2023 AUSTRALASIAN FLUID MECHANICS SEMINAR SERIES

FRICTION DRAG REDUCTION CONTROL FOCUSING ON QUASI-COHERENT FLOW STRUCTURE OF WALL TURBULENCE

DR. AIKO YAKENO (TOHOKU UNIVERSITY)

WEDNESDAY 22 MARCH 2023 (4:00PM AEDT)

ZOOM: LINK ID: 889 3189 6565 PWD: 758869

IN-PERSON: SEMINAR ROOM 311, LEVEL 3, MECH ENG BUILDING, UNI MELB

Abstract: The flow behaves in an orderly manner near the wall surface. At present, that quasi-coherent movement of wall turbulence is mainly explained by a mechanism called self-sustaining or regeneration, which consists of streak structure and streamwise vortices. Streamwise vortices generate Reynolds shear stress near the wall and are known to be the main factor of frictional drag increase. In recent years, streak structure generation has been proposed to be explained by transient amplification of turbulence energy in finite time, called transient energy growth or nonmodal, non-orthogonal energy growth.

Flow control has a long history of practical use, and it seems that active control of wall turbulence has its roots in the verification of v or w-control of streamwise vortices by direct numerical simulation by Choi et al. (1994). Among them, the pre-determined control gives a flow action by spatio-temporal driving of a predetermined frequency on a relatively larger scale than the streamwise vortices, and is considered to be closer to practical use. In fact, it has developed into an attempt to realize oscillation control by the three-dimensional riblet shape of the wall surface. Within the background, I (and collaborators) decided to work on clarifying the mechanism of pre-determined control of spanwise wall oscillation that reduces friction drag by more than 40% by oscillating the upper and lower walls of channel turbulence in the spanwise direction.

In order to investigate the changes in Reynolds shear stress in more detail from the viewpoint of turbulence structure, the flow around streamwise vortices was obtained by conditional extraction. We use the second invariant of the velocity gradient tensor to determine the center position of each vortex, and average the flow around it for each control phase. As a result, it became clear that the strength and weakness of each vortex is brought by a larger-scale action than previously expected. It is the effect that the direction of the velocity shear in the Stokes layer changes the tilting angle of the vortex axis, which changes the energy redistribution within a vortex.

Another approach is focusing on the streak generation. The optimum period of spanwise wall oscillation control is T ~ 100, which corresponds to the time to reach the streak structure length of 1000 when the advection velocity is about 10 on the viscosity scale. It was thought that we should investigate the influence of control on streak structures as well. This is because it was thought that weakening the strength of the streak structure would suppress secondary instability, and as a result, streamwise vortices, which are the main cause of drag, would be less likely to occur.

We computed the maximum energy amplification rate by adjoint analysis for the oscillatory turbulent channel. It was confirmed that the value is reduced from the original value no matter what phase the control is started. Oscillation control restrained the growth of streak structures. In addition, the amplification rate of the structure with a 20-degree tilt in the spanwise direction increased slightly compared to the non-controlled state. This is consistent with the trend in direct numerical simulation.

Bio: Aiko Yakeno is an Assistant Professor at the Institute of Fluid Science, Tohoku University, and belongs to the Aerospace Fluid Engineering Laboratory. Her interest is in flow dynamics and its control. She won the Ryumon Prize in 2022, one of the awards given to young researchers by the Japan Society of Fluid Mechanics. She was also the youngest recipient of the Frontier Award by Japan Society of Mechanical Engineers (JSME), Fluid Engineering Division. Check out her full profile here.

