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EDITORIAL / EDITORIAL

Once a year I get to share my thoughts about the journal with you. Owing to a slight rescheduling this year, you hear my voice in June rather than in March. Let me begin by saying that the Canadian Acoustics Journal is running smoothly with the assistance of the journal team of Chantal Laroche, Steve Bilawachuck, Jason Tsang and the new Assistant Editor Ralph Baddour, who solicits articles for the journal. My sincere thanks to them all.

Canadian Acoustics is being evaluated to be included in the Publishing ISI index. If we are successful, all the articles will be indexed in the ISI list. A wider publicity for the articles and the authors would thus be assured. We will know the evaluation results by the end of this year and we will keep you posted.

This issue of Canadian Acoustics is a special dealing with wind turbine noise. The impetus for this special came about as a result of the conference held in May 2005 in Banff, Alberta, under the auspices of the Alberta Energy Board. Thanks to the assistance of David DeGagne and Anita Lewis, we have a set of diverse articles on wind turbine noise including a review of a book on Wind Turbines. Let me also convey my appreciation to our Director Rich Peppin for assisting in soliciting articles for this special of Canadian Acoustics. Our Associate Editor, Chantal Laroche, in her March editorial, requested our Canadian members to write more articles. I am happy to inform you that four articles in this issue have been written by Canadian members.

The idea of issuing Canadian Acoustics specials led me to contemplate the real possibility of increasing the number of journal to six a year. However, the financial viability of such a venture forced us to rethink the idea. The Board requested us to develop a financial plan for the viability of adding one more issue, i.e., five per year. We should have some answers for the next AGM in Halifax. We can then decide whether to bring out five issues in 2008.

Finally, Nicole Collison and her team are feverishly working on presenting a great meeting in Halifax in October. Do come to the meeting, present a paper, and make the Halifax team happy and proud.

Ramani Ramakrishnan
Editor-in-Chief

Une fois par an, je partage mes pensées du journal avec vous. À cause de certaines imprévues dans la cédule de cette année, vous avez de mes nouvelles un peu plus tard que d'habitude, i.e. au mois de Juin plutôt qu'au mois de Mars. Laissez-moi commencer par vous dire que le journal Acoustique Canadienne fonctionne très bien avec l'assistance de Chantal Laroche, Steve Bilawachuck, Jason Tsang, et le nouvel assistant en rédaction Ralph Baddour, qui sollicite des articles pour le journal. Mes remerciements les plus sincères pour tous.

Acoustique Canadienne est en évaluation pour être inclus dans l'index de publication ISI. Si nous réussissons, tout les articles seront mis en index de la liste du ISI. Ce qui ferait une plus grande publicité pour les articles et les auteurs. Nous aurons les résultats de cette évaluation vers la fin de l'année en cours et nous vous tiendrons au courant.

Ce numéro du journal de Acoustique Canadienne est spécialement dédié aux bruits des éoliennes. Ce sujet résulte de la conférence de 2005 tenue à Banff, Alberta, avec le support de "Alberta Energy Board". Je tiens à remercier en particulier David DeGagne et Anita Lewis pour leurs supports dans cette initiative. Nous avons une panoplie d'articles variés sur le bruit des éoliennes, y compris une revue d'un livre sur le bruit des éoliennes. J'aimerais aussi remercier notre directeur Rich Peppin pour son support à la sollicitation d'articles pour cette édition spéciale. Notre rédactrice, Chantal Laroche, a demandé à nos membres canadiens dans l'édition du mois de Mars de soumettre plus d'articles. Je suis content de vous informer que quatre articles de ce numéro ont été écrits par des membres canadiens.

L'idée de publier un numéro spécial de Acoustique Canadienne m'a permis de considérer d'augmenter le nombre de publication du journal à six par an. Cependant, la situation financière actuelle ne le permet pas encore. Le comité de directeurs nous a demandés de développer un plan de financement pour le rajout d'un numéro par an, i.e. cinq par année. Nous aurons quelques réponses pour la réunion annuelle du comité qui se déroulera à Halifax. Nous déciderons à ce moment là si on passe à cinq éditions par an pour 2008.

Finalement, Nicole Collison et son équipe, sont très actives dans la préparation d'une grande conférence à Halifax au mois d'Octobre prochain. Venez nombreux assister, présenter des articles, à cet évènement afin de rendre l'équipe de Halifax content et fier.

Ramani Ramakrishnan
Rédacteur en chef

Wind Turbine Noise Primer

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ABSTRACT

A wind turbine is a modern machine that generates electricity from wind. Wind turbines generate four types of noise: tonal, broadband, low frequency, and impulsive. Another way to look at wind turbine noise is to consider its sources. There are two fundamental categories, mechanical and aerodynamic. Mechanical noise is transmitted along the structure of the turbine and is radiated from its surfaces. Aerodynamic noise is produced by the flow of air over the blades. In the United States, wind farm siting often requires compliance with state and/or local noise regulations. Common practice is to determine minimum setback distances from residences to comply with the most stringent noise limit. Geographic Information Systems (GIS) is a valuable tool in this type of analysis, particularly when current aerial photographs are available in GIS-ready format. Although recent technology advances has decreased overall noise levels, tonal noise still remains a concern during the planning process. Detailed meteorological data is available for most portions of the United States, however it is not commonly used to evaluate wind turbine noise. The authors of this paper are studying the creation of a GIS-based model that utilizes detailed met data in the propagation of wind turbine noise.

RÉSUMÉ

Une éolienne est une machine moderne qui produit de l'électricité par le vent. Les éoliennes génèrent quatre types de bruit: tonal, à large bande, de basse fréquence et impulsif. Une autre façon de voir le bruit des éoliennes est de considérer ses sources. Il y a deux catégories fondamentales, soit mécanique et aérodynamique. Le bruit mécanique est transmis le long de la structure de la turbine et est émis de ses surfaces. Le bruit aérodynamique est produit par le flot d'air à travers les pales. Aux États-Unis, les nombreuses centrales d'éoliennes doivent être conformes à la réglementation sur le bruit de l'état et/ou de la région. Une pratique commune est de déterminer la distance minimale des résidences pour mettre en application la limite de bruit la plus sévère. Les Systèmes d'Information Géographique (SIG) (« Geographic Information Systems ») représentent un outil valable pour ce type d'analyse, particulièrement lorsque les photographies aériennes actuelles sont disponible sous des formats 'GIS-ready' (GSI-ready format). De plus, des progrès technologiques récents ont fait décroître le niveau de bruit total, mais le bruit tonal reste toujours une inquiétude lors du procédé de planification. Des données météorologiques détaillées sont disponibles pour la majorité du territoire américain, cependant ces données ne sont pas utilisées couramment pour évaluer le bruit des éoliennes. Les auteurs de cet article ont étudié la création d'un modèle basée sur les SIG qui utilise des données détaillées pour la propagation du bruit des éoliennes.

1. INTRODUCTION

A wind turbine is a modern machine that generates electricity from wind. Wind turbines may or may not be a familiar sight in your area, but their image is not unfamiliar. It is easy to envision a tall, slender, yet massive tower capped with a box-like structure. Propeller blades are held in place by an aerodynamic noise cone. The image is reminiscent of windmills in Holland, though more modern-looking. Rather than harnessing wind energy to drive pumps or to grind grain, modern wind turbines generate electricity.

A wind turbine consists of numerous components. There is a tower or mast that is typically between 50 and 80 meters tall and made of tubular steel. The tower rests on a footing, generally made of reinforced concrete, and often nine feet tall (thick) and 20-feet wide. At the top of the tower is the nacelle, the box-like housing. Inside the nacelle are the electrical generator, the gearbox, and other control equipment. The blades make up the propeller-like structure called the rotor. Typically there are three blades on a rotor; each blade may exceed 30 meters long (SEDA, 2002, 1). When a group of wind turbines exist together in an area, it is called a wind farm.

2. CHARACTERIZATIONS

2.1 Wind Turbine Noise Types

Wind turbines generate several types of noise: tonal, broadband, low frequency, and impulsive.

Tonal: Tonal noise is defined as noise at discrete frequencies.

It is caused by wind turbine components such as meshing gears, non aerodynamic instabilities interacting with a rotor blade surface or unstable flows over holes or slits or a blunt trailing edge (non-pointed wing tip).

Broadband: This is noise characterized by a continuous distribution of sound pressure with frequencies greater than 100 Hz. It is often caused by the interaction of wind turbine blades with atmospheric turbulence. A more tangible way to describe this type of noise is to describe it as a characteristic "swishing" or "whooshing" sound.

Low frequency: Noise dominated by frequencies in the range of 20 to 100 Hz is mostly associated with downwind turbines (turbines with the rotor on the downwind side of the tower). It is caused when the turbine blade encounters localized flow deficiencies due to the flow around a tower.

Impulsive: This noise is described by short acoustic impulses or thumping sounds that vary in amplitude with time. It is also caused by the interaction of wind turbine blades with disturbed air flow around the tower of a downwind machine (Rogers and Manwell, 2004, 2).

2.2 Wind Turbine Noise Sources

Another way to look at wind turbine noise is to consider its sources. There are two fundamental categories, mechanical and aerodynamic. Mechanical noise is transmitted along the structure of the turbine and is radiated from its surfaces. Aerodynamic noise is produced by the flow of air over the blades. A summary of each of these noise mechanisms follows. A more detailed review is included in the text of Wagner, et al. (1996, 3).

2.2.1 Aeroacoustical noise

Aeroacoustical noise refers to noise created by the rotor blades. Quite a bit of research has been performed to evaluate how noise is generated by the blades. This is comparable to research performed on aircraft wings, propeller blades, and helicopter blades. It is fundamentally an issue of viscous flow across an airfoil. Aeroacoustical noise can be categorized into six types, and noise emissions occur when the blade interacts with turbulent layers of air.

- Laminar boundary layer vortex – laminar flow occurs where the air streamlines are smooth and regular, and air flow moves smoothly along a streamline. This results in a zone behind the blade that produces shedding noise.
- Turbulent boundary layer trailing edge noise occurs at the down-wind edge of the blade. A turbulent layer of air occurs where the air streamlines break up, and a fluid element moves in a random, irregular fashion.
- Leading edge inflow turbulence noise occurs in front of the blade. An area of turbulence exists in front of the blade as it moves through the air. As the blade moves toward and into this turbulent layer, scattering occurs at the leading edge of the blade, radiating noise.
- Blunt trailing edge noise occurs as a result of air movement past the blunt end of the blade tip creating turbulent vortices.
- Separation noise arises due to very high angle of attack (of the rotor blade) relative to the air flow (high incidence angle). When the incidence angle is flat, air pressure on rotor blades is perpendicular to the surface and balances on the top and bottom surface of the blade. Air flow over a rotor blade is smooth. But as the angle of incidence increases, air flow over the top of the blade becomes separated from the blade itself, creating a zone of turbulence over the top of the blade. This zone of turbulence creates noise.
- Blade tip noise occurs when air flows across the blade tip interacts with turbulence created at the trailing edge of the blade (Anderson, 1978, 4) – (Milgiore, 2002, 5).

Rogers and Manwell (2004) summarized wind turbine noise aerodynamic noise mechanisms in Table 1.

Table 1. Wind Turbine Aerodynamic Noise Mechanisms

Type or Indication	Mechanism	Main Characteristics and Importance
Low-frequency Noise		
Steady thickness noise; steady loading noise	Rotation of blades or rotation of lifting surfaces	Frequency is related to blade passing frequency, not important at current rotational speeds
Unsteady loading noise	Passage of blades through tower velocity deficit or wakes	Frequency is related to blade passing frequency, small in cases of upwind turbines/possibly contributing in wind farms
Inflow turbulence noise	Interaction of blades with atmospheric turbulence	Contributing to broadband noise; not yet fully quantified
Airfoil Self-noise		
Trailing-edge noise	Interaction of boundary layer turbulence with blade trailing edge	Broadband, main source of high frequency noise (770 Hz < f< 2 kHz)
Tip noise	Interaction of tip turbulence with blade tip surface	Broadband; not fully understood
Stall, separation noise	Interaction of turbulence with blade surface	Broadband
Laminar boundary layer noise	Non-linear boundary layer instabilities interaction with the blade surface	Tonal, can be avoided
Blunt trailing edge noise	Vortex shedding at blunt trailing edge	Tonal, can be avoided
Noise from flow over holes, slits and intrusions	Unstable shear flows over holes and slits, vortex shedding from intrusions	Tonal, can be avoided

Researchers study airfoil design to minimize friction and turbulence. Blade tip design is also a research topic, as it also creates turbulence and noise. Recent research efforts evaluated serrated blade tip edges in an attempt to minimize turbulence and noise. Researchers have also focused on how to maximize the conversion of wind energy to rotational energy and minimize blade noise emissions.

2.2.2 Mechanical Noise

Mechanical noise originates from the relative motion of mechanical components and the dynamic response among them. There are several sources: Wagner, et. al. (1996) provides estimates of their relative structure-borne (sb) and air-borne (ab) sound power (Lw) contributions for a sample 2 MW turbine whose total sound power is 102.2 dBA. These sources include:

- Gearbox – the hub rotates on an axle that connects to the gearbox. The gearbox converts rotational energy into mechanical energy. The gearbox is considered one of two dominant sources of mechanical noise. Gearbox noise is radiated through the nacelle and through the tower (Lw sb = 9 7.2 dBA). It is also radiated directly through vents or openings in the nacelle (Lwab = 84.2 dBA).
- Generator – the second of two dominant sources of mechanical noise (Lwab = 87.2 dBA).
- Auxiliary Equipment – including hydraulics used to control pitch and yaw of the rotors, cooling fans used to regulate the temperature of the generator inside the nacelle, and yaw drives used to control the rotational speed of the rotor, yaw drives adjust the angle of individual blades relative to the direction that the wind is blowing from (Lwab = 76.2 dBA).
- Hub – the axle upon which the rotors turn (Lwsb = 89.2 dBA).

Since the emitted noise is associated with the rotation of mechanical and electrical equipment, it tends to be tonal (of a common frequency), although it may have broadband components. For example, pure tones can be emitted at the rotational frequencies of shafts and generators, and the meshing frequencies of the gears.

In addition, the hub, rotor, and tower radiate the mechanical noise. They act as loudspeakers, transmitting the mechanical noise and radiating it. The transmission path of the noise can be air-borne or structure-borne. Air-borne means that the noise is directly propagated from the component surface or interior into the air. Structure-borne noise is transmitted along other structural components before it is radiated into the air (Rogers and Manwell, 2004)

3. PRACTICAL CONSIDERATIONS

3.1 Range of Regulatory Programs

In the United States, wind farm siting often requires compliance with state and/or local noise regulations. Often, wind turbine noise emissions are evaluated during both daytime and nighttime hours at the nearest noise-sensitive receptors which are typically rural residences. In the authors' experience, noise limits often range from 60 to 70 dBA during the daytime and 45 to 55 dBA during the nighttime, where nighttime compliance is the biggest concern. Common practice is to determine minimum setback distances from residences to comply with the most stringent noise limit. For example, modern wind turbines with a hub height of approximately 80 meters could have an overall noise level of 50 dBA predicted at distances between 600 to 1000 feet from the turbine. Buffer zones are often greater than 1000 feet, making compliance with regulatory levels obtainable in most cases.

3.2 Evaluation Strategies and Issues

Geographic Information Systems (GIS) is a valuable tool in this type of analysis, particularly when current aerial photographs are available in GIS-ready format. In this instance, the noise model calculates the distance to the threshold noise level, which is used as a noise contour or buffer distance. The noise analyst then uses GIS to plot buffers around each wind turbine. This allows confirmation that each wind turbine has been sited in a location that does not have a noise-sensitive land use within the minimum noise contour distance.

Strategies for evaluating wind turbine noise are driven by the analysis goal. The authors deal with one of two primary strategies - compliance with local noise regulations (maximum allowable noise levels) or controlling increases of background noise levels at nearby noise-sensitive receptors (residences) in rural locations.

Common practice in evaluating the wind turbine noise for compliance with noise regulations is to use simple propagation equations to predict setback distances. Because regulatory limits are typically broadband levels, demonstration of compliance does not require a spectral analysis or an in-depth analysis of wind profiles, temperature gradients, and terrain features. Other than simple propagation equations, wind speed and temperature profiles aren't included in typical calculations and variations in wind noise/turbine noise aren't simulated by current algorithms.

Wind turbine noise analyses can get interesting when the goal is to ensure there is no net increase in noise levels at the nearest noise sensitive receptors. The quality of the noise monitoring data becomes very important, and the locations at which it is measured become critical. Sometimes indoor noise levels are also a concern. This raises the issue of whether or not a particular residence was constructed in a manner, and using materials, that provide adequate insertion loss to noise propagated from outdoors to indoors.

The authors have been involved in a project where site visits evaluated the type and materials used in the construction of homes in a project area. Concerns over potential increases of indoor noise levels required knowledge of the potential insertion loss of specific residential structures. This is more often associated with airport noise mitigation analyses than wind turbine noise analyses.

Air pollutant dispersion models utilize detailed meteorological data collected at a height of 10 meters. Those models use power laws to calculate wind speed profiles at different heights as a function of atmospheric stability. If, during a wind farm siting exercise, meteorological data were collected at the hub height, that data could be processed using the same power laws – and a wind speed and temperature profile could be determined (using the same algorithms used for air pollutant dispersion modeling). The authors currently are investigating the potential application of these resources in the development of a wind turbine noise model that incorporates detailed meteorological data and propagates noise on a spectral basis.

Such a model might alleviate the use of "apparent wind turbine sound power levels." Apparent wind turbine sound power levels exist because of the uncertainty caused by the relationship of wind noise and wind turbine noise. At low wind speeds, wind turbine noise is most noticeable. As wind speeds increase, wind noise increases, and wind turbine noise becomes less distinct. Apparent wind turbine sound power levels are calculated to account for this phenomenon.

This phenomenon contributes to the notion that there are benefits to modeling turbine noise rather than monitoring it because the modeled turbine noise levels eliminate contributions from non-turbine noise sources. Wind noise, vegetation noise, traffic noise, animal noise, and noise from anthropogenic sources compose the ambient acoustic environment in ways that sometimes complicate wind turbine noise analyses. It becomes difficult to isolate the wind turbine noise component of the overall acoustic environment.

For example, this becomes an issue when a noise complaint is filed. The development plans for some wind farms require noise monitoring when complaints are filed about wind turbine noise. Noise data collected in response to a complaint has potentially limited value, because it will be difficult to reproduce the meteorological conditions during the period when the noise complaint originated. Noise modeling can be a useful tool to assess what turbine noise levels may have been like when the complaint originated.

These notions illustrate the relative infancy of wind turbine noise assessment methodologies. While this is true, we note the early stages of an apparent paradigm shift. The emphasis on pre-construction and post-construction noise monitoring has dwindled as familiarity with wind turbine technology, and understanding of their effect on view shed, wildlife, property values, quality of life, and general acceptance grows.

3.3 Tonal Concerns

Although recent technology advances has decreased overall noise levels, tonal noise still remains a concern during the planning process. Evaluating tonal noise emissions has improved with the introduction of standardized methods for measurement. The International Electrotechnical Commission standard (IEC 61400-11) Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques provides methodology for measurement of wind turbine noise at incremental wind speeds from 6 to 10 m/s and for identification of dominant noise level frequencies. The standard has aided manufacturers and acousticians in evaluating wind turbine broadband and tonal noise for comparison with background noise levels. The standardized method tends to provide more consistent and accurate data allowing wind farm planners to more easily assess various turbine models.

4. CONCLUSIONS

Wind turbines are becoming increasingly common sources of energy. The mechanisms, sources and types of noise emitted by wind turbines are becoming better understood. The existing body of aerodynamic and aeroacoustic knowledge supplements the understanding of wind turbine noise. Research continues to expand that body. The dynamic nature of this knowledge suggests that the state of the art of wind turbine noise analysis is one of relative infancy.

An interesting area of research is the development of automated control systems to run turbines below nominal power during nighttime hours. This noise control strategy is not in widespread use, yet has potential to reduce turbine noise during low wind conditions while still allowing electrical generation. Improvements in structure (blade technology, rotors downwind of mast, etc.) are more common examples of the evolution of wind turbine design that also reduce turbine noise emissions.

5. REFERENCES

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Wind Turbine Noise – An Overview

Mark Bastasch[1], Jeroen van Dam[2], Bo Søndergaard[3] and Anthony Rogers[4]
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ABSTRACT

This paper presents a general overview of wind turbine noise including sources, measurements standards, psychoacoustics, infrasound, propagation and regulatory perspectives. The authors presented similar material at the National Wind Coordinating Committee's special meeting on "Technical Considerations in Siting Wind Developments" [1] held in Washington D.C. In addition, many relevant papers can be found in the proceedings of the First International Conference on Wind Turbine Noise 2005 [2], some of which are summarized here.

RÉSUMÉ

Cet article présente un survol général du bruit des éoliennes, incluant les sources, les standards de mesures, la psychoacoustique, les infrasons, la propagation et les perspectives de réglementation. Les auteurs présentent du matériel similaire à la rencontre spéciale du Comité Coordonnateur National du Vent ("National Wind Coordinating Committee's") [1] sur le "Technical Considerations in Siting Wind Developments" tenu à Washington D.C. De plus, plusieurs articles pertinents peuvent être trouvés dans les actes de la Première Conférence Internationale du Bruit des Turbines à Vents en 2005 [2], Quelques un de ces articles sont résumés ici.

1. OVERVIEW

Wind turbines have many parts that generate noise but they can be broadly classified as either aerodynamic or mechanical. Mechanical sources of noise include the gearbox, cooling fans, the generator, the power converter, hydraulic pumps, the yaw motor and bearings. Modern turbines incorporate many mechanical noise-reducing features such as nacelle insulation, gearbox isolation, and silenced ventilation. Aerodynamic noise sources are a function of blade geometry (refer to Figure 1). Similar to a fan, the level of aerodynamic noise is highly correlated with the tip speed. Reducing aerodynamic noise is subject of current research [3].

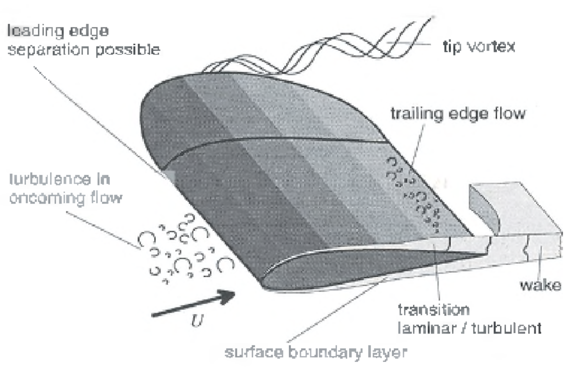

Figure 1: Schematic of flow around the outer part of rotor blade [4]

Modern turbines often have the ability to control their noise emissions through a combination of reduced rotor (and tip) speed and blade pitch angle adjustment. This typically comes at the cost of a reduced electrical power output. Typical sound power values for commercial scale wind turbines are in the range of 96-108 dB(A), LWA between cut-in and rated power.

2. MEASUREMENT STANDARDS

The International Energy Agency (IEA) has established guidelines for measuring the immisions of wind turbine at receptors, including Part 10, "Measurement of noise immission from wind turbines at noise receptor locations [5]." Because wind turbines do not generate noise, or at least not their normal noise level, under calm or low winds, typical guidelines for measuring noise from industrial or transportation sources are often inappropriate. The fact that background noise increases with wind speed, tending to mask turbine noise, complicates measurement interpretation. Typical background noise sound pressure levels range from 30-45 dB(A). Although the IEA provides recommendations to increase the signal to noise ratio, at more distant receptors it can be difficult to distinguish between turbine and background noise. It is for this reason that measuring noise levels closer to the turbine, where the signal to noise ratio is greater, and then calculating levels at greater distances may be preferred by some.

Most, if not all, turbine manufacturers provide sound power level data determined in accordance with International Electrotechnical Commission's (IEC) International Standard IEC 61400-11, *Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Technique (2002)*. This standard defines reproducible measurement techniques that are accepted by the industry and often used in certification, guarantee and permitting applications. The microphone is placed on a reflective plate at ground level to reduce the effects of wind induced noise and to simplify the ground effect to +6 dB at all frequencies. The measurement location is downwind and one hub height plus half the rotor diameter away from the source.

The IEC 61400 standard establishes sound power levels for integer wind speeds between 6 and 10 m/s at a reference height of 10 meters. The reference to 10-meter height wind speeds in the IEC 61400-11 method is often misunderstood. The noise standards in the Netherlands [6] and guidance documents in Britain [7] and Australia [8, 9] often refer to wind speed measurements at 10-meters. This should not be confused with the IEC 61400-11 reference to 10 meters as IEC 61400-11 does not require noise measurements to be made when the winds at 10 meter height are at 6, 7, 8, 9 or 10 m/s or that the microphone is located at a height of 10 meters. In fact, the preferred method (which is required for declaration or certification measurements) does not allow wind speed to be measured with a 10 meter met tower (rather the electrical output of the turbine is the basis for determining the wind speed). The reference to 10-meter wind speeds in IEC 61400-11 is simply to ensure that manufacturers are standardizing their data in a similar fashion so that sound power levels of different turbines can be compared on a level playing field.

This is an important topic to understand particularly when assessing compliance with a relative or ambient degradation standard that limits the increase in noise levels. This is increasingly important as technology improves and the height of turbines continues to increase. Today it is not unusual to see wind turbines mounted on 80- or 100-meter towers, while several years ago 50-meter towers were more common. As the height of the towers increases, the correlation between the 10-meter wind speeds and those at hub height would likely decrease. It is for these reasons that the standardized IEC 61400 sound power levels must be adjusted to account for site specific variable such as roughness length and hub height when evaluating the increase in noise levels at specific wind speeds. Figure 2 shows an example where using the standardized values instead of the adjusted site specific values "will result in an underestimation of the noise contribution from the wind turbine at low wind speeds, and an overestimation of the noise contribution at higher wind speeds" [10]. Numerous papers are available to clarify this common misperception [11, 12].

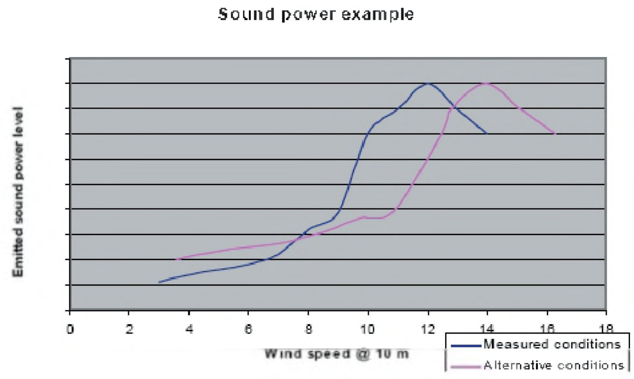

Figure 2: Sound Power Level Example [10]

Besides the determination of the sound power level, the IEC 61400-11 also provides a method for determining the severity of potential tones in the wind turbine noise. The same measurements are used as those taken for the calculation of the sound power level, though now the levels of individual frequency bands are determined. For each potential tonal frequency, its level is compared to the level of neighboring frequencies. The neighboring frequencies, or critical band, have the ability to mask the tone, making it less audible to the human ear. If tonal noise is present, local regulations may require a penalty in the form of reduced acceptable overall level, ultimately resulting in larger setback distances.

Within a population of wind turbines of the same make and model there will be variability in the measured sound power level and tonality values. This variation can be the result of different sub components or different suppliers of identical turbine components. IEC 61400-14, "Declaration of sound power level and tonality" provides a method to combine multiple test results from a population into a declared value that is not expected to be exceeded by 95% of the turbines in that population. This value can then be used by the manufacturer to set warranted levels.

IEC 61400 does not quantify other noise characteristics such as amplitude variation, or low frequency noise. Further discussion of those characteristics is given below.

3 PSYCHOACOUSTICS

Noise from wind turbines can be a major community concern. Complaints about wind turbine noise are not only a function of the ambient sound pressure levels, but also of the nature of human perception of noise.

It has long been known that annoyance from noise is not related to the noise levels themselves. For example, a meta-analysis of 136 community noise studies (Fields, 1993) [13] found that noise annoyance is only weakly related to noise levels. This analysis found that annoyance is related to:

- Noise sensitivity
- Fear of danger from the noise source

- Attitudes toward noise prevention
- Attitudes about the importance of the noise source
- Annoyance with non-noise aspects of the noise source

Even at low noise levels, a small percentage of people in these studies were highly annoyed.

The same conclusions apply to annoyance from wind turbine noise. A 1993 study by Wolsink et al. [14] looked at 564 people exposed to a sound pressure level (SPL) of 35 dB(A) +/- 5 dB. Only 6% of those surveyed were annoyed, with only a weak relationship between annoyance and A-weighted SPL. Variables related to annoyance included stress related to turbine noise, daily hassles, visual intrusion of wind turbines in the landscape, and the age of the turbine site. (Annoyance decreased the longer the facility was in operation.)

A more recent noise sensitivity study (Pederson and Waye, 2005) [15] looked at 518 people in a rural setting. Respondents were divided into six SPL categories. Annoyance was found to increase with noise level, but factors other than noise levels also were found to strongly affect annoyance. The authors found that the perception of annoyance due to wind turbine noise rises more quickly than with other stationary industrial noise sources at similar sound pressure levels. People with negative attitudes toward wind turbines and their impact on the landscape were more easily annoyed by turbine noise and people with positive or neutral attitudes toward wind turbines and their impact on the landscape were rarely annoyed. Negative attitudes toward wind turbines (and corresponding annoyance in response to turbine noise) was greater when respondents:

- saw the countryside as a place for peace and quiet rather than a place for economic activity and for making one's living;
- felt a lack of control (lack of awareness turbines were going to be built, inability to stop the noise when it annoyed them) or a lack of influence;
- sensed that they were being subjected to an injustice or that others did not understand (the implications of living close to a wind turbine).

Careful work at the planning stages of a project may help to address some of these factors, thus mitigating the surrounding communities' noise concerns.

4 INFRASOUND

Infrasound (acoustic energy at frequencies below 20 Hz) is an issue of concern but one that is often misunderstood by wind turbine project opponents.

There are many sources of ambient infrasound, both natural and anthropogenic. Natural sources of infrasound (between .001 Hz and 2 Hz) include ambient air turbulence and waves on the seashore. Man-made sources of infrasound include road vehicles, aircraft, machinery, artillery, air movement machinery, compressors and wind turbines.

Human perception of infrasound is primarily through auditory channels and is experienced as a change of static pressure, the periodic masking of higher frequencies and vibrations of objects excited by the infrasound. The human perception threshold increases as the sound frequency decreases. At frequencies of 20 Hz, the threshold of hearing is typically greater than 80 dB. At 10 Hz the average perception threshold is 100 dB and the standard deviation is about 6 dB. Therefore, at 10 Hz, there will be a very small percentage of people whose threshold is two standard deviations from the mean (less than 88 dB or greater than 112 dB.

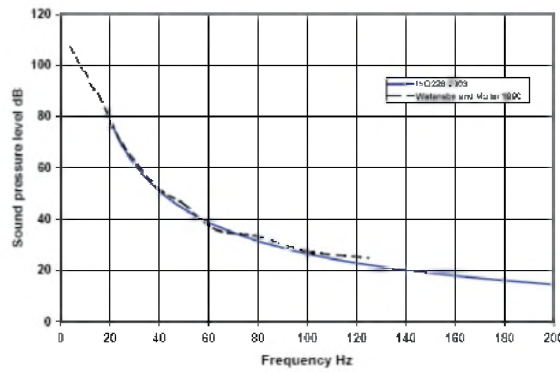

Figure 3: Low Frequency Thresholds [20]

At the same time, human sensitivity to increases in sound pressure levels is greater at lower frequencies. For example, a 10 dB increase at 1000 Hz is perceived as a doubling in the loudness, while only a 5 dB increase at 20 Hz is required to be perceived as doubling loudness. Given the variability in human perception levels and increased sensitivity to increases in sound pressure levels at low frequencies, small differences can have a highly variable impact on different people in terms of how annoying the sound is.

Infrasound is not dangerous unless it is very loud. Some humans may experience fatigue, apathy, abdominal symptoms, or hypertension when exposed to infrasound levels at about 115 dB. At 10 Hz, the threshold of pain is about 120 dB. Exposure to infrasound at 120-130 dB for a period of 24 hours causes physiological damage. It is important to reiterate, however, that *there is no evidence of adverse effects below 90 dB.*

The effects of low-frequency noise and infrasound are a topic of several studies and numerous press reports. The Western Morning News article titled "More Attention Must Be Paid to the Harmful Effects [16]" sites the work of Dr. Amanda Harry, a physician in the United Kingdom, who conducted a study that identifies health impacts from wind farms. Some of these impacts have been attributed to low-frequency noise, and similar claims have appeared in numerous anti-wind publications [17]. It appears that many of the effects may not be in whole or in part the result of low-frequency noise: “Another complaint which I encountered when talking to these neighbors of turbines is the effect of the rotating blades in the sunlight—this characteristically causes a strobe effect . . . this effect is not only obtained by direct vision of the blades but also from the shadow flicker caused by the blades in the light. The people questioned stated that this was a cause of headaches, migraines, nausea, vertigo and disorientation in many residents . . .[16]”

Dr. Geoff Leventhall author of "A Review of Published Research on Low Frequency Noise and its Effects" [18] is correctly quoted in the Western Morning News articles that low-frequency noise is a “background stressor which leads to inadequate reserves of coping and may lead to chronic psychological and physiological damage [16]”. However, Dr. Leventhall’s statements have been taken somewhat out of context with respect to low-frequency noise and wind turbines. When Dr. Leventhall was asked specifically about the effects of low-frequency noise from wind turbines, he responded. “There is only a relatively small amount of low-frequency noise from wind farms, where low-frequency noise is taken to mean 10 Hz to about 200 Hz. The noise is mainly mechanical, and gear related. Considering infrasound as below 20 Hz, there is very little from wind turbines. You have to distinguish between what is technically interesting and what is relevant to subjective effects. Available information shows that infrasound levels at approximately 100 meters from a turbine rise to 60 to 70 dB at 10Hz, where the average hearing threshold is nearly 100 dB. I really do not expect infrasound from modern wind turbines to be an issue, but because of the publicity which has been given to low frequency noise, we have to take this on board in order to find out the true facts [19]”. Dr. Leventhalls recent paper [20] on the matter concluded:

Specialists in noise from wind turbines have work to do in educating the public on infrasound and low frequency noise. Specifically,

- Infrasound is not a problem,
- Low frequency noise may be audible under certain conditions,
- The regular 'swish' is not low frequency noise.

Advice to objector groups in this connection could be that, by dissipating their energy on objections to infrasound and low frequency noise, they are losing credibility and, perhaps, not giving sufficient attention to other factors.

In another publicized controversy, the Advertising Standards Authority in the UK adjudicated a complaint regarding an anti-wind pamphlet titled “Facts About Wind Power” [17]. In this case, the Authority ruled that claims, including that “wind turbines still create noise pollution, notably 'infrasound'—inaudible frequencies which nevertheless cause stress-related illness” was misleading.

Concern about infrasound from wind turbines may have originated from the experience of neighbors of early wind turbine designs with downwind rotors (rotors downwind of the tower). The effect of the sudden decrease in wind speed behind the tower on the flow around the blades created objectionable levels of infrasound. In contrast, all modern utility scale wind turbine have upwind rotors that produce significantly lower infrasound emissions. When standing close to a modern wind turbine one may hear a swish-swish sound at the blade passing frequency. This is an amplitude modulation of higher frequency blade tip turbulence and does not contain low frequencies.

Recently Rogers [21] reviewed examples of sound profiles measured at 80 to 118 m from various turbines that showed the range of sound pressure levels at various frequencies, including the infrasound range. For turbines ranging from 450 kW to 2 MW, maximum infrasound sound pressure levels were well below the perceptibility threshold of 90 dB. For example, at 10 m/s wind speed, the infrasound level measured at a distance of 80 m from a 850 kW Vestas turbine peaked at 70 dB, well below perceptible levels. Infrasound levels 118 m from a 2 MW wind turbine also peaked at 70 dB. Levanthal [22] used measurements taken at 100 m from a single turbine to calculate low frequency sound pressure levels at a distance of 400 m from a wind farm with 19 wind turbines. His results showed that at 25 Hz the sound pressure levels would be 25 dB below the sensitivity threshold of the most sensitive 2% of the population. Due to increasing threshold levels and only slightly higher sound pressure levels in the infrasound range, infrasound levels would be even more than 25 dB below the sensitivity threshold of the most sensitive 2% of the population.

Thus, research suggest that modern turbines do emit infrasound, but at levels below the minimum threshold of perception for most of the population, and well below the threshold for any adverse effects.

5 PROPAGATION OF NOISE FROM WIND TURBINES

There are multiple noise propagation models commercially available (ISO 9613-2, VDI 2714, Concawe, BS 228, General prediction method (Danish), Danish EPA guidelines, Netherlands guidelines 1999, Swedish methods for land and sea). Most of these were developed for noise from industry, for wind speeds below 5 m/s, and for downwind propagation.

In ISO9613-2 for example, all receiver locations are assumed to be downwind. A receiver on the east and west sides of a turbine are both assumed to be downwind simultaneously. The model assumes wind blows from each turbine to each receiver, every receiver is assumed to be downwind and every source upwind [23].The wind cannot at any time blow in all directions from every wind turbine, so this method results in a worst case analysis [24].

In some situations it may be advantageous to account for the shadow zone in the upwind direction (depicted in Figure 4). The Nord2000 model is one model capable of modeling upwind propagation [25].

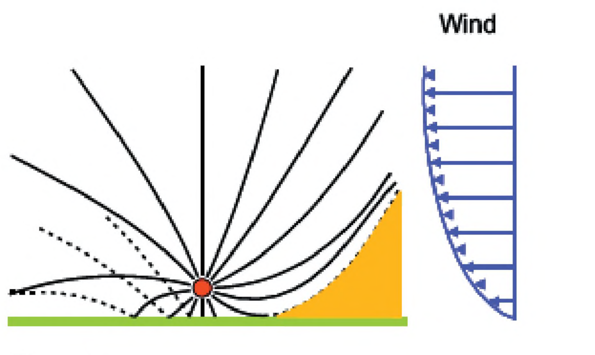

Figure 4: Illustration of wind influence on sound propagation: Upwind of the source a shadow zone (hatched) occurs. [25]

The upper part of Figure 5 shows an example of a terrain profile in a mountainous area with grass-covered ground. A wind turbine with 90 m hub height is situated at the left side and a receiver at 1.5 m above the ground to the right. The middle part of Figure 5 shows the terrain profile near the receiver in more detail and reveals a terrain edge screening the sound from the turbine.

