Pressure Statistics from Direct Simulation of Turbulent Boundary Layer

A.G. Gungor, J.A. Sillero and J. Jiménez
Corresponding author: gungor@torroja.dmt.upm.es

School of Aeronautics, Universidad Politécnica de Madrid, 28040 Madrid, Spain.

Abstract: The effect of inflow boundary condition, primarily on the pressure statistics is discussed for direct numerical simulation of turbulent boundary layers with Reynolds numbers in the range $Re_\theta = 1100 - 6650$.

Keywords: Direct Numerical Simulation, Turbulent Boundary Layers, Pressure Fluctuations.

1 Introduction

The pressure fluctuations in turbulent boundary layers are of special interest in many engineering applications. Pressure fluctuations at the wall beneath turbulent boundary layers contribute to aerodynamic noise generation and flow-induced vibrations. The characteristics of the wall-pressure have been extensively studied in both experimental and theoretical investigations, and reviews of earlier work may be found in [1, 2]. However, from the experimental perspective, the knowledge on the behavior of pressure fluctuations has not advanced as much as that of velocity fluctuations. This is due to the lack of pressure-measuring instruments that can accurately measure the fluctuating quantity.

In experiments, common problems are the contamination of the pressure data due to acoustic disturbances from the experimental facilities, and attenuation of the data caused by the finite-size of the transducer [3]. In computations, similar problems might arise, and that is the focus of this paper. We will discuss how the pressure statistics are affected by the inflow conditions in direct simulations of a zero-pressure-gradient, spatially developing, turbulent boundary layer.

2 Numerical Method

The new boundary layer simulation on which this paper is based performed in a parallelepiped with a no-slip wall, spanwise periodicity, and streamwise non-periodic inflow and outflow. This numerical experiment spans $Re_\theta = 1100 - 6650$, matching the range of available channels at $Re_\tau = 550 - 2000$. The numerical code is discussed in [4], including a full discussion of the numerical scheme, and examples of applications to other problems. The numerical parameters of the boundary layer is summarized in table 1. The proper turbulent inflow condition, key in boundary layers, is generated by an auxiliary simulation BL^* at lower resolution and Reynolds number. That auxiliary layer uses the rescaling technique to generate its own inflow data, and is used to feed the inflow of the main simulation, $BL6000$.

Table 1: Parameters of the turbulent boundary layer simulations. L_x, L_y and L_z are the box dimensions along the three axes, N_x, N_y, and N_z are the corresponding grid sizes, and the Δ values are the resolutions in wall units. The momentum thickness, θ, is given at the middle of each box, the boundary layer thickness, δ_{99t} at the transfer plane of the auxiliary simulation.

	Re_θ	$(L_x, L_y, L_z)/\theta$	$\Delta x^+, \Delta y^+, \Delta z^+$	N_x, N_y, N_z	L_y/δ_{99t}
BL^*	1100-2970	$481 \times 47 \times 191$	$13 \times 0.32 \times 7.3$	$3585 \times 315 \times 2560$	4.20
$BL6000$	2780-6650	$547 \times 29 \times 84$	$7 \times 0.32 \times 4.1$	$15361 \times 535 \times 4096$	5.80

3 Results and Future Work

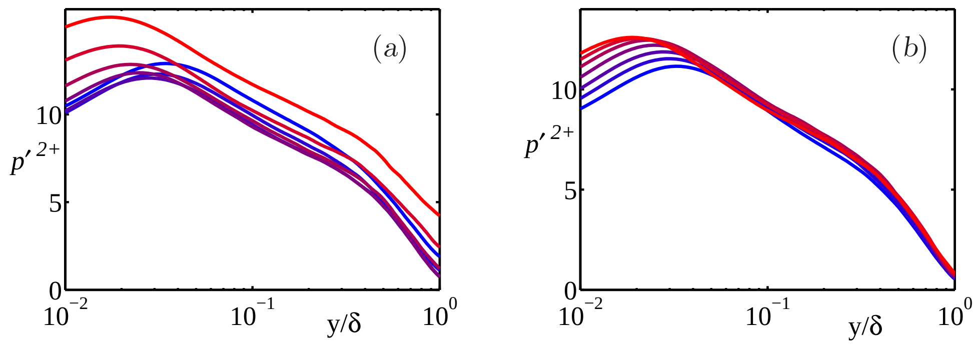

Figure 1: Profiles of the pressure fluctuation intensities along the boundary layer in the range $Re_\theta = 3000$(blue)-6000(red) with an increment of 500.

Figure 1 presents pressure fluctuation intensities along the boundary layer. The contamination of the pressure data due to the problems associated with the inflow conditions are displayed in figure 1a. The profiles in figure 1b, which come from a new simulation with a correction at the inflow, collapse well in outer units, showing a clear Reynolds number dependence near the wall, in agreement with the previous experimental and numerical observations. Final paper will discuss the effect of inflow condition on the pressure data, along with comparisons of results with experiments and other numerical studies.

References

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