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Bo Søndergaard
DELTA Acoustics & Electronics
Kongsvang Allé 33
DK 8000 Århus C

Policy and Planning for Offshore Wind, Environmental Impact, Certification

Noise Measurements on off-shore Wind Turbines, Why and How

Abstract

The noise from wind turbines are usually measured according to IEC 61400-11 **Fejl! Henvisningskilde ikke fundet.** and the results are used for declaration purposes, comparison between wind turbines, noise calculations etc. The measurements are conducted with a microphone on a board on the ground. This however cannot be copied to offshore applications for obvious reasons. The presentation will give a short presentation on the measurement method and include results from a project carried out for the Danish Environmental Protection Agency **Fejl! Henvisningskilde ikke fundet.**.

Why make off-shore noise measurements?

This is the first question you meet when you mention off-shore noise measurements. And it is a relevant question. Most off-shore wind farms are located at a considerable distance from the coast line and the noise should be reduced to almost nothing. Experience however shows that noise from wind turbines is giving more adverse reactions than other types of noise. This is indicated in Figure 1where the annoyance of different types of noise is compared. It can be seen that more people are annoyed from wind turbine noise than from traffic noise at the same noise level.

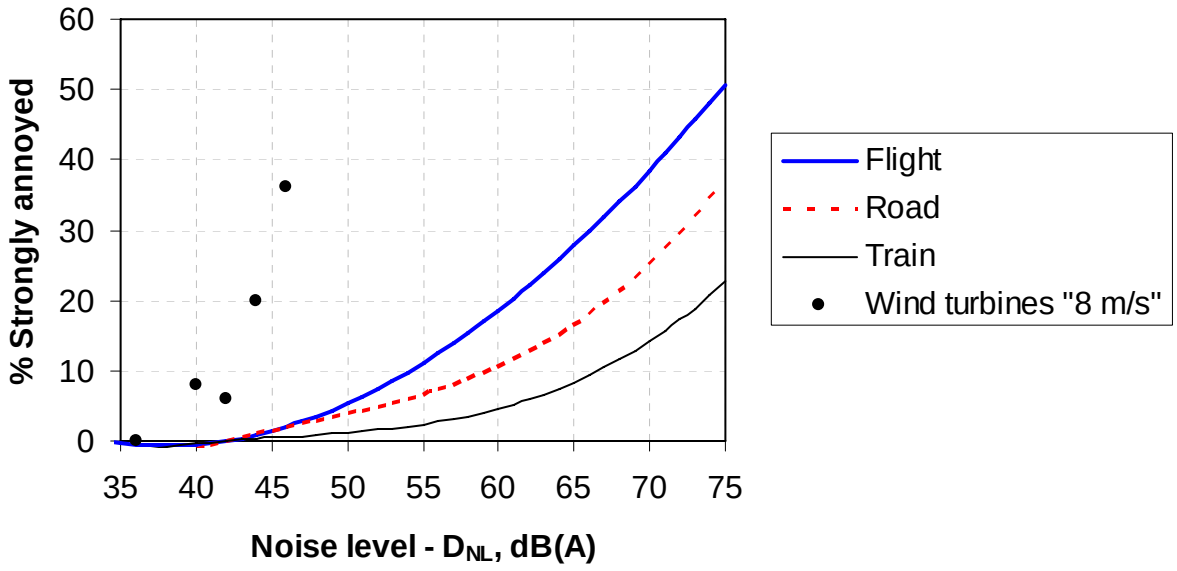

Figure 1 Noise annoyance for different types of noise

E.g. at a noise level of 45 dB(A) app 30 % is strongly annoyed by wind turbines while less than 5 % is strongly annoyed by other types of noise.

This was not anticipated by the authorities when the first wind turbines were erected on-shore. At the time there was a strong belief that the noise from wind turbines was similar in character to wind induced noise in vegetation and that masking would solve the problems. It has proven not to be the case and the results in figure 1 and a lot of complaints are the result. For that reason the authorities want facts for their decisions and not just “common sense”.

Off-shore noise propagation

What makes off-shore noise propagation different from on-shore noise propagation? The main difference is that the ground (water) reflects the noise whereas the ground (usually soil) on-shore absorbs the noise to some extent. For large distances where the noise is reflected from the sea surface several times without significant attenuation. Different models exist for noise propagation from wind turbines e.g.:

- The Danish model described in [5]
- A Swedish model described in [6] which distinguishes between land and water
- NORD2000 a new model described in [8] and [9] which can handle complex terrain with varying surface conditions and varying terrain and meteorological conditions.