The bottom part of Figure 5 shows the calculated effect of ground and screening per one-third octave in the frequency range from 25 Hz to 10 kHz with Nord2000. The solid line shows the result with 8 m/s downwind (wind from turbine to receiver), the dotted line for zero-wind (crosswind) and the dashed line for 8 m/s upwind (wind from receiver to turbine). The attenuation of the noise depends strongly on the weather with much lower noise levels during crosswind and upwind than during downwind. This is due to screening and shadow zone formation.

Figure 6 shows the variation in wind turbine noise source strength as a function of the wind speed in the top of the figure while the bottom of the Figure 6 shows the corresponding overall A-weighted noise levels according to Nord2000 at 1240 m distance at a flat site as a function of the wind speed. This figure includes both source strength variation and weather-induced variation in transmission path attenuation. At all wind speeds Nord2000 gives lower noise levels than ISO 9613-2 for hard ground and higher noise levels for porous ground.

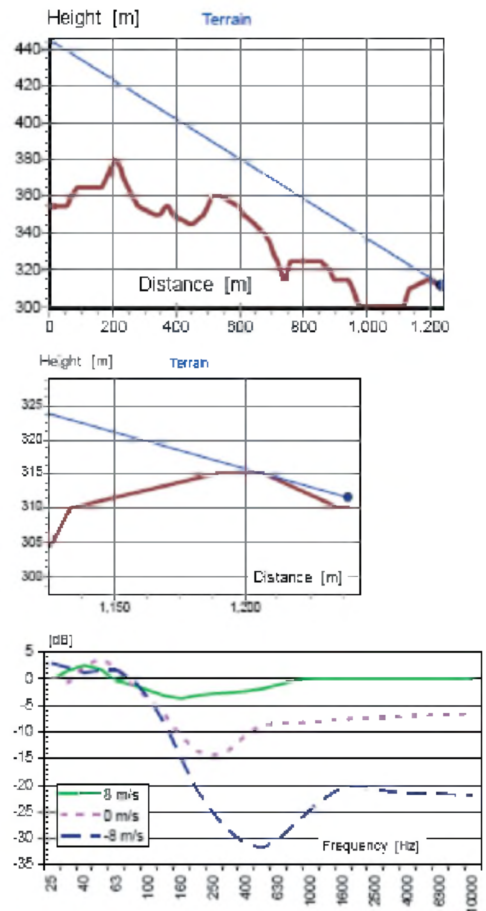

Figure 5: Vertical section through source and receiver (top), a zoom-in near the receiver (middle), and the combined ground and screening effect [dB] (bottom) calculated for 8 m/s downwind, zero-wind, and 8 m/s upwind, respectively. [25]

Figure 7 shows the ground effect calculated with Nord2000 on the sound propagating over water from a wind turbine with a hub height of 100 m at distances from 100 to 10,000 m assuming the source spectrum of a modern 2MW wind turbine at a wind speed of 8 m/s at 10 m height. 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. A flow resistivity of σ = 20,000,000 Nsm^{-4} corresponding to a hard surface has been assumed.

Figure 7 shows that the crosswind ground effect does not deviate much from the downwind ground effect. It also shows that the ground effect may be slightly higher (higher noise levels) during crosswind than during downwind at large distances. This is because the path length difference of the direct wave from source to receiver and the wave reflected from the ground is smaller in a homogeneous atmosphere than in a downward refracting atmosphere (meaning that the reflection from the ground is more likely to approach a +6 dB effect in the former case at large distances). The same effect can be seen for upwind at distances just below the distance where the shadow zone occurs. In the upwind direction, large attenuations are observed above a given distance due to a meteorological shadow zone. Below this distance the ground effect corresponds to the situation for the other wind directions.

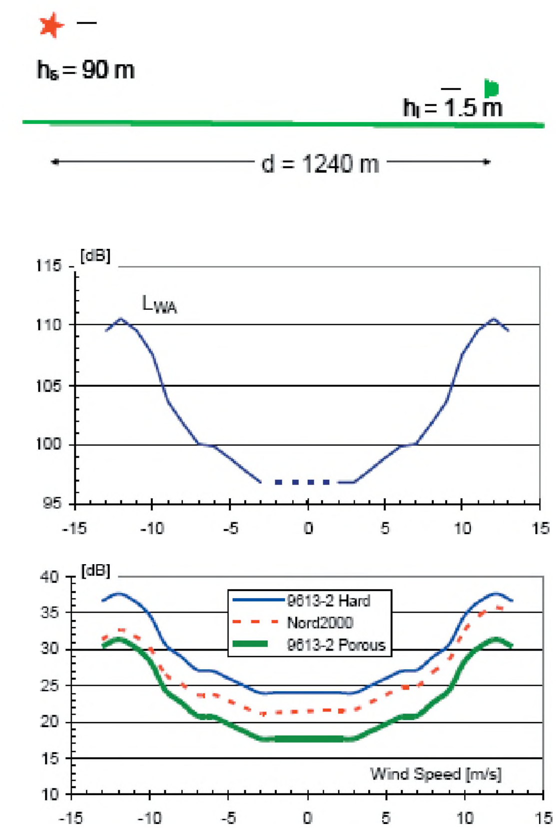

Figure 6: Source strength LWA (top) and calculated noise level (bottom) from a wind turbine as a function of the wind speed [25]

6 REGULATION OF WIND TURBINE NOISE IN THE UNITED STATES

In the United States, noise is regulated at the federal, state, and local levels. Only a few state or local governments have developed noise regulations specifically for wind turbines.

6.1 Federal Noise Regulation

The National Environmental Policy Act (NEPA) provides the regulatory framework for federal regulation of environmental impacts, including noise. However, the federal agencies (e.g., Federal Energy Regulatory Commission (FERC), the Federal Highway Administration, the Federal Aviation Administration, etc.) utilizing this framework have leeway to establish their own standards for what constitutes acceptable noise levels (refer to Table 1 and Figure 8).

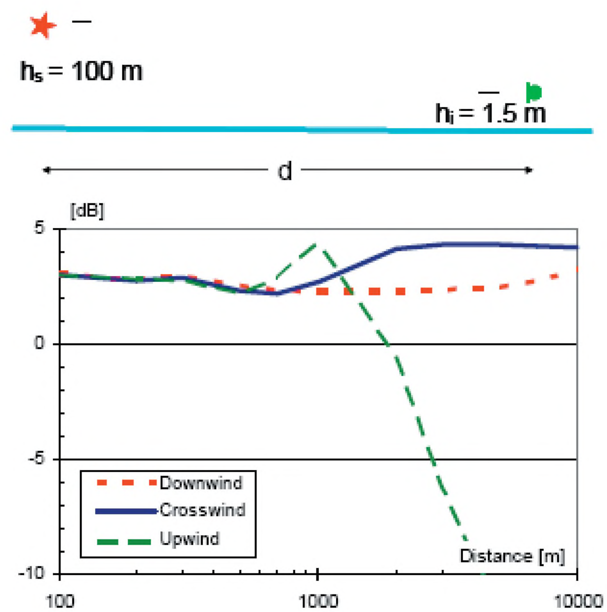

Figure 7 – Calculated ground effect on sound propagating over water from a wind turbine with a hub height of 100 m at distances from 100 to 10,000 m [25]

Table 1: Summary of Federal Guidelines/Regulations for Exterior Noise (dBA)

Agency	L_{eq}	DNL
Federal Energy Regulatory Commission (FERC)	[49]	55
Federal Highway Administration (FHWA)	67	[67]
Federal Aviation Administration (FAA)	[59]	65
U.S. Department of Transportation—Federal Rail and Transit Authorities (FRA & FTA) [26, 27]	Sliding scale, refer to Figure 8	Sliding scale, refer to Figure 8
U.S. Environmental Protection Agency (EPA) [28]	[49]	55
U.S. Department of Housing and Urban Development (HUD) [29]	[59]	65

Note: Brackets [59] indicate calculated equivalent standard. Because FHWA regulates peak noise level, the DNL is assumed equivalent to the peak noise hour.

The U.S. Department of the Interior (DOI), Bureau of Land Management (BLM) is the federal agency charged with managing federal public lands and is responsible for the development of wind energy resources on BLM-administered lands. The BLM recently prepared a programmatic EIS in accordance with the requirements of NEPA to establish a "Wind Energy Development Program" [30].

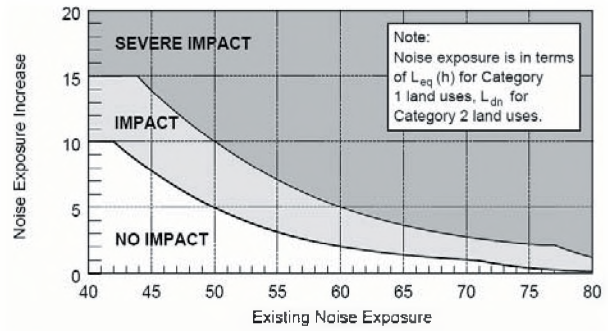

Figure 8: FRA & FTA Allowable Increase in Cumulative Noise Level. (Note: Residential uses are included in Category 2) [26, 27]

Several key findings/statements relevant to assessing noise impacts of a wind project are quoted below:

- At many wind energy project sites on BLM-administered lands, large fluctuations in broadband noise are common, and even a 10-dB increase would be unlikely to cause an adverse community response.
- For a typical rural environment, background noise is expected to be approximately 40 dB(A) during the day and 30 dB(A) at night, or about 35 dB(A) as DNL.
- The EPA guideline recommends a day-night sound level (L_{dn}) of 55 dB(A) to protect the public from the effect of broadband environmental noise in typically quiet outdoor and residential areas (EPA 1974). This level is not a regulatory goal but is "intentionally conservative to protect the most sensitive portion of the American population" with "an additional margin of safety."
- Geometric spreading alone results in a sound pressure level of 58 to 62 dB(A) at a distance of 50 meters (164 feet) from the turbine, which is about the same level as conversational speech at a 1-meter (3-foot) distance. At a receptor approximately 2,000 feet (600 meters) away, the equivalent sound pressure level would be 36 to 40 dB(A) when the wind is blowing from the turbine toward the receptor. This level is typical of background levels of a rural environment.
- To estimate combined noise levels from multiple turbines, the sound pressure level from each turbine should be estimated and summed. Different arrangements of multiple wind turbines (e.g., in a line along a ridge versus in clusters) would result in different noise levels; however, the resultant noise levels would not vary by more than 10 dB.
- Proponents of a wind energy development project should take measurements to assess the existing background noise levels at a given site and compare them with the anticipated noise levels associated with the proposed project.
- Noise generated by turbines, substations, transmission lines, and maintenance activities during the operational phase would approach typical background levels for rural areas at distances of 2,000 feet (600 meters) or less and, therefore, would not be expected to result in cumulative impacts to local residents.

While the above are not regulations, they provide detail on how BLM will assess the "significance" of noise impacts on individual projects and provide guidelines on how individual projects will need to address noise.

6.2 State and Local Regulations

According to a 1997 survey, only 13 states had state-level noise regulations [31]. Five of those states had regulations "on the books," but did not enforce them, although state permitting processes may require compliance. Some states, such as New York and California, do not have noise regulations, but do have guidance or model ordinances. For the most part, noise in the United States is regulated at the local level. Note that at both the state and local levels, noise regulations tend not to be written by acoustic professionals and are ambiguous. Regulations are discussed more thoroughly in Reference [32], below is a summary.

Colorado. Colorado's noise regulations stipulate that noise shall "not be objectionable due to intermittence, beat frequency, or shrillness," and impose a 5 dBA penalty for "periodic, impulsive, or shrill noises." However, none of these terms are defined in the regulations, and there are over 340 local jurisdictions which may impose additional standards.

California. Wind turbines are not regulated by the California Energy Commission (CEC), but the California Environmental Quality Act (CEQA) requires assessment of project-related noise increases. Local ordinances vary with some specifically addressing wind turbines and others not.

Riverside County establishes two thresholds for noise, one for permitting and another for operational compliance. An acoustical study is not required by the county when permitting a project where a 2,000-foot setback is maintained on projects consisting of 10 turbines or less or 3,000 feet when there are more than 10 turbines. When these setbacks are not maintained, an acoustical study must document wind project noise to be less than or equal to 55 dBA. Unless a more restrictive limit is established, operational noise (compliance measurements) is limited to 60 dBA.

In a recent permit for a wind project, PPM Energy's Shiloh project, Solano County limited a wind projects noise to 50 dBA CNEL or 44 dBA L_{eq}. It appeared to presume that level would be met if a 2,000-foot setback was maintained, but the county maintained the 50 dBA CNEL or 44 dBA L_{eq} level as enforceable upon receipt of a complaint.

The Kern County General Plan requires proposed commercial and industrial uses or operations to be designed or arranged so that they will not subject residential or other noise sensitive land uses to exterior noise levels in excess of 65 dB L_{dn} and interior noise levels in excess of 45 dB L_{dn}. For wind projects, Chapter 19.64 WIND ENERGY (WE) COMBINING DISTRICT of the Kern County Code establishes a not-to-exceed level of 50 dBA and an $L_{8.3}$ of 45 dBA. It also establishes for a waiver provided that the affected property owners consent and a permanent noise easement is recorded with the county.

For wind projects Chapter 88-3 WIND ENERGY CONVERSION SYSTEMS of the Contra Costa County Code establishes a maximum noise limit of 65 dBA at the property line. The noise element of the general plan states that noise levels up to 60 dBA L_{dn} are normally acceptable at residential receptors.

Oregon. The State of Oregon has a new wind turbine noise (WTN) standard that [33]:

- establishes minimum existing ambient noise levels (26 dBA) – resulting in a 36 dBA maximum project level (if landowners choose not to waive it),
- requires maximum sound power level to be used in predictions ("worst case" analysis);
- allows wind developers to negotiate with landowners; with an upper limit of 50 dBA

7 EUROPEAN PERSPECTIVES ON NOISE CONTROL

Noise standards vary from one country to another. Denmark has one perspective, but Germany has a different one, Spain yet another, and so on. In Denmark and the northern part of Europe, noise limits are based on outdoor sound pressure levels, whereas further south, they are based on indoor sound pressure levels. This affects whether or not and how you take into account background noise. Distance requirements likewise vary from one place to another. In Denmark, the required minimum setback is four times the total turbine height from the nearest residence.

The 42nd IEA Topical Expert meeting, "Acceptability in implementation of wind turbines in social landscapes" was held in 2003 in Stockholm. One of the conclusions of this meeting was the importance of collaborative rather than "hierarchical" planning.

8 CONCLUSIONS

This paper presented a general overview of wind turbine noise including sources, measurements standards, psychoacoustics, infrasound, propagation and regulatory perspectives. Findings include:

Turbine noise level strongly correlates with tip speed.

The IEC 61400 standard governs the measurement (Part 11) and declaration (Part 14) of turbine sound power level.

It is important to understand the meaning of 10 meter high reference wind speed and site specific factors that influence correlation with hub height wind speeds.

Wind turbine noise can be perceived as annoying, particularly when negative attitudes toward wind turbines already exist.

Wind turbines do emit infrasound, but not at levels that should be cause for concern.

Propagation of wind turbines under various meteorological conditions can be evaluated with Nord2000.

Wind turbine noise regulations vary widely. Some allow for louder levels at "project participants".

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Ontario Ministry of the Environment Noise Guidelines on Wind Power Projects

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ABSTRACT

In response to the anticipated introduction of large scale wind power projects for electricity generation in Ontario, the Ministry of the Environment (MOE) prepared specific guidelines for assisting proponents of such project to address the current environmental regulatory requirements. This article is a brief overview of the MOE review and approval process concerning environmental noise impacts of wind energy projects.

RÉSUMÉ

En réponse à l'introduction prévue de projets d'éoliennes à grande échelle pour la production d'électricité en Ontario, le ministère de l'Environnement (MOE) a préparé des directives spécifiques pour aider les promoteurs d'un tel projet à adresser les obligations environnementales courantes. Cet article est une brève vue du processus de revue et d'approbation du MOE au sujet des impacts sonores dus à de tels projets.

1. INTRODUCTION

Under Section 9 of the Environmental Protection Act (EPA), it is required to obtain an approval before construction, alteration, extension or replacement of any equipment or structure that may emit, or from which may be emitted, a contaminant such as noise or vibration into the natural environment. Consequently, wind power projects require a Certificate of Approval (Air & Noise) from the MOE for the installation of wind turbine generating units including any associated equipment, such as power transformers, that emits noise or vibration. One of the purposes of the certificate is to allow clear enforcement of the noise and vibration limits indicated in the MOE guidance documents.

However, for wind power projects of 2 MW and greater generating capacity the proponent is required first to conduct an Environmental Screening Process in accordance with the MOE: "Guide to Environmental Assessment Requirements for Electricity Projects", dated March 2001 [1]. This process includes the environmental assessment requirements which are set out in Regulation 116/01, referred to as the "Electricity Projects Regulation", made under the Environmental Assessment Act (EAA).

Wind power projects of 2 MW and greater generating capacity may not receive approvals under the EPA, or commence construction, until it has met the Environmental Screening Process requirements under the EAA. Consequently, applications for Certificates of Approval should be submitted after this process has been completed.

Some municipalities may have additional requirements concerning wind power projects prepared under the Municipal Planning Act, above and beyond of the requirements of the provincial environmental legislation and guidelines. Similarly, some projects may be subject to the Canadian Environmental Assessment Act. Therefore, in order to facilitate reviews of project proposals during the Environmental Screening Process, MOE encourages proponents to coordinate, if applicable, the provincial, federal, and municipal noise requirements and address them in one noise assessment study and report.

On the other hand, some selected types of residential and agricultural wind turbine generators, are exempted under Section 9(3) of the EPA and by the Certificate of Approval Exemption Regulation (O.Reg. 524/98).

2. REVIEW PROCESS

Unlike with most industrial facilities, noise abatement measures for large wind power developments, if necessary, may be problematic or impractical to implement. Proper planning of each wind turbine location relative to all noise sensitive receptors and supported by complete noise impact assessments are essential for demonstrating feasibility of compliance with the MOE noise limits. Consequently, the MOE advises proponents of wind power projects to assess noise impacts early in the Environmental Screening Process.

The results of the screening process can have significant impacts on necessary setback distances, and the number and location of wind turbines that could be constructed at a site, and would be of interest to nearby residents. Therefore MOE has set up a review process intended to facilitate the ultimate result by having reviews at an early stage along with public consultation. Specifically, MOE has offered to perform technical review of the complete noise impact assessment report at the stage of the Environmental Screening Process. This review should take place prior to issuing the notice of completion and initiating the public and agency commenting period.

The results of the MOE technical review of the complete noise impact assessment report at the screening stage, if found to be acceptable, will be later used during the subsequent review of the corresponding application for a Certificate of Approval under Section 9 of the EPA. Provided that the proposal is not changed and the completed report remains accurate, then the application will be processed based on the prior technical review. Any changes to the proposal or to the completed report at the time of the application for Certificate of Approval may require further review and/or consultation.

3. NOISE LIMITS

The MOE noise level limits applicable to sources and facilities in general are described in the Publications NPC-205 and NPC-232 [2, 3]. These limits are set with respect to Point of Reception, which is typically at residential properties that may be impacted by the noise(s) under review. For wind power projects the noise limits are consistent with those of References 2 and 3, but it includes an allowance for the wind generated background noise at wind speeds of 7 m/s and greater. All reference to wind speeds in the MOE documents correspond to data observed at the 10 metres height above grade.

At low wind velocities, below 8 m/s, there are two sets of sound level limits dependent on the general noise environment prevailing in the area at the Point of Reception. Areas generally characterized as "rural" are categorized as a Class 3 Area and would be subject to the lower sound level limits. This is the most usual categorization of Point of Reception encountered in the vicinity of wind power projects. However, in an "urban" noise environment the categorization becomes as Class 1&2 Area and the corresponding limits are higher. Furthermore, the noise limits apply for continuous operation at any time of day or night.

Proponents of wind power projects are required, therefore, to demonstrate compliance at the Point(s) of Reception with the following sound level limits, under specific wind speed conditions, and expressed in terms of the hourly energy-equivalent sound level, Leq (1h):

The noise levels limits for wind turbines are shwon in Table 1. Note that the values corresponding at wind speeds 7 m/s and greater were derived from average values of wind noise measured outdoors in terms of L90 plus 5 dB.

In situations where a particular Point of Reception is found to be affected by existing higher levels of background noise, such as from regular vehicular traffic adjacent to a highway, then the above noted limits may be increase accordingly. However, there must be sufficient supporting information, based on hourly noise monitoring or traffic counts data, to allow an increase in the above noted criteria. This is consistent with the Publications NPC-205 and NPC-232 [2, 3].

4. NOISE IMPACT ASSESSMENT AND REPORT

Guidance for proponents of wind power projects for the preparation of noise impact assessments and report is given in a document titled "Interpretation for Applying MOE Technical Publications to Wind Turbine Generators" – July 2004. [4]. This brief document is intended to assist proponents in understanding the MOE requirements that would be expected when applying for the Certificate of Approval. It is advisable that proponents of such projects be familiar with this information early in their planning and public consultation activities.

Consistent with the Publications NPC-205 and NPC-232 all noise impact assessments are required to be considered under the principle of a "worst case scenario". Some of the factors under this principle include:

- Reliable sound emission data (in octave bands) from all sources, at maximum operating capacity, including equipment associated with the project such as a transformer facility.
- Thorough identification of all Points of Reception up to at least 1000 metres from the nearest wind turbine generator unit.
- Accurate determination of the locations (x,y,z coordinates) of each wind turbine noise source and each Point of Reception and their corresponding distances between the two sets.
- Accounting for noise impact level at each Points of Reception due to the aggregate of all sources and propagation with downwind direction.

In the event that proposed layout of the entire wind power project is such that all wind turbine units are at a distance from any Point of Reception in excess of 1000 metres, then the report does not require including a noise impact assessment. However all other information must be included so that compliance with the MOE requirements can be verified.

5. CONCLUSIONS

In order to assist proponents of wind power projects to include in their design at the planning stage the necessary re-

Wind Speed at 10 m height, (m/s)	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Class 3 Area	**40**	**40**	**40**	**43**	**45**	**49**	**51**	**53**
Class 1 & 2 Areas	**45**	**45**	**45**	**45**	**45**	**49**	**51**	**53**

Table 1. Wind Turbine Generated Maximum Sound Level Limits, Hourly L_{EQ}, dBA

quirements that would facilitate achieving the MOE noise limits requirements and for ultimate compliance with Section 9 of the EPA, a guidance document was made available. A brief overview of the document and the required approval process as well as assessment procedures were highlighted in this article.

6. REFERENCES

1. "Guide to Environmental Assessment Requirements for Electricity Projects." Ontario Ministry of the Environment, March 2001 is available at www.ene.gov.on.ca/envision/gp/4021e.pdf
2. "Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)." Ontario Ministry of the Environment Publication NPC-232, October 1995.
3. "Sound Level Limits for Stationary Sources in Class 1 and 2 Areas (Urban)." Ontario Ministry of the Environment Publication NPC-205, October 1995.
4. "Interpretation for Applying MOE Technical Publications to Wind Turbine Generators." Ontario Ministry of the Environment, July 2004, is available on the MOE web site at www.ene.gov.on.ca/envision/gp/4709e.pdf
5. "Wind Power Projects and the Approval Process." Ontario Ministry of the Environment, is available on the MOE web site at www.ene.gov.on.ca/envision/gp/5135e.pdf

Development of Regulatory Requirements for Wind Turbines in Alberta

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ABSTRACT

The process of developing regulations of any type is extremely challenging in that they must be relatively simple, easy to understand, technically correct, defensible in their need and approach, and enforceable. The Energy and Utility Board (EUB) recognized that the use of wind turbines for electrical generation in Alberta was growing at an alarming rate and that noise was going to be a significant issue for individuals and communities situated near wind farms. This paper examines the considerations that were taken by the EUB to understand the issues around noise and what ultimately influenced the regulatory requirements that will be incorporated in the new edition of the province's Noise Control Directive.

RÉSUMÉ

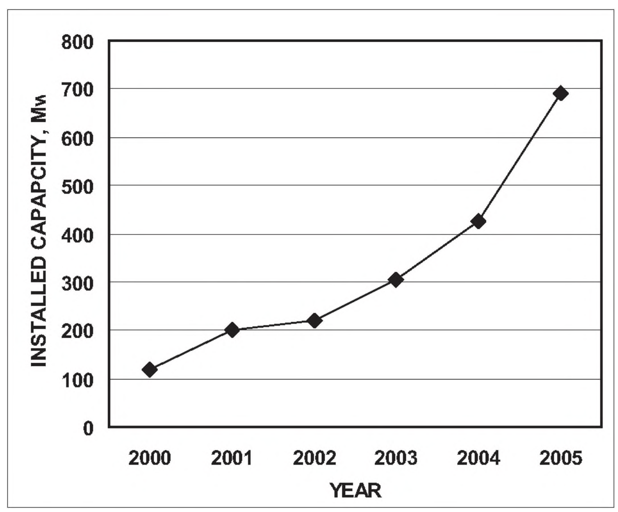
La procédure de développement de réglementation de tous types pose un énorme défi. En effet, les réglementations doivent être relativement simples, faciles à comprendre, techniquement appropriées, défendables dans leur besoin et approche, et réalisables. L'EUB a reconnu que l'utilisation des éoliennes pour la production d'électricité a crû à un taux alarmant et que le bruit deviendrait un problème significatif pour les individus et les municipalités situées près des parcs d'éoliennes. Cet article se penche sur les études faites par l'EUB pour comprendre les problèmes reliés au bruit et ce qui ultimement influence les requis pour les réglementations qui seront incorporées dans la nouvelle édition la « Directive de Contrôle de Bruit » de la province.

1. INTRODUCTION

In Alberta, like much of Canada, alternative forms of energy are being considered with ever greater scale to serve society's needs. The desire for clean, renewable energy using the existing distribution infrastructure makes wind turbines a logical source for electrical generation. Improvements in wind turbine technology have also contributed to this increased popularity by reducing the generation costs to be more competitive with traditional carbon based processes (coal, oil, and natural gas). Consequently, developers have seized on this opportunity and are planning large scale wind turbine farms that maximize investment. Statistics from the Canadian Wind Energy Association given in Figure 1 show the growth of Wind energy production in Canada which is expected to continue to increase at an aggressive rate.

When the first wind turbine energy generation occurred in Alberta (in the 1980s), there was no legislation in place for this type of project. The Energy Banking System was developed to handle small independent generation projects. It was similar to a banking system where the power was sent to the grid and the operator was allowed to take out the same amount.

In 1989, the Alberta Energy & Utilities Board (EUB) was asked to recommend a method to handle small power generation projects. The result was the Small Power Research and Development Act. This Act allowed for provisions for wind-related power generation projects up to a maximum of 50 MW for Alberta. In 1993, the 50 MW was reached peaking at 8 applications that year. In 1996, The Electric Utilities Act was created and it addressed wind-related power generation. It was an open market where projects could sell power to the Alberta grid. The average pool price was approximately $30/MW-hr and only existing operators applied for new projects.



• Average annual growth rate (2000-2005): 38%
• Growth is accelerating: 54% growth in 2005
• Growth will exceed 50% again in 2006

Figure 1. Rapid Growth of Wind Energy.

The number of applications changed dramatically after 2000 (Figure 2) when the average pool price for the year was greater than $100/MW-hr. This created a peak in application in 2001 where the EUB received 33 wind-related applications. The applications included new plants, alterations to existing plants, connection applications, etc. Since then, the number of applications has decreased; however, the applications are much larger in scale (current pool price averages between $60/MW-hr to $70/MW-hr). Naturally these new wind turbine farms will likely come in direct contact with existing rural residents resulting in some level of inevitable impact.

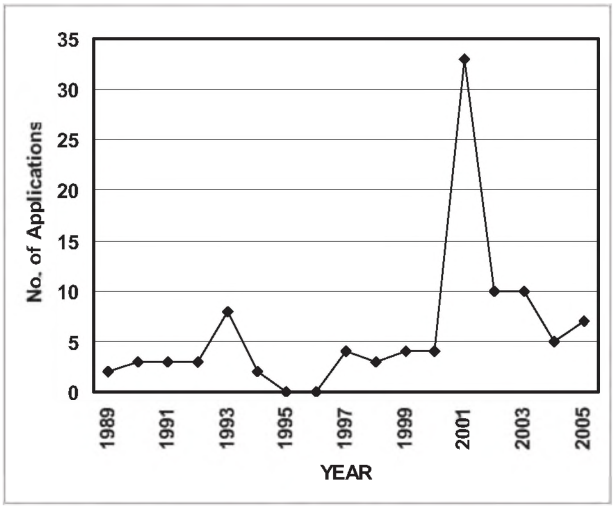


Figure 2. Wind Related Applications in Alberta

Wind turbine noise is one such potential impact and the mandate to regulate the energy industry in Alberta falls to the EUB. Although the EUB has had noise control regulations in place since 1973, they have typically been applicable to continuous mechanical noise from equipment that operates 24 hours a day every day and is not dependant on the weather. Wind turbines on the other hand are somewhat of an enigma in comparison to traditional energy industry requirements in that turbine noise increases nearly in direct proportion to increased wind noise (which is slightly higher as shown in Figure 3 below) from increased wind speeds.

This masking effect therefore, creates significant challenges in modeling and monitoring wind turbine noise for

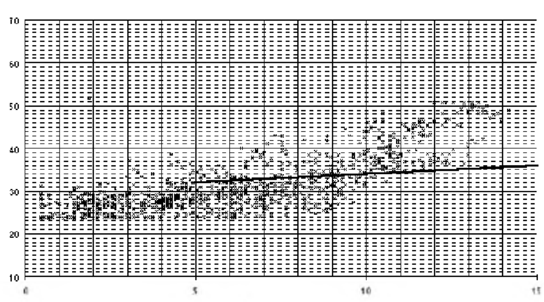


Figure 3. Wind Speed Effects on Turbine Noise and Ambient Noise.

Note: ..... Ambient Sound; -- Turbine Noise
X Axis -Wind Speed and Y Axis - Noise Level in dBA

new and existing installations. The EUB realized that the noise control legislation needed to be modified to remain effective and account for this growing sector of the industry. Over the course of several years technical specialists and staff from the EUB have undertaken a systematic approach to learn more about the noise emitters associated with wind turbines including conducting extensive literature reviews on estimating and measuring wind turbine noise, and finally on what other jurisdictions are doing to ensure noise impacts are kept to acceptable minimums for nearby residents.

This paper looks at the information that was gathered and how it influenced the suggested regulatory changes proposed by the expert multi-stakeholder committee charged with the review, upgrade, and consolidation of EUB Noise Control Directive ID 99-08 and companion Guide G-38 into the new Directive 38.

2. HUMAN PERCEPTION OF NOISE

Most people find it pleasant listening to the sound of waves at the seashore, and quite a few of us are annoyed with the noise from the neighbour's radio, even though the actual sound level may be far lower. Apart from the question of your neighbour's taste in music, there is obviously a difference in terms of information content. Sea waves emit random "white" noise, while your neighbour's radio has some systematic content which your brain cannot avoid discerning and analyzing. If you generally dislike your neighbour you will no doubt be even more annoyed with the noise.

"Noise," when one is talking about wind energy projects, basically means "any unwanted sound." Whether a noise is objectionable will vary depending on its type (tonal, broadband, low frequency, impulsive, etc.) and the circumstances and sensitivity of the individual who hears it (often referred to as the "receptor"). As with beauty, often said to be "in the eye of the beholder," the degree to which a noise is bothersome or annoying is largely in the ear of the hearer. What may be a soothing and relaxing rhythmic swishing sound to one person may be quite troublesome to another. Since the distinction between noise and sound is a highly psychological phenomenon, it is not easy to make a simple and universally satisfactory model of sound phenomena. Because of this, there is no completely satisfactory and impartial way to measure how upsetting a noise may be to any given person. In fact, a recent study done by the Danish research institute DK Teknik seems to indicate that people's perception of noise from wind turbines is governed more by their attitude to the source of the noise, rather than the actual noise itself. The EUB has found that this has also been true in a very small number of the mainstream energy industry noise complaints as well making resolution of the matter extremely difficult and in rare instances impossible. Still, it is possible to objectively measure how loud a noise is and that must remain a key component to determining compliance and thus acceptability.

It should be noted that while the regulatory requirements could not account for perception issues, they would be based on the best information on what are deemed to be annoyance levels as published in peer reviewed psycho-acoustic studies as a way to minimize potential psychologically based reactions.

Noise from wind turbines can more or less be distinguished depending on the difference between noise from the wind turbine and the background noise. The background noise, for example traffic noise, noise from industries and the whistling in bushes and trees, vary from site to site and also from day to night. The local environment at the dwelling can also cause a difference in wind speed between the wind turbine and the listener. Also less extreme local physical circumstances such as the placing of houses, may shelter the site from wind on the ground, lowering the background noise so that the noise from the wind turbine will be more easily heard. Only a few field studies on noise annoyance among people living close to wind turbines have been carried out. One study suggested that noise produced by the blades lead to most complaints and most of the annoyance was experienced between 4 p.m. and midnight. Another study was able to identify four variables that had an impact of noise annoyance: stress caused by wind turbine noise, daily hassles, perceived effects of wind turbines in the landscape (visual intrusion) and the age of the turbine site (the longer it has been operating, the less annoyance). If left unchecked, extreme annoyance can ultimately result in health problems.

3. WIND TURBINE NOISE AND HEALTH

According to the definition made by the World Health Organization (WHO), health is a state of complete physical, mental and social well-being and not merely the absence of infirmity. The WHO Guidelines for Community noise lists specific effects to be considered when setting community noise guidelines: interference with communication; noise-induced hearing loss; sleep disturbance effects; cardiovascular and psycho-physiological effects; performance reduction effects; annoyance responses; and effects on social behaviour. Interference with communication and noise-induced hearing loss is not an issue when studying effects of noise from wind turbines as the exposure levels are too low. No studies have been found exploring cardiovascular and psycho-physiological effects, performance reduction effects and effects on social behaviour specifically with regard to noise from wind turbines. A number of articles have though explored the relationships between exposure of other sources of community noise (road traffic, aircraft, railway traffic) and health effects. Evidence in support of health effects other than annoyance and some indicators of sleep disturbance is weak.

On the basis of Swedish studies on effects of noise from aircraft and road traffic, there is some evidence of noise causing psychosocial or psychosomatic nuisance. The effects are related to individual factors (sensitivity to noise and capacity to cope with stress) and to annoyance rather than to sound pressure level. Annoyance itself is an undesired effect on health and well-being. In a review of studies performed in 1993-1998 to evaluated adverse physiological health effects of occupational and community noise, most of the studies concern sources of noise with higher sound pressure levels than those of wind turbines. Even so, it was difficult to find correlation between exposure and cardiovascular or immunological effects. The limited data shows that the observed threshold for hypertension and ischaemic heart disease was at outdoors sound levels above 70 dBA. One can only infer from the results of these studies that there is no conclusive evidence that noise from wind turbines could cause cardiovascular and psycho-physiological effects.

Annoyance response however is probably the most studied health effect regarding wind turbines. Noise annoyance appears even at low sound pressure levels. Another health effect that may be relevant for people living near wind turbines is sleep disturbance. The WHO guidelines for community noise recommend that the outdoor noise levels in living areas should not exceed 45 dBA Leq at night, as sleep disturbance may occur at higher sound levels with open windows.

Although there is limited information on wind turbines, a review of health effects of road traffic noise, finds that there is no evidence that indicates that environmental noise could provoke psychiatric disease. Nevertheless we do know that noise is a factor of stress, and can induce symptoms among sensitive individuals. Regardless further research is needed especially in sleep disturbance as noise from wind turbines can have a unique characteristic (amplitude modulation, swishing) that is easily detected from normal background noise and this may increase the probability for annoyance and sleep disturbance. The combination of different environmental impacts (intrusive sounds, visual disturbance and the unavoidable source in the living environment) may also contribute to a low-level stress-reaction.

Summarizing the findings, there appears to be no solid scientific evidence that noise at levels emitted by wind turbines could cause health problems other than annoyance. Therefore the regulatory requirements should attempt to reduce the potential for annoyance and any ancillary stressors that may result.

4. CHARACTERISTICS OF WIND TURBINE NOISE

The noise output from a modern wind turbine contains energy spread across the audible frequency range and, like most sounds in the environment, has some (inaudible) energy in the infrasound range. Early wind turbines installed in the USA in the 1980s, however, were designed with the blades located downwind of the turbine tower such that the wind had to travel past the tower before it struck the blades. This caused the sound output from this type of turbine to generate a strong low frequency pulse, which also had significant levels of energy in the infrasound range. Largely as a consequence of this, wind turbine design was subsequently changed such that the blades were moved upwind of the tower. Coupled with this, the stand-off distance between the blades and the tower was increased in order to minimize any residual possibility that the blades may interact with disturbed air flow upwind of the tower. The consequence of these developments was to dramatically reduce tower interaction effects and the generation of high levels of low frequency noise by wind turbines. Noise from modern wind turbines is normally clearly audible on a wind farm site and a listener may readily perceive that the sound does not contain any of the strong low frequency pulsing described above, although the sound does change slightly close to an individual wind turbine as the blades pass through the air and change their distance from the listener. As the listener moves away from the site, the noise level decreases due to the increasing distance.

The noise character is also likely to change due to air absorption, which increases with increasing frequency, meaning that although the energy across the frequency range is reduced, higher frequencies are reduced more than lower frequencies. This effect may also be observed with road traffic noise or natural sources, such as the sea, where higher frequency components are diminished relative to lower frequency components at long distances. Wind turbines are not, therefore, a significant source of low frequency or infrasonic noise but, as with noise from any other sound source, the high frequency components are reduced when heard from a distance and overall levels are very low.

The noise from a wind turbine comes from both the mechanical gearing and from the aerodynamic properties of the rotating blades. The former can to a degree be controlled and insulated thus making some makes of turbines quieter than others.

Mechanical noise, i.e. metal components moving or knocking against each other may originate in the gearbox, in the drive train (the shafts), and in the generator of a wind turbine. Machines from the early 1980s or before do emit some mechanical noise, which may be heard in the immediate surroundings of the turbine, in the worst cases up to a distance of 200 m (600 ft.).

A survey on research and development priorities of Danish wind turbine manufacturers conducted in 1995 showed that manufacturers considered mechanical noise not to be a problem any longer, and therefore, no further research in the area was considered necessary. The reason was that within three years, noise emissions had dropped to half their previous level due to better engineering practices.

