Investigation of Large Scale Motions in Zero and Adverse Pressure Gradient Turbulent Boundary Layers Using High-Spatial-Resolution PIV

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Abstract

Particle image velocimetry (PIV) has been used to capture the high-spatial-resolution (HSR) two-component, two-dimensional (2C-2D) velocity fields of a zero-pressure-gradient (ZPG) turbulent boundary layer (TBL) and of an adverse-pressure-gradient (APG) TBL. Proper Orthogonal Decomposition (POD) is performed on the measured velocity fields to characterize the velocity fields as large or small scale motions (LSMs or SSMs), with further characterisation of the LSMs into high and low momentum events. This paper reports the findings of the PIV experiment and the subsequent analysis of the high Reynolds number ZPG and APG TBLs.

1   Introduction

The investigation of LSMs in TBL flows is essential in order to identify and characterize the dominant coherent structures in these flows. LSMs are coherent patterns of alternating regions of high and low momentum, such as the velocity streaks of the buffer layer. Proper Orthogonal Decomposition (POD) is performed on the velocity field to study the coherent structures in turbulent flow. This allows the investigation of distribution of turbulent kinetic energy (TKE) as a function of scale in the TBL flows that are inhomogeneous in the streamwise direction Liu et al. (2001). POD allows for LSMs to be characterized as structures whose contribution to the domination spatial mode is above a threshold, with further characterization into high and low momentum events based on the temporal coefficient.

2   Experimental Methodology

High-spatial resolution (HSR) 2C-2D single-exposed PIV images were taken in the $x - y$ plane of the turbulent boundary layers in the LMFL High-Reynolds-Number Boundary Layer Wind Tunnel at Laboratoire de Mécaniquedes Fluides de Lille (LMFL), Lille, France. This facility has a $2m$ wide, $1m$ high and $20.6m$ long test section with the ZPG, favourable-pressure-gradient (FPG) and APG sections, as shown in Figure 1.
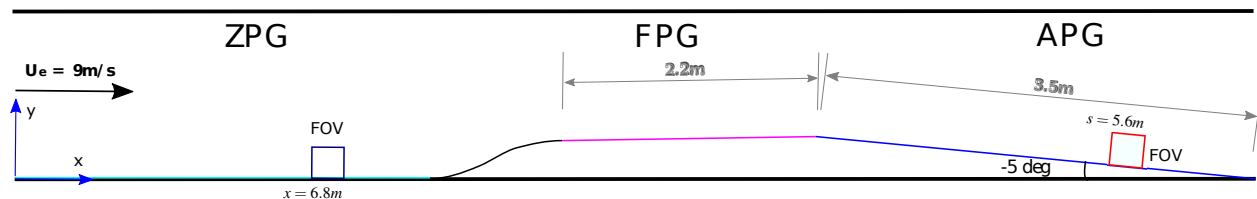

Figure 1: Schematic of the test section in the LML Wind Tunnel. Figure adapted from Cuvier et al. (2017).

The FOVs shown in Figure 1 were illuminated using a dual-cavity BMI Nd:YAG laser with a wavelength of $532nm$ and an output energy of up to $200mJ$. This enabled an Imperx Bobcat B6640 $29MP$ camera to image the seeding with a mean diameter of $1\mu m$ produced by a seeder using a water-glycol mixture. Over 10,000 single-exposed image pairs were captured, which were subsequently analysed using an in-house multigrid/multipass cross-correlation PIV algorithm written by Soria (1996). Due to the physical sensor array size of the camera, dewarping was used to correct for lens distortion, as done in Sun et al. (2021).

3 Results and Discussion

The results obtained from this experimental campaign are in good agreement with the Eu-HIT results from Cuvier et al. (2017) which were collected in the same facility under identical operating conditions. The EuHIT results were captured with more cameras than the current experiment, which allowed measurement of a longer domain at significantly less spatial resolution. The analysis is performed using the snapshot POD method, and the results allow for the velocity fields used in the POD to be characterized as LSMs that are high or low-momentum events, which aide in the investigation of the effect of LSMs on the turbulent statistics. Figure 2 shows that the results for the mean streamwise velocity profile of the ZPG-TBL, which shows that the high momentum LSMs have a higher mean

Figure 2: Mean streamwise velocity profile (U^+) with high momentum LSMs (U_h^+) and low momentum LSMs (U_l^+).

streamwise velocity than the original ensemble and that the low momentum LSMs have a lower mean streamwise velocity than the original ensemble. Similar results were observed for the APG-TBL, which along with the effect of these events on the second-order turbulent statistics, will be presented. Further details are available in Shehzad et al. (2021).
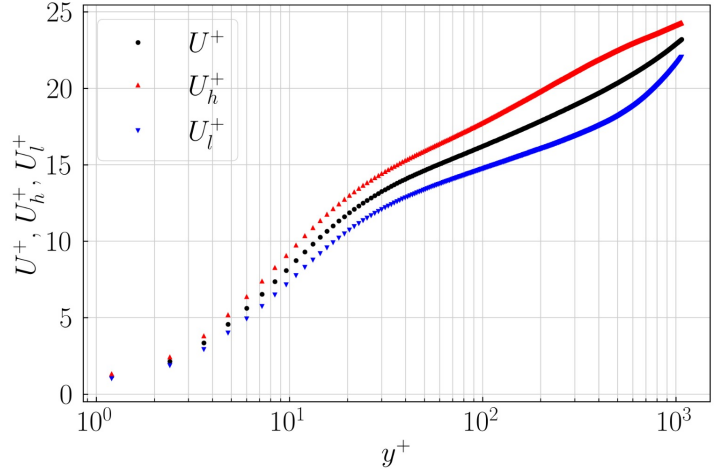
4 Acknowledgements

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