EXPERIMENTAL INVESTIGATION OF DRAG REDUCTION EFFECT IN WALL TURBULENCE OVER TRAVELING WAVE-LIKE RUBBER SHEET

Yuho Ishiwata[1], Hiroya Mamori[1], Kaoru Iwamoto[1*] & Akira Murata[1]
[1]*Dep. of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, Tokyo, Japan*
[*] *Corresponding author: iwamotok@cc.tuat.ac.jp*

Abstract Drag reduction effect in fully developed turbulent channel flow over traveling wave-like rubber sheet is investigated experimentally. An oscillator composing an amplified piezoelectric actuator generates a vibration of rubber sheet, which propagates in the downstream direction. The propagation of the wave is confirmed by laser displacement meters. A pressure difference over the wave at a downstream location decreases below that of a turbulent and laminar flows over a flat surface, while increases at upstream locations. A particle image velocimetry measurement clarifies the turbulent statistics. Decrease of a Reynolds shear stress is confirmed.

INTRODUCTION

Control to decrease skin friction drag in wall turbulence is expected to contribute to energy utilization. Min *et al.* [1] performed a direct numerical simulation of an incompressible turbulent channel flow to investigate a skin-friction drag reduction effect due to a blowing and suction from the walls in a form of traveling wave. The large skin-friction drag reduction was found when the wave travels in the downstream direction. Moreover, a resent result [2] shows the turbulent fluctuation is found to completely vanish (i.e., relaminatization) when the wave travels in the downstream direction.

Instead of using blowing and suction, a drag reduction effect by downstream traveling wave-like wall deformation was also experimentally found almost 40 years ago. Taneda and Tomonari [3] reported turbulence is suppressed when the wave travels faster than the uniform velocity in a boundary layer flow. In their experimental system, the travleing wave is created by the rubber sheet which supported by ribs. The rib reciprocated vertical motion by means of a cam. Recently, Nakanishi *et al.* [4] found a relaminarization in turbulent channel flow due to the wave control by means of the direct numerical simulation.

The objective of the present study is to investigate the drag reduction effect in wall turbulence controlled by the downstream traveling wave-like rubber sheet in the wind channel, experimentally. The wave is a propagation of a displacement of a rubber sheet which is vibrated by single oscillator. The generation system of the wave is simpler than that of Taneda and Tomonari [3].

EXPERIMENTAL SETUP AND SAMPLE RESULTS

A schematic of a wind channel is shown in Fig. 1. A working fluid is air, which driven by a blower. The entrance section is designed to obtain the fully developing flow at the inlet of the test section. The channel-half width is $\delta = 10\mathrm{mm}$. At the test section, the lower wall is covered by an elastic rubber sheet. The upstream end of the rubber sheet is attached on the top of an oscillator. This oscillator consists of an acrylic bar and a piezoelectric actuator. An input frequency of oscillator is kept at $160\mathrm{Hz}$.

Figure 2 shows the time trace of the displacement of the rubber sheet at $x/\delta = 150$ and $\mathrm{Re}_b \approx 5200$ (based on the mean bulk velocity and δ) . The displacement is measured by two laser displacement meters. Since there is a time delay between two waves, the wave is found to propagate in the downstream direction.

Figure 3 displays the nondimensional pressure difference, $C_{\Delta P}$, as a function of the bulk Reynolds number for different measurement locations. The pressure difference is mesured at the pressure taps located on the upper wall of test section. At the upstream location ($x/\delta = 25$), $C_{\Delta P}$ is found to increase above a skin-friction coefficient of turbulent flow over flat surface. However, as for the downstream locations (i.e., $x/\delta = 75$ and 150), $C_{\Delta P}$ decreases below the laminar level at $\mathrm{Re}_b > 7000$ and is negative for low bulk-Reynolds number.

Figure 4 shows the turbulent statistics at $x/\delta \approx 170$: a mean streamwise velocity, a root-mean-square value (hereafter, referred as the rms value) of the streamwise and wall-normal velocities, and a Reynolds shear stress. The PIV measurement is done by using a YAG laser and a high speed camera. The estimated bulk Reynolds number is $\mathrm{Re}_b \approx 5300$. The statistics over the flat surface are in a reasonable agreement with the DNS data [5], excepting an overestimation of the rms value of the streamwise velocity. Due to the wave, the mean velocity slightly decreases below that of the flat surface at $y^+ < 10$. The rms values of the streamwise velocities decreases, while the rms of the wall-normal velocity does not. The decrease of the Reynolds shear stress at $y^+ < 70$ implies the reduction of the skin-friction drag [6].