To illustrate the differences to be expected between the sound propagation of offshore wind turbines and land-based wind turbines, a number of calculations were made with the propagation models mentioned above.

At first calculation of the ground effect of sound propagating from a wind turbine with a hub height of 30 m at distances from 100 to 10,000 m was made. A height of 30 m corresponds approximately to the heights which are the basis of the Danish and Swedish method mentioned above (the typical height of a wind turbine were 30 to 40 m at the time the methods were developed). In the calculations with Nord2000 the source spectrum of a Modern 2MW wind turbine measured at a wind speed of 8 m/s at 10 m height has been used. The ground effect has been defined as the difference between the A-weighted sound pressure level and the A-weighted free-field sound pressure level. When calculating the sound pressure levels the air absorption corresponding to an ISO-atmosphere (15° C and 70% RH) has been used. At propagation over ground a flow resistivity of 200,000 Nsm-4 is assumed corresponding to grass-covered ground and at propagation over water a flow resistivity of 20,000,000 Nsm-4 corresponding to a hard surface. The calculations are compared to measurement results from [7] at low frequencies where the ground is expected to be reflective like water.

In Figure 2 the following results from calculations or measurements are shown:

- Propagation over ground, Nord2000
- Propagation over ground, Danish method
- Propagation over ground, Swedish method
- Propagation over water, Nord2000
- Propagation over water, Nord2000, but coherent addition for multiple reflections
- Propagation over water, Swedish method

- Measurements from [7]for low frequencies (8-16 Hz, propagation distances above 300 m and up to 20 km in downwind and 3 km in upwind)

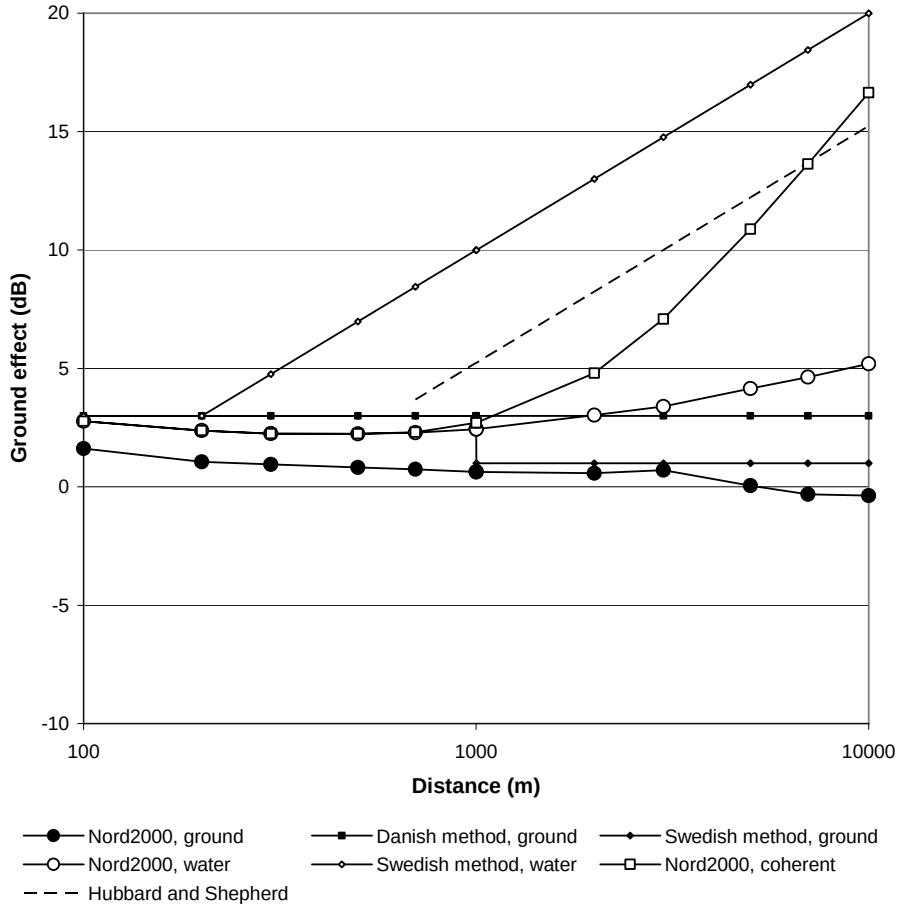

Figure 2
Ground effect for a wind turbine with a hub height of 30 m predicted according to different models at propagation both over ground and water.

