EXPERIMENTAL CHARACTERISATION OF LARGE SCALE STRUCTURES IN A HIGH REYNOLDS NUMBER TURBULENT BOUNDARY LAYER

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Abstract A very large field of view (4δ x 1δ) with a good spatial resolution owing to the use of four 2k x 2k pixel cameras was conducted in a flat plate boundary layer at two Reynolds numbers (Re_θ ≈7,500 and 20,000). Comparing the flow statistics with previously obtained hot-wire data under similar flow conditions show good agreement. The goal of this experiment is to detect and characterise the large scale motions which develop in the log region of a high Reynolds number turbulent boundary layer.

INTRODUCTION

Near wall turbulence is characterised by the presence of eddy structures or coherent motions over a wide range of scales [1]. The study of the organisation of these structures is thus imperative for understanding the physics of wall turbulence and for the development of reliable turbulence models. Using hot wire measurements, Hutchins *et al* [2] showed the presence of very long meandering structures extending to over 20δ (with δ the boundary layer thickness) in length in the log and lower wake regions, which interact with the near-wall flow. Recently, de Silva *et al* [3] used a multi-camera, multi-resolution PIV configuration to study the large and small scale interactions in a turbulent boundary layer at high Reynolds number. With cross-correlation, they identify a link between large scale events and wall shear stress intensity but they do not concentrate on large scale structure characteristics due to small amount of PIV snapshots. Kähler *et al* [4] have also conducted high resolution PIV measurements over a large field of view to study the flow characteristics of a turbulent boundary layer. However, the large field of view resulted in sacrificing on spatial resolution.
The current experimental setup uses an adequate resolution to capture the large scale structures in the outer region of the flow and also the small scale ones in the inner region. A large amount of PIV fields (at least 22,000) was taken to ensure convergence on large scale statistics.

EXPERIMENTAL SETUP

The experiment was performed in the boundary layer wind tunnel at the Lille Mechanics Laboratory (LML) having a test section 2m wide, 1m high and 20m long. The tests were conducted at two free stream velocities of 3m/s and 10m/s corresponding to Reynolds numbers $Re_\theta \approx 7{,}500$ and $Re_\theta \approx 20{,}000$ respectively. To capture the large streamwise wall normal field, four 12bits Hamamatsu cameras having a resolution of 2048x2048 pixels were installed side by side to observe a region 1.16m (~4δ) long and 0.3m (~δ) high (see Fig 1). Nikon lenses of 50mm focal length were set on the cameras. The software HIRIS was used to acquire the images of the four cameras simultaneously. The flow was seeded with 1μm Poly-Ethylene glycol and illuminated by a double-pulsed NdYAG laser at 400mJ/pulse. The modified version of the MatPIV toolbox by LML, under Matlab® was used to process the acquired images from the 2D2C PIV. The final pass was 28x28px corresponding to 33x33 wall units ($Re_\theta \approx 7{,}500$) and 100x100 wall units ($Re_\theta \approx 20{,}000$) with a mean overlap of 65%. Image deformation was applied before the final pass. The final interrogation window of the grid was optimised by comparing the spectrum, mean velocity and turbulent intensity profiles obtained from PIV with that of the hot wire. The final grid then had 766 points along the wall and 199 points in the wall normal direction with grid spacing of 1.5mm corresponding to 11 wall units and 35 wall units for the test cases at $Re_\theta \approx 7{,}500$ and 20,000 respectively.

RESULTS

Figure 2 shows the mean streamwise velocity profiles and the turbulent intensity profiles obtained from PIV at $Re_\theta \approx$ 7,500 and 20,000 (U_∞ =3m/s and 10m/s respectively), compared with hot wire anemometry. For the mean profiles, the agreement with hot wire data is good except for the first point due to PIV uncertainty in the near wall region occurring with strong gradient effects, out of plane motion and principally wall reflection. The mean velocity field is then well resolved from $y^+ \approx 30$ and 90 for $Re_\theta \approx 7{,}500$ and 20,000 respectively. Comparisons of the turbulent intensity profiles show a fairly good match with the hot wire data. At $Re_\theta \approx 20{,}000$, there is a plateau around $100 \leq y^+ \leq 300$ which is not present at $Re_\theta \approx 7{,}500$ and linked to large scale structures [2]. Close to the wall, the turbulent intensities obtained with PIV are slightly underestimated for both Re_θ showing a little filtering of the PIV result in the near wall region [5].

