Some Limitations and Errors in Current Turbine Noise Models

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Limitations in modeling assumptions

Harvey Hubbard's paper, gives an overview of many of the assumptions made in Wind Turbine noise modeling

Wind Turbine Acoustics Harvey Hubbard.pdf

These assumptions are:

1. Incoherent addition is a sum of the random-phase multiple noise sources at any arbitrary receiver distance.

2. Each source radiates equally in all directions

3. Propagation is over fiat, homogeneous terrain

4. That a logarithmic wind-speed gradient is present

Recent Findings that address these Limitations

Just like a map, isn't the territory, since it's not possible to include all the relevant information in a map.

Likewise a physical model is never the same as reality. If the assumptions are technically correct then the model can approach the results obtained in the real situation.

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Godefridus Petrus van den Berg

Godefridus Petrus van den Berg Thesis.zip

Day and Night Differences

"There is a distinct audible difference between the night and daytime wind turbine sound at some distance from the turbines. On a summer's day in a moderate or even strong wind the turbines may only be heard within a few hundred meters and one might wonder why residents should complain of the sound produced by the wind farm. However, in quiet nights the wind farm can be heard at distances of up to several kilometers when the turbines rotate at high speed. In these nights, certainly at distances from 500 to 1000 m from the wind farm, one can hear a low pitched thumping sound with a repetition rate of about once a second (coinciding with the frequency of blades passing a turbine mast), not unlike distant pile driving, superimposed on a constant broad band 'noisy' sound. A resident living at 1 km from the nearest turbine says it is the rhythmic character of the sound that attracts attention: beats are clearly audible for some time, then fade away to come back again a little later. A resident living at 2.3 km from the wind farm describes the sound as 'an endless train'. In daytime these pulses are usually not audible and the sound from the wind farm is less intrusive or even inaudible (especially in strong winds because of the then high ambient sound level). In the wind farm the turbines are audible for most of the (day and night) time, but the thumping is not evident, although a 'swishing' sound –a regular variation in sound level- is readily discernible. Sometimes a rumbling sound can be heard, but it is difficult to assign it, by ear, to a specific turbine or to assess its direction"

Predicting average sound levels is like predicting the average depth of a swimming pool. It tells you little about the risks involved.

> In my experience it is the fact that stable environmental conditions at night produce increased wind at hub height, and increased noise which disrupt sleep. These conditions occur on clear starry night sand result in significant increases in the source sound power, increased tonality and sound fluctuations which are not represented in the manufacturers turbine sound power levels.. These are the frequently occurring worst case conditions that occur regularly in near wind turbines in rural communities

van den Berg shows that adjacent turbines cannot be treated as incoherence random-*phase sources in Stable Wind Conditions*

"In a stable atmosphere turbines in a wind farm can run almost synchronously because the absence of large scale turbulence leads to less variation superimposed on the constant (average) wind velocity at each turbine. In unstable conditions the average wind velocity at the turbines will be equal, but instantaneous local wind velocities will differ because of the presence of large, turbulent eddies at the scale of the inter turbine distance. In a stable atmosphere the turbulence scale decreases with a factor up to 10, relative to the neutral atmosphere and even more relative to an unstable atmosphere [Garratt 1992]. In stable conditions turbines in a wind farm therefore experience a more similar wind and as a consequence their instantaneous speeds are more nearly equal. This is confirmed by long term measurements by Nanahara et al. [2004] who analyzed coherence of wind velocities between different locations in two coastal areas. At night wind velocities at different locations were found to change more coherently than they did at daytime [Nanahara 2004]. The difference between night and day was not very strong, probably because time of day on its own is not a sufficient indicator for stability.1 The decay of coherence was strongly correlated with turbulence intensity, which in turn is closely correlated to stability.

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Thus several turbines can be nearly synchronous: sometimes two or more turbines are in phase and the blade passing pulses coincide, and then they go out of phase again causing beats.

The maximum error depends on the number of turbines, and how close to being in-phase they are. In a recent email George Kamperman pointed out "No turbine is more than 60 degrees out of phase with any other turbine. Yes you could in theory measure +6 dB (in phase) but no cancellation".

This is due to the fact that most of the periodic noises are generated as a blade passes the turbine support post. If they are close to speed synchronicity, as van den Berg has shown the maximum difference in timing between the turbines is ½ of the 120 degree spacing of the blades.

