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Measuring infrasound from wind turbines: the benefits of a wind-shielding dome

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Summary

Measuring infrasound from wind turbines is a challenging task. A device for the signal-to-noise ratio improvement of wind turbine emitted acoustic pressure at low and infrasound frequencies has been designed and tested. The semi-spherical shape chosen aimed at maximizing the pressure averaging of large atmospheric turbulent eddies. In addition, the wind shielding dome should still be reasonably compact for easy handling. A computational fluid dynamic study was conducted with Fluent to find the optimal porosity of the windbreak textile used to constitute the outer surface of the dome. For a range of different inflow conditions, the most suited porosity was found to be 40% when minimizing the inside dome wind speed and related turbulence parameters. The dome fence's acoustic absorption in absence of flow was tested in a semi-anechoic chamber. The maximum absorption observed in the lower part of the test signal's spectrum was less than 0.1 dB, making the dome almost fully transparent for the frequency range of main concern. The dome was also tested outdoors with a free and a dome-covered low-frequency microphone. The test was performed under different wind speeds, measured turbulence intensities and wind directions. Reductions of wind-induced noise of 12 dB were observed for frequencies down to 0.1 Hz, while maximum reductions of more than 14 dB were measured for frequencies around 1 Hz. It can thus be concluded that the wind shielding dome is able to strongly improve the infrasound signal-to-noise ratio, opening possibilities to more accurately measure the infrasonic emissions from wind turbines.

1. Introduction

The need for renewable sources of energy is resulting in an increment in the construction of wind farms. While wind turbines have a good reputation as efficient devices for the generation of green energy, their noise emissions are often reported as the main negative impact on the environment. Health problems related to long-term noise exposure and the potentially long distances infrasound can propagate in the atmosphere are reasons for concern.

The scientific community agrees that the effect of wind turbine infrasound on human health is currently unclear. Infrasound exposure from wind turbines is typically lower than the threshold of hearing (van Kamp & van den Berg, 2018), while intrinsic human body pressure variations could create infrasound signals in the inner ear that are larger. Psychological factors are thought to have prominence on the genesis of annoyance and health disorders (Leventhal, 2013). On the other hand, physiological studies on the sensitivity of the human ear have revealed that although infrasound is not able to generate a hearing sensation, it could still produce neuronal signals whose impacts are unknown (Salt & Huller, 2010). Furthermore, the studies on prolonged exposure to low intensity infrasound are still sparse (Baliatsas, et al., 2016).

Characterizing wind turbines' infrasound also presents difficulties. Infrasound emissions from wind power generators occur simultaneously with other environmental noise sources. In particular, wind-induced noise will mask wind turbine infrasound. The large turbulent eddies convected by the wind produce pressure fluctuations at these very low frequencies. Fully discriminating between the two sources is often not possible. The standard methodology applied in relation to wind turbine measurements is insufficient to produce a good signal-to-noise ratio in the infrasonic frequency range. Large wind fences have been proposed for military applications still showing limited SPL reductions at the frequency range of interest. In addition, the dimensions of such devices make them impractical for day-to-day operation.

A large porous structure can reduce the mean wind speed and will affect the turbulence structures present in the flow. Studies from spherical wind screens suggest that they act as pressure-averaging devices providing pressure fluctuation reductions for turbulence eddies larger than their characteristic length (Hedlin & Raspet, 2003). A wind fence designed using this principle could therefore be a good candidate for efficient wind infrasound mitigation.

2. Methodology

2.1 Dome design

The optimal shape of the dome fence was based on designs applying the principle of spherical wind screens to reduce wind-induced noise in the infrasound range starting from frequencies of approximately 0.1 Hz. A retaining structure of 220 cm height and with a 360 cm base diameter was used.

