Spanwise forcing for turbulent drag reduction: the meaning of the optimal oscillation period

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Spanwise forcing for turbulent drag reduction (oscillating wall or streamwise-travelling waves) yields large reductions of turbulent friction drag, is attractive for high-Re applications[1], and can be applied locally in a complex flow to create a large global effect[2]. Currently, practical actuators are not available.

Despite the available literature, the working mechanism of spanwise forcing remains elusive. For the oscillating wall, an optimal oscillation period $T^+ = 100$ exists for a given oscillation amplitude. Does the optimal period imply a characteristic flow timescale? A characteristic streamwise lengthscale, obtained via the near-wall convection velocity U_c as $\lambda = U_c T$? A characteristic wall-normal lengthscale, i.e. the thickness $\delta(T) = \sqrt{\nu T/\pi}$ of the spanwise Stokes layer?

To decide on the proper interpretation, we carry out via DNS a thought experiment for a turbulent channel flow at $Re_\tau = 400$: the spatially-averaged spanwise velocity profile W, instead of ensuing from the wall oscillation, is enforced as:

$$W(y,t) = A \exp\left(-\frac{y}{\delta}\right) \sin\left(\frac{2\pi}{T} t - \frac{y}{\delta}\right). \tag{1}$$

The analytical expression is the same of the classic Stokes layer, but T and δ are now two *independent* parameters. Preliminary results (approx. 100 simulations, still running) of the DNS campaign are shown in figure 1. The information available so far, limited to the line representing the true Stokes layer, did not provide a comprehensive view: the "optimal value" $T^+ = 100$ does not possess any special meaning. The truly optimal periods are smaller, and the ability to create a thick Stokes layer with a fast oscillation promises to nearly double drag reduction.

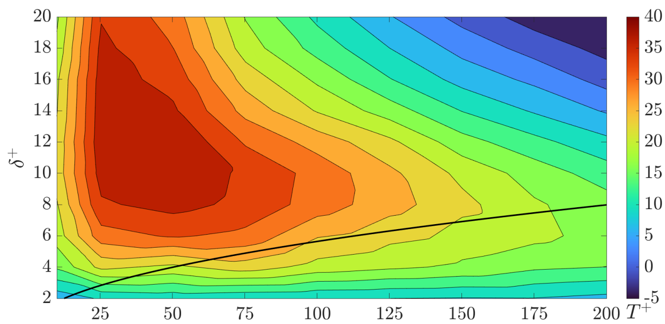

Figure 1: Drag reduction (at $Re_\tau = 400$ and $A^+ = 12$) obtained by the synthetic Stokes layer described by Eq.(1). The black line is the true Stokes layer.

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[1] Gatti et al. J. Fluid Mech. **802**:553-558 (2016)

[2] Quadrio et al J. Fluid Mech. **942**:R2 (2022)