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Multi-level hierarchical MDO formulation with functional coupling satisfaction under uncertainty, application to sounding rocket design.

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Abstract

At early design phases, taking into account uncertainty in the optimization of a multidisciplinary system is essential to establish its optimal characteristics and performances. Uncertainty Multidisciplinary Design Optimization (UMDO) methods aim at efficiently organizing not only the different disciplinary analyses, the uncertainty propagation and the optimization, but also the handling of interdisciplinary couplings under uncertainty. Coupled approaches involving MultiDisciplinary Analysis (MDA) have been proposed to solve UMDO problem with formulations such as MultiDisciplinary Feasible (MDF) [1]. However, the repeated discipline evaluations due to MDA result in a prohibitive computational cost for the design of complex systems. Decoupled UMDO formulations have therefore been investigated to overcome this computational burden. These approaches ensure the multidisciplinary system consistency for some particular realizations of the uncertain coupling variables or for their first statistical moments but they do not ensure the multidisciplinary consistency of the system design for all the uncertain variable realizations [2]. However, in order to ensure the physical feasibility of the obtained designs, coupling satisfaction, which results from the solving of an interdisciplinary system of equations, have to be verified for all the realizations of the uncertain variables.

A new multi-level UMDO formulation (named Multi-level Hierarchical Optimization under Uncertainty) with functional coupling satisfaction (*i.e.* for all the realizations of the uncertain variables) is presented in this paper. First, a functional representation of the coupling variables through Polynomial Chaos Expansion is proposed to decouple the disciplines to overcome the computational burden induced by MDA. Then, to ensure the interdisciplinary coupling satisfaction, a new integral form of coupling constraint is introduced. This approach allows maintaining the mathematical equivalence between the coupled and decoupled formulations. Secondly, a multi-level UMDO formulation is developed by introducing disciplinary optimizers in addition to the system level optimizer in order to distribute the UMDO problem complexity over different dedicated discipline optimizations. The proposed formulation relies on the iterative construction of PCEs in order to represent, at the problem convergence, the functional coupling mappings between the disciplines. Finally, the proposed formulation is compared to MDF on the multidisciplinary design of a two stage sounding rocket.

References

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