The optimal porosity of the screening textile was found based on a CFD study with Ansys Fluent 17.1. The dome was discretized in a 2D domain as a surface area-equivalent hemisphere of 2 m radius and simulated under inflow wind conditions of 5 m/s and 10 m/s at 10 m height. The k-ε model was used. Pressure jump coefficients for different porosities were derived from actual measured values of this type of windscreens (Dierickx, 1998).

Reductions of the flow parameters with respect to the free field at the centre of the wind-shielding dome were compared for different porosities and flow conditions. More precisely, mean wind speed and turbulence intensities were investigated resulting in an overall optimal porosity of 40%. The textile was manufactured on demand. The wind-shielding dome was first tested in a semi-anechoic room to assess its acoustic absorption. The dome was shown to be fully acoustically transparent.

2.2 Field test

The dome's wind-shielding efficiency was tested in an open field. Simultaneous measurements were performed with a microphone inside the dome and compared to an uncovered microphone at close distance. Both microphones used a standard spherical windscreen.

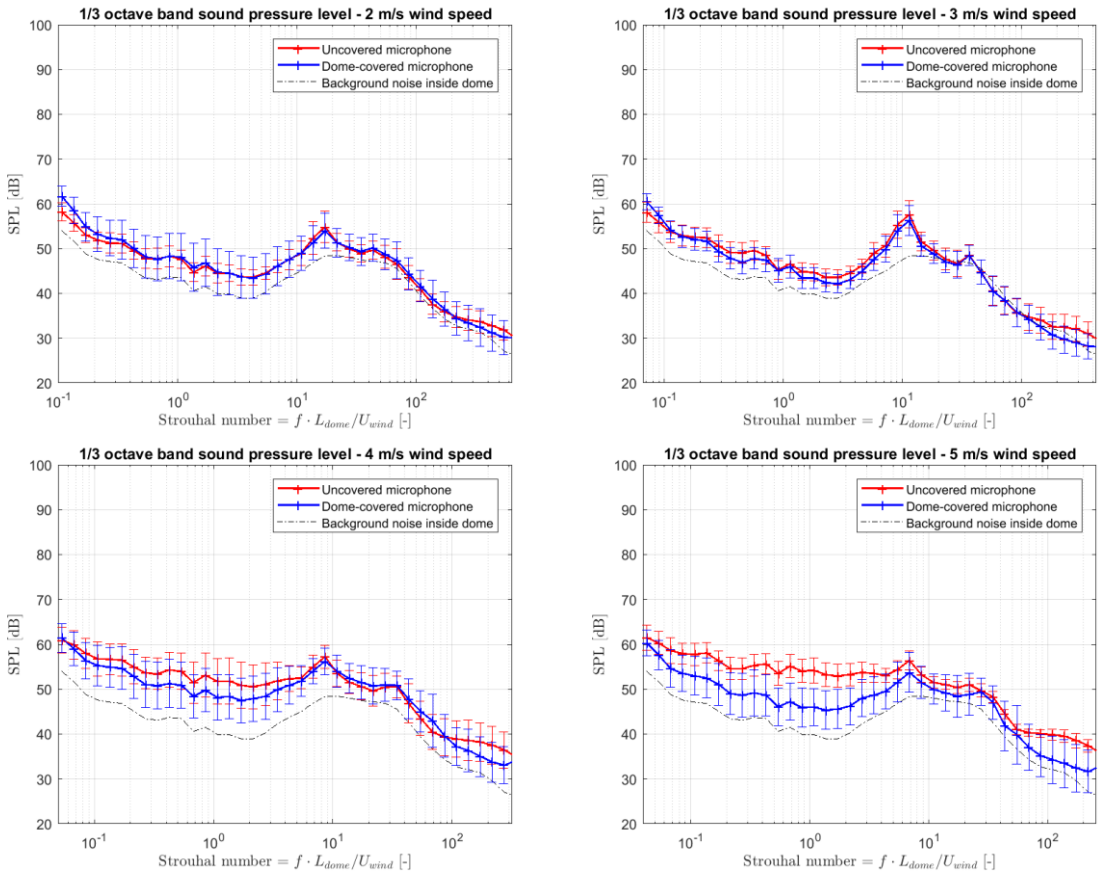
The test was performed in a rural environment approximately 400 m away from a rail road, national secondary roads and an inhabited village. A wind farm composed of seven wind turbines of 2.3 MW was near the test location. Two GRAS 46 AZ low frequency microphones and preamplifiers were used and equipped with rain protection and wind screens of 10 cm. Wind flow parameters were monitored at 10 m height with a 3D sonic anemometer.

