3D Flow Dynamics in a Turbulent Slot Jet: Time-resolved Tomographic PIV Measurements

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Jet in a slot channel has a number of features, which significantly distinguish it from free jets and flows in channels. The presence of the bounding surfaces limits characteristic scales in one direction. Development of Kelvin-Helmholtz vortices in the jet shear layer is accompanied with a strong influence of wall friction. The jet includes small-scale 3D turbulence, with a maximum scale of the order of a channel depth, and quasi-2D large-scale flow with the characteristic scales much greater than the depth (Bilsky et al. 2011, 2012).

We experimentally investigated the 3D structure and evolution of a quasi-two dimensional turbulent jet in a narrow channel. This work focuses on characteristics of 3D vortex structures in the flow. We investigated development of the secondary flows downstream, their interaction with each other and evolution into large-scale quasi-2D vortices. The time-resolved tomographic PIV technique (with repetition rate up to 25 kHz for 1 Mpx CMOS cameras) was used to measure subsequent 3D velocity distributions. We analyzed two ratios of the nozzle width to depth, viz., 1 and 2.5. The analysis showed that the secondary flows existed up to 10d from the nozzle exit. The 3D structures were generated near the corners of the nozzle and grew under a stretch downstream the slot channel. Finally, decelerated vortices united into bigger agglomerates. The analyzed behavior of the secondary structures in the slot jet configuration are useful to understand development of large-scale quasi-2D vortex structures in other shear flows in confined spaces.

The experimental setup consisted of a closed hydrodynamic contour, including a tank, a pump, flow meter, and measurement section. The measurement section was a narrow channel formed by two parallel plates made of organic glass (size: 307×270 mm, thickness: 20 mm), located at a distance 4 mm from each other.

The time-resolved tomographic PIV system was composed of a high-repetition Nd: YAG laser (Photronix DM-532-100 with 10 mJ at 10 kHz), four high speed CMOS cameras (Photron FASTCAM SA5 with resolution of 1024×1024 px of 12 bit images at 7 kHz). The photo is shown in Fig. 1.

High speed tomographic PIV measurements allowed us to observe formation and dynamics of vortex structures. Vortex structures are formed in the shear layer owing to Kelvin-Helmholtz instability. Downstream these vortex structures interact with the other forms vortex structure of a larger scale. Large-scale vortex structures are arranged in staggered order on the left and right sides of the jet. Each vortex structure is associated with streamwise vorticity component which causes secondary flows (for example, see the time-averaged flow pattern in Figure 2). Further jet dynamics is determined by large scale vortex structure development.

References


Bilsky A.V., Markovich D.M.; Shestakov M.V., Tokarev M.P.

Tomographic PIV and planar Time-resolved PIV measurements in a turbulent slot jet // Proc. of the 16th international symposium on applications of laser techniques to fluid mechanics, Lisbon, pp 09–12 July, 2012

Fig. 1 Photograph of the experimental setup

Fig. 2 Secondary flows as red and blue surfaces of the mean streamwise vorticity component (|Wy| = 0.3). Semi-transparent central surface corresponds to the mean streamwise velocity component (b) for Re = 18 000