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MULTI-FIDELITY DESIGN UNDER UNCERTAINTY FOR THE JAMES WEBB SPACE TELESCOPE

Abstract

A simulation-based framework for multi-fidelity uncertainty quantification is presented, whose goal is to inform and guide the design process of complex, large-scale systems throughout their life cycle by incorporating uncertainty upstream in the design process. Propagating the uncertainty effects through the system model helps to determine the dominant effects contributing to the system's performance or robustness degradation. In this framework, the uncertainty in system model parameters 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. A variance-based global sensitivity analysis is used to find and rank the critical system parameters, based on their contribution to the variance of the quantities of interest. These parameters could thus be targeted by additional research through optimal parameter inference experiments in order to reduce their variability. By so doing, one incorporates uncertainty in the model and updates the model iteratively as new parameter information becomes available. This 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). When coupled 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, simulation-based design under uncertainty becomes highly efficient and makes it possible to work with multidisciplinary, large-scale models. As a case study, this paper presents results from the application of this framework to the James Webb Space Telescope's integrated model, which encompasses multiple disciplines (e.g., structural, thermal, optical, etc.) and is used to verify key requirements of the nominal temperature predictions for the benchmark hot-to-cold slew thermal analysis cases.