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Improving the reliability of turbulent flow predictions using Clustered Model Aggregation

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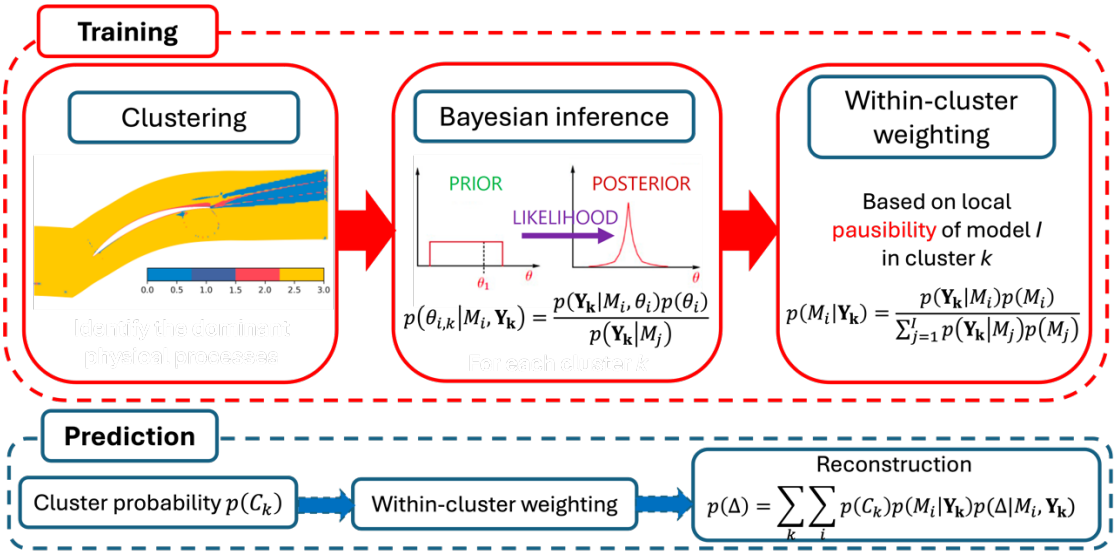
Abstract

Despite growth in computing power, Direct Numerical Simulation (DNS) or Large Eddy Simulations (LES) remain far too expensive for industrial flow configurations such as turbomachinery flows, of interest for the present study. Coarse-grained approaches based on the Reynolds-Averaged Navier-Stokes (RANS) equations supplemented with a turbulence model remain the industry standard but introduce large uncertainties that affect the reliability of flow predictions. In general, there is no consensus on which RANS model performs the best, and model selection is generally based on expert judgement, while model closure parameters are also highly uncertain. In this work, we use Bayesian inference and unsupervised machine learning to (i) infer local updates of closure parameters for a set of well-known turbulence models depending on the dominant flow processes and (ii) mix the predictions of the updated models based on local cluster probabilities to predict an unseen flow. The model mixture provides estimates of the solution mean and variance under turbulence modelling uncertainty. Specifically, high-fidelity datasets are partitioned into clusters representative of different flow processes using Gaussian Mixture models, based on the similarity between features describing the flow locally. Then, the coefficients of the RANS models are updated using Bayesian inference based on the data observed in each cluster. Finally, each model from each cluster is used to predict a flow configuration and a weighted average of the predictions is obtained by using the in-cluster model plausibilities and the cluster probabilities. The trained GMM is applied to unseen configurations starting from an initial guess of the solution provided by the baseline models. The approach is used to predict the flow around a cascade of NACA65 V103 compressor blades, showing improved accuracy over the baseline RANS models and consistent estimates of the predictive uncertainty.

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