The sound of high winds

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II ACOUSTICAL PRACTICE AND SOUND RESEARCH

II.1. Different points of view

In 2001 the German wind farm Rhede was put into operation close to the Dutch border. Local authorities as well as residents at the Dutch side had opposed the construction of the 17 wind turbines because of the effects on landscape and environment: with 98 m hub height the 1.8 MW turbines would dominate the skyline of the early 20th century village of Bellingwolde and introduce noise in the quiet area.
With the turbines in operation, residents at 500 m and more from the wind farm found the noise (and intermittent or flicker shadow, which will not be dealt with here) worse than they had expected. The wind farm operator declined to take measures as acoustic reports showed that German as well as Dutch noise limits were not exceeded. When the residents brought the case to a German court, they failed on procedural grounds. For a Dutch court they had to produce arguments that could only be provided by experts.

Science Shops are specifically intended to help non-profit groups by doing research on their behalf. For the Science Shop for Physics in Groningen noise problems constitute the majority of problems that citizens, as a group or individually, come up with. Although the aim of our research is the same as for acoustic consultants –to quantify sound levels relevant for annoyance- the customers are different: consultants mostly work for the party responsible for the sound production, whereas the Science Shop mostly works for the party that is affected by the sound. This may lead to different research questions. In the case of wind farm Rhede a consultancy will check the sound production of the turbines and check compliance of the calculated sound immission level with relevant limits. However, the Science Shop, taking the strong reaction from the residents as a starting point, wanted to check whether the real sound immission agrees with the calculated one and whether sound character could explain extra annoyance.

In the Dutch professional journal 'Geluid' it was shown, on the basis of 30 acoustic reports, that acoustic consultants tend to rely too much on information from their customers, even when they had reason to be critical about it [Van den Berg 2000]. As consultants' customers are usually noise producers and authorities, the point of view of those that are affected by noise is not usually very prominent. This book shows that for wind turbines a similar case can be made.

II.2 Results from our wind turbine research

The results of the investigation of the sound from the wind farm Rhede are given in the next chapters. Here the results will be dealt with briefly. The main cause for the high sound level perceived by residents is the fact that wind velocities at night can, at 100 m height, be substantially higher than expected. As a consequence a wind turbine produces more sound. As measured immission levels near the wind farm Rhede show, the discrepancy may be very large: sound levels are up to 15 dB higher than expected at 400 m from the wind farm. The important point is not so much that the maximum measured sound level is higher than the maximum expected sound level (it was, around +2 dB, but this was not an effect of the wind velocity profile). The point is that this maximum does not only occur at high wind velocities as expected, accompanied by high wind induced ambient sound levels, but already at relatively low wind velocities (4 m/s at 10 m height) when there is little wind at the surface and therefore little wind induced background sound. Thus, the discrepancy of 15 dB occurs at quiet nights, but yet with wind turbines at almost maximum power. This situation occurs quite frequently.

A second effect that adds to the sound annoyance is that the sound has an impulsive character. The primary factor for this appeared to be the well known swishing sound one hears close to a turbine. For a single turbine these 1 – 2 dB broad band sound pressure fluctuations would not classify as impulsive, but at night this swish seems to evolve into a less gentle thumping. Also, when several turbines operate nearly synchronously the

pulses may occur in phase increasing pulse strength further. At some distance from the wind farm this sound characteristic, described as thumping or beating, can be very pronounced though in the wind farm, close to a turbine, we never heard this impulsiveness.
Indeed, close to a turbine it seems that most sound is coming from the downgoing blade, not when it passes the tower. One has to be careful in estimating blade position, as an observer at, say, 100 m from the foot of the tower is 140 m from a 100 m hub and therefore hears the sound from a blade approximately half a second after it was produced, in which time a blade may have rotated over some 30°. At the Berlin WindTurbineNoise conference Oerlemans [2005] explained this phenomenon: when the blade comes down and heads towards the observer, the observer is at an angle to the blade where most sound is radiated (see remark on directivity just below equation B.5 in Appendix B). On top of that the high tip velocity (70 m/s) causes a Doppler amplification. Both effects increase the sound level for our observer. However, this observation cannot be used for a distant turbine as in that case the observer sees the rotor sideways. Then the change due to the directivity of the sound is small, and also the Doppler effect is nil as the change in the velocity component towards the observer is negligible.

II.3 Early warnings of noisy wind turbines?

One may wonder why the strong effect of the nightly wind profile or the thumping was not noticed before. In the 1998 publication IEC 16400 only the neutral logarithmic wind profile is used [IEC, 1998]. As recent as 2002 it was stated that wind turbine sound is not impulsive [Kerkers *et al* 2002], which was concluded from assumed, not from measured sound level variations.