Long-term measurements were performed in two configurations. In the first one, the two microphones were positioned at 200 m from each other, while the free-standing microphone was 100 m close to the wind farm. In the second configuration, the two microphones were positioned at 30 m from each other and at 300 m from the wind farm. Rainy periods were excluded as well as periods with noise from agricultural machine or trains. In the second configuration, data relative to a wind direction parallel to the two microphones were also excluded to avoid the influence of the dome's wake on the response of the uncovered microphone.

Ten-minutes 1/3rd octave bands were sorted for nacelle-position, mean wind speeds and turbulence intensities. For each group, results were averaged and compared for the two receivers. Background noise measurements were also recorded; these were performed with the wind farm fully off at 2 m/s mean wind speed.

3. Results

Preliminary results of the aforementioned measurement campaign are discussed in this section. Figure 1 illustrates the values of the 1/3rd octave bands for the measurements acquired by the two receivers in the second configuration at different wind speeds. The measurements are presented over non-dimensional frequencies representing the ratio between the dome's characteristic length (L_{dome}) and the atmospheric turbulence's characteristic length scale.



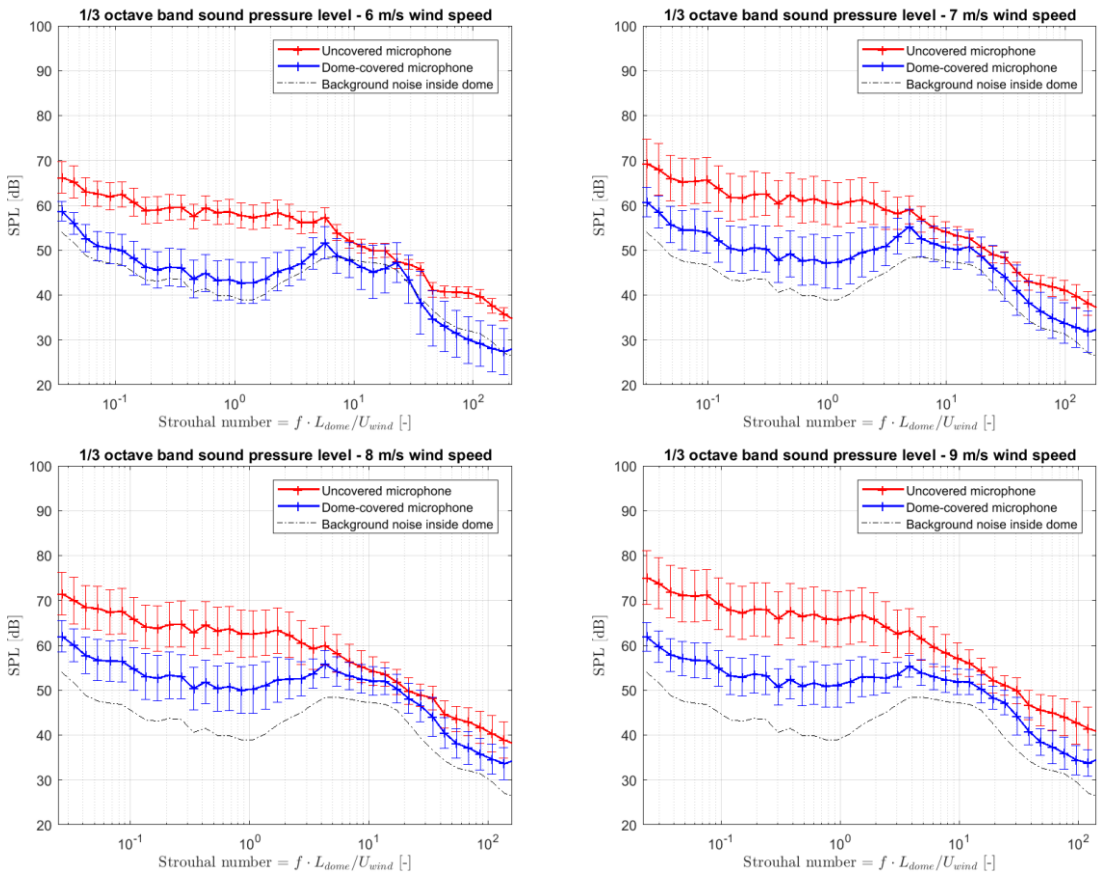


Figure 1: SPL in 1/3rd octave bands over the Strouhal number for free and dome-covered receiver under different mean wind speeds. f is the frequency of the acoustic wave and U_{wind} is the mean wind speed. Total error bars are double the standard deviations