Figure 2 show that for propagation over ground both the Danish and Swedish method predict a ground effect of +3 dB up to 1000 m while the calculations with Nord2000 at a wind speed of 8 m/s are 1 or 2 dB lower. At distances above 1000 m the Swedish method is 2 dB lower than the Danish method and thus shows good agreement with Nord2000.

Figure 2 show for propagation over water good agreement between Nord2000 and the Danish method, although Nord2000 has a slightly increasing tendency above 1000 m, however without the differences becoming pronounced. If coherent summation is used in Nord2000, a somewhat larger increase of ground effect and therefore of the sound pressure level due to multiple reflections is seen, and at large distances a good agreement is seen with the measurements at low frequencies in [7]. Nord2000 shows, however, that the distance must be larger than 1000 m even at coherent summation in the whole frequency range before the multiple reflections become of any importance. Viewed in the light of the calculations and the results in [10] it seems unrealistic that this effect occurs below 1000 m as indicated in the Swedish method.

In addition calculations have been made of the ground effect of the sound propagating from a wind turbine with a hub height of 100 m, which corresponds to the size of wind turbines relevant today (Modern MW-turbines is approx. 80-90 m). Figure 3 shows the results of the calculations for this turbine height.

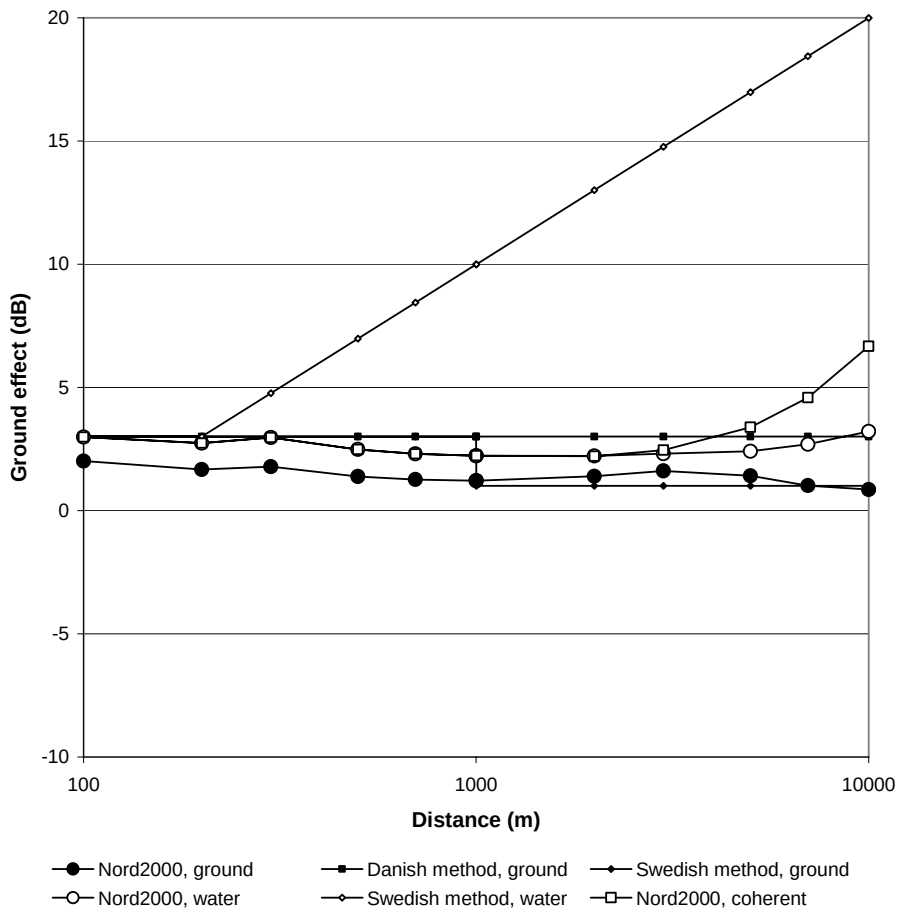

Figure 3
Ground effect for a wind turbine with a hub height of 100 m calculated according to different models at propagation both over ground and water.

