Reduced order modelling and control of fluid instabilities

The objective of the course is to introduce and adapt reduced-order-modelling and modern control techniques in order to stabilize flow instabilities and therefore delay transition to turbulence. These issues play a crucial role in both aeronautical and mechanical engineering applications.

Topics covered include:
- Amplitude equations and open-loop control: multiple time-scale analysis, compatibility condition, bifurcation analysis in real systems.
- Model reduction with balanced truncation and closed-loop control: input/output dynamics, observability and controllability Gramians, Hankel singular-values, balanced basis.
- Proper Orthogonal Decomposition and Galerkin projection of Navier-Stokes equations
- Koopman-based reduced order modelling of nonlinear dynamics

All concepts will be illustrated on cylinder and open-cavity flows with codes based on the free open source software platform FreeFem++ and python.

For the evaluation, the participants are given articles that propose new techniques and algorithms and build on the provided FreeFem++/python codes to implement and illustrate the new techniques.

Prerequisite: Fundamental notions of fluid mechanics, hydrodynamic instabilities, skills in applied math (linear algebra, Taylor expansions, series, integration by parts, …) and scientific computing (python programming).

Bibliography:

- D. Sipp. Open-loop control of cavity oscillations with harmonic forcings, J. Fluid Mech., 708, 439-468, 2012.
- D. Sipp and P.J. Schmid. Linear Closed-Loop Control of Fluid Instabilities and Noise-Induced Perturbations: A Review of Approaches and Tools. Appl. Mech. Rev., 68(2), 020801, 2016.
- Ma, Z., Ahuja, S., & Rowley, C. W. (2011). Reduced-order models for control of fluids using the eigensystem realization algorithm. Theoretical and Computational Fluid Dynamics, 25, 233-247.
- Schmid, P. J. (2022). Dynamic mode decomposition and its variants. Annual Review of Fluid Mechanics, 54, 225-254.

Timing: The Course is offered in the second part (December-February) of the M2 year.

Credits: 3 ECTS

Hours: 36 hours.