1st SIG Online Event: Data Assimilation in Fluid Mechanics

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Denis Sipp (Onera, France)

Reconstruction of time-averaged and unsteady data in open-flows using non-linear optimization techniques and hydrodynamic stability

The accurate reconstruction of time-averaged and unsteady data in wind-tunnels from few measurements has become an important topic in the aerospace industry. We will show here how the use of time-averaged (Reynolds-Averaged Navier-Stokes) and fully unsteady (Navier-Stokes) models may help reconstruct a whole flow field from scarce measurements using non-linear optimization techniques. This will be illustrated on experimental and numerical configurations exhibiting separation, such as bluff-bodies, backward facing step flows or jet flows. Finally, we will show how the knowledge of the time-averaged flow and its hydrodynamic stability properties may provide an alternative efficient way of reconstructing large-scale and low-frequency unsteady features in turbulent flows.

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Luca Magri

Overview of data assimilation: Variational methods vs Statistical learning

Data assimilation provides a way to answer the big question of some fluids modellers: "How can I make a qualitative model quantitatively predictive?" The answer to this question allows practitioners and industry to better trust reduced-order models for engineering design. To answer the big question, three technical questions need to be addressed: (1) How do we accurately predict the time evolution of a flow (state estimation)? (2) How do we optimally calibrate a reduced order model every time that measurements from sensors become available (parameter estimation)? (3) Can we quantify how "good" or "bad" are our modelling assumptions given experimental evidence (model deficiencies)? Data helps answer these questions. Data assimilation is the technique that combines the information from both data and a model to improve our knowledge on the state, parameters, and model deficiencies. Time permitting, the two main approaches for data assimilation in fluids will be presented. The first approach is based on constrained optimisation, which is performed by a variational method. The second approach is based on statistical learning, which is performed by a Bayesian approach. The pros and cons of the two approaches will be discussed through examples of applications in turbulent and non-turbulent multi-physics flows. Ongoing work and future challenges for data assimilation in fluid mechanics will conclude the talk.

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Yongyun Hwang & Bruno Eckhardt.

An optimisation-based quasi-linear approximation for linearly stable shear flows: application to turbulent channel flow up to Re_tau=20,000.

A quasi-linear approximation for linearly stable mean flow is proposed and applied to turbulent channel flow. The velocity field is decomposed into a mean profile and fluctuations. While the mean is obtained from the nonlinear equations, the fluctuations are modelled by replacing the nonlinear self-interaction terms with an eddy-viscosity-based turbulent diffusion and stochastic forcing. The stochastic forcing is then determined self-consistently by solving an optimisation problem which minimises the difference between the Reynolds shear stresses from the mean and fluctuation equations, subject to a constraint that the averaged Reynolds shear-stress spectrum is sufficiently smooth in the spatial wavenumber space. The proposed quasi-linear approximation is subsequently applied to channel flow for Reynolds number Re_tau ranging from 500 to 20,000. The best result is obtained when the Reynolds stress is calculated by retaining only the two leading POD (proper orthogonal decomposition) modes, which further filters out the modelling artifact caused by the unphysical stochastic forcing. In this case, the resulting turbulence intensity profile and energy spectra exhibit the same qualitative behaviour as DNS data throughout the entire wall-normal domain, while reproducing the classical predictions made by Townsend (1956).

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Pranav Chandramouli (TU Delft)

4D Variational assimilation of wake flow with a dynamics error model

A novel variational assimilation technique (4D-Var) is presented to reconstruct time resolved incompressible turbulent flows from measurements on two orthogonal 2D planes. The proposed technique incorporates an error term associated to the flow dynamics using concepts borrowed from large-eddy simulation and stochastic turbulence models. A reconstruction algorithm, termed snapshot optimisation (SO), is also presented for recreating 3D data from two 2D orthogonal planes of data obtained over a long-period of time. The proposed 4D-Var algorithm is successfully applied on a 3D turbulent wake flow in the transitional regime without specifying the obstacle geometry. The algorithm is analysed on synthetic data emulating large-scale experimental PIV observations reconstructed using the SO algorithm.

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Matthew Juniper, Hans Yu, Francesco Garita, Luca Magri.

Assimilation of 100,000 experimental datapoints of a thermoacoustic instability: turning a qualitative model into a quantitative model.

We combine a thermoacoustic experiment with a thermoacoustic reduced order model using Bayesian inference to accurately learn the parameters of the model, rendering it predictive. The experiment is a vertical Rijke tube containing an electric heater. The heater drives a base flow via natural convection, and thermoacoustic oscillations via velocity-driven heat release fluctuations. The decay rates and frequencies of these oscillations are measured every seven seconds by acoustically forcing the system via a loudspeaker placed at the bottom of the tube. More than 320,000 temperature measurements are used to compute state and parameters of the base flow model using the Ensemble Kalman Filter. A wave-based network model is then used to describe the acoustics inside the tube. We balance momentum and energy at the boundary between two adjacent elements, and model the viscous and thermal dissipation mechanisms in the boundary layer and at the heater and thermocouple locations. Finally, we tune the parameters of two different thermoacoustic models on an experimental dataset that comprises 100,000 experiments. This study shows that, with thorough

Bayesian inference, a qualitative model can become quantitatively accurate, without overfitting, as long as it contains the most influential physical phenomena.

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Luca Cantarello

A modified shallow water model for inexpensive data assimilation research

A modified shallow water model able to mimic convection and precipitation has been developed at the University of Leeds to conduct idealised forecast-assimilation experiments, facilitating inexpensive data assimilation research in an operational context. Exploiting a twin-setting configuration, pseudo-observations are derived from a high-resolution 'nature run' simulation and subsequently combined with lower-resolution model runs by means of an Ensemble Kalman Filter. Idealised satellite data assimilation constitutes the current focus of our research, which has required both a partial model revision and the development of a more complex pseudo-observing system, including a non-linear observation operator.