Subcritical transition to turbulence in wall-bounded flows : the case of plane Poiseuille flow

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In wall-bounded flows the transition to turbulence is sub-critical and develops all along a transitional range marked by the spatial coexistence of laminar and nontrivial flow at intermediate values of the Reynolds number R [1]. Pomeau's early conjecture [2] that this transition is governed by directed percolation (DP) has recently received some support from experiments in a quasi-one-dimensional (1D) cylindrical Couette flow configuration [3] and by numerical simulations of a model of shear flow without walls in a quasi-two-dimensional (2D) geometry [4], among a few other cases. Pressure-driven flow through a wide rectangular duct, usually called *channel flow* or plane Poiseuille flow, is one such case for which agreement has been found with 2D-DP universality in a decay experiment from uniform turbulence [5]. This result is however contradicted by the observation of oblique localized turbulent bands (LTBs) in numerical [6] or laboratory experiments [7]. Our numerical study reveals how these two contradictory results can be reconciled by identifying a transition that preempts the DP scenario slightly above its critical point. When the turbulent fraction is small enough, at decreasing R, LTBs develop from an intermittent loose continuous laminar-turbulent network. Within the LTB regime, a threshold is found separating an upper range where LTBs obliquely propagate symmetrically with respect to the stream-wise direction, hence genuinely 2D turbulence invasion, from a lower range where all the LTBs move essentially in one of the two in-plane directions allowed by the flow symmetries. A simple differential model is developed for this symmetry breaking, supporting the super-critical pitch-fork character of the bifurcation at decreasing R. The DP process however keeps some relevance since, above that threshold and within the laminar-turbulent network regime, the turbulent fraction is seen to grow as $(1 - R_{\mathrm{DP}}/R)^\beta$ where R_{DP} is the extrapolated DP critical point and $\beta \approx 0.58$ is close to the standard value for DP in 2D. We conclude that the development of LTBs is impeded when the particular protocol described in [5] is followed, while the DP critical point becomes unreachable in more typical circumstances. On general grounds, we observe that abstract considerations legitimating an expectation for universality may be smashed by the existence of specific processes developing in the system of interest.

Références

1. P. Manneville, Mechanical Engineering Reviews **3**, 15 (2016).
2. Y. Pomeau, Physica D **23**, 3 (1986).
3. G. Lemoult *et al.*, Nature Physics, **12**, 254 (2016).
4. M. Chantry *et al.*, J. Fluid Mech. **824**, R1 (2017).
5. M. Sano & K. Tamai, Nature Physics **12**, 249 (2016).
6. J. Tao *et al.*, Physical Review Fluids **3**, 011902 (2018).
7. C.S. Paranjape *et al.*, http://www.delegia.com/app/data/8684/Abstract/29766/ETC16_Paranjape.pdf