Uncertainty quantification – overview

The uncertainty quantification group consists of eight projects covering three different challenges: (i) the combination of observation data and computational methodologies, (ii) the development of efficient and accurate approaches for the propagation of uncertainties and (iii) the application of established methodologies to realistic fluid dynamics simulations.

Data Assimilation (DA) provides an attractive framework for integrating observations into computational models, taking into account uncertainty in the model and in the observations. This analysis can be formulated as an inverse problem. Two projects focused on the implementation of data-driven numerical models in order to stochastically estimate the distribution of model parameters that lead to a simulation that is consistent with the observations. Marxen *et al.* performed an inverse analysis of a laminar-to-turbulent transition model. In this model, intermittency measurements determine the transition onset location. These data were assimilated with a Markov Chain Monte Carlo (MCMC) method to characterize the statistics of randomly occurring boundary-layer disturbance wavepackets that cause laminar-to-turbulent transition. A verification experiment was first carried out using synthetic measurements. Then, the algorithm was applied to real data. In the project by Rochoux *et al.*, the assimilation of time-dependent parameters of a fire spread model was performed via the assimilation of airborne-like fire front observations, in order to improve the simulation and forecast of the fire propagation. An Ensemble Kalman Filter (EnKF) was applied to reduce the uncertainties in the atmospheric and vegetation parameters for the Rate Of Spread (ROS) model. In order to reduce the computational cost of the algorithm, a surrogate model based on a Polynomial Chaos (PC) approximation was used in place of the actual model. The merits of using the EnKF algorithm based on the PC approximation were investigated by performing numerical experiments involving both synthetic and real measurements.

The next three projects focused on developing new algorithms for uncertainty propagation. The project by Abgrall *et al.* investigated problems containing multi-resolution features in both physical space and uncertainty space. This is a typical situation in supersonic flows under inflow or geometric uncertainties where small changes in parameters describing the uncertainties lead to large variations of the solution structure in physical space. An adaptive refinement scheme in the whole physical-uncertainty space was developed and successfully demonstrated on the Burgers equation. Along similar lines, the project by Lucor *et al.* developed and demonstrated the iterative generalized Polynomial Chaos (i-gPC) method to solve uncertainty quantification problems for shock-dominated problems non-intrusively. The proposed approach, based on polynomial chaos, successively adapts the approximation basis in the stochastic space to improve the overall accuracy without requiring additional solutions to the original problem. The project by Blonigan *et al.* aimed at quantifying numerical and modeling uncertainties in high-fidelity turbulence simulations using the adjoint method. To overcome the exponential divergence of traditional adjoint solutions due to chaotic dynamics, two methods were investigated: (i) a stabilization approach and (ii) a novel multigrid-in-time formulation named the Least Square Sensitivity adjoint.

The last group of projects involved the propagation of uncertainties in more realistic fluid dynamics problems. Moreau *et al.* investigated two challenging problems involving noise prediction; the first used high-fidelity large eddy simulation to study the effect of geometrical uncertainties in a rod-airfoil configuration, while the second focused on a low-order model based on RANS simulations and semi-analytical models. The last project by Hiroki *et al.* investigated the possibility of introducing uncertainty analysis within an optimization loop. A wind turbine airfoil profile is studied under angle-of-attack uncertainties and constraint optimization aimed at reducing the effect of variability on the aerodynamic coefficients.

Gianluca Iaccarino
Stéphane Moreau
Sophie Ricci
Qiqi Wang