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CONTROL OF TURBULENT STREAKS BY ACTIVE WALL MOVEMENT

Philippe Konieczny*, Alexis Renotte**, Bertrand Nogarede**, Alessandro Bottaro*
*IMFT, EMT2 Group, Allée du Professeur Camille Soula, FR 31400 Toulouse, France
**INPT, LEEI, EM^2 Group, Rue Camichel, BP 7122, FR 31071 Toulouse, France

Summary Experimental results on the near-wall structures of turbulent boundary layers subject to a dynamic deformation of the wall are presented. The wall is moved on the basis of computational evidence which shows that a spanwise forcing in the form of a standing or traveling wave of the right amplitude, wave length and frequency can produce a significant turbulent drag reduction. This wave is supposed to act on the near-wall coherent structures, whose dynamics controls the turbulence production. The control is first tested on a model of the near-wall turbulent boundary layer, streamwise vortices and streaks are produced artificially by an array of roughness elements in a Blasius boundary layer. The control in the form of a standing wave has been tested and work is in progress to appraise the effectiveness of a spanwise travelling wave. So far, it has been found that the most effective excitation wave has a period of oscillations close to 50 viscous units of time, in agreement with experimental and theoretical results on similar configurations. Future work will consider the effect of the actuation module in turbulent flows.

INTRODUCTION

The dynamics of turbulent and transitional boundary layers is closely related to the self-sustaining wall-cycle. In the near-wall region, the coherent structures are correctly detected nowadays but if the formation of low and high-speed streaks is well understood, the regeneration of longitudinal vorticity is still under assessment. Linear perturbation analysis reveals that a streak velocity distribution $U(y,z)$, and the process known as the transient growth mechanism, capable of producing large linear amplification by secondary instabilities [2], contribute to the generation of streamwise vortices.

This work aims at finding efficient means to reduce skin friction drag in a turbulent boundary layer. It starts from the realization that a spanwise forcing can significantly reduce the wall shear stress and turbulence intensities. The forcing acts on the streaks hampering the "cycle".

CONTROL STRATEGY

The control procedure by a large-scale spanwise forcing attempts to moderate the streak instability. Forcing through large-scale streamwise vortices induced by vortex generator jets [3] have produced conclusive results. A significant reduction of mean and fluctuating skin friction is observed, that can locally attain 50%. The turbulence production is also hampered by the action of a spanwise volume force, which can be applied in a form of a standing or a travelling wave [4]. The oscillatory force results, with the (sub-)optimal forcing parameters, in a shear stress reduction by more than 30% and by a weakening of the streaks' intensity. Spanwise oscillations of the plate [5] produces similar results to the case of the oscillatory force. The characteristic parameters seem to be the oscillating period and the amplitude of the velocity, around 110 wall time unit and at least $15u_\tau$, respectively, for the optimal case [6]. The effect of a control in the form of a travelling wave are nearly the same, however for a forcing frequency twice, but allowed a vanishing of the streaks. In the present work, the forcing is generated by a moving wall, which is able to induce a spanwise wave.

Control module

To generate the spanwise wave, a control module composed by two arrays of 12 piezo-ceramic actuators is mounted flush at the wall. Each actuator consists of a cantilever beam and is driven by a multilayer piezo-ceramic element. The ceramic elongation induces, via a system of leverage points, a vertical displacement of the beam. The actuators work in pairs and each pair is out of phase with the neighbours, allowing the generation of different wave configurations. The controller active area is 25 cm long and 16 cm wide. To prevent leakage, the module is covered by a thin latex film.

Model system

We aim at producing a scaled-up model of the turbulent viscous layer by artificially generating regular streaks and vortices in a laminar boundary layer, in order to isolate events which appear to be important and to be able to describe more precisely the effect of the wave on the streaks' secondary instabilities. Roughness elements are installed along the span and we introduce "wall" units to scale the model, using the length scale (ν/u_τ), with u_τ the skin friction velocity based on the Blasius velocity distribution at the position corresponding to half-way through the control module. However, the streamwise axis is normalized with the distance of the roughness elements from the leading edge.

