The phase space of turbulent Taylor-Couette flow

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Surface In this lecture I will summarise our recent advances in understanding turbulent Taylor-Couette flow (TC), i.e. the flow between two coaxial and independently rotating cylinders were performed. In the first part I will present our numerical simulations, in which shear Reynolds numbers of up to $3 \times 10^5$, corresponding to Taylor numbers of $Ta = 4.6 \times 10^{10}$, were reached. Effective scaling laws for the torque are presented. The transition to the ultimate regime, in which asymptotic scaling laws for the torque are expected to hold up to arbitrarily high driving, is analysed for different radius ratios, different aspect ratios and different rotation ratios. We furthermore calculate the local angular velocity profiles and visualize different flow regimes that depend both on the shearing of the flow, and the Coriolis force originating from the outer cylinder rotation. Two main regimes are distinguished, based on the magnitude of the Coriolis force, namely the co-rotating and weakly counter-rotating regime dominated by Rayleigh-unstable regions, and the strongly counter-rotating regime where a mixture of Rayleigh-stable and Rayleigh-unstable regions exist. The work culminates in phase spaces in the inner vs outer Reynolds number parameter space and in the Taylor vs inverse Rossby number parameter space, which can be seen as the extension of the Andereck et al. (J. Fluid Mech. 164, 155-183, 1986) phase space towards the ultimate regime.

In the second part I will report on our experiments with our Twente turbulent TC (T3C) setup, in which we achieve $Ta$ up to $2 \times 10^{12}$ Kolmogorov’s 1941 paradigm suggests that for so strongly turbulent flows with their many degrees of freedom and large fluctuations, there would only be one turbulent state as the large fluctuations would explore the entire higher dimensional phase space. Here we report the first conclusive evidence of multiple turbulent states for turbulent Taylor-Couette flow in the regime of ultimate turbulence, by probing the phase space spanned by the rotation rates of the inner and outer cylinder. The manifestation of multiple turbulent states is exemplified by providing combined global torque- and local-velocity measurements. This result verifies the notion that bifurcations can occur in high-dimensional flows (that is, very large Re) and questions Kolmogorov’s paradigm.