Time resolved, near wall PIV measurements in a high Reynolds number turbulent pipe flow

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ABSTRACT

We report on near wall measurements of a turbulent pipe flow at shear Reynolds numbers up to $Re_\tau = 40000$ acquired in the CICLoPE facility near Bologna, Italy [1]. With 900 mm inner diameter, 115 m length and air at ambient pressure as the working medium, the facility offers a well-established turbulent flow with viscous length scales ranging from $y^+ = 85$ µm at $Re_\tau = 5000$ to $y^+ = 11$ µm at $Re_\tau = 40000$ (Figure 1). These length scales can be resolved with a high-speed PIV camera at image magnification near unity. For the PIV measurements the light of a high-speed, double-pulse laser is focused into a ≈300 µm thin light sheet that is introduced radially into the pipe (Figure 2, left). The light scattered by 1 µm water-glycerol droplet seeding is observed from the side by the camera via a 1 mm thin high-aspect ratio mirror with a field of view covering 20 mm in wall-normal and 5 mm in stream-wise direction (Figure 2, right). With increasing Reynolds number facility vibrations of up to 50 µm peak-to-peak were present and could be accounted for using image processing thereby providing measurements with a spatial resolution at the wall unit level (Figure 3, left). Statistically converged velocity profiles could be achieved using up to 70000 samples per sequence acquired at low laser repetition rates (100 Hz). Higher sampling rates of 10 kHz provide temporally coherent data from which frequency spectra can be derived. The image data was processed using conventional cross-correlation PIV analysis with sample sizes of 6 pixel in wall-normal direction corresponding to 0.8 y^+ at $Re_\tau = 5400$ and increasing to 6.1 y^+ at $Re_\tau = 40000$.

Figure 1: Photograph of the 115 m long CICLoPE facility with the measurement location seen at the far end

Preliminary analysis of the data seems to indicate that the profiles of the mean velocity and its fluctuations shown in Figure 3 only differ marginally from those of turbulent channel flows and flat plate boundary layers from the wall up through the logarithmic layer. The present data shows a well resolved inner peak of the streamwise velocity fluctuations $\langle u^+ u^+ \rangle$ that grows with increasing Reynolds number (Figure 3, right) which so far could not be clearly documented in previous measurements of high-Re pipe flows such as the Princeton SuperPipe (see e.g. [3,4]). While the maximum of $\langle u^+ u^+ \rangle$

matches the DNS channel flow data at Re_τ = 5400 the further increase at higher Re falls short of the predictions made in [2,5]. This is believed to be caused by increased spatial smoothing introduced by the finite sized PIV sampling window and may be improved by reprocessing the image data with particle tracking analysis (PTV). Although limited to the lower 20 mm of the pipe's turbulent boundary layer (y/R ≤ 0.044) the spatial domain of the present measurements is sufficient to also document the steady growth of the outer peak of streamwise fluctuations. A distinct outer peak is visible for $Re_\tau \geq$ 20 000 that shifts away from the inner peak, a behaviour that is in good agreement with data acquired in the SuperPipe facility [3,4].

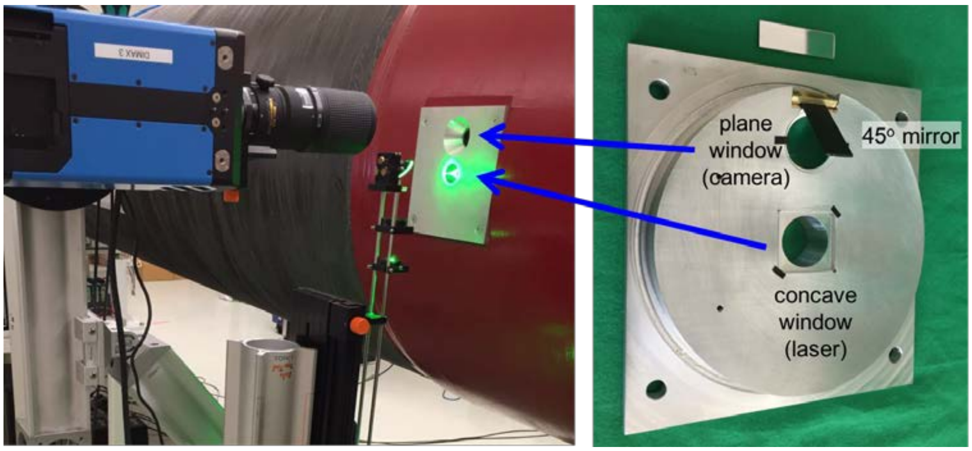

Figure 2 PIV-setup on the CICLoPE facility (left), insert for near-wall PIV measurements (right).

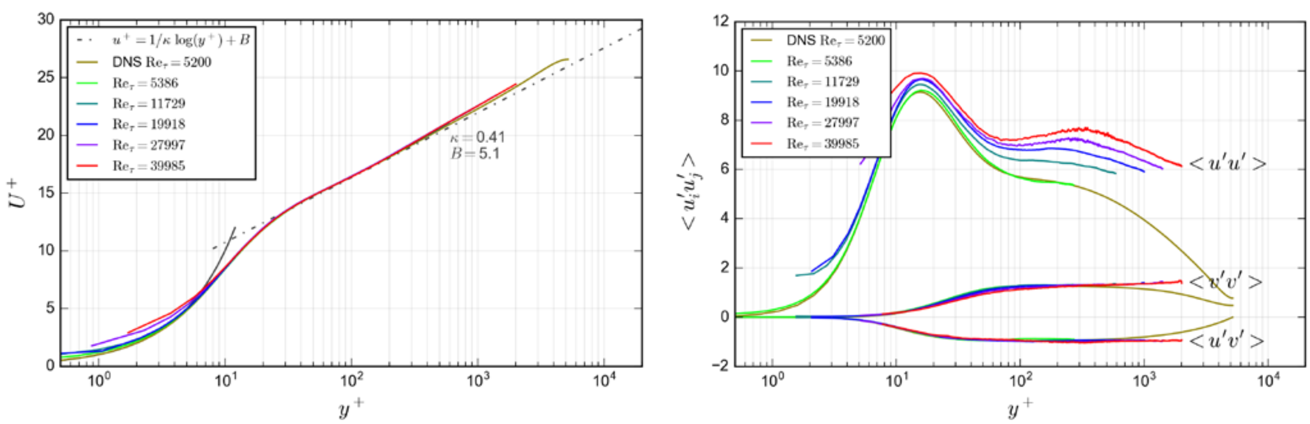

Figure 3: Left: mean streamwise velocity scaled with inner coordinates. Right: variances and co-variances of the streamwise and wall-normal velocity components. DNS turbulent channel flow data from Lee & Moser [2].

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