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MULTI-FIDELITY DESIGN UNDER UNCERTAINTY FOR COMPLEX, LARGE-SCALE SYSTEMS

Abstract

A simulation-based framework for multi-fidelity uncertainty quantification is presented, whose goal is to inform and guide the design process of complex, multidisciplinary, large-scale systems throughout their life cycle. In this framework, the uncertainty in system models is identified, categorized, modeled and propagated in an integrated manner by direct incorporation of these four aspects into the analysis cycles needed to design systems and verify their compliance to key performance requirements. As a result, the dominant effects contributing to the system's performance or robustness degradation are identified and analyzed.

The methodology first finds the critical system parameters that most significantly create variance in the quantities of interest through a global sensitivity analysis. These parameters can be targeted by additional research through optimal parameter inference experiments in order to reduce their variability. The experimental data thus collected can be used in Bayesian inference methods (e.g., Markov Chain Monte Carlo) to update the model systematically. This process is iterative and the outcome of each step informs the validation procedures for the subsequent step. Finally, model inadequacy is also addressed by exploring different functional forms and is used to analyze its impacts on model predictive capabilities. This entire process increases one's knowledge about the system, its subcomponents and all of their mutual interactions, and represents a crucial commodity when important design decisions are to be made. If applied early in a project's life-cycle, it can potentially reduce mission costs related to resources (e.g., mass or power) and processes (e.g., design, verification and validation).

The methodology presented here is developed with a multi-fidelity approach, i.e., adopting simplified and computationally efficient models to replace the high-fidelity and computationally intensive ones, while establishing accuracy and/or convergence guarantees on the final result.

As a case study, this paper presents results from the application of this framework to the James Webb Space Telescope's integrated model, with emphasis on the thermal and structural contributions. This integrated model is used to verify key requirements of the nominal temperature predictions for the benchmark hot-to-cold slew thermal analysis cases.