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Drag-reducing characteristics of the generalized spanwise Stokes layer: experiments and numerical simulations

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Abstract

The streamwise-traveling waves of spanwise velocity [1] will be described with emphasis on their ability to affect turbulent friction drag when applied at the wall of a wall-bounded flow. After a short introduction that motivates the interest of spanwise forcing for turbulent drag reduction, performance of the waves in terms of the energetic indexes described in [2] will be discussed. After that, and on the basis of recent simulations carried out at constant mean pressure gradient (where drag reduction manifests itself via an increase of the flow rate), it will be shown that most turbulence statistics are unaffected by the change of boundary conditions.

To understand better the action of the waves on the turbulent flow, the effect of the same waves applied to a laminar Poiseuille flow is described. The waves produce a thin, oscillating boundary layer of spanwise velocity, that we call the Generalized Stokes Layer (GSL) because it reduces to the conventional Stokes layer when the wave length tends to infinity. It is shown that the Poiseuille flow is unaffected by the GSL, which is coupled to the streamwise flow (in the turbulent case this coupling is two-way). An analytical solution based on the Airy function is determined for the GSL. From it, the dependency of the GSL thickness on wavelength and frequency of the waves can be easily computed. In the turbulent case, it is found that the *laminar* GSL thickness correlates very well to the amount of *turbulent* drag reduction.

From the experimental side, the only available experiment to date will be described. Although limited to low Reynolds and measuring percentage variations of friction only, this experiment confirms very well the trends highlighted by the DNS described in [1]. Moreover, it brings to light the first-order effect of the spatial discretization with which the sinusoidal waveform is discretized. An ad hoc Fourier analysis will be used to highlight the true harmonic content of a discretized traveling wave.

In the conclusive part, the travelling waves will be critically reviewed to highlight major obstacles still preventing their deployment in applications as a drag-reducing device.

References

[1] Quadrio, M., Ricco, P, and Viotti, C., Streamwise-travelling waves of spanwise wall velocity for turbulent drag reduction, *J. Fluid Mech.* **627**, 161-178 (2009).

[2] Kasagi, N., Hasegawa, Y., and Fukagata, K., Toward cost-effective control of wall turbulence for skin friction drag reduction, *Advances in Turbulence XII*, Springer, 189-200 (2009).