Global turbulent efficiency in plane Couette and Poiseuille flows

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Abstract:

Comparing different turbulent flows in a global sense requires the definition of a suitable criterion, to be expressed non-dimensionally. We extend the work by Gatti *et al.* [1], who developed a power-input-based criterion to compare turbulent Poiseuille flows with and without drag reduction; we then aim at comparing two uncontrolled yet different turbulent flows, namely plane Couette and Poiseuille. Comparison is based on both a new dataset of direct numerical simulations (DNSs) and literature data.

The turbulent efficiency of a flow (meaning, how effective a flow is at producing turbulence) is defined as the fraction of power input that gets dissipated because of turbulence. Crucial to such definition is, in addition to the classic Reynolds' decomposition, the separation of the time-averaged flow into a Stokes solution and a (mean) deviation field; this process takes the name of *extended Reynolds decomposition*. Figure 1 contains a graphical representation of the integral energy balances obtained with such decomposition. We derive analytical expressions, that are the energy-flux equivalents of the FIK identity [2], and that can be applied across the different flows to relate every energy flux with two wall-normal integrals of the Reynolds stresses. Turbulent efficiency can be identified with an energy flux named *laminar production* $\mathcal{P}^L$ from figure 1; in both Couette and Poiseuille flows, $\mathcal{P}^L$ is represented by the same function of a purposely defined Reynolds number Re_ϕ. Such analytical relation is explicit and is represented in figure 2 alongside with numerical data. The same figure reports the trends of Re_ϕ against the power Reynolds number Re_π; the latter is defined so that keeping it constant across two flows means comparing them at constant power input. What can be evinced from data is that Couette produces a higher turbulent efficiency (hence, higher losses) in such conditions. This is in apparent contradiction with both literature [3] and the additional finding, that a Couette flow is more efficient at converting a power input into a flow rate; it will be explained during the course of the conference how these findings are mutually compatible.

Additional insights into the physics of Couette and Poiseuille flows are obtained by feeding their fluctuation fields with the same fraction of power. It is found that, in such conditions, Couette dissipates a smaller percentage of power as turbulent dissipation. A decomposition of the fluctuating field into large and small scales is adopted to explain this feature. Indeed, Couette develops stronger large-scale structures [4], which are found to be effective at changing the mean flow without significantly contributing to dissipation. A net inverse power transfer from small to large scales is finally observed in a Couette flow already at a relatively low Reynolds number; similar results were already obtained by [5], who observed this inverse power transfer for the Reynolds shear stress on a limited experimental dataset.

References

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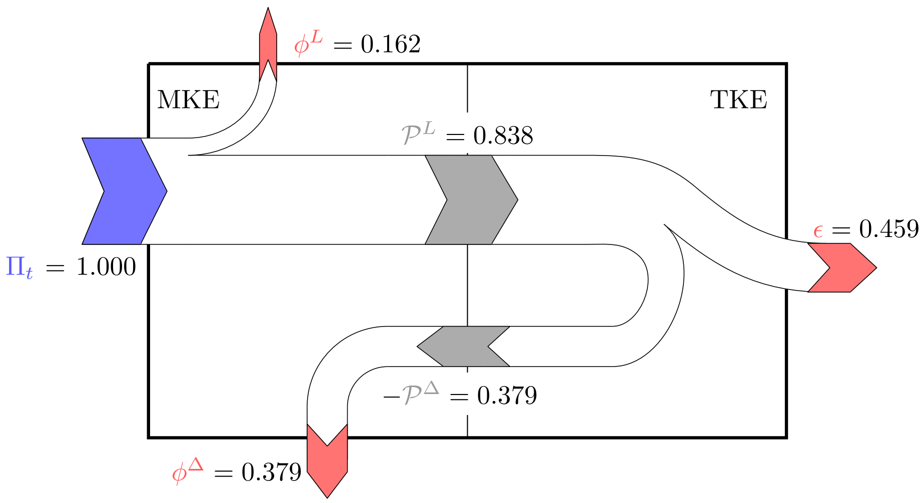

Figure 1: *graphical representation of the extended-Reynolds-decomposed energy balance for a Couette flow at* $h^+ = 101$*, where* h^+ *is the Kármán number.*

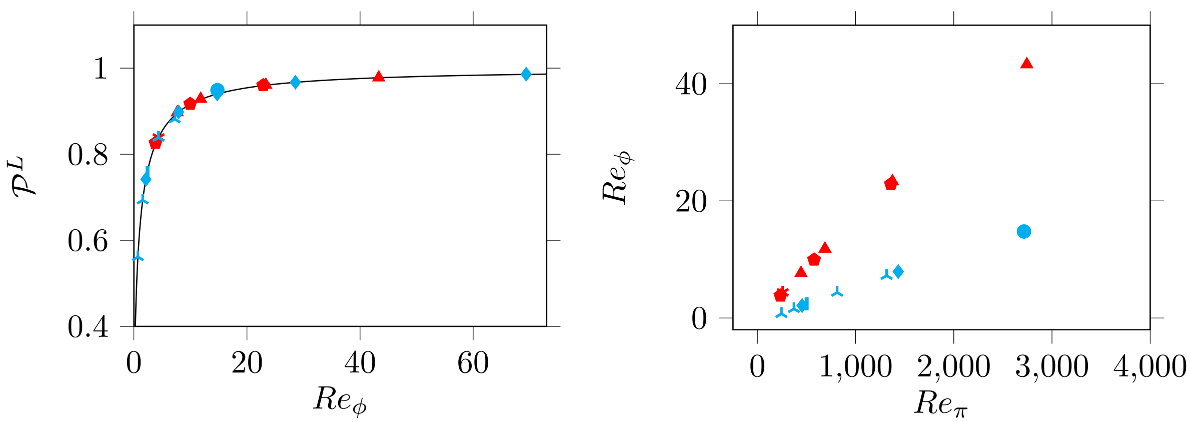

Figure 2: *on the left: trend for the turbulent efficiency* $\mathcal{P}^L$ *against the Reynolds number* Re_ϕ*. Solid line: analytical curve. Numerical data is represented as scatter points; blue is used for Poiseuille, red for Couette. On the right: trend for* Re_ϕ *against* Re_π*; a constant* Re_π *corresponds to a constant power input.*

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