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John P. Harrison[1]

Abstract

Following an introduction to noise and noise regulation of wind turbines, the problem of adverse health effects of turbine noise is discussed. This is attributed to the characteristics of turbine noise and deficiencies in the regulation of this noise. Both onshore and offshore wind farms are discussed.

Keywords

wind turbines, turbine noise, onshore and offshore noise propagation, noise regulation, turbulence

Introduction

The most common complaint about wind turbines is that they are noisy. There is audible noise perceived by the ear/brain system and the so-called inaudible infrasound felt by the body. The ear detects sound as pressure waves. The ear/brain system detects the loudness and pitch of the sound. The way the system works is that as the pressure in a sound wave increases by three times, the ear/brain combination perceives a doubling of the loudness. The ear/brain system for audible sound is effective from about 50 to 4,000 Hz with a gradual decrease in sensitivity at either end.

Engineers use a decibel scale to describe loudness as perceived. The scale is logarithmic to mimic the behavior of the ear. The scale is weighted to reflect the sensitivity of the ear to the frequency of the sound. The most common weighting is the A-scale. With this scale, familiar noises have approximate decibel levels as shown.

Background at night in a rural area:	25 dBA
Recommended bedroom level:	25 dBA
Living room:	40-45 dBA
A busy office:	60-65 dBA
Heavy street traffic:	90 dBA

An increase of 3 dBA is noticeable and an increase of 10 dBA is perceived as a doubling in loudness. Sound from extraneous sources is referred to as noise and is an annoyance and potential health problem.

The response to infrasound (<20 Hz) is not as well understood. However, there are receptors in the body for infrasound and it is detected at levels well below the audible sound threshold (Salt & Hullar, 2010).

Most noise regulations are derived from regulations designed for other noise sources, such as traffic or industry. However, anecdotal evidence and field studies suggest that turbine noise has a character that makes it far more annoying and stressful than other sources of noise at the same A-weighted sound level. The reasons for this are believed to include the amplitude modulation associated with the blade passage past the tower, the quiet rural environment in which turbines are placed, the turbulence of the air that blows past the blades, the variability of manufacture and assembly, the dominance of low frequencies in the received sound spectrum, and the association between the acoustic and visual impacts. This article reviews the annoyance and its impacts, the character of the turbine noise, and suggests revisions to regulations required to avoid adverse health effects.

Regulation of Wind Turbine Noise

Most jurisdictions have noise regulations to protect our environment from industrial, traffic, and other sources of noise. Regulation of wind turbine noise is used to determine the setback of turbines from homes and other sensitive receptors. For a review of regulations worldwide, see Orville Walsh (2010). The noise limit varies from 35 dBA for quiet regions of New Zealand and for nighttime in Germany to 50 dBA in many jurisdictions in the United States.

In Ontario, there is an Environmental Protection Act, which, among other thing, protects the health and the enjoyment of property of residents. As of September 2009, the limit for turbine noise at a sensitive receptor is 40 dBA. There is in addition a minimum setback of 550 meters from sensitive receptors. Typically, the ambient nighttime noise in a rural area is 25 dBA. The 15 dBA intrusion of the turbine noise above

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[1] Queen's University, Kingston, Ontario, Canada

Corresponding Author:
John P. Harrison, Department of Physics, Engineering Physics & Astronomy, Queen's University, 99 University Avenue, Kingston, Ontario, K7L 3N6, Canada
Email: harrisjp@physics.queensu.ca

ambient corresponds to a sound three times as loud as the ambient, well above the 3 dBA detectability.

Ontario is now unique in allowing the noise limit to rise with the wind speed, up to 51 dBA at a wind speed of 10 m/s. The justification is based on masking noise from the wind. This is discussed further below.

Significance of Turbine Noise Regulation

It is usual when planning a wind farm to base the setback of the turbines from homes on the local noise regulation. Of course, there are many wind farms in unpopulated regions and noise is not a concern. However, in many cases turbines are being "shoe-horned" (Rolf Miller, Director of Wind Assessment at Chicago-based Acciona Windpower, quoted in Del Franco, 2011) in and noise is the dominant concern. The protocol is to base the siting of turbines on the prediction of the noise at a receptor. There is no routine testing for compliance postconstruction and therefore no feedback on the planning of future wind farms. In cases where complaints have led to noise audits that have demonstrated noncompliance, the receptors have been compensated but still no feedback.

