The drag-reduction oscillating-wall problem: new insight after 20 years

Pierre Ricco*, Claudio Ottonelli†, Yosuke Hasegawa‡, Maurizio Quadrio§

Twenty years have passed since Jung *et al.*[1] first showed that a sustained turbulent drag reduction can be achieved by large-scale sinusoidal wall oscillations along the spanwise direction. This flow has been studied widely through turbulence statistics, flow visualizations, and simplified models attempting to explain the physics behind drag reduction. In spite of such efforts, the fundamental question: "Why does the turbulent kinetic energy and the friction drag decrease?" has remained unanswered. Our direct numerical simulations in the turbulent channel flow geometry at constant mean pressure gradient and $Re_\tau = u_\tau h/\nu = 200$ (where u_τ is the wall friction velocity and h is half the channel height) offer new insight on the physical mechanism for drag reduction[2]. Three stages of the transient evolution from the wall-motion start-up to the new fully developed regime are distinguished and shown in figure 1. During the **Short** stage, the oscillatory Stokes layer $\widetilde{W}$ enhances the turbulent enstrophy $\boldsymbol{\omega}^2$ by stretching the vorticity lines through the enstrophy-production term $\widetilde{\omega_z \omega_y} \partial \widetilde{W} / \partial y$ in the turbulent enstrophy equation.[3] The total turbulent viscous dissipation $\mathcal{D}_\mathcal{T}$ increases, thus causing the drop in turbulent kinetic energy (TKE) during the **Intermediate** stage. As the intensity of $\widetilde{uv}$ decreases, the momentum balance reveals why the mean flow $\widetilde{U}$ accelerates and the wall-shear stress drops transiently. The flow slowly adapts to the new regime with increased bulk velocity (**Long** stage). Flow visualizations and a simple model elucidate the physical action of $\widetilde{\omega_z \omega_y} \partial \widetilde{W} / \partial y$. The volume-integral of this terms is shown to be related linearly to the drag reduction.

*Dep. Mechanical Engineering, The University of Sheffield, United Kingdom.
†Dép. d'Aérodynamique Fondamentale et Expérimentale, ONERA, France.
‡Dep. Mechanical Engineering, The University of Tokyo, Japan.
§Dip. Ingegneria Aerospaziale, Politecnico di Milano, Italy.
[1] Jung, Mangiavacchi, Akhavan, *Phys. Fluids* **4**, 1605 (1992).
[2] Ricco, Ottonelli, Hasegawa, Quadrio, *J. Fluid Mech.* **700**, 77-104, 2012.
[3] The streamwise, wall-normal, and spanwise directions are indicated by x,y,z, and the tilde indicates averaging along x,z. All quantities are scaled by viscous units.

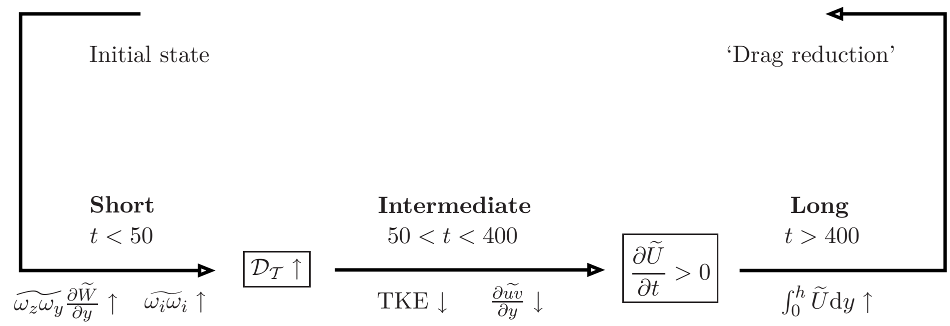

Figure 1: Schematic of the drag-reduction physical mechanism.