Title:

Low-order dynamical modelling of highly turbulent flow using machine-learning approaches.

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Host Laboratory : Pprime institute, Poitiers, France

Keywords: reduced order model, turbulent flow, fluid/structure interaction, Auto-Encoder

Context of the study:

The increasingly important development of machine learning approaches is opening new routes to explore and model non-linear complex fluid mechanics [Vinuesa & Brunton 2022] such as encounters at fluid-solid interface related problems, among which near-wall turbulence or flow-induced vibrations for example.

Turbulent flows dictate the performance characteristics of numerous industrial equipment and environmental applications. One important consequence of turbulence is to increase the mixing momentum leading to high friction drag on surfaces, the increase relative to laminar conditions easily reaching factors of 10-100 depending on the Reynolds number of the flow. In many applications, the friction drag is extremely influential to the operational effectiveness of the device or process. This applies specially to transport, involving either self-propelling bodies moving in a fluid or fluids being transported in ducts and pipes. In this context, the industrial and scientific communities are encouraged since many decades to reduce transport-related emissions for which friction drag is a major constituent. On the other hand, enhancing the turbulent fluxes within the wall-bounded region is generally beneficial for the heat transfer. Thus, in the case of heat exchangers, a balance needs to be found between drag-induced losses and heat transfer. For a wide variety of engineering applications, whether for a cooling or heating process, improving heat-exchanger capacity is a crucial technological challenge towards efficiency and addressing industrial and societal requirements for cost-effective energy transfer. For any viscous fluid in motion relative to a solid, the velocity decreases to zero at the wall inducing a shear layer. Although emphatically chaotic, flow produced by this shear layer has some coherent structural components that are of major influence on the momentum-mixing process and consequently to the drag and heat exchange} The stronger the shear layer is, richer and more complex is the dynamics, which renders the study of near-wall turbulence extremely fascinating and challenging. Turbulent boundary layer is populated with a wide spectrum of structures ``eddies'' that cover a range bounded by the Kolmogorov length, at one end, and multiples of the boundary-layer thickness, at the other.

Objective:

Relying on the recent efforts made by the partners of the consortium on these aspects, the current PhD project is first intended to introduce a data-driven method capable of deriving an interpretable low-dimensional dynamic model from complex flow configurations. As a secondary objective, such method will then serve as a basis to determine new control strategies. The existing databases will be explored by a large spectrum of statistical algorithms and new data-driven approaches such as autoencoder [Agostini 2022] or variational autoencoder [Eivazi et al. 2022]. Due to the broadband spectrum of scales driving the dynamics of turbulent channel flows, leading to a large complexity, the first developments will be carried out on the case of a circular cylinder experiencing induced-vibrations. The existing database for this configuration will be enriched during the project using the code xcompact3d [Bartholomew 2020].

Main Tasks:

- Develop algorithms for mining large databases
- Leverage various approaches from the machine learning community for building low-dimensional dynamical model : (a) AE and VAE will be used for building an ``interpretable'' skeleton of the model, and (b) other methods such as convolutional network, or transformer, or reservoir computing … will be used for determining the dynamical link between the different parts of the skeleton

Secondary Tasks:

- Running Direct Numerical Simulation using xcompact3d
- Carried out additional experiments for the FIVs might be requiered

Mandatory Skills:

- Master degree in Fluid Mechanics or applied Mathematic.
- Knowledge in Machine learning is highly recommended.

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