Figure 3 shows that the ground effect calculated with Nord2000 for a wind speed of 8 m/s is slightly higher than for the 30 m wind turbine, by which the difference between the Danish method and Nord2000 is correspondingly reduced. It should be particularly noted in the figure that the effect of multiple reflections does not occur until at very large distances (above 4000 m). For these high wind turbines it must be concluded that the Danish method regarding ground effect yields good results for a wind speed of 8 m/s, and that multiple reflections are without importance in the area of distance which is of practical importance.

The Danish and Swedish method is only valid for sound propagation in downwind. To illustrate the effect of the meteorological conditions in crosswind and upwind, calculations were made with Nord2000 of the ground effect of sound propagating both over ground and water for a wind speed of 8 m/s for the three wind directions (downwind, crosswind, upwind). The results of the calculations are shown in Figure 4 to Figure 6.

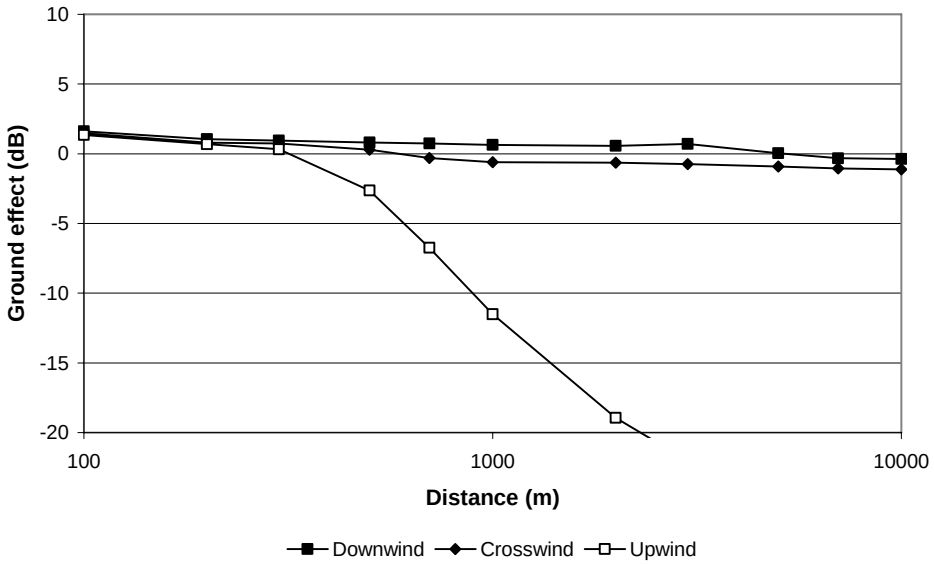

Figure 4
Ground effect for a wind turbine with a hub height of 30 m calculated with Nord2000 for different wind directions for propagation over ground.

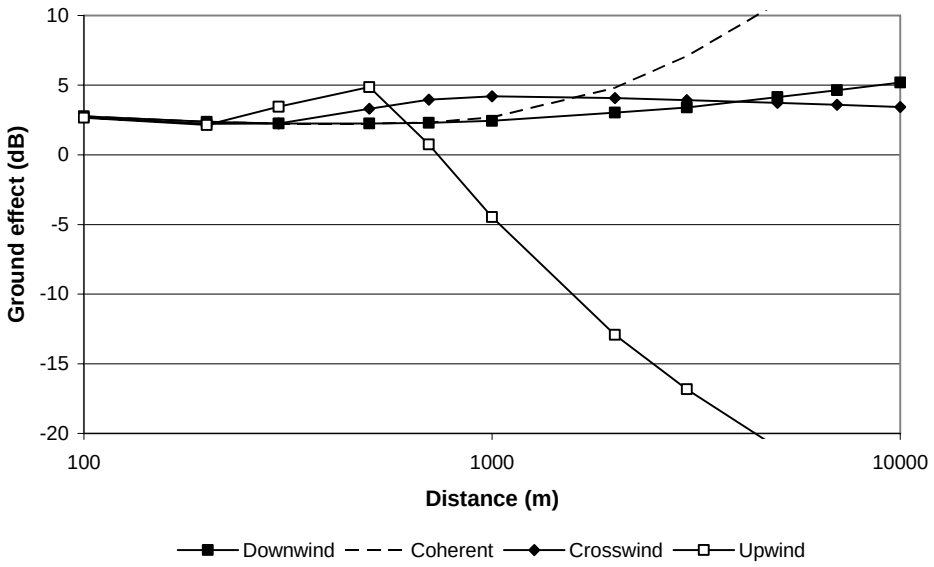

Figure 5
Ground effect for a wind turbine with a hub height of 30 m calculated with Nord2000 for different wind directions for propagation over water.

