Towards uniformly turbulent pipe flow?

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ABSTRACT

The transition to turbulence in pipes is of great theoretical and practical importance. Osborne Reynolds observed that at low flow rates this transition does not occur from smooth to fully disordered dynamics, but it is instead characterized by 'flashes' of turbulence in a laminar background [1]. In this regime laminar and turbulent regions compete and organize themselves in striking large-scale patterns, whose dynamics are qualitatively captured by simplified models featuring spatio-temporal intermittency (STI). We here investigate the connection between these large-scale turbulent-laminar patterns with uniform shear flow turbulence. By increasing the Reynolds number, constant size *puffs* are replaced by *slugs*, which are turbulent spots that propagate along the pipe while steadily growing in size. Inside a slug turbulence appears to be homogeneous and therefore the transition from puffs to slugs is typically associated to the onset of uniform turbulence. However, despite the large body of research devoted to this transition, it has not yet been possible to determine a critical Reynolds number.

We have investigated the transition from puff to slug turbulence by performing direct numerical simulations of the incompressible Navier–Stokes equations. In order to quantify these apparently distinct flow states we have adopted the following strategy. First, a localized perturbation is introduced in the pipe and quickly evolves into a puff. Subsequently, we let this puff expand until it fills the pipe, i. e. until the periodic boundary conditions are felt. After allowing for a relaxation time, snapshots of the velocity field are stored to follow the dynamics of the turbulent-laminar regions. From these snapshots, the sizes of the turbulent spots and laminar gaps are collected and sorted to produce cumulative size distributions. Our results show that the probability distributions of the length of turbulent and laminar sizes are independent of the computational pipe length. In addition, we find that both laminar and turbulent lengths are exponentially distributed, which matches previous conjectures based on coupled map lattices [2]. Finally, although the characteristic turbulent lengths scale faster than exponentially with Reynolds number, they remain bounded. This supports that there is no transition that separates localized and homogeneous turbulence, or in other words that puffs and slugs are the same object.

REFERENCES

[1] Osborne Reynolds *An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinuous, and of the law of resistance in parallel channels*, Proc. R. Soc. London **35**, 84-99, 1883.

[2] Hugues Chaté and Paul Manneville *Spatio-temporal intermittency in coupled map lattices*, Physica D **32(3)**, 409-422, 1988.