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Suppressing Very-Large-Scale Motions in Turbulent Couette Flows

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1 Introduction

Very-large-scale motions (VLSMs) have long been observed in turbulent wall-bounded flows (Hutchins & Marusic 2007) and it has long been conjectured that their suppression might be an effective drag-reducing control strategy as the Reynolds number increases (Hwang 2013). Many authors, as for instance De Giovannetti *et al.* (2016), have attempted quantifying the contribution of large scales to skin friction by exploiting the FIK identity or similar integral relations, suggesting that VLSMs account for 20-30% of the total drag. The same authors also quantified the impact of VLSMs in a channel flow at a moderate Reynolds number by numerically removing them, either through modal damping or by restricting the spanwise simulation domain. In both cases, modest drag reduction values of 7-8% were obtained; these values contrast with the ones delivered by the FIK identity, as well as with more recent experimental evidence that targeting large scales is indeed a viable drag-reducing strategy (Marusic *et al.* 2021).

To shed light on the topic, we use a different strategy to numerically suppress VLSMs in turbulent Couette flows. The suppression is achieved by applying a body force defined as the Coriolis force that would be associated to a spanwise rotation of the frame of reference; this is known to dampen the VLSMs without significantly affecting smaller scales (Bech *et al.* 1995), as long as the intensity of the forcing remains limited. Couette flows are chosen as they exhibit VLSMs already at low Reynolds numbers (Lee & Moser 2018), which helps reducing computational costs. Moreover, the VLSMs are almost monochrome in the spanwise direction, meaning that they are associated to a spectral energy peak appearing on a restricted number of spanwise Fourier modes. This simplifies their identification.

2 Method and results

We perform direct numerical simulations (DNSs) of turbulent Couette flows, solving the Navier-Stokes equations with the addition of a body forcing term:

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} + \nabla P = \frac{1}{Re} \nabla^2 \vec{u} - 2 Ro\, \hat{z} \wedge \vec{u} \tag{1}$$

where $\vec{u}$ is the velocity vector, P the pressure, Re is the Reynolds number, Ro is the rotation number controlling the intensity of the forcing, $\hat{z}$ is the unit vector in the spanwise direction and $\wedge$ denotes the vector product. The equations are made non-dimensional with the speed U_w^* of the counter-moving walls and the channel half height h^*; the asterisk denotes dimensional quantities.

To assess the response of the flow to the forcing, we perform a parametric analysis with varying rotation number Ro; the value of the Reynolds number is fixed to $Re = 1667$, corresponding to a friction Reynolds number $Re_\tau \approx 100$ in the case $Ro = 0$. The friction Reynolds number is defined as $Re_\tau = h^* u_\tau^* / \nu^*$, where u_τ^* is the friction velocity and ν^* the kinematic viscosity of the fluid.

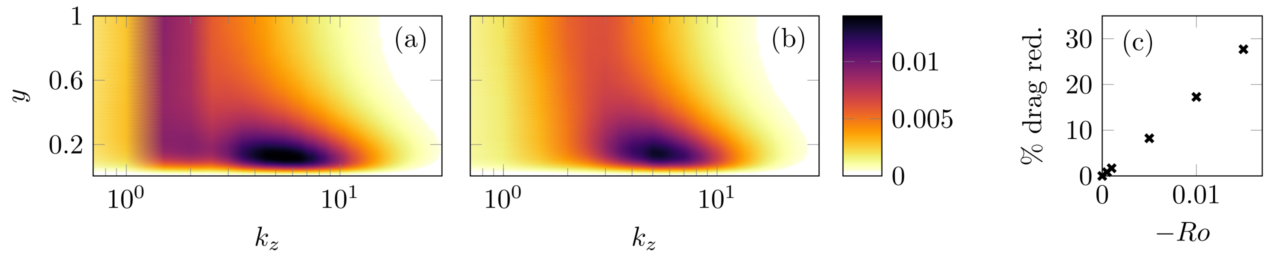

Figure 1. Premultiplied spanwise energy spectrum of the streamwise velocity fluctuation for $Ro = 0$ (panel a, reference case) and $Ro = -0.01$ (b). Percentage drag reduction for varying Ro (c).

Results are shown in figure 1 for the energy spectrum of the streamwise velocity fluctuation; there, y denotes the wall-normal coordinate and k_z the spanwise wavenumber. The spectral peak at $k_z \approx 2$ extending all across the channel is commonly associated to the VLSMs (Lee & Moser 2018); a comparison between panels (a) and (b), where the Coriolis forcing is absent or active respectively, reveals that suppression of the VLSMs is successful. Also, with increasing intensity of the Coriolis force, substantial values of drag reduction are observed (panel c); notice that the control force does not extract nor provide power from or to the flow, as it is by definition orthogonal to the velocity.

3 Conclusions

We here show a body force that suppresses very-large-scale motions (VLSMs) in a turbulent Couette flow without leading to a power exchange to or from the flow. Although significant values of drag reduction are observed ($\approx 20\%$ for $Ro = -0.01$), further investigation is required to better ascertain how much of the observed drag reduction can be associated to the suppression of VLSMs. Indeed, the forcing also affects smaller scales of turbulence, albeit slightly; this issue could be solved by limiting the action of the Coriolis force to a certain spanwise bandwidth in the Fourier domain. Moreover, investigation of the flow at Reynolds numbers of practical interests would be crucial to assess the effectiveness of targeting VLSMs to achieve drag reduction.

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