Patterning at the upper transitional range of plane Couette flow

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The transition to/from turbulence in wall-bounded flows is a long-standing problem, aspects of which remain open [1]. On general grounds, laminar flow is known to experience a subcritical bifurcation towards nontrivial flow resulting from some "self-sustaining process" and a wide transitional range of Reynolds numbers R exists where quasi-laminar flow competes with turbulence in physical space. At the low-R end of this range R_{g} ("g" for "global stability"), the consensus is that the decay of turbulence takes place according to a directed-percolation scenario. In contrast, a regime of uniform ("featureless") turbulence is recovered at very large R, possibly beyond a well-characterised upper threshold usually called R_{t}. Between these two thresholds, turbulence develops in the form of domains of quasi-laminar flow coexisting with the chaotic flow, often organised in regular laminar-turbulent patterns somewhat above R_{g}, as in plane simple shear flow (Couette, PCF), and similarly in cylindrical geometry [2], or channel flow (Poiseuille, PPF) [3]. Up to now, the mechanism responsible for this patterning is subject to conjectures, and the exact nature –continuous or discontinuous– of the pattern's emergence, is still controversial [4,5].

Here, paralleling our study of PPF [3], we present the result of fully resolved numerical simulations of PCF in a wide periodically-continued domain $(L_x \times L_z) = (500 \times 250)$ performed by MS in Osaka. Patterning is studied using Fourier spectra of the crossflow-energy field $E_{\mathrm{cf}}(x, z; t) = v^2 + w^2$ cleared from the dominant but confusing contribution of streamwise streaks u. Focussing on the regime around and above R_{t}, we observe that a weak long-wavelength modulation of the turbulence intensity is already present at large R in the form of wide bumps centred at wavevectors already similar to those corresponding to the peaks that develop when the pattern is present below R_{t}. The spectra fulfil the expected spanwise symmetry of PCF all along the featureless regime, which helps us improve the statistics by considering appropriately symmetrised spectra. This symmetry is broken for $R \sim 410$, and sharp peaks associated with the emerging pattern rapidly grow. The transition is abrupt but continuous, with no trace of hysteresis, Our results reproduce those of Prigent [2], who estimated $R_{\mathrm{t}} \simeq 415$, more closely than simulations where the flow is modelled using the quasi-1D Barkley–Tuckerman oblique domain framework [4], or at reduced resolution [5], limitations of which are both raised in our wide-domain fully-resolved simulations. Our better agreement is perhaps because the latter approaches over-emphasise the flow coherence in the upper transitional range, giving the temporal "turbulence reentrance" they describe too much significance.

The mechanism responsible for the instability of the uniformly turbulent regime, similar to that described in [6] for PPF, the pre-patterning above R_{t}, and the focusing that turns it into a bona fide pattern amenable to the noisy Ginzburg–Landau-like formalism discussed in [2], remains a challenging problem, with the generation of large-scale flows by the phase dynamics of small-scale chaos in perspective [7,8].

References

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