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Machine learning-based aerodynamic optimization with extreme fidelity cost imbalance

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Abstract

The increasing pressure to reduce the carbon footprint of Aeronautic/Aerospace devices calls for radical innovations to drastically reduce or suppress emissions. This requires a step change in models and design. For the aerodynamic design of complex turbomachinery configurations, only so-called "high-fidelity" CFD methods, and in particular LES, can capture the wealth of physical phenomena characteristic of such flows accurately enough, but, despite advances in high performance computing, their cost remains too high for multi-query applications such as shape optimization. One way to overcome this problem is to use machine learning techniques to fuse LES and cheaper, lower fidelity models into multi-fidelity surrogate models, in conjunction with dimensionality reduction and adaptive infill techniques to minimize the number of calls to the expensive solver.

For most multi-fidelity optimization studies, the fidelity hierarchy consists in grid refinement differences for which the cost ratio between the expensive and cheap solutions lies somewhere between 10 and 100. Infill criteria considering the fidelity cost ratio to decide with which fidelity to compute new samples may then be used. When dealing with complex turbulent problems exhibiting transition and unsteady features, RANS/LES fidelity levels are considered instead. The cost ratio then lies between 1000 and 10,000 for Reynolds number comprised between 100,000 and 1,000,000. Standard criteria are not applicable anymore and the decision on when to compute high-fidelity samples must be made a priori and with great care to meet the computational budget.

This work focuses on such conditions by considering the multi-objective optimization of a compressor cascade at Reynolds 100,000. The high order CFD solver MUSICAA is used to compute low- and high-fidelity solutions obtained with RANS and LES simulations, respectively. Starting from a baseline geometry parametrized and perturbed with free-form deformation, data reduction is used to reduce the problem dimensionality. Surrogate-assisted optimization is then performed by coupling a multi-fidelity Gaussian process and a multi-objective Bayesian infill strategy under strong budget constraints. Finally, perspectives are given with regard to the expected increase in the use of high-fidelity simulations for aerodynamic shape optimization.

Keywords: Aerodynamic Shape Optimization; Data Reduction; Multi-Fidelity Gaussian Process; Bayesian Adaptive Infill; RANS Simulation; LES Simulation; Turbomachinery;