3D3C Tomographic PIV Measurements in Grid-generated Homogeneous Isotropic Turbulence

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ABSTRACT

Grid-generated turbulence is an important flow in both fundamental and practical fluid mechanics. The fundamentals of grid-generated turbulence are relatively well understood and allows the testing of theoretical ideas related to the properties of homogeneous isotropic turbulence (HIT) and turbulent decay (Comte-Bellot & Corrsin, 1966). From a practical point of view, HIT is well suited to conduct precise measurements of the mean turbulent energy dissipation rate (\(\langle \varepsilon \rangle\)), the mean-square vorticity (\(\langle \omega^2 \rangle\)) and energy spectra. Therefore, 3D3C measurements in grid-generated HIT are conducted using tomographic Particle Image Velocimetry (tomo-PIV). Since all three velocity components (and gradients) are measured instantaneously and simultaneously, the data allow the calculation of the energy dissipation rate and mean square vorticity without the assumption of isotropy or axis-symmetry (Hinze, 1975). The effect of experimental parameters such as spatial resolution on the turbulent kinetic energy, dissipation rate and turbulent statistics are considered in this work. The focus of the current HIT measurements is on the intermediate to far range (20 \(\leq x/M \leq 60\)) where the turbulence intensities are relatively low.

The measurements are performed in a small-scale water tunnel with a cross-section of 100\(\times\)100 mm\(^2\) and homogeneous, isotropic turbulence is generated via a rectangular grid at the entrance of the test section. Two grids are tested with respective mesh sizes, \(M = 12\) mm and 20 mm and solidity, \(\sigma = 0.438\) and 0.278. The mean velocity in the channel is \(U = 0.12\) ms\(^{-1}\), which corresponds to a bulk flow Reynolds number of approximately 6000 and a mesh size based Reynolds number of 1440 and 2400. The flow is seeded with 11 µm hollow glass spheres and illuminated with a 120 mJ Nd:YAG laser. Tomo-PIV measurements are conducted in a streamwise plane using four digital CCD cameras (PixelFly, 1240 \(\times\) 1024 pixel\(^2\)) with 55 mm Micro Nikkor lenses for recording. The cameras are positioned under an angle of \(\pm 45^\circ\), 30\(^\circ\) and 90\(^\circ\) and the recorded image are processed with an in-house MLOS-SMART algorithm for volume reconstruction and subsequent FFT based cross-correlation (Atkinson and Soria, 2009).

The mean velocity profile in the centre of the test section is flat with variations of less than 1% of the mean velocity. The field of view is approximately 40\(\times\)40 mm\(^2\) and the flow is homogeneous within this area. The axial and transversal power spectra of the velocity fluctuations are plotted in Figure 1. Due to the relatively low Reynolds number (\(Re_\lambda = \delta_u \nu / \nu \approx 9.5\)) the resulting energy spectra have a steeper slope than -5/3, which follows from Kolmogorov theory (Hinze, 1975). This means that energy is not only dissipated at the Kolmogorov scales, but also by the larger eddies. The first results of the measurements evidence good quality data and are consistent with earlier measurements in grid-generated HIT (Comte-Bellot & Corrsin, 1966).

Figure 1: axial and transversal spectra at \(x/M = 49\)