

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

P. Kumar<sup>1</sup>, B. Sanderse<sup>1</sup>

<sup>1</sup> Centrum Wiskunde & Informatica, Science Park 123, Amsterdam.

Author contact email: b.sanderse@cwi.nl

Keywords: aero-elastic turbine model, BEM, sensitivity analysis, model uncertainty

## 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 and drag variables at these sections are numbered Cl1 - Cl4 and Cd1 - Cd4 respectively. Uncertainty enters by multiplying the reference lift and drag curves by a random variable (see Fig. 1). The chord and twist are perturbed via a number of control points that define the NURBS representation; we use 5 chord (Ch1 - Ch5) and 6 twist (Tw1 - Tw6) control points and perturb each value randomly following a uniform distribution. Examples of 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 the sensitivity of the different geometric and model parameters on the power output. In this case, we observe the important result that the uncertainty in model parameters is at least as important as the uncertainty in geometric parameters. Furthermore, within the geometric parameters, the chord distribution shows a significantly higher sensitivity compared to the twist variables.

## 5 Conclusions

We have shown how Sobol indices computed using sparse adaptive polynomial expansion can be used for high-dimensional global sensitivity analysis of both geometric and model uncertainties. In the full paper, we will extend the sensitivity assessment to include more model uncertainties, such as parameters in dynamic stall and tip loss models. The identified sensitive model parameters will be utilized in future work to develop calibrated BEM models with built-in uncertainty estimates as part of the *WindTrue* project, and is connected to IEA Task 29.

## References

- [1] K. Boorsma, F. Grasso, and J.G. Holierhoek. Enhanced approach for simulation of rotor aerodynamic loads. Technical Report ECN-M-12-003, 2012.
- [2] Tony Burton, Nick Jenkins, David Sharpe, and Ervin Bossanyi. *Wind Energy Handbook, Second Edition*. John Wiley & Sons, 2001.
- [3] Fernando Echeverría, Fermín Mallor, and Unai San Miguel. Global sensitivity analysis of the blade geometry variables on the wind turbine performance. *Wind Energy*, 20(9):1601–1616, sep 2017.

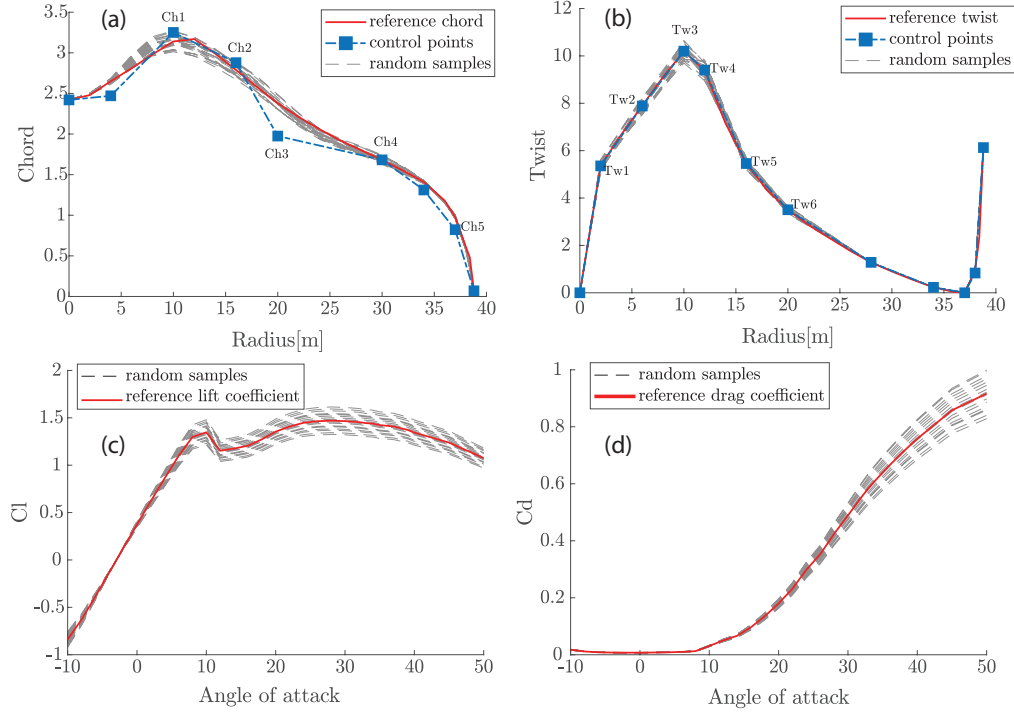


Figure 1: Random realization of chord, twist, lift- ( $Cl_2$ ) and drag-polars ( $Cd_2$ ).

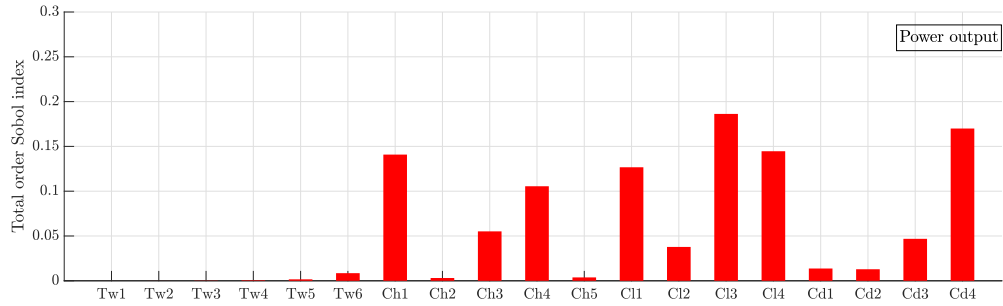


Figure 2: Sensitivity of power output towards geometric and model parameters, expressed by Sobol indices.

- [4] Stefano Marelli and Bruno Sudret. *UQLab: A Framework for Uncertainty Quantification in Matlab*, pages 2554–2563.
- [5] Jennifer M. Rinker. Calculating the sensitivity of wind turbine loads to wind inputs using response surfaces. *Journal of Physics: Conference Series*, 753:032057, 2016.
- [6] Amy Robertson, Latha Sethuraman, and Jason M. Jonkman. *Assessment of Wind Parameter Sensitivity on Extreme and Fatigue Wind Turbine Loads*.
- [7] M. Sayed, L. Klein, Th Lutz, and E. Krämer. The impact of the aerodynamic model fidelity on the aeroelastic response of a multi-megawatt wind turbine. *Ren. Energy*, 140:304–318, 2019.
- [8] N. Trolborg, C. Bak, H. Aagaard Madsen, and W.R. Skrzypinski. Danaero mw: Final report. Technical Report DTU Wind Energy E-0027, 2013.