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Comparing on- and off-shore aerodynamic turbulence by measurement

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Abstract

In order to examine the turbulence structure of onshore/ offshore wind fields high frequency aerodynamic turbulence is measured by piezo electric transducer at different test sites. A further objective is the analysis of the resulting influence of the turbulence level on the transition of laminar to turbulent flows followed by blade profile optimization. The onshore measurements show that reasonable results can be achieved and that time-averaged parameters are comparable to those of cup anemometers. The offshore measurements will be realized at FINO3, a scientific measurement platform, and will start this autumn. The measurement is accompanied by CFD calculations of two-dimensional blade profiles.

Objectives

- Measurement on-shore at test-site Kaiser Wilhelm Koog, Germany
- Measurement offshore at FINO3, which is located 80 km west of the island of Sylt (see figure1), beginning this autumn
- Measurement of the high frequency fluctuations of the wind velocity with a robust piezo-electric pressure sensor, which was tested against hot–wire in a wind tunnel
- Utilisation of results for transition calculation with FLOWer-code (DLR) and blade (profile) optimization

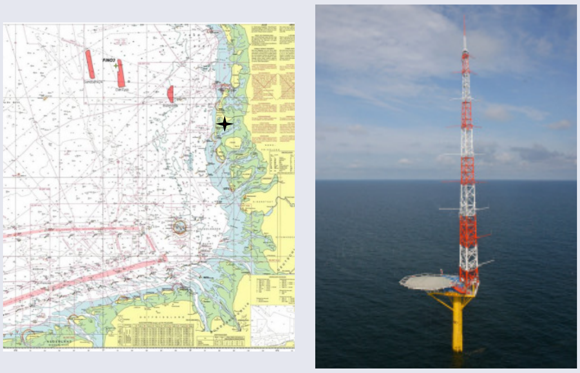

Figure 1: Location and outline of the offshore measurement platform FINO3

Methods

Measurement

High frequency (> 10 Hz) turbulence measurements are very rare. The onshore measurements were conducted using a piezo-electric sensor with a 50 kHz resolution and a range of 100 seconds. The sensor is able to determine high frequent pressure fluctuations which are caused by velocity fluctuations. The piezo-sensor is mounted at a pylon about 60 m above ground level onshore and 80 m above sea-level offshore. The onshore measurement was realized for different averaged wind velocities: 6, 12 and 16 m/s and for different wind directions: from seaside/ from landside.

Simulation

In order to predict the point of transition at a blade profile an e^N-method is used. It is assumed that the transition is caused by perturbations of the inflow, the so called Tollmien-Schlichting waves. N describes the critical perturbation amplitude which characterises the transition from laminar to turbulent flow. N is dependent of the turbulence level and can be directly estimated using Mack's correlation, which was developed for the flow conditions in wind tunnel tests. The research code FLOWer, developed by DLR, combines the solution of the Reynold's averaged Navier-Stokes equations with a simplified e^N-method for two-dimensional, incompressible boundary layers [2].

Results

Onshore measurement

The measured data is evaluated by frequency analysis. The obtained power spectral density is shown in figure 2. There is no significant difference for spectra of the land or seaside. The decrease of the energy spectrum follows a potential law. Kolmogorov and Obukov [1] proposed different potential factors -3.3 resp. -2.3 for the decrease and their results are also presented in figure. 2. Our prediction, which is obtained by averaging several measurement results, is -2.8 for landside and -2.5 for seaside.

Furthermore it was found, that the piezoelectric-sensor is able to resolve fluctuations up to 3 kHz. Time averaged parameters like turbulence level and standard deviation are comparable to those of cup-anemometers.

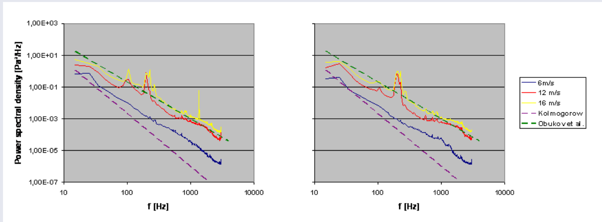

Figure 2: Power spectral density for averaged wind velocities 6, 12, 16 m/s from landside (left) and seaside (right)

Further Investigation

For further investigation a new sensor, a LCA (Laser Cantilever Anemometer) will be added to the equipment. This sensor was developed by the Hydrodynamic Group of the Carl von Ossietzky University of Oldenburg and can resolve fluctuation of higher frequencies than the piezo-sensor. Figure 3 gives an impression of the layout of the LAC. The microscopic cantilever bends when exposed to a flow. The cantilever displacement is detected by a laser beam [3]. After calibration the velocity can be directly calculated.

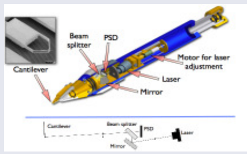

Figure 3: Layout of the LCA (University of Oldenburg)

Simulation

The results of the stability analysis for an E 206 blade profile, a Reynold's number of $2{,}9{\cdot}10^7$ and an angle of attack of zero degree is shown in figure 4. The N-factor is calculated as a function of the dimensionless chord length for perturbations of different frequencies. After the definition of an envelope the point of transition can be estimated for a given N-factor. For example the transition occurs at 0.38 x/t for N=6. For this profile only high frequent perturbations (> 7000 Hz) induce transition for ordinary used N-factors in the range between 5 and 9. The energy spectra in figure 2 show however that perturbations with frequencies higher than 5000 Hz appear rarely. It is unlikely, that transition occurs under the chosen conditions.

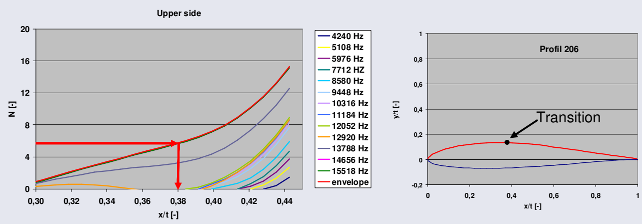

Figure 4: N-Factor as function of the dimensionless chord length for perturbations of different frequencies (left), estimated point of transition for N=6 (right)

Conclusions

An experimental set-up to measure high-frequency wind-speed fluctuations was defined, installed and verified. The chosen piezo-electric sensor is able to resolve fluctuations up to 3 kHz and shows reasonable results. In order to determine fluctuation higher than 3 kHz a laser cantilever anemometer will be installed. The analysis of the experimental findings is supported by the stability investigation which can identify the relevant frequencies for transition.

References

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3. On a high-resolving LCA Laser Cantilever Anemometer, *Advances in Turbulences IX, Proceedings of the Ninth European Turbulence Conference*