Abstract. Experiments using stereoscopic high-speed particle image velocimetry (PIV) to take measurements in a cross-stream (i.e. wall-normal/spanwise) plane in a turbulent boundary layer have been used to produce full 3D velocity fields. The 3D fields were constructed from planar 3C fields by using Taylor’s hypothesis to create a pseudo-spatial $x$-dimension from the temporally resolved measurements. This has produced a 3D view of the elongated regions of high and low streamwise momentum found in the boundary layer, often referred to as ‘long structures’, and provided information on the arrangement, length and characteristic angle of these structures. Long structures are also seen to be associated with regions of high Reynolds stress. Vortical motions are visualised using swirling strength, and indicate that there is a prevalence for vortices to surround the low speed long structures. The vortices are characterised, and are found to resemble hairpin vortices in some respects.

1 Introduction

This experiment was performed to show the structures present in the turbulent boundary layer. Structures that are of interest are ‘long structures’. These are elongated regions of high and low streamwise momentum that have previously been found in a turbulent boundary layer using hot-wires (Hutchins & Marusic[6]), and PIV measurements taken from a streamwise/spanwise plane in the log region (Ganapathisubramani et al.[4]). As well as PIV measurements in a streamwise/wall-normal plane in the outer region (Adrian et al.[2]), and Direct Numerical
Simulations (Ringuette et al.[8]). These long structures are of interest because they have been found to contain a substantial portion of the Reynolds stress (Ganapathisubramani et al.[5]), and have an influence on the near-wall motions (Hutchins & Marusic[7]). Also of interest are hairpin vortices, vortex packets, and the relationship between long structures and the vortex arrangement in the boundary layer, see Adrian[1] for an overview of these.

2 Experiment

The experiments were performed using high-speed, stereoscopic PIV to take measurements in a cross-stream (i.e. wall-normal/spanwise) plane in the Cambridge University Engineering Department’s turbulent boundary layer water tunnel research facility. This facility has a 0.9m × 0.5m × 8m long working section, and has been specially designed to produce thick turbulent boundary layers. The flow is tripped at inlet, and the measurement plane is 5m downstream. At this location the boundary layer thickness is $\delta = 90\text{mm}$, the freestream velocity is $U_\infty = 0.69\text{m/s}$, the Reynolds Number based on momentum thickness is $Re_\theta = 4685$. The water is seeded with silver-coated hollow glass spheres with 10μm mean diameter.

The stereoscopic system consisted of a New Wave Pegasus-PIV laser, and two LaVision HighSpeedStar 4 CMOS cameras. It provided all three components (3C) of the velocity vector, and the use of a cross-stream measurement plane meant that the flow was advected through the measurement plane, and therefore full 3D velocity fields could be constructed from the planar 3C fields by using Taylors hypothesis to create a pseudo-spatial $x$-dimension from the highly resolved temporal measurements, which is shown to be valid for short distances in Dennis & Nickels [3]. A similar technique to this was used by vanDoorne [9] (on a smaller scale), in a pipe.

3 Results

Figure 1 presents a result showing a grey iso-surface representing a region where the streamwise velocity component is 90% of the local mean, (i.e. $u_{iso} = -0.1\bar{U}$), alongside a meshed iso-surface representing a region where the streamwise velocity component is 110% of the local mean, (i.e. $u_{iso} = 0.1\bar{U}$). These two iso-surfaces are good representations of low and high speed structures in the flow.

In this example the low speed structure is found to be $2.5\delta$ in length, with the height of its upper surface increasing with downstream distance such that it is at an angle of $\approx 11^\circ$ to the wall. This is found to be fairly indicative of all the structures in the dataset as a whole. The length of structures reached a maximum of $8.4\delta$, but such a long structure was quite rare with almost half found to be between $2-3\delta$, and 97% below $7\delta$ in length. This is supported by the two-point correlation of the streamwise velocity fluctuation ($R_{uu}$), which extends to about $5\delta$, and is strong for around $2\delta$. The angle to the wall varies considerably across structures, but there is a