PO.103

Wake parametrization and surrogate modelling for loads prediction

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Abstract

In a wind farm, the wind velocity field hitting a rotor has some specificities. Indeed, when a wind turbine (WT) is located inside a warm, it experiences a modified wind field compared to the ambient one. Typically, inside a wake, the wind exhibits a reduced mean velocity and an increased turbulence intensity.

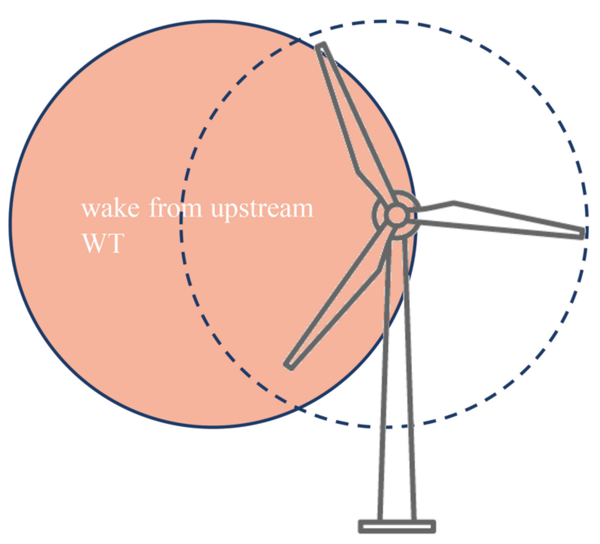
The current design approach for wake induced load analysis just consists in using a kind of equivalent turbulence intensity that would cause the same damage as the wake induced wind field [1]. But this simplified approach does not account for the specific shape of the wake velocity field and may lead to inappropriate (conservative or under-conservative) load predictions especially for rotors operating in partial-wake conditions.

Objectives

The objective of the approach presented here is to elaborate an efficient turbine specific wake induced wind field parameterization and to achieve surrogate modelling for load predictions (extreme and fatigue load prediction). The overall goal is to build a general computational framework that could be used in an arbitrary wind farm layout and should tackle the impact of:

✓added turbulence and

✓velocity deficit shape.



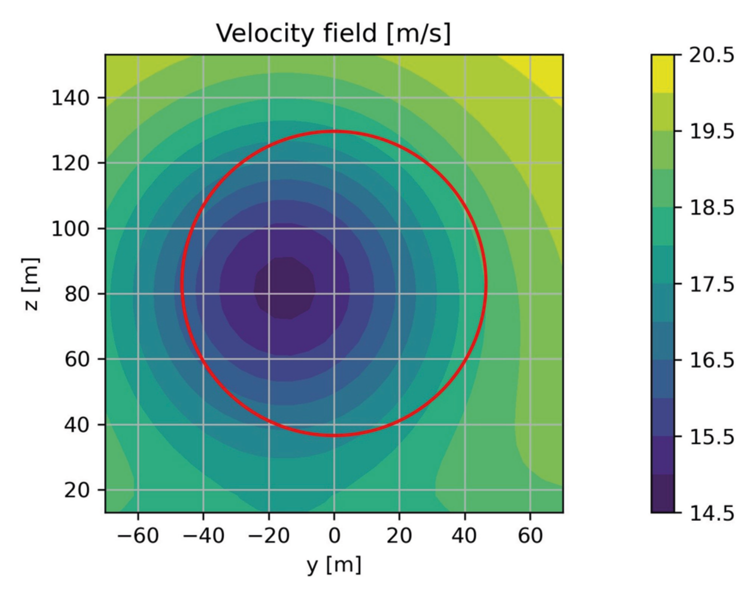
Partial wake condition: the blade experience here an additional load variation due to the partial wake overlapping. This phenomenon is not explicitly taken into account in current design standards

Methods

The wind farm parametrization proposed here considers a "mean wind speed profile-oriented parametrization". Let's define a turbulent wind field that is "free" of WT influences, by a 10 min average speed u_0 at hub height $\hat{z}$ and a vertical shear coefficient α following the standard power law profile. The spatial distribution of wake modified time average wind speed, obtained by means of e.g. static wake simulations with a model like FarmShadow™ of IFPEN [3], is assumed to be of greatest influence on WT loads than other wake modified parameters like turbulence. A suitable parameterization is then chosen to represent the yz vertical plane distribution at the WT location, with a model function inspired from the shape of the wake in static models:

$$\varphi(y,z) = u_0 \left(\frac{z}{\hat{z}}\right)^{\alpha} \left(1 - \sum_{i=1}^{N} a_i e^{-\frac{1}{\sigma_i^2}\left[(y-\hat{y}_i)^2+(z-\hat{z})^2\right]}\right)$$

