Streamwise evolution of the interface between freestream turbulence and a turbulent boundary layer

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Freestream turbulence (FST) effects on the statistics of turbulent boundary layers (TBLs) have been investigated in several studies, including spatial development of the statistics[1]. Nevertheless, the streamwise evolution of the instantaneous structures of a TBL subjected to FST has remained unexplored. A prerequisite for such analysis would be to identify an interface which separates the instantaneous FST and TBL. How to identify this interface is certainly debatable as different scholars have opted for different methods[2,3,4]. Accordingly, by introducing a novel technique to identify the interface, this study investigates the streamwise evolution of FST effects on the interface and TBL structures.

An active grid with a mesh length of $M = 100$ mm was placed at the entrance of a water channel ($18M$ width $\times$ $110M$ length), where a TBL grows beneath FST. The water height was $2.2M$. The grid was operated using three different operational sequences, resulting in three FST cases referred to as 'A', 'B', and 'C' with increasing FST intensities. Planar PIV measurements were performed in streamwise–wall-normal planes by capturing 3000 image pairs for each case. To explore the streamwise evolution, several downstream locations, e.g., $55M$, $65M$, $72M$ and $85M$, were tested.

FST and a TBL possess different vortical structures; hence, the spanwise vorticity distributions on both sides of the interface should differ from one another. A velocity threshold is identified for each instantaneous field, whose continuous contour line marks the interface between the instantaneous TBL and FST. The vorticity distribution differs from one another for the regions above and below this interface. Figure 1(a) shows that increased FST intensities broaden the distributions of the velocity threshold values, emphasizing the necessity of employing instantaneous thresholds to identify the interface. Tracking the location of the interface shows that increased FST intensity generally pushes it toward the wall (figure 1b), while the interface location recovers in the streamwise direction with the decay of turbulence intensity (figure 1c).

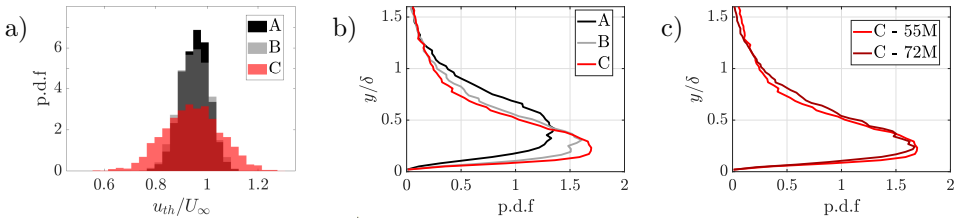

Figure 1: The distribution of (a) the velocity thresholds, and (b) the interface location, at $55M$ for all cases. (c) the distribution of the interface location for case C at $55M$ and $72M$.

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[2]Wu et al., *Phys. Fluids* **31**, 045104 (2019).

[3]You and Zaki, *J. Fluid Mech.* **866**, 526 (2019).

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