Reductions in sound pressure levels by the presence of the dome in the infrasonic frequency range were found up to 14 dB. For low mean wind speeds, 2 and 3 m/s, SPLs inside and outside the dome are similar. As the mean wind speed increases, at 4 and 5 m/s, the levels at the uncovered receiver start increasing for Strouhal numbers (Sr) between 0.1 and 6. A maximum reduction of the wind induced noise inside the dome of 3 dB at 4 m/s and 7 dB at 5 m/s can be observed at Sr equal to 1. For higher wind speeds, from 6 to 9 m/s, absolute levels inside and outside the dome increase. However, this increase is much slower inside the dome, highlighting the wind-induced noise reduction produced by the dome. A maximum reduction of approximately 14 dB is observed at at Sr of 1. The dome reduces the mean wind speed of the flow and acts on the turbulence eddies as a pressure averaging device, mitigating the resulting pressure fluctuations at the microphone. The effect is maximum for turbulence length scales of the same order of magnitude as the dome's characteristic length. For smaller Sr numbers the reduction is almost constant down to Sr 0.1 with reductions of 12 dB or higher. The dome shows to reduce turbulence-induced noise from turbulence structures larger than its characteristic length scale. For Sr numbers higher than 1, thus smaller turbulences, the reductions are smaller.

Results from the first setup, with 200 m separation between the two receivers, confirm the aforementioned results. Figure 2 presents the behaviour of the dome at 5, 10 and 25% turbulence intensities for a low wind speed of 3 m/s. Figure 3 depicts the case of 6 m/s mean wind speed and turbulence intensities of 10, 15 and 25%.

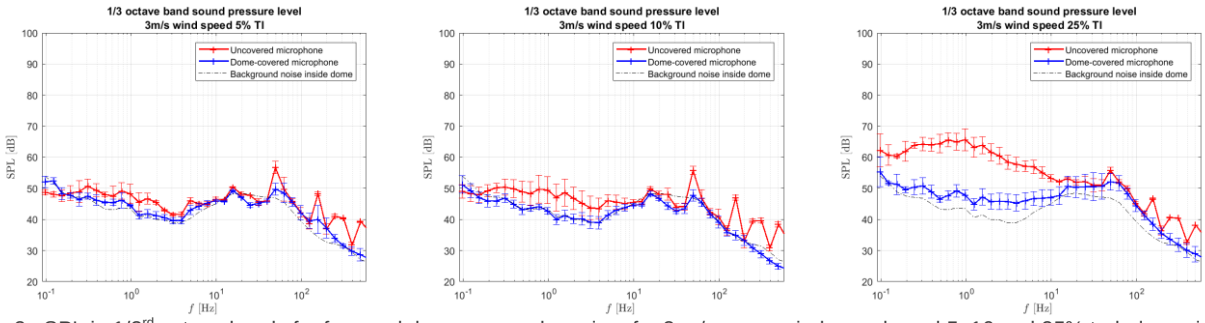


Figure 2: SPL in 1/3rd octave bands for free and dome-covered receiver for 3 m/s mean wind speeds and 5, 10 and 25% turbulence intensity; total error bars are double the standard deviations.

