 10a (0 degrees). This same phenomenon is also observed for the 10 degrees offset (figure 10b). The instantaneous velocity field of the radial jet for both angles is highly turbulent. Figure 11a and 11b illustrate the turbulence intensity for the 0 degrees and 10 degrees opposing jets normalized by the exit velocity, respectively. These figures reveal an increased level of turbulence ($\sim 30\%$) at the impingement region, i.e. stagnation region. This turbulence is due to the large scale oscillation of the radial jet around the stagnation point.

Similar instability was observed [1] in air (although frequencies in water are quite different) using 5 cm and 10 cm diameter jets with a peak of approximately 2.5 Hz (St=0.127, Re=13000). The present PIV measurements can not give any information about

[1] The 10 degrees situation is the projection on the center-to-center axis



(a)



(b)

FIGURE 6: VARIATION OF VELOCITY MAGNITUDE PROFILE OF IMPINGING JETS WITH 10 DEGREES ANGLE.

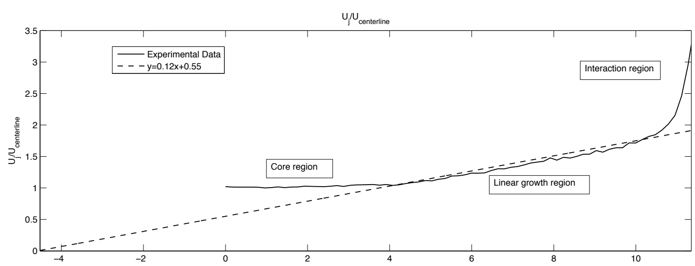


FIGURE 7: AXIAL VELOCITY.

the fluctuation frequency, because the frequency of the PIV is not high enough. Mechanism of radial jet oscillations and their scaling effect are further being studied at the moment, the use of high-speed video or time resolved PIV will give help understanding this effect. In future research, it is important to study the frequency of this instability.

DISCUSSION

This research project set out to study, experimentally, the flow field in the two opposing round jets. Water was chosen as the medium of this case in order to accurately map and analyze the data without the interference inherent in an atmospheric environment. It was found that the behavior of the jets of the opposing jets remains similar to the the single jet, except near the stagnation region within about two diameters downstream. Radial jets formed emerging out of the stagnation region between the collision of the two central jets. The aim of continued research is to determine and interpret the mechanisms of oscillation further. With use of experimental designs (high speed camera) and analytical study, it is hoped that clarity and better comprehension of fluid dynamics will benefit newly-formed projects.

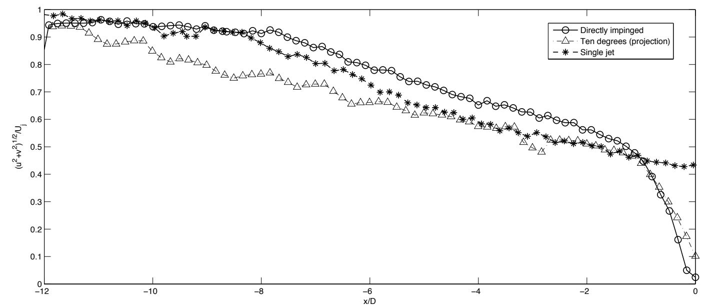


FIGURE 8: COMPARISON OF OPPOSING JETS WITH SINGLE JET, WITH $x = 0$ AT THE STAGNATION POINT.

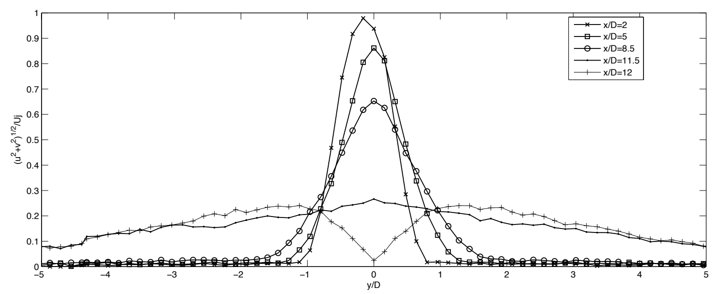


FIGURE 9: VARIATION OF VELOCITY MAGNITUDE PROFILE OF THE RADIAL JET.

