Open Invited Track : Flow Control Strategies And applications

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Abstract: Fluid flow control problems exist in a multitude of applications including ground, maritime and airborne transportation, renewable energy, like wind- or water-turbines, mitigation of combustion instabilities and improvement of industrial processes in which fluid flows or heat transfer convection are present.
Flow control rapidly progresses by exciting multidisciplinary activities with researchers from fluid mechanics, physics, applied mathematics, computer sciences (machine learning) and control theory. Each discipline brings in its own knowledge and understandings of the problem. This track shall fertilize cross-disciplinary interactions.
Topics covered include (but not limited) theoretical, numerical and experimental developments on flow control with :

- Feedback and robust control
- Adaptive or model-free control
- Machine learning, genetic algorithms, any evolutionary algorithms
- Model-based control (reduced-order model : ODE, PDE)
- Direct Numerical Simulations (of Navier-Stokes equations)
- Turbulence control and nonlinear flow control
- Coupling approaches

Keywords: control of fluid flows and fluids-structures interactions; model reduction; evolutionary algorithms Output feedback control, robust control, nonlinear control, adaptive control, direct numerical simulations

Fluid flow control problems exist in a multitude of applications ranging from everyday life to industrial processes. Examples include ground, maritime and airborne transportation, renewable energy, like wind- or water-turbines, mitigation of combustion instabilities and improvement of industrial processes in which fluid flows or heat transfer convection are present. Flow control can be a critical enabler to improve efficiency and performance and to save energy. In particular active feedback control has rapidly evolved since the 90's when actuation and sensing hardware has become more advanced, reliable and affordable and the control theory entered mainstream fluid mechanics. Since a few years, machine learning approaches have overcome hitherto unsolvable challenges complementing more traditional approaches. Many literature studies can be grouped in two groups: model-based control for numerical simulations up to moderate Reynolds numbers and robust, adaptive or model-free control for experimental turbulence.

Computational flow control efforts start with a discretization of the governing Navier-Stokes equations. For more realistic Reynolds number flows this often implies a very large computational effort: physical time and spatial scales to be resolved easily span several orders of magnitudes. This results in large grid sizes and small integration time steps. Today, common grid sizes range from 1 to 200 millions of nodes. In these cases, control design becomes quite a challenging task. Model-based control design requires some form of reduced-order model (ROM). During the last decades many ROMs have been developed. Examples are based on linearized perturbation equations, simple PDEs like Boundary Layer Equations, or Galerkin models with stability modes, Proper Orthogonal Decomposition (POD) models of data obtained by an accurate Direct Numerical Simulation (DNS). Thus, control-oriented ROM of manageable dimension from few to below one hundred can be derived. Companion control design has to respect the range of model validity and the relevant nonlinear actuation mechanisms.

Experimental feedback turbulence control efforts are often based on a working open-loop control. The feedback loop may optimize one- or few actuation parameters in response to varying operating conditions or a tracking task. In-time feedback control has been greatly augmented by recent discovery of machine learning control (MLC). Here, control design is considered as a regression problem and the control law is evolved with an evolutionary algorithm optimizing a given cost functional. Examples of regression techniques includes neural networks, genetic algorithms for parameters of a given control law or genetic programming for arbitrary control laws. Here, no model for actuation response is required. The control laws are tested directly in the experiment.

Flow control, and in particular turbulence control, has remained a grand challenge problem despite increasing interdisciplinary efforts around the world. One reason is the large physical complexity of turbulence because of the intrinsic nonlinearity of the Navier-Stokes equations, the high dimension of the state-space and potentially significant convective time delays. Nonlinearity, high dimension and time-delays are key challenges for any control design, particularly, for model-based variants. Robustness for varying operating conditions is another challenge.

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