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HIERARCHICAL OPTIMIZATION: MULTI-LEVEL ALGORITHMS, MULTI-DISCIPLINARY OPTIMIZATION, ROBUST DESIGN AND SOFTWARE ENVIRONMENTS

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ABSTRACT

Multi-Level Algorithms: Nested Parameterizations for Shape Optimization, Metamodels

To improve the cost efficiency, we have developed multi-level geometrical strategies using nested parameterizations of the same target shape, that mimick multigrid methods. In particular, we have defined optimum-shape methods based on *Nested and Self-Adaptive Bézier Parameterizations*. There, we have tested the Full Multi-Level Optimum Shape Algorithm (analogous in logical structure to the classical Full Multigrid Method) and proposed a technique for parameterization self-adaptivity.

We have also developed a two-level modeling strategy to treat problems that are both stiff and multimodal. We include in the design procedure a low-cost modeling technique beside the expensive CFD solver, which allows to avoid some expensive evaluations without degrading the accuracy of the result.

Particularly, metamodels, i.e. models of models, are under consideration here as methods to interpolate data from prior computations, thanks to their capability to predict non-linear behaviors.

Robust Design

Two approaches have been developed to estimate performance statistics (mean, variance), instead of computing a performance value only :

- The first method consist in using an Automatic Differentiation (AD) software to compute the first and second derivatives of the efforts with respect to uncertain parameters. Then, we assume that the effort fluctuations can be described by a second-order Taylor series expansion and statistics are evaluated by analytic integration (method of moments).
- In the second method, we compute the efforts for a few number of uncertain parameter values to build a database. It is then used to construct an inexpensive metamodel (Radial Basis Functions, kriging) that describes the effort fluctuations. Statistics are computed by numerical integration or Monte-Carlo simulation on the basis of the metamodel.

These methods will be demonstrated on a testcase of robust design of a supersonic business jet (SSBJ) in which the mean and the variance of the drag are minimized, subject to random fluctuations of the Mach number and angle of attack.

Multi-Disciplinary Optimization

Recently, a theory has been developed to treat multi-criterion cases in which a natural hierarchy exists between two criteria. The absolute optimum of the primary criterion is first identified, presumably numerically. Then, a secondary criterion is improved in a virtual Nash game, in which the design variables have been split, according to the diagonalization of a *reduced Hessian*, and assigned to the two virtual players, in a way that is devised to cause the least possible degradation to the primary criterion from its absolute optimum. Additionally, the theory puts in evidence the existence of a continuum of Nash equilibrium points originating from the initial absolute optimum of the primary criterion considered alone.

This methodology of split has been applied very succesfully in the recent thesis of B. Abou El Majd. There, a wing shape has been optimized first w.r.t. an aerodynamic criterion; then a structural criterion has been improved in a second phase of optimization through a virtual Nash dynamic game. Despite the fragility of the aerodynamic criterion in this difficult exercise, an aerodynamically-relevant result has been achieved, corresponding to a structurally improved design, and the physical pertinence of the mathematical split, although automatic, is evident.

Computer science aspects

Our Project Team OPALE is also involved in works related to the computer science aspects of multi-physics and multidisciplinary optimization. The goal is to provide support to the optimization methods and tools developed by the project in order to benefit from the most advanced high-performance computing technologies and to cross-fertilize with the optimization approaches. It is assumed that high-performance computing facilites provided by large computing infrastructures, e.g, supercomputers, large PC-clusters and grid computing environments, provide large-scale testbeds for numeric optimization experiments. But it is also explored here how the combined use of both these computing infrastructures with the numerical approaches most recently devised can be cross-blended in a smooth way to yield innovative and high-performance methods.