Robust performance assessment for an oscillating airfoil using a Time-Spectral-Method and uncertainty propagation

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Abstract: The power extracted by an oscillating airfoil is analyzed with the fluctuations of the pitching frequency and amplitude taken into account. The computational cost is reduced thanks to an implicit time spectral (TSM) method. Uncertainties are propagated using an original semi-intrusive (SI) method. The TSM / SI strategy is compared, in terms of accuracy and robustness, with a more conventional dual-time-step / polynomial chaos approach.

Keywords: oscillating airfoil, Time-Spectral-Method, uncertainty quantification, robust design

1 Motivation

The energy that may be extracted from an incoming flow by a heaving and pitching airfoil has been numerically quantified by Kinsey and Dumas [1]. These authors performed a parametric study of the airfoil performance using a dual-time-step (DTS) method for describing the unsteady flow evolution in the heaving reference frame and provided the frequency and pitching-amplitude maximizing the amount of power extracted. Though somewhat limited in its scope (single airfoil, laminar-flow conditions) this study gives guidelines for designing actual power-extraction systems. The robustness of the optimal operating point in the pitching frequency/amplitude space should also be taken into account for an actual design. This will be investigated by propagating the design uncertainty through the simulation to yield a mean power and its variance. Two main issues must be addressed : i) the uncertainty propagation (UP) must remain stable and accurate ; ii) the computational cost must be reduced as much as possible.

2 Computational strategy

The cost of time-periodic flows can be significantly reduced by using a Time-Spectral Method (TSM) which converts this flow computation into the solution of $2N + 1$ coupled steady computations with N the number of harmonics retained in the Fourier analysis. While well developed for compressible flows, the TSM approach has only been recently extended to incompressible flows using a finite-volume formulation of the Artificial Compressibility system on general moving unstructured grids [2]. The oscillating airfoil studied by Kinsey and Dumas was computed with a conventional DTS approach describing the whole transient behavior and the implicit TSM approach to prove TSM could afford a substantial cost reduction. A straightforward strategy for UP couples the CFD solver with a non-intrusive Polynomial Chaos (PC) : mean and variance are obtained by series of computations whose outputs are combined with predefined weights (see [3] for a detailed application). This approach is expensive : using a PC of order p with

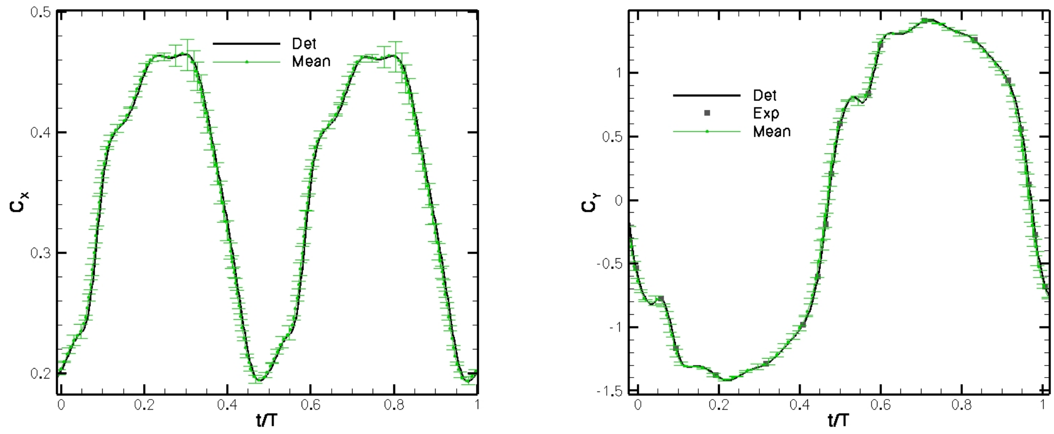

Figure 1: Left: evolution of the deterministic and mean C_x with error bar computed using DTS and PC(2). Right: evolution of the deterministic and mean C_y with error bar and comparison with experiment [1].

M uncertainties, $(p+1)^M$ computations are needed to estimate the mean and variance. As an illustration (see Fig. 1), the laminar flow (Reynolds 1100) over an oscillating NACA0012 airfoil (pitching amplitude 23° and mean frequency 0.12) is computed with a ±3% uniform variation of the frequency around its mean value. Using a 2nd-order PC, 3 deterministic computations are performed to obtain the time-evolution of the force coefficients including the error bars introduced by the frequency fluctuation only. Note PC(2) might not be sufficient to ensure an accurate computation of the statistical moments. As an alternative to PC, a recently proposed [4] semi-intrusive (SI) uncertainty quantification method is investigated. It relies on a finite-volume discretization of the stochastic space and is said semi-intrusive because it requires only minor modifications to the original deterministic solver. The approach has been successfully applied to unsteady 1D shocked flows in [4]; its application to 2D unsteady incompressible flows is truly original. The Conference paper will analyze the robust performance of the oscillating airfoil in power-extracting regime using both DTS and TSM in association with non-intrusive PC and the SI method. The focus will be on the assessment of accuracy and robustness properties when computing the extracted power mean and variance. The selected robust optimum will also be compared with the previous results of Kinsey and Dumas.

References

[1] T. Kinsey, G. Dumas. Parametric Study of an Oscillating Airfoil in a Power-Extraction Regime. *AIAA Journal*, 46:1318-1330, 2008.

[2] S. Antheaume, C. Corre. Implicit Time Spectral Method for Periodic Incompressible Flows. *AIAA Journal*, 49:791-805, 2011.

[3] P. M. Congedo, C. Corre, J.-M. Martinez. Shape optimization of an airfoil in a BZT flow with multiple-source uncertainties. *Comp. Meth. in Appl. Mech. and Eng.*, 200:216-232, 2011.

[4] R. Abgrall, P.M. Congedo, C. Corre, S. Galéra. A simple semi-intrusive method for uncertainty quantification of shocked flows, comparison with a non-intrusive polynomial chaos method *ECCOMAS CFD 2010*, 1-17. 2010.