Directed percolation and the onset of turbulence in shear flows

M. Chantry[1], L.S. Tuckerman[2], D. Barkley[3]

[1]Atmospheric, Oceanic and Planetary Physics, University of Oxford, Clarendon Laboratory, UK

[2]Laboratoire de Physique et Mécanique des Milieux Hétérogènes (PMMH), CNRS, ESPCI Paris, PSL Research University; Sorbonne Université, France

[3]Mathematics Institute, University of Warwick, UK

The transition to turbulence in wall-bounded shear flows has been studied for well over a century, and yet, only recently have experiments, numerical simulations, and theory advanced to the point of providing a comprehensive understanding of the route to turbulence in such flows. Of late, research has focused on how turbulence first appears and becomes sustained. The issue is that typically wall-bounded shear flows undergo subcritical transition, meaning that as the Reynolds number is increased, turbulence does not arise through instability of laminar flow, but instead appears directly as a highly nonlinear state. Moreover, the flow does not simply become everywhere turbulent beyond a certain Reynolds number. Rather, turbulence initially appears as transient patches interspersed within laminar flow. The resulting flow takes on a complex spatiotemporal form with competing turbulent and laminar domains. This, in turn, greatly complicates the quantitative analysis of turbulent transition in subcritical shear flows.

In the 1980's the connection was developed between spatially extended dynamical systems and subcritical turbulent flows. Pomeau [1] observed that subcritical fluid flows have the characteristics of systems exhibiting non-equilibrium phase transitions and therefore that these flows might fall into the universality class of directed percolation. This would imply a continuous transition to sustained turbulence with certain very specific power laws holding at onset. Since then considerable effort has been devoted to investigating these issues.

We will discuss the status of our understanding for prototypical subcritical shear flows: pipes [2,3], channels [4], and Couette flow [5]. We will emphasize that the case of two spatial dimensions is fundamentally different from that of one spatial dimension. We present a numerical study of a planar shear flow of unprecedented lateral extent and show that the onset of turbulence in this flow is continuous and is in the universality class of directed percolation.

[l] Y. Pomeau, Physica D **23**, 3 (1986).
[2] K. Avila, et al., Science **333**, 192 (2011).
[3] D. Barkley, J. Fluid Mech. **803**, P1 (2016).
[4] M. Sano, K. Tamai, Nat. Phys. **12**, 249 (2016).
[5] G. Lemoult, et al., Nat. Phys. **12**, 254 (2016).