Theoretical Considerations about Near-Wall Turbulence and Resulting Flow Control Schemes

Bettina Frohnapfel, Technical University Darmstadt
Jovan Jovanovic, University Erlangen
Yosuke Hasegawa, University of Tokyo
Nobuhide Kasagi, University of Tokyo

Since turbulent drag consumes large amounts of energy its reduction is of great economical and ecological interest. Our work aims at providing further understanding of the mechanism of viscous drag reduction.

Based on analytical considerations about how near-wall turbulence needs to be modified in order to reduce the momentum loss towards solid walls and to yield lower energy losses, a mechanism of turbulent drag reduction is proposed. This mechanism suggests that drag reducing flow control at high Reynolds numbers should be designed to minimize the turbulent dissipation rate. A review and analysis of existing DNS data bases for which drag reduction has been reported shows that the proposed drag reduction mechanism is found for a variety of different flow control techniques. Based on the obtained knowledge we develop active and passive flow control schemes for viscous drag reduction.

In respect to active flow control, we have developed a flow control loop based on upstream sensing of the streamwise wall shear stress. Presently, a numerical assessment for the application of this control loop to skin friction control with plasma actuators is carried out.

In the field of passive flow control we propose a tentative surface structure with grooves aligned in the flow direction. The drag reducing performance of the surface structure is tested experimentally by comparing the pressure drop in a channel with grooved surfaces with the one in a smooth channel. It is found that a significant reduction in pressure drop is only obtained for grooves in the order of one viscous length scale, which corresponds to approximately the Kolmogorov scale of the flow.