Noise levels, particularly the low-frequency 'thump' each time a blade passes the turbine tower, are the subject of much research. The UK regulatory authority spends more of its budget researching noise from wind turbines than on all other environmental noise problems. "For existing wind farms we are satisfied that there are cases of individuals being subject to near-continuous noise during the operation of the turbines, at levels which do not constitute a statutory nuisance or exceed planning conditions, but which are clearly disturbing and unpleasant and may have some psychological effects." [See British Wind Energy Association 2005]

The genuine difficulty that developers face is that noise levels are very difficult to predict fully in advance - and the industry has had moderate success in controlling blade noise. Development work on turbines has focused primarily on efficiency.

In addition, local resident reaction to wind turbines has not always been kind. This is particularly apparent from New Zealand Standard 6808 [39] Note to paragraph 1.3 "WTGs (Wind Turbine Generators) may produce sound at frequencies below (infrasound) and above (ultrasound) the audible range" and the statement from the Darmstadt Manifesto: "More and more people are describing their lives as unbearable when they are directly exposed to the acoustic and optical effects of wind farms. There are reports of people being signed off sick and unfit for work and there are a growing number of complaints about symptoms such as pulse irregularities and states of anxiety, which are known to be from the effects of infrasound." [See Australian EPA 2003 and Anderson et. al. 1997].

Recent reports from Denmark indicate government buy-back of residential property in an increasing radius from wind turbines, particularly down-wind.

5. TURBINE TECHNOLOGY

Almost all wind turbines that produce electricity for the grid consist of a tower between 40 and 80 metres high, a nacelle (housing) containing the gearbox and generator mounted on top of the tower, and three blades that rotate around a horizontal hub protruding from the nacelle. This type of turbine is referred to as a horizontal axis machine.

There are two potential sources of noise: the turbine blades passing through the air as the hub rotates, and the gearbox and generator in the nacelle. Noise from the blades is minimized by careful attention to the design and manufacture of the blades. The noise from the gearbox and generator is contained within the nacelle by sound insulation and isolation materials. Standing next to the turbine, it is usually possible to hear a swishing sound as the blades rotate, and the whirr of the gearbox and generator may also be audible. However, as distance from the turbine increases, these effects are reduced. Wind turbines may also be designed in different ways and many of the differences have come about from a desire to minimize noise emissions.

Upwind & Downwind Machines: The majority of horizontal axis turbines are designed in such a way that the blades are always upwind of the tower. This has the effect of minimizing any airflow changes as the blades pass the tower. Some turbine designs, particularly some of those installed in the USA, have the turbine blades downwind of the tower. With this type of design, a strong pulse can sometimes be heard with each passing of a blade behind the tower. However, most turbines currently operating in Alberta are of the upwind design.

Twin Speed and Variable Speed Machines: Most horizontal axis turbines rotate at a constant speed, usually between 25 and 50 rpm, irrespective of wind speed. However, twin speed machines operate at a reduced speed when the wind is light. This produces less noise and means the noise of the turbine is also significantly lower by up to 10 dB(A). Variable speed machines change speed continuously in response to changes in wind speed and, although noise output may be higher at higher wind speeds, it is lower at low wind speeds where the low background levels occur.

Direct Drive Machines: Direct drive turbines are the latest design concept in turbine technology. Simply put, these machines have no gearbox or drive train, and consequently no high speed mechanical (or electrical) components. Direct drive turbines are therefore much quieter than gearbox machines as they do not produce mechanical or tonal noise.

When planning a wind turbine project, careful consideration must be given to any noise that might be heard outside nearby houses. Inside, the level is likely to be much lower even with windows open. The potential noise impact is usually assessed by predicting the noise that will be produced when the wind is blowing from the turbines towards the houses. This is then compared to the background noise that already exists in the area without the wind farm operating.

There is an increase in turbine noise level as wind speed increases. However, the noise from wind in nearby trees and hedgerows around buildings and over local topography also increases with wind speed but at a faster rate. Thus, it is difficult to detect an increase in turbine noise because of the increase in the background sound level. Also, wind turbines do not operate below a specified wind speed referred to as the cut-in speed (usually around 15 km per hour). Wind data from typical sites suggests that wind speeds are usually below the cut-in speed for about 30% of the time.

It has been suggested by some regulators that turbine noise level should be kept within 5 dB(A) of the average existing evening or night-time background noise level. This is consistent with standard approach the EUB uses for noise impact assessment of energy industry sources, except for construction related noise that currently has no specific limit.

6. A REVIEW OF WIND TURBINE NOISE REGULATIONS IN OTHER JURISDICTIONS

A summary of limits and regulations regarding noise from wind turbines in many countries around the world are consistent with those the EUB has established for typical rural residences in Alberta. From energy industry noise sources of 40 dBA Leq (nighttime) at the receiver location. For example the recommended highest sound pressure level for noise from wind turbines in Sweden today is 40 dBA outside dwellings. In noise sensitive areas as in the mountain wilderness or in the archipelago, a lower value for the highest sound pressure level is preferable. The EUB also allows for lower levels in pristine areas. The penalty for pure tones is 5 dBA. In practice, the sound pressure levels must be predicted for dwellings nearby a planned wind turbine site to meet the noise limits as part of the process of applying for permission to build. Measurements on site are only performed in case of complaints. When this happens, the measurements are taken at the dwelling of the complainant at wind speeds of 8 m/s at 10 m height.

Denmark on the other hand has a special legislation governing noise from wind turbines. The limit outside dwellings is 45 dBA and 40 dBA Leq for sensitive areas. Sensitive areas are areas planned for institutions, non-permanent dwellings or allotment-gardens, or for recreation. In case of complaints noise measurements are performed according to the legislation, i.e. on a plate on the ground at a distance of 1-2 times the hub height of the turbine. Noise levels at the dwelling of the complainant are then calculated.

The legal base for noise pollution in Germany is the Federal clean air act from 1974 (Bundes-Immissionschultz-Gesetzes). BimSchG, Germany, 1974). The limited values for the sound pressure levels are defined in TA Lärm (Technische Anleitung Lärm, Germany, 1998).

Table 3: German Noise Regulation

Area	Day	Night
Industrial Area	70/65 dBA	70/50 dBA
Mixed residential area or Residential area mixed with industry	60 dBA	45 dBA
Purely residential area	55/50 dBA	40/35 dBA
Areas with hospitals, health resorts etc.	45 dBA	35 dBA

Calculation of sound propagation is done according to DIN ISO 9613-2. All calculations have to be done with a reference wind speed of 10 m/s at 10 m heights4.

The French legislation used in the case of wind turbines is the neighbour noise regulation law. This legislation is based on the principle of noise emergence above the background level and there is no absolute noise limit. The permitted emergence is 3 dBA at night and 5 dBA at day. The background noise level has to be measured at a wind speed below 5 m/s. The legislation is not adjusted to wind turbine cases, and in practice, the noise measurements are made at 8 m/s when the wind turbine noise is expected to exceed the background noise levels the most.

New regulations on noise including noise from wind turbines were introduced in the Netherlands 2001. The limits follow a wind speed dependent curve. For the night time period the limit starts at 40 dBA at 1 m/s and increases with the wind speed to 50 dBA at 12 m/s. For daytime, the limit starts at 50 dBA and for evenings at 45 dBA.

In Great Britain, noise limits should be set relative to the background noise and only for areas for which a quiet environment is desirable. More precisely, noise from wind farms should be limited to 5 dBA above background noise for both day- and night-time. The LA90, 10 min descriptor should be used both for the background noise and for the noise from the wind farm. The argument for this is that the use of the

LA90, 10 min descriptor allows reliable measurements to be made without corruption from relatively loud, transitory noise events from other sources. A fixed limit of 43 dBA is recommended for nighttime. This is based on a sleep disturbance criterion of 35 dBA. In low noise environments, the daytime level of the LA90, 10 min of the wind farm noise should be limited to an absolute level within the range of 35-40 dBA. The actual value chosen within this range should depend upon the number of dwellings in the neighbourhood of the wind farm, the effect of noise limits on the number of kWh generated, and the duration of the level of exposure.

In the Province of Ontario, the Ministry of Environment has established a tiered approach based on the classification of the wind turbine and the area in which it is situated. For example, the lowest sound level limit at a Point of Reception in Class 1 & 2 Areas (Urban), under conditions of average wind speed up to 8 m/s (29 km/h), expressed in terms of the hourly equivalent sound level (Leq) is 45 dBA or the minimum hourly background sound level established in accordance with requirements in Publications NPC-205/NPC-233, whichever is higher. The lowest sound level limit at a Point of Reception in Class 3 Areas (Rural), under conditions of average wind speed up to 6 m/s (22 km/h), expressed in terms of the hourly equivalent energy sound level (Leq) is 40 dBA or the minimum hourly background sound level established in accordance with requirements in Publications NPC-232 or NPC-233, whichever is higher. The sound level limit at a Point of Reception in Class Areas 1 & 2 (Urban) or in Class 3 Areas (Rural), under conditions of average wind speed above 8 m/s and 6 m/s respectively, expressed in terms of the hourly equivalent energy sound level (Leq), is the wind induced background sound level, expressed in terms of ninetieth percentile sound level (LA90) plus 7 dB, or the minimum hourly background sound level established in accordance with requirements in Publications NPC-205/NPC-232/NPC-233, whichever is higher.

The New Zealand Standard NZS 6808 sets the predicted base level (LAeq) at 40 dBA higher than the approach of these guidelines, but the specified propagation model to be used in accordance with that standard does not account for factors such as ground absorption and topography effects that can substantially reduce the noise level in practice. In addition, the New Zealand Standard requires the criteria to be met at all receivers, regardless of their relative amenity or relationship with the wind farm development.

In Australia, the Environment Protection (Industrial Noise) Policy 1994 limits the noise level from non-domestic noise sources including wind farms to 40 dB(A) or the lowest typical background noise level plus 5 dB(A) (whichever is the greater) in rural areas from 2200 hrs until 0700 hrs the following day. This limit applies to existing noise sources and does not necessarily reflect the preferred noise criterion for new (planning) development. The general approach for new development applies a nighttime level of 35 dB(A) to significant development in a rural location. Further, to prevent adverse impacts from the increased noise of wind turbines under high wind conditions, the increasing noise level must also be compared to the corresponding background noise at the relevant receiver.

7 EUB APPROACH TO WIND TURBINE REGULATORY REQUIREMENTS

While wind energy in Alberta has been under development for more than twenty years, it has only been within the last decade that the scale of projects has required a more systemic examination of the noise potential and an integrated approach to its regulation. To accomplish this, EUB has been collecting data, conducting research and investigating what other jurisdictions are doing around the world in hopes of enhancing current requirements and modifying them specifically for wind turbines and wind turbine farms. The key areas that the EUB believed need to be considered were:

- Appropriate models and modeling methodologies that would best reflect the noise potential of wind turbine(s) at a receptor location typical of actual atmospheric and topographical conditions.
- Techniques that would identify the presence of Low Frequency Noise.
- Measurement (monitoring) practices that would provide a realistic quantification of turbine noise without the masking effect of the wind.
- An understanding of the potential impact on human health (annoyance, stress, sleep depravation, etc.) and wildlife indicators (morbidity, mortality, and performance).

From this work, the EUB, together with its multi-stakeholder Noise Directive Review Committee, came to the conclusion that the established energy industry Permissible Sound Levels (PSL) for rural residences in the current legislation would be appropriate for wind turbine(s) which is essentially 5 dBA above the average rural ambient noise level typically resulting in a 40 dBA Leq nighttime limit. These levels, according to the peer reviewed literature, should result in minimum annoyance levels for nearby residents, including potential for stress factors and sleep disturbance; thus, assuring minimum effects on human health.

From the peer reviewed wildlife research, the most significant impact to animals is in avian and bat mortality from contact with the moving blades on the wind turbine. The scientific literature also suggests that a great deal of improvement has been made to blade design to improve visual recognition by birds of the rotating blades resulting in a significant decrease in bird hits. Bats on the other hand have a very acute echo location capability that allows avoidance of turbine blades especially in the fixed speed variety. While any unnecessary loss to wildlife is unfortunate the EUB does not believe that addressing the noise aspect will have any measurable reduction of accidents between birds and wind turbines. It should be noted that an application for wind turbine farms must generally pass a complete environmental impact assessment that takes wildlife impacts into consideration before approval can be granted.

With respect to modeling, the EUB has developed requirements for both modeling of noise and measurement of noise from wind turbines which will be contained in Directive 38 to be released in 2006. In the case of measuring wind turbine noise, current requirements were not effective as the "cut in" wind speed of the turbine exceeded the maximum wind speeds for an acceptable comprehensive sound survey. Therefore, to accurately measure the noise output from the turbines, it was necessary to minimize the wind noise impact on the results. To achieve this, the EUB recommended that noise measurements for comprehensive sound surveys be conducted for wind turbines at speeds between 4 m/s to 6 m/s (approximately 14 km/hr to 22 km/hr) which is typically the "cut in" speed of the turbine. In addition, the measurement of the sound pressure level and wind speeds should be measured at a height above grade that is level with where people may reside (i.e., two story house must have the microphone at the same height as the top floor).

Perhaps the most significant modification to the Noise Control Directive is in the area of Low Frequency Noise (LFN) that is not only a component of concern for wind turbines but for all industrial installations in general. The PSL as noted earlier is acceptable from a human health standpoint except if LFN is present. Research and experience have confirmed that in a small percentage of noise complaints investigated that while the PSL was achieved by industry the impact to residents (annoyance, stressors, and sleep disturbance) was inconsistent with the results. In these cases, LFN could be pinpointed as the culprit, and once addressed, resulted in an improved perception of quality of life factors. The approach to be taken in the new Noise Control Directive is to use a simple C weighting minus A weighting calculation. If the difference is greater than 20 dB and a tonal component exists in the spectrum below 250 Hz, there may exist a LFN problem. As a result, the industrial operator is then required to investigate for possible sources and address accordingly.

Ultimately, the safeguard used by the EUB is to ensure that a new or proposed facility or modification is designed with appropriate noise control considerations in place so that once built, the likelihood of compliance is strong. Therefore, prior to the submission of an application, a Noise Impact Assessment (NIA) must be completed. For example in the case of wind turbine(s), licensees are encouraged to take special care in positioning of wind turbines to maximize the distance to any residences downwind. Also, wind turbines are to be modeled at wind speeds of 6-9 m/s to obtain worst case conditions. At these wind speeds, the wind turbine noise should be greater than or equivalent to the wind noise. At speeds greater that 9 m/s, the wind noise tends to mask the turbine noise. The predicted wind turbine noise will be compared to the PSL.

8. CONCLUSIONS

Currently, the EUB has registered a very small number of noise complaints annually with respect to wind turbines in the operational phase. Typically, concerns are raised by the public during the application stage. Wind turbine farm operators, however, have been provided little guidance so far with respect to the EUB's expectations to environmental noise management as well as other issues that are associated with these types of projects. Consequently, the industry would like more clarity in order to focus on social and regulatory performance measures in a more focused and effective manner.

From the regulatory standpoint, it seems abundantly clear for now that the future of wind turbine electrical generation in Alberta is on a road to significant growth. Some estimates suggest that wind power can contribute between 10 – 20 % of the total electrical demand in the province. Regardless if this is the case, the number of turbines will likely expand by orders of magnitude. It is timely, therefore, to institute effective noise control regulation designed specifically for the potentials presented by wind turbines. The attention given to the noise impacts and associated technological challenges by the Directive Review Committee will ensure that new regulatory requirements remain reasonable, effective and responsible in dealing with wind turbine noise.

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Infrasound from Wind Turbines – Fact, Fiction or Deception

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ABSTRACT

Infrasound is discussed in terms of what it actually is, how the media has dealt with it and what those with limited knowledge say about it. The perception of infrasound occcurs at levels higher than the levels produced by wind turbines and there is now agreement amongst acousticians that infrasound from wind turbines is not a problem. Statements on infrasound from objectors are considered and it is shown how these may have caused avoidable distress to residents near wind turbines and also diverted attention from the main noise source, which is the repeating sound of the blades interacting with the tower. This is the noise which requires attention, both to reduce it and to develop optimum assessment methods

RÉSUMÉ

L'infrason est discuté en termes de ce qu'il est réellement, son traitement dans les médias et par ceux avec des connaissances limitée à son sujet. La perception de l'infrason est qu'il existe à des niveaux plus hauts que ceux produits par des éoliennes, mais il y a maintenant accord parmi les acousticiens que l'infrason des éoliennes n'est pas un problème. Des rapports sur l'infrason par des protestataires sont considérés et on montre comment ceux-ci ont pu causer de la détresse évitable aux résidants près des éoliennes et également divertir l'attention de la source principale de bruit: le son répétitif de l'interaction des lames avec la tour. C'est ce bruit qui exige de l'attention, pour le réduire et pour développer des méthodes optimales d'évaluation.

1. INFRASOUND

A definition of infrasound is: Acoustic oscillations whose frequency is below the low frequency limit of audible sound (about 16Hz). (IEC 1994)

This definition is incorrect, as sound remains audible at frequencies well below 16Hz. For example, measurements of hearing threshold have been made down to 4Hz for exposure in an acoustic chamber (Watanabe and Møller 1990b) and down to 1.5 Hz for earphone listening (Yeowart, Bryan et al. 1967)

The limit of 16Hz, or more commonly considered as 20Hz, arises from the lower frequency limit of the standardized equal loudness hearing contours measured in units of phons, which is a difficult measurement at low frequencies, not from the lower limit of hearing.

2. THE AUDIBILITY OF INFRASOUND

Hearing sensation does not suddenly cease at 20Hz when the frequency is reduced from 21Hz to 19Hz, but continues from 20Hz down to very low frequencies of several Hertz. It is not possible to define an inaudible infrasound range and an audible audio range as separate regions, unless the infrasound range is limited to naturally occurring infrasound of very low frequencies. The range from about 10Hz to 100Hz can be considered as the low frequency region, with possible extensions by an octave at each end of this range, giving 5Hz to 200Hz. There is a very fuzzy boundary between infrasound and low frequency noise, which often causes confusion.

Hearing thresholds in the infrasonic and low frequency region are shown in Fig 1. The solid line above 20Hz is the low frequency end of the ISO standard threshold (ISO:226 2003). The dashed curve, 4Hz to 125Hz, is from Watanabe and Møller (Watanabe and Møller 1990b). There is good correspondence between the two threshold measurements in the overlap region.

The slope of the hearing threshold reduces below about 15Hz from approximately 20dB/octave above 15 Hz to about 12dB/octave below. (Yeowart, Bryan et al. 1967). The common assumption that "infrasound" is inaudible is incorrect, arising from an unfortunate choice of descriptor. "Real" infrasound, at levels and frequencies below audibility are largely natural phenomena, although human activities, such as explosions, also produce infrasound. Microphone arrays for the detection of airborne infrasound are a component of the monitoring for the Nuclear Test Ban Treaty

The median hearing threshold is not a simple delineation between "Can hear - Can't hear", but the threshold is rather variable between individuals, depending on their genetics, prior noise exposure and age (ISO7029 2000). The standard deviation of threshold measurements is typically about 6dB.

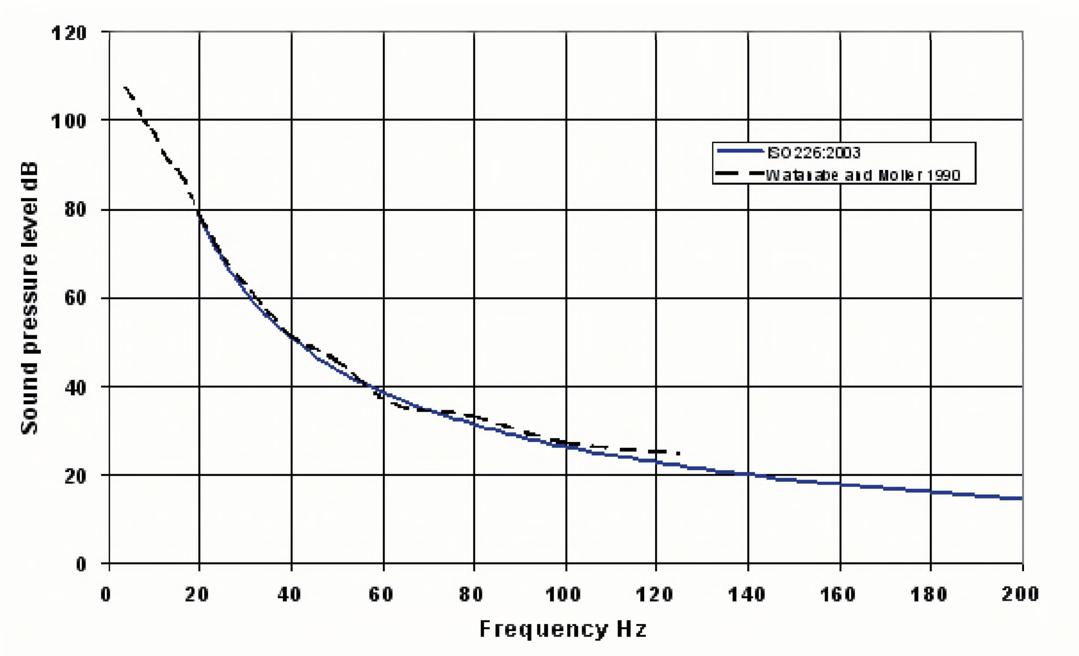

Figure 1. Infrasonic and low frequency threshold

Therefore, it is most unlikely that anyone will be able to hear sound at any frequency which is more than, say, 20dB below its median threshold.

The false concept that infrasound is inaudible, when coupled with the many common misconceptions about its subjective effects, has spawned concerns, particularly expressed in popular publications, which are best described as mythology, rather than fact.

A report reviewing low frequency noise (Leventhall, Benton et al. 2003) is available on the internet.

High levels at very low frequencies: These may result in aural pain, which is not a hearing sensation, but arises from displacements of the middle ear system beyond its comfortable limits. Persons with both hearing ability and hearing loss, and with normal middle ears, exhibit aural pain at a similar stimulus level, which is at about 165dB at 2Hz, reducing to 145dB at 20Hz. Static pressure produces pain at 175 -180dB, whilst eardrum rupture occurs at 185 -190dB (von Gierke and Nixon 1976). A pressure of 5 x 104 Pa, which is about half atmospheric pressure, falls in the 185 -190dB range. A child on a swing experiences infrasound at a level of around 110dB and frequency 0.5Hz, depending on the suspended length and the change in height during the swing.

Natural infrasound: We are enveloped in naturally occurring infrasound, which is in the range from about 0.01 Hz to 2Hz and is at inaudible levels. The lower limit of one cycle in a hundred seconds separates infrasound, as a propagating wave, from all but the fastest fluctuations in barometric pressure. There are many natural sources of infrasound, including meteors, volcanic eruptions, ocean waves, wind and any effect which leads to slow oscillations of the air. Man made sources include explosions, large combustion processes, slow speed fans and machinery. Much natural infrasound is lower in frequency than 1 Hz and below the hearing threshold. (Bedard and George 2000). Our evolution has been in the presence of natural infrasound.

Alternative receptors: The question arises of whether there is a hierarchy of receptors, of which the ear is the most sensitive except at the lower frequencies, when other receptors may come into prominence. Several vibration and contact detectors reside in the skin, covering different frequency ranges (Johnson 2001). The Pacinian corpuscles are the most sensitive, with a threshold displacement of about 0.002mm in the region of 200Hz,. Their sensitivity into lower frequencies reduces at approximately 50dB per decade from the maximum sensitivity.

The threshold displacement of 0.002mm at 200Hz is similar to the particle displacement in air of a 200Hz sound wave of 94dB (1 Pa) pressure. Since the particle displacement in a sound wave of fixed pressure doubles as the frequency is halved (20dB per decade) inaudible sound waves will not excite these subcutaneous receptors.

There is no reliable evidence that infrasound at levels below its hearing threshold has an adverse effect on the body (Berglund and Lindvall 1995). A recent French study of wind turbine noise confirms that infrasound from wind turbines is not a problem. (Chouard 2006)

Body vibrations: It is known that high levels of low frequency noise excite body vibrations (Leventhall, Benton et al. 2003). The most prominent body response is a chest resonance vibration in the region of 50Hz to 80Hz, occurring at levels above about 80dB, which are audible in this frequency range. The low frequency perception thresholds of normal hearing and profoundly deaf subjects have also been investigated (Yamada, Ikuji et al. 1983), when it was shown that the profoundly deaf subjects perceived noise through their body only at levels which were in excess of normal thresholds. The threshold of sensation of the deaf subjects was 40-50dB above the hearing threshold of those with normal hearing up to a frequency of 63Hz and greater at higher frequencies. For example about 100dB greater at 1 kHz, at which level perception was by the subjects' residual hearing. Deaf subjects experienced chest vibration in the same frequency range as normal hearing subjects.

The much repeated statement that "infrasound can be felt but not heard" is not supported by these measurements. The erroneous thought processes which led to this confusion are possibly:

Infrasound causes body vibrations - (correct at very high levels)
But infrasound is inaudible - (not correct at very high levels)
Therefore infrasound can be felt but not heard - (not correct)

neglecting that the levels to produce body vibrations are well above the hearing threshold. But, as will be shown later, infrasound is not a problem for modern wind turbines.

The dimensions of noise: Noise is multidimensional. A one dimensional view of noise is the A - weighting, which considers only levels and neglects frequencies. Another one-dimensional view is to consider only frequencies and neglect levels. Developing the dimensions further, two dimensions include both frequency and level (the spectrum), three dimensions adds in the time variations of the noise, whilst higher dimensions include subjective response.

Many lay people take the one dimensional view of infrasound, which is based on frequency alone. They express concern at the presence of any infrasound, irrespective of its level. This is a significant failure of understanding.

Public Perceptions: The Public has been misled by the media about infrasound, resulting in needless fears and anxieties, which possibly arise from confusion of the work on subjective effects, which has been carried out at high, audible levels with the popular mindset that infrasound is inaudible. There have also been misunderstandings fostered in publications and popular science books, considered later.

Early work on low frequency noise and its subjective effects was stimulated by the American space program. Launch vehicles produce high noise levels with maximum energy in the low frequency region. Furthermore, as the vehicle accelerates, the crew compartment is subjected to boundary layer turbulence noise for about two minutes after lift-off. Experiments were carried out in low frequency noise chambers on short term subjective tolerance to bands of noise at very high levels of 140 to 150dB, in the frequency range up to 100Hz (Mohr, Cole et al. 1965). It was concluded that the subjects, who were experienced in noise exposure and who were wearing ear protection, could tolerate both broadband and discrete frequency noise in the range 1 Hz to 100Hz at sound pressure levels up to 150dB. Later work suggests that, for 24 hour exposure, levels of 120 -130dB are tolerable below 20Hz. These limits were set to prevent direct physiological damage, not for comfort. (Mohr, Cole et al. 1965; Westin 1975; von Gierke and Nixon 1976).

The American work did not attract media attention, but in the late 1960's two papers from France led to much publicity and speculative exaggerations. (Gavreau, Condat et al. 1966; Gavreau 1968). Although both papers carry "infrasound" in their titles, there is very little on frequencies below 20Hz (Leventhall 2005). Some rather casual and irresponsible experiments of the "try it and see" variety were carried out on exposure of the laboratory staff, primarily using high intensity pneumatic sources at frequencies mainly at the upper end of the low frequency range, or above. For example, 196Hz at 160dB sound level and 340Hz at 155dB sound level. A high intensity whistle at 2600Hz is also included in the "infrasound" papers.

Infrasounds are not difficult to study but they are potentially harmful. For example one of my colleagues, R Levavasseur, who designed a powerful emitter known as the 'Levavasseur whistle' is now a victim of his own inventiveness. One of his larger whistles emitting at 2600Hz had an acoustic power of 1 kW. . ... This proved sufficient to make him a lifelong invalid. (Gavreau 1968)

Of course, 2600Hz is not infrasound, but the misleading implication is that infrasound caused injury to Levavasseur. A point source of sound of power 1 kW will produce a sound level of about 140dB at 1 m, which is a very undesirable exposure at 2600Hz.

Referring to the exposure of 160dB at 196Hz:

...after the test we became aware of a painful 'resonance' within our bodies - everything inside us seemed to vibrate when we spoke or moved. What had happened was that this sound at 160 decibels........ acting directly on the body produced intense friction between internal organs, resulting in sever irritation of the nerve endings. Presumably if the test had lasted longer than five minutes, internal haemorrhage would have occurred. (Gavreau 1968)

96 Hz is not infrasound, but the unpleasant effects at 160dB are described in a paper which is said to be about "Infrasound". Internal haemorrhage is often quoted as an effect of exposure to infrasound. Exposure levels were not given for frequencies of 37Hz and 7Hz, although the 7Hz caused subjective disturbance and vibrations of the laboratory walls. Unfortunately, these papers by Gavreau were seized upon by the press and presented to claim that infrasound was dangerous . For example "The silent killer all around us", London Evening News, 25 May 1974. When work by other investigators detected moderate levels of infrasound in, for example, road vehicles, the press was delighted, leading to "The silent sound menaces drivers" - Daily Mirror, 19 October 1969.

"Danger in unheard car sounds" The Observer, 21 April 1974.

The most deplorable example, in a book which claimed to have checked its sources, was in "Supernature" by Lyall Watson (Coronet 1973). In this it is claimed that the technician who gave one of Gavreau's high power infrasound sources its trial run "fell down dead on the spot" and that two infrasonic generators "focused on a point even five miles away produce a resonance that can knock a building down as effectively as a major earthquake".

T hese ficticious statements are, of course, totally incorrect but are clear contributors to some of the unfounded concerns which the public feels about infrasound. One can detect a transition from Gavreau and his colleague feeling ill after exposure to the high level of 196Hz to "fell down dead on the spot" and a further transition from laboratory walls vibrating to "can knock a building down", transitions which resulted from repeated media exaggerations over a period of five or six years.

The misunderstanding between infrasound and low frequency noise continues to the present day. A newspaper article on low frequency noise from wind turbines (Miller 24 January 2004) , opens with:

Onshore wind farms are a health hazard to people living near them because of the low-frequency noise that they emit, according to new medical studies. A French translation of this article for use by objectors' groups opens with:

De nouvelles etudes medicales indiquent que les eoliennes terrestres representent un risque pour la sante des gens habitant a proximite, a cause d'emission d'infrasons.

The translation of low frequency noise into infrasons continues through the article. This is not a trivial misrepresentation because, following on from Gavreau, infrasound has been connected with many misfortunes, being blamed for problems for which some other explanation had not yet been found e.g., brain tumours, cot deaths of babies, road accidents.

Infrasound, and its companion low frequency noise, now occupy a special position in the national psyche of a number of countries, where they lie in wait for an activating trigger to re-generate concerns of effects on health. Earlier triggers have been defence establishments and gas pipelines. A current trigger is wind turbines.

3 INFRASOUND AND LOW FREQUENCY NOISE FROM WIND TURBINES

Early designs of downwind turbines produced pressure pulses at about once per second, which were high enough to cause vibrations in lightweight buildings nearby. (Shepherd and Hubbard 1991). A series of pulses occurring at one per second analyses into a harmonic series in the infrasound region, which is the origin of the link between wind turbines and infrasound One could discuss whether the Fourier time-frequency duality is misleading on this point, since it was the effects of peaks of the pulses which caused the building vibration, not a continuous infrasonic wave. Similar vibration would have occurred with a faster stream of pulses, with the limiting condition that the pulse repetition rate was lower than the period of the vibration.

Modern up-wind turbines produce pulses which also analyse as infrasound, but at low levels, typically 50 to 70dB, well below the hearing threshold. Infrasound can be neglected in the assessment of the noise of modern wind turbines (Jakobsen 2004)

Fig 2 shows the infrasonic and low frequency noise at 65m from a 1.5MW wind turbine on a windy day. The fol-

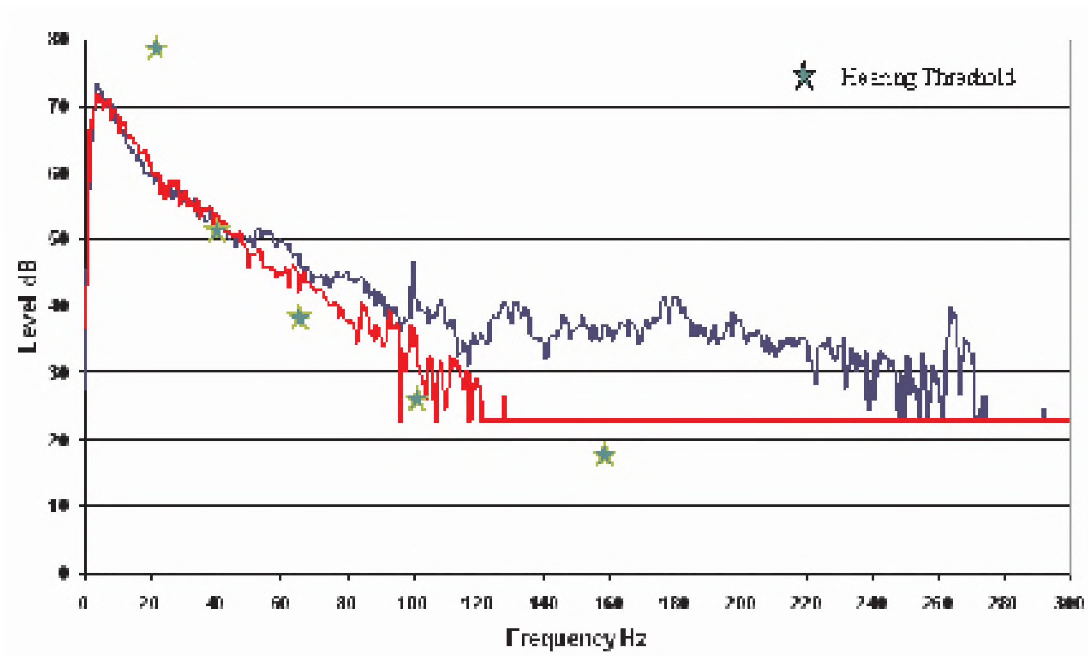

Figure 2. Spectrum of a modern upwind wind turbine - Upper trace Wind Turbine Noise. Lower trace Background noise.

lowing should be noted.

- The fall off below about 5Hz is an instrument effect. The background noise actually increases down to the frequencies of atmospheric pressure variations .
- Frequencies below 40Hz cannot be distinguished from background noise due to wind.
- The wind turbine noise and background noise separate above about 40Hz and both rise above the median hearing threshold.
- The measurements were taken at 65m. Levels are likely to be about 15dB lower at normal separation distances

On the occasions, such as unusually turbulent inflow conditions, when low frequency noise is produced by wind turbines, it may not be perceived as a noise, but rather as an unidentified adverse component in the environment, which disappears if the turbines stop, or if the inflow conditions change. This is because we are not accustomed to listening to low levels of broad band low frequency noise and, initially, do not always recognise it as a "noise", but more as a "disturbance" in the environment. An analogy is with air-conditioning rumble noise, which is noticed when it stops.

What Objectors Say Objectors have eagerly grasped the media hype on infrasound and low frequency noise and used it to engender concerns about wind turbine developments. In this they have, possibly, done a disservice to the communities they were established to help, through raising false concerns and diverting attention from more important aspects of the development. Two examples are as follows.

In the UK there is an Advertising Standards Authority(ASA), to which deceptive adverts can be referred for assessment. An objectors' group (Ochils Environmental Protection Group) issued a leaflet "FACTS ABOUT WIND POWER". containing a number of assertions including:

. "... wind turbines still create noise pollution, notably 'infra sound' - inaudible frequencies which nevertheless cause stress-related illness ..."

In their Judgment (April 02, 2004), the ASA concluded that the objectors had not produced evidence to substantiate their claim.

In the USA, a high profile objector (Nina Pierpont of Malone NY) placed an advertisement in a local paper, consisting entirely of selected quotations from a previously published technical paper by van den Berg (Van den Berg 2004). However the comment "[i.e. infrasonic]", as shown in Fig 3, was added in the first line of the first quotation in a manner which might mislead naive readers into believing that it was part of the original.

The van den Berg paper was based on A-weighted measurements and had no connection with infrasound. So, not only is the advertisement displaying the advertiser's self deception, but this has also been propagated to others who have read it. To mistakenly connect the noise to infrasound, which has unpleasant associations is, however, a way to gather support . (When a person has adopted a particular mindset, new information is processed to support that mindset. We all do this.)

It takes little technical knowledge to be aware that a modulated high frequency wave does not contain the modulation components. For example, an amplitude modulated radio wave contains the carrier wave and sidebands, which are close in frequency to the carrier. The fluctuations of wind turbine noise (swish – swish) are a very low frequency modulation of the aerodynamic noise, which is typically in the region of 500 - 1000Hz. The modulation occurs from a change in radiation characteristics as the blade passes the tower, but the modulating frequencies do not have an independent and separate existence.

The comment, [i.e. infrasonic], added into Fig 3 gives incorrect information. Claims of infrasound are irrelevant and possibly harmful, should they lead to unnecessary fears.

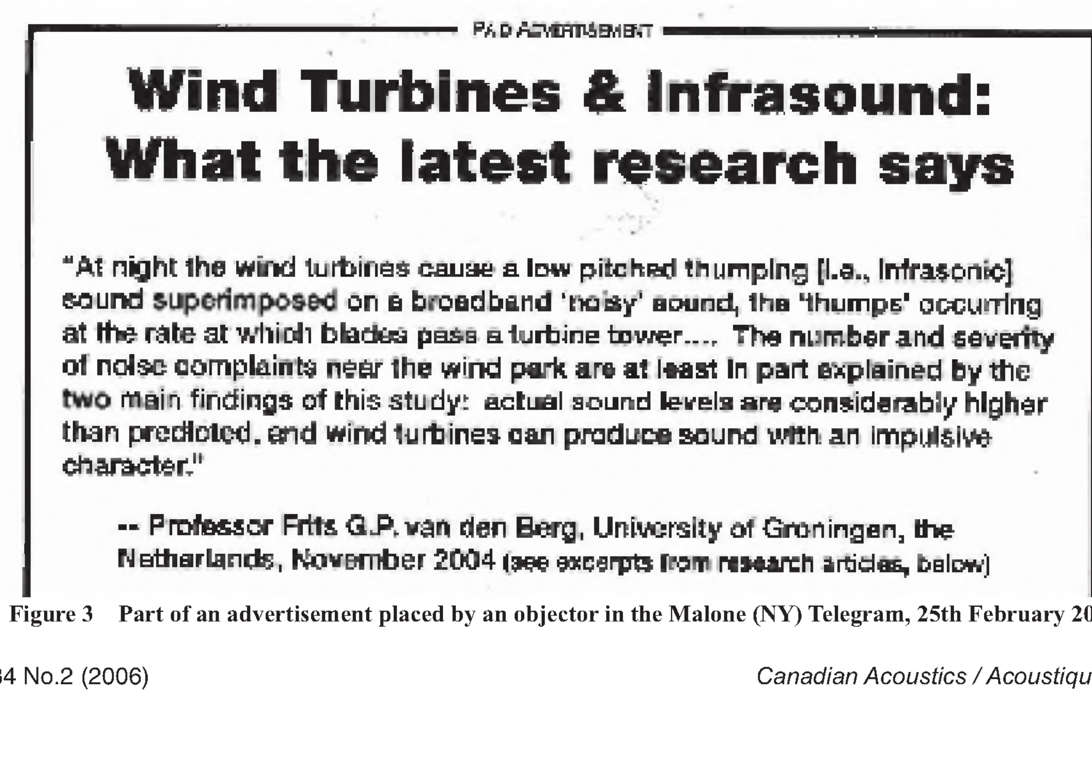

Figure 3 Part of an advertisement placed by an objector in the Malone (NY) Telegram, 25th February 2005.

