INSTABILITY OF TURBULENCE

Daviaud Francois[1], Saint-Michel Brice[1], Cortet Pierre-Philippe[2], Herbert Eric[2], Marié Louis[3], Ravelet Florent[4] & Dubrulle Bérengère[1]

[1]*Laboratoire SPHYNX, SPEC, DSM, CEA Saclay, CNRS URA 2464, 91191 Gif-sur-Yvette, France*
[2]*Laboratoire FAST, CNRS, Univ Paris Sud, UPMC Univ Paris 06, France*
[3]*Laboratoire de Physique des Océans, UMR 6523 CNRS/IFREMER/IRD/UBO, Brest, France*
[4]*Laboratoire Dynuid, ENSAM ParisTech, CNRS EA92, 151, boulevard de l'Hôpital 75013 Paris, France*

Abstract We study the instabilities and transitions observed in a fully turbulent von Karman flow. We show that, in a given geometry, the turbulence states depend on the way energy is injected into the flow.

Phase transitions are ubiquitous in physical systems and generally associated with symmetry breaking. For example, ferromagnetic systems are well known to undergo a phase transition from paramagnetism to ferromagnetism at the Curie temperature Tc. This transition is associated with a symmetry breaking from the disordered paramagnetic—associated with a zero magnetization—toward the ordered ferromagnetic phase—associated with a finite magnetization. In the context of fluid dynamics, symmetry breaking also governs the transition to turbulence that usually proceeds, as the Reynolds number Re increases, through a sequence of bifurcations breaking successively the various symmetries allowed by the Navier-Stokes equations coupled to the boundary conditions. Finally, at large Reynolds number, when the fully developed turbulent regime is reached, it is commonly admitted that all the broken symmetries are restored in a statistical sense, the statistical properties of the flow not depending anymore on Re. However, both natural systems and recent experimental studies of turbulent flows have shown the possible existence of turbulent transitions between some "mean states".

Using the von Karman flow as a model turbulent experiment, we first show the sequence of bifurcations leading to chaos and turbulence and describe the characteristics of the turbulent states [1]. We then study the transitions observed for different forcing conditions from Re $=10^2$ to Re $= 10^6$.

(i) *Supercritical transition:* we report a divergence of the susceptibility to symmetry breaking at a critical Reynolds number Re $= 4.10^4$ revealing a phase transition, analogous to the para-ferromagnetic transition. This transition is furthermore associated with a change in the statistical properties and a peak in the amplitude of fluctuations of the instantaneous flow symmetry corresponding to intermittencies between spontaneously symmetry breaking metastable states.

(ii) *Subcritical transition:* above Re $= 10^4$, the mean flow presents multiple turbulent solutions, the bifurcation between these states is highly subcritical and the system keeps a memory of its history [4]. The transition exhibits very peculiar statistics.

In the first case, we introduce the notion of instability of a turbulent von Karman flow, thanks to the monitoring of the spatio-temporal spectrum of the velocity fluctuations, combined with projection onto suitable Beltrami modes. It is shown that the turbulent time averaged flow, which is initially axi-symmetric, obeys a sequence of Eckhaus instabilities when the Reynolds number Re is varied from 10^2 to 10^6. This sequence results in non-axisymmetric modulations with increasing azimuthal wavenumber from 1 to 3. These modulations are stationary or nearly statistically stationary until Re $\approx 4 \times 10^3$. Above, they become periodic with an increasing frequency. We describe these modulations and show in particular that they are connected with coherent structures of the mixing shear layer [5]

In the second case, we study the influence of the energy injection on the steady turbulent states, at constant impeller speed, or at constant torque. We find that the different forcing conditions change the nature of the stability of the steady states and reveal dynamical regimes that bear similarities with low-dimensional systems. We suggest that this forcing dependence may be an out-of-equilibrium analogue of the ensemble inequivalence observed in long-range interacting statistical systems, and that it may be applicable to other turbulent systems [6].

References

[1] Ravelet F., Chiffaudel A., Daviaud F., J. Fluid Mech. **601**, 339 (2008)
[2] P.-P. Cortet, A. Chiffaudel, F. Daviaud, and B. Dubrulle, Phys. Rev. Lett. **105**, 214501 (2010)
[3] P.-P. Cortet, E. Herbert, A. Chiffaudel, F. Daviaud, B. Dubrulle and V. Padilla, J. Stat. Mech. **P07012** (2011)
[4] Ravelet F, Mari_e L, Chiffaudel A and Daviaud F, Phys. Rev. Lett. **93** 164501 (2004)
[5] E. Herber, P.-P. Cortet, F. Daviaud, and B. Dubrulle, Eckhaus type instability of a mean turbulent von K´arm´an flow, submitted to Phys. Fluids (2013)
[6] B. Saint-Michel, B. Dubrulle, L. Marié, F. Ravelet and F. Daviaud, Forcing-type-dependent stability of steady states in a turbulent swirling flow, submitted to Phys. Rev. Let. (2013)