Low Reynolds Number Effects on Jets from Round, Square and Elliptical Orifices

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Introduction

Turbulent jets have variety of applications in engineering such as combustion, HVAC and chemical processes. To date, most of the investigations on turbulent jets focused on the relatively simpler far field region of round and plane jets. Research on the effects of initial conditions such as Reynolds number and nozzle-exit geometry on the near and intermediate regions is less numerous in spite of the dynamic importance of these regions in turbulent transport and mixing in fluid-thermal systems. While research on jets produced from contoured and orifice round nozzles covered a wide range of Reynolds numbers, Re = 1500 - 184000, most of the studies on noncircular nozzles pertained to relatively high Reynolds numbers. It should be noted that Reynolds number effects, if present, will be more prominent at relatively lower Re values. The objective of this paper is to investigate low Reynolds number effects on mixing characteristics and turbulent transport phenomena in the near and intermediate regions of free jets produced from orifice nozzles whose cross-sections were round (RD), square (SQ) and ellipse of aspect ratio 3 (ELP3).

Experimental procedure

The experiments were conducted in an open water channel which was 2500 mm long, 200 mm wide and 200 mm deep. To facilitate comparison of the jets from the different nozzles (i.e., RD, SQ and ELP3), the equivalent diameter of each nozzle was kept constant at d = 9 mm. For each nozzle geometry, measurements were performed at 4 Reynolds numbers, Re = 2500, 4300, 8500 and 17000; where Re = $U_{max}d/\nu$ and U_{max} is the maximum velocity. A particle image velocimetry system was used to conduct detailed velocity measurements in the symmetry planes that extend from the jet exit up to x/d = 15. Note that for the ellipse, measurements were made in both the minor and major axes. The flow was seeded with 10 µm silver coated hollow glass spheres, and illuminated with a Nd:YAG. The field of view of a 12-bit CCD camera was set to 72 mm × 72 mm, and 6000 instantaneous images were captured in each measurement plane and post-processed using adaptive correlation option of Dynamic Studio.

Preliminary results

Due to space limitation, only selected plots are reported herein. Contour plots of streamwise mean velocity and Reynolds shear stress at Re = 2500 for the round and both minor and major planes of the ellipse are shown in figure 1. Beyond an initial portion in which the velocity decay and spreading are relatively negligible, the round jet grows almost linearly. As the ellipse is not a symmetric nozzle, the flow characteristics are different along the major and minor planes. For example, the spreading in the major plane (Fig.1c) is initially greater than in the minor plane (Fig, 1b). Axis-switching occurs at x/d = 2.7, and beyond this location, the shear layer in the minor plane grows much faster than in the major plane. Axis-switching refers to a phenomenon in which the jet's axes rotate although the cross-section remains similar to those of the jet nozzle. It has been suggested that axis-switching phenomenon is the principal reason for the enhanced entrainment and mixing properties of noncircular nozzle compared to a round nozzle. The Reynolds shear stress contours show higher values in the case of ellipse, and a sign change at the axis-switching point at major plane. Results from experiments conducted at Re = 17000 (not shown) indicate that an increase in Reynolds number leads to a decrease in jet widths and therefore less entrainment of ambient fluid.

Profiles of half-velocity width ($y_{0.5}$/d) are shown in Fig. 2a. Upstream of the axis-switching point, the ellipse jet shrinks in the direction of major plane while it grows in the minor plane and lead to a jet with equal axes at the point that axis-switching occurs. The widths of the round and square jets increased gradually from jet-exit but at different rates. Downstream of the x/d = 2.7 the shear layer widths of all jets constantly increase; however the growth rates of $y_{0.5}$/d are classified into 2 regions of 3 < x/d < 6 and 6 < x/d < 15. In the former, spreading rate of ELP3_equivalent ($y_{0.5\,Eq} = \sqrt{y_{0.5\,minor} \times\ y_{0.5\,major}}$), square and round are 0.121, 0.0979 and 0.0846 respectively which show faster spreading of ELP3 than square and round nozzles, but within 6 < x/d < 15 the effect of nozzle geometry on $y_{0.5}$/d is less and the values lie between 0.10 - 0.12.

Figures 2b-d show selected lateral profiles of streamwise mean velocity, turbulence intensity and Reynolds shear stress at Re = 2500. The effect of geometry on turbulence intensity profiles was observed; however at low Reynolds numbers, apart from close to the nozzle exit, this effect is not considerable at x/d ≤ 5. It should be noted that regardless of Reynolds number the discrepancies among the profiles of streamwise mean velocities at x/d ≤ 3 for all geometries are not noticeable.

Final paper

In the final paper, we will provide complete review of previous studies, experimental procedure and measurement uncertainties. Decay and spread rates as well as contour and one-dimensional plots of mean velocities, Reynolds stresses, and two-point correlation for the various test conditions will be analyzed to elucidate the effects of nozzle shape and Reynolds number on mixing and turbulent transport in the near and intermediate regions.