It has been shown that fear of a noise source, for example that aircraft might crash, increases the extra annoyance of a person with a high fear of a crash by up to 19dB DNL equivalent, compared with a person who has no fear (Miedema and Vos 1999).

Fear of a source is not the same as fear of the noise itself, but it is understandable that those who fear the effects of a noise upon their health will be less tolerant of the noise than those who do not fear it. We can only speculate upon the harm which objectors might have done by, for example, taking a one dimensional view of infrasound and publicising the subjective effects of high levels of both infrasound and low frequency noise in a manner which implies that the effects may also be caused by the low levels produced by wind turbines.

4 WIND TURBINE NOISE

It has been shown above that there is insignificant infrasound from wind turbines and that there is normally little low frequency noise. Turbulent air inflow conditions cause enhanced levels of low frequency noise, which may be disturbing, but the overriding noise from wind turbines is the fluctuating audible swish, mistakenly referred to as "infrasound" or "low frequency noise". Objectors uninformed and mistaken use of these terms (as in Fig 3), which have acquired a number of anxiety-producing connotations, has led to unnecessary fears and to unnecessary costs, such as for re-measuring what was already known, in order to assuage complaints.

Attention should be focused on the audio frequency fluctuating swish, which some people may well find to be very disturbing and stressful, depending on its level. The usual equivalent level measurements and analyses are incomplete, as these measurements are taken over a time period which is much longer than the fluctuation period and information on the fluctuations is lost. A time varying sound is more annoying than a steady sound of the same average level and this is accounted for by reducing the permitted level of wind turbine noise. However, more work is required to ensure that the optimum levels have been set.

5 CONCLUSIONS

- Infrasound from wind turbines is below the audible threshold and of no consequence.
- Low frequency noise is normally not a problem, except under conditions of unusually turbulent inflow air.
- The problem noise from wind turbines is the fluctuating swish. This may be mistakenly referred to as infrasound by those with a limited knowledge of acoustics, but it is entirely in the normal audio range and is typically 500Hz to 1000Hz. It is difficult to have a useful discourse with objectors whilst they continue to use acoustical terms incorrectly. This is unfortunate, as there are wind turbine installations which may have noise problems.
- It is the swish noise on which attention should be focused, in order to reduce it and to obtain a proper estimate of its effects. It will then be the responsibility of legislators to fix the criterion levels. However, although the needs of sensitive persons may influence decisions, limits are not normally set to satisfy the most sensitive.

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Note: Continued on Page 32

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WIND FARM NOISE ASSESSMENT IN AUSTRALIA AND MODEL COMPARISON

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ABSTRACT

Wind farm development in Australia has grown significantly since 1999. From 2003 to 2005, there were several proposals submitted for approval with numbers of turbines ranging from 30 to over 100. Noise impacts from wind farms remains a contentious issue for the community and statutory authorities, but there is no nationally agreed approach to assessment. Prediction methods can include computer modelling, but there are no preferred models and it is up to the developer to justify the model. Very little, if any, data has been published comparing the accuracy of models. Compliance assessment is only required at the nearest residential or noise sensitive locations. Operators seem loathe to provide actual data to allow such comparisons to be made and provide some confidence in the predictions. This paper describes the noise assessment process for wind farms in Australia and compares the predictions of a number of models, including two commonly used industrial noise packages and one model specially developed for wind turbines.

RÉSUMÉ

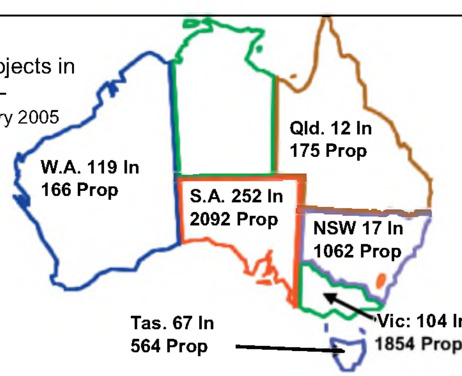
Le développement des parcs d'éoliennes en Australie a connu une croissance élevée depuis 1999. Entre 2003 et 2005, plusieurs propositions avec un nombre de turbines variant de 30 à plus de 100 ont été soumises pour approbation. L'impact au niveau du bruit des parcs d'éoliennes demeure un problème contentieux pour les autorités municipales et légales, mais il n'y a pas d'approche d'évaluation du bruit acceptée dans l'ensemble du pays. Les méthodes de prédiction peuvent inclure la modélisation par ordinateur mais il n'y a pas de modèle privilégié et la justification d'un modèle incombe au développeur. Très peu de données ont été publiées comparant la précision des modèles. La conformité est seulement requise à la plus proche résidence ou endroit sensible au bruit. Les opérateurs semblent réticents à fournir des données mesurées qui permettraient d'effectuer des comparaisons et donner une certaine confiance dans les prédictions. Cet article décrit la procédure d'évaluation du bruit des parcs d'éoliennes en Australie et compare les prédictions d'un certain nombre de modèles, incluant deux suites de modèles de bruit industriel utilisées couramment ainsi qu'un modèle spécialement développé pour les éoliennes.

1. INTRODUCTION

The first modern wind turbine generator installed in Australia was a 60kW unit in 1987 (1). Early developments were generally single units, although there were some 6 and 9 turbine developments. Most were in remote or rural coastal areas. From about the year 2000, larger wind farms with larger units began to be installed, with numbers of generators being from 12 to 46 in the one installation, with power ranges from 600 kW to 1.75 MW. In 2005, two wind farms of over 50 turbines of 1.65 MW were installed. The currently installed generating capacity from wind farms in Australia is 572 MW, with a further 5,914 MW proposed – see Figure 1 (1). There are likely to be many more in planning. The rate of development depends to some extent on Government policy, with the Commonwealth and State governments requiring fixed percentages of power generation to be from renewable resources. Technology development has also assisted, with the newer wind farms proposed having 2 to 3 MW generators in projects of over 100 turbines in the one area.

In Australia, as in most countries, proposals for industrial developments require statutory approval from local and State authorities. These require the preparation of an environmental impact assessment to support the development and assist authorities and the public determine the suitability of the project. For wind farms, the assessment of impacts range from archaeological to visual, radio-transmission, bird-strikes

Figure 1:
Wind Energy Projects in Australia -
AUSWEA February 2005



and noise. In most cases, noise assessment requires the use of computer software prediction modelling. Noise models have been used for prediction of industrial projects since the mid 1980's. In Australia, one model was developed with national government funding to provide a common approach to prediction and assessment across the country. This model, ENM, was released in 1987 and has been successfully used in Australia and other countries since that time, with many projects providing verification of its accuracy for Australian conditions. However, when it came to prediction of wind turbine noise, results were much higher than expected. Alternative models were used and some acousticians modified ENM. However there was no consistent approach. Some States require the use of a geometric spreading algorithm without consideration of ground topography or ground absorption, while others allowed any model to be used – justification was up to the developer.

In Europe, concern had also been raised about predicting noise from wind farms in the 1990's, and the EU Commission funded a research project into noise from wind turbines – measurement, propagation, immission and tonality (2). One of the outcomes of the EU Project was a software prediction model for wind turbines, known as WiTuProp. As a part of the Project, there were validation studies published for European conditions.

An earlier paper in 2004 (3) described the approach to noise assessment of wind farms in Australia. This will be described in this paper. The 2004 paper also described predicted sound levels using ENM and some other models, including WiTuProp. The difference in predictions between models was significant, with up to 24 dB difference in sound level at 1000 metres for a single turbine being reported. In late 2004, the developer of ENM issued a technical note that was intended to provide improved accuracy for ENM with elevated noise sources, such as wind turbines (4). A subsequent paper in 2005 (5) compared the results of the modified ENM predictions with predictions from other software. The difference still remained significant. Other authors have also published comparisons of predictions from other software models or algorithms. Further analysis with WiTuProp has identified an error in the results presented in the 2004 and 2005 papers, and this paper will present corrected values for comparison.

Despite the work on model development and comparison pf predictions between them, little work has been done on verification of model predictions for accuracy. Individual model developers may have tested the accuracy of their models with one or two wind turbines, but there has been no detailed publication of model validation – that is comparing predicted sound levels with measured sound levels for the same meteorological conditions. This is considered to be a consequence of compliance assessment of wind farm developments only being required at the residential receivers. If the software predictions in the environmental noise assessments are anywhere near accurate, the sound levels at the residential receivers should be less than or within the ambient sound levels and very difficult to measure. Measurements at closer distances may be required to verify the predictions, but they cost money because of the additional work required. So verification of predictions is not done and model accuracy remains unknown.

This fact was discussed at the October 2005 Wind Turbine Noise Conference in Berlin (6). One suggestion has been made that a round robin type of approach be taken to model verification. Real wind farm operating data at distances where the wind turbine sound levels can be accurately measured, should be provided for calculation using the models that people have. Accuracy of predictions can then be published.

Validation and accuracy of predictions is an important issue for the further development of the wind generation industry. Until the community, both professional and the general public, have confidence in the predictions made, there will be opposition to wind farm developments. Once accuracy is known, noise as an issue can be easily addressed.

This paper describes the two approaches to noise assessment of wind farm projects taken in Australia. It also presents comparisons of some prediction software models for the same conditions and corrects previously presented material. A combination of setting acceptable objective sound levels based on the measurements of existing background, along with the predictions made from widely used or verified models, can help in ensuring environmental noise from wind farms is not an issue for future developments.

2. ASSESSMENT OF WIND FARM NOISE IN AUSTRALIA

Within Australia's six states and two territories, there are two main methods of noise assessment of wind farms. States and territories have jurisdiction over environmental approvals of industrial developments. There are some common quality objectives in other areas of environmental assessment, such as air and water quality. But each assesses noise and set quality objectives in different ways.

Most wind farms are located in rural or coastal locations because of resource location and minimal environmental impact. This can at times cause objections from those who see rural living as an alternative lifestyle to their former, noisier urban environments. Earlier wind farms may have been located much closer to houses and had much smaller (power and height) turbines than the latest generation of turbines, and there is always anecdotal evidence of how noisy they are. The general approach to wind farm noise impact assessment is the same as for any industrial development. Noise objectives for the proposed project are developed from measurements of existing background sound levels – that is sound levels without the contribution of wind farms. Rural environments can have very low sound levels, but these occur when there is no wind. At these times, wind farms do not operate. So the assessment needs to cover the range of wind conditions that occur when a wind turbine will operate.

Objectives are set differently in different States. In Victoria (7) and Tasmania (8), assessment and objectives are based on the approach given in the New Zealand Standard NZS 6808-1998 (9). The background noise is measured at the noise sensitive location over a period long enough to provide a range of wind conditions during which a wind farm would operate. Ten-minute measurement intervals are used to match meteorological data, to obtain a statistical analysis of sound levels over a period typically of at least two weeks. The objective is based on a regression analysis of the LA95.10-min sound level at the residential receiver location, with the wind speed at 10 metres in the location of the wind farm. The objective for the contribution sound level from the wind farm is set at an LAEQ.10-min of 40 dB(A) or LA95.10-min +5 dB(A), which ever is greater, over the range of operating wind speeds. Figure 2 shows this analysis for one site. Tasmania requires predictions of sound level to be made down to the 35 dB(A) noise contour. The intent of this approach is to achieve an internal sound level of less than 30 to 35 dB(A).

South Australia developed a guideline in 2003 and this is also used in New South Wales (10). A similar period of background noise measurement is done, with at least 2000 data points required. The objective sound level is based on the regression analysis of LA90.10-min at the noise sensitive location, with the wind speed at the wind farm location. The objective for the contribution sound level from the wind farm is set at an LAEQ.10-min of 35 dB(A) or LA90.10-min +5 dB(A), which ever is greater. Figure 3 shows this analysis for the same site data as used in Figure 2. This LA90 based objective is considered to be tighter or lower than that in Figure 2. Figure 4 compares the two objectives with the LAEQ data for the same site. If the Victorian approach is used, there will be times when the objective sound level will be 10 dB(A) or more above the background LAEQ.

Figure 2: Development of Objectives for Victoria and Tasmania based on NZ Standard (LA95 + 5) for one site

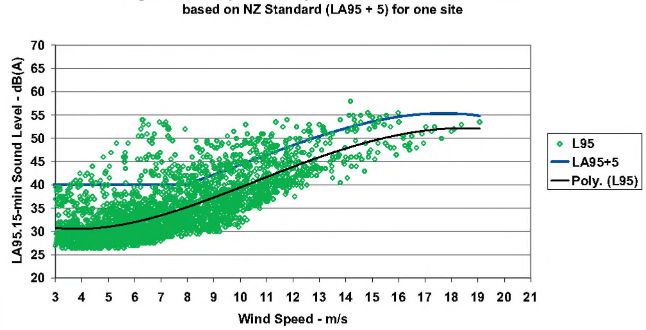


Figure 3: Development of Objectives based on SA approach (LA90+5 for the same site as Figure 2

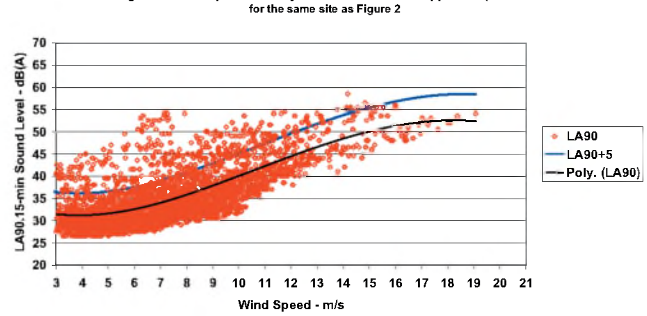
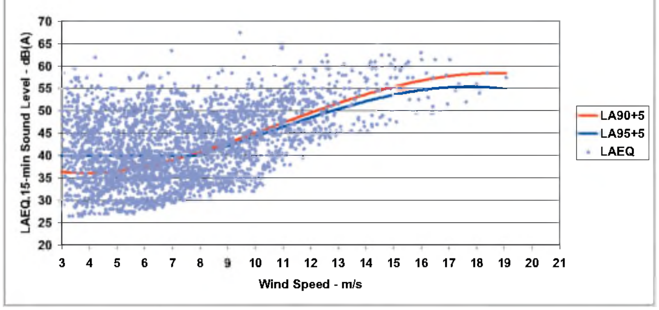


Figure 4: Comparison of Measured LAEQ with Objectives based on SA approach (LA90+5) and NZ Standard approach (LA95 + 5) for one site



3. PREDICTION MODELS

This sections describes models used in the comparison in Section 4. In Victoria and Tasmania, the approach to assessment requires that predictions of sound levels from wind farms be made according to the New Zealand Standard. This uses the simple algorithm

$$L_R = L_w - 10Log(2\pi R^2) - \Delta L_a \qquad (1)$$

where:

- L_R is the sound pressure level at a distance R
- L_w is the sound power level (PWL) in dB(A)
- ΔL_a is the attenuation caused by atmospheric absorption over distance R

This is considered by some to be a conservative model because it does not consider topographical effects or ground surface absorption between the source and receiver. However, with higher-powered wind turbines with increased low-frequency energy, it may not provide adequate accuracy. Tasmania required in 2004 that compliance assessment include measurements to validate the prediction model used (8). An interactive version of this algorithm is provided on the National Physical Laboratory (NPL) web-page **Wind turbine Noise Model**. This allows the user to have either spherical or hemi-spherical spreading and include or ignore an atmospheric attenuation rate of 5 dB/km (11).

Use of a required model or algorithm is not unusual, allowing for all projects to be assessed on the same basis. Set algorithms are known to be required in the Netherlands, Germany, Sweden, Norway and Denmark (12).

Some other software models use a similar approach to the above algorithm, with the ΔL_a term set at a typical 2 dB/km attenuation rate. However this does not take account of the frequency content of the source sound spectrum. **WindFarmer** is one such model (13). **CadnaA** is a noise prediction model developed for industrial noise sources, and has different algorithms for different types of sources, such as road, rail, and aircraft (14). It is used more in Europe and North America than in Australia. ENM is an Australian developed program that has been used and verified widely in Australia.

ENM and CadnaA were originally used for low level sources such as industrial sources, but both have had algorithms or modifications made for other sources, such as road and rail traffic, and elevated sources such as wind turbines. Other models that include wind turbine noise propagation include WindPRO and Nord2000.

The two main models used in this comparison are ENM and WiTuProp. ENM in its original form predicts unusually high noise levels for wind turbine types of noise sources (3). Because of this difference, the developer issued a technical note to recommend a correction to the wind speed used in the model (4). The note explains that the ENM wind effect algorithm is based on measurements reported by Parkin and Scholes in 1964 and 1965, for a source height of 1.8m above grass and wind speed measured at the standard meteorological height of 10m. As wind effects are related to wind gradient, and wind gradients are significantly lower at the 60 to 120m elevation of wind turbine noise sources than they are at ground level, it was not surprising that the ENM algorithms did not appropriately address the sound propagation of wind turbines. For source heights of greater than 10m, a correction needed to be applied to the wind speed used in the ENM model. For example, for a source height of 100m, a 10m-wind speed of 8m/s and an open exposed terrain category, the wind speed correction factor is 0.129, giving a modelling wind speed of 1.032m/s. The technical note explains how the correction factor is derived.

WiTuProp is a heuristic model, based on classical geometrical ray theory for a non-refractive atmosphere, modified for a refractive atmosphere (2, 15, 16). It was developed from a European Commission funded joint project, to investigate wind turbine noise measurement methods, the knowledge of noise propagation under different meteorological conditions, measurement of immission at dwellings and the assessment of possible tonal noise from machinery components. The study was a collaboration between nine European partners in six countries, which commenced in January 1997. The noise propagation model aspects of the study were undertaken by Delta Acoustics & Vibration, of Denmark. One of the outcomes of this project was the development and validation of a noise propagation model for wind turbines, known as WiTuProp. This algorithm was used by the author in a recent EIS. The need to understand the difference between its predictions and those of other methods is one of the reasons for the work reported in this paper. Those involved with environmental regulation in Australia have requested validation studies be presented for WiTuProp and other models using Australian conditions. Data to enable this to be done has yet to be obtained.

4. MODEL INPUTS AND SCENARIOS

Model input parameters are similar on basic components and as they become more complex, and hopefully more accurate, the number of parameters increases. Basic inputs include distance, source height, source sound power level, and wind speed and direction. More detailed inputs include source spectrum, topography, ground absorption, air temperature and humidity, lapse rate and wind speed profile.

Some parameters have more influence than others once the basic distance, and source sound power level are set. The main determining parameter is the wind speed, which affects both turbine sound power level and sound propagation rates. Wind direction and lapse rate are probably the next ranked parameters for influence on the final sound level, followed by ground absorption, temperature and humidity. These details will be illustrated in the graphs and tables for WiTuProp and ENM.

The basic scenario used for comparison of several models was a single 2MW wind turbine of 105 dB(A) PWL, set at 70m hub-height above a flat rural landform with a surface absorption of 200 CGS Rayls. Figure 5 shows the sound power level increase with increasing wind speed for this type of turbine, and Figure 6 shows the spectra for four wind speeds, including the spectrum used for 8m/s wind. Meteorological conditions were 5oC and 95% rh, to represent a cold winter's morning in Australia and other temperate countries, with a low atmospheric attenuation for sound propagation. Lapse rate used, where it was a variable in the equation, was –0.66oC/100m. Use of positive (inversion) lapse rates was not made for the general comparison on the basis that with at least 4m/s of wind speed – the starting speed of many turbines, an inversion would not be present. (However, lapse rate sensitivity has been checked for WiTuProp and ENM.)

The basic comparison has been made at a wind speed of 8m/s at 10m elevation, and downwind. This is the standard wind condition for reporting of sound power level in IEC-614100-11 (17), although amendments to the Standard will also require reference to the wind speed at hub-height.

Figure 5: 2MW 105 dB(A) Wind Turbine - PWL vs Wind Speed

Figure 6: 2MW Wind Turbine PWL Spectra at increasing wind speed

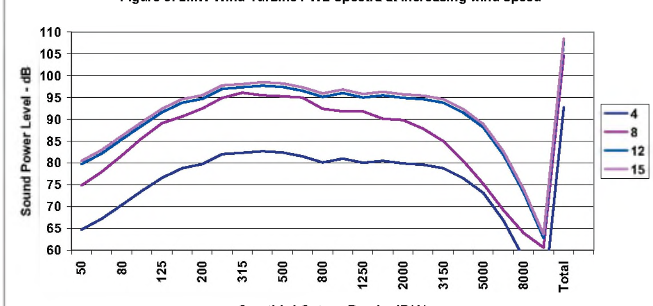
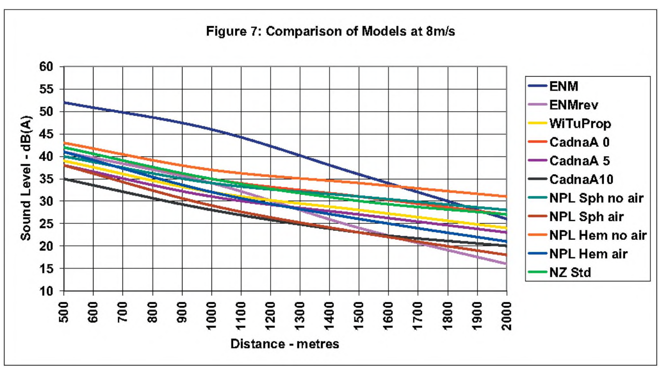


Table 1 and Figure 7 show the comparison of results from four models or algorithms, with different settings. Figure 8 reduces the number of results to those of four models. The results for the original ENM calculations are not included in the statistical review at the bottom of Table 1, as they have been shown to not be relevant.

Model or Algorithm	Sound Level dB(A) at Distance metres			
	500	1000	1500	2000
ENM	*52*	*46*	*42*	*39*
ENMRev	41	34	24	16
WiTuProp	39	32	28	24
CadnaA 0	42	35	31	27
CadnaA 0.5	38	31	27	23
CadnaA 1.0	35	28	23	20
NPL Sph$_{no\ air}$	40	34	31	28
NPL Sph $_{air}$	38	29	23	18
NPL Hem$_{no\ air}$	43	37	34	31
NPL Hem$_{air}$	41	32	26	21
NZ Std	42	35	30	27
Max*	***43***	***37***	***34***	***31***
Min*	***35***	***28***	***23***	***16***
Difference	***8***	***9***	***11***	***15***
Average*	***40***	***33***	***28***	***24***

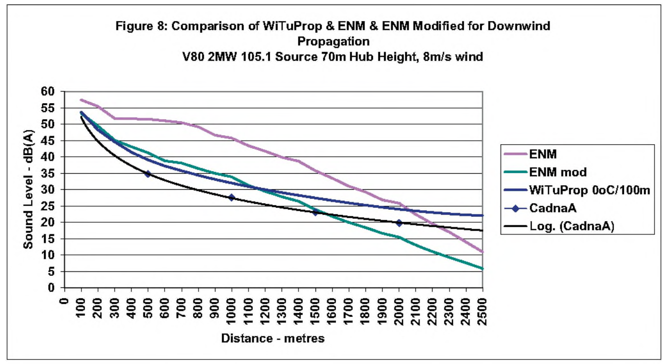
Note: * Calculations of Maximum, Minimum and Average in Table 1 do not include the ENM original results.

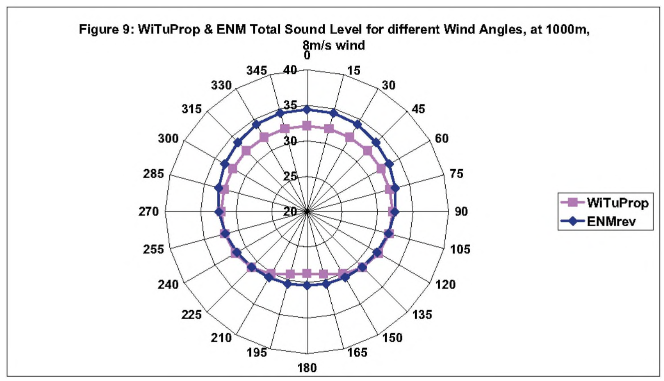
Table 1: Comparison of Predictions for 8 m/s



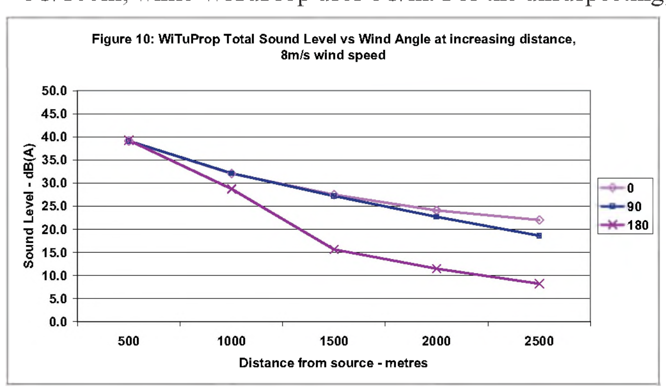
At 1000m, the range between highest and lowest result is 9 dB, and this increases as wind speed increases. This difference is considered to be significant in terms of the expected accuracy of the commercial models. It also has a significant potential effect on the predicted acceptability of a wind farm project. CadnaA with a surface absorption of 1.0 (fully absorptive) gives the lowest result out to 1500m, when the revised ENM becomes the lowest. One of the main comparisons that can be noted between ENM and the other methods is that the ENM calculated results continue to reduce with increasing distance at a greater rate – most of the other models approach a logarithmic curve.

Effects of wind direction have been calculated at the same 8m/s wind speed and 1000m distance for WiTuProp and ENMrev, and are shown in Figure 9. WiTuProp is the same as ENM for cross-wind but lower in upwind or downwind. Figure 10 shows the effect of increasing distance and wind direction for WiTuProp - after a distance of 1500m, the difference between upwind and other directions remains relatively constant at 10 to 13 dB.





Lapse rate can have a significant effect on received sound levels at distances of more than about 500m. As noted earlier, the calculations have been done assuming a normal lapse rate of –0.66oC/100m. Some situations can arise where inversions do occur and wind speed is sufficient to power wind turbines, so an understanding of the effect of lapse rate is also important. Figure 11 compares the results for the same conditions modelled in Table 1 with WiTuProp, using four different values of lapse rate. Even with a relatively strong inversion of 7 oC/100m, the difference at 2000m is only 2dB. Figure 12 compares results for ENMrev and WiTuProp models with lapse rate variation. It should be noted by ENM and WiTuProp users that ENM uses a lapse rate input value of oC/100m, while WiTuProp uses oC/m. For the unsuspecting,



including the author, this difference can cause a significant effect on calculated results, if –0.66 oC/m is used in WiTuProp rather than the correct –0.007 oC/m. The difference in calculated sound level at 1000m is 10 dB. Unfortunately, this error was made in previous papers (3, 5).

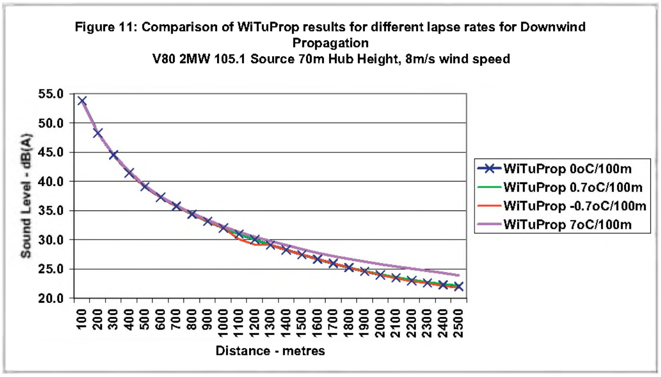


Figure 11: Comparison of WiTuProp results for different lapse rates for Downwind Propagation
V80 2MW 105.1 Source 70m Hub Height, 8m/s wind speed

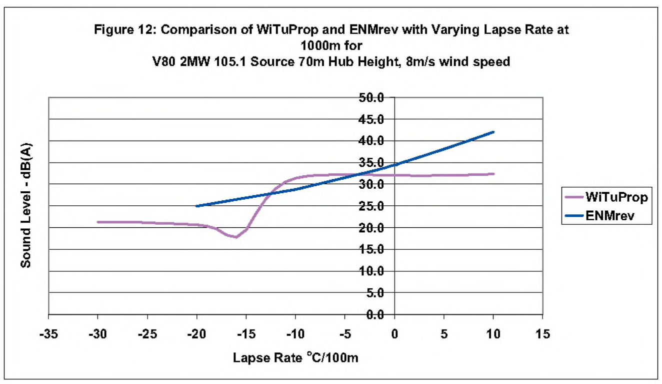


Figure 12: Comparison of WiTuProp and ENMrev with Varying Lapse Rate at 1000m for
V80 2MW 105.1 Source 70m Hub Height, 8m/s wind speed

The effect of wind speed on calculated result is the major determinant in most calculations. It affects the sound power level of the noise source, and the propagation rate. Figures 13 and 14 compare the downwind sound levels for increasing distances using ENM and WiTuProp for four different wind speeds, while Figures 15 and 16 show the sound levels for increasing wind speeds at six different wind speeds.

It is interesting to compare the increase in PWL in Figure 5 with the increase in sound level in Figures 15 and 16. These are shown in Figures 17 and 18 for a distance of 1000m. The increase in calculated sound level and sound power level is greatest in the speed range 4 to 7 m/s. The increase in the WiTuProp result is higher for that range than for ENM or PWL, but all are relatively similar on other ranges shown.

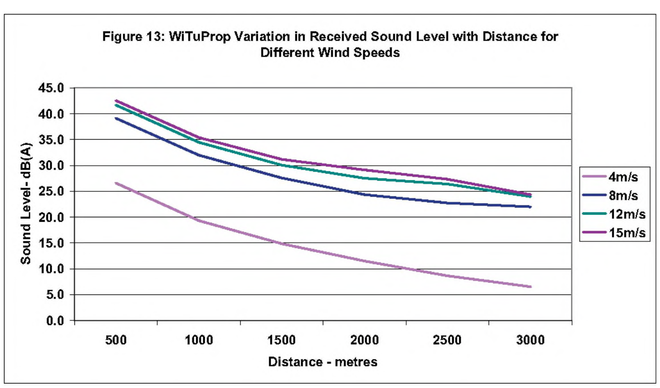


Figure 13: WiTuProp Variation in Received Sound Level with Distance for Different Wind Speeds

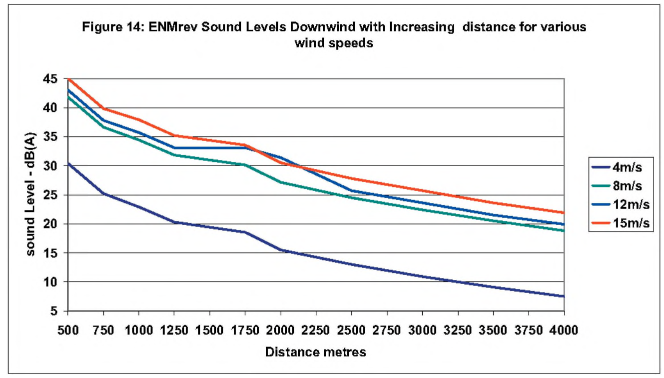


Figure 14: ENMrev Sound Levels Downwind with Increasing distance for various wind speeds

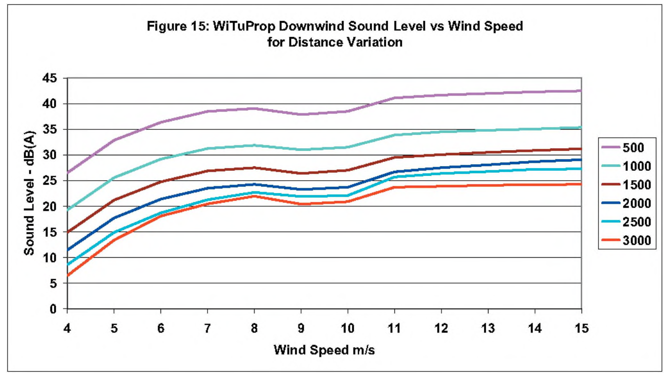


Figure 15: WiTuProp Downwind Sound Level vs Wind Speed for Distance Variation

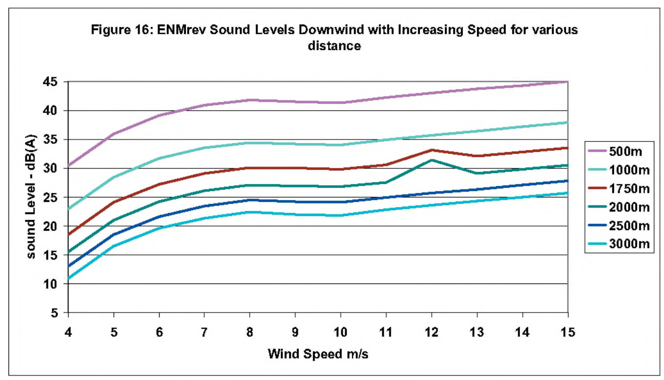


Figure 16: ENMrev Sound Levels Downwind with Increasing Speed for various distance

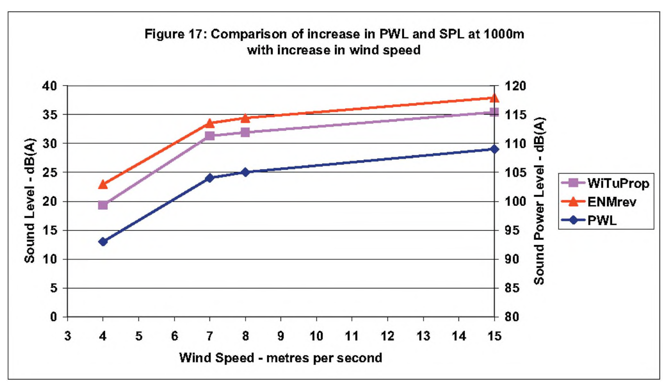
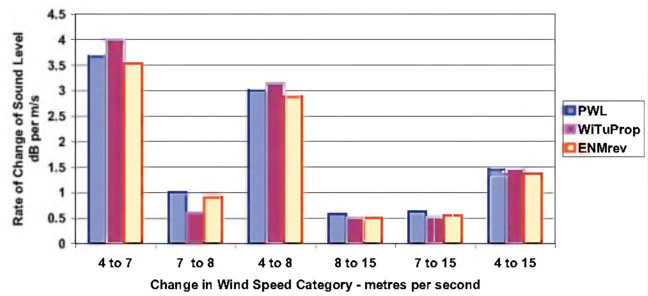


Figure 17: Comparison of increase in PWL and SPL at 1000m with increase in wind speed

5. COMPLIANCE ASSESSMENT

The current approach to compliance assessment once the wind farm is operating, is to measure the sound levels at the nearest residences or noise sensitive areas over the range of operation of the wind turbine. This approach generally repeats the

Figure 18: Comparison of rate of increase in PWL and SPL at 1000m with wind speed



measurements at the locations where the background sound levels were measured and compares the measured sound levels with objectives – increases in sound level and tonality are to be identified, along with turbine operational conditions.

The difficulty with this approach is that the accuracy of predictions of the model used is rarely obtained. For example, if an objective is set at 40 dB(A) for a 6m/s wind speed, as in the data of Figure 3, the existing background LAEQ sound level will be well above the objective most of the time. The assessment needs to include measurement of sound levels at distances close enough to the turbines to provide an accurate measurement of the immission sound level from the turbine. This means it has to be at least 6 dB and preferably more than 10 dB above the background sound levels measured for the area. Tasmania is the only State in Australia at present to require by regulation, a validation of the model predictions made in the EIS.

For the examples and calculations presented in this paper, this means measurements for validation of predictions need to be taken in the range of 200m to 500m from the turbine. And such measurement locations would also preferably need to be measured as part of the background noise studies, because location will affect the range of background sound levels – distance to trees and vegetation cover, local topography and associated vegetation cover will all have a significant effect.

Planning for compliance assessment will also require involvement of construction scheduling. If the wind-farm site is on a hill or ridge or bluff, then suitable measurements at some locations will not be possible because of the landform. Other suitable locations at the range of distances required could very likely also be the site of other turbines. This means that the timing of measurements would need to be done before noise from the operation of other turbines influences the sound levels being measured. The alternative would be to shut-down operating turbines to allow the measurements to be done, and this is likely to be unattractive to the wind farm operator.

Most models have yet to be validated against the measured results of several wind farms, either in Australia or elsewhere. As time proceeds, this will be done, but at present this provides a difficulty for developers and the involved acoustical profession. This gap in credibility could be overcome with specific measurement projects, to allow measured data be made available to prediction modellers to provide comparative predictions. Only when this comparison is widely available will credibility over noise be answered.

6. CONCLUSIONS

Noise immission from wind turbines remains an emotive issue affecting proposed and existing wind farms in Australia and other countries. The setting of objectives is considered reasonable and defensible in terms of community health and amenity goals.

Noise emission from wind farms and their wind turbine noise sources has been described by agreed international standards. (14). These are continuing to develop and will improve with subsequent revisions and amendments.

Prediction models have been used to assess the impacts of proposed wind farms for the range of conditions expected. The models generally indicate that a distance of about 1.2 to 1.5km is required from a multi-turbine wind farm to achieve a sound level of less than the ambient sound level under most conditions.

The missing part in the analysis, and that which provides a credibility gap for developers and regulators, is validation of the models. Until this occurs, the public and affected communities will continue to claim that wind farms are noisy. International round-robin model validation could be done through the provision of measurement data on a website, with predictions for the measurement conditions passed on to a body such as the technical committee responsible for IEC 614100 – 11.

By way of example, an Australian ABC TV news article of an approved wind farm in a rural village area of southern NSW on 24 February 2006, residents claimed it would be too noisy (18). This type of argument can be reduced to a much lower significance, through improved and known accuracy in prediction modelling, that shows wind farms can achieve acceptable objective sound levels.

