CONTROL OF NEAR-WALL STRUCTURES IN A TURBULENT BOUNDARY LAYER USING SYNTHETIC JETS

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INTRODUCTION

A significant portion of turbulence production in a turbulent boundary layer is believed to be associated with the naturally forming and evolving hairpin/horseshoe vortices that populate the region above the buffer layer and the log-layer. These vortices are thought to induce low and high speed streamwise streaks observed in the viscous sublayer. In this scenario, the bursting of the sublayer streaks provides the main mechanism of turbulence production in the near-wall region of a turbulent boundary layer [1]. By introducing artificial streamwise vortical structures using round synthetic jets in a controlled manner into the near-wall region, the turbulent activities could be suppressed resulting in a reduction of turbulence production and of skin friction drag.

In this experimental work a zero-pressure-gradient (ZPG) turbulent boundary layer is forced by an array of five synthetic jets. Velocity measurements are carried out by means of Particle Image Velocimetry to evaluate the effect of the forcing both on the mean velocity profile as well as on the turbulence intensity and the Reynolds shear stress profiles. The characteristics of the sublayer streaks are preliminarily examined through Liquid Crystal Thermography, using a digital video camera to assess the nature of the turbulent boundary layer under investigation in the near-wall region and highlight the size and strength of the largest coherent structures to be controlled.

CHARACTERISTICS OF THE TURBULENT BOUNDARY LAYER UNDER INVESTIGATION

All the experiments are performed in a ZPG *turbulent boundary layer* developing on a flat plate in a *water flow* at a free-stream velocity of about *0.1 m/s.* The boundary layer is tripped just downstream the leading edge. At the location of interest the boundary layer thickness is about 30 mm and the Reynolds number based on the momentum thickness is about Re_θ=300.

At first, the characteristics of the sublayer streaks are examined by applying a coating of *thermochromic liquid crystals* on the surface and a resistive heater underneath the surface. This technique was used in previous works mainly as flow visualization tool in turbulent boundary layers and turbulent spots [2,3,4]. In this work the technique is refined by using a digital video-camera acquiring images at a frame rate of 10 Hz, in order to extract quantitative spatial-temporal information on the near-wall structures. Results are in agreement with literature [1]. In particular the spanwise spacing of the streaks was observed to be about 18-20 mm, more or less 100 ν/u_τ , i.e. 100 viscous units[1]. Figure 1 reports the temporal evolution of the passage of a streak at six successive instants. The formation, the passage and successive disappearance of the streak are clearly observed.

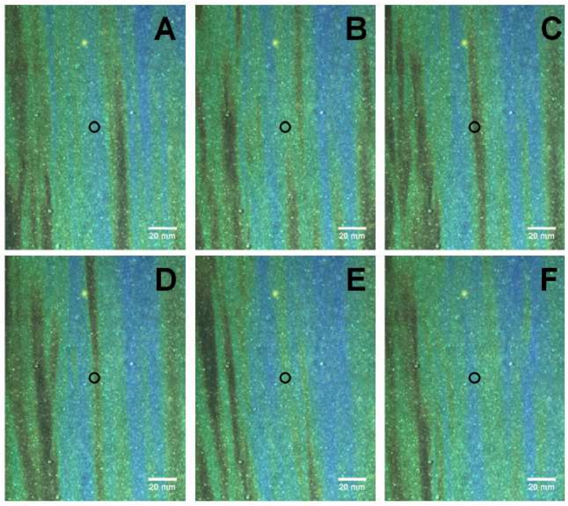

Figure 1 – Frames correspondent to six successive time instants signaling the passage of a single streak with liquid crystals

PIV STUDIES OF TURBULENT BOUNDARY LAYER FORCING USING A SYNTHETIC JET ARRAY

Successively the boundary layer at the same freestream conditions is forced by a synthetic jet array consisting of 5 circular orifices, of diameter 5 mm each and spanwise separation of 9 mm. Figure 2 shows a schematic of the designed flat plate model. The size of the orifices and their spacing are based on the previous analysis with liquid crystals. The jets generate an oscillating mass-less fluid flow from the orifices. The operating conditions of the synthetic jets can be varied by altering their diaphragm oscillation frequency and amplitude independently. Two non-dimensional parameters are defined to evaluate the synthetic jet performance: 1) the velocity ratio VR, which defines the ratio of the jet to freestream velocity: 2) the non-dimensional stroke length L, which is proportional to the length of the fluid column pushed out of the orifice during the blowing part of the cycle. The jets produce artificial trains of hairpin vortices convecting in-phase

[1] In this notation ν is the kinematic viscosity of the fluid and u_τ is the skin friction velocity

downstream according to extensive studies carried out in previous works [5]: this happens typically when VR is lower than 0.4.