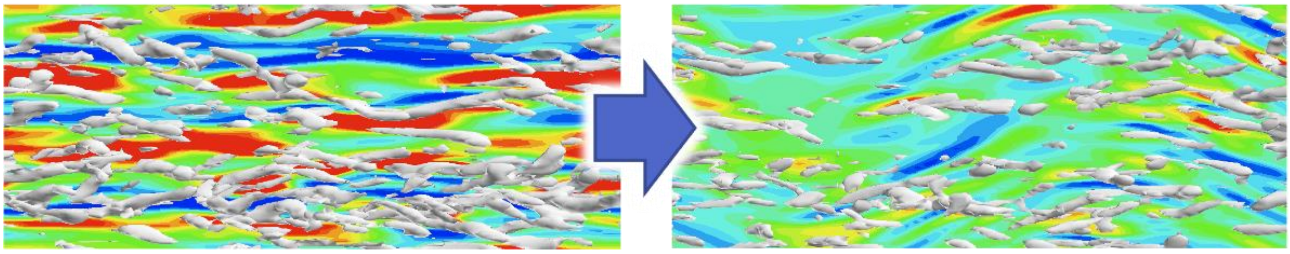

Fig. 1 Spatially periodic control (Yakeno, Hasegawa and Kasagi, in proceeding of TSFP6 (2009), Yakeno, Hasegawa and Kasagi, Trans. JSME, B (2010) in Japanese)

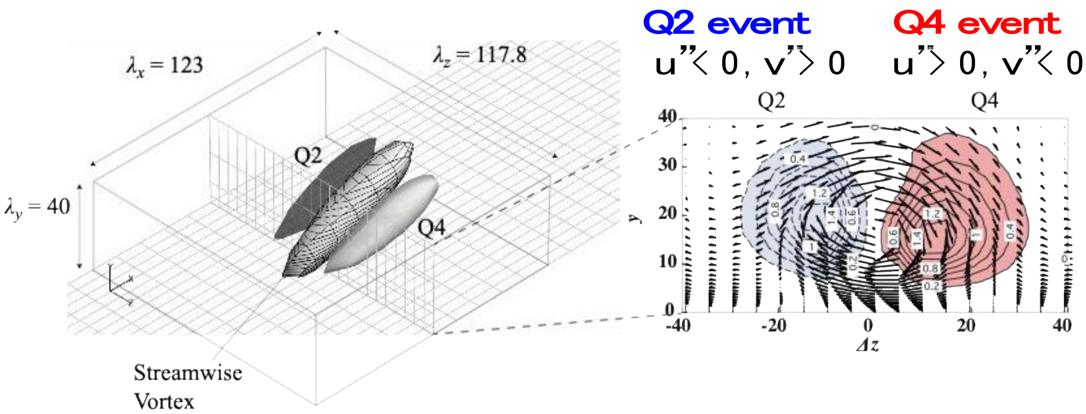

Fig. 2 Conditionally extracted streamwise vortex and Reynolds shear stress of Q2 and Q4 events distribution (Yakeno, Hasegawa and Kasagi, Physics of Fluids (2014)).

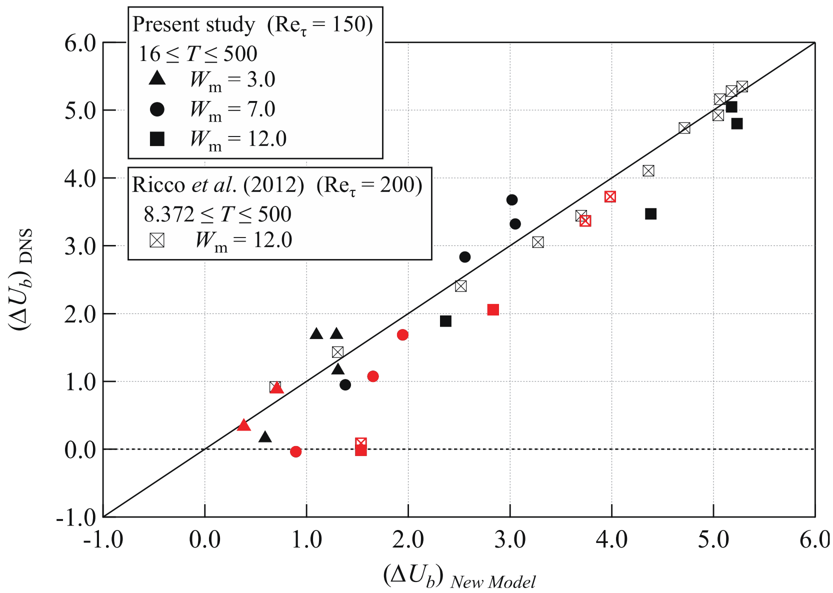

Fig. 3 Increase in flow due to drag reduction using my proposed shear acceleration prediction method (Yakeno, Physics of Fluids (2021)).

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