Paper ID: 18891
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student

SPACE SYSTEMS SYMPOSIUM (D1)
Poster Session (P)

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PRELIMINARY DESIGN OF SPACE SYSTEMS SUBJECT TO MIXED ALEATORY-EPISTEMIC UNCERTAINTY

Abstract

In the early phases of the design of a space mission, several design parameters are known with a degree of uncertainty. This uncertainty is either due to a stochastic variation of some quantities (aleatory uncertainty), or to lack of knowledge on the system (epistemic uncertainty). Whereas aleatory uncertainty can be described by Probability Theory, epistemic uncertainty can be conveniently treated with Evidence Theory, as it allows for the uncertain parameters to be expressed as intervals or opinions. The Belief function, a measure of the lower limit of the probability that a given proposition is true (e.g. the spacecraft mass will be below 1000 kg), provides a quantitative trade-off among different design solutions under epistemic uncertainty. However, in real scenarios both aleatory and epistemic uncertainty are present. One way to solve mixed aleatory-epistemic uncertainty problems is to use probability boxes (p-boxes). In this paper we propose a simple alternative approach in which aleatory uncertainty is reduced to epistemic one, and then treated with Evidence Theory. The integral of the probability distribution associated to each aleatory uncertain interval is computed, and then the value is taken as the basic belief assignment for its uncertain interval. The problem is therefore reduced to an epistemic uncertainty one and can be solved with the tools developed so far in previous research work: an evolutionary optimization algorithm finds the design parameters and budgets at which the Belief is zero (minimum) and one (maximum), and all the intermediate values, providing the full trade-off curve. In addition, in order to alleviate the computational burden deriving from the use of expensive models representing the subsystems of a satellite, surrogate models such as Kriging and Artificial Neural Networks have been integrated into the optimization algorithm. Moreover, a focal element-based surrogate modelling technique has been devised. Current results on the solution of epistemic uncertainty problems by means of a multi-objective surrogate-based optimization algorithm show that the actual Pareto front can be approximated with a maximum error of 8%. The focal element-based surrogate model proved to be three times more accurate than a classical approach in which the full uncertain space is approximated by one single surrogate model. In addition, the surrogate modelling reduced the calls to the expensive real models by 15 times. The aim of this paper is to extended these results to the preliminary design of space systems in which both aleatory and epistemic uncertainty affect the design variables.