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Environmental Noise Assessment of Wind Farms

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ABSTRACT

Energy recovered from wind farms is becoming very popular in North America. However, the environmental impact of large wind farms is still under study and regulations are being fine-tuned to alleviate the impacts. Noise is perceived to be a major environmental concern of wind farms. The overall characteristics of wind farms and its noise potential will be discussed in this short review paper through a case study. Appropriate regulatory guidelines will be applied and the noise impact of wind farms are assessed and discussed in this paper.

RÉSUMÉ

L'énergie récupérée des centrales d'éoliennes devient de plus en plus populaire en Amérique du Nord. De plus, l'impact environnemental des grandes centrales d'éoliennes est sous étude et les réglementations vont être raffinées afin d'atténuer les impacts. Le bruit est la principale inquiétude environnementale concernant les centrales d'éoliennes. L'ensemble des caractéristiques des centrales d'éoliennes et leur bruit potentiel seront traités dans ce bref compte-rendu, et ce, par l'entremise d'une étude de cas. Des lignes directrices réglementaires appropriées seront appliquées et l'impact du bruit des centrales d'éoliennes sera évalué et traité dans le présent article.

1. INTRODUCTION

Recently there has been major emphasis, particularly in Ontario and Alberta, on developing facilities to generate electricity from wind energy. Wind power, in spite of its "green" energy source, can have significant impacts on neighbours of wind turbine installations. One of the major concerns is noise.

2. WIND TURBINE CHARACTERISTICS

The size and power generating capabilities of wind turbines vary widely from small units capable of several kilowatts (KW) to large commercial units capable of megawatts (MW). The small units are often mounted on a communications style tower. These wind powered generators can be quite noisy because of the high rotational speed. The propeller blades of smaller units are relatively short, one to several metres in diameter. Thus, to develop any amount of power, they must rotate at high speed. Another undesirable characteristic of small wind turbines is that they respond directly and quickly to both wind direction changes and wind speed changes/wind gusts. Thus, the sound generation can be highly variable, increasing the annoyance potential.

Commercial wind farms use large wind turbines, usually with capability of at least 1.5 MW per unit. The typical commercial wind turbine is supported on a cylindrical mast about 80 m tall and has three blades, each about 40 m long. These units are constant speed devices, with the ability to vary the pitch of the propeller blades to maintain a relatively constant speed, regardless of wind speed. The angular speed of rotation is relatively slow, at about 14 rpm (as opposed to hundreds or thousands of rpm for small turbines).

The turbine gear head, controls and generator are located in a nacelle, about the size of a bus, at the top of the tower. Wind speed and direction are monitored by a computer control system that points the propeller head to the desired direction relative to the wind, with an active drive system. Mechanical noise generated by the various moving parts is minimal and of no concern at the distances to the receptors of concern (including at the base of the mast).

Usually a minimum wind speed of about 12 km/hr is required for a useful amount of power to be generated. About 75 km/hr is the maximum sustained wind speed, at which large wind turbines would usually be shut down.

Although the rotational speed of large units is slow, because of the length of the blades, the linear speed of the tips of the blades is relatively high, at about 125 m/sec (450 km/hr). Thus, some sound is generated by the movement of the blades through the air. However, the major sound generation appears to occur as a blade passes past the mast. This results in a broadband "swishing" sound. In any event, the large, modern, commercial wind turbines are relatively quiet and usually much quieter than the smaller, high speed devices.

3. CHARACTERIZING WIND TURBINE SOUND EMISSIONS

International Standard IEC 61400 11, Wind Turbine Generator Systems, Part II: Acoustic Noise Measurement Techniques [1], provides a standardized method of measuring the sound emissions from wind turbines, for purposes of providing data for specifications and for noise assessments. This method is relatively sophisticated and complex. It provides the A weighted sound power level of a wind turbine, including variation with wind speed and directivity. The acoustic measurements include octave and third octave as well as narrow band spectra. The sound measurements are made with a microphone flush mounted in a hard reflecting board on the ground, relatively close to the wind turbine, to minimize the influence of terrain effects, wind noise at the microphone and atmospheric conditions. Simultaneous measurements of wind speed and direction must be made at a height of at least 10 m, within four diameters of the rotor and normalized to 10 m, regardless of the wind turbine hub height.

The end result is a set of data providing sound power levels as a function of wind speed. This data is the basis for assessing off site sound levels and the potential noise impact.

4. NOISE ASSESSMENT CRITERIA

Alberta and Ontario both have environmental noise criteria to which wind turbine installations must comply.

4.1 ALBERTA

All new, permanent, energy related facilities under the jurisdiction of the Alberta Energy Utilities Board (AEUB), such as compressor stations, electric power plants, pumping stations, etc., including wind turbine electricity generation facilities (wind farms), must take environmental noise impact into account in their design and prepare a Noise Impact Assessment (NIA). The same applies to modifications to an existing permanent installation where there is a reasonable expectation of continuous or intermittent sound emission.

The objective is to keep increases in environmental sound exposures to acceptable minimums and not adversely affect the quality of life at neighbouring properties, especially in rural areas. Indoor sound levels and sleep interference are identified concerns.

The requirements are contained in Noise Control Directive ID 99 08 [2]. The directive is receptor based and includes taking into account the ambient sound environment of the receptors. However, specific quantitative noise criteria are not provided in the Directive. Site specific consideration on a case by case basis is permissible, to determine what is considered to be a reasonable Permissible Sound Level (PSL) that should apply to the facility at the nearest or most impacted receptor (residence).

The Noise Control Directive is supported by a much longer guide document [3], that provides technical background, such as calculation of Leq, sound level at a distance, addressing tonal components, etc., a method of determining PSL, requirements for the NIA, as well as procedures for dealing with noise complaints.

The PSL is computed from the Basic Sound Level (BSL) plus adjustments for day versus night, seasonal operation, tonal/impulse characteristics and ambient sound environment. The BSL at a receptor starts at 35 dBA and is adjusted upwards to account for location relative to roadways, presence of industry and density of development. The BSL nighttime values typically range from 40 to 56 dBA.

4.2 ONTARIO

Ontario Ministry of Environment (MOE) has established guidelines, specifying noise limits, applicable to industrial and commercial sound sources [4, 5]. A stationary source is the site of a facility as a whole, including all relevant sound (noise) sources, even if they can move around the site. A wind turbine or wind farm qualifies as a stationary source. In Ontario, under the Environmental Protection Act (EPA), most permanent processes, facilities, equipment, or things that can emit what are identified as contaminants into the natural environment, first require a Certificate of Approval (C of A). To obtain a C of A, it must be shown that the operation will comply with defined emission levels. Noise (and vibration) are defined as environmental contaminants. Unlike defined chemical substances for which there are regulations under the EPA, there are no regulations for noise (and vibration). In the case of noise, there must be compliance with the noise guideline criteria limits of References 4 and 5. Like in Alberta, the criteria limits apply at sensitive receptors and not at the property line of the facility.

Recently, MOE issued an adaptation of the noise guidelines, specifically for wind turbines. In the Ontario noise guidelines, three types of receptor environments are defined:

Class 1: Urban, where the ambient sound environment is determined by the activities of man, usually by road traffic and where Aurban hum@ is ever present.

Class 2: Where the daytime sound environment resembles that in Class 1 areas but where night, and possibly evening, are much quieter and are more like Class 3 (see below).

Class 3: Rural, where the ambient sound environment is dominated by the sounds of nature because there is little or no road traffic and no significant population or industry nearby.

The noise criteria specific to wind turbines in each type of area are shown in Figure 1. The requirement is that in any hour of operation, the sound levels at any sensitive receptors (in terms of one hour Leq in dBA) must not exceed the indicated limits or the one hour Leq ambient, primarily due to road traffic, whichever is greater. The numerical limits in Figures 1 are referred to as exclusion limits (sources do not need to be lower than the exclusion limits regardless of the ambient).

The noise guideline limits increase as a function of wind speed, recognizing that even in very quiet undeveloped (rural) areas, the ambient, background sound levels will be higher in the presence of wind, increasing with wind speed. The criteria are increasingly more stringent from Class 1 to

Class 3 areas; Class 3 being 5 dBA lower at night. Except for individual wind turbines in urban areas for demonstration purposes, commercial wind farms will use a significant number of turbines, and inherently would be located primarily in Class 3 areas. Even if in a largely undeveloped area, some receptors may be in a Class 2 area (and possibly a Class 1 area), if located near a major roadway such as a provincial highway or freeway, where the ambient due to road traffic is elevated for much of the time due to road traffic. The exclusion limits range from 40 dBA to 53 dBA, subject to the ambient environment applicable to each receptor.

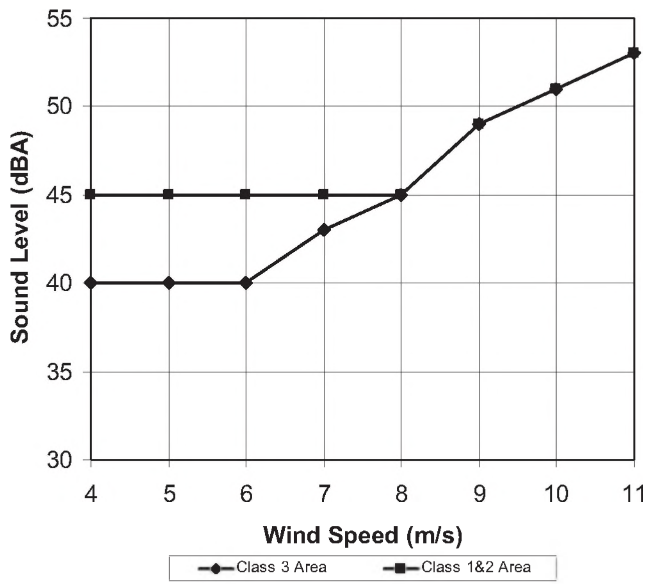

Figure 1. Ontario Wind Turbine Noise Criteria

5. ENVIRONMENTAL NOISE ASSESSMENT

A major commercial wind farm could consist of from about 80 to 120 wind turbines up to several hundred units. A small operation could be as few as a dozen turbines. The placement of turbines within a wind farm depends on a number of factors including exposure to wind, topography, distance from obstructions that could create wind shadows, presence of environmentally sensitive areas and habitat, suitability for construction of the foundations for each turbine, access and presence of neighbouring receptors of concern. To minimize interference of "stealing each others wind," large wind turbines are typically spaced about 500 m from each other. Also, proper wind farms are planned so that the minimum distance from any receptor of concern to the closest wind turbine would be at least 400-500 m. As a result, a wind farm of 100+ turbines will require a very large area, possibly 40,000 to 50,000 acres. This can result in a situation of several hundred receptors that can, potentially, be within the noise influence area of a different group of wind turbines, even in a sparsely populated rural area. Each receptor must be analysed individually taking into account the distance, terrain, topographical elevations, atmospheric absorption and screening.

Thus, assessing potential noise impact from a large wind farm is only practicable with the use of some sort of computerized acoustical modelling procedure. In the case of Ontario, the analysis must also be done over the range of wind speeds indicated in Figure 1. Also, in Ontario, the wind turbine noise guideline procedures specifically indicate that only wind turbines within 1000 m of any receptor need be included in the calculations. This can sometimes be an important factor in the analysis since an extra fraction of a decibel can result in the sound level for some receptors being marginally in excess of the limit and therefore, in the category of non compliance. Typically there is a great emphasis by the proponents/clients to be able to submit a "clean" proposal, where the noise levels from all turbines satisfy the noise criteria limit even if some potential excesses would be marginal and acoustically insignificant. For example, wind turbines at distances of 5 15 km would generate noise levels at a receptor that would be inaudible and hence, of no impact and of no concern. However, if enough sources each producing inconsequential sound levels are automatically included in the calculation, the resulting total can artificially exceed the regulatory limit. Table 1 shows an example from an actual wind farm noise assessment where 32 turbines are included; 22 of which are beyond 1000 m from the receptor. The result is non compliance, by one decibel, in the analysis for this receptor. When only noise sources within 1000 m are included (T101 – T110), compliance with the 40 dBA criterion is indicated, as seen in the subtotal in Table 2.

Wind turbines, responsible for legitimate excess over the sound level limit at any receptor, must be identified and either relocated or eliminated. This is the only practicable mitigation measure. Where excesses occur, it is usually not the case that a particular turbine, individually, exceeds the limit. The excess is usually due to the cumulative effect (energy summation) of a number of sources. Thus, the decisions as to how to resolve excesses are not necessarily simple or as straight forward as eliminating one offending source.

The algorithms with which the analysis of the propagation of sound from each source to receptor is done are normally based on International Standard ISO 9613 Part II. The computer model usually includes some form of digital terrain modelling to account for topography. If topographical mapping is available electronically, with the contours encoded in three dimensions (3 D), this aspect of the analysis is simplified, since the terrain model will automatically read in the topography. Otherwise, if this information must be handled and entered manually, the process can be very time consuming and tedious.

Figure 2 shows a sample result from the graphical output of a computerized, 3 D, acoustical model of a wind farm with over 120 wind turbines. The sources (wind turbines) are indicated with plus signs. The indicated sound levels are one hour Leq values, in dBA, giving the cumulative effect of all sources within 1000 m of each receptor, in this case. Also shown are sound level contours in one decibel increments. Topographical contours are also shown in the background.

Turbine	T101	T102	T103	T104	T105	T106	T107	T108	T109	T110
Sound Level, dBA	34.1	33.9	32.7	31.5	30.9	27.8	24.5	25.5	21.6	21.4
Sum, dBA	**40** (Sum of T01 to T110)									
Turbine	T111	T112	T113	T114	T115	T116	T117	T118	T119	T120
Sound Level, dBA	19	18.9	18	16.7	16.6	15.4	15.2	14.8	14.7	13.9
Turbine	T121	T122	T123	T124	T125	T126	T127	T128	T129	T130
Sound Level, dBA	13.4	12.8	12.6	11.7	11.1	11	9.6	9.4	9.2	8.6
Turbine	T131	T132								
Sound Level, dBA	8.3	2.8								
TOTAL, dBA	**41** (Sum of all 32 turbine noise level)									

Table 1. Examples of individual source contributions.

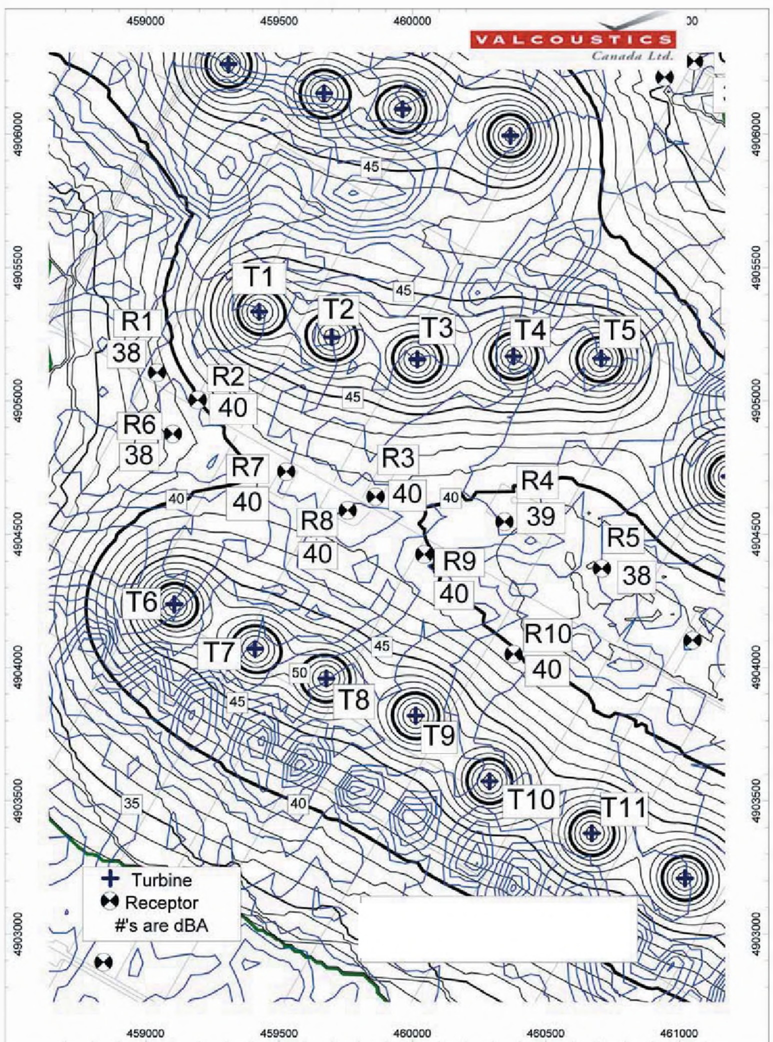

Figure 2. Results of Outdoor Noise Propagation Model.

Separate calculations should be done for daytime and nighttime, even if source and environmental conditions remain the same because the receptor heights for daytime are normally at first floor height or standing height above grade; receptor heights for nighttime are at upper storey bedroom windows - second or higher storey height. Also, individual analyses over the range of wind speeds is typically required.

6. CONCLUSIONS

Major wind farms for electricity generation use large wind turbines, usually located in quiet rural areas, with low ambient sound levels. Jurisdictions, such as Alberta and Ontario, have stringent noise restrictions, as low as 40 dBA at adjacent receptors. Modern, large, wind turbines are usually quiet. Thus, it is practicable to meet the applicable noise criteria, due to the large distances (at least 400-500 m) between wind turbines and between the receptors and the closest turbines. Turbines beyond 1000 m normally result in sound levels of no significance. Even very large wind farms can be designed for insignificant noise impact on neighbouring receptors, since only a small group of the total number of turbines will affect any individual receptor. Because of the complexity due to the large number of sources and receptors, complicated topography, and various factors such as different wind speeds, the noise analyses are facilitated by modern, computerized, 3D, acoustical modelling techniques that address propagation of sound outdoors.

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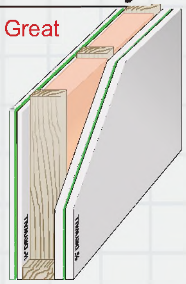

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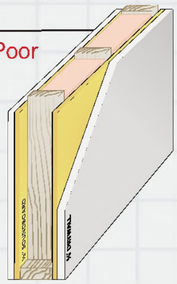
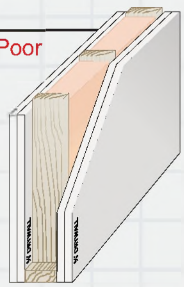
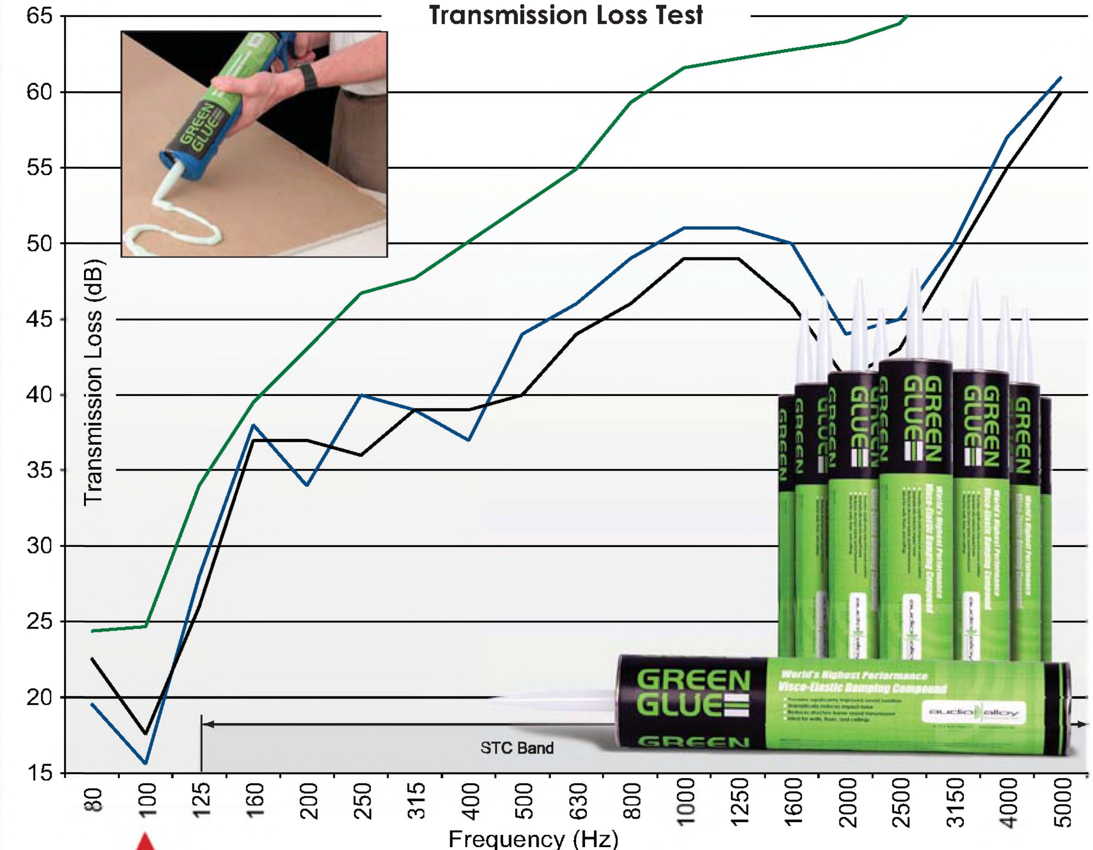


Conventional Drywall

Low Frequency: Poor
44 STC Rating
33 OITC





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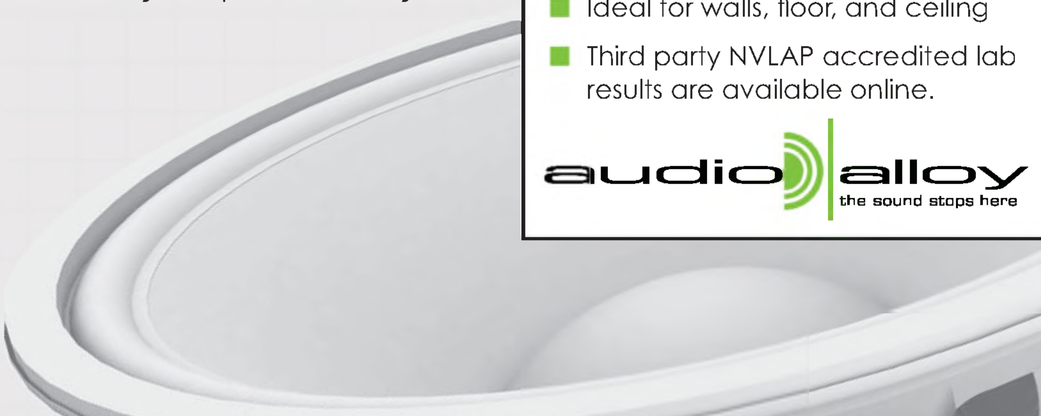

Acoustic and Geophysical Measurement of Infrasound from Wind farm Turbines

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ABSTRACT

An experiment was conducted to measure and characterize infrasound (and higher frequency acoustic energy) from turbines at a wind farm in Southern Alberta. Simultaneous telemetry and point measurements were acquired from three sensor types: low frequency geophones, acoustic microphones, and a precision sound analyzer. Measurements were recorded for three wind states: low, medium, and high. Down wind telemetry measurements were recorded for thirty (30) continuous 50m offsets, up to a distance of 1450 m from the wind farm. Point measurements, coincident with the telemetry measurements, were acquired with a low frequency precision sound analyzer for two offsets: 50m and 1000m from the turbines. The same measurements were recorded with the turbines on, and with the turbines off. The low frequency results of the experiment are presented in this paper.

RÉSUMÉ

Une expérience a été menée pour mesurer et caractériser les infrasons (et une forme d'énergie acoustique à hautes fréquences) provenant des éoliennes d'un parc dans le sud l'Alberta. La télémétrie simultanée et le mesurage par points ont été faits avec trois types de capteurs : géophones à basse fréquence, microphones acoustiques et un analyseur de son à haute précision. Des mesures ont été enregistrées pour trois états de vents : bas, moyen et élevé. Des mesures télémétriques ont été prises dans le sens du vent pour trente (30) déplacements continus de 50 m jusqu'à une distance de 1450 m du parc d'éoliennes. Des mesures par points, coïncidents avec les mesures télémétriques, ont été prises avec analyseur de son de précision de basses fréquences pour deux déplacements : à 50m et 100m des éoliennes. Les mêmes mesures ont étéUne expérience a été menée pour mesurer et caractériser les infrasons (et une forme d'énergie acoustique à hautes fréquences) provenant des éoliennes d'un parc dans le sud l'Alberta. La télémétrie simultanée et le mesurage par points ont été faits avec trois types de capteurs : géophones à basse fréquence, microphones acoustiques et un analyseur de son à haute précision. Des mesures ont été enregistrées pour trois états de vents : bas, moyen et élevé. Des mesures télémétriques ont été prises dans le sens du vent pour trente (30) déplacements continus de 50 m jusqu'à une distance de 1450 m du parc d'éoliennes. Des mesures par points, coïncidents avec les mesures télémétriques, ont été prises avec analyseur de son de précision de basses fréquences pour deux déplacements : à 50m et 100m des éoliennes. Les mêmes mesures ont été .

1. INTRODUCTION

The Castle River Wind Farm in southern Alberta, shown in Figure 1, contains one (1) 600 MW turbine and fifty-nine (59) 660 MW wind turbines. The terrain is relatively flat prairie to the east (downwind), and rolling hills to the foothills and Rocky Mountains to the west. The land is primarily agricultural, with grain farming to the east, and cattle ranching to the west. No other significant industrial activity is present in the vicinity.

The experiment employed sensors and methods to measure the acoustic (atmospheric), and geophysical (terrestrial) sound levels. Data was recorded for three wind states, low, medium, and high. For each wind state, data were recorded with the entire wind farm operating (turbines ON), and with the entire wind farm stopped (turbines OFF).

Figure 1. Castle River Wind Farm from the East.
Prevailing wind is from the West. (Photo © courtesy of Vision Quest WindElectric ®)

2. EXPERIMENTAL OBJECTIVES

Characterization of ambient noise levels, and sound emitted by turbines in the Castle River Wind Farm were the chief objectives of the study. Explicit measurements of any low frequency components, during different scenarios, were important. Six scenarios were investigated: low wind – turbines on and off, medium wind – turbines on and off, and high wind – turbines on and off. Calibrated point measurements of the acoustic environment were acquired with a Bruel and Kjaer (B & K) 2260 precision sound level meter. Experimentation and application of the geophysical data acquisition and processing techniques were also objectives of the test.

Measurements were taken to allow determination of the sound levels, dependence on wind speed, frequency content – especially below 200 Hz, 1/3 octave band levels, tonality, and attenuation with distance. Measurements included: voltage output from thirty 4.5 Hz geophones, voltage output from thirty calibrated microphones, and Leq and LIM (conforming to IEC 804 and IEC 804 Appendix B) with the B & K 2260 Precision Sound Analyser. Other data recorded included: wind speed and direction, atmospheric pressure, atmospheric temperature, and other turbine related data. Visual observations included: atmospheric conditions, extraneous sources of noise such as aircraft, trains, vehicular traffic, highway noise, bird song, crickets, and the rotational state of the turbines.

3. MICROPHONE CALIBRATION

The electret condenser microphones were calibrated prior to data acquisition, and also following data acquisition. The microphones were powered by new 9V batteries. Calibration equipment included: a Tektronix TDS 420A 4 channel Digitizing Oscilloscope, an HP 33120A 15 MHz Arbitrary Waveform Generator, a lab speaker with two ports for microphone insertion, and a TES 1352A Sound Level Meter. Several calibration runs were performed. For the pre- acquisition calibration, the microphones were measured for voltage output for the following 3 tests:

1 Constant Input Voltage and Constant Frequency Test
2 Constant Input Voltage and Stepped Frequency Response Test
3 Constant Speaker Output SPL Test.

Following data acquisition, all microphones were measured again for output voltage at 25 Hz 1.98 V RMS input, and for output voltage at 100 Hz 600 mV RMS input. Fourteen microphones were rejected due to nonlinear output voltage failures (with differences pre and post of >29%). Two post processing spectral analysis data sets were recorded to DVD, one with all microphones included, and one with the rejected microphones zeroed in the data set, to facilitate further analysis.

The appropriate response factors were applied to each microphone voltage response, in order to correct for response differences between microphones, and to normalize the microphones to the reference at ground station 102 (serial number 189). Normalization to the microphone at station 102 permitted comparison of the spectral analyses from the 30 electret microphones with the calibrated dB results from the B & K 2260 precision sound analyzer. Some differences were expected, due to variations in field acquisition conditions and near field effects. In addition, differences due to processing, particularly the spectral analysis, are expected between the electret microphone data, and the data from the precision sound analyzer.

4. PROJECT AREA DESCRIPTION

A cross country road runs East to West at the test site, near the South boundary of 36-6-1 W5M. The site map, details of instrument loction and schematics of test set-up are shown in Figures 2 through 4. The road is located east of Turbines 21 and 22 at the Castle River Wind farm, Alberta. It was

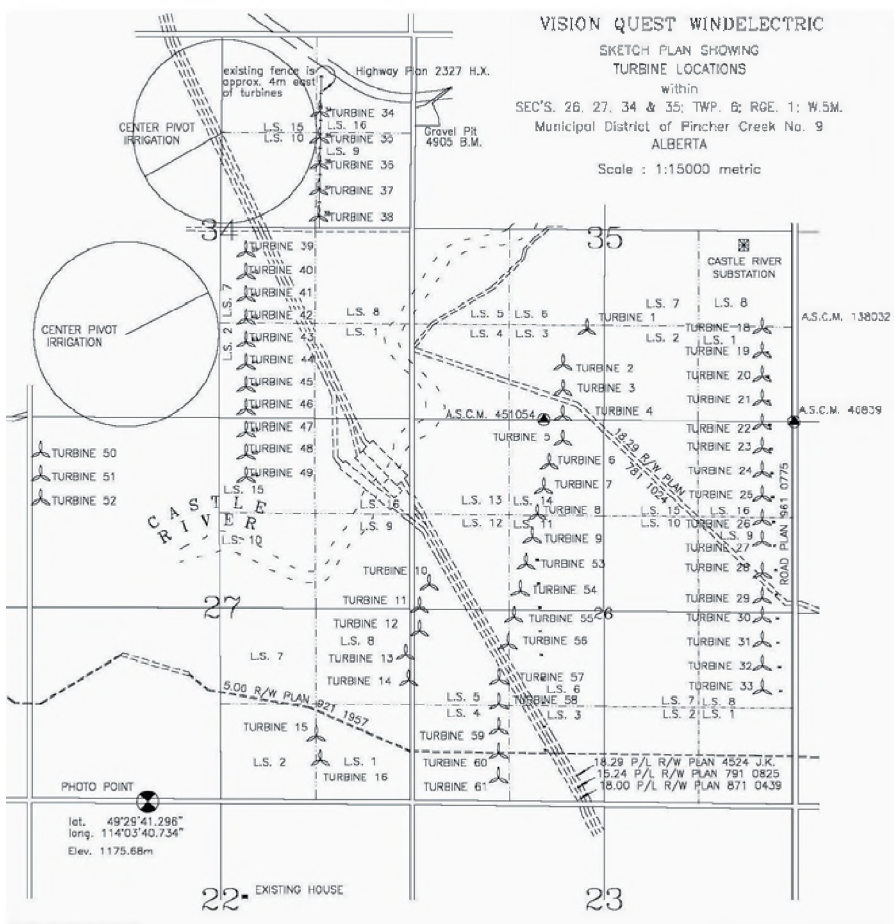


Figure 2. Map showing location of turbines.
(Map © courtesy of Vision Quest WindElectric ®).

decided that 30, 4.5 Hz geophones, would be planted in a linear array, parallel to the road, with a station interval of 50 m. The recording spread was 1450 m in length. The first station (101) was placed between turbines 21 and 22. The remaining stations were placed to the East, downwind from the wind farm.

5. METHODOLOGY AND PARAMETERS

5.1 Survey and Placement of Ground Stations

From the eastern most bank of turbines, a line was surveyed directly east, along the south side of the road allowance. Prior to data acquisition, the ground stations were placed with RTK (Real Time Kinematic) GPS survey equipment. Pin flags and flagging were placed at each station, with the appropriate station number marked on the flag. The survey data tolerance was +/- 20 cm. The survey data were processed and output in the form of a standard SEG P1 data file. The station interval was 50m, with stations numbered from 101 to 130 inclusive. Station 101 was at zero distance from the bank of turbines, and station 130 was 1450 m from the wind farm.

At each station, a hole with a diameter of 15 cm, was drilled to a depth of 30 cm. At the bottom of each hole, a 4.5 Hz geophone with a spiked base, was planted. The geophones were recorded as telemetry line 1. Coincident with each 4.5 Hz geophone was a calibrated acoustic microphone. The microphones were recorded as telemetry line 2. Both lines had identical station numbers and coordinates for those stations. The geophones were recorded on channels 1 to 30, and the microphones were recorded on channels 31 to 60.

The acoustic microphones were placed with care, to avoid any vibration from wind blown cables or connectors. The microphones were approximately 5 cm below ground level, in order to reduce effects of turbulent flow at the surface. The microphones were deployed in a systematic fashion, depending upon the measured response characteristics. The order of deployment placed the microphone with the highest output closest to the wind turbines at station 101, followed at the next station (102) 50 m away, by the microphone with the lowest output. At station 103, the microphone with the second highest output was placed, followed at station 104 by the microphone with the second lowest output. The purpose for the order of deployment was to allow statistical analysis between stations (if required) and to eliminate any systematic errors with a biased spread. The ground equipment was deployed in advance of data acquisition. Following post acquisition recalibration, it was evident that there was indeed a systematic failure mode for the acoustic microphones, and data from 14 microphones were rejected.

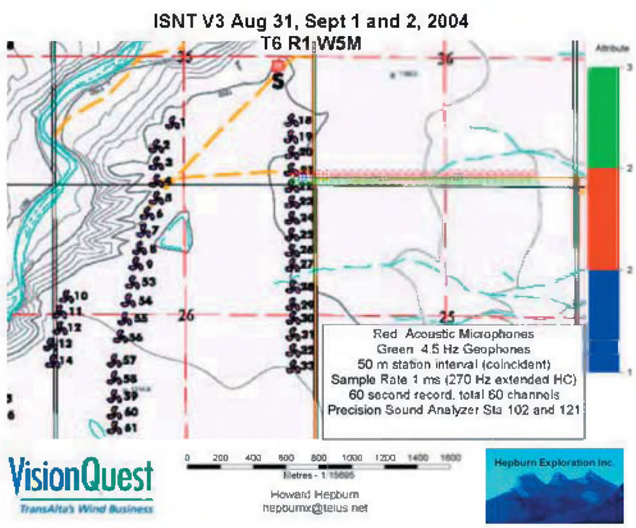


Figure 3. Topo map showing location of turbines, geophones, microphones, and B & K 2260.

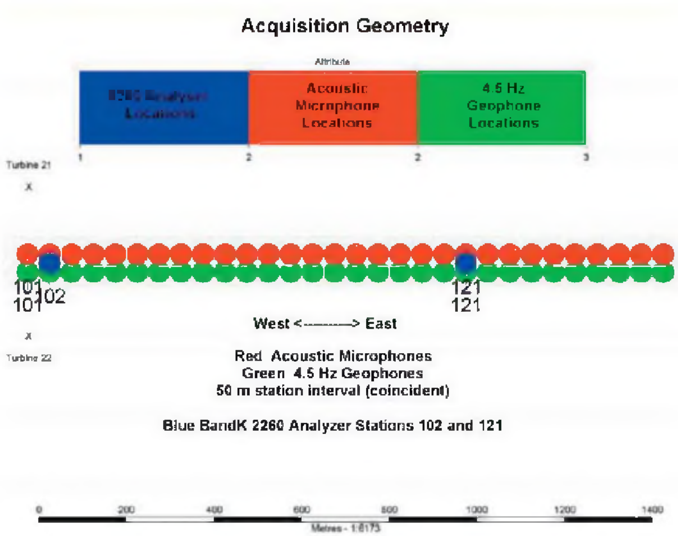


Figure 4. Schematic of acquisition geometry, location of turbines (on left), microphones, geophones, and B & K 2260.

5.2 Data Recording Methods

5.2.1 Telemetry Data Acquisition

It was decided that a 60 second record length would be used to allow sufficient sampling of any slow, low frequency events. Measurements were taken to quantify: sound frequency, sound amplitude, atmospheric pressure and temperature, wind speed, and from precise time measurements, terrestrial and atmospheric noise propagation velocities.

A truck mounted I/O System II seismic data recording system, rather than a smaller portable unit, was used, due to superior equipment, interior mounting, and software compatibility. Three sound data sets were acquired simultaneously, to provide verification and validation of the experimental method. The three data sets included: acoustic (atmospheric) records with the B&K 2260 Precision Sound Analyser at point locations, geophysical (terrestrial) records with 30 Mark Products L1B 4.5 Hz geophones, and acoustic (atmospheric) records with 30 calibrated electret condenser microphones coincident with the geophones.

The geophone and microphone data were acquired with the I/O System II telemetry recording instrument at a sample rate of 1 ms, which allowed for accurate recording of any signal and noise frequencies up to 270 Hz. The precision sound analyzer data were acquired with a B & K 2260, running software version BZ7206 ver 2.1. For each telemetry measurement (60 second records of 60 channels) of the geophone and microphone data, a measurement (60 second record) with either the dBA or dBL scale was made with the B & K 2260 (with correction for a 90 mm windscreen). Full data sets for the dBA scale and the dBL scale were acquired for all operational conditions. Details of the system and its parameters are outlined in Tables 1 and 2.

5.2.2 Precision Sound Analyzer Data Acquisition

The B & K 2260 Investigator Precision Sound Analyzer (running software version BZ7206 ver 2.1) was used to collect acoustic data sets concurrent with the telemetry data acquired from the 30 geophones and 30 electret microphones. The sound analyzer was calibrated prior to acquisition, according to the applicable ISO standards (including initial factory calibration traceable under ISO 9001), with a standard 1 kHz 94 dB calibrator at 30/08/2004 10:26:22 AM. The calibration and equipment meet the requirements of ANSI S1.4-1983 type 1, ANSI S1.43-2004 Type 1, S1.4A-1985, S1.1-1986 1/3 Octave Bands Order 4, Type 0-B, and S1.40-1984. Since the 2260 is a single sensor unit, the location of the 2260 data was limited to one station. The 2260 was moved to provide measurements at varying distances from the turbines. The data collected by the 2260 was concurrent with the other telemetry data, and the data sets can be compared with the assumption that the same time frame exists between data sets. The fast response sample rate was 125 ms, the slow response sample rate was 1 s.