There is routine software that starts with the coordinates of the proposed turbine sites and the turbine noise specifications and outputs noise contours for the area of the wind farm. The contour maps are drawn for a range of wind speeds. The noise specification is the sound power, with the total sound power from the extended source (the blades and nacelle) treated as a spherical source of area 1 m^2, as a function of the wind speed and sound frequency. The software uses a sound propagation algorithm such as ISO 9613-2. In turn, this algorithm requires a ground effect parameter and an atmospheric absorption parameter. The algorithm basically accounts for spherical spreading of the sound wave from the source, reflection and absorption by the ground, and frequency-dependent absorption by the atmosphere.

A typical result, expressed as sound pressure level in dBA as a function of distance of the turbine from a receptor, is shown in Figure 1. A turbine sound power level of 105 dBA was chosen for the example. The lower curve corresponds to a single turbine and the upper curve to 3 turbines equidistant from the receptor. Highlighted on the figure are regulated noise limits of 35 and 40 dBA.It is seen that a 40 dBA noise limit, calculated in this way, corresponds to a setback of about 500 meters. Rarely is a receptor overlooked by a single turbine. For three equidistant turbines, the 40 dBA limit corresponds to a setback of 800 meters. Seen in this light, it is clear that the 550 meters minimum setback specified by the Ontario Ministry of the Environment as part of the Green Energy Act turbine noise regulation is meaningless.

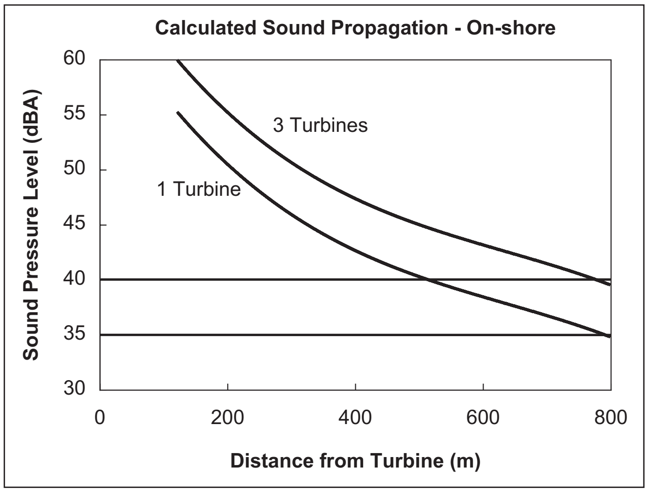

Figure 1. Predicted sound pressure level versus distance from turbine

Noise and Adverse Health Effects

Turbine noise causes annoyance, sleep disturbance and deprivation, and can result in adverse health effects (see, e.g., Frey & Hadden, 2007; Harry, 2007; McMurtry, 2009; Pierpont, 2010). On the basis of the study of widespread complaints of adverse health effects due to turbine noise, various health authorities have recommended setbacks in the range 1.5 to 2 kilometers from homes and other sensitive receptors. In addition to the "one on one" interactions between health professionals and complainants, there have been field studies of the annoyance caused by turbine noise. Perhaps the most significant are the Netherlands study recently reported by Pedersen, van den Berg, Bakker, and Bouma (2009) and the earlier Swedish studies reported by Pedersen and Persson Waye (2004, 2007); the significance is based on the size of the samples, the experience of the investigators and the intercomparison between the studies.

The results are summarized in Tables 1 and 2. The authors used five categories for the response to turbine noise of those survey respondents: did not notice, noticed but not annoyed, slightly annoyed, rather annoyed, and very annoyed. The sound level at the respondents' homes was calculated using ISO 9613-2. The resulting sound levels were checked against two other algorithms with no significant difference found (<1 dBA). A ground absorption parameter of 1 (perfectly absorbing) was used in the ISO calculation. This is the same value as used by Ontario, for instance.

