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AERODYNAMIC OPTIMIZATION OF TURBINE AIRFOILS USING MULTI-FIDELITY SURROGATE MODELS

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Abstract: For many applications numerical simulations are available in a varying degree of fidelity and computational expense. On the one hand, in an accurate and time-consuming high-fidelity (HiFi) version, that is used as a reference for design and optimization, and on the other hand, in a low-fidelity (LoFi) version that is faster but less accurate. In the field of computational fluid dynamics (CFD), for example the flow simulation of turbine airfoils, an accurate 3D solver accounts for the HiFi model and a faster 2D solver for the LoFi model, where the 2D simulations are performed on multiple radially stacked airfoil sections (quasi 3D). Assuming the LoFi model captures the basic effects reasonably well, a great quantity of inexpensive LoFi data may be coupled with a small amount of expensive HiFi data to enhance the accuracy of a surrogate model in comparison to a surrogate model that relies solely on the HiFi data. Used in a surrogate based optimization these multi-fidelity surrogate models can be used to speed up the optimization. Conventional multi-fidelity surrogate models approximate the HiFi objective function by aligning the low-fidelity predictions to the high-fidelity results. This is commonly achieved by interpolating the error between both fidelity models, e.g. in form of a kriging based interpolation. The design space variables are the independent variables of this interpolation. In this paper a different approach is presented. Instead of using the design space variables directly, LoFi coordinates in a low-dimensional subspace are used for the interpolation of the HiFi objective values. The low-dimensional subspace representation is obtained by Proper Orthogonal Decomposition (POD) of the LoFi computational domain to identify the most important modes of variation. In comparison to a kriging surface based on design space variables, the advantages are a lower-dimensional kriging model and a simpler, i.e. smoother, response surface. The multi-fidelity surrogate models are applied to predicting aerodynamic performance of a second stage gas turbine vane. Comparing the surrogate prediction to the actual objective value from the HiFi model, the multi-fidelity models are found to be more accurate than a single-fidelity kriging model. Based on these surrogates multi-fidelity optimizations are carried out utilizing a kriging based Expected Improvement strategy. Especially the POD based method shows a fast convergence and outperforms a single-fidelity optimization.