Large-scale Turbulent Secondary Flows Induced by Spanwise Alternatively Distributed Strips Control

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In aerodynamics, flow separation can often result in increased drag, particularly pressure drag and it is reported that the separation pressure drag accounts for 50 to 90 % of the total aerodynamic drag [1]. The generation of large-scale streamwise vortex (LSSV) in a turbulent boundary layer is closely linked to the turbulent mixing process and its potential impact on supressing flow separation and aero drag. In this study, direct numerical simulations (DNS) of a weakly compressible turbulent channel flow with Spanwise Alternatively Distributed Strips (SADS) control are conducted to investigate the characteristics of the LSSV induced by small-scale wall actuation. SADS is obtained by applying out-of-phase control (OPC) [2] and in-phase control (IPC), namely active wall-normal velocity fluctuations, alternatively arranged along the spanwise direction at the bottom wall of the channel, as presented in Figure 1 (a). DNS of an unperturbed plane channel flow is first validated against the incompressible DNS data of Moser et al. [3]. It is then used to simulate a perturbed channel flow in which the turbulent coherent structures are alternatively enhanced and suppressed by SADS, as presented in Figure 1 (b). From Figure 2 we can see that the instantaneous and mean velocity fields present large-scale motions in the *y*-*z* plane. Large-scale low-speed region can be observed above the OPC strips and looking closer at the mean velocity field, the low-speed region exhibits steady flow streak structures, leading to a thicker viscous boundary layer in the corresponding region. The near-wall velocity is larger above the IPC region because the turbulence is enhanced there. Turbulent kinetic energy (TKE) and Reynolds shear stress (RSS) in the *y*-*z* plane are presented in Figure 3. They both increase in the near-wall region above the IPC strips, which can be attributed to the activated near-wall turbulence due to the IPC presence. However, in the region above the OPC strips, we can also find large-scale clusters with higher values of TKE and RSS close to the central part of the channel, although the turbulence coherent structures in the near-wall region are supressed by OPC. This could be caused by the ejection of the large-scale counter-rotating streamwise vortices at a scale up to the half-height of the channel generated between IPC and OPC strips, represented as white arrows in Figure 3. Therefore, the LSSV generated by the current small-scale wall actuation presents a strong ability to enhance turbulence momentum transport and mixing. In the next step, we will study SADS in a spatially developing turbulent boundary layer with and without separation flows to investigate its ability to simulate attached and separated flow controls.

References

1 Hucho, W.H., Aerodynamic Drag of Passenger Cars, in: Aerodynamics of Road Vehicles, Butterworth-Heinemann, 1987, Chapt. 4, pp. 106–213.

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3 Moser, R.D., Kim, J., Mansour, N.N. Direct Numerical Simulation of Turbulent Channel Flow up to $Re_\tau = 590$. Physics of Fluids, 1999, Vol. 11, pp. 943-945.

Code(s) used: Advanced flow Simulator for Turbulence Research (ASTR).

Time usage on ARCHER (approx. kAU): The AUs will be used in August.

Database produced (including web link if available): No.

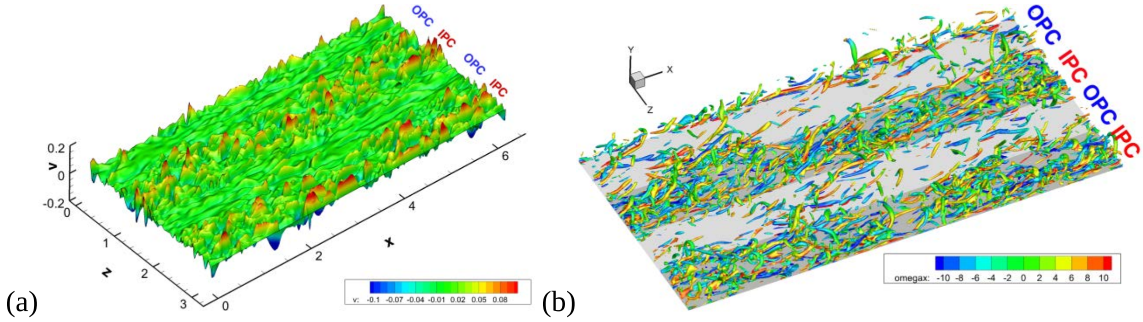

Figure 1: Instantaneous normal velocity at wall (a) and turbulent coherent structures (b) in the channel with SADS.

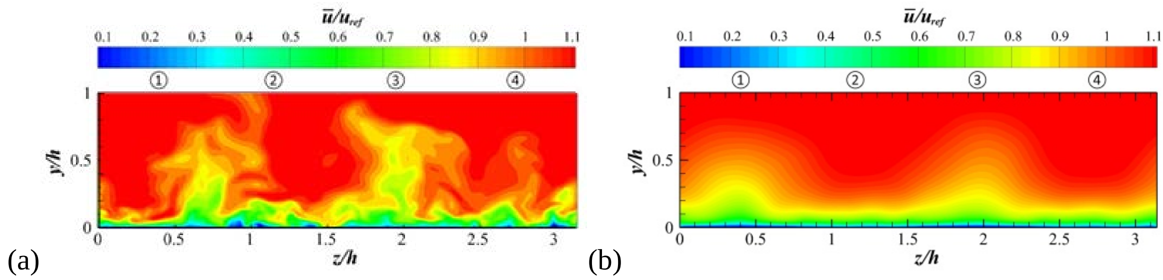

Figure 2: Instantaneous (a) and mean streamwise velocity (b) in the channel flow with SADS. The characters of ①&③ and ②&④ represent the regions of OPC and IPC, respectively.

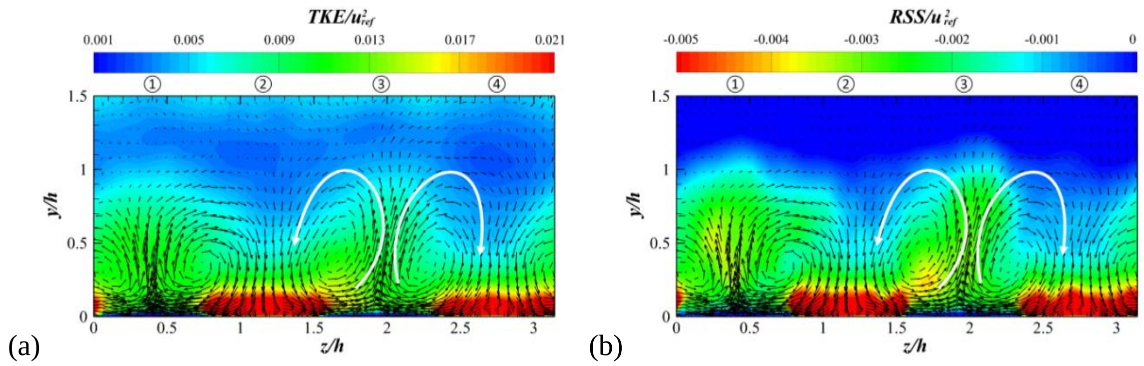

Figure 3: Turbulent kinetic energy (a) and Reynolds shear stress (b) as well as mean velocity vectors in the channel flow with SADS. The white arrows represent the local sweep and ejection motions.