It would appear that a noise limit of 40 dBA will result in annoyance (rather plus very annoyed) for about 20% of the population subject to that noise level. Again, for many wind farms in low-populated regions this is not a problem because there is no need to site to the noise limit. However, where rural populations are denser and where turbines are being "shoe-horned" in, this is a problem. Southern Ontario, Quebec,

Table 1. Respondents in Rural Sweden (*N* = 1095)

Noise (dBA)	Rather Annoyed (%)	Very Annoyed (%)	Total (%)
35-40	3	6	9
40-45	10	19	29

Table 2. Respondents in Rural Netherlands (*N* = 586)

Noise (dBA)	Rather Annoyed (%)	Very Annoyed (%)	Total (%)
35-40	14	6	20
40-45	7	18	25

Nova Scotia, and Prince Edward Island are obvious examples from Canada.

For comparison, it is interesting to note that Miedema and Vos (1998) found that just 2% to 4% of respondents were annoyed by traffic noise at the 40 dBA level.

Reconciliation Between Regulation and Adverse Health Effects

There is a problem. Noise regulation in the range 40 to 50 dBA allows turbines to be placed within 500 meters of homes and other sensitive receptors. Subsequently, in a significant fraction of such homes, residents are being annoyed, are suffering sleep deprivation and disturbance, and in many cases, are suffering adverse health effects. Yet for other noise sources the limit appears reasonable. We now know that turbine noise has characteristics that contribute to this situation. We also know that there are factors not considered when applying the noise regulations. Finally, there is a reluctance to test for compliance. One can understand the reluctance; each turbine costs about $5 million to put in place and unlike industrial machinery there is no possibility of shielding the noise at source. Nevertheless, regulation without compliance testing is unethical.

The characteristics of turbine noise that contribute to annoyance and sleep disturbance are as follows: The sound from turbines is amplitude modulated at the blade passage frequency. The modulation level is typically 3 to 5 dBA (van den Berg, 2005) but higher levels have been measured (Moorhouse, Hayes, von Hünerbein, Piper, & Adams, 2007). Two things arise: The peak sound is higher than the average used for noise regulation and the modulation enhances the audibility of the sound to such an extent that the turbine noise can be detected even when the sound is below ambient (Hanning, 2010). The noise emitted by a turbine is broadband; however, at a distance of 500 meters and more, the higher frequencies have been absorbed by the atmosphere so that it is predominantly low-frequency noise that reaches a receptor. This low-frequency noise enhances annoyance and is more readily able to penetrate walls and resonate inside rooms. Many people report a thumping, rumbling, or impulsive character to the turbine noise (e.g., Frey & Hadden, 2007; Harry, 2007); the reason is not clear.

Deficiencies With Present Noise Regulation

As noted above, the character of turbine noise makes it especially intrusive. This is exacerbated by the fact that wind turbines are sited in rural areas where the ambient noise level can be about 25 dBA. An intrusion of 15 dBA is too large. Germany has a nighttime noise limit of 35 dBA; this should be the international absolute maximum.

Also as noted above, the standard algorithm for predicting noise at a receptor is ISO-9613-2. But, this was never designed for turbine noise. The ISO manual is specific in limiting its use to noise sources close to the ground such as "road or rail traffic, industrial noise sources, construction activities, and many other ground-based noise sources." Turbine noise derives from blades rotating, typically, between 35 to 125 meters above ground level. When used without compliance, testing the results of the predictions have little meaning.

The authors of noise prediction algorithms appreciate that there is uncertainty in the calculations. For instance, the manual for ISO 9613-2 puts the uncertainty at ±3 dBA for a source to receptor distance in the range 100 to 1,000 meters. The turbine makers know that there is variability in manufacture; this is put at ±1 or ±2 dBA. Combining these, the predictions can be no better than ±4 dBA. This uncertainty is ignored by the wind energy developers and by the regulatory authorities. This is despite the fact that the final siting plans are signed off by professional engineers and approved by professional engineers.

