A variable-accuracy scheme for simulation-based multidisciplinary design optimization affected by uncertainty

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ABSTRACT

A strategy for efficient simulation-based Multidisciplinary Robust Design Optimization (MRDO) affected by uncertainty is presented. The design of complex engineering system requires computer simulations, addressing the interaction of mutually coupled disciplines. Real world applications are affected by uncertainty and require uncertainty quantification (UQ) and MRDO formulations. The numerical solution of the MRDO represents a challenge from both the algorithmic and computational viewpoints, especially if computationally expensive simulations are required. Three essential parts (simulation-based multidisciplinary analysis, MDA; UQ; and design optimization) have to be connected effectively and efficiently, in order to define an optimal solution at a reasonable (and feasible) computational cost.

The objective is the development and validation of a variable-accuracy scheme for surrogate-based MRDO, for simulation-based design. The approach encompasses a variable level of refinement of the design of experiments (DoE) used for the metamodel training, a variable accuracy of the UQ and a variable level of MDA coupling between disciplines. Herein, the MDA is solved iteratively; the UQ is carried out using the Monte Carlo (MC) method; the design optimization is solved using DoE, metamodels and a Particle Swarm Optimization (PSO) algorithm. Using subsequent optimization stages, the DoE is built increasing the density of the numerical experiments on smaller subdomains; the level of UQ accuracy and the MDA coupling are also increased [1]. The methodology is compared with a standard MRDO, used as a benchmark and solved by fully coupled MDA and fully accurate UQ, and without metamodels.

Two industrial problems are presented. Specifically, a steady fluid-structure interaction (FSI) problem of a racing-sailboat fin subject to stochastic yaw angle is solved. A two-way coupled hydroelastic system is modelled, including fluid mechanics by CFD and structural analysis by FEM. The objective function is the expected value of the fin efficiency over the stochastic variation of the yaw angle, whereas the design variables pertain to the fin geometry [1, 2]. The second application is the bare hull optimization of an oceanic yacht, subject to stochastic speed. Hydrodynamic loads by CFD and the body equation of motion form a two-way coupled system. The objective function is the expected value of the total resistance over the stochastic speed; the design variables pertain to the modification of the bare hull shape.

The effectiveness and the efficiency of the method are evaluated in terms of optimal design performances and number of simulations required to achieve the optimal design. Results obtained for the FSI problem reveal that the current method is capable of identifying the optimal design (within a very narrow region) at 1/10 of the computational cost of the benchmark solution. The analysis for the oceanic yacht is in progress and will be included in the final paper and presentation.

[1] C. Leotardi, M.Diez, A. Serani, U.Iemma and E.F. Campana, “A framework for efficient simulation-based multidisciplinary robust design optimization with application to a keel-fin of a racing sailboat”, International Conference in Engeneering and Applied Sciences Optimization, Kos, Greece, June 4-6, 2014 - ISSN: 2241-9098, ISBN: 978-960-99994-5-8.

[2] M. Diez, D. Peri, G. Fasano and E.F. Campana, “Hydroelastic optimization of a keel fin of a sailing boat: a multidisciplinary robust formulation for ship design”. Struct Multidisc Optim doi:10.1007/s00158-012-0783-7.