Three stations used the B & K 2260: 101, 102, and 121, at distances from the turbines of 0m, 50m, and 1000m respectively. The B & K 2260 was mounted upon a tripod, with the microphone oriented directly west. The microphone was at a measured distance of 1.25 m above ground level, and had a standard 90 mm acoustic grade windshield. Sixty second records were acquired with the 2260, simultaneous with the 60 second records acquired with the I/O System II. The time stamps on the I/O System II and the B&K 2260 were calibrated to a GPS time signal, but may have drifted slightly, during the course of observations. In any event, the recording start times for both the B&K 2260 and the I/O System II were controlled by the GPS time signal which was announced with a radio. The data acquired with the B & K 2260 precision sound analyzer was processed with the Evaluator 7820 version 4.4 software.

5.3 Operational Conditions

Three scenarios existed for wind conditions: low wind, medium wind, and high wind. Two scenarios existed for the operational state of the turbines: on and off. B & K 2260 data were captured for dBA and dBL (Linear) scales for all three wind conditions (turbines on and off). The geophone and microphone data were recorded simultaneously with the precision sound analyser. Data acquisition was dependent upon weather, extraneous noise sources, and notification of the provincial transmission administrator.

Quantity	Item	Comment
1	I/O system II telemetry recording system	Truck mounted, 1 LIM
30	4.5 Hz geophones	Spike base, Kooter 2 pin connectors
10	LIUs (line input units)	6 channels per LIU
10	Cables, 50 m takeouts, Kooter 2 pin	
2	Line tap units Geophones on line 1 and	microphones on line 2
2	Line tap cables	1 line tap - geophones, 1 line tap - microphones
30	Acoustic microphones	Kooter 2 pin
1	Weight drop calibration mass	15.0 kg from 49.3 m height

Table 1. List of telemetry recording equipment for geophones and microphones.

Number of 4.5 Hz geophones	30
4.5 Hz geophone station interval (m)	50
Number of acoustic microphones	30
Microphone station interval (m) coincident with the 4.5 Hz geophones	50
Dimensions of hole for sensors – width (cm) and depth (cm)	15 and 30
Recording sample rate (ms)	1
Record length (s)	60
Recording format (SEG D Demultiplexed 8048) 24 bit	IEEE
Recording high cut filter, extended alias	270 Hz
Recording low-cut filter (implicit 3 Hz)	Out
Number of scenarios: Turbines on & off, for low, medium , & high wind states	6
Recording preamp gain (36 dB FFID 1 to 5) all other FFIDs:	48 dB
Recording gain	defloat
Geophones on line 1, stations 101 to 130, channels 1 to 30	
Microphones on line 2, stations 101 to 103, channels 31 to 60	Coincident w geo.

Table 2. Telemetry data acquisition parameters.

5.3.1 Low or no wind

Under low or no wind conditions, wind turbines will be either stationary, or will be idling without generating power at the optimum rate. The ambient wind noise will be at the lowest level for this condition. In addition, the sound emitted from the turbines will also be at the lowest level. Since blade tip speed in idle mode is far less than when operational, the noise emitted is negligible. In these zero or low wind speed conditions it can be presumed that the wind turbine will have little or no effect on the existing background noise level.

5.3.2 Medium wind

Medium wind conditions are those at which the wind turbine just starts to generate power and slightly above. As the turbines start to produce power, the emitted sound level will increase. With medium wind conditions, the ambient wind noise will still be relatively low, but increasing. Medium wind speed conditions (6 - 10 m/s) are the most critical, as far as audibility is concerned.

5.3.3 High wind

Sound emitted from wind turbines increase as wind speed increases. However, the increase in sound generated by the turbines is less than the increase in background noise levels. The rate of increased sound generation decreases at higher wind speeds, since the wind turbine does not increase rotational speed. Above a wind speed of typically 25 m/s, the wind turbines shut down and therefore do not emit any sound.

It is not straightforward to obtain accurate measurements of wind turbine noise. Noise reduction features have been considered in the design of most commercially available wind turbines. Some manufacturers have taken extensive steps to further reduce the aerodynamic noise. Sound levels emitted by wind turbines will be highest in the down wind direction.

Other data were also acquired during the sound data acquisition, including atmospheric and turbine data. That data may be incorporated into the results from the three acoustic data sets.

5.4 Data Acquisition and Processing Summary

The data were acquired on August 31, September 1, and September 2, 2004. Records with all systems were acquired for the three wind states, and for the two operational states of the turbines. Sound analyser values for the spectra were output from the Evaluator 7820 version 4.4 software. The output was transferred to a spreadsheet for graphical display purposes. For each wind state, and for the two turbine states (On and OFF), the 2260 spectral data are presented in section 6. For obvious reasons, two dB scales were used for data acquisition, the dBA scale, and dBL (Linear) scale. Due to the attenuation of low frequency amplitudes with the dBA scale, only the dBL data are presented. The graphs contain the data for the acoustic contributions of the turbines and the ambient sound levels.

5.5 Telemetry Data Processing - I/O System II for Telemetry Data

The geophone and acoustic microphone data were processed to be true amplitude, with all efforts made to quantify amplitudes relating to specific signal levels. The data were processed with ProMAX seismic data processing software. Further analysis will allow quantification of atmospheric and terrestrial noise levels in terms of frequency, amplitude, wavelength, velocity of propagation, and attenuation with distance. Details of the data flow are presented in Table 3.

6.0 RESULTS AND DISCUSSIONS

The data that has been accumulated is divided into three groups for discussion: The analyzer data; Distance attenuation and Telemetry sound data. The details of the three groups are presented below.

6.1 Low Frequency Analyzer Data

The sound pressure level spectra collected from the Bruel and Kajer precision sound level meter, type 2260, are presented in Figures 5 through 17.

Figure 5 shows the LLeqs for the ON and OFF conditions for low wind speeds, measured 50 m from the turbines. At 16 Hz and below, the turbines emit sound more than +20 dB above the ambient wind noise. Above 50 Hz the turbines do not contribute significant sound above the background. It is seen that ambient noise levels are fairly uniform from 6.3 Hz to 200 Hz. (File 30). For the low wind speed condition,

Data Input from disk (preamp gain applied data set)
FFID sort and kill, FFID Include: 4-23, 28, 31-37, 39-63, Trace Display
Trace Edits: according to visual inspection and to list of rejected microphones
Note geophones on line 1, stations 101 to 130, channels 1-30
Note microphones on line 2, stations 101 to 130, channels 31-60
Trace scalar amplitude normalization for microphones only, according to specified calibration scalars
Single function empirical trace scalar to match 2260 data at station 102 (1×10^6)
1/3 Octave band filtering, (each trace for geophones and microphones) according to ISO filters
Spectral analysis on 1/3 octave bands producing LLeqs for each band
Output of dBL values, relative to zero, maximum dB scale constant at 120 dB

Table 3. Telemetry data processing flow.

ambient wind noise levels are independent of distance from the wind farm.

Figure 6 shows the ON and OFF conditions for medium wind speeds, measured 50 m from the turbines. Above 50 Hz, the turbines emit sound about +20 dB above the ambient wind noise. Note that the lowest frequency components of the ambient noise levels have increased considerably (turbines OFF), compared to the previous figure.

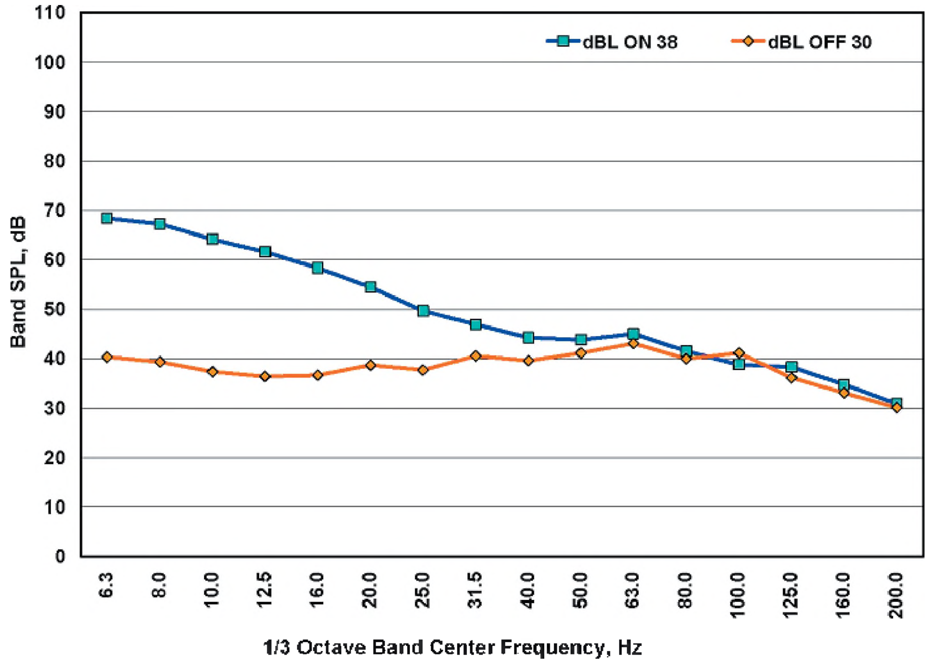


Figure 5. 1/3 octave LF spectra,

file 38: dBL, low wind, turbines ON, 50 m; file 30: dBL, low wind, turbines OFF, 50 m

Figure 7 shows the ON and OFF conditions for high wind speeds, measured 50 m from the turbines. Ambient wind noise exceeds sound from the turbines by approximately +8 dB up to about 50 Hz. Above 100 Hz, the turbines emit sound about +7 dB above the ambient wind noise. Below 80 Hz, turbine operation decreases ambient wind noise.

It must be pointed out that turbine rotational speed does not increase from the medium to high wind condition.

The effect of increasing wind speed at larger distance from the turbine farm is shown in Figures 8 and 9. Figure 8 shows the ON and OFF conditions for low wind speeds, measured 1000 m from the turbines. Below 25 Hz, the ambient wind noise exceeds levels when the turbines are ON by about +8 dB. The wind farm appears to decrease low frequency ambient noise levels at a distance of 1000 m. Above 50 Hz the turbines emit sound about +5 dB above the ambient wind noise.

For the same conditions, 50 m from the turbines (figure 5 above), the turbines emit sound about +20 dB above the ambient wind noise below about 16 Hz.

Figure 9 shows the ON and OFF conditions for high wind speed, measured 1000 m from the turbines. The turbines appear to contribute about +2 to +6 dB at most frequencies. However, ambient wind noise is the dominant factor at high wind speeds, and some variability in ambient noise levels may be a factor between the two conditions. The ON conditons for high wind speed, measured at 50 m and 1000 m from the turbines are shown in Figure 10. Negligible attenuation with distance confirms the dominant sound contributor is the wind.

The effect of wind speeds with distance on the resulting sound pressure levels are shown in Figures 11 through 13.

Figure 11 shows the LLeqs for the ON condition for medium wind speed, measured 50 m and 1000 m from the turbines. Significant attenuation at all frequencies is seen with an increase in distance from the turbines, from 50 m to 1000 m. As expected, attenuation with distance increases with increasing frequency, for medium wind speeds.

Figure 12 shows the ON conditions for high wind speed, measured 50 m and 1000 m from the turbines. It would ap-

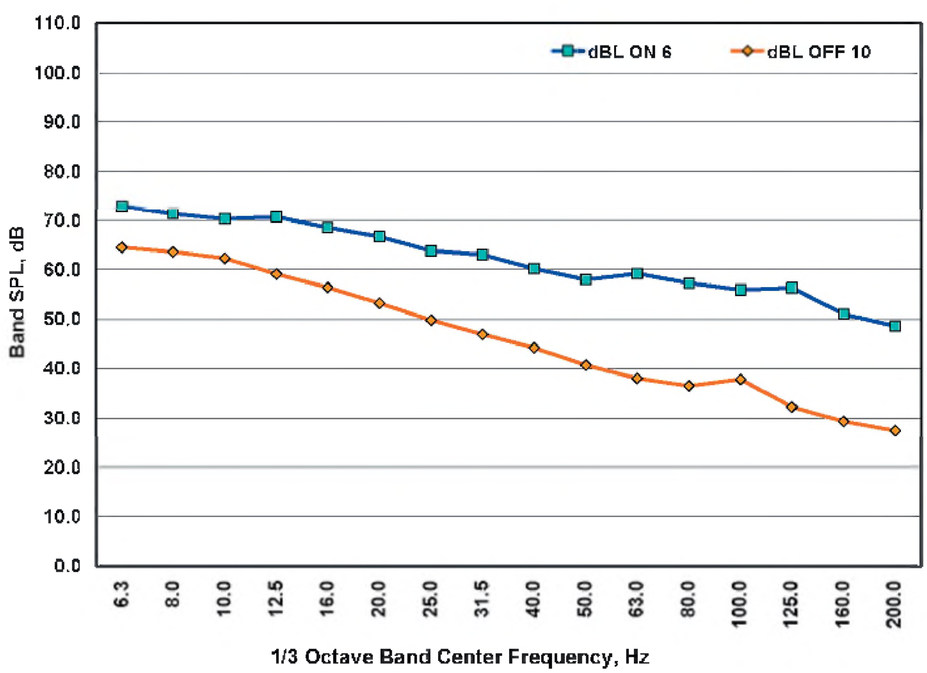


Figure 6. 1/3 octave LF spectra, file 6: dBL, medium wind, turbines ON, 50m

file 10:dBL, medium wind, turbines OFF, 50m

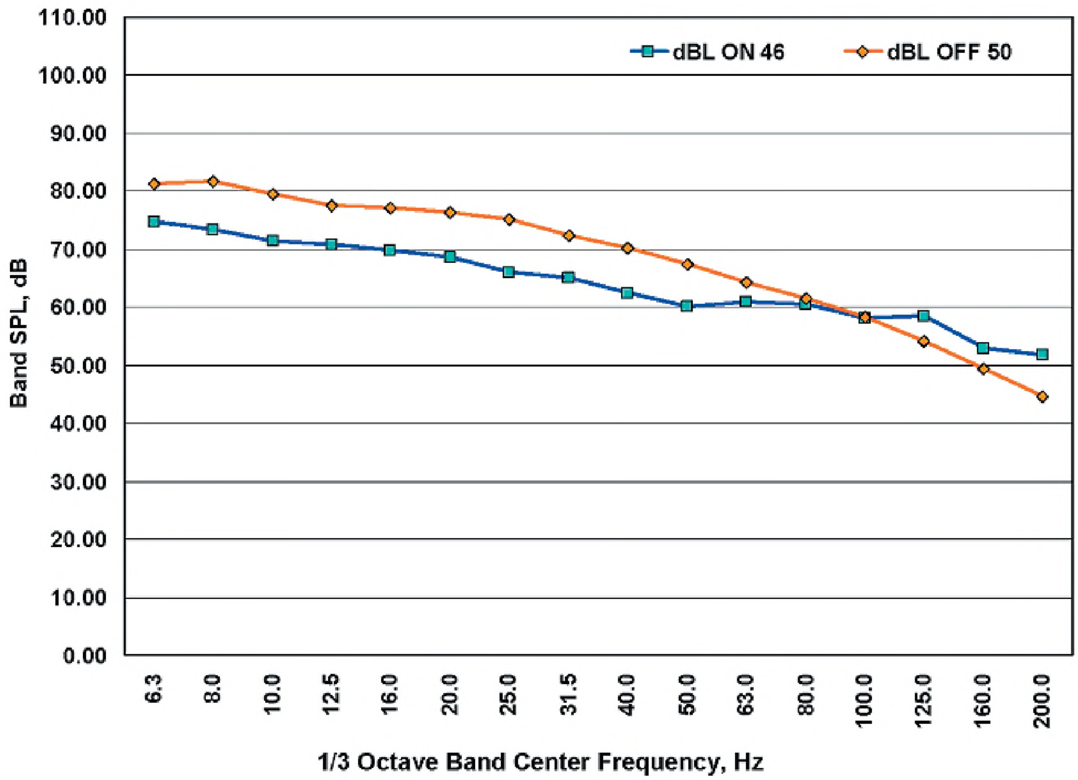


Figure 7. 1/3 octave LF spectra. file 46: dBL, high wind, turbines ON, 50 m; file 50: dBL, high wind, turbines OFF, 50 m

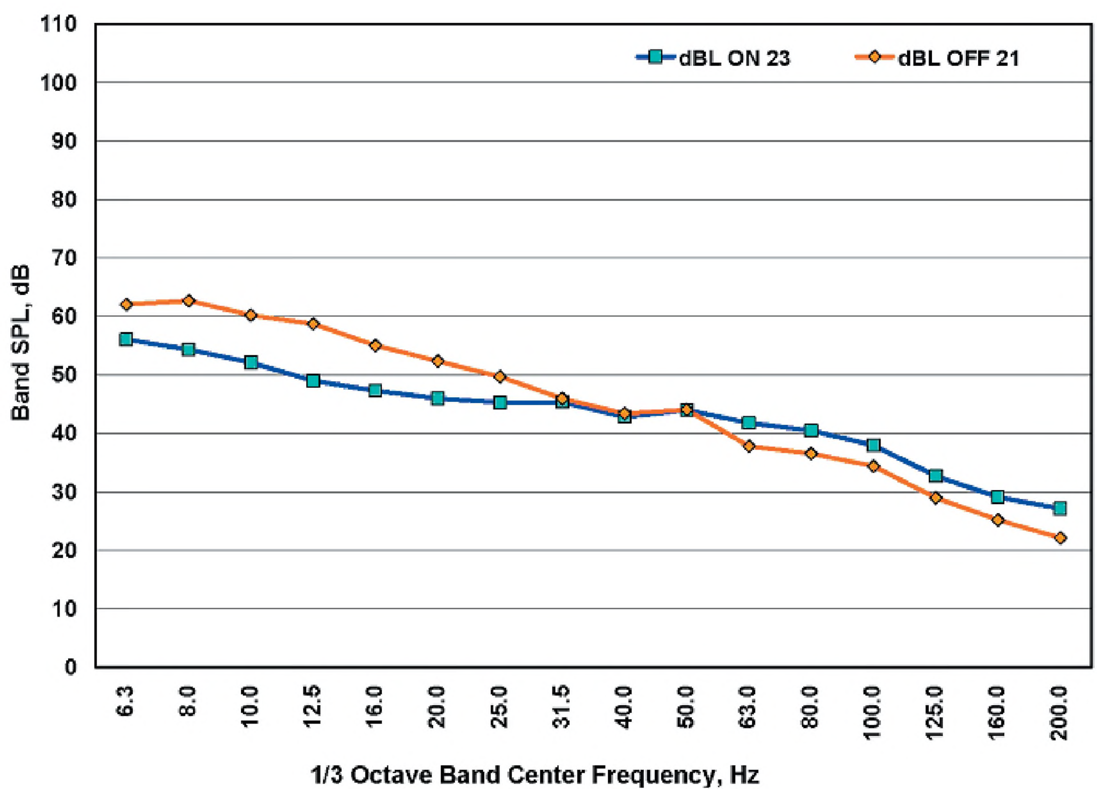


Figure 8. 1/3 octave LF spectra. file 23: dBL, low wind, turbines ON, 1000 m; file 21: dBL, low wind, turbines OFF, 1000 m

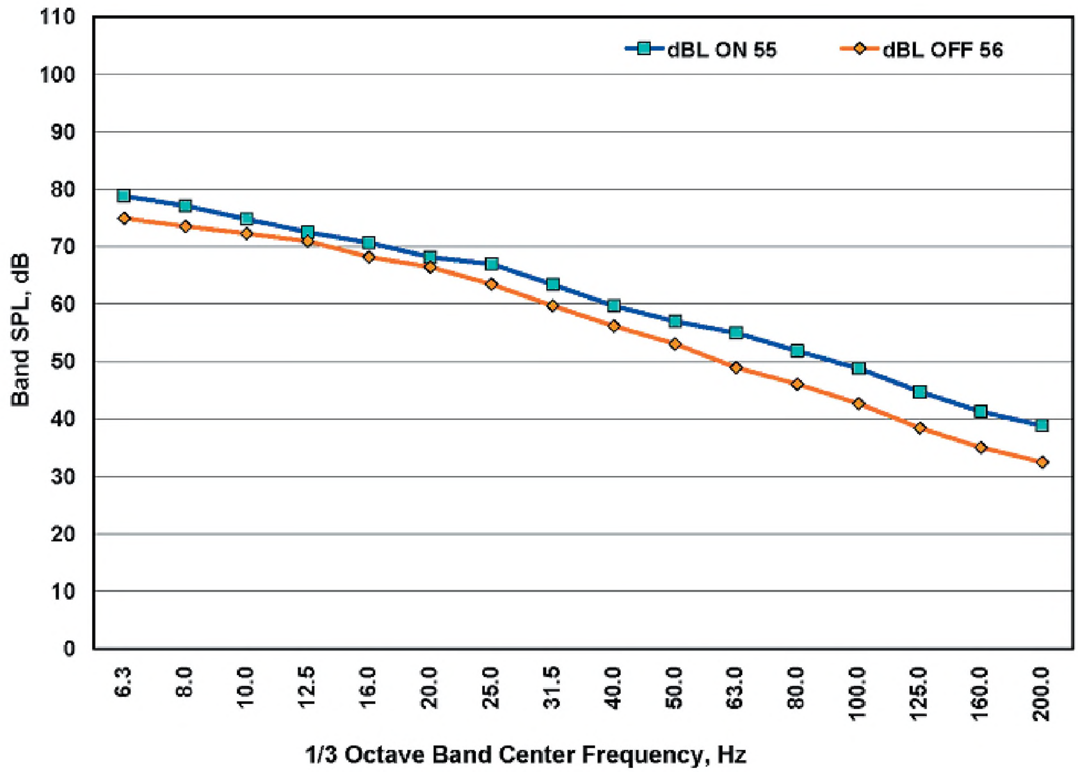


Figure 9. 1/3 octave LF spectra. file 55: dBL, high wind, turbines ON, 1000 m ; file 56: dBL, high wind, turbines OFF, 1000 m

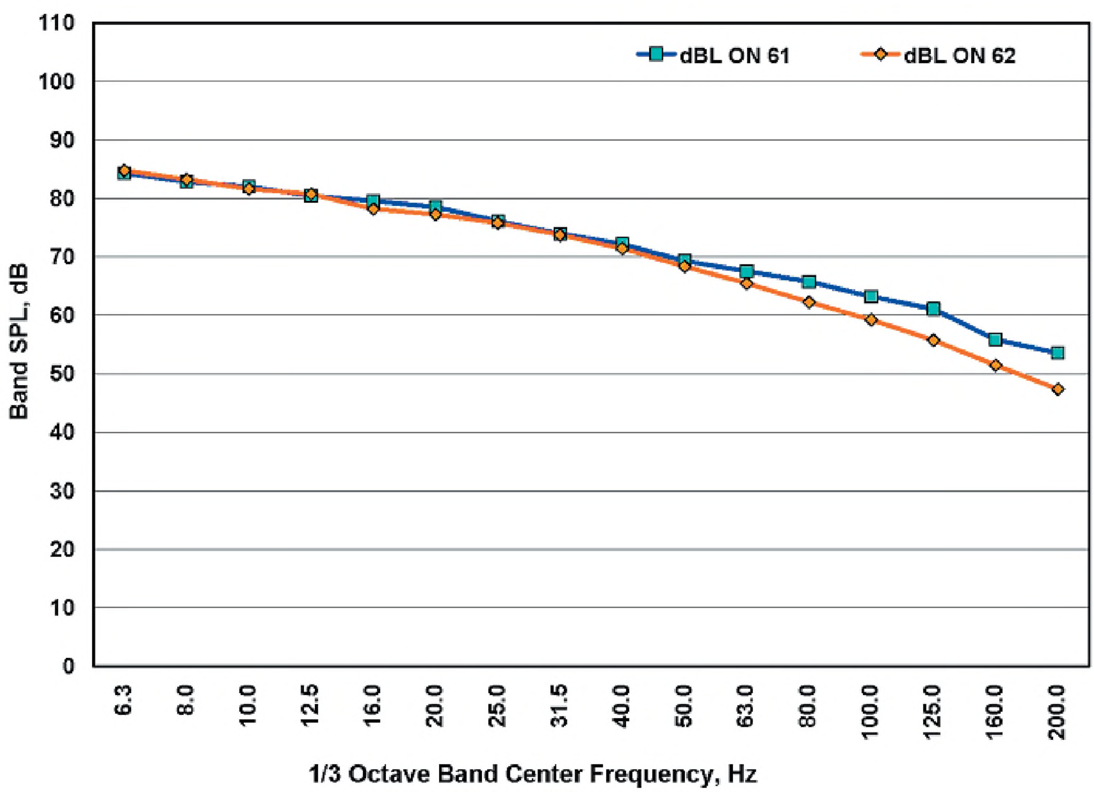


Figure 10. 1/3 octave LF spectra. file 61: dBL, high wind, turbines ON, 50 m; file 62: dBL, high wind, turbines ON, 1000 m

pear that very little difference exists from 50 m to 1000 m, however, the ambient wind noise is the main factor at high wind speeds. Wind noise is not attenuated with distance.

Some higher frequency attenuation of acoustic energy, with increasing distance, is seen with distance, above about 80 Hz.

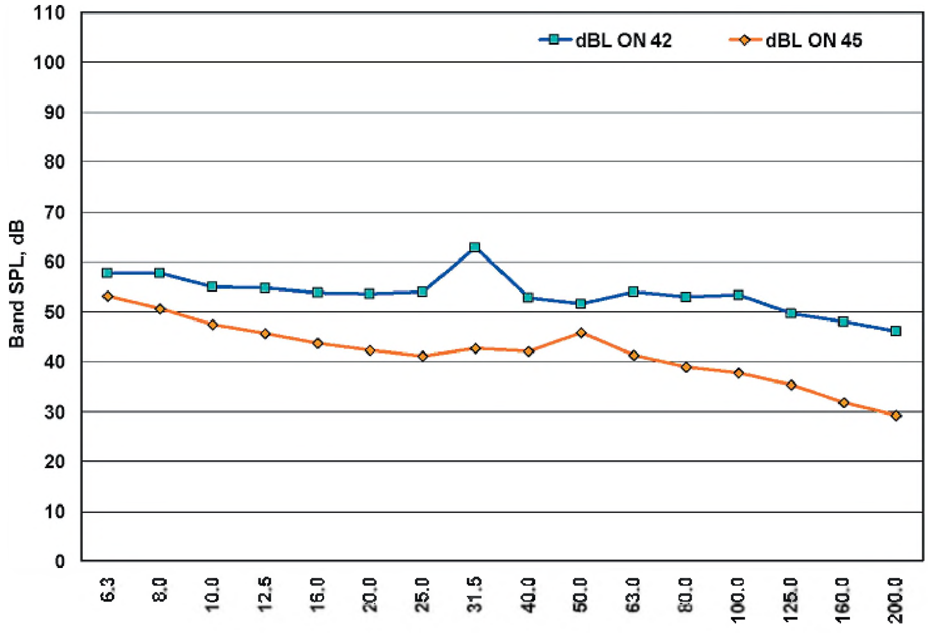


Figure 11. 1/3 octave LF spectra. file 42: dBL, medium wind, turbines ON, 50 m file 45:dBL, medium wind, turbines ON, 1000 m

Figure 13 shows the ON and OFF conditions for very low wind speed, measured 50 m (ON) and 1000 m (OFF) from the turbines. Below 31.5 Hz, less than +12 dB is contributed from the turbines. Above 31.5 Hz, very little contribution from the turbines is seen.

Figure 14 shows the effect of increasing wind speed (low to medium to high) at 50 m from the turbines, with all the turbines ON. Note that all LLeqs increase from low wind speed to medium wind speed, but do not increase appreciably from medium to high wind speed.

Figure 15 shows the effect of increasing wind speed (low to medium to high) at 50 m from the turbines, with all the turbines OFF. Note that the ambient wind noise, below about 50 Hz, increases from low wind speed to medium wind speed. With an increase in wind speed from medium to high, the ambient wind noise increases at all frequencies by about +20 dB. At high wind speeds, the ambient wind noise will exceed the sound output from the turbines. Note also that for the high wind condition, the LLeqs are higher when the turbines are OFF.

Figure 16 shows the LLeqs between low wind speed and high wind speed, with the turbines ON at a distance of 1000 m from the turbines.

Figure 17 shows the LLeqs between low wind speed and high wind speed, with the turbines OFF at a distance of 1000 m from the turbines.

An increase of +10 to +12 dB in ambient wind noise is apparent at most frequencies when the wind speed increases from low to high. The wind speed for file 56 was about 1.5 m/s lower than the wind speed for file 55 above (figure 16). Note that for the low wind condition, the ambient wind noise is higher than when the turbines are operating.

6.2 Attenuation With Distance: Calculated Vs Observed Laeq

For the three operational conditions: low wind, medium wind, and high wind, the median observed value for LAeq (turbines ON) at 50 m, as recorded with the 2260, was used as the starting point for the calculated attenuation. The observed data points are shown enlarged on the graph below. The attenuation due to distance was calculated for a line source, at –3dBA per dou-

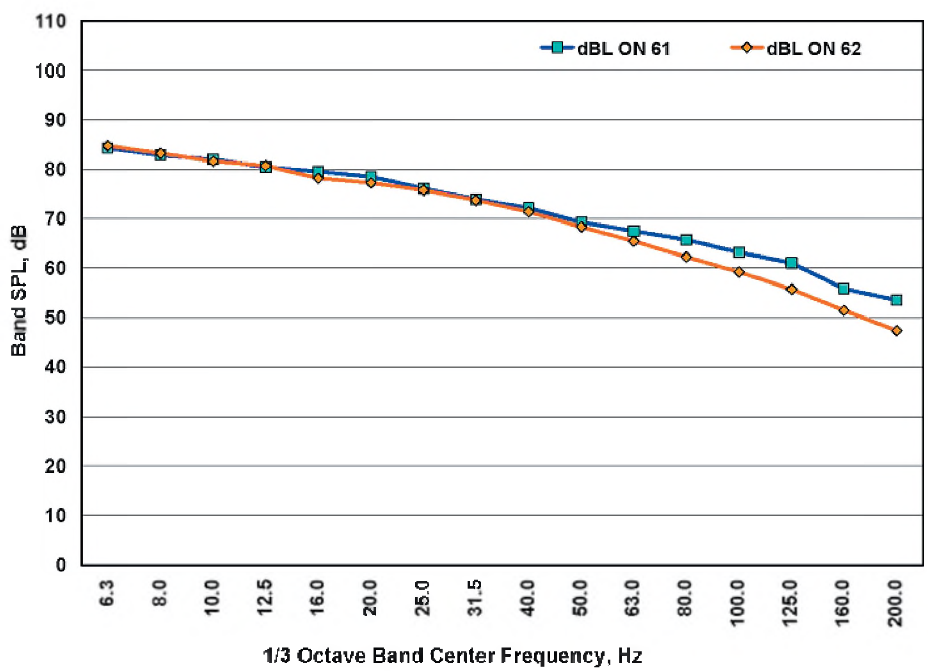


Figure 12. 1/3 octave LF spectra. file 61: dBL, high wind, turbines ON, 50 m file 62: dBL, high wind, turbines ON, 1000 m

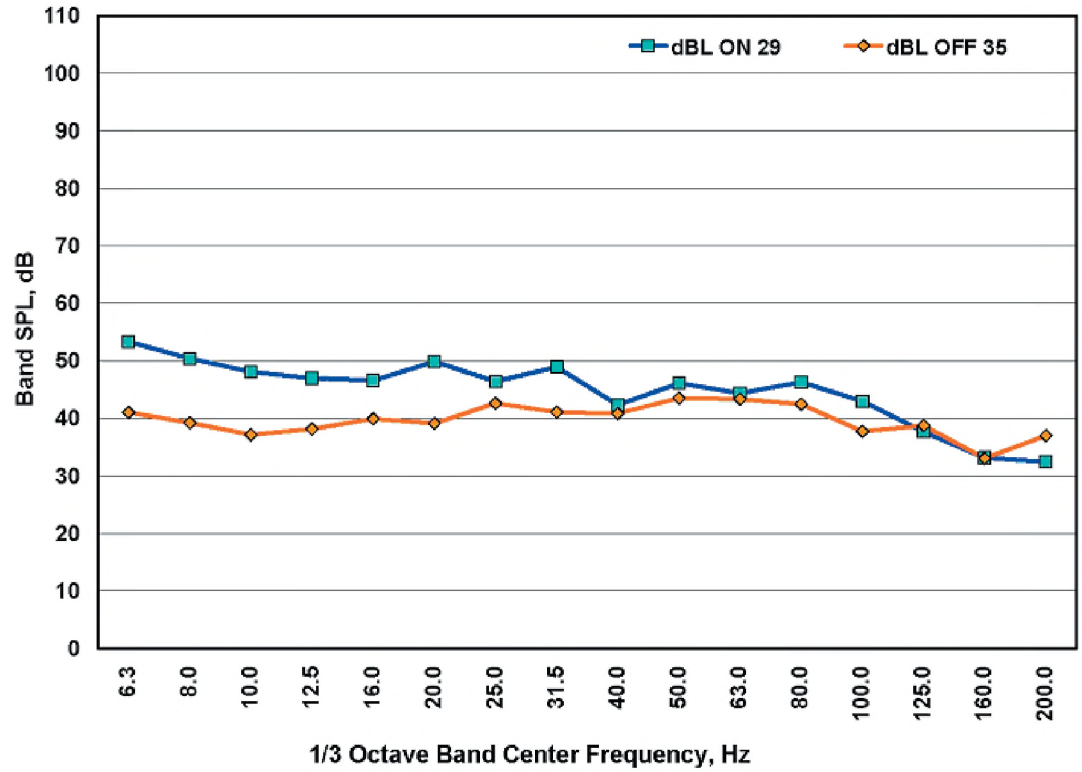


Figure 13. 1/3 octave LF spectra. file 29: dBL, very low wind, turbines ON, 1000m ; file 35: dBL, very low wind, turbines OFF, 50 m

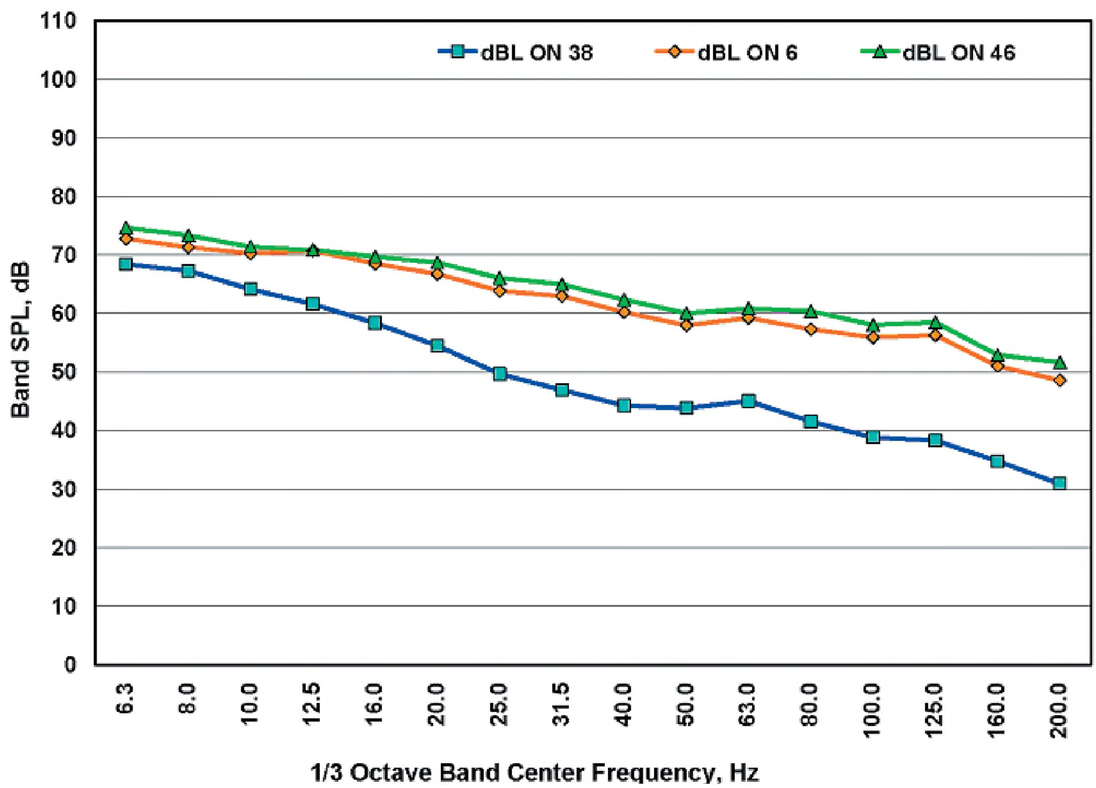


Figure 14. 1/3 octave LF spectra. file 38: dBL, low wind, turbines ON, 50 m
file 6: dBL, medium wind, turbines ON, 50 m; file 46: dBL, high wind, turbines ON, 50 m

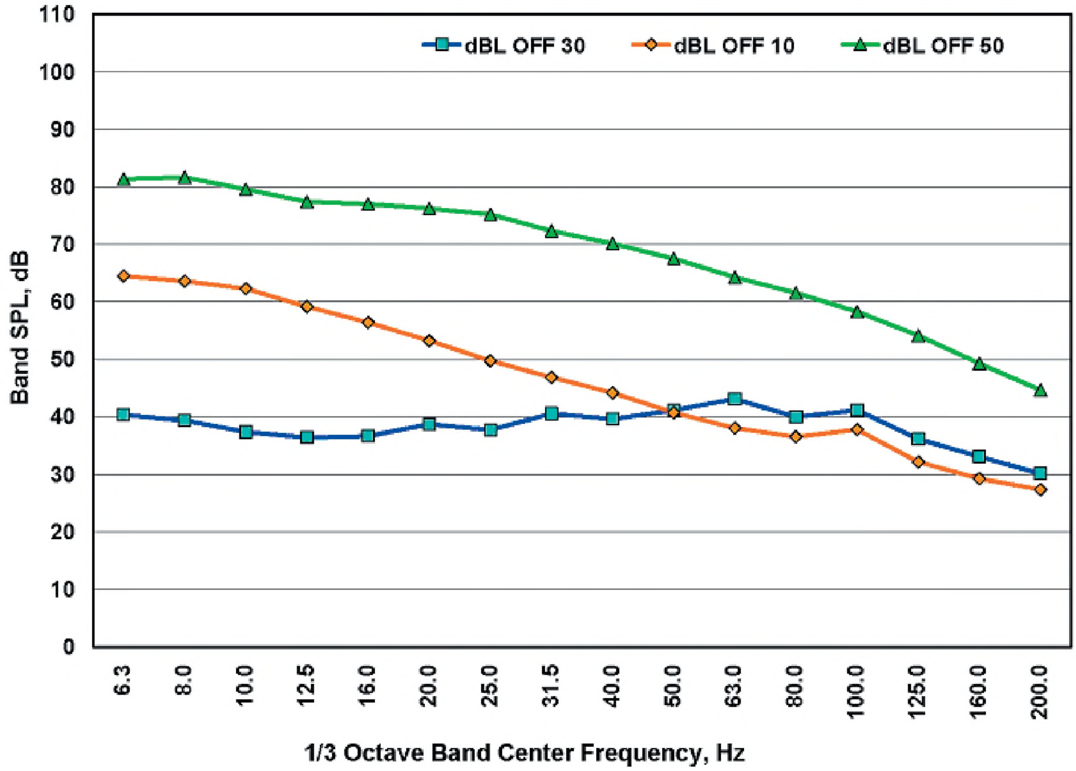


Figure 15. 1/3 octave LF spectra. file 30: dBL, low wind, turbines OFF, 50 m file 10: dBL, medium wind, turbines OFF, 50 m; file 50: dBL, high wind, turbines OFF, 50 m

