DOI: 10.61782/fa.2023.0618

VALIDATION OF A WIND TURBINE NOISE PROPAGATION MODEL AGAINST FIELD MEASUREMENTS

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ABSTRACT

Predicting the noise radiated by a wind farm needs to take into account many parameters such as wind turbine operational conditions, wind and temperature profiles, atmospheric turbulence, ground impedance and topography. In this study, we aim at validating a wind turbine noise prediction model that combines Amiet's theory to calculate trailing edge noise and turbulence interaction noise with a wide-angle parabolic equation valid in moving media to account for long range acoustic propagation effects. The model considers the wind turbine as an extended and rotating noise source. The model predictions are compared to field measurements recorded during ten days around an eight-turbine single row wind farm. As the terrain is flat and the roughness is relatively homogeneous, the meteorological lidar and a mast data are supposed to be range-independent. Using representative values for the ground parameters, the model gives the correct interference patterns in the third octave band spectrum. Accurate predictions of the third octave band spectra averaged over 10 minutes are obtained for propagation distances up to 1300 meters, although the influence of background noise becomes more significant as the distance increases.

Keywords: *parabolic equation, aeroacoustics, atmospheric turbulence, wind shear*

1. INTRODUCTION

The prediction of wind farm noise at a long-range observation point requires an aerodynamic noise source model and an outdoor sound propagation model. While various aeroacoustic models have been successfully validated against field measurements [1–3], studies aiming at validating both source and propagation models are scarce [4]. This is indeed a difficult task, as wind farm noise depends on a large number of parameters, related to atmospheric conditions, ground impedance and topography, and operating conditions. The goal of this study is to compare predictions obtained by a comprehensive wind turbine noise model developed in recent years [5–7] to a large database of field measurements performed in 2020 in the framework of the PIBE project (Predicting the noise impact of wind turbines, `https://www.anr-pibe.com/en`) [8,9].

2. EXPERIMENTAL CAMPAIGN

The PIBE measurement campaign was carried out in a wind farm composed of eight wind turbines of 3 MW nominal power, with a rotor diameter of 90 m and a hub height of 80 m. The wind turbines are positioned almost linearly at an angle of around 60° with respect to North, and are named WT1 to WT8 from right to left, as shown in Figure 1. As the terrain is flat and the roughness is relatively homogeneous, the meteorological lidar and mast data recorded close to WT6 are supposed to be range-independent.

Five sound level meters, labeled "Long duration points" in Figure 1, recorded data for a period of 410 days

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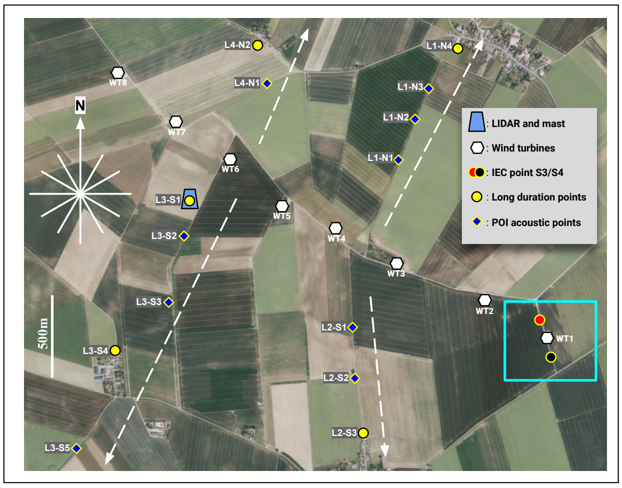

Figure 1. Site map of the studied wind farm.

between February 2020 and April 2021. They were placed at a height of 1.5 m, except L4-N2 that was placed at a height of 2.6m. Nine additional sound level meters, labeled "POI acoustic points" in Figure 1, recorded data during a period of intensive observation for 10 days from 23 June 2020 to 02 July 2020. Finally, two sound level meters were placed close to WT1 on the ground level at the IEC position. They are in the highlighted section of Figure 1, and were used by Mascararenhas *et coll.* to validate a wind turbine noise source model [10].

For the comparison with model predictions in Section 4, both meteorological and acoustic data are averaged over 10-minute periods. In the following, we assume that the wind velocity profile $U(z)$ follows a power law:

$$U(z) = U_{ref} \left(\frac{z}{z_{ref}} \right)^{m}, \tag{1}$$

with U_{ref} the reference wind speed obtained from the LIDAR data at a height $z_{ref} = 85\,\mathrm{m}$, and m the wind shear coefficient estimated from the LIDAR data between heights of 40 m and 130 m.

3. WIND TURBINE NOISE MODEL

In order to correctly account for ground interference effects, and to predict the right distance to the shadow zone in upwind conditions, an extended source model needs to be used [6]. To this end, we divide each wind turbine blade into M segments, and calculate the sound pressure level $L_p(f, \beta)$ of each segment at frequency f and angular position β using the point source approximation [6]:

$$\begin{aligned} L_p(f, \beta) = L_W(f, \beta) - 10 \log_{10}(4\pi R(\beta)^2) \\ + \Delta L(f, \beta) - \alpha(f) R(\beta), \end{aligned} \tag{2}$$

where $L_W(f, \beta)$ is the sound power level, $\Delta L(f, \beta)$ is the sound pressure level relative to free field, $\alpha(f)$ is the absorption coefficient in dB/m and $R(\beta)$ is the source-receiver distance.

