Turbulent skin-friction drag reduction in the constant power input framework

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Direct Numerical Simulation (DNS) of turbulent flows in channels is the standard tool to study effects and physics of flow control strategies for turbulent drag reduction, thanks to the wealth of information it delivers. In setting up such simulations, an important choice needs to be taken, regarding how the flow is driven through the channel. Two classic possibilities are to drive the flow at Constant Flow Rate (CFR) or at Constant Pressure Gradient (CPG). While the different choices yield identical turbulent statistics for canonical flows [1], they have significant implications on statistics of drag-reduced turbulent flows. For instance, at CFR drag reduction masifests as a reduction of friction but as an increase of bulk velocity at CPG. In neither cases, the power transferred to the flow stays constant upon application of drag-reducing control and nor does the rate of production and dissipation of turbulent kinetic energy. Therefore, it is not possible to address the physics of drag reduction techniques from the energetic standpoint, because the uncontrolled and drag-reduced flows energetically differ.

In this work, we exploit the recently-proposed Contant total Power Input (CtPI) approach [2], in which the power transferred to the flow through pumping and imposition of a control is kept constant, to address how drag-reduction obtained via several wall-based strategies modifies energetic properties of turbulent channel flows. First, the effect of the control on the integral production and dissipation of mean and turbulent kinetic energy are computed and shown. Then, starting from the generalized form of the Kolmogorov equation [3], the energy fluxes simultaneously occurring in the space of scales and in the physical space of wall-turbulent flows are studied to highlight differences among controlled and unmodified flows.

The action of the control is limited in a near-wall portion which lies below the region of maximum positive balance between turbulent energy production and dissipation. In particular, the effect of the wall actuation appears as a modification of the flux towards the wall of the energy emerging from the peak of energy source, and, hence of the near-wall dissipation.

References

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