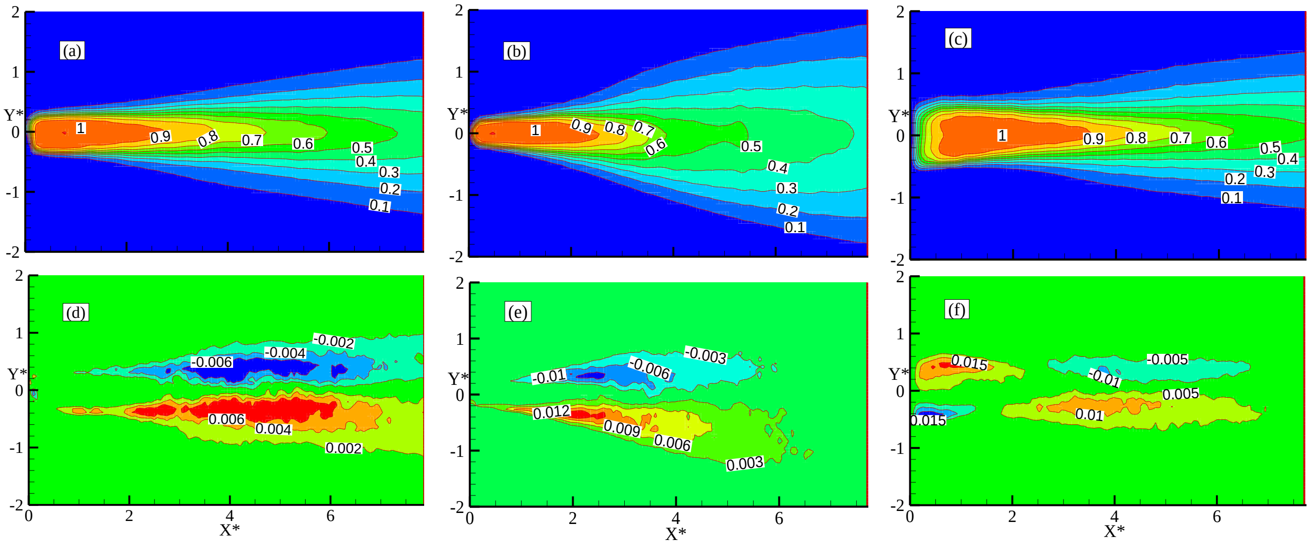

Figure 1. Contours of dimensionless streamwise mean velocity (top) and Reynolds shear stress (bottom) at Re = 2500, a and d: round nozzle, b and e: EPL3 at minor plane, c and f: EPL3 at major plane

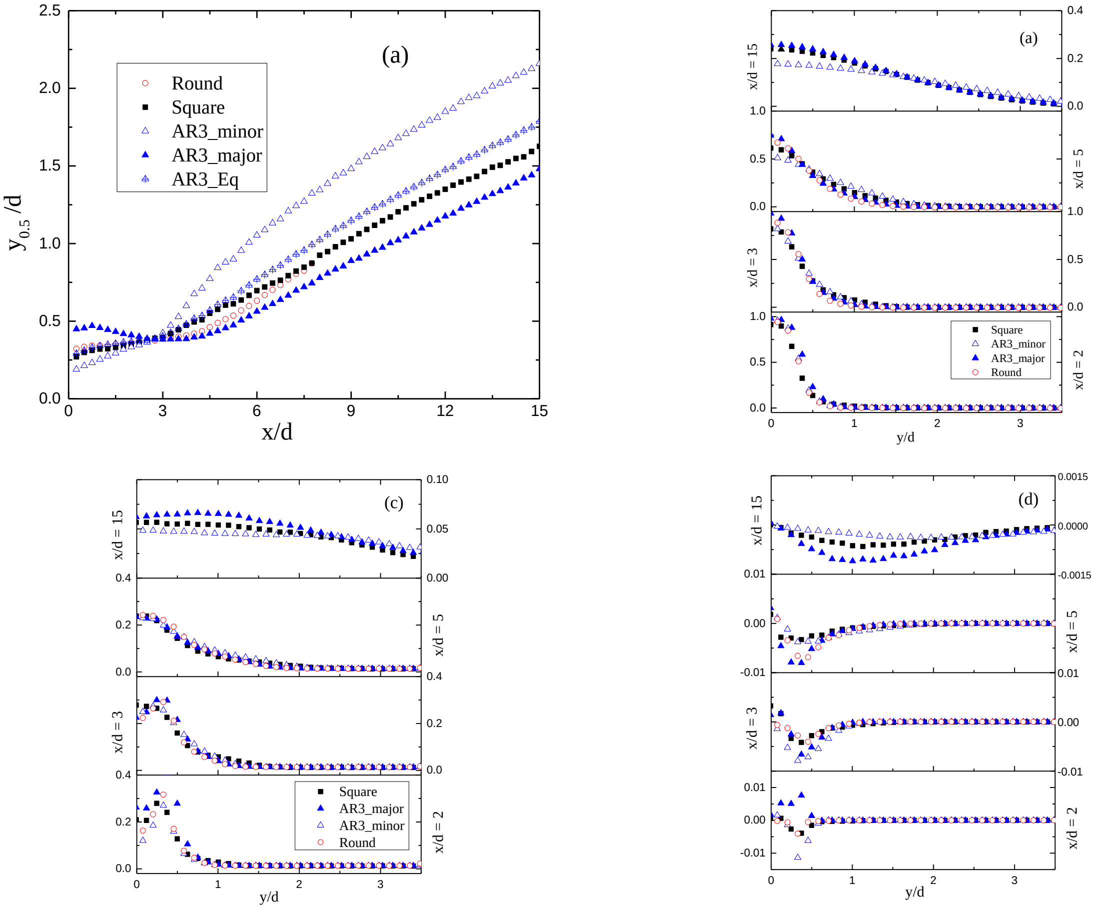

Figure 2. Dimensionless profiles of half-velocity width (a), streamwise mean velocity (b), streamwise turbulence intensity (c), and Reynolds shear stress (d) at Re = 2500