There have been some warnings, though. In 1998 Rudolphi concluded from measurements that wind velocity at 10 m height is not a good measure for the sound level: at night the (58 m hub height) turbine sound level was 5 dB higher than expected [Rudolphi 1998]. This conclusion was not followed by more thorough investigation. Since several years residential groups in the Netherlands and abroad complained about

annoying turbine sound at distances where they are not even expected to be able to hear the sound. Recently Pedersen *et al* [2003, 2004] found that annoyance was relatively high at calculated maximum sound immission levels below 40 dB(A) where one would not expect strong annoyance.
As wind turbines become taller, the discrepancy between real and expected levels grows and as more tall wind turbines are constructed complaints may become more widespread. In the Netherlands residents near the German border were the first Dutch to be acquainted with turbines of 100 m hub heights.

It may be that earlier discrepancies between real and projected sound immission were not sufficient to evoke strong community reactions and that only recently turbines have become so tall that the discrepancy now is intolerable.
There are other reasons that early warnings perhaps did not make much impression. One is that sound emission measurements are usually done in daytime. It is hard to imagine the sound would be very different at night time, so (almost) no one did. Until some years ago, I myself could not imagine how people could hear wind turbines 2 km away when at 300 to 400 m distance the (calculated) immission level was, for a given wind velocity, already equal to the ambient background sound level (L_{95}). But it proved I had not listened in a relevant period: an atmospherically stable night.
What is probably also a reason is the rather common attitude that 'there are always people complaining'. Complaints are a normal feature, not as such a reason to re-investigate. Indeed Dutch noise policy is not to prevent any noise annoyance, but to limit it to acceptable proportions. Added to this is a rather general conviction of Dutch authorities and consultants that routine noise assessment in compliance with legal standards must yield correct results. If measurements are performed it is to check actual emission levels –usually in normal working hours, so in daytime. It is quite unusual to compare the calculated sound immission from a wind turbine (farm) with measured immission levels (so unusual that it is likely that we were the first to do so).

A third reason may be partiality to the outcome of the results. Wind turbine operators are not keen on spending money that may show that sound levels do not comply with legal standards. And if, as expected, they do comply, the money is effectively wasted. Apart from this, we have the experience that at least some organisations that advocate wind energy are not interested in finding out why residents oppose wind farms.

II.4 The use of standard procedures

Although our objective was to measure immission sound levels, we also wanted to understand what was going on: if levels were higher than expected, was that because emission was higher or attenuation less? Could there be focussing or interference? We therefore also measured sound emission as a function of rotational speed of the variable speed turbines. An interesting point that came up with the emission measurement was that compliance with the recommended standard [Ljunggren 1997 or IEC 1998] was impossible. As the farm operator withdrew the co-operation that was previously agreed upon, we had to measure emission levels with the full wind farm in operation, as we obviously did not have the means to stop all turbines except the one to be measured, as the standard prescribes. To measure ambient background sound level, even the last turbine should be stopped.

According to the recommended standard the sound emission should be measured within 20% of the distance to the turbine equal to hub height + blade length. However, to prevent interference from the sound from other turbines the measurement location had to be chosen closer to the turbine.

The primary check on the correctness of the distance (i.e. not too close to other turbines) was by listening: the closest turbine should be the dominant source. If not, no measurement was done, and usually a measurement near another turbine was possible. Afterwards we were able to perform a second check by comparing the measured sound immission of the wind farm at a distance of 400 m with the level calculated with a sound propagation model with the measured emission level of all (identical) turbines as input. The calculated difference between a single turbine sound power level and the immission level was 58.0 dB (assuming a constant spectrum this is independent from the power level itself). The measured average difference

was 57.9 dB, with a maximum deviation of individual measurement points of 1.0 dB. So our measurements proved to be quite accurate, deviating only 0.1 ± 1.0 dB from the expected value! In fact, from our measurements one may conclude that, to determine turbine sound power level, it is easier and cheaper to determine total sound emission by measurements at some distance from a wind farm than measuring separate turbines. The wind induced ambient sound, that easily spoils daytime measurements, is not an important disturbance in many nights!
Using a 1 m diameter round hard board, again to comply with the standard, was quite impractical and sometimes impossible. *E.g.* at one place potato plants would have to be cleared away, at another place one would have to create a flat area in clumps of grass in a nature reserve, both unnecessarily. Instead of the large board we used the side (30·44 cm^2) of a plastic sound meter case. We convinced ourselves that (in this case) this was still a good procedure by comparing at one location sound levels measured on the case on soft ground with sound levels measured on a smooth tarmac road surface a few meters away, both at the same distance to the turbine as in the other measurements: there was no difference.

