Gradient-enhanced Adaptive Collocation Methods for Uncertainty Analysis in Wind Energy

Large-Scale Uncertainty and Error Analysis for Time-dependent Fluid/Structure Interactions in Wind Turbine Applications

G. Iaccarino, J. Alonso, K. Duraisamy, J. Witteveen, G. Tang
Stanford University
M. Eldred, M. Barone, S. Domino
Sandia National Laboratories
D. Xiu
Purdue University

Abstract

Wind turbine reliability plays a critical role in the long-term prospects for cost-effective wind-based energy generation. The computational assessment of failure probability or life expectancy of turbine components is fundamentally hindered by the presence of large uncertainties in the environmental conditions, the blade structure, and the physical models chosen to simulate the systems. Rigorous quantification of the impact of such uncertainties can fundamentally improve the state-of-the-art in computational predictions and, as a result, aid in the design of more cost-effective devices.

In the initial phase of this effort, we have developed a computational framework constructed around tools developed by the National Renewable Energy Laboratory (NREL). These tools are deterministic: once the wind-turbine configuration and other input conditions are specified, the solution is uniquely determined. On the other hand, uncertainties are always present in the definition of the environment, in the structural blade properties, and in the simplified physical models used to capture the complex interplay of aerodynamics, material behavior, acoustics, etc. As a consequence, the results need to be expressed in a non-deterministic fashion either probabilistically (aleatory uncertainties), as ranges of possible outcomes (epistemic uncertainties), or in mixed form.

We follow two non-intrusive collocation-based approaches in which we perform an ensemble of deterministic analyses using the NREL tools in unmodified form, construct the stochastic solution as a function of the random variables, and then compute the output statistics from this stochastic representation. Both techniques use polynomial bases to reconstruct the outputs; the first one is based on adaptive collocation using structured sparse grids while the second relies on a simplex discretization of the input space using unstructured grids. Both techniques have been extended in this project by including adaptive refinement and gradient-enhanced construction of the polynomial representations. Adaptivity allows one to selectively increase either the spatial resolution (h-refinement) or the polynomial order (p-refinement) in the regions of the stochastic domain having the greatest importance for resolving statistical quantities of interest, thereby increasing the overall efficiency of the techniques and allowing their application to larger, more complex problems. In addition, solution gradients, particularly as computed through adjoint techniques, can be employed to partially mitigate the *curse of dimensionality* by providing a richer data set per collocation evaluation, increasing the scalability of these techniques for high dimensional input spaces.

We have compared the two techniques in a variety of test problems and have initiated applications to the assessment of the effect of uncertainties in wind conditions on the energy extraction of a realistic turbine. We will discuss the details of the implementation of both the adaptive methodology and the gradient-enhancement, with applications to both the NREL framework and simulations based on high-fidelity modeling of both the aerodynamics and the structure.