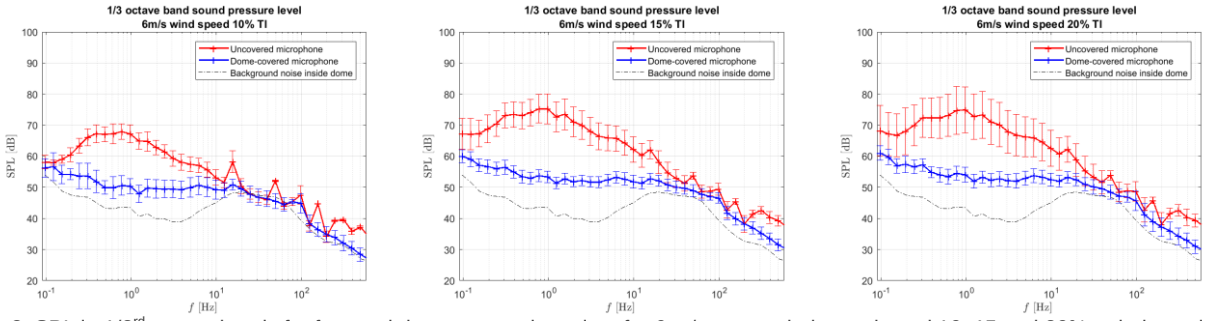


Figure 3: SPL in 1/3rd octave bands for free and dome-covered receiver for 6 m/s mean wind speeds and 10, 15 and 20% turbulence intensity; total error bars are double the standard deviations.

Figure 3 shows that the wind-induced noise does not simply correlate with the mean wind speed but it is also influenced by the turbulence intensity. For 3 m/s mean wind speed, the wind induced noise at the free receiver is quite low at 5 and 10% turbulence intensity in the infrasonic range. For the case of 25% turbulence intensity, the wind induced noise at the uncovered microphone undergoes an increment of approximately 15 dB at 1 Hz. SPLs inside the dome undergo a slight increase at high turbulence intensities, but this effect is limited to 5 dB at 1 Hz. For the highest turbulence intensity analysed here the dome gives a wind-induced noise reduction of 15 dB at 1 Hz at 3 m/s.

For the 6 m/s mean wind speed, a reduction of approximately 14 dB can be observed already for 10% turbulence intensity at 1 Hz inside the dome. This gives 20 dB at the same 1/3rd octave for the case of 25% turbulence intensity.

4. Conclusions

A wind-shielding dome for infrasound wind-induced noise was designed and tested. Its optimal geometry was based on wind screen theory and its porosity was optimized based on CFD simulations. The dome's performance was tested outdoors where pressure fluctuations recorded at a free-standing microphone where compared with a dome-covered microphone.

The dome shows the capability of reducing wind-induced noise in the infrasound spectral range up to 14 dB, having its maximum effect on atmospheric turbulences of comparable characteristic length. Wind noise reductions can be observed down to 0.1 Hz. The preliminary results show reductions correlated to mean wind speed and to turbulence intensity. For low mean wind speeds, the infrasonic sound pressure levels at a free-standing microphone show to be strongly influenced by the turbulence content in the flow resulting in an increase of circa 15 dB between low and high turbulence at the same low mean wind speed. For higher mean wind speeds and high turbulence intensities, reductions in sound pressure level by the dome reach 20 dB at 1 Hz. The dome, although still reasonably compact, allows to significantly increase the signal-to-noise ratio in the infrasonic range. This opens possibilities for accurately characterizing wind turbines infrasonic emissions.

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