REFERENCES

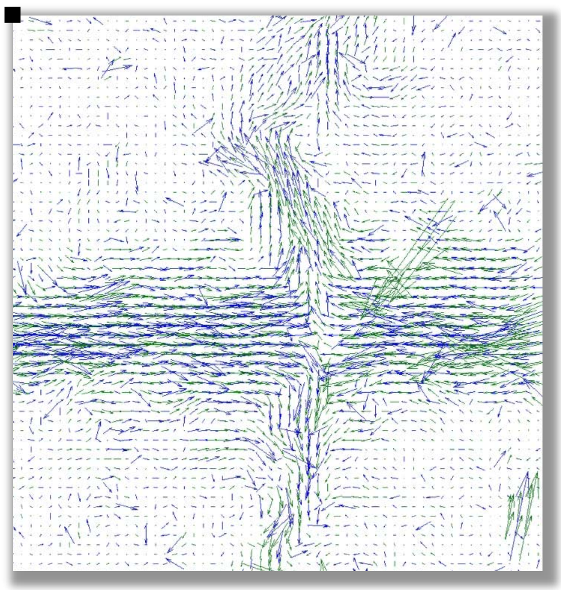
[1] Liu, C., Higuchi, H., Arens, E., and Zhang, H., 2009. "Control of the microclimate around the head with opposing jet local ventilation.". *Proceeding, Healthy Building, Syracuse NY*.

[2] Fanger, P., Melikov, A., Hanzawa, H., and Ring, J., 1988. "Air turbulence and sensation of draught". *Energy and Buildings*, ***12***(1), pp. 21–39.

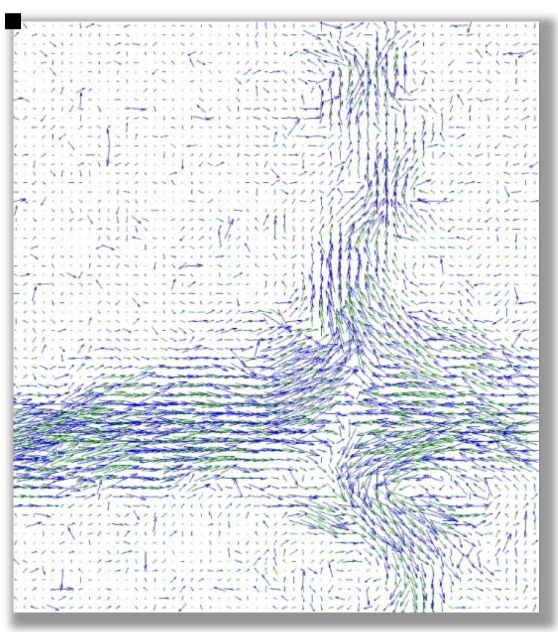
[3] Pope, S., and Pope, S., 2000. *Turbulent flows*. Cambridge Univ Pr.

[4] Besbes, S., Mhiri, H., Le Palec, G., and Bournot, P., 2003. “Numerical and experimental study of two turbulent opposed plane jets”. *Heat and mass transfer,* ***39***(8), pp. 675–686.

[5] Arens, E., Zhang, H., Kim, D., Buchberger, E., Baumann, F., Huizenga, C., and Higuchi, H., 2008. “Impact of a task-ambient ventilation system on perceived air quality”. *Indoor Air 2008, Copenhagen*.

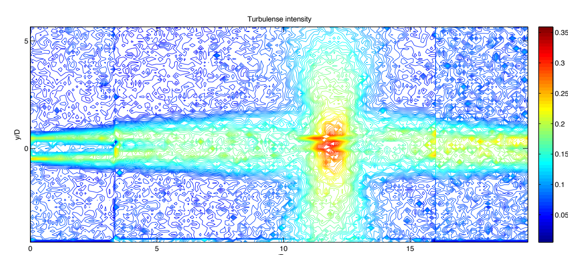


(a) DIRECTLY OPPOSING JETS.

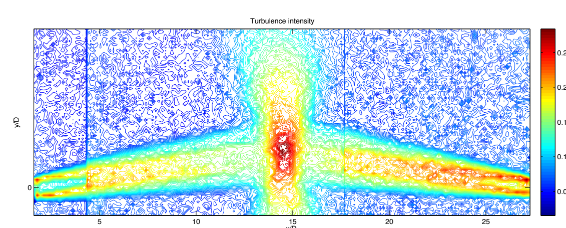


(b) OPPOSING JETS WITH 10 DEGREES ANGLE.

FIGURE 10: INSTANTANEOUS DATA.



(a) DIRECTLY OPPOSING JETS.



(b) OPPOSING JETS WITH 10 DEGREES ANGLE.

FIGURE 11: TURBULENCE INTENSITY.