Study of energetics in drag-reduced turbulent channel flows

Davide Gatti [1], M. Quadrio [2], A. Cimarelli [3], Y. Hasegawa [4] and B. Frohnapfel [1]

[1] Institute of Fluid Mechanics, Karlsruhe Institute of Technology, Karlsruhe, Germany
[2] Department of Aerospace Science and Technologies, Politecnico di Milano, Milano, Italy
[3] Department of Engineering Sciences and Methods, Universitá degli studi di Modena e Reggio Emilia, Modena, Italy
[4] Institute of Industrial Science, University of Tokyo, Tokyo, Japan

key-words: turbulent drag redution, CPI, constant power input, scale energy

An important choice needs to be taken when setting up Direct Numerical Simulations (DNS) of turbulent channel flows, 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 similar turbulent statistics for canonical flows [1], they have significant implications on statistics of drag-reduced turbulent flows. For instance, at CFR drag reduction manifests as a reduction of friction but as an increase of bulk velocity at CPG. In neither case, 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. Since the uncontrolled and drag-reduced flows differ energetically, it is difficult to address the physics of drag reduction techniques from the energetic standpoint.

In this work, we exploit the recently-proposed Constant 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 via the so-called energy-box [3]. Then, starting from the generalized form of the Kolmogorov equation [4, 5], the scale energy fluxes simultaneously occurring in the space of scales and in the physical space of wall-turbulent flows are studied (Figure 1) to highlight differences among controlled drag-reduced and unmodified flows. Spanwise wall oscillation [6] and opposition control [7] are chosen as model active control strategies.

Figure 2 shows the maps of scale energy source term and scale energy fluxes in the near wall region for the uncontrolled channel, and for the channel manipulated via opposition control and spanwise wall oscillations. Clearly, the morphology of scale energy production and dissipation is structurally modified by the control, also in this non trivial case in which the total power input to the system is kept constant. At the conference, these control-induced modifications are discussed in detail and linked with the properties of the various control strategies.

References

[1] M.Quadrio, B.Frohnapfel, Y.Hasegawa, *Does the choice of the forcing term affect flow statistics in DNS of turbulent channel flow?*, Eur. J. Mech. B / Fluids, 55, 2016.

[2] Y.Hasegawa, M.Quadrio, B.Frohnapfel, *Numerical simulation of turbulent duct flows with constant power input.*, J. Fluid Mech., 750, 2015.

[3] P.Ricco, C.Ottonelli, Y.Hasegawa, M.Quadrio *Changes in turbulent dissipation in a channel flow with oscillating walls.*, J. Fluid Mech., 700, 2012.

[4] N.Marati, C.Casciola, R.Piva, *Energy cascade and spatial fluxes in wall turbulence.*, J. Fluid Mech., 521, 2004.

[5] A.Cimarelli, E.De Angelis, C.Casciola, *Paths of energy in turbulent channel flows.*, J. Fluid Mech., 715, 2013.

[6] M.Quadrio, P.Ricco, *Critical assessment of turbulent drag reduction through spanwise wall oscillation.*, J. Fluid Mech., 521, 2004.

[7] H.Choi, P.Moin, J.Kim, *Active turbulence control for drag reduction achievable by near-wall turbulence manipulation at high Reynolds numbers.*, Phys.Fluids, 17, 1994.

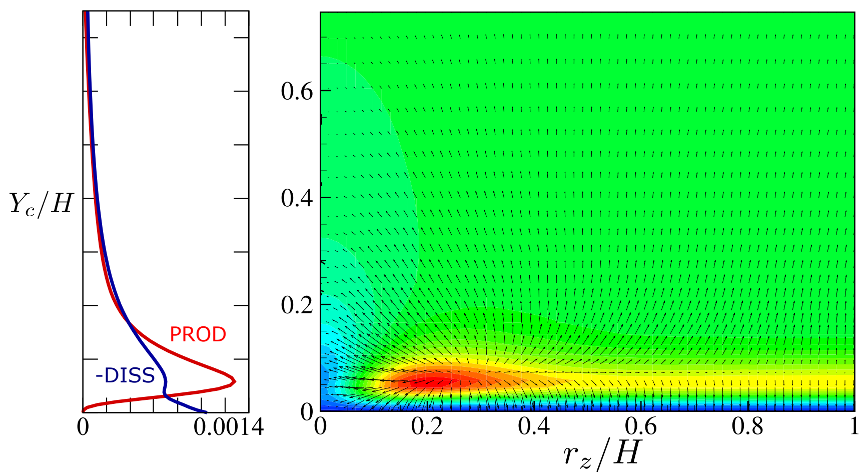

Figure 1: Left: single point turbulent kinetic energy budget for a turbulent channel flow driven with CtPI at $Re_\tau = 200$. Right: map of energy source at spanwise scale r_z and wall-normal position Y_c. Red: energy production; blue: energy dissipation. The arrow indicates the energy fluxes across scales r_z and in space across the wall-normal direction Y_c.

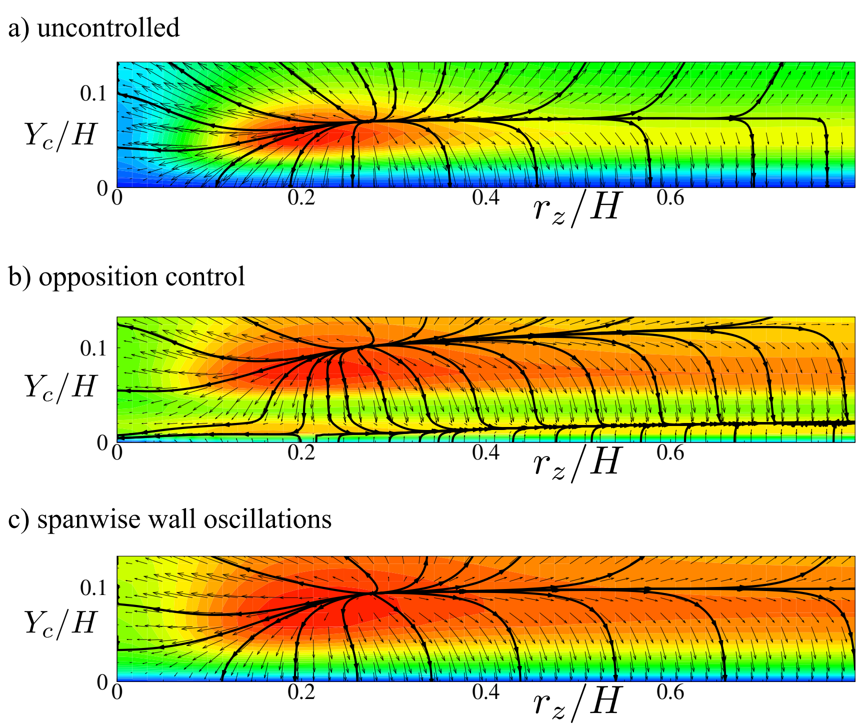

Figure 2: Scale energy source map for an uncontrolled channel flow (a), for a channel modified by opposition control (b) and by spanwise wall oscillations (c). In all cases the total power is kept constant.