Comparison of the near-field flow structures of free and confined triangular jets

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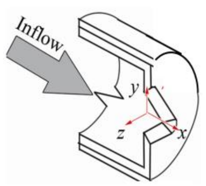
A small flow ejecting into a relatively large specific chamber can produce large-scale low-frequency oscillations — this flow is complex and termed as a self-excited oscillating jet. Compared with relatively simple, non-oscillating, free jets, e.g. round or triangular jets, the self-excited oscillating jet produces greater spreading rate, higher velocity decay rate and larger-scale velocity fluctuations which are all a source of large-scale turbulent mixing [1]. It is found that the non-circular, especially triangular orifice can enhance the oscillation process, relative to the circular inlet case. The oscillating triangular jet (OTJ) flow is highly unsteady and complex, so that much detailed information on the flow structure inside the chamber from experimental results is still lacking. Xu et al. [2] first successfully used Large Eddy Simulation (LES) to visualize the in-chamber OTJ flow structure. Note that the LES, once validated, can provide the quantitative and three-dimensional detail of the whole flow. However, it is still difficult to understand the formation mechanism of the oscillation. The present work is part of the study whose objective is to eventually address this deficit. We use LES to visualize and compare both the in-chamber OTJ flow structure and that of a free triangular jet (FTJ). The simulations were performed for the same Reynolds number of Re = 17,900, where $Re \equiv U_1 D_e/\nu$ with U_1 being the mass-averaged velocity at the orifice-inlet, D_e the orifice equivalent diameter and ν the kinematic viscosity of the fluid.

Figure 1 shows a schematic diagram of the FTJ and OTJ nozzle used in present study. The FTJ nozzle is an orifice plate with an equally-triangular inlet of equivalent diameter D_e =7.6mm connected to a smooth straight pipe. Correspondingly, the OTJ nozzle comprises a circular chamber of diameter D = 26.5 mm and length L = 2.5D connected to the FTJ nozzle. The chamber exit diameter d_2 = 0.82D. Here x, y and z denote the streamwise, spanwise and lateral coordinates, respectively. Their origin is located at the centre of the triangular inlet.

(a)



(b)

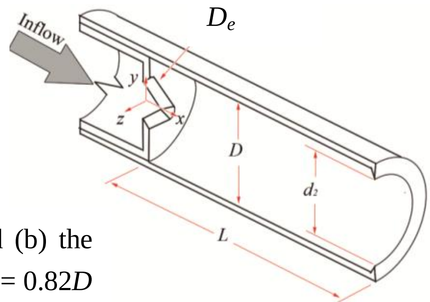
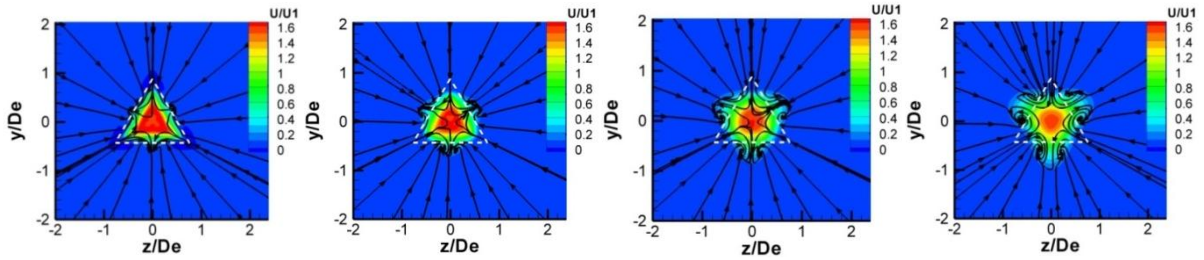


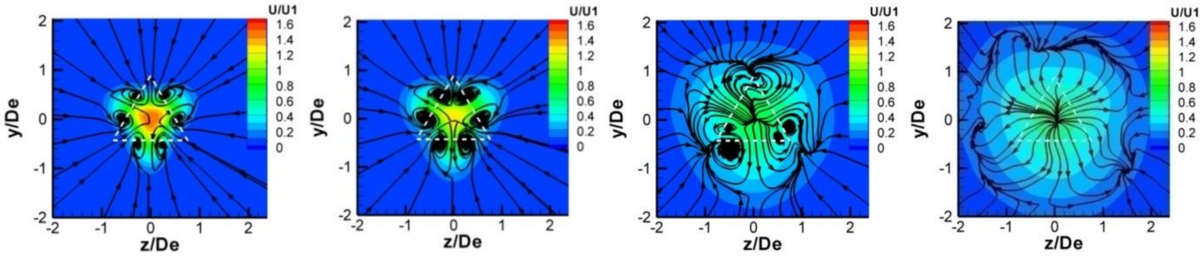
Fig. 1 A schematic diagram of (a) free triangular jet and (b) the OTJ nozzle showing notation. Here D_e= D/3.5, L=2.5D, d_2 = 0.82D

