Graduate School Event

Thesis Defense: Transition to turbulence: Data-, solution-, and pattern-driven approaches

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The overarching goal of this thesis is to break down the complexity of turbulent flows in terms of enumerable, coherent structures and patterns. In a five-paper series, we adopt a variety of perspectives and techniques to relate the properties of systems of increasing complexity to their underlying coherent structures.Initially, we take a dynamical systems point of view, seeing turbulent flow as a chaotic trajectory bouncing between exact unstable solutions of the underlying equations of motion. Using persistent homology, the main tool of topological data analysis capturing the persistence across scales of topological features in a point cloud, we introduce a method that quantifies visits of turbulent trajectories to unstable time-periodic solutions, also called periodic orbits. We demonstrate this method first in the Rössler and \KS{} systems. Using this method in 3D Kolmogorov flow, we extract a Markov chain from turbulent data, where each node corresponds to the neighbourhood of a periodic orbit. The invariant distribution of this Markov chain reproduces expectation values on turbulent data when it is used to weight averages on the respective periodic orbits.In more realistic, wall-bounded settings, such as plane-Couette flow (pcf) driven by the relative motion of the walls, or plane-Poiseuille flow (ppf) driven by a pressure gradient, finding exact solutions is difficult. We use dynamic mode decomposition (DMD), a dimensionality reduction method for sequential data, to identify and approximate low-dimensional dynamics without knowing any exact solutions. Most spatially-extended systems are equivariant under translations, and in such cases spatial drifts dominate DMD, hindering its use in the search for and modelling of low-dimensional dynamics. We augment DMD with a symmetry reduction method trained on turbulent data to stop it from seeing translations as a feature, improving its ability to extract dynamical information in translation-equivariant systems. We find segments of turbulent trajectories that linearize well with their symmetry-reduced DMD spectra, akin to dynamics near exact solutions. Searching for harmonics in the spectra gives leads for periodic orbits with spatial drifts, one of which converges to a new solution.In larger domains, turbulence can localize and coexist with surrounding laminar flow. Our preceding approaches are global, taking all of a domain into account at once, and cannot readily treat each localized patch individually. Working first in a minimal oblique domain that can host a single 1D-localized turbulent patch, we find that turbulence in ppf is connected to a stable periodic orbit at a flow velocity much lower than when turbulence is first onset. We show that, well in advance of sustained turbulence, chaos sets in explosively, and for long time horizons, time series are consistent

with that of a random process.Finally, in much larger domains, we study and compare 2D-localized turbulence that appears as large-scale inclined structures, called stripes, in ppf and pcf. While appearing similar, we find that stripes in these two settings differ significantly in terms of how they sustain themselves, and in higher velocities, how they proliferate.

Friday, May 9, 2025 10:30am - 11:30am

Office Bldg West / Ground floor / Heinzel Seminar Room (I21.EG.101)

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