Assume the turbine reference sound power is 0db
For two equal ***incoherent*** turbines the total is increased by +3db
For two equal *coherent* turbines the total is increased by +6db
For four equal ***incoherent*** turbines the total is increased by +6db
For four equal *coherent* turbines the total is increased by +12db

Some Limitations and Errors in Current Turbine Noise Models

Take for example 4 adjacent turbines ***rotating in close synchronicity***. The increase in sound power for coherent sources is of the order 20 log 4 or 12 db.

The increase for 4 adjacent turbines treated as ***random-phase not rotating in close synchronicity*** multiple noise sources is only +6db.

This is an increase not accounted for in the existing models

Clifford Schneider

Accuracy of Model Predictions and the Effects of Atmospheric Stability on Wind Turbine Noise at the Maple Ridge Wind Power Facility, Lowville, NY - 2007.pdf

New York State is currently on a "fast-track" for developing sources of renewable energy – the goal is renewable energy constituting 25% of all energy sold in New York by 2013.

At present there are six commercial wind farms operating in New York State, with four more under construction. There are another 30 projects that are under some stage of environmental review, and there are undoubtedly more that are being considered. There are a number of important issues that confront developers in getting their projects approved; one of them is dealing with wind turbine noise. Although wind farm noise may be low compared to a big municipal airport, in a quiet rural setting even low level noise can pose a significant problem. Wind power developers use mathematical models to predict the impact of wind turbine noise on nearby residents. However, no one knows if predicted noise impacts are high, low or on target. Developers, planning boards and residents are all assuming that model predictions are accurate and that they do not require any validation. ***Regrettably, there have been no compliance surveys done on any of the six operational wind farms in New York State.***

The main objective of this study was to measure the noise levels at two sites within Atlantic Renewable Energy Corporation's Maple Ridge Wind Power Project located in Lewis County, New York, and compare actual levels with the model predictions that were available in the preconstruction Draft Environmental Impact Statement (DEIS).

The second objective was to examine atmospheric stability at Maple Ridge. Atmospheric Stability was identified as a significant problem at a wind farm on the Dutch-German border. Stability occurs when ground level winds, where people live and reside, are decoupled from those at wind turbine hub-height. This can occur at the end of the day when the land mass begins to cool. It affects wind turbine noise because wind turbines can be operating and making noise when ground level winds are calm and we expect quiet surroundings.

This study demonstrated that *summer, night-time noise levels* exceeded levels predicted for two sites within the Maple Ridge Wind Farm. For winds above generator cut-in speed (e.g., 3.0 m/s @ 80-m), the **measured noise was 3-7 dBA above predicted levels.**

Measuring Background Noise clif Schneider Internoise 2009 .pdf

The decoupling of ground level winds from higher level winds, i.e., atmospheric stability, was apparent in the noise data at both sites during evening and night-time periods. At wind speeds below 3.0 m/s, when wind turbines were supposedly inoperative, noise levels were 18.9 and 22.6 dBA above the expected background levels for each of the sites and these conditions occurred a majority of the time. The same results were evident in the evening period. Furthermore, digital recordings revealed prominent wind turbines sounds below cut-in speeds. The fact that nearly all measurements exceeded Atlantic Renewable's predicted impacts suggests there is a problem with the choice of a model and/or how the models are configured. The model protocol used by Atlantic Renewable is very common; most wind power developers in New York use the same protocol. However, different models used in wind farm noise assessments have been shown to produce different results, and the model used by Atlantic Renewable was not designed to model elevated sources of sound, i.e., wind turbines.

In response to sound studies from commercial wind developers, a series of background noise surveys were conducted in Cape Vincent, NY between May and July 2008. The survey approach included sampling at night under stable atmospheric conditions and systematically selecting monitoring stations at 1.6 km intervals. ***Stable conditions occurred in 67% of nights*** and in 30% of those nights, wind velocities represented worst-case conditions where ground level winds were less than 2 m/s and hub-height winds were greater than wind turbine cut-in speed, 4 m/s. The median A-weighted L90A,9-hr sound pressure level was 25.7 dBA for five, fixed monitoring stations. For two mobile surveys, the medians (L90A,5-min) were comparable, 25.5 and 26.7 dBA.

