Uncertainty Quantification for MDAO

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Abstract

This presentation will discuss recent research on uncertainty quantification (UQ) in multidisciplinary analysis and optimization, particularly with respect to uncertainty propagation, model error estimation, and strategies for computational scalability.

The first challenge is aleatory uncertainty propagation in systems that require multidisciplinary iterative analyses between two or more coupled component models. The estimation of the converged coupling variables is treated analogous to likelihood-based parameter estimation, thus leading to a likelihood-based approach for multidisciplinary analysis (LAMDA). The calculation of the probability distributions of the coupling variables is theoretically exact and does not require a fully coupled system analysis. This approach is extended to high-dimensional problems using a Bayesian network. The Bayesian network approach is found to be advantageous for further extension to MDO under uncertainty.

The second challenge is how to estimate the epistemic uncertainty regarding model parameters and model errors in coupled multi-physics systems. While some model parameters are local to individual models, other parameters may be shared between models. Further, each disciplinary model has its own error, and the error aggregates through the MDA iterations; however, often the data available for parameter and error estimation does not correspond to individual model outputs. A Bayesian state estimation approach is found to be effective in the estimation of model form errors and in the extrapolative estimation of prediction uncertainty in untested scenarios.

A third challenge is computational effort in the above uncertainty analyses. Surrogate models are often built to replace the original physics models if they are time-consuming. However, the generation of training data to construct surrogate models can be expensive, especially in the presence of multiple disciplines and high dimensionality. The combination of dimension reduction, active learning, and resource allocation for adaptive surrogate model refinement is explored to achieve high accuracy with low computational effort.

The above UQ and optimization methods are illustrated for multi-disciplinary problems in aero-thermo-elastic response of aircraft and in additive manufacturing. The presentation summarizes research efforts funded by AFOSR, NASA, Airbus and Mitsubishi.

Bio-sketch

Professor Sankaran Mahadevan has 36 years of research and teaching experience at Vanderbilt University in uncertainty quantification, reliability analysis, machine learning, structural health monitoring, and optimization under uncertainty. His research has been extensively funded by NSF, NASA, FAA, DOE, DOD, DOT, NIST, General Motors, Chrysler, Union Pacific, Mitsubishi, ABS, Airbus, American Railroad Association, and several DOE national laboratories. His research contributions are documented in more than 700 publications, including two books and 350 journal papers, receiving more than 30,000 citations and a h-index of 90 according to Google Scholar. He has directed 56 Ph.D. dissertations and 24 M. S. theses so far, and has taught many industry short courses on uncertainty quantification and risk and reliability methods. He is a Fellow of AIAA, Engineering Mechanics Institute, and Prognostics & Health Management Society, and has won prestigious awards such as the IASSAR Senior Distinguished Research Award, ASCE George Winter Medal, and the NASA Next Generation Design Tools Award. He was recently President of the ASCE Engineering Mechanics Institute, and managing editor of the ASCE-ASME Journal of Risk and Uncertainty (Part B: Mechanical Engineering). He is currently Chair of the ASME VVUQ Subcommittee on Advanced Manufacturing.

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