8th European Fluid Mechanics Conference
Bad Reichenhall, Germany
13-16 September 2010

Flow Control for Skin Friction Drag Reduction Based on Sensing of the Streamwise Wall-shear Stress

B. Frohnapfel[a], Y. Hasegawa[a,b], N. Kasagi[b]

Many research efforts in the field of skin friction drag reduction are directed to feedback flow control schemes since they are known to not only yield high drag reduction but also large energy gain[1]. All feedback flow control loops require sensor information obtained at the wall. In this respect wall shear stress sensors are considered one of the most feasible candidates. While the spanwise wall shear stress is well-known to be suitable for state estimation of near-wall turbulence, the streamwise wall shear stress, which is easier to measure in practice, is rather seldom used for flow control loops.

Based on physical reasoning about the regeneration cycle of near-wall turbulence, we investigate the spatial correlation between the streamwise wall shear stress and other flow properties that are commonly used in flow control schemes. We find, for example, that the spanwise gradient of the streamwise wall shear stress, $\partial\tau_x/\partial z$, can be used to estimate the streamwise vorticity or the spanwise wall shear stress further downstream. In order to test the feasibility of this upstream sensing, we investigate flow control loops based on sensing of $\partial\tau_x/\partial z$ in direct numerical simulation of a turbulent channel flow and evaluate them in comparison to existing closed loop control schemes. The results demonstrate that the upstream sensing of $\partial\tau_x/\partial z$ can successfully be employed in flow control schemes in such a way that sensor placement in a range of upstream locations is possible. This might be used to optimize the placement of finite size sensors and actuators as they are to be used in a real system.

[a] Technische Universität Darmstadt, Center of Smart Interfaces, Germany
[b] The University of Tokyo, Department of Mechanical Engineering, Japan
[1] Kasagi et al., Advances in Turbulence **XII**, Springer, 189 (2009).

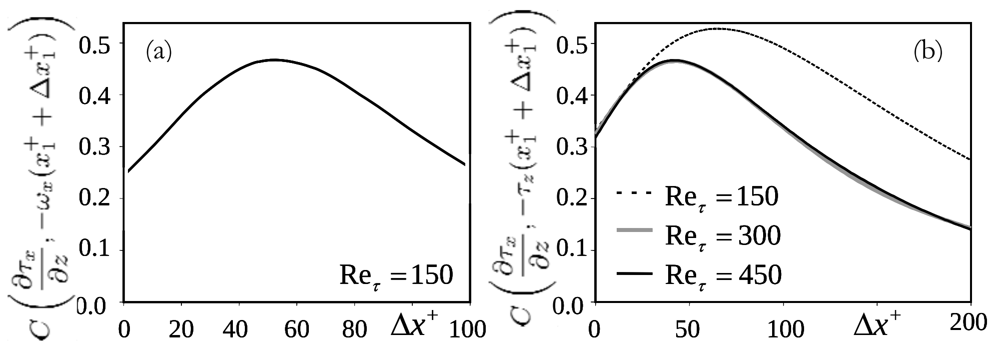

Figure 1: Spatial correlation between $\partial\tau_x/\partial z$ and (a) the streamwise vorticity (b) the spanwise wall shear-stress in a channel flow as a function of streamwise distance Δx^+.