Reduction of the complexity of an open cavity air-flow by catching the spatial flow organization within a few dynamical modes

Luc Pastur[1,2], François Lusseyran[1], Jérémy Basley[1,2], & Nathalie Delprat[1,3]

[1] LIMSI-CNRS
[2] Université Paris Sud 11
[3] Université Pierre et Marie Curie
luc.pastur@limsi.fr

Most open systems in fluid dynamics potentially own an infinite number of degrees of freedom, which makes questionable approaches in terms of dynamical system analysis. However, in many situations, the flow complexity actually reduces to very coherent features together with few characteristic structures in space and time, suggesting that the actual number of degrees of freedom is small. The resulting flow organization, therefore, can often be considered as the projection of the full dynamics over some central variety, whose dimension is small, such that a few modes may be selected as relevant with respect to the long-time dynamics (associated to vanishing or close to imaginary eigenvalues), all the other modes being slaved to them. In a very recent work, Schmid and Sesterhenn (2008) have shown how to compute modes relevant with respect to the non-linear state evolution of such systems. The method is empiric, the mode computation being directly done based on successive, time-resolved, realizations of some observable (velocity field, pressure, etc), without any explicit knowledge of the evolution-operator (which may be by the Navier-Stokes equation). The resulting modes of the decomposition are called "dynamical modes" by Schmid and Sesterhenn because they are the eigen-modes of some operator-evolution in the functional space of the observable acting on the fully non-linear state. In the limit of infinite horizon time, beyond transient phenomena, when the dynamics evolves on an attractor, the dynamical modes reduce to the Koopman modes, which are well-estimated by the discrete (time) Fourier transformed (spatial) modes, as shown by Rowley et al (2009). Based on this assumption, we have identified the dynamical modes characteristic of an experimental cavity air-flow. The cavity is rectangular and the flow incompressible (low Mach number limit), which is an academic configuration for studying self-oscillating flows. Such flows are known to exhibit narrow-banded power spectra, due to the enhancement of self-sustaining oscillations. In such strongly organized flows, dynamical or Koopman modes provide an efficient way for reducing the flow complexity, for they catch the spatial structures characteristic of the flow with respect to its space-time dynamics.

Schmid and Sesterhenn (2008), Schmid P. and Sesterhenn J., (2008) "Dynamic mode decomposition of numerical and experimental data", Sixty-First Annual Meeting of the APS Division of Fluid Dynamics, San Antonio, Texas, USA.

Rowley et al (2009), Rowley C. W., Mezic I., Bagheri S.,Schlatter P. and Henningson D. S. (2009) "Spectral analysis of nonlinear flows", Journal of Fluid Mechanics, pp. 1-13