Reactive control of spatially developing turbulent boundary layer

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Reduction of losses caused by turbulent skin friction drag is of great economical and ecological interest. One of the promising turbulence control strategies is a reactive control, where instantaneous flow field information captured by sensors is used in order to determine actuator operation. Such control schemes exhibit high energy gain due to low power consumption. Although most previous control schemes have been assessed in fully developed turbulent channel flows, their applicability in spatially developing turbulent flows are not fully investigated.

We focus on opposition control proposed by [1] as a representative reactive control scheme. The investigation is performed using direct numerical simulations of a turbulent boundary layer with zero pressure gradient in a Reynolds number range of $\mathrm{Re}_\Theta = 400 - 750$. Opposition control is applied partially in the middle of domain between $x^* = 250$ and 350 covering 16.6% of the total domain length.

The total drag reduction is estimated as 13.8% with net energy saving rate of 13.2% and local energy gain up to 23. It is found that the reduction of skin friction is mainly caused by the reduction of the turbulent term and the spatial development term appearing in the FIK-Identity [2]. Whereas the turbulent term is decreased due to a decrease of Reynolds shear stress, the spatial development term is mainly affected by the streamwise gradient of the streamwise velocity fluctuations, $\partial\overline{u'u'}/\partial x$, and streamwise gradient of streamwise mean velocity product, $\partial UU/\partial x$. While $\partial\overline{u'u'}/\partial x$ demonstrates essential deviations from the uncontrolled state in the beginning and at the end of the control area, $\partial UU/\partial x$ shows a decrease over the entire control area.

In the presentation we will report the influence of control area length on the control performance and on the flow state in the recovery region.

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