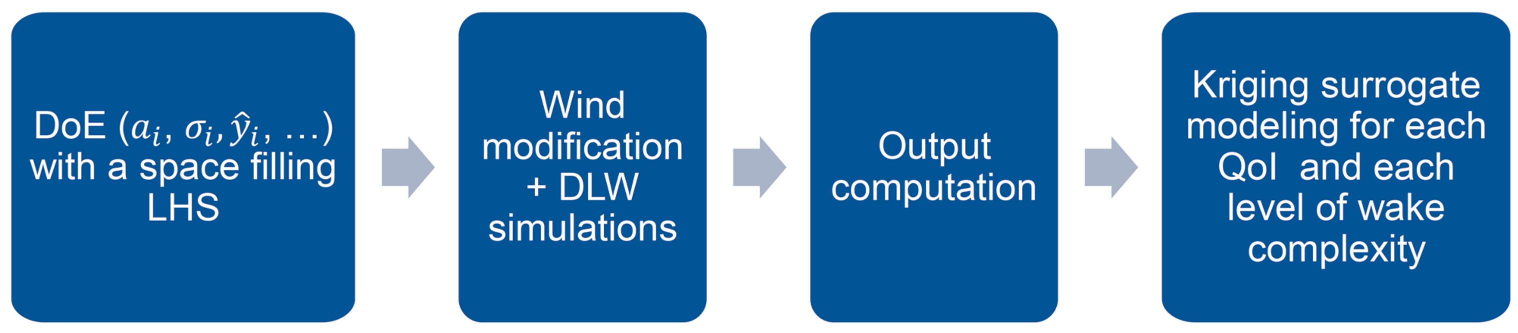
Where a_i is the amplitude of the i^th wake, $\hat{y}_i$ is the y-coordinate of the i^th wake center, σ_i is the characteristic wake width of the i^th Gaussian and N the total number of Gaussians.



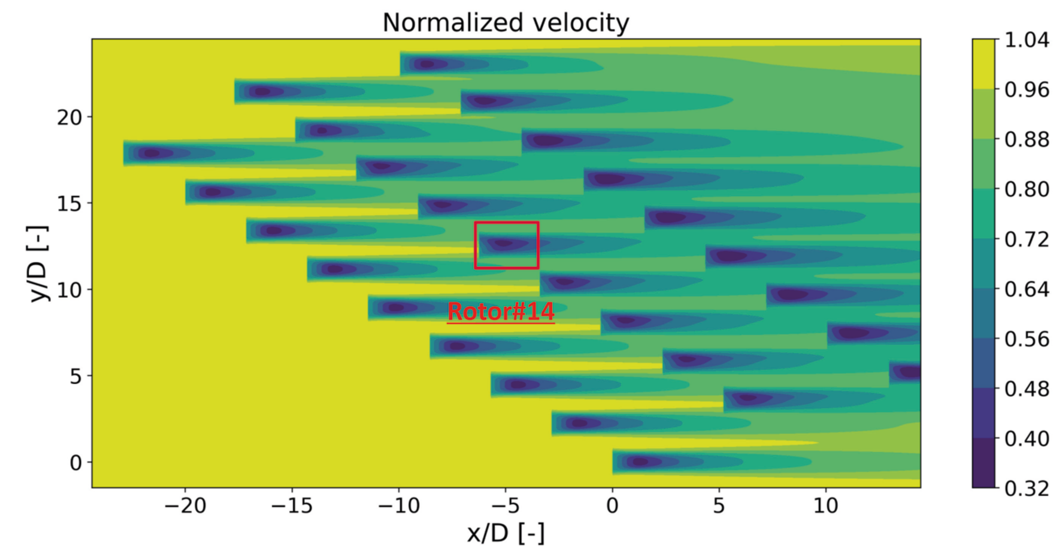
An example of a mean longitudinal wind velocity profile hitting a rotor (the red circle represents the border of the rotor)

Here the objective is to build a surrogate model that would provide the mapping between both the ambient condition parameters u_0, α and the wake induced parameters (a_i, σ_i, $\hat{y}_i$and Iu, the turbulence intensity averaged on the rotor) on one side and the loads (fatigue load or extreme load) on the other side. Aero-servo-hydro-elastic simulations are performed by means of Deeplines WindTM (DLW), a software for offshore WT simulations [2].