All prediction algorithms assume spherical spreading of the sound from the turbines. This is not necessarily always so. Sound propagation experiments over hard surface, such as water or packed sand, have demonstrated a transition from spherical to cylindrical spreading even for distances of less than 1 kilometer (Boué 2007; Hubbard & Shepherd, 1991). Packed snow would be another example of a hard surface. The cylindrical spreading is a result of refraction of sound in the atmosphere and channeling of sound between the atmosphere and the ground (Søndergaard & Plovsing, 2005).The distance at which the transition occurs depends on the wind speed and temperature gradients in the low atmosphere and will vary with time of year, time of day, and weather.

Turbines leave behind them a turbulent wake and a wind speed deficit. Turbulence is known to exacerbate turbine noise (Amiet, 1975; Moriarty, 2004; Moriarty, Guidati, & Migliore, 2004, 2005; Moriarty & Migliore, 2003; Romera-Sanz & Matesanz, 2008). Turbulence occurs naturally in the atmosphere but the wake turbulence can equal this natural turbulence out to 5 blade diameters (Barthelmie et al., 2003). Experiments with an isolated turbine at the National Renewable Energy Laboratory in the United States have demonstrated this excess noise for measured natural turbulence and compared it with turbulent inflow noise calculations (Moriarty, 2004). Below 200 Hz, the turbulent inflow noise dominates over all other aerodynamic sources for turbulent intensities above 10%. No account of this excess noise is included in any noise regulation.

The use of masking noise to justify an increase of the noise limit with wind speed was laid to rest by the pioneering work of van den Berg (2004). He argued that in a stable atmosphere there can be a large vertical wind speed gradient such that the turbine is generating power and noise while at ground level there is insufficient wind to generate masking noise. He supported his argument with meteorological tower wind speed measurements. At that time, only the Netherlands, New Zealand, and Ontario were permitting wind developers to use the masking noise allowance. The Netherlands and New Zealand have since dropped the allowance. Ontario persists but since October 2008 (Ministry of the Environment, 2008) does require that developers justify its use by making on-site wind speed gradient measurements. Needless to say, the developers are not able to justify its use. The pity of it is that so many wind farms have been built with setbacks based on the allowance years after van den Berg had so clearly made his case.

The Way Ahead

At a minimum, the following need to be introduced into noise regulation of wind turbines.

The noise limit needs to be reduced to 35 dBA at nighttime and, where applicable, reduced to 40 dBA for daytime. This is still intrusive in rural areas but will help bring setbacks to those recommended by health authorities. Wind energy and the wind industry have flourished in Germany with these regulations, despite a population density 20 times that of Ontario.

A penalty of 5 dBA needs to be added to the time-average predicted noise levels; this is to compensate for the enhanced audibility of the amplitude-modulated and impulsive character of turbine noise.

Uncertainty in design calculations is the norm in engineering practice. The ±4 dBA is real and should be tolerated in the noise prediction calculation. For the wind developers, erring on the side of caution could protect their very large investments when testing for compliance does become the norm.

A great deal is known about the excess noise due to turbulent inflow. Wind energy developers need to make test tower measurements of local natural turbulence and make calculations of wake turbulence to predict this excess noise.

Compliance is not so difficult. It is common practice to check for compliance in all manner of industrial situations. Atkinson & Rapley Consulting (2011), is association with Astute Engineering, in New Zealand has developed a fully automatic environmental noise measurement system. This is in service in New Zealand for compliance testing of wind turbine noise. Compliance testing is vital because it leads to reconsideration of noise prediction calculations. Where noise audits have been done, such as that at a home near Shelburne in Ontario, turbine noise well in excess of the noise limit has been demonstrated. In such cases, the wind energy company pays compensation or buys out the home-owner; no iterative use is made of the audit.

With the above changes to the regulation of noise: a 35 dBA nighttime noise limit, penalties of 5 dBA for the periodic or impulsive character of turbine noise, 4 dBA for uncertainty in noise prediction, and a penalty for turbulent inflow noise the setback from homes will approach the 1.5 to 2 kilometers recommended by health authorities.