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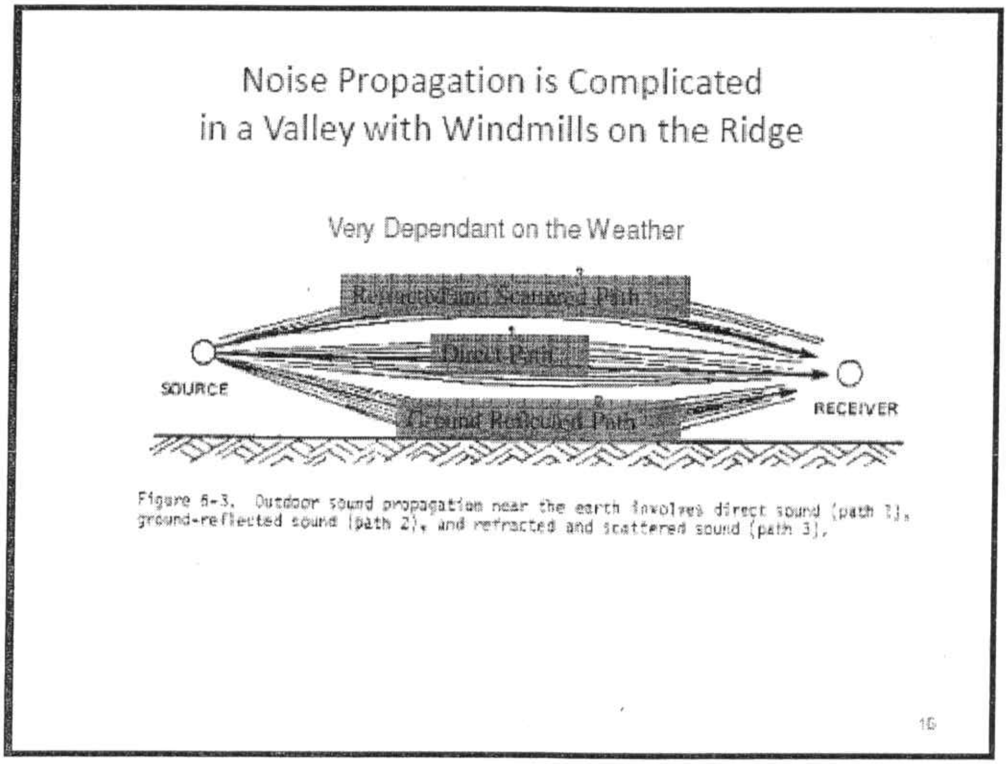
Extracts from a a presentation given in Allegheny, NY

weather_effects_on_noise_handout_ebbing.pdf

The refracted noise paths from the Turbines placed on ridge above a valley path is very dependent on the direction and wind speed versus height and is not a factor considered in the current computer models.

The ground reflected path includes the valley below which also involves refracted energy from the ridge turbines which directs additional sound to the valley below.