Surrogate model building process

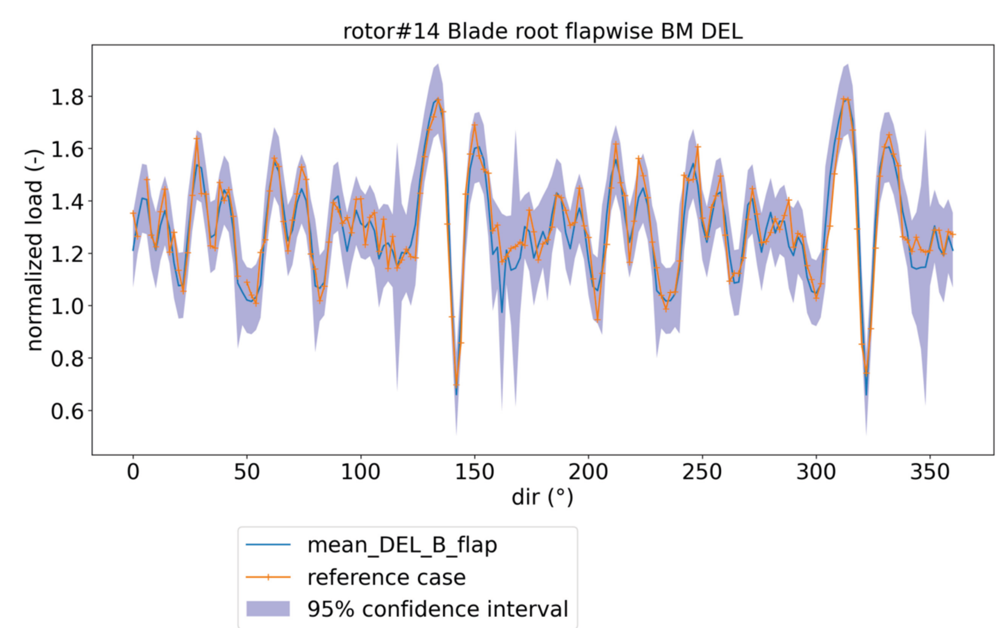


Study case: a 2.3MW fixed offshore WT of EDF Teesside wind farm (UK)



Hub-height normalized velocity at Teesside EDF wind farm for a wind coming from west.

The velocity is normalized with respect to the free stream velocity at hub height and D is the rotor diameter



Blade root flapwise bending moment Damage Equivalent Load (DEL) kriging prediction vs DLW reference simulations, wrt. to wind direction (W = 0°, S=90°, E=180° and N=270°)

Conclusions

✓The parametrization approach proposed here offers a farm independent parametrization that is based on the shape of the wake velocity deficit only.

✓The association of this parametrization with a kriging based surrogate modeling has permitted to build fatigue and extreme loads mapping. In particular, the surrogate model is able to reproduce some typical load variations when the wake interacts with the wind turbine

✓A Global Sensitivity Analysis (GSA) has been performed for the Teesside wind farm case: the free stream mean wind speed at hub height u_0, the rotor averaged turbulence intensity and the wake location parameter are the most important factors

✓In the context of Hiperwind project, an alternative wake parametrization approach is presented by our partner DTU on poster PO051

References

1. IEC, « IEC 61400-1:2019 - Wind energy generation systems - Part 1: Design requirements ». 2019.
2. PRINCIPIA, « DEEPLINES WINDTM ». https://www.principia-group.com/blog/product/deeplines-wind/
3. F. Blondel et M. Cathelain, « An alternative form of the super-Gaussian wind turbine wake model », Wind Energy Sci., vol. 5, no 3, p. 1225-1236, sept. 2020, doi: 10.5194/wes-5-1225-2020.

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