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Aerodynamic shape optimization of 2D and 3D wings under uncertainties

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ABSTRACT

In this work, an algorithm for shape optimization under uncertainties is presented and applied to 2D and 3D wings using gradient based optimization. A polynomial chaos based uncertainty quantification method is combined with adjoints for optimization under uncertainties (or robust optimization). The uncertain design objective is characterized by its mean and its variance using polynomial chaos expansion. The gradient based optimization requires the overall gradient, i.e. the gradient of both quantities. These gradients are obtained from the polynomial chaos expansion of the gradient of the objective. The proposed approach is applied to the optimal shape design of the RAE2822 airfoil and the ONERA M6 wing under operational uncertainties where the objective is to minimize the mean and the standard deviation of the drag coefficient simultaneously with a constraint in the mean lift coefficient. It is observed that the convergence is achieved within few iterations (an order of 10). The coefficients of variance are reduced significantly when the uncertainties are introduced in the optimization process, thus making the wings robust against the uncertainties.

METHODOLOGY

Robust optimization is an extension of conventional optimization where uncertainties are also included in the design procedure [1, 2, 3, 4, 5]. The presence of uncertainties brings several difficulties to the optimization process. Due to the uncertainties in a design process, the objective becomes non-deterministic and can be characterized by its mean and standard deviation, i.e. in a robust design the optimization becomes multi-objective. Gradient based optimization of the mean objective and of the standard deviation of the objective therefore requires the gradient of both quantities.

In stochastic applications, the stochastic objective function is usually written as the weighted sum of its statistical moments. A new objective function can be defined as a linear combination of the mean and the standard deviation of the original objective function. A detailed flowchart for the proposed robust optimization model is depicted in Figure 1.

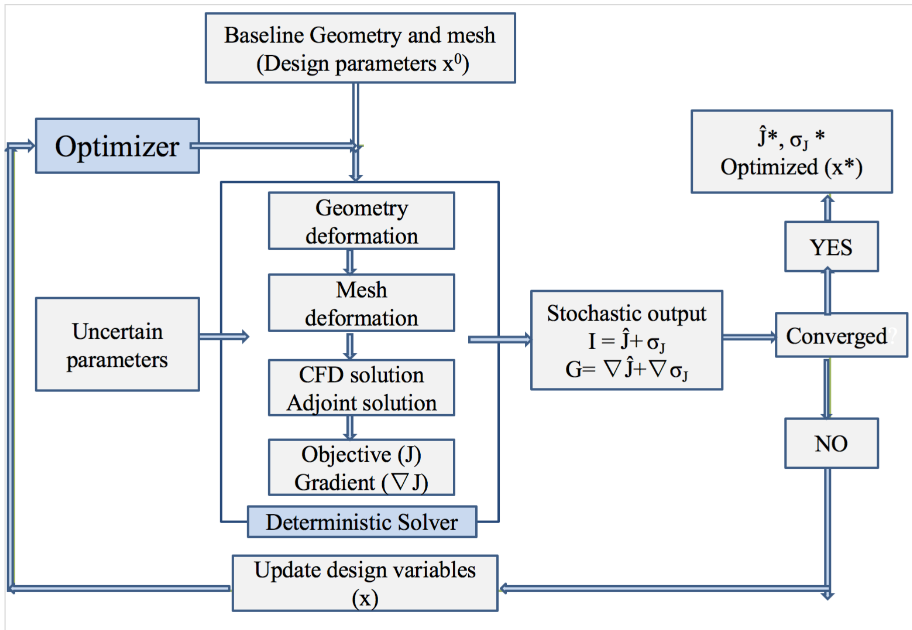

Figure 1: *Flowchart: Robust optimization*

To validate the developed methodology, the robust optimization approach is applied to one of the basic test cases of the UMRIDA project, the RAE2822 airfoil in transonic viscous flow and a 3D wing, the ONERA M6 in Euler flow. For both test cases, the Mach number and the angle of attack are considered as uniformly distributed uncertain parameters.

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