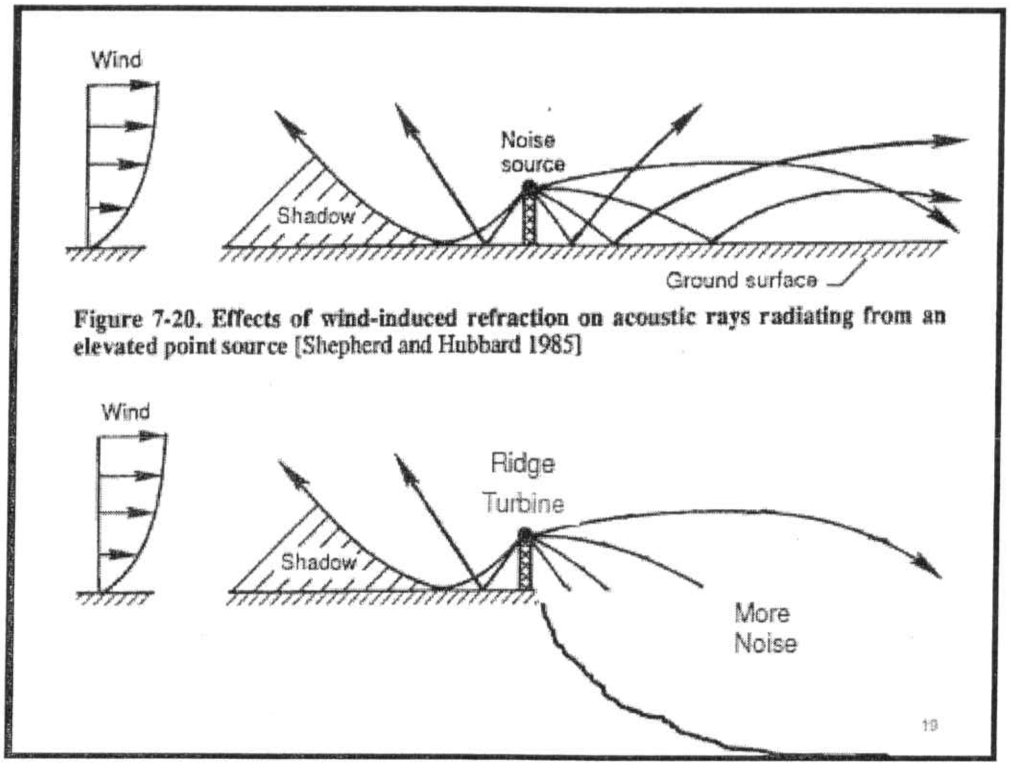


Figure 7-20. Effects of wind-induced refraction on acoustic rays radiating from an elevated point source [Shepherd and Hubbard 1985]

The upper figure taken from, *Wind Turbine Acoustics Harvey Hubbard.pdf* and illustrates that downwind of a turbine the sound rays are initially refracted downward and reflect off the adjacent level ground surface

When the turbines line the ridge as shown in the lower figure, wind velocity changes with height from the ground refracts much of the sound into the valley which is not included in the computer models.

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Wind Turbines on Ridges
Some Thoughts

Teresa Drew and Roger Treagus, Golder Associates Ltd

- To account for noise, the site selection process needs to be broader than is often the case with other developments.
- ***Because sound carries farther downwind***, it's important to know both the ***dominant direction*** and how often the wind deviates from it.
- The minimum distance, or setback, from a "receptor" such as a farm house or subdivision (including those planned for the future) ***should be increased if it is frequently downwind of the wind farm.***
- A ***worst case wind direction analysis*** seems appropriate to determine if which operating conditions will have ***most impact on intrusive noise into the community*** and to control the operation of the wind farm appropriately.
- The ***topography and ground conditions can significantly affect noise*** propagation. Studies have shown that ***lining a ridge with turbines*** produces "shadow zones" on its slopes: ***noise levels are actually lower near the turbines than at a distance in the valleys below***. For sites near a body of water, remember that reflections off the water's surface can amplify noise.
- Sound ***level projections are more acceptable if they are based on real-world results.*** Developers need to conduct thorough preconstruction projections of a project's noise impacts and ***then verify them later***.

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Location, Location, Location,

An investigation into wind farms and noise by the Noise Association

John Stewart

- Mid Wales - a land of hills and valleys. A place where the wind blows frequently and the population tends to be thinly spread. Ideal for wind farms. And, not surprisingly, many are planned. ***The best place very often for the turbines to catch the wind is close to the top of a hill. It means that the wind turbines can be at their most productive.***
- ***But it also means that the noise may cascade down the surrounding valleys. To makes matters worse***, many of the scattered hamlets within the valleys snuggle into corners protected by the hills and the mountains where the background noise level is very low indeed.
- **You only need to visit these areas to hear the 'swish, swish, swish' of the turbines – particularly downwind – over a mile away from the wind farm.**

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Mars Hill

- Mountainous typography especially ***arising from plains or rolling hills***, such as Mars Hill Ridge and its immediate surroundings, ***give rise to broadly varying atmospheric conditions over relatively short distances.***

- For example, ***vigorous ridgeline winds*** may be consistent with **up-wind low elevation surface conditions**, but be contrasted ***downwind at surface levels by light or even calm conditions.***

- Given these potential variations, ***upwind receptors*** would experience high level masking and "shadow" atmospheric refraction conditions minimizing ridgeline source sounds, whereas ***downwind receptors*** would ***experience minimal masking and atmospheric refraction lapse conditions that would enhance ridgeline source sounds.***

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Mars Hill

Calm surface conditions do not necessarily correlate with hub level wind speed. This is often seen in a neutral atmosphere in the evening and nighttime hours or downwind conditions on the leeward side of the ridge, when hub level wind speeds maybe considerable, but ***contrasting surface conditions are calm or light and variable.***

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Present computer models do not do an adequate job of modeling the case where noise predictions are made in the valley below. For these to be valid, the model used must be verified by showing the model results do indeed agree with an actual noise measurements within reasonable bounds for an array of turbines above a valley

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