Assessment of tomographic PIV using experimental and DNS data in turbulent channel flows

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In this paper we study the influence of experimental parameters such as camera positioning in three-dimensional space, seeding density, interrogation volume size and spatial resolution on tomographic particle image velocimetry (Tomo-PIV) measurements in turbulent channel flows. To perform this, Tomo-PIV simulations are carried out that employ camera modelling, a Mie scattering illumination model, lens distortion effects and a calibration model. Further analysis of Tomo-PIV is performed by conducting experiments in a channel flow facility, with matched flow characteristics to the direct numerical simulation (DNS) data used in the simulation study.

Simulation study

The accuracy of Tomo-PIV is predominantly driven by image quality and the algorithms used for reconstruction and cross-correlation. In addition to these parameters, the accuracy of Tomo-PIV is also influenced by several experimental parameters which are analysed in this simulation study. The novelty of the simulation study presented herein is the application of channel flow DNS data at Reₚ = 934 (del Alamo et al., 2004) to displace the synthetic particles, providing a realistic vector flow field for a wall-bounded turbulent flow with a large wall-normal heterogeneity.

Results presented in this simulation study include an analysis on camera position and orientation in three-dimensional space to obtain an optimal reconstruction quality for a given Tomo-PIV experiment. Previous studies performed by Elsinga et al. (2006) have documented the effect of adjusting the angle between the laser sheet and the camera position by projecting 1D images onto a 2D array of pixels. Here, we aim to simulate the effect of moving each camera in three-dimensional space by adjusting the camera’s azimuthal (θ) and elevation (ϕ) angles as shown in figure 1.

Fig. 1 Parameters used for camera positioning. The elevation angle is ϕ and θ is the azimuthal angle (de Silva et al., 2012).

In addition, a ratio relating the number of particles and the interrogation volume size is proposed which can be used to determine the required seeding density concentration (S₀) (de Silva et al., 2012). Furthermore, a quantitative analysis is performed on the accuracy of first and second order flow statistics by comparing the simulation results to the DNS data. These include the mean and the turbulence intensity of the velocity components.

Experimental Study

The applicability of the results observed for camera positioning, seeding density, interrogation volume size and spatial resolution in the simulation study is verified by analysis of a data set from a Tomo-PIV experiment (shown in figure 2). Since it is practically infeasible to run several experiments at each camera position and spatial resolution, the experiment is configured for the optimal values determined during the simulation study. This enables us to obtain a realistic assessment of the attainable accuracy in a Tomo-PIV experiment for wall-bounded turbulent flows, and report on its limitations for this application.

Experimental results indicate that mean flow statistics can be determined to within an accuracy of approximately 0.1% in comparison to the DNS statistics, and the turbulence intensity statistics to within 5%. A comparison between simulation and experimental indicates that the simulations provide a good estimate on the achievable accuracy in a Tomo-PIV measurement.

Fig. 2 Experimental setup for Tomo-PIV in channel flow.(de Silva et al., 2012)

References