Hierarchical Multifidelity Models with Calibration for Turbulent Flows

Saleh Rezaeiravesh†*, Timofey Mukha†, Ricardo Vinuesa† and Philipp Schlatter†

† SimEx/FLOW, KTH Engineering Mechanics, Royal Institute of Technology, Stockholm, Sweden
† Swedish e-Science Research Centre (SeRC), Stockholm, Sweden
e-mail: salehr@kth.se, tmu@kth.se, rvinuesa@mech.kth.se, pschlatt@mech.kth.se -
Web page: www.kth.se

ABSTRACT

Despite the need for understanding the complex physics of the turbulent flows, conducting high-fidelity experiments and scale-resolving numerical simulations can be prohibitively expensive, particularly at high Reynolds numbers which are most relevant to engineering applications. On the other hand, accurate yet cost-effective models are required to be developed for uncertainty quantification (UQ), prediction and robust optimization for problems involving turbulent flows, where exploration of the space of inputs and design parameters demands a relatively large number of flow realizations. A remedy could be to use multifidelity models (MFM) which aim at predicting accurate quantities of interest (QoIs) and their statistical moments by combining the data obtained from different fidelities.

In this regard, the present study reports our recent progress on further developing and exploiting a class of multifidelity models which rely on Gaussian processes. Following Goh et al. [1], at each hierarchical level in the MFM, the Kennedy-O'Hagan model [2] is used which allows for considering both model inadequacy and aleatoric uncertainties in the process of data fusion. As a main advantage of the present approach, the calibration parameters as well as the hyperparameters appearing in the Gaussian processes are simultaneously estimated within a Bayesian framework using a limited number of realizations (mostly by running low-fidelity simulations). The constructed MFM can then be employed for uncertainty propagation and prediction over the whole input/design parameter space. Another main advantage of the present MFM over other approaches used with regards to turbulent flows is the possibility of incorporating different types of uncertainty in the predictions.

The described MFM is applied to periodic hill [3] where both attached and separating turbulent boundary layers exist, so the results could be relevant to applications in marine technology. The design parameters include those defining the geometry of the curved surfaces. When estimating the resulting uncertainties in the QoIs, the influence of the calibration parameters such as modelling and numerical parameters in RANS are also considered.

REFERENCES

[1] J. Goh et al., Prediction and computer model calibration using outputs from multifidelity simulators, *Technometrics*, Vol. **55**, 4, pp. 501-512, 2013.

[2] M. C. Kennedy and A. O'Hagan, Bayesian calibration of computer models, *J. R. Statist. Soc. B*, Vol. **63**, Part 3, pp. 425-464, 2001.

[3] J. Fröhlich, C.P. Mellen, W. Rodi, L. Temmerman, M.A. Leschziner, "Highly resolved large-eddy simulation of separated flow in a channel with streamwise periodic constrictions", Journal of Fluid Mechanics, vol. **526**, pp. 19–66, DOI: 10.1017/S0022112004002812