UNCERTAINTY PROPAGATION IN CFD
USING SURROGATES AND AUTOMATIC DIFFERENTIATION

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ABSTRACT

Computational Fluid Dynamics (CFD) has been an active research topic for the last years and is now applied to industrial problems. Thanks to the improvement of CFD codes in terms of accuracy, robustness and convergence, flow prediction is now used in design optimization procedures. However, everyday life is subject to uncertainty. It is well known that uncertainty can significantly degrade the performance of a system which has been optimized for some precise operational conditions. Therefore, robust design methods that take into account uncertainty are currently developed. These methods require not only an accurate prediction of the objective function, but also an estimate of its uncertainty due to the fluctuation of operational conditions. This paper aims at comparing two approaches to estimate the uncertainty of an aerodynamic objective function (based on lift or drag coefficients) for a practical testcase. We consider the wing of a business aircraft subject to uncertainty of operational conditions (Mach number, angle of attack). Our goal is to estimate the expectation and the variance of the objective function accounting for the Probability Density Function (PDF) of operational conditions. Two approaches are studied :

- The use of surrogates to describe the variation of aerodynamic coefficients due to the fluctuation of operational conditions. These surrogates are interpolating values stored in a database that is supplied using a few CFD simulations for different operational conditions. Then, statistics of the objective function are computed using a Monte-Carlo estimate based on surrogates only.

- The application of the Automatic Differentiation (AD) software Tapenade to the CFD code (3D Eulerian flow solver) to produce a new code that computes first and second derivatives of the aerodynamic coefficients with respect to operational conditions. Then, statistics of the objective function can be easily obtained by integrating its Taylor series expansion with respect to operational conditions.

Next table and figures compare the results obtained: the drag expectation and variance predicted by a Kriging method with 8 training points and a second-order Taylor series expansion around the mean operating conditions are compared with reference values obtained from 21×21 CFD analyses.

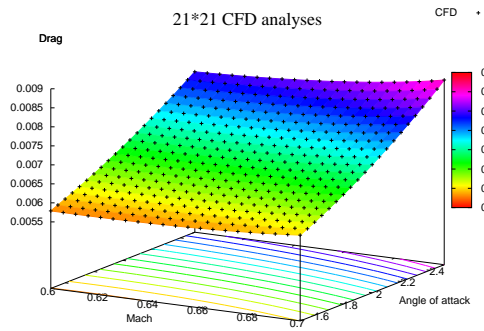|	Reference	Surrogate	Taylor series
Expectation	$6.857 \, 10^{-3}$	$6.852 \, 10^{-3}$	$6.861 \, 10^{-3}$
Variance	$1.553 \, 10^{-7}$	$1.551 \, 10^{-7}$	$1.557 \, 10^{-7}$

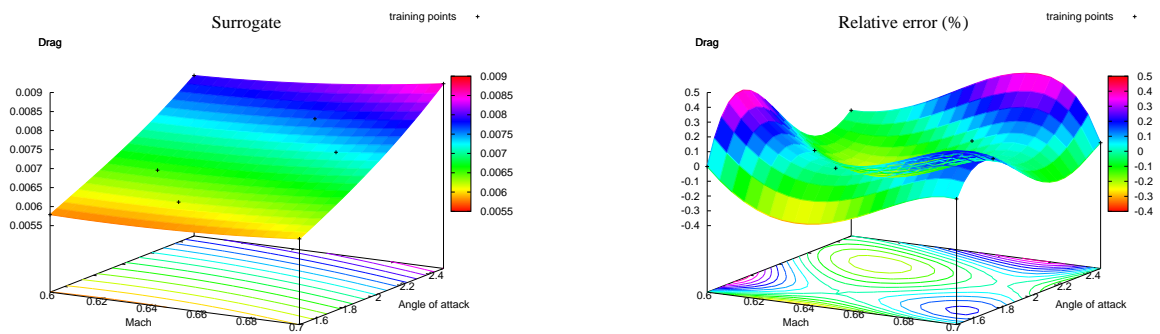Figure 1: Drag predicted by 21×21 CFD analyses.

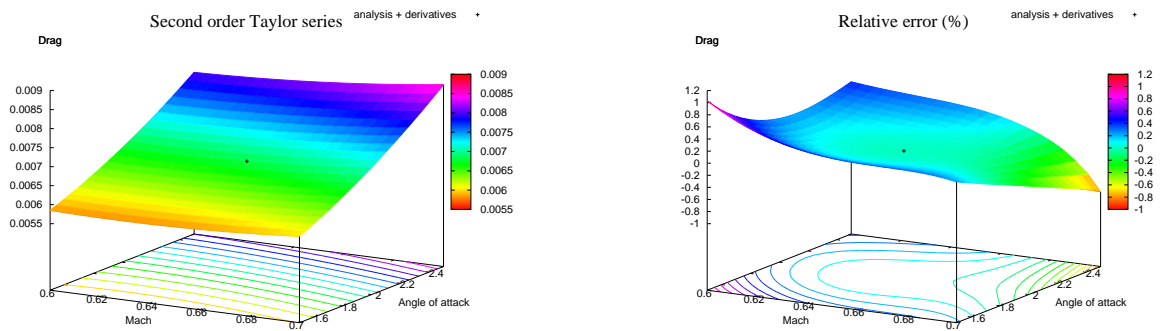Figure 2: Drag predicted by surrogates (Kriging - 8 training points).

Figure 3: Drag predicted by second-order Taylor series expansion around the mean point.