Stochastic attractors in a turbulent von Kármán flow

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We discuss the existence of a low-dimensional attractor in time-series issued from a laboratory model flow in highly turbulent conditions. Our reconstruction is based on the combination of tools from dynamical systems theory and on ideas borrowed from the field of stochastic processes. The results demonstrate the possibility to describe the behavior of a turbulent flow as a dynamical system with fluctuating control parameter. Such fluctuations represent, via a noise term, the influence of the small scales on the dynamics.

In our experiment, we generate turbulence in a vertical cylinder of length $H = 180$ mm and radius $R = 100$ mm filled with water, and stirred by two coaxial, counter-rotating impellers with rotating frequency f_1 and f_2 and torque C_1 and C_2. The symmetry of our experimental set-up suggests to choose $\gamma = (C_1 - C_2)/(C_1 + C_2)$ as the control parameter. and the quantity $\theta = (f_1 - f_2)/(f_1 + f_2)$ as the variable tracing deviations from the top-bottom symmetry in the flow. By embedding the partial maxima θ_m in a three dimensional space, we can reconstruct the associated turbulent attractor as a function of the average forcing γ imposed. When $\gamma = 0$ the top and the bottom impeller are exchangeable. In absence of any symmetry breaking mechanism, we expect the flow to react such that θ is also zero. Therefore the embedding of θ returns just a noisy fixed point. For increasing $|\gamma|$, first an unstable limit cycle appears, then the cycle stabilizes and and bifurcates again in another limit cycle[**?**].

We then look for the simplest model matching the quantitative properties of the experimental flow, namely the number of quasi-stationary states and transition rates among them, the effective dimensions, and the continuity of the first Lyapunov exponents. Such properties can neither be recovered using deterministic models nor using stochastic differential equations based on effective potentials obtained by inverting the probability distributions of the experimental global observables. One needs a three dimensional systems featuring a non-linear stochastic oscillator, e.g. the stochastic Duffing equations. Our findings open the way to low dimensional modeling of systems characterized by a large number of degrees of freedom and multiple quasi-stationary states.

Références

1. Faranda, D., Sato, Y., Saint-Michel, B., Wiertel, C., Padilla, V., Dubrulle, B., & Daviaud, F. (2016). Stochastic chaos in a turbulent swirling flow. arXiv preprint arXiv :1607.08409.