Optimal seeding for high spatial resolution instantaneous volumetric measurements: application to low velocity ratios Jets in Cross-Flow

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To optimize the spatial resolution of experimental 3D three components velocity measurements, the relations between seeding of tracer particle, illumination thickness of the measurement volume and the onset of screening phenomena are investigated using an hybrid 3D Defocusing Digital Particle Image Velocimetry/3D Particle Tracking Velocimetry system. Depending on the thickness of the illuminated measurement volume, we find the appropriate seeding to obtain the optimal 2D concentration of particle by sensor unit which maximizes the final 3D concentration of raw velocity vectors. This optimal concentration corresponds to the maximal seeding without triggering screening phenomena. We consider that screening phenomena appear when the number of particle masked by a particle located on the front of the illumination volume becomes statistically significant.

Experimental Facility

Experiments were conducted in a low speed hydrodynamic channel. 50 µm PSP Dantec particles, with a concentration of 5·10^5 particles.pixel^-1 were used. Volumetric illumination is generated using a 200 mJ pulsed YAG laser and two perpendicular cylindrical lenses. The flow is illuminated through the upper wall and the particles are tracked using three cameras facing the side wall. 3D DDPIV measurements are performed using a system designed by TSI. Intensity peaks are detected in each camera frame for each time step. Using a space calibration, the triplets of 2D particle coordinates are used to reconstruct for each time step a 3D field of particle positions. A particle tracking step, between t and t+dt, leads to the raw instantaneous velocity field. Finally, a last step which interpolates this raw velocity field on a grid is performed in order to be able to use classical visualization tools (slice, isosurfaces, pathlines, streamlines) and more generally to post-process the data. 1000 time steps are used both for the temporal averaging process and for instantaneous statistics.

Application to a jet in crossflow

This methodology is then applied to the case of a round jet in cross-flow at low velocity ratios r = V_j/U_∞ ranging from 0.1 to 2. This complex 3D flow brings into play many shear-layers together with multiple swirling structures and proves to be a perfect test case to assert the validity of our methodology. Two distinct instantaneous flow topologies are identified. In each case the mean and instantaneous flow topologies and their main vortical systems are identified. For high velocity ratios, when the jet penetrates deeply in the crossflow, we recover the traditional topology proposed by Lim & al 2001 [2]. For very low velocity ratio, due to the very weak jet momentum, the jet is periodically swept by the cross-flow and forms an alley of hairpin vortices following the flow topology proposed by Blanchard & al 1999 [1].

For a close to one velocity ratio, visualizations of individual velocity fields proved to be harder to interprept. In order to precisely determine the flow regime and a value of the critical velocity ratio when sweeping transition occurs, a statistical approach displaying the instantaneous swirling structures in the symmetry plane of the jet is used.

The spatial distribution of the horseshoe vortices proved to be a valid criterion to assess the flow regime and determine the critical velocity ratio. Indeed it ceases to exist when the jet stops to provide a sufficiently permanent obstacle allowing for the horseshoe vortex formation process to happen. Finally, this very low velocity ratio transition takes place between r=0.18 ± 0.03 and r=0.32 ± 0.04.