Offshore Turbine Noise

At present there are no freshwater offshore wind farms and therefore no reported adverse health effects. Nevertheless, they are under consideration for Great Lakes both north and south of the border. It is our common experience that sound propagates readily over water and therefore it is expected that turbine noise will be a bigger problem for offshore wind farms. The science of noise from offshore wind turbines has been reviewed in a report for the Danish Ministry of the Environment (Søndergaard & Plovsing, 2005). They emphasize the "Swedish Model" (2001), which allows for a transition from spherical spreading to cylindrical spreading beyond a certain distance from the turbine. As noted above, the cylindrical spreading results from refractive reflection from the atmosphere and reflection from the water as a hard surface. The transition distance is a parameter that depends on the wind speed and temperature gradients.

This Swedish propagation model, for distances larger than a transition distance d, is written as

$$L = L_s - 20\log(r) - 11 + 3 - \Delta L_a + 10\log\left(\frac{r}{d}\right),$$

where L is the sound pressure level at the observer, L_s is the turbine sound power (e.g., 105 dBA), 11 is $10\log(4\pi)$, 3 is 3 dBA of ground reflection, ΔL_a is the integrated frequency dependent absorption coefficient, a function of r, and r is the distance from turbine hub to the observer. The second term on the right gives the spherical spreading and the final term corrects for cylindrical spreading beyond the distance d. Søndergaard and Plovsing (2005) have calculated the integrated absorption coefficient and show the result in figure 17 of their report. For instance, at a distance of 5 kilometers, it is 8 dBA. The transition distance for the onset of cylindrical spreading was uncertain but was assumed to be less than 1 kilometer.

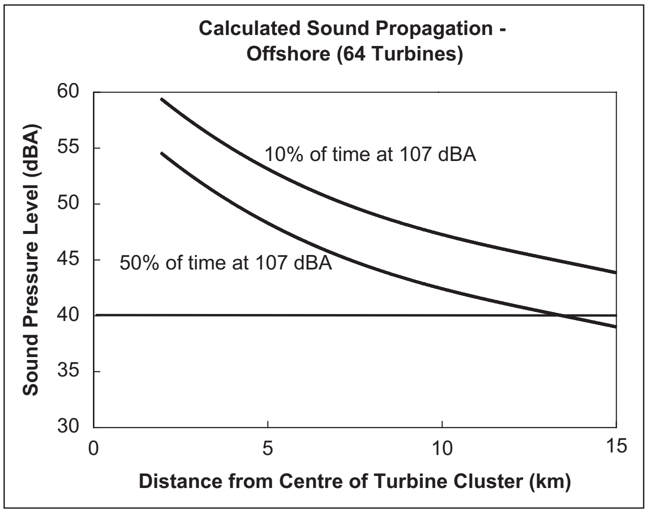

Figure 2. Predicted sound pressure level versus distance from group of 64 offshore turbines

The work of Søndergaard and Plovsing (2005) was followed up by sound propagation experiments over sea in the Kalmar Strait between Sweden and the Öland island in the Baltic Sea (Boué, 2007). The separation between source and receiver was 9.7 kilometers. Measurements of *average* sound transmission loss showed agreement with the Swedish propagation model with a transition distance of 700 meters for the break between spherical and cylindrical spreading. Furthermore, the measured TL(90), the transmission loss exceeded 90% of the time, was in agreement with the Swedish propagation model with the 200 meter transition distance. Therefore, Boué's measurements allow a reliable estimate of the sound pressure level as a function of distance over water from a turbine. Interestingly, Dickinson (2010) in New Zealand has found the break point of 750 meters for turbine noise propagation over land.

At large distances, such as 5 kilometers, the path difference between the direct and reflected pathways from turbine to receptor become small. For instance, at a distance of 5 kilometers, the path difference is equal to or less than a quarter wavelength for frequencies ≤1700 Hz. That is, for the spectrum of sound that reaches a receptor the direct and reflected sound waves add coherently. This adds 3 dB to the sound pressure level.