Whether a turbine produces impulsive sound is usually determined by listening to and measuring the sound near a single turbine (along with measurements to determine sound power and spectral distribution). In the Netherlands impulsivity is judged subjectively (by ear), not by a technical procedure as in Germany, though judgement can be supported with a sound registration showing the pulses. Interestingly, in Dutch practice only an acoustician's ear seems reliable, though even their opinions may disagree. From our measurements the impulsive character can be explained by the wind profile and the interaction of the sound of several turbines. Even at a time the impulsive character can be heard near residents' dwellings, it cannot clearly be heard close to the turbines in the wind farm (as explained in section II.2). So here also there was need to do measurements where people are actually annoyed, and not to rely on source measurements only, certainly not from a single turbine.

When noise disputes are brought to court, it is clearly advantageous to have objective procedures and standards to assure that the technical quality, which can hardly be judged by non experts, is sufficient and therefore the results are reliable. In the case made here however, a standard may be non-applicable for valid reasons. Nonetheless, the emission measurements have been contested on procedural grounds (*viz.* we have not complied to the standard [Kerkers 2003]), even though the immission sound levels were the primary research targets and we did not really need the sound emission measurement results (which, however, proved very accurate).
The tendency to put all noise assessment into technical standard procedures has the disadvantage that when there is a flaw in a legally enforced standard, still the standard is followed, not reality. It is hardly possible for non experts, such as residents, to bring other arguments to court. They, the annoyed, will have to hire an expert to objectify their annoyance. This is not something every citizen can afford.

II.5 Modelling versus measurements

Being able to calculate sound levels from physical models is a huge advantage over having to do measurements (if that, indeed, is possible) especially as in practical situations conditions keep changing and other sounds disturb the measurements. Because of its obvious advantages models have become far more important for noise assessment than measurements. In the Netherlands usually sound emission measurements are carried out close to a source to determine sound power levels. Then, with the sound power level, the immission level is calculated, usually on façades of residences close to the sound source. It is not common to measure immission levels in the Netherlands; in some cases (e.g. railway, aircraft noise) there is not even a measurement method (legally) available to check calculated levels.

However, a physical model is never the same as reality. As will be shown in this book, the widely used standard to quantify sound emission from wind turbines is implicitly based on a specific wind profile. This profile is

not correct at night, although the night is the critical period for wind turbine noise assessment.
Even a perfect physical model will not reproduce reality if input values are not according to reality. An example is to apply sound power levels from new sources (cars, road surfaces, aeroplanes, mopeds, vacuum cleaners, etc.), maybe acquired in a specific test environment, to real life situations and conditions. Another example is a wind farm south of the Rhede wind farm where a turbine produced a clearly audible and measurable tonal sound, probably caused by damage on a blade. It is very hard for residents to convince the operator and authorities of this annoying fact, partly because most experts say that modern wind turbines do not produce tonal sound.
Incorrect models and incorrect input may well occur together and be difficult to separate. It is important that calculation models are checked for correctness when they are used in new applications. Situations where (strong) complaints arise may indicate just those cases where models do not cover reality.

II.6 Conclusion

In modelling wind turbine sound very relevant atmospheric behaviour has been ‘overlooked’. As a consequence, at low surface wind velocities such as often occur at night, wind turbine noise immission levels may be much higher than expected. The discrepancy between real and modelled noise levels is greater for tall wind turbines. International models used to assess wind turbine noise on dwellings should be revised for this atmospheric effect, at least by giving less attention to the 'standard' neutral atmosphere.

A discrepancy between noise forecasts and real noise perception, as a result of limited or even defective models, cannot always be avoided, even not in principle. However, its consequences can be minimised if immission levels are measured at relevant times and places. This relevancy is also determined by observations of those affected. It should always be possible to check noise forecasts by measurement.

For wind turbine noise (and other noise sources) standard measurement procedures require co-operation of the operator to be able to check emission sound levels. This introduces an element of partiality to the advantage of the noise producer. This is also generally a weak point in noise assessment: the source of information is usually the noise producer. Hence there should always be a procedure to determine noise exposure independently of the noise producer.

Standard technical procedures have the benefit of providing quality assurance: when research has been conducted in compliance with a standard procedure lay persons should be able to rely on the results. It may however also have a distinct disadvantage for lay people opposing a noise source: when an assessment does not comply with a standard procedure it is not accepted in court, regardless of the content of the claim. A consequence is they have to depend on legal as well as acoustical expertise. If citizens are forced to use expert knowledge, one may argue that they should be given access to that knowledge. An important obstacle is the cost of that access.