Streamwise-traveling waves of spanwise velocity at the wall of a turbulent channel flow

Maurizio Quadrio[1]

[1] Dip. Ingegneria Aerospaziale, Politecnico di Milano, Milano, Italy

Abstract:

Taming turbulence to alter its dynamics in the near-wall region of a boundary-layer-type flow presents a fundamental and applied interest. Here we study via a large number of DNS the effects of spanwise velocity waves traveling in the streamwise direction along the wall of a turbulent channel flow.

We consider waves of spanwise velocity that are oscillating in time and modulated in space along the streamwise direction: the phase speed makes the waves travel (forward or backward) in the same direction of the mean flow. The waves are described by

$$w_w(x,t) = A \sin\left(\kappa_x x - \omega t\right), \tag{1}$$

where w_w is the spanwise component of the velocity vector at the wall, x is the streamwise coordinate and t is time, A is the amplitude of the forcing, $\kappa_x = 2\pi/\lambda_x$ is the forcing wavenumber in the x direction and $\omega = 2\pi/T$ its frequency.

Such waves represent a generalization of two, previously considered wall-based forcings. One is the oscillating-wall technique:

$$w_w(t) = A \sin\left(\omega t\right), \tag{2}$$

and the other one is the standing-wave technique:

$$w_w(x) = A \sin\left(\kappa_x x\right). \tag{3}$$

The forcing (2) is a traveling wave with infinite phase speed, has been introduced by [1], and its performance has been described for example in [2]. The recently studied [4] standing-wave forcing (3) is a wave with zero phase speed, that has been shown [3] to behave similarly to (2) when x is converted in time through the convection velocity of the near-wall turbulent fluctuations.

More than 200 demanding Direct Numerical Simulations of turbulent channel flow are carried out, each with a spatial resolution of $320 \times 320 \times 160$ modes/points, and the resulting friction coefficient is measured as a function of the parameters κ_x and ω in eq. (1) with A fixed. The results in terms of friction reduction / increase are summarized in figure 1, that reveals an unexpected and complex pattern.

The traveling waves are found to be very effective in altering the frictional drag. Waves that are slowly traveling forward in the streamwise direction produce a large reduction of drag. Faster waves, with a phase speed corresponding roughly to the convection velocity of turbulence fluctuations at the wall, lock to the convecting near-wall turbulence structures and yield a totally different outcome, i.e. a drag increase. Above this critical speed, the waves are found to yield drag reduction again, and the same is found for backward-traveling waves, at any speed.

At the conference further details will be given, together with a tentative interpretation and a discussion of the extremely interesting energetic properties of this new type of forcing.

References

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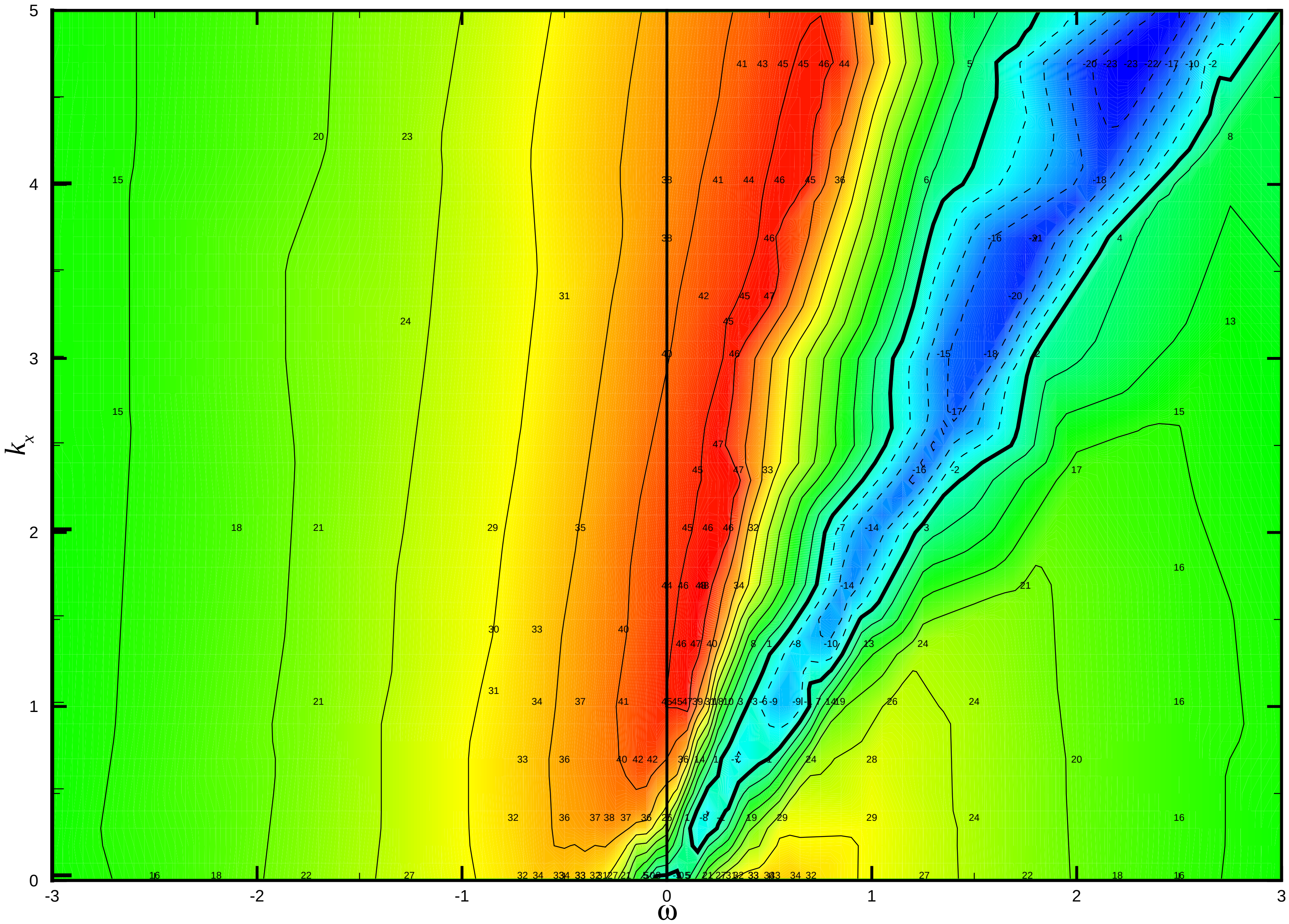

Figure 1: *Percentage change in friction coefficient as a function of wavenumber and frequency of the traveling wave (1). The numbers indicate actual DNS data, whereas color contours are the result of linear interpolation. Contours by 5% increments, thick line is zero and negative values are dashed.*