Wall shear stress distribution in a turbulent channel flow

Omid Amili¹, Julio Soria²

1: Laboratory for Turbulence Research in Aerospace and Combustion, Department of Mechanical and Aerospace Engineering, Monash University, VIC 3800, AUSTRALIA, omid.amili@eng.monash.edu.au
2: Laboratory for Turbulence Research in Aerospace and Combustion, Department of Mechanical and Aerospace Engineering, Monash University, VIC 3800, AUSTRALIA, julio.soria@eng.monash.edu.au

Keywords: Film-based sensor, Instantaneous wall shear stress measurement, Turbulent channel flow

In turbulence research, to understand the dynamics of the near wall momentum transfer, high spatial resolution measurements of wall shear stress distribution are needed. The present study is aimed at measuring instantaneous wall shear stress distribution in a turbulent channel flow using an in-house developed film-based shear stress sensor.

1. Sensor description

The film-based shear stress sensor which used to directly measure the wall shear stress consists of mounting a thin elastic film on the solid surface. The sensor is made of a homogeneous, isotropic, and incompressible material and satisfies the linear elastic solid characteristics within the desired range of operation. The geometry and mechanical properties of the film are measured, and particles are embedded on the film’s surface to act as markers. An optical technique is used to measure the film deformation caused by the flow (Amili et al, 2009). The static calibration of the sensor involves applying a constant shear load on the film’s surface and measuring the film deformation under different loading conditions. The effect of the loading rate on the sensor behavior was investigated via transfer functions obtained using a dynamic calibration apparatus and procedure developed for this specific purpose.

2. Experimental setup

Wall shear stress measurement was performed in the open-circuit wind tunnel facility with the aspect ratio of 9.75:1 at a position approximately 41 channel height downstream of the test section entrance. The experiment was conducted at the Reynolds number of 130,000 based on the bulk flow velocity and the channel full height. The turbulence intensity at the centerline of the channel is approximately 1.7%. The sensor used for the experiment has the shear modulus of 80 Pa and thickness of 2 mm. Deformation of the film was imaged at 1 KHz using an 8-bit Motion Pro X3 high speed camera at full CCD size of 1280×1024 px in combination with a 200 mm Nikkon Micro-Nikkor lens.

3. Two-dimensional wall shear stress distribution

An example field of the instantaneous fluctuating wall shear stress distribution is shown in Figure 1a. The vector field represents the instantaneous wall shear stress fluctuations. The contour indicates the normalized streamwise fluctuating wall shear stress, $\tau'_x/\tau_{x, rms}$. The sensor detects the existence of low- and high-shear regions aligned in the streamwise direction. The coherent motions dominate the two-point correlations of the streamwise and spanwise wall shear stress fluctuations. The spanwise two-point correlation of the streamwise wall shear stress fluctuations, $R_{\tau_x/\tau_x} (\Delta z)$ with outer scaling are shown in Figure 1b for comparison with other wall shear stress estimations found in the literature. Elongated positive correlation region in the streamwise direction is accompanied by negative correlation behavior at spanwise sides.

4. Conclusions

The sensor shows the existence of low- and high-shear regions elongated in the streamwise direction. Measurement of the fluctuating wall shear stress distribution reveals the imprint of small-scale hairpins or counter-rotating streamwise vortex pairs existing in the near-wall region. The spanwise extent of the positive two-point correlations of the streamwise fluctuations provides the average width of 244 ℓ’ for the near-wall coherent structures.

References