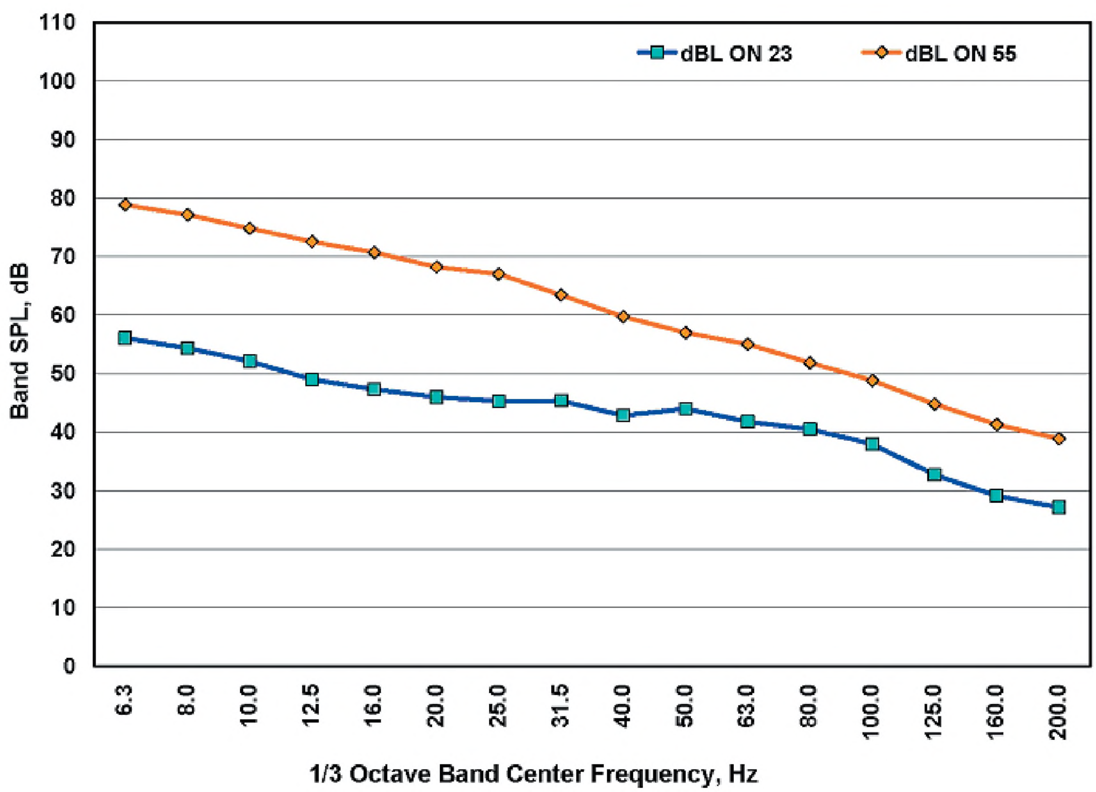


Figure 16. 1/3 octave LF spectra. file 23: dBL, low wind, turbines ON, 1000 m ; file 55: dBL, high wind, turbines ON, 1000 m

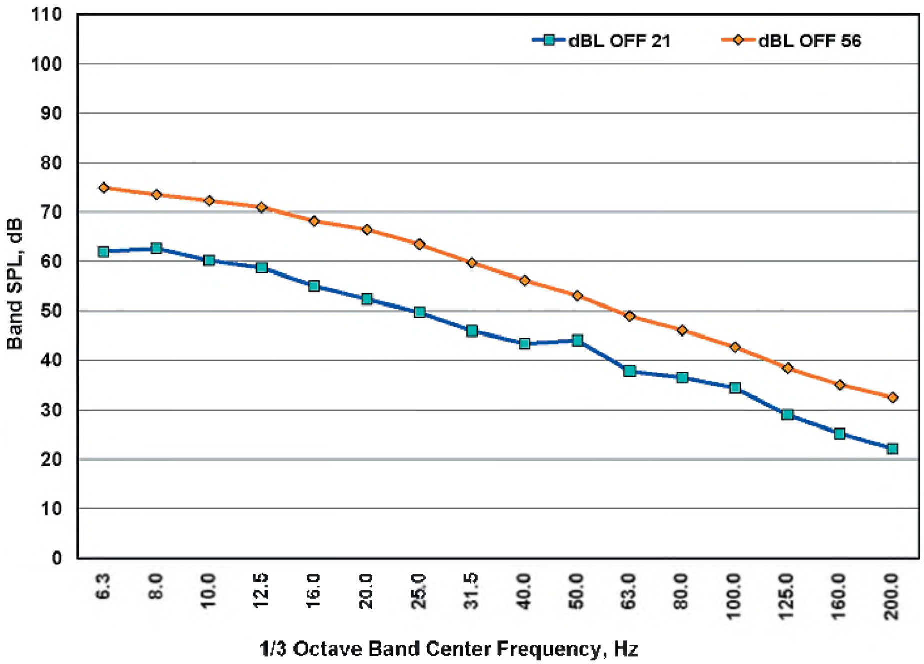


Figure 17. 1/3 octave LF spectra. file 21: dBL, low wind, turbines OFF, 1000 m file 56: dBL, high wind, turbines OFF, 1000 m

bling of distance. The following formula was used:

L(R2) = L(R1) – 10 Log10 (R2/R1) (1)

Where: R1 and R2 are distances in meters and L = dBA or sound level in dB for octave bands.

For the low wind condition, the observed dBA at 1000m exceeded the calculated dBA by 7.5 dB. The observed attenuation was less than the calculated attenuation since the ambient wind noise, albeit low, exceeded the output from the turbines at 1000 m. In other words, wind noise would not be attenuated with distance.

For the medium wind condition, the initial dBA at 50m was close to the measured initial dBA for high wind at 50m, since the turbines do not generate more sound at higher wind speeds. The behavior of the attenuation curve and observed values for the high wind condition indicates that the medium wind condition should behave in a similar manner, and attenuation for both conditions should closely follow the above formula. The observed dBA for high wind at 1000 m was actually lower than the calculated value, indicating an additional –3 dBA of attenuation. This indicates that the turbines decrease ambient wind noise. It is acknowledged that variability in wind speed and ambient noise could cause variability in measured LAeqs.

6.3 Telemetry Data Results and Analysis

The telemetry analysis provided time domain records for each of the three operational conditions of the turbines: low wind, medium wind, and high wind. In addition, for each operational condition, there were two operational states: ON and OFF. Those records are also shown. For each record, the first 30 traces (1 to 30 on the right) are the geophones, and the next 30 traces (31 to 60 on the left) are the acoustic microphones. The calibration scalars have been applied to the microphone data. The telemetry records are identified with an FFID (field file identifier).

Following the time domain records, the frequency domain amplitude spectra are presented, where possible, incorporating the calibrated data from the appropriate 2260 record. Data from the 2260 are identified as a file, rather than an FFID. The spectra are grouped for each of the three operational conditions. Within the spectra, data are often presented to compare operational states, ie. ON and OFF, or distance from turbines (50m or 1000m).

On each FFID, the first 30 channels (1 to 30 on line 1, stations 101 to 130) are 4.5 Hz geophones. The last 30 channels (31 to 60 on line 2, stations 101 to 130) are acoustic microphones. Stations on both lines have the same location (ie. Line 1 station 102 is the same location as Line 2 station 102). The line numbers differ to allow separation of the geophones and microphones on two cables in the field. The geophones and microphones were coincident on the stations. The vertical scale is time (ms). The horizontal scale is distance, with 50 m between traces. For all wind conditions, occasional

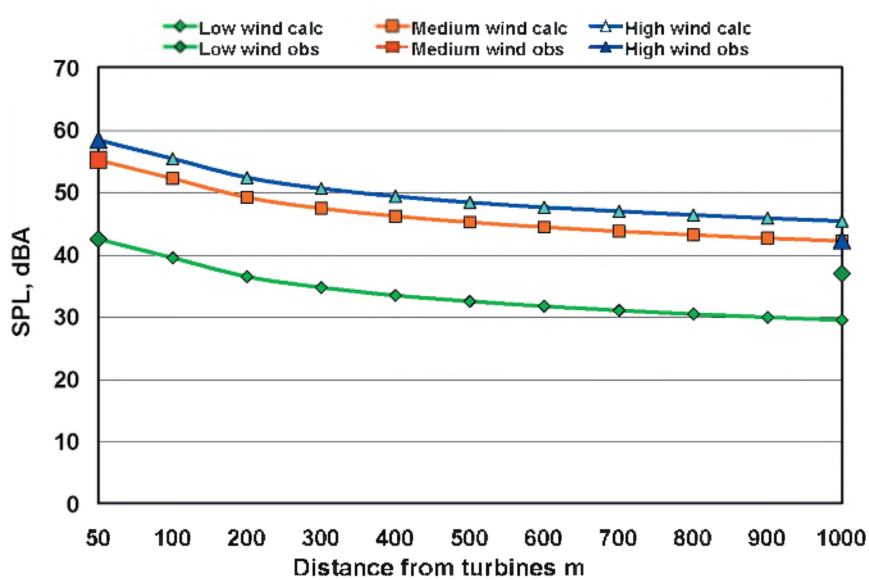


Figure 18. Calculated LAeq and observed LAeq: attenuation with distance.

noise bursts may be seen. These can generally be attributed to a wheat combine nearing the telemetry spread while working in an adjacent field.

The telemetry data analysis is presented only for the high wind conditions, since the dramatic variations are easily seen. Instead of the complete data set, only a discussion summary is presented for the low and medium wind conditions.

6.3.1 High Wind Conditions

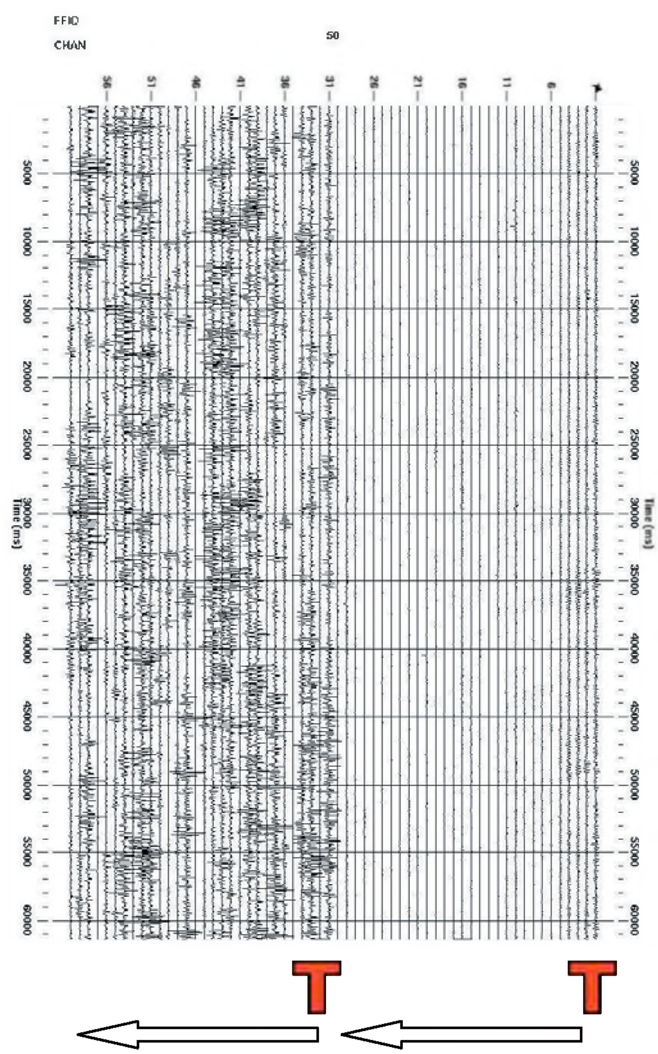
Fir the case of the turbines OFF, the microphones on the left half of figure 19 show that the wind noise at all offsets exceeds the sound levels for the same microphones on the left side of figure 20 (turbines ON). Similar results were found for the low and medium wind condiitons

The geophone traces on the right half of figure 19 are fairly quiet. The spurious events on the geophones close to the turbines were again caused by the wheat combine about 600 m north of the recording spread.

With the turbines ON, the acoustic energy recorded on the microphones has decreased at all offsets, due to the rotation of the turbines. The acoustic energy recorded on the geophones closest to the turbines has increased, due to the rotation of the turbines.

The above time domain records conclusively demonstrate that the wake effect of the turbines significantly decreases ambient noise for high wind speeds in the down wind direction, for the frequency band 3 Hz to 207 Hz.

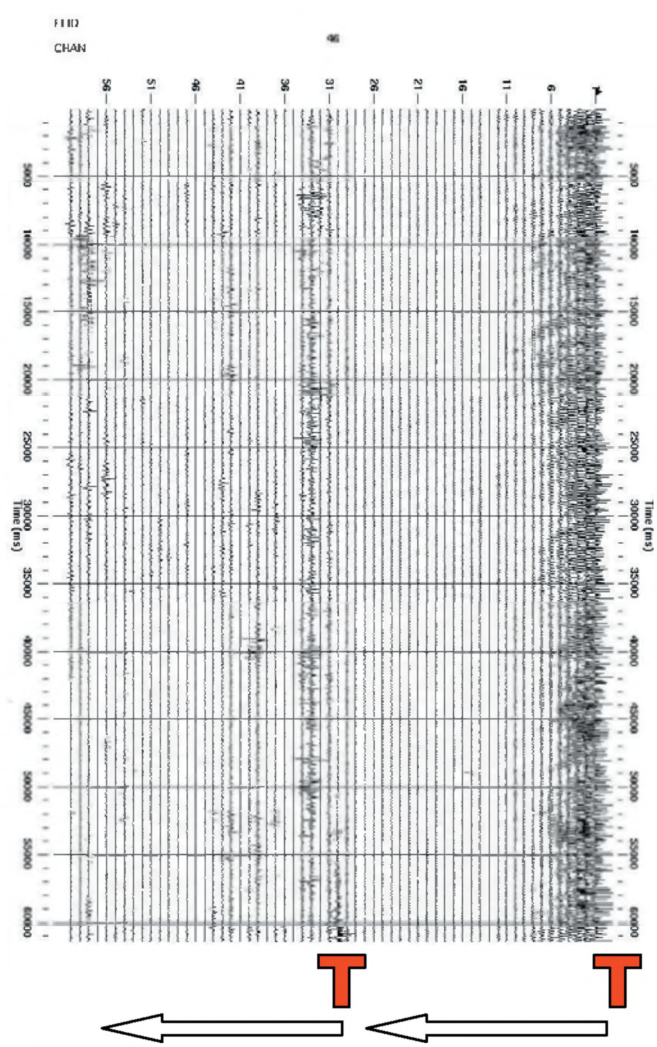
Figure 21 shows the LLeqs measured at station 102 with high wind speed and the turbines ON. The data is out of range for B&K 2260 meter below 6.3 Hz, but were measured by the geophones and microphones. The telemetry data are empirically referenced to the 2260 data. Note that the geophone amplitudes decrease very rapidly with increasing frequency



Microphones every 50m Geophones every 50m

Figure 19. Time domain telemetry record (3 Hz to 207 Hz). FFID 50, high wind, turbines OFF.

Geophone traces 1 to 30, coincident with microphones on traces 31 to 60. The red T indicates the location of the closest turbines. Down wind direction to left of turbine location.



Microphones every 50m Geophones every 50m

Figure 20. Time domain telemetry record (3 Hz to 207 Hz). FFID 46, high wind, turbines ON.

Geophone traces 1 to 30, coincident with microphones on traces 31 to 60. The red T indicates the location of the closest turbines. Down wind direction to left of turbine location.

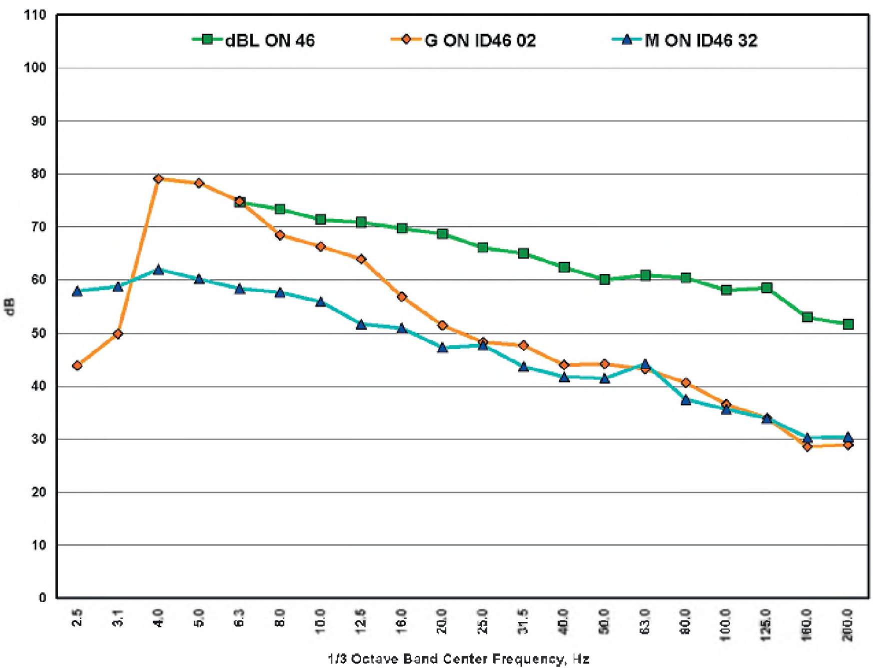


Figure 21. 1/3 octave LF spectra files: 46, FFID 46, ON, high wind, near trace LLeqs. file 46: dBL, 2260, high wind, turbines ON, 50 m, station 102 ; ID46 02: dBL*, geophone, high wind, turbines ON, 50 m, station 102; ID46 32: dBL*, microphone, high wind, turbines ON, 50 m, station 102; * indicates empirical calibration to 2260 acoustic data.

(-10 dB/octave). Microphone amplitudes also decrease with increasing frequency (-6dB/octave). 2260 LLeqs decrease with increasing frequency (-5dB/octave.) Interestingly, the amplitude dependence on frequency is almost identical to the medium wind case at 50 m.

Note that the microphone LLeqs for the high wind case are lower than LLeqs for the medium wind case, suggesting that the wake effect from the wind farm diminishes ambient noise, even at 50 m. The 2260 data are strongly affected by turbulent wind noise.

Figure 22 shows the LLeqs measured at station 121 with high wind speed and the turbines ON. The 2260 data were measured at station 102 (50m from the turbines). The telemetry data were measured 1000 m from the turbines. The attenuation due to distance for the geophones is not entirely linear, between 4 and 63 Hz approx -20 to -26 dB. The attenuation for the microphone data was about -5 dB, and was more linear with increasing frequency.

Figure 23 shows the LLeqs measured at 50m and 1000 m from the turbines, with high wind speed and the turbines ON. Figure 24 shows attenuation due to distance from 50m to 1000m, with high wind speed and the turbines ON. The microphone data are attenuated less than -10 dB over the range of 2.5 Hz to 200 Hz, with about the same attenuation at higher frequencies. The geophone data are attenuated from -5 dB to -32 dB over the same range, with more attenuation at lower frequencies. The attenuation with distance for the high wind case should be compared with the medium wind case. The attenuation for the geophones is very similar, however, the microphone amplitudes are not as strongly attenuated. Wind noise is more of a factor in the high wind case.

Figure 25 shows the LLeqs for the ON and OFF conditions, with high wind speed at a distance from the turbines of 50 m for the telemetry data, and 50 m for the 2260 data. The microphone data show largest decreases in amplitude, especially at low frequencies. The 2260 data show increases in amplitude at lower frequencies, showing the dominant effect of wind noise. Note the apparent tonal component at 63 Hz for OFF mic data (FFID50).

Figure 26 shows the difference between the ON and OFF conditions at a distance of 50 m from the turbines, with high wind speed. Geophone amplitudes decrease from –19 dB to +6 dB. Microphone amplitudes show a decrease in amplitude of about –30 dB for most frequencies, especially for frequencies below 40 Hz.

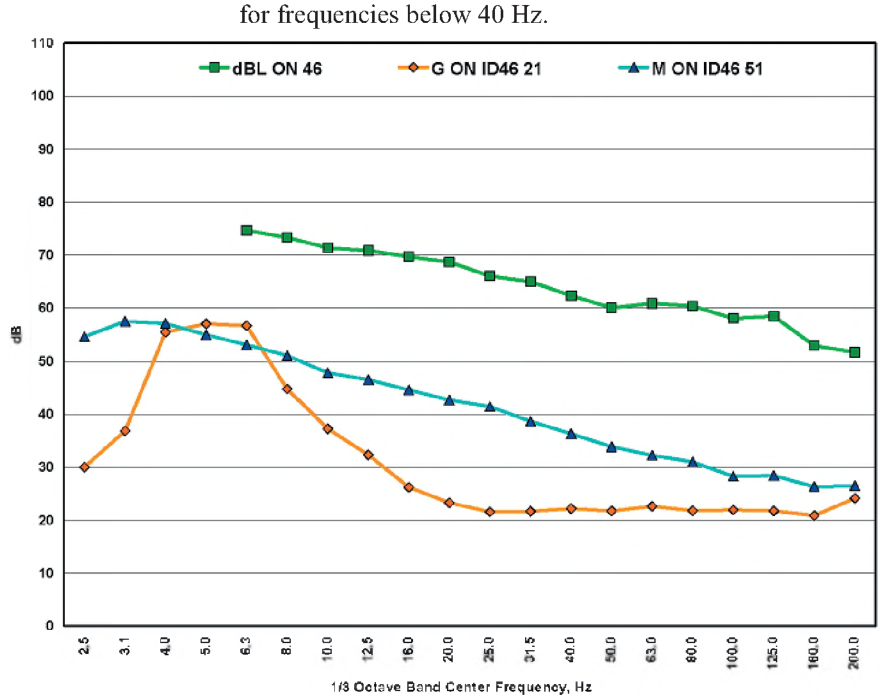


Figure 22. 1/3 octave LF spectra files: 46, FFID 46, ON, high wind, far trace LLeqs. file 46: dBL, 2260, high wind, turbines ON, 50 m, station 102 ; ID46 21: dBL*, geophone, high wind, turbines ON, 1000 m, station 121; ID46 51: dBL*, microphone, high wind, turbines ON, 1000 m, station 121

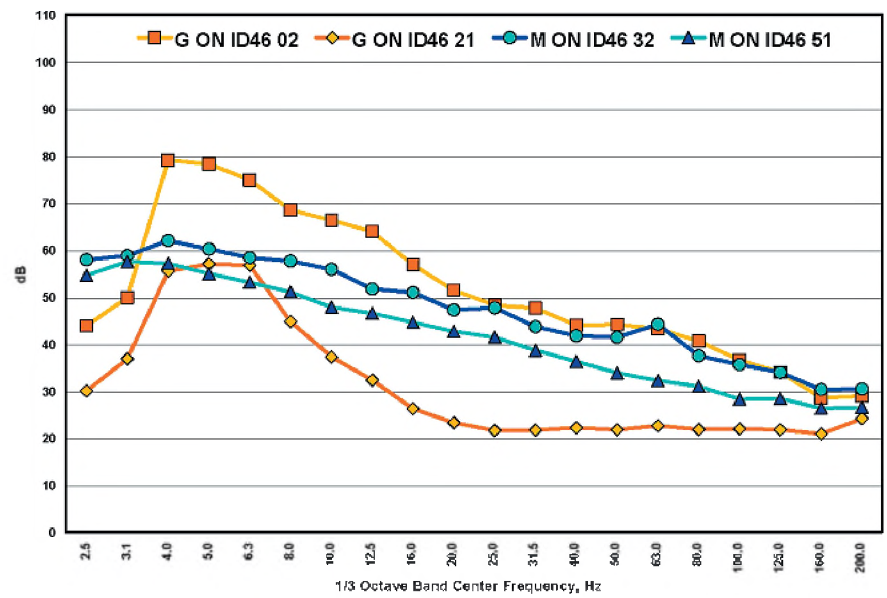


Figure 23 1/3 octave LF spectra

files: FFID 46, ON, high wind, near and far trace LLeqs.; ID46 02: dBL*, geophone, high wind, turbines ON, 50 m, station 102; ID46 21: dBL*, geophone, high wind, turbines ON, 1000 m, station 121; ID46 32: dBL*, microphone, high wind, turbines ON, 50 m, station 102 ; ID46 51: dBL*, microphone, high wind, turbines ON, 1000 m, station 121

The 2260 data show an increase in LLeqs from +6 dB to +9 dB for frequencies below 63 Hz, illustrating the dominance of wind noise at high wind speeds. The 2260 data confirm that wind farm operation at high wind speeds decreases the turbulent wind noise, even at 50 m. The microphones were protected from the turbulent flow, since they were about 2 inches below the surface.

Figure 27 shows the LLeqs measured for the ON and OFF with high wind speed at a distance of 1000 m from the turbines for the telemetry data, and 50m for the 2260 data. Amplitudes, as measured by the 2260 at 50 m from the turbine, are higher with the turbines OFF, as in figure 25 above. The geophone and microphone data at a distance of 1000 m, also show some increase in amplitude with the turbines OFF.

Figure 28 shows the differences measured for the ON and OFF conditions at a distance of 50m (2260 data) and 1000 m (telemetry data) from the turbines, with high wind speed. At most frequencies, the LLeqs increase when the wind farm is OFF, as measured with the 2260 at 50 m. The microphone amplitudes increase by about +12 to + 18 dB when the wind farm is OFF. The small decrease in amplitudes for the geophones, below about 8 Hz, confirm that there was not much coupled terrestrial energy from the turbines at high wind speeds. A +10dB increase in geophone amplitudes above 20 Hz confirm that wind noise, rather than sound output from the turbines, is a dominant factor.

9. CONCLUSIONS

Measurements of frequencies down to 6.3 Hz, obtained with the 2260, showed that infrasound emission from the Castle River Wind Farm is present in close proximity to the turbines, but is not a significant concern. Lower frequencies, down to approximately 2.5 Hz, were measured in the telemetry data set. The telemetry data demonstrate that in close proximity to the turbines, the largest infrasound levels are terrestrially coupled, and are detected on the geophones. The infrasound frequencies detected by the geophones are strongly attenuated with distance from the turbines. All data sets confirm that atmospheric infrasound emissions from the turbines are not significantly above the ambient wind noise levels at a distance of 1000 m, and that for the low wind and high wind conditions, infrasound levels are actually lower when the turbines are operating.

Ambient infrasound levels, when the turbines are not operating, are significant for the medium and high wind conditions. For the high wind condition, at a distance of 1000 m from the wind farm, infrasound LLeqs range from 76 to 82

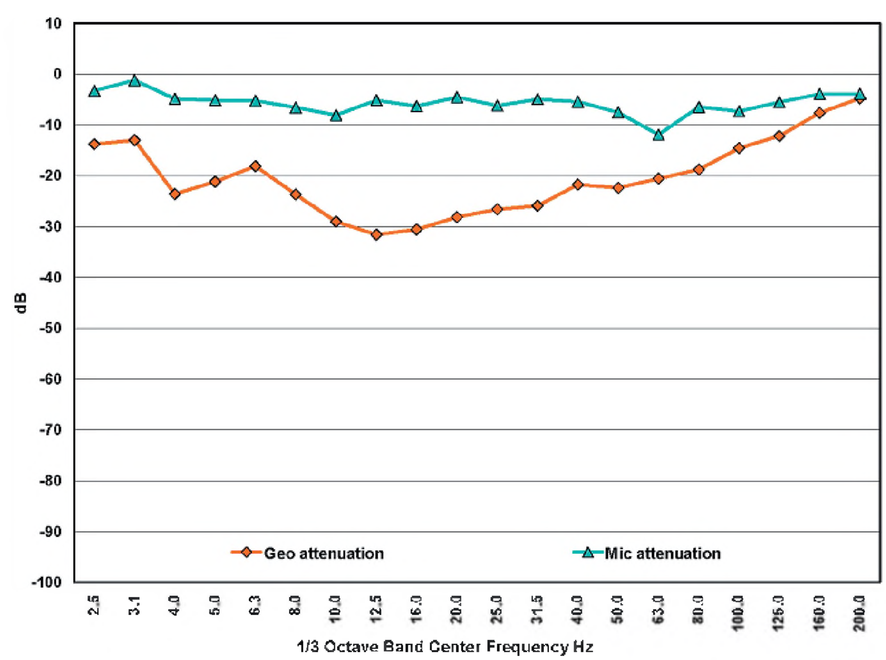


Figure 24. 1/3 octave attenuation.

FFID 46, ON, high wind, attenuation due to distance; FFID46: dBL*, geophone, high wind, turbines ON, attenuation from 50m to 1000m; FFID46: dBL*, microphone, high wind, turbines ON, attenuation from 50m to 1000m

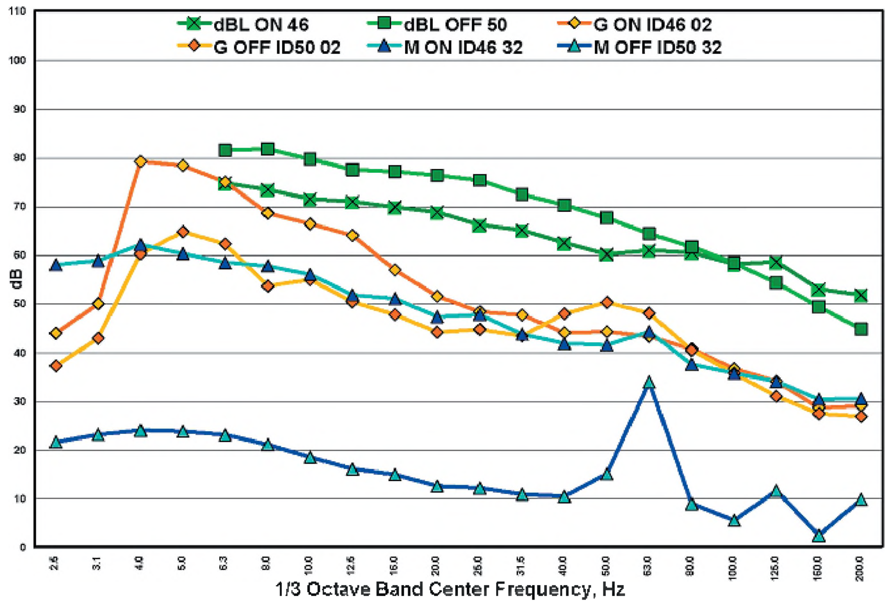


Figure 25. 1/3 octave LF spectra

file 46: dBL, 2260, high wind, turbines ON, 50m; file 50: dBL, 2260, high wind, turbines OFF, 50m; FFID46 02: dBL*, geophone, high wind, turbines ON, 50m; FFID50 02: dBL*, geophone, high wind, turbines OFF, 50m; FFID46 32: dBL*, microphone, high wind, turbines ON, 50m. FFID50 32: dBL*, microphone, high wind, turbines OFF, 50m.

dBL when the turbines are OFF, exceeding the infrasound LLeqs when the turbines are ON. The telemetry data confirm the 2260 data. For the medium wind condition, ambient infrasound LLeqs range from 53 to 65 dBL, when the turbines are OFF. For the low wind condition, ambient infrasound LLeqs range from 53 to 62 dBL, exceeding the infrasound LLeqs when the turbines are ON. The telemetry data confirm the 2260 data.

Attenuation of acoustic energy with distance was measured. The observed LAeqs at 1000 m, for low wind speed, was higher (+7.5 dBA) than calculated, due to the fact that ambient wind noise is not attenuated with distance, and the ambient wind noise exceeded the attenuated output from the turbines. The observed value at 1000 m, for high wind speed, was –3.1 dBA lower than calculated, indicating attenuation of the wind noise during operation of the wind farm. All data support the conclusion that some attenuation of wind noise occurs when the wind farm was operating in low and high winds. The time domain telemetry data for the frequency band of 3 Hz to 207 Hz support the same conclusion for all wind conditions, particularly at a distance from the turbines of 200 m and greater. Variation of environmental conditions may have introduced some variability into the data.

The full band (3 Hz to 207 Hz) time domain telemetry data clearly show the remarkable effect of wind noise reduction on the microphones, when the turbines are operating at all wind speeds. The 1/3 octave band spectra demonstrate that at low and high wind speeds, wind noise is attenuated when the wind farm is in operation. The ambient wind noise levels are higher when the turbines are not turning. Clearly, the wake effect is a significant factor in reduction of wind noise.

10. ACKNOWLEDGEMENTS

The author is grateful for the support and permission to present these data. Vision Quest Windelectric, TransAlta's Wind Business, is recognized for their commitment to safeguarding the environment through proactive efforts, including the support of this independent experiment. The author also appreciates the cooperation of CREWES (Consortium for Research into Elastic Wave Exploration Seismology at the U of Calgary). The assistance of CREWES staff Malcolm Bertram and Eric Gallant was valuable, particularly for the microphone calibrations. Dr. Peter Cary of Sensor Geophysical provided additional expertise during the telemetry data processing.

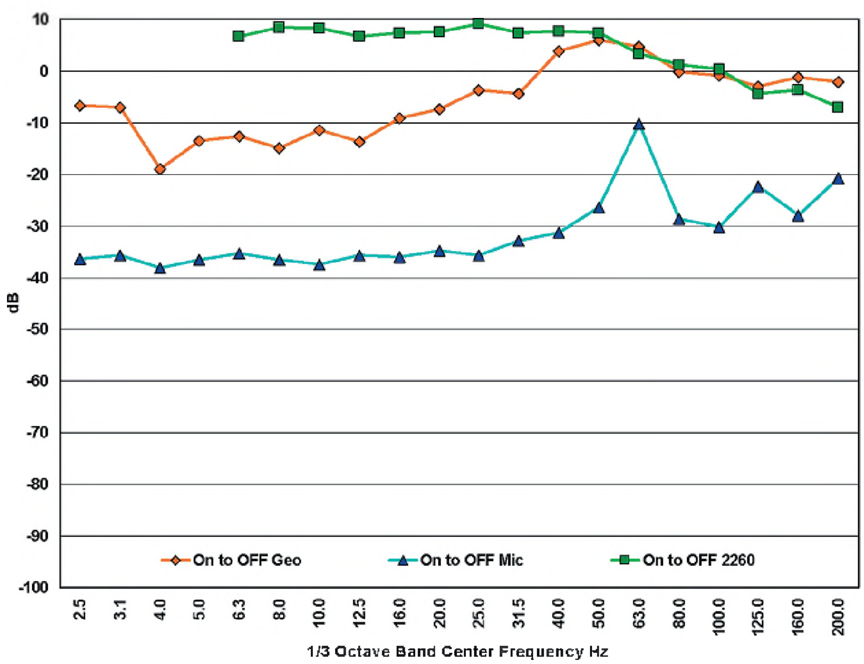


Figure 26. 1/3 octave difference

file 46, 50: dBL, 2260, high wind, turbines ON and OFF, 50m, residual above background; FFID 46, 50: dBL*, geophone, high wind, turbines ON and OFF, 50m, residual above background; FFID 46, 50: dBL*, microphone, high wind, turbines ON and OFF, 50m, residual above background.

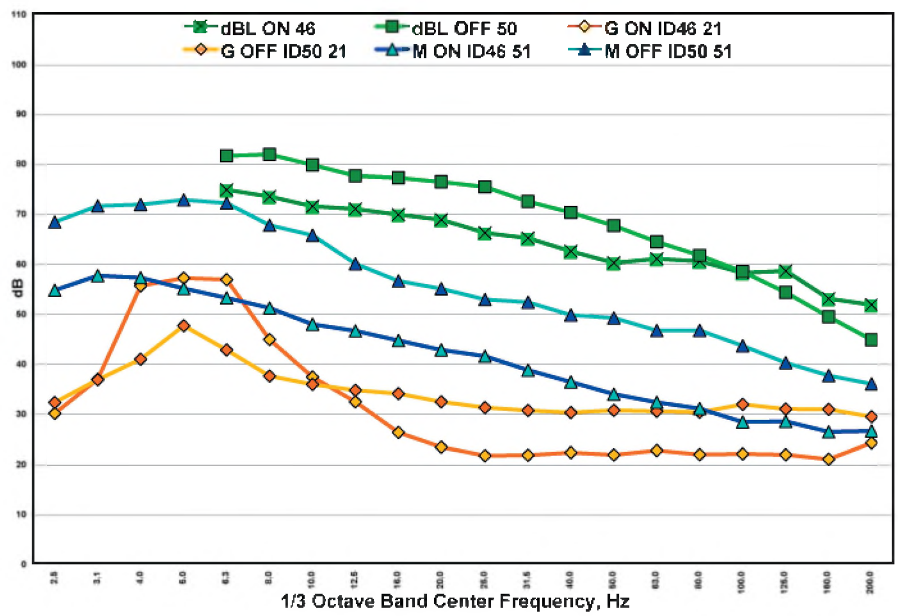


Figure 27. 1/3 octave difference

files: 46, 50, FFIDs 46&50, ON&OFF, high wind, far trace LLeqs. file 46: dBL, 2260, high wind, turbines ON, 50m; file 50: dBL, 2260, high wind, turbines OFF, 50m; FFID46 21: dBL*, geophone, medium wind, turbines ON, 1000m; FFID50 21: dBL*, geophone, medium wind, turbines OFF, 1000m; FFID46 51: dBL*, microphone, medium wind, turbines ON, 1000m FFID50 51: dBL*, microphone, medium wind, turbines OFF, 1000m.