The sound power level $L_W(f, \beta)$ is calculated using Amiet's theory for trailing edge noise and turbulence interaction noise, including the rotation effects. The model is detailed in Ref. [5], with some recent modifications given in Ref. [7]. The main input parameters for the trailing edge noise model are the boundary layer parameters that are calculated with Xfoil at 99% of the chord. The main input parameter for the turbulence interaction noise model is the turbulence dissipation rate ϵ, that is estimated from 3D ultrasonic anemometer data acquired at a height of 80 m on the meteorological mast.

The refraction and ground reflection effects are calculated using a wide-angle parabolic equation model valid in moving media [11]. Using this model, wind speed gradients can be directly included without using the effective sound speed approximation, although this approximation has been shown to produce small phase errors in the context of wind turbine noise [12]. The ground impedance is estimated using the Miki model with an effective flow resistivity $\sigma = 150\,\mathrm{kNs/m^4}$ and an effective thickness $e = 4\,\mathrm{cm}$.

4. RESULTS

Two validation cases are presented in this section, that are described in Table 1. These two cases correspond to periods with relatively constant atmospheric conditions. The downwind period has a duration of of two hours, which corresponds to 12 samples of 10 minutes, while the upwind period has a duration of of one hour, which corresponds to 6 samples of 10 minutes.

The comparison between predicted and measured third-octave band spectra are shown in Figure 2 for the downwind case and Figure 3 for the upwind case, using three acoustic points along line 1. The point L1-N2 is at 738 m from the closest wind turbine (WT4), while L1-N3 is at 1021 m and L1-N4 is at 1318 m. The contributions for all eight wind turbines are included in the predictions, as considering only the closest wind turbines degrade the agreement between model predictions and measurements.

Table 1. Mean parameters used for the selected downwind and upwind cases .

Case	Wind speed (m/s)	Wind shear m	Wind direction (degrees)
Downwind	8	0.34	-131
Upwind	7	0.30	73

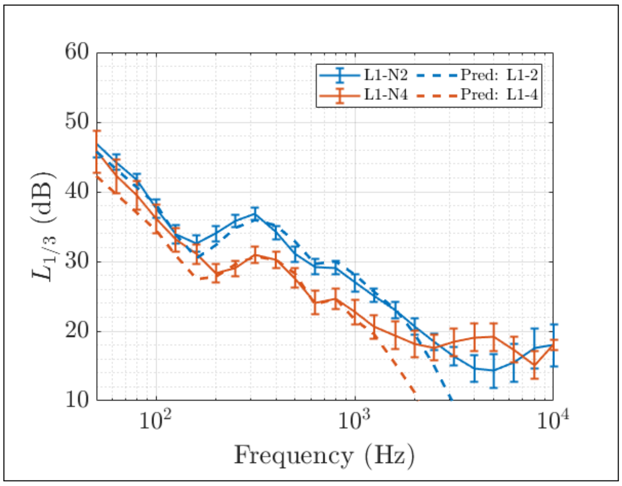

Figure 2. Third-octave band spectra of the measured (solid lines) and predicted (dashed lines) sound pressure levels for the downwind case described in Table 1.

The agreement between predicted and measured spectra is relatively good up to 2 kHz approximately. Above this value we suspect that background noise dominates, as the standard deviation increases significantly and the predicted levels are extremely low. The model predictions tend to underestimate the measured sound pressure levels for the point L1-N4, located more than 1.3 km from the closest wind turbines, especially below 200 Hz downwind and above 400 Hz (differences of approximately 2 dB). This can be due to the effect of background noise, as the standard deviations are relatively high on these frequency bands. Also, it can be seen that the interference patterns due to the ground effect are well captured for both downwind and upwind cases, which validates *a posteriori* the choice of the ground parameters in the Miki model.

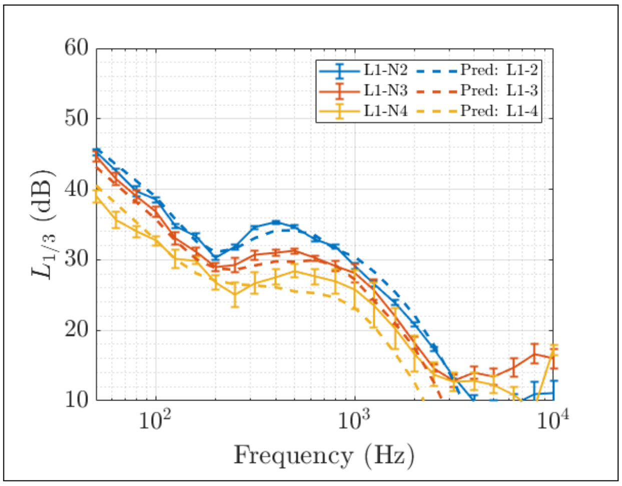

Figure 3. Third-octave band spectra of the measured (solid lines) and predicted (dashed lines) sound pressure levels for the upwind case described in Table 1.

5. CONCLUSION

In this paper, we have shown that accurate predictions of the third octave band spectra averaged over 10 minutes can be obtained up to a distance of 1.3 kilometer, both in downwind and upwind conditions. Other configurations will be investigated and presented during the conference.

6. ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 812719, and from the French National Agency for Research within the convention ANR-18-CE04-0011.

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