A numerical example demonstrates the difference between sound propagation over land and water. Figure 2 shows the predicted sound pressure level as a function of distance from a group of 64 offshore turbines. The example uses the Siemens 2.3 MW turbines, which reach their maximum sound power level of 107 dBA when the electrical power output is just 25% of the turbine nameplate power output. The wind farm will have some extension of course. The distance is the mean distance from the group. The lower curve is based on the average transition distance of 700 meters determined by Boué; the upper curve corresponds to the sound pressure level expected for 10% of the time that the turbines are operating at a capacity factor of 25% or greater. For the "worst case scenario" the setback of the wind farm needs to be 20 kilometers offshore.

Conclusion

Wind turbines are noisy and cause annoyance in about 20% of residents living within a distance considered acceptable by regulatory authorities. For many of this 20%, the annoyance and sleep disturbance leads on to adverse health effects. This is a far larger proportion than for those living with traffic and industrial noise at the same level. The annoyance and adverse health effects are attributable to the character of turbine noise and to deficiencies in noise regulations. Specifically, given the amplitude modulation, the allowed intrusion above ambient is far too high; there is no account taken of uncertainty in the prediction of noise at a home; there is no account taken for the excess noise caused by turbulent inflow, both natural and up-wind turbine wake; and the lack of compliance testing leaves the adverse health effects to compound from one completed wind farm to the next one being designed.

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References

Amiet, R. K. (1975). Acoustic radiation from an airfoil in a turbulent stream. *Journal of Sound and Vibration, 41*, 407-420.

Atkinson & Rapley Consulting. (2011). *SAM: The spectro-acoustic-meter*. Retrieved from http://www.atkinsonrapley.co.nz/SAM.html

Barthelmie, R. J., Folkerts, L., Ormel, F. T., Sanderhoff, P., Eecen, P. J., Stobbe, O., & Nielsen, N. M. (2003). Offshore turbine wakes by sodar. *Journal of Atmospheric and Oceanic Technology, 20*, 466-477.

Boué, M. (2007). *Long-range sound propagation over the sea with application to wind turbine noise*. (Project Report No. 21597-3). Swedish Energy Agency. Retrieved from http://www.vindenergi.org/Vindforskrapporter/V-201_TRANS_webb.pdf

Del Franco, M. (2011, January 27). Johns Hopkins study examines proper wind turbine spacing. *North American Windpower*. Retrieved from http://nawindpower.com/e107_plugins/content/content.php?content.7257

Dickinson, P. J. (2010). Sounds from wind turbines: Theory, practice, assumptions and reality. In B. Rapley & H. Bakker (Eds.), *Sound, noise flicker and the human perception of wind farm activity* (p. 175). Palmerston North, New Zealand: Atkinson & Rapley.

Frey, B. J., & Hadden, P. J. (2007). *Noise radiation from wind turbines installed near homes: Effects on health*. Retrieved from http://docs.wind-watch.org/wtnoisehealth.pdf

Hanning, C. (2010, October). *The torment of sleep disturbance*. Paper presented at the First International Symposium on The Global Wind Industry and Adverse Health Effects: Loss of Social Justice?, Picton, Ontario, Canada. Retrieved from http://docs.wind-watch.org/07-swv_symposium_presentation_the_torment_of_sleep_disturbance.pdf

Harry, A. (2007). *Wind turbines, noise and health*. Retrieved from http://www.wind-watch.org/documents/wind-turbines-noise-and-health/

Hubbard, H. H., & Shepherd, K. P. (1991). Aerocoustics of large wind turbines, *Journal of the Acoustical Society of America, 89*, 2495-2508.

McMurtry R. (2009). Deputation to the Standing Committee on General Government regarding Bill C-150. Retrieved from http://windconcernsontario.files.wordpress.com/2009/04/deputation-to-standing-committee-mcmurtry.pdf and http://windconcernsontario.files.wordpress.com/2009/04/ontario-health-survey-april-22-2009.pdf

Miedema, H. M., & Vos, H. (1998). Exposure response relationship for transportation noise. *Journal of the Acoustical Society of America, 104*, 3432-3445.

