Assessment of the accuracy and precision of 3D-PTV

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Abstract Artificial circular trajectories have been used to assess the quality of 3D-PTV experiments carried out with a single camera setup, in a range of velocity between 0.25 and 1.9 m s^{-1}. The accuracy, precision and repeatability were satisfactory at all the investigated conditions. Further post-processing showed that there were not relevant effects on accuracy and precision due to the direction of the motion and to the calibration routine.
Keywords: tracking, velocimetry, PTV, trajectories, accuracy, precision, repeatability.

1 Objectives and methods

Flow field visualization has a critical importance in both academia and industrial applications. 3D Particle Tracking Velocimetry (3D-PTV) is a flexible, non-intrusive technique to measure all three dimensions of a velocity field. The technique involves the addition of tracer particles within the fluid and the acquisition of synchronous image sequences with a stereoscopic camera system. Stereo-imaging enables the reconstruction of the 3D positions of the particles. The particles are then tracked from frame to frame and a set of Lagrangian trajectories is obtained.
For any measurement technique, accuracy and precision are two crucial properties. The first is the degree of closeness of a measurement to the true value, while the second is a measure of the statistical variability of a set of measurements under the same conditions. Repeatability is also important, being the measure of the agreement between the results of successive experiments carried out under the same conditions.
The designed geometry shown in Fig. 1 has been used to assess the accuracy, precision and repeatability of 3D-PTV in a range of velocity which is of interest to us for future applications. The geometry consists of four cylinders of different diameter *D* with four control dots attached to a shaft. When the geometry is attached to a motor and the rotating speed *N* is set, the uniform circular motion of the dots is known a priori, and the experimental velocity measurements can be easily compared with their expected values (πDN).

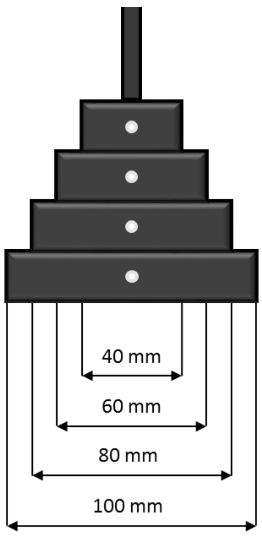

Fig. 1 Schematic of the designed rotating geometry.

The PTV setup in this work consists of (i) a high-speed camera equipped with a mirror arrangement [1]; (ii) a glass square tank filled with water; (iii) the rotating geometry; (iv) LED lights to illuminate the system.
The experiments were conducted at 120, 200 and 360 rpm, producing a maximum velocity of 1.9 m s^{-1}. The digital resolution of the camera was set at 1024 × 1024 $pixel^2$ and the frame acquisition was conducted at 3600 fps. Two revolutions of the reference body were recorded.

For each experiment, four circular trajectories, one for each control dot, were obtained. The trajectories extended within the angle where the control dots were visible in both the two parts of the frames. An example is pictured in Fig. 2. The velocity measurements along each trajectory were Gaussian distributed. The mean μ and the standard deviation σ were calculated via fitting of the data.

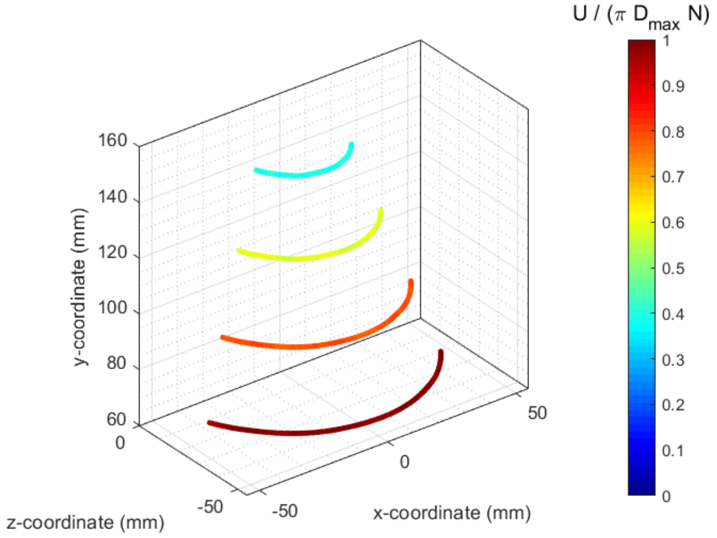

Fig. 2 Examples of circular trajectories obtained with the rotating geometry.

2 Main results

The results from post-processing of the trajectories show that the accuracy and precision were high at all the velocities investigated. The average relative error between the mean velocity measurement relative to a trajectory and the corresponding reference velocity (πDN) was equal to 0.89% and always lower than 3% (Fig. 3, left). The average standard deviation of the velocity measurements was equal to 0.019 m s^{-1} (Fig. 3, right).

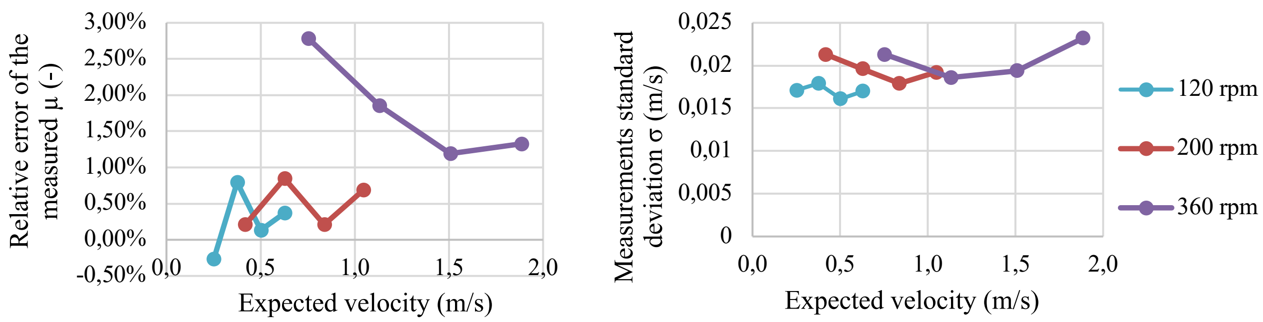

Fig. 3 Assessment of the accuracy (left) and precision (right).

The trajectories were also divided in three portions. Each part was analyzed individually to assess the consistence of the results above in function of the different direction of the motion. No relevant differences were found.
Two additional repetition were conducted at 360 rpm to assess the repeatability. The relative standard deviation of the mean velocity over the three experiments was between 2.5% and 5.9%.

References

[1] Alberini F, Liu L, Stitt E H, Simmons M J H (2017) Comparison between 3-D-PTV and 2-D-PIV for determination of hydrodynamics of complex fluids in a stirred vessel. *Chemical Engineering Science*, vol. 171, pp 189-203. doi: 10.1016/j.ces.2017.05.034.