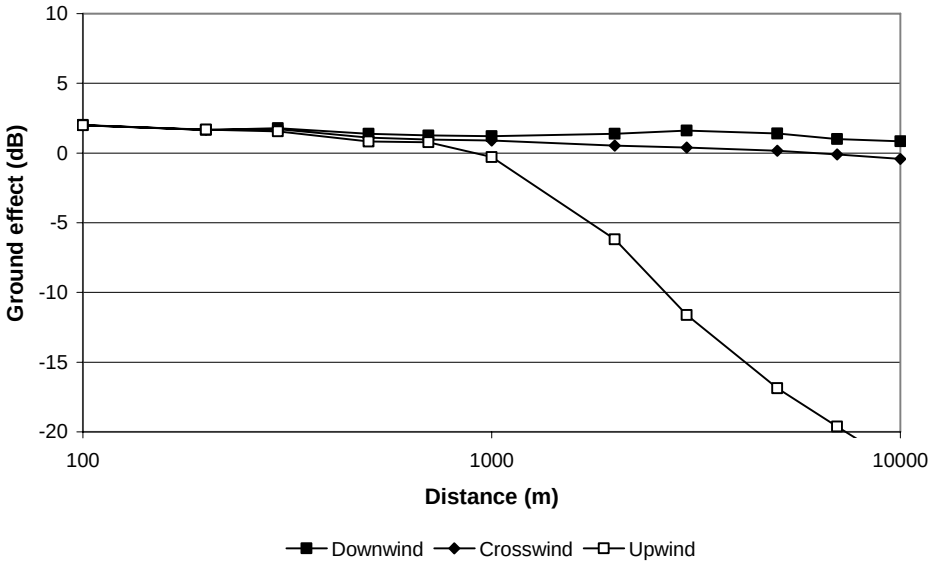

Figure 6
Ground effect for a wind turbine with a hub height of 100 m calculated with Nord2000 for different wind directions for propagation over ground.

The measurement method

The measurement method is described in **Fejl! Henvisningskilde ikke fundet.** shown in Figure 7.

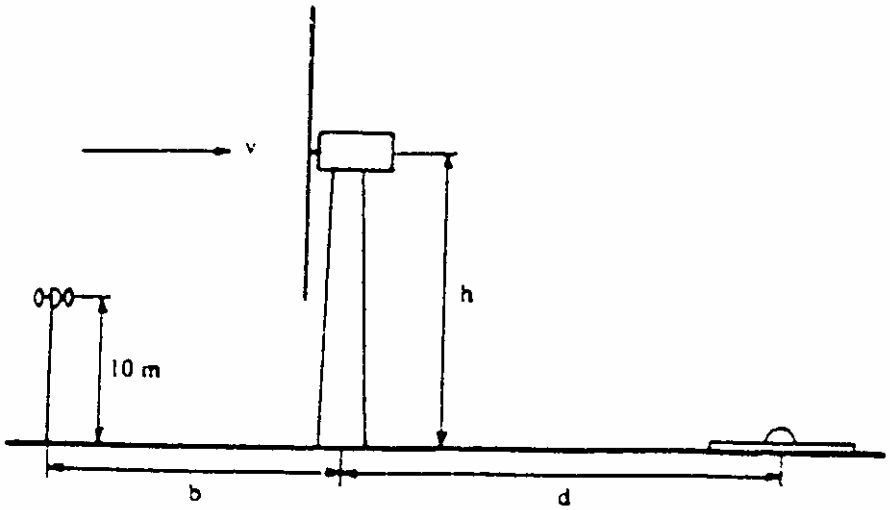

Figure 7 Measurement setup.

The microphone is mounted on a plate on the ground. The wind speed is measured through the produced power and a calibrated power curve. An anemometer is placed in front of the wind turbine making it possible to measure the wind when the wind turbine is stopped and the background noise is measured.

Measurement of noise emission from offshore wind turbines cannot in general be made with the standardized and generally accepted method in IEC 61400-11:2002 [1]. Most often the waves are so high that it is not safe to leave a microphone on a reflecting plate floating on the surface of the sea, and the noise produced by even small waves hitting the reflecting plate may exceed the noise level produced by the wind turbine.

