Subcritical Transition o Turbulence

O. Dauchot

CEA-Saclay - SPEC
91191 Gif-sur-Yvette, France

The problem of transition to turbulence in subcritical systems is discussed and illustrated by experiments and modelling attempts relative to plane and cylindrical shear flows.

There are two kinds of transition to turbulence, both belonging to the general class of problem where a system out of equilibrium is driven from order to disorder.
- In the first case, also called globally supercritical, the system experiences instabilities against infinitesimal perturbations saturating above threshold. In this case the classical tools of weakly non-linear analysis are appropriate to describe the transition. In particular, the saturation beyond threshold is dealt with by bifurcation theory of linear instability modes, and space modulations are treated within the multi-scale analysis framework. Key-words are mainly "envelopes", "patterns" and subsequently "space-time chaos". The successive bifurcated states involved in the transition then remain in some sense close to each other. "Turbulence" sets in at later stages in the form of interacting pattern defects, described in the framework of statistical mechanics. Rayleigh-Benard convection is a classical example where a physical simple mechanism is at work to produce the instability.
- In the second case, also called globally subcritical, the basic state remains stable against infinitesimal perturbations. Finite amplitude disturbances eventually drive an abrupt transition towards bifurcated states, which coexist at finite distance with the basic state. In physical space, this phase- space coexistence of different locally stable states leads to the coexistence of laminar and turbulent domains. The intrinsic discontinuity of this kind of transition gives little chance to obtain any relevant description in terms of perturbative methods and calls for a fully non-linear description and a global phase space approach of the transition.

In the present lecture we will deal with experimental studies and modelisations of plane Couette and cylindrical Couette flows, two prototype flows for globally subcritical transition to turbulence.
- Triggering the flow by localized finite amplitude disturbances brings evidence of characteristic properties of the nonlinear response such as strong dependance on the initial condition, long-lived transient dynamics...

- Simple models, which mimics hydrodynamics properties provide a general background for discussing the origin of these properties and underline the role played by unstable finite amplitude solutions at finite distance from the basic state. The impact of non-normal effects will be specifically discussed.
- Experimental evidence of finite amplitude solutions will be provided and their genericity to most open flows will be discussed.
- Considering the laminar-turbulent coexistence, it will be shown how the aspect ratios of the system plays a key-role on its spatio-temporal dynamics. We will discuss the relevance of a description in terms of phase transition, from first order spontaneous nucleation to second order directed percolation transition.
- Ultimately, looking at the transition from turbulent to laminar flows, it will be suggested that a globally supercritical scenario of the reverse transition can be proposed.

All along the lecture, we will try to illustrate how the fields (hydrodynamics, instability theory and statistical physics) which have contributed to a successfull description of supercritical transition, also provide suitable tools for the description of subcritical ones, at least if nonlinearity and intrinsic fluctuations are fully taken into account.