Ministry of the Environment. (2008). *Noise guidelines for wind farms: Interpretation for applying MOE NPC publications to wind power generation facilities*. Toronto, Ontario, Canada: Author. Retrieved from http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079435.pdf

Moorhouse, A. T., Hayes, M., von Hünerbein, S., Piper, B. J., & Adams, M. D. (2007). *Research into aerodynamic modulation of wind turbine noise: Final report*. Technical Report, Department for Business, Enterprise and Regulatory Reform, UK. Retrieved from http://usir.salford.ac.uk/1554/1/Salford_Uni_Report_Turbine_Sound.pdf

Moriarty, P. (2004, January). *Development and validation of a semi-empirical wind turbine aero-acoustic code*. Paper presented at the 42nd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV. Retrieved from http://pdf.aiaa.org/preview/CDReadyMASM04_665/PV2004_1189.pdf

Moriarty, P. J., Guidati, G., & Migliore, P. G. (2004). *Recent improvement of a semi-empirical aerocoustic prediction code for wind turbines*. Reston, VA: American Institute of Aeronautics and Astronautics. Retrieved from http://pdf.aiaa.org/preview/CDReadyMAERO04_1013/PV2004_3041.pdf

Moriarty, P. J., Guidati, G., & Migliore, P. G. (2005). *Prediction of turbulent inflow and trailing-edge noise for wind turbines*. Reston, VA: American Institute of Aeronautics and Astronautics. Retrieved from http://pdf.aiaa.org/preview/CDReadyMAERO05_1140/PV2005_2881.pdf

Moriarty, P., & Migliore, P. (2003). *Semi-empirical aeracoustic noise prediction code for wind turbines* (NREL Report No. TP-500-34478). Retrieved from http://www.amherstislandwindinfo.com/moriarty_nrel_noise_report.pdf

Pedersen, E., & Persson Waye, K. (2004). Perception and annoyance due to wind turbine noise. *Journal of the Acoustical Society of America, 116*, 3460-3470.

Pedersen, E., & Persson Waye, K. (2007). Wind turbine noise, annoyance and self-reported health and well-being in different living environments. *Occupational and Environmental Medicine, 64*, 480-486.

Pedersen, E., van den Berg, G. P., Bakker, R., & Bouma, J. (2009). Response to noise from modern wind farms in the Netherlands. *Journal of the Acoustical. Society of America, 126*, 634-643.

Pierpont, N. (2010). *Wind turbine syndrome: A report on a natural experiment*. Santa Fe, NM: K-Selected Books.

Romera-Sanz, I., & Matesanz, A. (2008). Noise management on modern wind turbines. *Wind Engineering, 32*, 27-44.

Salt, A. N., & Hullar, T. E. (2010). Response of the ear to low frequency sounds, infrasound and wind turbines. *Hearing Research, 268*, 12-21.

Søndergaard, B., & Plovsing, B. (2005). *Noise from off-shore wind turbines* (Project No. 1016). Danish Ministry of the Environment, Environmental Protection Agency. Retrieved from http://www2.mst.dk/udgiv/publications/2005/87-7614-687-1/pdf/87-7614-689-8.pdf

Swedish Model. (2001). *Ljud från vindkraftverk* [Sound from wind turbines]. Naturvårdsverket [Swedish Environmental Protection Agency]. Retrieved from http://swedishepa.com/Documents/publikationer/620-6241-7.pdf

van den Berg, G. P. (2004). Effects of the wind profile at night on wind turbine sound. *Journal of Sound and Vibration, 277*, 955-970.

van den Berg, G. P. (2005). The beat is getting stronger: The effect of atmospheric stability on low frequency modulated sound of wind turbines. *Journal of Low Frequency Noise, Vibration and Active Control, 24*, 1-24.

Walsh, O. (2010, October). *No global standards*. Paper presented at the First International Symposium on The Global Wind Industry and Adverse Health Effects: Loss of Social Justice?, Picton, Ontario, Canada. Retrieved from http://docs.wind-watch.org/01-swv_symposium_presentation_no_global_standards.pdf

Bio

John P. Harrison has expertise in the properties of matter at low temperatures with emphasis on high frequency sound waves (phonons). For the past 5 years he has studied wind turbine noise and its regulation. He has presented invited talks on the subject at 3 conferences, including the 2008 World Wind Energy Conference.