Experimental procedure

The experiments are performed in a close circuit low-turbulence-level wind tunnel at a free-stream velocity of $2m/s$. Mean and fluctuating velocity profiles are measured by hot-wire anemometry. Velocity fields have also been taken in the streamwise-spanwise plane by particle image velocimetry (PIV) downstream of the active area, at a fixed vertical position of 3mm, i.e. within the boundary layers thickness. Flow visualization has been carried out by injecting a sheet of smoke through a little slit on the wall placed at the same streamwise position of the roughness elements. This technique is able to show the artificial streaks undulations and their destabilization by secondary instabilities. The objective is to show the effect of the control, both on the synthetic turbulence model and on the turbulent boundary layer triggered at the leading edge: for this we have carried out a parametric study with the forcing wave characteristics (wavelength λ_z, period T, amplitude A) which will be mostly given in wall units (λ_z^+, T^+, A^+).

RESULTS

Only results in which the control has the form of a standing wave are given here. The case without control and the measurements of artificial streaks are documented in [7] and show a sinuous instability mode. In the same configuration, and for the same roughness elements, a flow velocity of $2m/s$ generates streaks'amplitudes of roughly 10% of the free-stream velocity, at a downstream position of 1.7. The actuation module is located between $x = 1.2$ and $x = 2.0$.

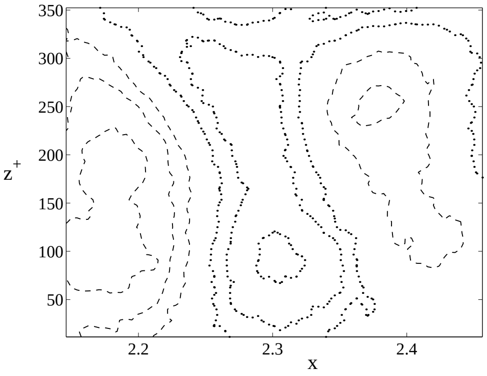

Figure 1. Spanwise velocity induced downstream of the active area generating a standing wave: $\lambda_z^+ = 700$, $T^+ = 30$, $U = 2m/s$. Wave crests are located at $z = 0$ and $z = 350$. Isolines correspond to $\pm 1, \pm 2$ and $\pm 3cm/s$.

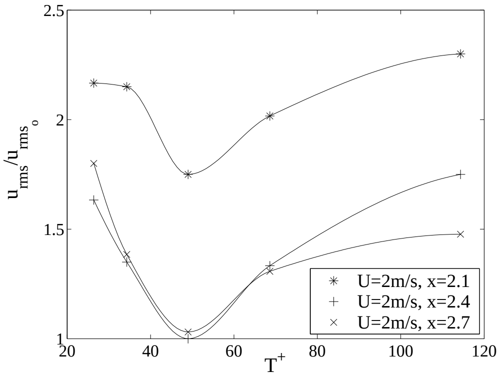

Figure 2. Mean fluctuating velocities in different cross sections along the streamwise direction; u_{rms_0} denotes no action at each given x.

PIV technique is the most efficient mean to measure the transverse forcing produced by the actuators. The largest action is obtained for the wavelength $\lambda_z^+ = 700$ (figure 1), and the velocity induced by the control module does not exceed $5cm/s$ (at $y^+ = 15$) in the window examined. Hot-wire measurements have shown for this case a slight effect (figure 2). Streaks are excited, and the response to the excitation is function of the actuation frequency. Around $T^+ = 50$, the energy of fluctuations reach a minimum. Flow visualizations show that the "wall" wave excite secondary instabilities which depend of the actuating period.

Some measurements by hot-wire and PIV have been taken for a case of a turbulent boundary layer, but no conclusive effects have been discerned yet.

CONCLUSION

Preliminary results seem to indicate that an optimal excitation period close to 50 viscous units of time on the *model flow* yields the most effective control, in agreement with numerical results on similar configuration [4] by a travelling wave. Current work considers the effect of the actuation module in turbulent flows and action in the form of a travelling wave.

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