Global sensitivity analysis of model parameters in aeroelastic wind-turbine codes

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1 Introduction

Aeroelastic models such as the Blade Element Momentum (BEM) method [2] continue to play a critical role in the design, development and optimization of modern wind turbines. The accuracy of BEM predictions is affected by uncertainties and inaccuracies, for e.g., in the external conditions (wind parameters), in the turbine specifications (geometric parameters), and in the BEM equations itself (model parameters). For the purpose of design, uncertainty quantification and optimization, it is crucial to limit the number of parameters, typically by performing sensitivity studies. Most studies focused on the effect of uncertainties in the external conditions and geometry, see e.g. [3, 6].

2 Objectives

The long-term objective of this study is to develop calibrated BEM models that give users an indication of the uncertainty associated with the predictions (loads, power, etc.) originating not only from external conditions and geometry but also from the model formulation itself. For this purpose, we will calibrate the model parameters present in BEM models. Examples of such model parameters are the time constant in dynamic stall models, the wake correction factor, the tip loss model parameter, and the lift- and drag-polars [7]. To limit the number of model parameters involved in the calibration process, *the objective of the current study is to perform a global sensitivity study of the outputs of the BEM model towards both geometric and model uncertainties*.

3 Methodology

To compute parameter sensitivities we use a global sensitivity analysis (GSA) based on the Sobol expansion approach, which decomposes the total variance of the quantity of interest (model output) into contributions from individual parameters and their combinations, similar to [3, 5]. We employ

the uncertainty quantification toolbox `UQLab` [4], which computes the Sobol indices from a sparse polynomial chaos expansion. `UQLab`'s modular structure allows for easy integration with available BEM codes.

The geometric uncertainties currently considered are chord and twist distribution, whereas the model uncertainty enters via uncertainty in lift- and drag-polars. To express the chord, twist, lift and drag distributions along the turbine blade, an efficient parameterization is needed that gives flexible control over the prescribed uncertainty while limiting the number of required parameters. We have chosen to use Non-Uniform Rational Basis Splines (NURBS) for this purpose, similar to [3].

4 Results

The aeroelastic code that we use is the `ECN Aero-Module` [1] and the turbine is the 2MW NM80 turbine (blade radius of 38.8m) from the DANAERO project [8]. The data for airfoil lift- and drag-polars are available at four locations along the blade at 11.87m, 17.82m, 28.97m and 35.53m. The lift variables are numbered from Cl1 - Cl4 and drag from Cd1 - Cd4 along the blade radius. Random samples of chord, twist, lift- and drag-polars are obtained by perturbing the control points with a uniformly distributed random number. Each of the control points for chord (Ch1 - Ch5) and twist (Tw1 - Tw6) are perturbed independently. Thus, by locally perturbing the chord and twist curves, we can identify locations along the blade that are sensitive to turbine response. For a given lift and drag curve, all control points are perturbed (globally) using the same random number. Here, we are interested in knowing at what locations the inaccuracies in polars may lead to the most variations in the turbine output. Random samples for these input parameters are presented in Fig. 1. In Fig. 2, we show the total order Sobol indices as a measure of sensitivity for different geometric and model parameters on the power output. We observe that the model parameters are relatively more sensitive than the geometric parameters. Within geometric parameters, chord distribution shows a significantly higher sensitivity compared to the twist variables.

5 Conclusions

We have shown that Sobol indices computed using sparse polynomial expansion is highly suitable for high-dimensional GSA. In the full paper, we will present a detailed sensitivity assessment that will include more model parameters. The identified sensitive parameters will further be utilized to develop calibrated BEM models.

References

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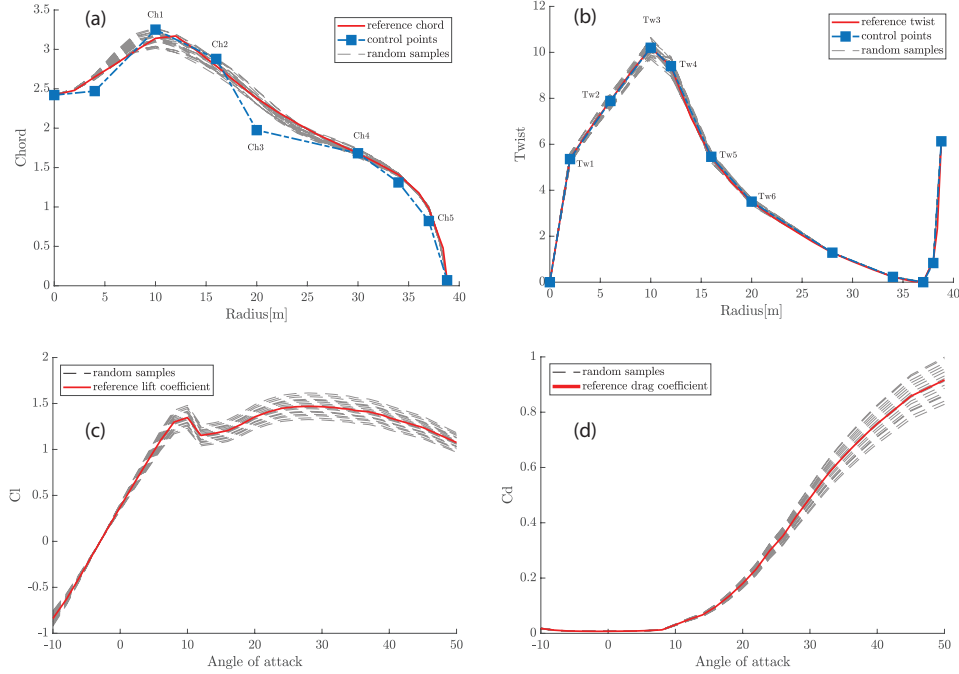
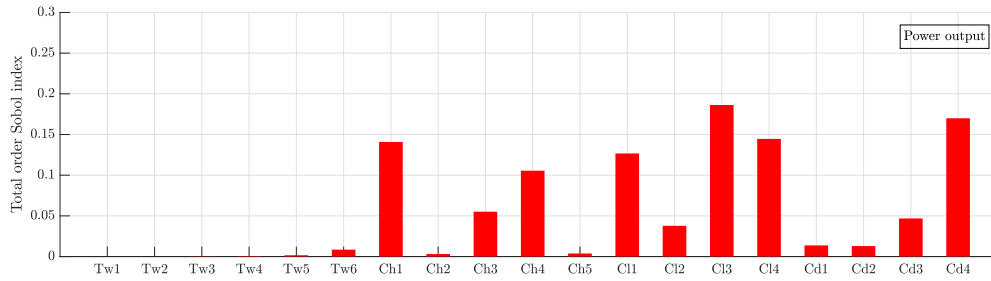Figure 1: Random realization of chord, twist, lift- (Cl2) and drag-polars (Cd2).

Figure 2: Total order Sobol indices for the sensitivity analysis of geometrical and model parameters.

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