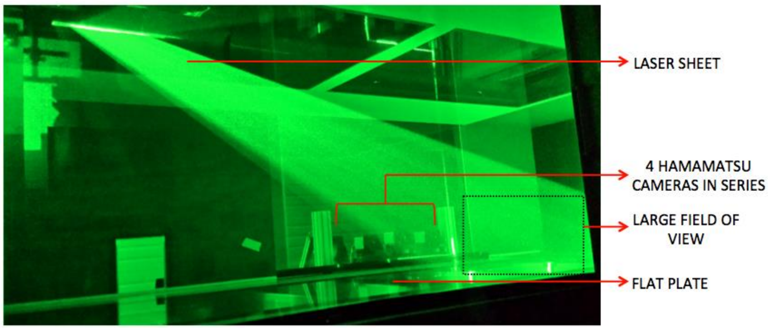

Figure 1. Photo of the experiment conducted on the ZPG turbulent boundary layer

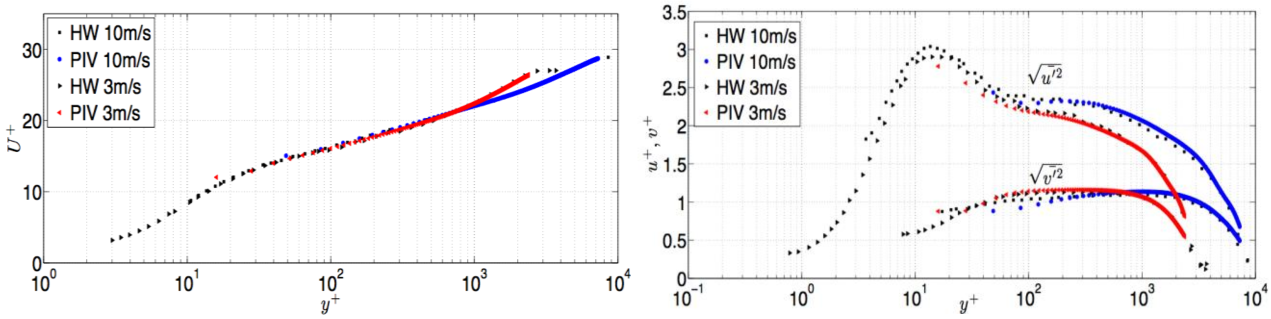

Figure 2. Mean streamwise velocity profiles (left) and turbulent intensity profiles (right) at $Re_\theta \approx 7{,}500$ (U_∞ =3m/s) and $Re_\theta \approx 20{,}000$ (U_∞ =10m/s) obtained by PIV and compared with hot wire

Figure 3 shows a snapshot of the streamwise velocity fluctuation (u') after merging the four PIV systems at $Re_\theta \approx 20{,}000$. Very long regions of positive and negative fluctuations are observed which might indicate the presence of large scale phenomena. The contour in black indicates the region where $|u'|<0.6\sigma_u$ with σ_u the rms velocity of the streamwise velocity component taken at $y^+ = 300$. The study of this large scale organisation is under process using both structure analysis and conditional correlations. As the spatial resolution is fine enough close to the wall, the near wall structures such as streaks, sweeps or ejections can also be detected to characterise the link between the large scale motions and near wall flow organisation.

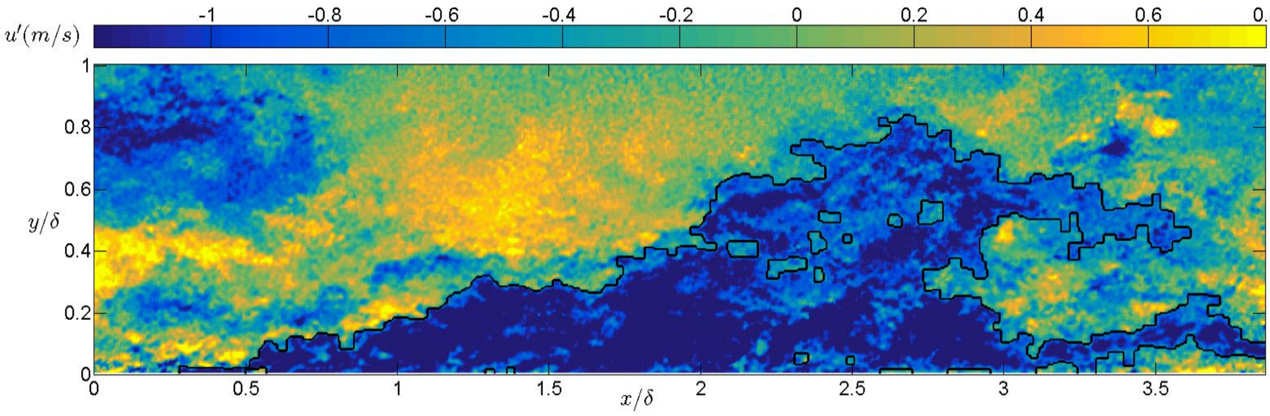

Figure 3. Snapshot of a fluctuating streamwise velocity field after merging the four PIV systems at $Re_\theta \approx 20{,}000$

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