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Puffing along

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Patches of turbulence in straight pipe flow ('puffs') display collective dynamics that is not well understood. Now, this dynamics is shown to harbour a phase transition of the directed percolation type, displaying jamming at high puff density.

Flow down a pipe becomes turbulent as its speed is gradually increased. At the lowest flow speeds where turbulence still occurs, it is scattered in puffs¹. Puffs can trigger new puffs and their long-time collective dynamics is an ongoing object of study. However, it has become clear that neither laboratory set-ups nor numerical simulations from first principles can cope with the time and length scales at play². But now, writing in *Nature Physics*³, Grégoire Lemoult and colleagues have quantitatively described the statistical steady state in the limit of infinitely many puffs.

The transition from perfectly laminar to turbulent flow with increasing flow speed is a problem as old as the study of turbulence itself⁴. Below a critical flow speed, all perturbations die in a finite time, and so there is no turbulence in the flow. Above it, the flow features almost identical localized patches of turbulence, called puffs (see Fig. 1), which are well understood on an individual level. As they travel downstream, puffs interact on a longer timescale by splitting, merging or annihilating each other⁵.

Lemoult and colleagues³ addressed the problem of collective puff dynamics using a minimal modelling approach, where each puff was described by its abscissa on a line. Puffs were found to interact according to a simple short-range repulsion rule depending only on their mutual distance, calibrated using real-lab water experiments. Their probability to split or decay was also measured directly from experiments. The resulting coupled dynamical system could be simulated and the model allowed for very large numbers of interacting puffs, unreachable in experiments, let alone in simulations of the Navier–Stokes equations.

Two main results emerged. Close to the onset of turbulence, the transition from laminar to turbulent is analogous to a phase transition of the continuous type. This implies the existence of a critical parameter, at which correlations in space and time diverge⁶. Moreover, all related critical exponents were consistent with the universality class of directed percolation. The model could also address the statistical steady state away from the critical point. The puffs, as their density increased, were jammed into an irregular sequence. The occurrence

of ordered regions of puffs increased away from the critical point of directed percolation.


All outcomes from the model were consistent with the team's experimental results. It was made possible by long observation times not attempted before. The success of the modelling approach came from the awareness of the demanding timescales inherent to the problem. It is noteworthy that no first principles were explicitly invoked in the derivation of the model. In particular, it rests neither on the Navier–Stokes equations nor on their numerical simulations but only on quantitative experimental measurements.

The effective one-dimensionality of the pipe geometry leaves open the question of turbulence proliferation in higher dimensions, where particle-like models seem irrelevant. Recent evidence for intermittently laminar and turbulent flow in planar geometries⁷ has suggested a different pathway: it emerges directly from fully turbulent flow – rather than from laminar – as a hydrodynamical instability⁸. Three-dimensional equivalents of these hydrodynamic regimes pose an even bigger challenge.

Confirming the directed percolation hypothesis is certainly academic given the narrow parameter range where it is observed in practice. But the present results go beyond by demonstrating that the main obstacles were indeed finite-size effects. The prediction of one-dimensional jammed regimes suggests new analogies with other physical phenomena such as traffic jams or silo clogging. This bodes well for exciting debates and theoretical progress in the future.

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References

1. Reynolds, O. *Phil. Trans. R. Soc.* **174**, 935–982 (1883).
2. Vasudevan, M. & Hof, B. *J. Fluid Mech.* **839**, 76–94 (2018).
3. Lemoult, G. et al. *Nat. Phys.* <https://doi.org/10.1038/s41567-024-02513-0> (2024).
4. Eckert, M. *The Turbulence Problem: A Persistent Riddle in Historical Perspective* (Springer Nature, 2019).
5. Avila, M., Barkley, D. & Hof, B. *Ann. Rev. Fluid Mech.* **55**, 575–602 (2023).
6. Goldenfeld, N. *Lectures On Phase Transitions And The Renormalization Group* (CRC Press, 2018).
7. Tuckerman, L. S., Chantry, M. & Barkley, D. *Ann. Rev. Fluid Mech.* **52**, 343–36 (2020).
8. Kashyap, P. V., Duguet, Y. & Dauchot, O. *Phys. Rev. Lett.* **129**, 244501 (2022).
9. Duguet, Y., Willis, A. P. & Kerswell, R. R. *J. Fluid Mech.* **663**, 180–208 (2010).

Competing interests

The author declares no competing interests.

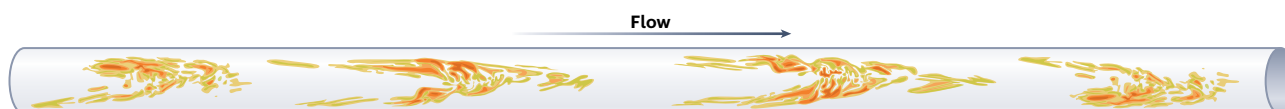


Fig. 1 | Puffs in pipe flow. Schematic of an intermittent sequence of puffs (localized coherent regions of turbulence) travelling down a cylindrical pipe. The transverse scale is intentionally exaggerated. Adapted from ref. 9., Cambridge University Press.