Experimental study on the effect of intermittent inflow on properties in the wind turbine wake

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Abstract
We present an experimental study on the influence of different turbulent flows on the wake of a wind turbine. Three different inflows with varying turbulence intensity and intermittency have been created in a wind tunnel, and a model wind turbine was placed in the flow. Hot-wire measurements were carried out downstream the turbine and the data were analyzed using two-point statistics. The results suggest that a unique, inflow-independent turbulence is created by the turbine in the wake. These results can simplify wake modeling and help to more precisely design turbines according to ambient turbulence.

Keywords: *wake modeling, turbulence, wind farms, wind tunnel experiments*

Experimental Scale

Introduction

Normally, wind turbines are assembled in wind farms. Thus, knowledge of the wakes of the upstream turbines is important to correctly predict the loads, bending moments and power generation of the downstream wind turbines. Characteristically, the velocity in the wake is reduced while the turbulence intensity $TI = \sigma/\bar{v}$ is increased [1]. Thus, typical wake models include the mean velocity $\bar{v}$, standard deviation σ and a simplified turbulence model. These quantities represent only one point statistics that do not reflect an important property of the atmospheric flow: the intermittency, i.e. gustiness of the flow [3]. This quantity was related by Tavner et al. to the lifetime of certain WEC components [2] and should therefore be considered in wake models.

Theory & Setup

To identify intermittency in a flow, we perform a two-point statistical analysis [3]. Given the velocities at two times t and $t+\tau$, the velocity increment at a time scale τ is defined as $\delta v(\tau) = v(t+\tau) - v(t)$. The probability density function (PDF) $p(\delta v(\tau)/\sigma_\tau)$ of these velocity increments, normalized to the standard deviation of the velocity increment time series, σ_τ, is Gaussian distributed in case of non-intermittent flow but will resemble a heavy-tailed distribution in case of intermittent flow.

In this wind tunnel study, we explore the influence of different turbulent inflows on the development and the intermittency in the wind turbine wake. All experiments have been carried out in an open-jet wind tunnel at the University of Oldenburg. A load-controlled model wind turbine (cf. [4]) with diameter D = 58 *cm* was centred in the flow and hot-wire measurements were carried out downstream the centre line of the rotor up to 4.5D. The inflow conditions were varied as follows: the open wind tunnel was used to create inflow with a low turbulence and high intermittency ($\bar{v} = 7.26\ m/s, TI = 0.9\%$), a regular grid created medium turbulent flow and Gaussian turbulence ($\bar{v} = 7.63\ m/s, TI = 5.3\%$) and an active grid (cf. [5]) was used to create turbulent intermittent inflow ($\bar{v} = 8.01\ m/s, TI = 11.8\%$). A characterization of the intermittency on rotor-related time scales τ inflow can be seen in figure 1.

Results

Figure 2 shows the increment PDFs in the wake on rotor-related time scales τ for the different inflow conditions. Despite the clearly differing inflow situations, the increment PDFs on the respective scales collapse and are Gaussian for scales corresponding to the rotor diameter at 2.97D distance from the model wind turbine. Compared to the regular grid-created inflow, the wake has a higher intermittency on small scales whereas the wake in case of the highly intermittent laminar inflow shows a weaker intermittency. Figure 3 shows a comparison of the power spectra of the inflow velocity measured at rotor plane with the corresponding spectra in the wake at 2.97D distance. The spectra in the wake reveal a clear difference to the spectra of the inflow conditions. Also, the spectra in the wake collapse and follow a -5/3 decay for approximately 4 orders of magnitude.

Discussion & Conclusion

These results lead to the conclusion that the turbine creates a unique turbulence in the centre region of the wake that is independent on the inflow conditions and the inflow intermittency. In case of intermittent inflow, this intermittency is reduced by the wind turbine. The decay of the power spectra according to a -5/3 law indicates the existence of homogeneous isotropic turbulence in this region. A consequence of these results can be a simplification of turbulence models in the wind turbine wake. Also, the number of extreme events for downstream turbines is reduced as the reduction of intermittency compared to the inflow intermittency indicates.

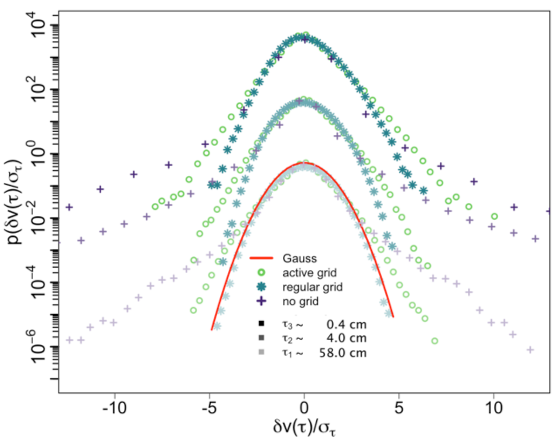

Figure 1 *Increment PDFs for the different inflow condition measured at rotor plane – the time scales correspond to rotor-related scales (τ_1~D, τ_2~chord length, τ_3~chord thickness); the PDFs are shifted vertically for clarification*

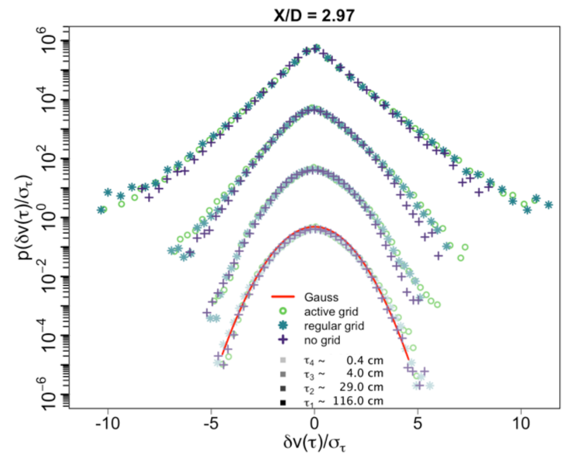

Figure 2 *comparison of increment PDFs in the wake for different inflow conditions at 2.97D distance plane – the time scales correspond to rotor-related scales (τ_1~2D, τ_2~D/2, τ_3~chord length, τ_4~chord thickness); the PDFs are shifted vertically for clarification*

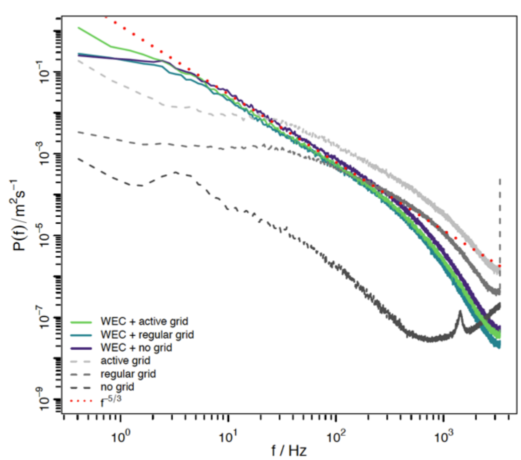

Figure 3 *Comparison of the power spectra of the different inflow conditions measured at rotor plane (grey) with the power spectra at 2.97D distance in the wake for the respective inflows*

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