6th European Conference on Computational Mechanics (ECCM 6)
7th European Conference on Computational Fluid Dynamics (ECFD 7)
11-15 June 2018, Glasgow, UK

UNCERTAINTY QUANTIFICATION AND ROBUST DESIGN FOR AERODYNAMIC APPLICATIONS, USING CONTINUOUS ADJOINT METHODS

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Keywords: *Uncertainty Quantification, Robust Design, Method of Moments, Intrusive Polynomial Chaos, Continuous Adjoint Methods*

In CFD-based applications, propagating uncertainties associated with the operating conditions or shape imperfections from the system input to its output, a.k.a. uncertainty quantification (UQ), and optimization under uncertainties (robust design) are at the cutting edge of research. In gradient-based robust design, the computation of the gradient of an objective function which accounts for all uncertainties is required. In this paper, two UQ methods are developed and presented; the first one is based on the Method of Moments (MoM, [1]) whereas the second on the intrusive Polynomial Chaos Expansion (iPCE), both for incompressible fluid flows. Regarding optimization, a combination of the mean value and standard deviation of a quantity of interest (QoI, for instance drag or lift) forms the objective function to be minimized; in this paper, a gradient-based method, supported by the continuous adjoint, is used to minimize it. The adjoint to both UQ methods is presented. The iPCE-based method requires the development and validation of the adjoint to the iPCE PDEs. With the first-order variant of the MoM, the objective function includes the first derivatives of the QoI with respect to (w.r.t.) the uncertain variables which are then differentiated w.r.t. the design variables to minimize it. To avoid costly computations, this paper proposes the computation of projections of the second-order mixed derivatives to vectors, instead of the Hessian matrix itself. A combination of the continuous adjoint and direct differentiation can efficiently compute this projection, leading to an overall cost per optimization cycle that is independent of the number of both the uncertain and the design variables. For the purpose of demonstration, the flow problem around an isolated airfoil is studied with all methods; the validation of the computed derivatives is presented.

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