EFFECTS OF EXTERNAL DISTURBANCES ON TURBULENT BOUNDARY LAYERS

Eda Dogan[1], Ronald Hanson [1] & Bharathram Ganapathisubramani [1]
[1] *Aerodynamics and Flight Mechanics Research Group, University of Southampton, UK*

Abstract The state of a turbulent boundary layer developing under the influence of different types of freestream turbulence (FST) is examined. Different FST conditions with different length scales and turbulence intensity levels are generated using an active grid. Experiments are performed using two different techniques allowing simultaneous measurements of the freestream and the boundary layer: single component hot-wire anemometry and multi-camera planar Particle Image Velocimetry (PIV). Penetration level of the freestream into the boundary layer and the effect on the near wall region are shown to depend on the turbulence characteristics of the freestream. These interactions will further be investigated using spectral analysis from hot-wire measurements and also coherent structures associated with these interactions will be studied using PIV data.

INTRODUCTION

FST is found above almost all naturally and industrially occurring turbulent boundary layers [1]. It acts as an external disturbance that adds a new length scale into the boundary layer and causes changes in the nature of momentum and energy transport within the boundary layer through interactions with the scales. The main focus of this study is to investigate these interactions using simultaneous measurements of the boundary layer and the freestream using single component hot-wire anemometry and multi-camera planar PIV.

EXPERIMENTAL SETUP

FST is generated using the active grid consisting of 11 vertical and 7 horizontal shafts which are independently controlled by stepper motors. The motors are operated at randomly generated different rotation rates and cruise times as in previous active grid studies [2, 3]. Downstream of the active grid, a flat plate is placed to establish a zero pressure gradient turbulent boundary layer. The experiments are performed in an open-circuit suction type wind tunnel at the University of Southampton. Simultaneous hot-wire measurements with two probes are performed at 3.5 m downstream of the active grid at an acquisition rate of 20 kHz: one probe is stationary in the freestream and another probe is traversing the boundary layer. Wide field planar PIV is performed with three CCD cameras of 16 MP each combined with a Nikon Nikkor 200 mm lens. 2000 image pairs are acquired using DaVis from LaVision.

RESULTS

This abstract will present some hot-wire results while the full paper will also include PIV results. Three cases are chosen among 22 cases for representing the behaviour of the interaction between the freestream and the turbulent boundary layer for two similar turbulence intensity levels ($T_u(\%)$) and for two similar Taylor Reynolds numbers ($Re_{\lambda 0}$) of the FST. Figure 1 shows the mean profiles of the streamwise velocity. In Figure 1a, it can be seen for grid turbulence cases when compared with no grid turbulence case that there is little or no velocity defect in the outer part of the boundary layer. This results in reduced wake strength as expected for a turbulent boundary layer under the effect of FST [1, 4].

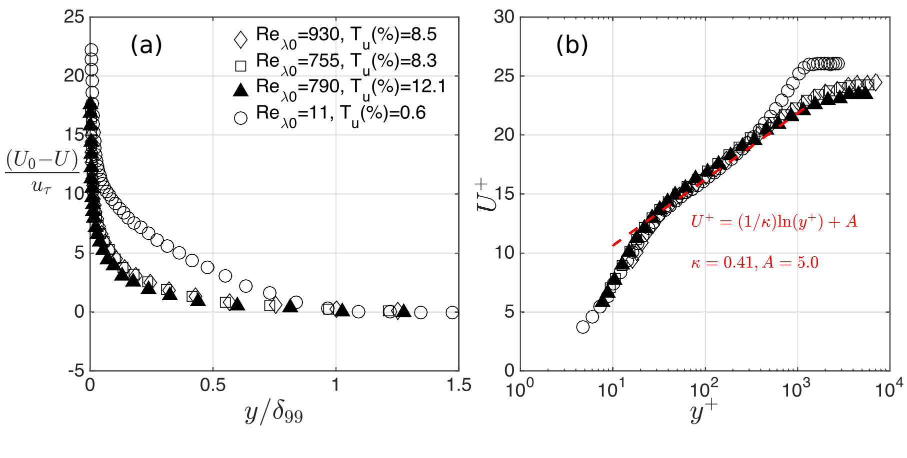

Figure 1. (a) Mean streamwise velocity defect profiles (b) Inner-normalized mean streamwise velocity profiles

When the mean profiles are plotted with inner scaling (Figure 1b), the collapse of the profiles below the outer region of the boundary layer is clearly seen. This suggests that the effect of FST on the mean flow in the inner region is to alter the value of skin-friction velocity and once this change is accounted for, there is self-similarity across the different cases. Variance profiles in Figure 2 show clearly the effect of different turbulence intensity levels of the FST on the near-wall peak of the boundary layer. Higher turbulence intensity cases have higher near-wall peak. When compared with no grid case, the near-wall peaks for grid cases also seem to occur at the same location.

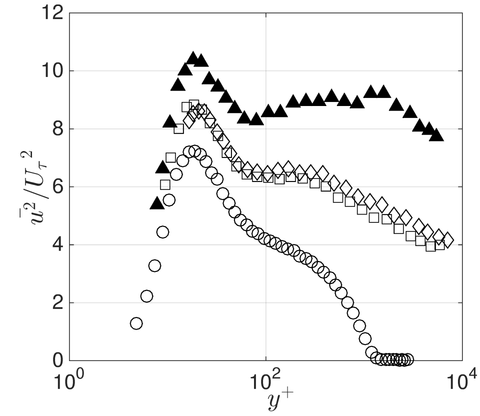

Figure 2. Inner normalized variance profiles of streamwise velocity fluctuations (Symbols are as given in Figure 1)

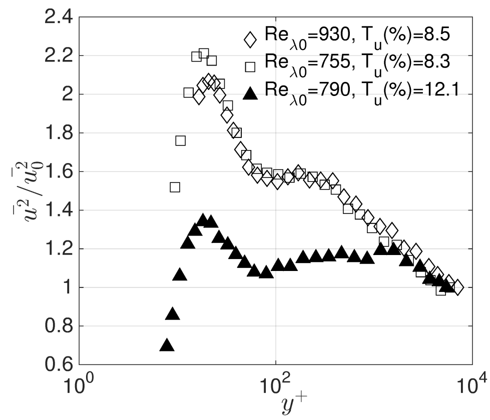

Figure 3. Local variance normalized variance profiles of streamwise velocity fluctuations

When variance profiles are normalized by local freestream variance (Figure 3), the relative effect of the FST at each wall normal location can be observed. The energy in the outer region is first amplified and then this effect is either sustained or both amplified and sustained in the logarithmic region of the boundary layer until the near-wall region takes over. In this figure, the effect of the length scale of the FST is seen as well as the turbulence intensity level. Although $Re_{\lambda 0} = 790$ has higher turbulence intensity, near-wall amplification is lower than the other cases. It is also observed that among lower range turbulence intensity cases, $Re_{\lambda 0} = 755$ case has more pronounced effect on the near-wall than $Re_{\lambda 0} = 930$ case. This leads to the discussion of different penetration levels of different freestream conditions depending on their turbulence intensity and length scale characteristics. To be able to further discuss this along with the energy contribution of freestream in the energy of the near-wall and the outer region of the boundary layer, spectral analysis is needed and will be investigated in the full paper of this abstract as well as PIV results.

References

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