Figs. 2 and 3 show cross-sectional views of longitudinal mean velocity contours and mean streamlines at different x/D_e for FTJ and OTJ, respectively. Based on the contours, for both the FTJ and OTJ, the intensely-spaced contours of the mean velocity ≥ 0.4U_1 well follow the exit triangular shape, immediately downstream from the inlet. As x increases, both FTJ and OTJ exhibits the 'axis-switching' phenomenon, which indicated by the jet cross-section appearing to 'rotate' anti-clockwise approximately by 60° over a certain distance (X). It is also shown that X = 1.5D_e for FTJ (Fig. 2c) and X = 2.5D_e for OTJ. Farther downstream (x/D_e > 7 for FTJ, x/D_e > 4.5 for OTJ), the 'memory' of the initial triangular shape of the FTJ and OTJ is almost lost on average. Further, Figs. 2 and 3 demonstrate that there exist three pairs of anti-rotating streamwise vortices for FTJ, each corresponding to one side of the exit 'triangle'. Totally different, however, there appear to be three single streamwise vortices present in the OTJ, all rotating anti-clockwisely . Evidently as well, these streamwise structures move along with the cross-sectional ‘rotating triangle’ sides. As the flow proceeds downstream, the vortices entrain and mix with the surrounding fluid, thus becoming larger in size for both the FTJ and OTJ.

The final paper will show more results of flow structures in the near field of the FTJ and OTJ, and give the explanation to their difference, which will be useful to understand the formation mechanism of the oscillation.

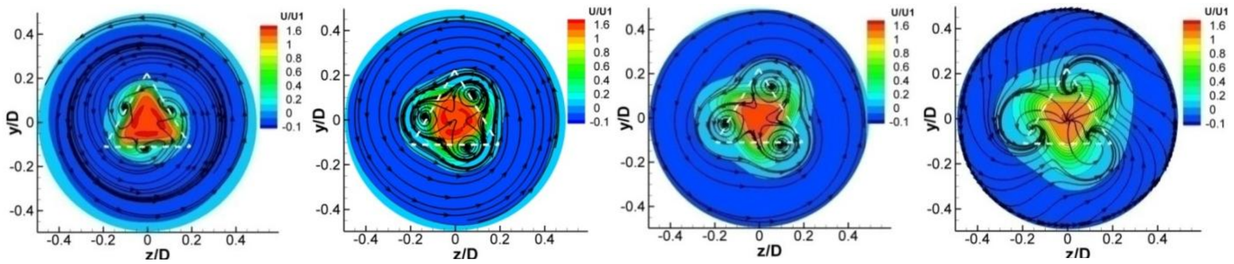


(a) x/D_e =0.5 (b) x/D_e = 1 (c) x/D_e = 1.5 (d) x/D_e = 2

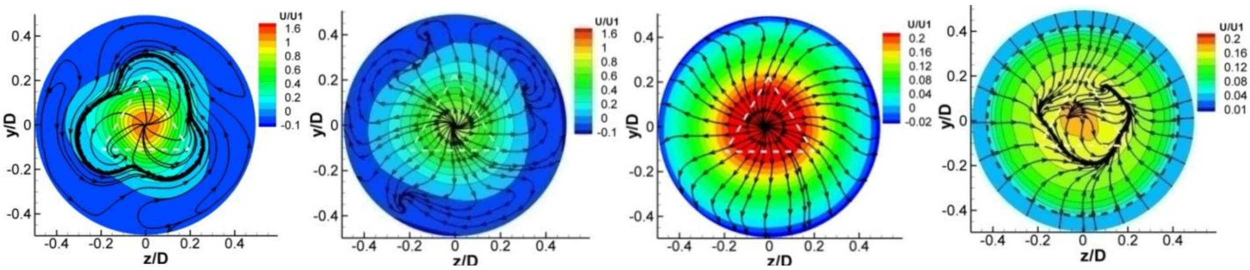


(e) x/D_e = 2.5 (f) x/D_e = 3 (g) x/D_e = 7 (h) x/De = 9

Fig. 2 FTJ’s cross-sectional views of longitudinal mean velocity contours and mean streamlines at different x/D_e.



(a) x/D_e = 0.35 (x/D = 0.1) (b) x/D_e ≈1 (x/D = 0.3) (c) x/D_e ≈ 1.75 (x/D = 0.5) (d) x/D_e ≈ 2.5 (x/D = 0.8)



(e) x/D_e = 3.5 (x/D = 1.0) (f) x/D_e ≈ 4.5 (x/D = 1.3) (g) x/D_e = 7 (x/D = 2) (h) x/D_e = 9 (x/D = 2.5)

Fig. 3 OTJ’s cross-sectional views of longitudinal mean velocity contours and mean streamlines at different x/D_e.

Key Words: vortex structures; triangular jet; axis-switching.

Reference: [1] Nathan, G.J. et al., *Progress in Energy and Combustion Science* **32**(5-6), 496-538 (2006).

[2] Xu M. et al., *Flow, Turbulence and Combustion*, **88**, 2012, 367-386.