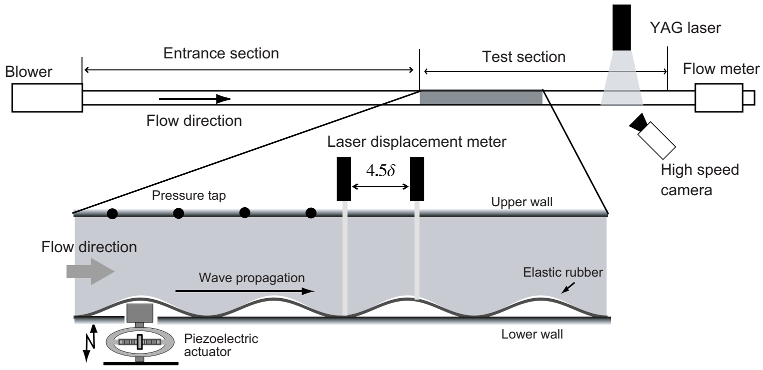

Figure 1. Schematics of the wind channel

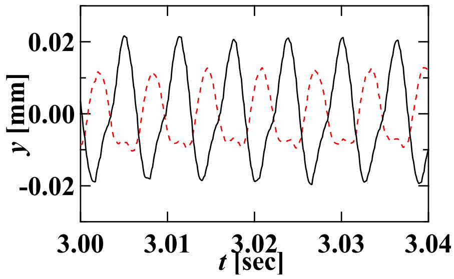

Figure 2. Displacement of rubber sheet measured at $x/\delta \approx 150$ and $\mathrm{Re}_b \approx 4300$: Solid and broken lines are measured by upstream and downstream laser displacement meters, respectively.

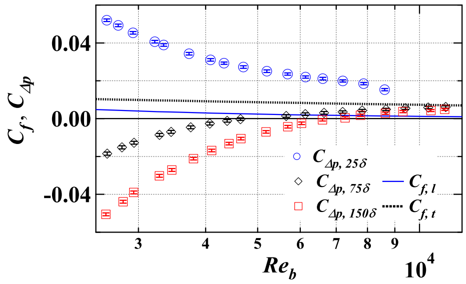

Figure 3. Nondimensional pressure difference for different locations ($C_{\Delta p}$) as a fuction of bulk-Reynolds number. Skin-friction drag coefficient of flat surface is also plotted: $C_{f,l}$, laminar flow; $C_{f,t}$, turbulent flow.

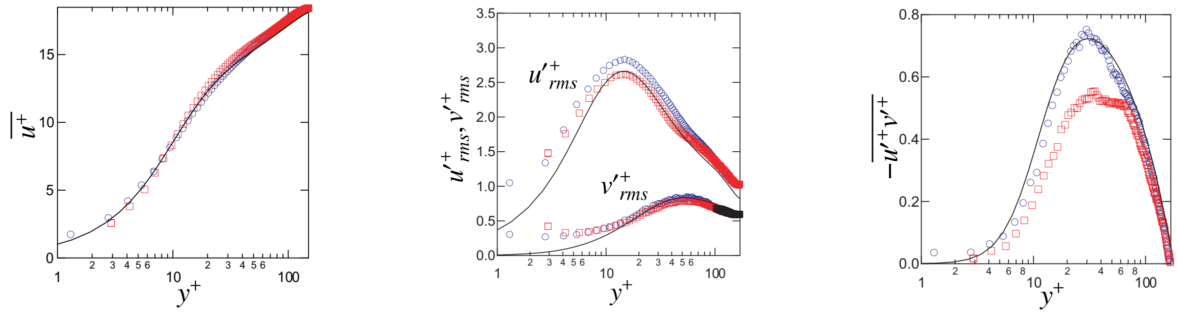

Figure 4. Turbulent statistics obtained by PIV measurement: left, mean streamwise velocity; top right, rms of the streamwise and wall normal velocity; bottom left, Reynolds shear stress. The marker denotes the experimental results: ◯, flat surface; □, wall deformation. Thin line, the DNS data ($\mathrm{Re}_\tau = 180$).

OUTLOOK

In the final paper, the turbulent statistics at the different locations will be shown by means of PIV measurement to deduce a mechanism of significant decrease of the nondimensionalized pressure difference. Moreover, the skin-friction drag reduction rate will be estimated by using an identity equation for the skin-friction drag coefficient [6].

References

[1] T. Min, S. M. Kang, J. L. Speyer, and J. Kim, Sustained sub-laminar drag in a fully developed channel flow, *Journal of Fluid Mechanics* **558**: 309–318, 2006.

[2] H. Mamori, K. Iwamoto, and A. Murata, Relaminarization mechanism of turbulent channel flow controlled by traveling wave-like blowing and suction, *Proc. 8th Int. Symp. on Turbulence and Shear Flow Phenomena* (to be presented), 2013.

[3] S. Taneda and Y. Tomonari, An experiment on the flow around a waving plate, *Journal of The Physical Society of Japan* **36**: 1638–1689, 1974.

[4] R. Nakanishi, H. Mamori, and K. Fukagata, Relaminarization of turbulent channel flow using traveling wave-like wall deformation *International Journal of Heat and Fluid Flow* **35**: 152–159, 2012.

[5] R. D. Moser, J. Kim, and N. N. Mansour, Direct numerical simulation of turbulent channel flow up to Re_τ=590, *Phyics of Fluids* **11**: 943–945, 1999.

[6] K. Fukagata and K. Iwamoto and N. Kasagi, Contribution of Reynolds stress distribution to the skin friction in wall-bounded flows, *Phyics of Fluids* **14**: L73–L96, 2002.