Instead an alternative method has been proposed where the microphone is moved from a position on a plate on the ground to a position 3 to 5 m above the sea surface. The direct sound from the wind turbine and the reflected sound from the surface of the sea are almost equal, and when the frequency band considered is wide enough, the reflection causes a doubling of the energy of the direct sound and a 3 dB increase in sound pressure level. Actually, this principle lies behind the standards for measurement of sound power level in a free field above a reflecting plane, e.g. the ISO 3740-series. The principle does not apply to determination of tone levels. Thus the proposed alternative method cannot be expected to give conclusive results regarding the tonality of the wind turbine noise.

To obtain an adequate signal-to-noise ratio, the microphone shall be fitted with extra wind noise reducing equipment, e.g. a standard spherical wind-shield 10 cm in diameter supplied with a secondary wind shield as described in [4]. In Figure 8 the mounting of the microphone with a secondary wind-shield used for the wind turbine noise measurements is shown.

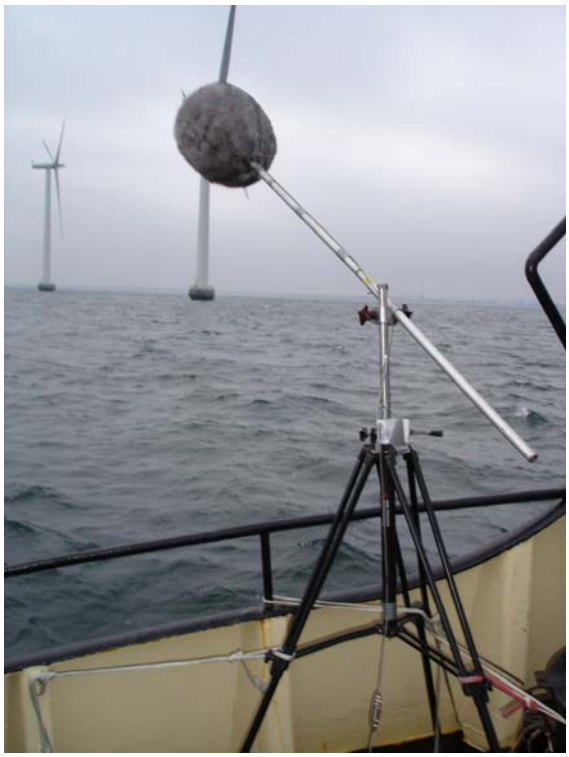

Figure 8. Microphone mounted with secondary wind shield.

An anemometer is placed onboard the same vessel as the microphone and at a height of 10 m above sea level. The anemometer is only used for the background noise measurements. The anemometer is expected to give the correct wind speed at 10 m height due to the small roughness length of the surface, and hence the normalization suggested in [1] is not necessary.

Conclusions

The method was tested on a 2 MW wind turbine in interior Danish waters. During the measurements the wind speed was varying between 7 and 10 m/s and the wave height was app. 1 m.

The results of the measurements indicate that it is possible to make noise measurements on offshore wind turbines according to the general principles in IEC 61400-11:2002 with a few changes.

The microphone is placed 3 m to 5 m above the surface of the sea free of reflecting obstacles. A position 1 m to 2 m from the vessel is preferred, but for practical reasons a position nearer the rail of the vessel is acceptable.
The anemometer is placed onboard the same vessel as the microphone and at a height of 10 m above sea level.
The Apparent Sound Power Level can be calculated from the noise measurements as:

$$L_{WA} = L_{Aeq,c} - 3 + 10 \cdot \log\left[\frac{4 \cdot \pi \cdot R_1^{\,2}}{S_0}\right]$$

where

LAeq,c is the background corrected A-weighted sound pressure level

R_1 is the slant distance in meters from the rotor centre to the microphone

and

S_0 is the reference area, S_0 = 1 m2

The background noise from the waves hitting the vessel is the main problem. To reduce the influence of this, it is recommended to use the shortest allowable measurement distance given in the standard, i.e. R0 – 20 %, and use as high a microphone position as possible.

References

[1] IEC 61400-11:2002 Wind turbine generator systems – Part 11:Acoustic noise measurement techniques

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[3] Report no. 150, 1994, "Annoyance from wind turbines" (in Danish) DELTA.

[4] Jakobsen, Jørgen: AV 50/97 "Investigations of Wind Screens, Insertion Loss and Attenuation of Wind Noise, Note 1, JOR3-CT95-0065" DELTA 1997.

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