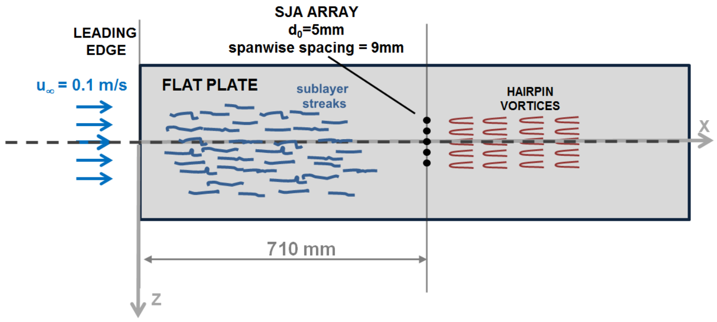

Figure 2 –Synthetic jet array configuration

Particle image Velocimetry is used to evaluate the effect of the forcing on x-z centre-plane. In every forced case, each one with different VR and L, 500 image pairs are taken at a frequency of 2.5 Hz and time-averaged velocity fields are calculated from them.

The effect of the forcing on the time-averaged streamwise velocity profile in the centre-plane at x=0.78 m from the leading edge is shown in Figure 3. A region of reduced momentum is found in the buffer layer and in the log-layer, between y^+=20 and y^+=100. Results are in a agreement with similar studies in literature [6,7,8].

In Figure 4 the effect of the forcing on the root mean square (RMS) of the streamwise turbulence intensity profile is shown. A reduction of the peak at the edge of the buffer layer, related to the production of turbulence associated with the bursting of the sublayer streaks, is observed. This indicates the weakening of the turbulence production mechanism mentioned above.

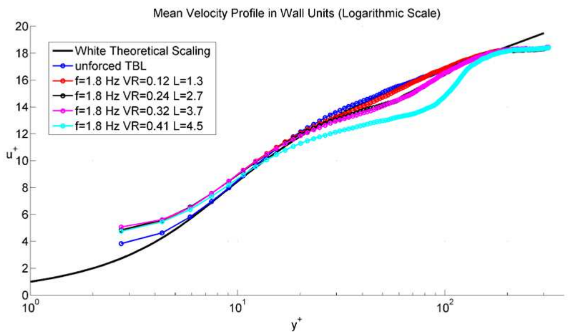

Figure 3 – Effect on the forcing on the mean velocity profile, x=780 mm

To evaluate the impact on skin friction reduction, a method has been developed to evaluate the mean skin friction coefficient from the mean velocity profile, based on [9]. The ratio of the skin friction in the forced case to that of the unforced cases is shown in Figure 5. The skin friction reduction seems to be more sensitive to the velocity ratio VR than to the stroke length L. The reduction is in agreement with the reduction for the turbulence intensity peak, shown in Figure 4. Further PIV experiments will be undertaken on off centered planes as to evaluate the overall effects of synthetic jet actuation on the potential reduction in the wall shear stress.

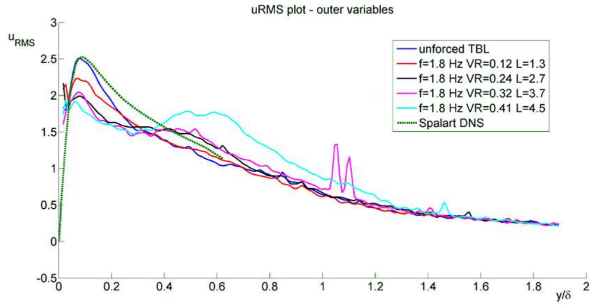

Figure 4- Effect of the forcing on the streamwise turbulence intensity, x=780 mm

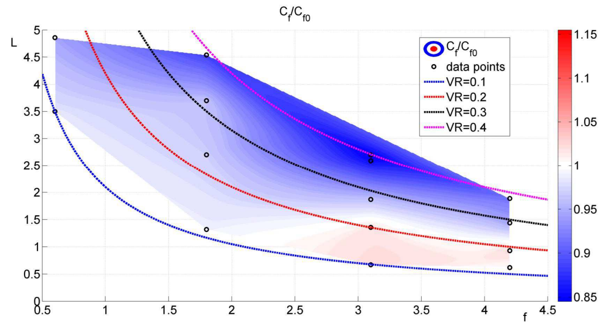

Figure 5 - Estimation of skin friction reduction in the forced cases as a function of VR and L, x=780 mm

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