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Sparse polynomial surrogates for uncertainty quantification in computational fluid dynamics

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SUMMARY

Because of the high complexity of fluid flow solvers, non-intrusive uncertainty quantification techniques have been developed in aerodynamic and aeroelastic simulations in order to compute the output quantities of interest that are required to evaluate the objective function of an optimization process, for example. Polynomial surrogate models based on homogeneous chaos expansions have commonly been considered in this respect. In most applications the polynomial expansion coefficients are evaluated by (possibly sparse) Gauss quadratures. However this approach becomes computationally very demanding for parametric spaces of high dimensions. Observing that the output quantities of interest of complex systems depend only weekly on the multiple cross-interactions between the variable inputs, one may argue that only low-order polynomials significantly contribute to their surrogates [4]. This feature prompts the use of reconstruction techniques benefiting from such a sparse structure, as compressed sensing (or compressive sampling) [1, 2, 3]. We show in this communication that the results obtained with two-dimensional aerodynamic computations and three-dimensional aeroelastic computations involving complex fluid flows corroborate to a large extend this expected trend. Efficient non-adapted polynomial reconstructions using sampling sets orders of magnitude smaller than the ones required by the usual techniques are achieved. The proposed methodology is illustrated on basic and advanced test cases considering moderately to high dimensional parametric spaces.

Keywords: Computational fluid dynamics, aerodynamics, aeroelasticity, polynomial surrogates, polynomial chaos, compressed sensing.

AMS Classification: 76H05, 74F10, 65C20, 65K05.

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