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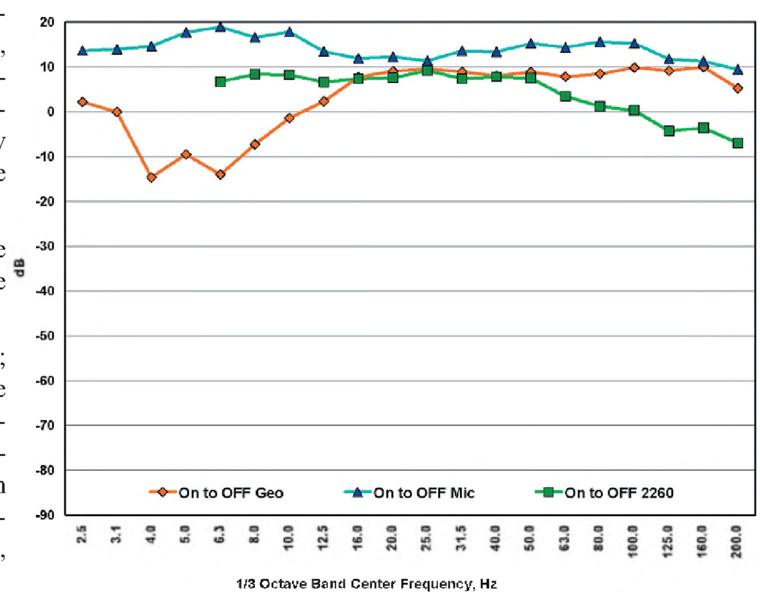

Figure 28. 1/3 octave difference

files: 46, 50, FFIDs 46&50, ON&OFF, high wind, far trace differences - file 06, 10: dBL, 2260, medium wind, turbines ON and OFF, 50m, residual above background; FFID 07, 11: dBL*, geophone, medium wind, turbines ON and OFF, 1000m, residual above background; FFID 07, 11: dBL*, microphone, medium wind, turbines ON and OFF, 1000m, residual above background.

Editor's Note: The following book review was originally written for the International Journal of Acoustics and Vibration and is reproduced here with permission.

Wind Turbines: Fundamentals, Technologies, Application, Economics, 2nd Edition
Erich Hau, Pages 783
Springer 2006 - ISBN 13 978-3-540-24240-6; US$199.00

A tome, like this book, always elicits the usual comment, "Everything one always wants to know." Wind Turbines attempts to provide a complete, but brief overview of the field populated by wind turbines.

The book is divided into twenty brief chapters and the contents are as follows: I) Windmills and Windwheels; II) Electrical power from the wind – the first attempts; III) Basic concepts of wind energy converters; IV) Physical principles of wind energy conversion; V) Rotor aerodynamics; VI) Load and structural stresses; VII) Rotor blades; VIII) Mechanical drive train and nacelle; IX) Electrical system; X) Control systems and sequence control; XI) Vibration problems; XII) The tower; XIII) The wind resource; XIV) Power output and energy yield; XV) Environmental impact; XVI) Commercial applications of wind turbines; XVII) Offshore wind energy utilization; XVIII) Wind turbine installation and operation; XIX) Wind turbine costs; and XX) Wind turbine economics.

I must begin with a confession. My background is in acoustics and vibration. Hence my review will be elementary for the most part. However, Erich Hau has covered the issues of wind turbines from all angles and through simple descriptions, which make this review easy.

The book begins with a list of commonly used symbols, a delight for engineering scientists. Chapter I tells us the story of windmills and wind wheels from ancient times till the early 1900s. Through copious high quality images, the chapter tells the story of the attempt made by man to harness the energy from atmospheric winds. The chapter concludes by tracing the technical advancements made all through history, to garner the energy in the most efficient way. Chapter II, similarly, provides a historical development of harnessing electricity from the wind. Starting with a detailed account of the efforts of Poul La Cour of Denmark in 1891 to the full-fledged wind farms in the USA, the second chapter sets the tone for the further developments described in the book. It also provides the tentative steps taken by different countries to develop seemingly clean energy.

Chapter III discusses the technical details of the concepts behind the wind energy technology. This is one of the briefest chapters of the book and presents, in a cursory fashion, the details behind the rotors, concentrators, as well as, solar winds. It concludes by including a list of the various terms used in the wind energy technology. Chapter IV is even briefer than Chapter III. In less than 10 pages, Hau describes the physical principles of wind energy conversion. Using Betz's momentum theory, he describes the mechanical energy that can be produced from wind. The upstream and downstream velocities, and their limits to produce maximum power through the "power coefficient" are described. Both the lift and drag methods of converting the wind energy to mechanical energy are touched upon.

Chapter V deals with rotor aerodynamics. As the author rightly points out, rotor aerodynamics and a proper design of the rotor provides a rationale for all systems connected with the wind turbine technology such as mechanical and electrical systems. Chapter V, as a result, is one of the longest, and is over 70 pages in length. From the basic flow models of fluid dynamics, through Betz's momentum theory, the various descriptors such as flow velocities, wake characteristics, and aerodynamic forces are presented in a brief summary. The main focus of this book, however, is the conversion of wind power to mechanical power through the rotor. A brief description of the power and torque coefficients as a function of the number of blades, rotor planform, airfoil aerodynamics, and blade twist are presented next. The wind farm system can function only within a set of speed ranges for different reasons and hence, the control of aerodynamic power is paramount in any wind turbine system design. Power control by rotor blade pitching, stall control methods, inherent problems of stall control, and furling techniques to turn the rotor away from the wind are also briefly touched upon. The chapter also discusses the rotor wake characteristics and their impact on downstream wind turbines that constitute the overall wind farm system. The various parameters that constitute the important design features of a rotor such as the number of blades, blade shapes, blade twist, airfoil, and blade thickness are presented next. This chapter also highlights the existing rotor designs that are available to a designer. The chapter adds a brief section on vertical axis rotor design and finally concludes with measurement techniques used to obtain the descriptors of rotor aerodynamics.

Chapter VI was also given copious space to discuss and calculate the loads and stresses that wind turbines are exposed to during their life cycle. The systems are subjected to both varying and steady loads and considerable attention is therefore necessary for a proper design. After enumerating the components of the loads such as aerodynamic, inertial and gravity forces, the chapter describes the different sources of the loading such as airflow, wind shear, cross winds, tower interference, wind turbulence and gusts, and gravity and inertial loads. Next, the assumptions that are common during the design processes are discussed leading to a summary presentation of the cases under which the loads need to be determined. After a brief enumeration of the ultimate and fatigue loading, procedures used to calculate these loads are highlighted. The chapter also contains the impact of the different design features presented in Chapter V. A short presentation of the tests that are usually applied to measure the loading as well as trials for subjugating the turbine systems through load cycles follows next. The chapter concludes with a listing of the standards and certification of wind turbines applied in Europe.

Chapters VII, VIII and IX deal with the structural components of a wind turbine system, such as rotor blades (Chapter VII), mechanical drive train and nacelle (Chapter VIII) and the electrical systems (Chapter IX). Brief but necessary information is presented in these chapters. For example, Chapter VII discusses rotor blades in terms of materials, past designs, current practice, and connections to the hub, and also provides a comparison of these designs. It also highlights rotor brakes, lightning protection as well as ice warning and de-icing techniques. Similar descriptions are given for the drive train containing the gear box in Chapter VIII. Chapter VIII also includes the nacelle that houses the drive train and the generator. Chapter IX discusses the electrical system with the main focus on the generator. The different generator designs that generate the electrical power and their connection to the power grid are touched upon in this chapter. There is also a brief section on the complete electrical system discussion and the chapter concludes with a preliminary comparison of the different electrical systems.

Any complex system requires a set of quality control systems even if the system's functions are operated manually. The control element system in the case of a wind turbine becomes that much more difficult as many wind farms are located in remote regions. Chapter X is, therefore, one of the important chapters of this book, and Mr. Hau has attempted to address the complexity of control systems by presenting an overview of the requirements of a solid and reliable control system. After outlining the areas that require control systems, the chapter discusses the requirements, design, and expectations of the control systems for wind measurements, yaw control, power and speed control, power limiting controls, and the usual systems for overall control by supervisors and operational states so any required actions can be accommodated easily.

Chapter XI deals with vibrational problems associated with the wind turbine set-up and is of interest to the present reviewer. This chapter, after highlighting the importance of the dynamic behaviour of the wind turbine, both as a whole as well as individual systems, presents a cursory overview of the vibration concerns. It discusses both aeroelastic behaviours and the natural dynamic behaviours of the systems. It does lead the reader to the important aspects of the natural frequencies and presents a simple summary of these in terms of individual components as well as the coupled response of the wind turbine as a whole system. The chapter also shows salient features of the mathematical models that can be applied to evaluate vibration concerns as well as, albeit in a circuitous way, possible design methods to reduce significant vibration responses of wind turbines.

Chapter XII is similar to Chapter VII as it deals with the structure of the tower. Brief summary discussions are presented for tower configurations, and then additional details are provided for free-standing steel towers, lattice towers, concrete towers as well as a comparison of these different designs. Interesting information such as climbing details and the tower foundation are also presented in this chapter.

The remaining eight chapters deal with issues such as environmental impacts, operational constraints, wind resources and economic analysis. Chapter XIII deals with the wind as a resource. Starting with the causes of wind flows, the chapter presents summary details of wind maps, and available areas with potential for wind power generation, the parameters that determine these potential areas as well as basic information required to locate a wind farm.. Chapter XIV discusses the available wind power and the resultant energy yield of a wind turbine (wind turbine farm). Power optimization schemes are also presented in this chapter. The chapter concludes with a brief discussion of the term "technical availability" used in the wind turbine industry. Technical availability refers to the theoretical potential of the turbine to deliver design goals in terms of time, power and energy.

Chapter XV deals with environmental impacts. Even though, wind energy can be deemed "user friendly," wind turbines and wind farms can have considerable impacts on the surrounding. Once again, only cursory treatment of potential impact hazards - breakaway of rotor blades, noise, shadow effects, signal interferences, bird life, land use, visual aesthetics, and climate effects are presented in this chapter.

The treatment of commercial applications is presented in Chapter XVI. Brief summaries of stand-alone applications, small-grid use of wind turbines, and large-grid interconnectivity are discussed in this chapter. It also highlights laying out a wind farm such as spacing and electrical cabling, wind turbine integration into power stations as well as market development of wind energy. The chapter concludes with a history of wind-energy use, and a listing of the major players in the wind energy industry. The potential of wind energy from the perspective of atmospheric effects, economic factors, and political acceptance are also included in this chapter.

A separate chapter, Chapter XVII is used to discuss off-shore installations of wind turbines. The constraints and resources of off-shore installations are highlighted through the examples of installations in the North Sea and the Baltic Sea. The legal ramifications of licensing off-shore installations are also explored in this chapter. The chapter concludes with the technology of off-shore siting such as wind turbine requirements, foundation on the sea floor, electrical infra-structure and transportation.

How to install and operate a wind turbine is detailed in Chapter XVIII. A step-by-step installation procedure is detailed through brief summaries, which include project development, planning and permits, transportation issues, site erection, grid connection, commissioning, operation and monitoring, safety issues and maintenance.

Finally, Chapters XIX and XX discuss the economic aspects of wind turbines. The various costs associated with wind turbines are presented in Chapter XIX. The life cycle cost analysis is undertaken in Chapter XX, and other details such as financing, cost comparison with other energy sources, economic viability of wind turbines, employment potential, and economics of renewable energy sources are also highlighted in Chapter XX.

In conclusion, this book is well put together, even though the translation is poor in places. If one wants a summary introduction to wind turbine issues, this book would suffice. On the other hand, if details of particular aspects of wind turbines and their constituents are required, one needs to research and find particular sources to obtain details. However, Erich Hau provides enough bibliography at the end of each chapter to help obtain those details. This reviewer was disappointed at the paucity of details of wind turbine vibration and noise aspects. One must therefore consider this book as a general introductory manual to wind turbine technology.

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22-26 August: 9th International Conference on Music Perception and Cognition, Bologna, Italy. Web: http://www.icmpc2006.org

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17-21 September: Interspeech 2006 - ICSLP. Web: www.interspeech2006.org

18-20 September: International Conference on Noise and Vibration Engineering (ISMA2006). Leuven, Belgium. Web: www.isma-isaac.be

18-20 September: ACTIVE 2006, 6th International Symposium on Active Noise and Vibration Control. University of Adelaide, South Australia, Australia. Web: www.active2006.com

18-20 September: 12th International Conference on Low Frequency Noise and Vibration and its control. Bristol, UK. Web: www.lowfrequency2006.org

18-21 September: INTERSPEECH 2006 - ICSLP. Pittsburgh, PA, USA. Web: www.interspeech2006.org

03-06 October: IEEE International Ultrasonics Symposium. Vancouver, Canada. Web: www.ieee-ultrasonics2006.org

11-13 October: Annual Conference of the Canadian Acoustical Association, Halifax, Nova Scotia. Web: http://www.caa-aca.ca/halifax-2006.html

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26-28 juin: 9e Conférence Western Pacific Acoustics. Seoul, Korea. Web: www.wespac8.com/WespacIX.html

26-29 juin: 11th International Conference sur Speech et Computer. St. Petersburg, Russia. Web: www.specom.nw.ru

3-7 juillet: 13th Congress Internationale sur Sound et Vibration (ICSV13). Vienna, Austria. Http://info.tuwien.ac.at/icsv13

17-19 juillet: 9th International Conference sur Recent Advances in Structural Dynamics. Southampton, UK. Web: www.isvr.soton.ac.uk/sd2006/index.htm

22-26 août: 9th International Conference sur Music Perception et Cognition, Bologna, Italy. Web: http://www.icmpc2006.org

6-8 septembre. 2nd International Symposium "Material - Acoustics - Place 2006". Zvolen, Slovakia. Web: www.acoustics.sk/map

13-15 septembre: Autumn Meeting de l'Acoustical Society du Japan. Web: www.asj.gr.jp/index-en.html

17-21 septembre: Interspeech 2006 - ICSLP. Web: www.interspeech2006.org

18-20 septembre: International Conference sur Noise et Vibration Engineering (ISMA2006). Leuven, Belgium. Web: www.isma-isaac.be

18-20 septembre: ACTIVE 2006, 6th International Symposium sur Active Noise et Vibration Control. University d'Adelaide, South Australia, Australia. Web: www.active2006.com

18-20 septembre: 12th International Conference sur Low Frequency Noise et Vibration et control. Bristol, UK. Web: www.lowfrequency2006.org

18-21 septembre: INTERSPEECH 2006 - ICSLP. Pittsburgh, PA, USA. Web: www.interspeech2006.org

03-06 octobre: IEEE International Ultrasonics Symposium. Vancouver, Canada. Web: www.ieee-ultrasonics2006.org

11-13 octobre: Annual Conference de l'Association Acoustical Canadiene, Halifax, Nova Scotia. Web: http://www.caa-aca.ca/halifax-2006.html

16-17 octobre. Institute d'Acoustics Autumn Conference.. Oxford, UK. Web: www.ioa.org.uk/viewupcoming.asp

18-20 October: 37th Spanish Congress on Acoustics. Joint with Iberian Meeting on Acoustics, Gandia-Valencia, Spain. Web: http://www.ia.csic.es/sea/index.html

25-28 October: 5th Iberoamerican Congress on Acoustics. Satiago, Chile. Web: www.fia2006.cl

2-3 November: Autumn Meeting of the Swiss Acoustical Society. Luzern Switzerland. Web: www.sga-ssa.ch

20-22 November: Joint Australia/New Zealand Acoustical Conference. Christchurch, New Zealand. Web: www.acoustics.org.nz

28 November – 2 December: 152nd meeting, 4th Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan, Honolulu, Hawaii. Contact: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; E-mail: asa@aip.org; Web: asa.aip.org

3 - 6 December: INTER-NOISE 2006, Honolulu HA, USA (Same Hotel at ASA meeting the week preceeding. Web: www.inceusa.org

2007

10-12 April. 4th International Conference on Bio-Acoustics. Loughboro, UK. Web: www.ioa.org.uk

17-20 April. IEEE International Congress on Acoustics, Speech, and Signal Processing (IEEE ICASSP 2007). Honolulu, HI, USA. Web: http://www.icassp2007.org

16-20 May: IEEE International Conference on Acoustics, Speech, and Signal Processing (IEEE ICASSP 2007). Honolulu, HI, USA. Web: www.icassp2007.org

04-08 June: 153rd Meeting of the Acoustical Society of America. Salt Lake City, Utah, USA. Web: www.asa.aip.org

9-12 July: 14th International Congress on Sound and Vibration (ICSV14). Cairns, Australia. Email: n.kessissoglou@unsw.edu.au

26-29 August: Inter-noise 2007. Istanbul, Turkey. Web: www.internoise2007.org.tr

27-31 August: Interspeech 2007. E-mail: conf@isca-speech.org

2-7 September 19th International Congress on Acoustics (ICA2007), Madrid Spain. (SEA, Serrano 144, 28006 Madrid, Spain; Web:www.ica2007madrid.org

9-12 September: ICA2007 Satellite Symposium on Musical Acoustics (ISMA2007). Barcelona, Spain. Web: www.isma2007.org

9-12 September: ICA2007 Satellite Symposium on Room Acoustics (ISMA2007). Sevilla, Spain. Web: www,isra2007.org

November 27 - December 02: 154th Meeting of the Acoustical Society of America. New Orleans, LA, USA. Web: www.asa.aip.org

2008

29 June - 04 July: Joint Meeting of European Acoustical Association, Acoustical Society of America, and Acoustical Society of France. Paris, France. Web: www.sfa.asso.fr/en/index.htm

18-20 octobre: 37th Spanish Congress sur Acoustics. Joint avec Iberian Meeting sur Acoustics, Gandia-Valencia, Spain. Web: http://www.ia.csic.es/sea/index.html

25-28 octobre: 5th Iberoamerican Congress sur Acoustics. Satiago, Chile. Web: www.fia2006.cl

2-3 novembre: Autumn Meeting de l'Acoustical Society Swiss. Luzern Switzerland. Web: www.sga-ssa.ch

20-22 novembre: Joint Australia/New Zealand Acoustical Conference. Christchurch, New Zealand. Web: www.acoustics.org.nz

28 novembre – 2 decembre: 152e rencontre, 4e Rencontre acoustique jointe de l'Acoustical Society of America, et l'Acoustical Society of Japan, Honalulu, Hawaii. Info: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tél.: 516-576-2360; Fax: 516-576-2377; Courriel: asa@aip.org; Web: asa.aip.org

3 - 6 decembre: INTER-NOISE 2006, Honolulu HA, USA (Same Hotel at ASA meeting the week preceeding). Web: www.inceusa.org

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2008

29 juin - 04 juillet - 04 July: Joint Meeting d'European Acoustical Association, Acoustical Society d'America, et Acoustical Society du France. Paris, France. Web: www.sfa.asso.fr/en/index.htm

7-10 July: 18th International Symposium on Nonlinear Acoustics (ISNA18). Stockholm, Sweden. E-mail: benflo@mech.kth.se

28 July - 1 August: 9th International Congress on Noise as a Public Health Problem. Mashantucket, Pequot Tribal Nation, (CT, USA). Web: www.icben.org

22-26 September: Interspeech 2008 - 10th ICSLP, Brisbane, Austrailia. Web: wwwinterspeech2008.org

2010

23-27 August: International Confress on Acoustics 2010. Sydney, Australia. Web: www.acoustics.asn.au

7-10 juillet: 18th International Symposium sur Nonlinear Acoustics (ISNA18). Stockholm, Sweden. E-mail: benflo@mech.kth.se

28 juillet - 1 août: 9th International Congress sur Noise as a Public Health Problem. Mashantucket, Pequot Tribal Nation, (CT, USA). Web: www.icben.org

22-26 septembre: Interspeech 2008 - 10th ICSLP, Brisbane, Austrailia. Web: wwwinterspeech2008.org

2010

23-27 août: International Confress sur Acoustics 2010. Sydney, Australia. Web: www.acoustics.asn.au

NEWS

We want to hear from you! If you have any news items related to the Canadian Acoustical Association, please send them. Job promotions, recognition of service, interesting projects, recent research, etc. are what make this section interesting.

EXCERPTS FROM "*WE HEAR THAT*", IN *ECHOS*, ASA

ASA Fellow **Sheila Blumstein** has been named to Fellowship in the American Association for the Advancement of Science (AAAS) for her contributions to our understanding of the relationships between language and the brain. She is the Albert D. Mead Professor of Cognitive and Linguistic Sciences at Brown University. She has used functional magnetic resonance imaging to better understand the brain.

ASA awarded $1000 to **Pen-Yuan Hsing** and **Wei-Kang Huang**, Taipei Municipal Lishan Senior High School for their project on "Enhanced Cooling of Microelectronic Devices by Using the Thermoacoustic Effect" entered in the 2005 Intel International Science and Engineering Fair. Honorable Mention awards went to **Courtney Anne Rafes**, Northwest High School, Justin, Texas for a project on "An Ear to the Track: An Ultrasonic Train Wreck Avoidance System"; and to **Jhe-Rong Wu**, Taipei Municipal Chien-Kuo Senior High School, Tapei City, Taiwan for a project on "Phylogenetic Analysis of Crickets by Acoustic Behavior and Mitochondrial DNA Sequencing." Each winner received a one-year ASA membership. Hsing and Huang also won expense-paid trips to attend the European Union Contest for Young Scientists in Russia. In the Physics category in the same competition, the Intel Foundation presented a $1000 award to **Emily Rae Drabek**, Eastern High School, Pekin, Indiana for her project on "A Vibroacoustical Study Comparing the Out-of-Plane Motion of Violin Bridges Under Different Boundary Conditions Using Holographic Interferometry."

Patricia Kuhl, Professor of Speech, University of Washington, has been elected Chair-Elect of the AAAS section on Linguistics and Language Science. Pat is a past president of ASA, an ASA Fellow, and a recipient of the Silver Medal in Speech Communication.

EXCERPTS FROM "*SCANNING THE JOURNALS*", IN *ECHOS*, ASA

Physicist **Seth Putterman**, well known to ASA members, is the subject of a biographical feature in the 27 October issue of Nature. "Ignoring the mainstream of physics," says the article, "Seth Putterman has a knack for bringing long forgotten mysteries back to the fore." A case in point is sonoluminescence, light generated by sound, which was known as long as 60 years ago but has recently become a "hot topic" in physics (see ECHOES Winter 1993, Spring 1997, Fall 1997, Winter 1998, Spring 2002, and Summer 2003, for example). Putterman firmly believes that the flash seen at the center of the bubble is created by electrons being shaken out of their atomic orbits, whereas others suspect more conventional chemistry is the culprit.

Micromachined fluid-filled variable impedance waveguides intended to mimic the mechanics of the passive **mammalian cochlea** have been fabricated, according to a paper in the January 21 issue of Proceedings of the National Academy of Sciences. Experimental tests demonstrate acoustically excited traveling fluid-structure waves with phase accumulations between 1.5 and 3 . radians at the location of maximum response. The achieved orthotropy ratio of 8:1 in tension is insufficient to produce the sharp filtering observed in animal experiments and many computational models that use higher ratios. A mathematical model incorporating a thin-layer viscous, compressible fluid coupled to an orthotropic membrane model is validated.

Bright and responsive "ultralight" **violins** may be the instruments of the future, according to an article in the 2 December issue of Science. The article reports mainly on the 33rd annual convention of the Violin Society of America held in King of Prussia, PA in November. Joseph Curtin, an Ann Arbor violin maker who recently won a MacArthur Foundation Fellowship (see Winter 2006 issue of ECHOES), is one of the makers featured in the article. Curtin was a presenter at the special session and workshop on Design and Construction of String Instruments at the ASA meeting in Vancouver (see Fall 2005 issue of ECHOES). Balsa wood and carbon-fiber composites are materials that have been used for experimental ultralight violins. Although few people will agree with Fan-Chia Tao that "Within a generation, the wood violin will be as obsolete as the wooden tennis racket or the wooden golf club," makers such as Curtin feel that some things in the traditional violin design can be improved. ASA members Carleen Hutchins, Gabriel Weinreich, and Norman Pickering are quoted in the article.

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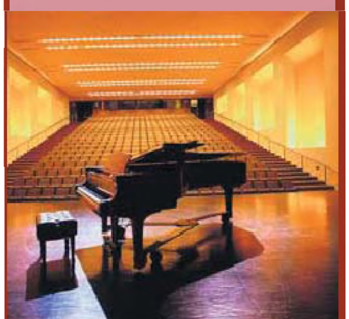

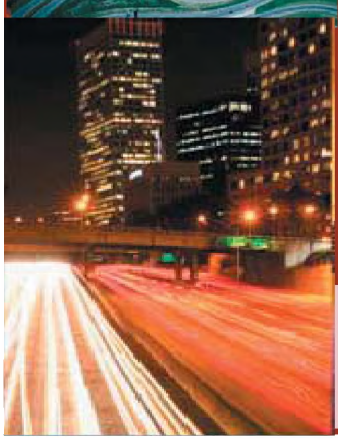

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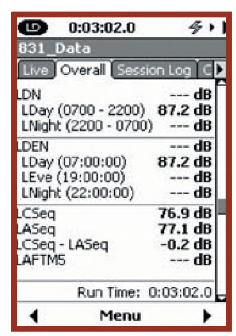

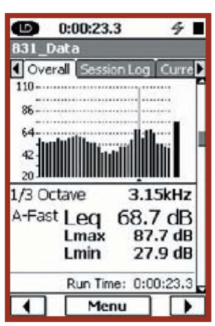

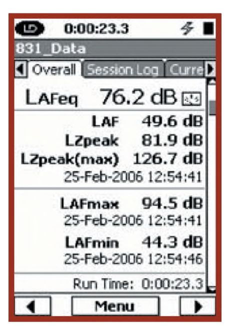

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Canadian Acoustical Association

Minutes of the Board of Directors Meeting
22 April 2006
Toronto, Ontario

Present: Stan Dosso (chair), Dalila Giusti, David Quirt, Alberto Behar, Vijay Parsa, Anita Lewis, Rich Peppin, Corjan Buma, Christian Giguère, Ramani Ramakrishnan, John Bradley, Nicole Collison

Regrets: Dave Stredulinsky, Mark Cheng

The meeting was called to order at 10:00 a.m. After a brief review of progress on action items, the minutes of Board of Directors meeting on 11 October 2005 were approved as published in Canadian Acoustics (December 2005 issue). *(moved A. Behar, seconded R. Ramakrishnan, carried).*

President's Report

Stan Dosso reported that there have been no major changes or problems in the affairs of the Association. He credits this to sustained efforts by Board members, who have kept all the major activities of the Association proceeding steadily.

Secretary's Report

David Quirt reported that the surges of new memberships associated with both the Ottawa and Vancouver meetings seem to have passed, so membership declined to 338 as of mid-April. On a more positive note, total renewals were marginally above last year, about half of the new members from Ottawa and Vancouver meetings have renewed, and the number of Sustaining Subscribers continues to rise.

Mailing list (15 April)	**Canada**	**USA**	**Other**	**Change**
Member	185	18	7	**-29**
Student	51	1	6	**-12**
Sustaining	38	3	1	**+3**
Direct	5	2	–	–
Indirect	9	8	4	–
		Total = 338		**-38**

To ease membership renewal, the Secretary and Treasurer have continued the option of payments by VISA, and 41% used this method. Changes to this process are contemplated, as discussed under the Treasurer's report, below. To strengthen CAA communication via e-mail, and to reduce errors in mailing *Canadian Acoustics*, systematic updating of membership address data including e-mail was continued in the renewal process.

With respect to CAA communications, David noted that the forms for our annual filing with Corporations Canada have just been received, and that a letter of thanks and a certificate of appreciation were received from Standards Council Canada, acknowledging our financial support for the IEC and ISO meetings in Toronto in June 2005.

Secretarial operating costs for FY2005/06 to date were $866 (slightly higher than last year), mainly for mailing costs and postal box rentals.

Issues of Noise News International were mailed as they arrived, to 50 members who requested this option, but shipment from the publisher in the USA is consistently 4-6 months late.

The report prompted an extended discussion about membership and services. A number of possible actions were debated: appointing a Membership Chair, trying new membership categories such as life membership, attracting international members or the Canadians who are active in other acoustics-related societies, a survey to identify services desired by CAA members. The executive decided to act now on two of these ideas:

- One group (Stan, Rich, David) will develop a list of Canadian members of ASA etc., so we can invite them to participate in the annual conference or other CAA activities.

- A second group (Christian, Ramani, et al) will take steps to develop a list of acoustics faculty and programs at Canadian universities and colleges.

Overall, the routine process of the Corporation is proceeding without major problems.
(R. Ramakrishnan moved acceptance of report, seconded V. Parsa, carried)

Treasurer's Report

The Treasurer, Dalila Giusti, submitted a report and a preliminary financial statement, for the fiscal year to date. It is a quite typical year financially, except that advertising revenue is delayed. Interest on our capital fund in 2005/06 will approximately cover the $5750 expense for prizes in October 2005, but would have been insufficient if all prizes were awarded. Most expenses were essentially as budgeted, and the conference in London made a significant profit. In the remainder of the fiscal year, income from advertising and interest on investments will offset planned expenses, so total assets should increase again this year.

Investment strategy for the capital fund was discussed. Interest on GIC's and government bonds (our traditional form of investment) has dropped to very low levels. It was agreed that the purpose of the capital fund is to provide income to fund our awards and that some risk of capital loss is acceptable to achieve a suitable level of revenue. The Treasurer was requested to propose a higher-yield investment such as a balanced mutual fund; if the Board approves by e-mail ballot, then immediate investment by the Treasurer of $40,000 of the capital fund in this manner is authorized.
(Moved A. Behar, second R. Peppin, carried).

Some options for fee changes were suggested, such as higher rates for Sustaining Subscribers or a surcharge for mailing the journal outside Canada, but it was noted that such changes must be approved at the Annual General Meeting. The Treasurer was requested to consult further, and present a proposed fee structure in October.

Handling payments by VISA causes operational problems for the treasurer and secretary, due to errors filling in the forms and changes in VISA accounts. The Executive have investigated options for online payment via the website, using a service provider for secure transactions. This seems promising for memberships and conference registration. The Board asked the Executive to investigate this more thoroughly, and present a detailed proposal at the next meeting.

The Treasurer proposed some specific changes in operational procedures, and consensus was established in the resulting discussion:

1. Travel subsidy rate should be changed to $0.40/km, with one claim per vehicle;
2. Set cut-off date of 1 December for receipt of student travel claims, to permit disbursement before year-end;
3. For VISA payments, require expiry dates at least one month after the date of submission (and note that limit on all payment forms).

The Board accepted the Treasurer's report, and authorized the three operational changes above.
(Moved N. Collison, second C. Buma, carried.)

Editor's Report

The Editor, Ramani Ramakrishnan, presented a brief report on issues related to content, appearance, and publication process for *Canadian Acoustics.* A special issue is planned in June 2006 featuring papers on wind turbine noise from a conference in Banff.

There was discussion of increasing the number of issues per year. Ramani feels the amount of available content would permit this, if there were one or two special issues each year. The Board agreed that 5/year would be a sensible next step, but concerns were raised about the financial side. An increase of 50% - or even 25% - seems prohibitively expensive unless costs are significantly reduced or advertising revenue is increased. The Editor was asked to cost the options and create a proposal for the Board to consider in October. The Board accepted the Editor's report.
(moved A.Behar, second V. Parsa, carried.)

CAA Website

Stan Dosso led an informal discussion of the CAA website. The Board expressed their heartfelt thanks to Dave Stredulinsky, who has agreed to continue as webmaster for the time being. There was enthusiastic support for the steadily improving features, especially the implementation of database capability to facilitate abstract and paper submission for the Halifax Conference. As noted above, the option of online payment is under consideration, and Dave has contributed strongly to researching our options and creating a prototype for that initiative.

Creation of an online archive of Canadian Acoustics was discussed. Current issues of the journal are being prepared in pdf form, and the Editor has agreed to create pdf versions for all issues in the last six years. We have a volunteer – Helen Ule – who is doing trial conversion of some older issues to assess what can readily be done. The Board decided that the archive should include all issues more than 2 years old, and be freely available online. *(Moved R. Peppin, second N.Collison, carried).*

CAA Conferences – Past, Present & Future

2005 (London): Vijay Parsa presented the final report on the London Ontario conference. Total registration was 96, and there were 70 papers, and three major special sessions: hearing aids, speech sciences, and biomedical ultrasound. Plenary speakers were Dr. Richard Seewald, and Dr. Brock Fenton. Ten exhibitors participated, and the coffee break sessions in the exhibit area seemed very successful. From a membership perspective, the conference added 4 new members and 13 student members; financially, it generated a profit of $6109. In summary, it was a very successful meeting. The Board thanked the London team.

2006 (Halifax): Nicole Collison reported on arrangements for the meeting planned in downtown Halifax on 11-13 October. Most aspects have been announced in *Canadian Acoustics,* and the CAA website has full details. Dave Stredulinsky has implemented a database for online submission of abstracts and papers as part of the website, and a broad range of special sessions are being organized. The Citadel Hotel seems to be just the right size for CAA – we will be using most of the hotel's meeting rooms.

2007 (Montreal): An organizing team is being assembled, with leadership from Dr. Rama Bhat of Concordia University, with the intent of hosting the conference in the Engineering and Visual Arts Building at Concordia.

Awards

Christian Giguère presented a report. Although this meeting preceded the submission deadline, there appear to be applications for all awards. Rules for specific prizes were considered:

- It has been suggested that the "full-time" requirement of the Shaw Prize might be waived. The Board confirmed the full-time rule for all awards *(Moved A.Behar, second R.Ramakrishnan, carried.)*
- The citizenship requirement is neither consistent among the prizes, nor clearly defined. The Board decided that mention of citizenship should be removed – a winner must be CAA member and at a Canadian institution. *(Moved R.Peppin, second R.Ramakrishnan, carried.)*
- The full name of the Bell prize is unsatisfactory in both official languages. It was agreed to change it to: "Speech Communication and Hearing" in English, "Communication orale et audition" in French. *(Moved C.Giguère, second R.Peppin, carried.)*

A master list of award winners is being created and will be added to the CAA website. The Board thanked Christian and his Coordinators.

Other Business

(InterNoise 2009 in Ottawa): Progress on organizing a bid for the InterNoise conference in Ottawa in collaboration with INCE-USA was presented to the Board. An organizing team (Trevor Nightingale as Chair, Brad Gover as Technical Chair, and a large supporting cast) prepared a proposal, which has received preliminary approval from the I-INCE Board, and will be presented for final approval at the upcoming

InterNoise Conference in Hawaii. It was suggested that the organizing team should revisit the issue of sharing risk and revenue with INCE-USA.

Potential partnership with ASA to host the ICA conference in 2013 was also discussed. ASA has suggested Montreal as the venue. There was support for sharing risk and profit, and the Board authorized the President to proceed with preliminary negotiations with ASA.

Adjournment

A. Behar moved to adjourn the meeting, seconded by R. Peppin, carried. Meeting adjourned at 3:46 p.m.

Action Items Arising from the Meeting:

S. Dosso: (1) With supporting team, develop list of Canadians working in acoustics who are not CAA members. (2) Preliminary negotiations with ASA for a joint bid to host ICA in 2013.

D. Quirt: Coordinate activity to develop pdf files of back issues of *Canadian Acoustics.*

D. Giusti: (1) Ballot by e-mail concerning proposed new investment, and (if approved) proceed with investment of $40k from Capital Fund. (2) Submit changed wording for website on operational procedures for travel subsidies and VISA payments. (3) Develop new fee structure for decision at the AGM in October.

R. Ramakrishnan: (1) Cost the options for X-issue / year budget for *Canadian Acoustics* and present for decision at next Board meeting in October. (2) Encourage a reduction of the backlog in advertising invoices and payments.

C. Giguère: (1) Proceed with website changes for prize rules, to implement decisions at this meeting. (2) With supporting team, develop list of acoustics activity at Canadian universities.

The Canadian Acoustical Association
L'Association Canadienne d'Acoustique

PRIZE ANNOUNCEMENT • ANNONCE DE PRIX

A number of prizes and subsidies are offered annually by The Canadian Acoustical Association. Applicants can obtain full eligibility conditions, deadlines, application forms, past recipients, and the names of the individual prize coordinators on the CAA Website (http://www.caa-aca.ca). • Plusieurs prix et subventions sont décernés à chaque année par l'Association Canadienne d'Acoustique. Les candidats peuvent se procurer de plus amples renseignements sur les conditions d'éligibilités, les échéances, les formulaires de demande, les récipiendaires des années passées ainsi que le nom des coordonnateurs des prix en consultant le site Internet de l'ACA (http://www.caa-aca.ca).

Deadline: Shaw, Bell, Fessenden, Eckel and Hétu Prizes: **30 April 2006**
Échéance: Prix Shaw, Bell, Fessenden, Eckel et Hétu: **30 Avril 2006**

EDGAR AND MILLICENT SHAW POSTDOCTORAL PRIZE IN ACOUSTICS • PRIX POST-DOCTORAL EDGAR AND MILLICENT SHAW EN ACOUSTIQUE

$3,000 for full-time postdoctoral research training in an established setting other than the one in which the Ph.D. was earned. The research topic must be related to some area of acoustics, psychoacoustics, speech communication or noise. • $3,000 pour une formation recherche à temps complet au niveau postdoctoral dans un établissement reconnu autre que celui où le candidat a reçu son doctorat. Le thème de recherche doit être relié à un domaine de l'acoustique, de la psycho-acoustique, de la communication verbale ou du bruit.

ALEXANDER GRAHAM BELL GRADUATE STUDENT PRIZE IN SPEECH COMMUNICATION AND BEHAVIOURAL ACOUSTICS • PRIX ÉTUDIANT ALEXANDRE GRAHAM BELL EN COMMUNICATION VERBALE ET ACOUSTIQUE COMPORTEMENTALE

$800 for a graduate student enrolled at a Canadian academic institution and conducting research in the field of speech communication or behavioural acoustics. • $800 à un(e) étudiant(e) inscrit(e) au 2e ou 3e cycle dans une institution académique canadienne et menant un projet de recherche en communication verbale ou acoustique comportementale.

FESSENDEN GRADUATE STUDENT PRIZE IN UNDERWATER ACOUSTICS • PRIX ÉTUDIANT FESSENDEN EN ACOUSTIQUE SOUS-MARINE

$500 for a graduate student enrolled at a Canadian academic institution and conducting research in underwater acoustics or in a branch of science closely connected to underwater acoustics. • $500 à un(e) étudiant(e) inscrit(e) au 2e ou 3e cycle dans une institution académique canadienne et menant un projet de recherche en acoustique sous-marine ou dans une discipline reliée à l'acoustique sous-marine.

ECKEL GRADUATE STUDENT PRIZE IN NOISE CONTROL • PRIX ÉTUDIANT ECKEL EN CONTRÔLE DU BRUIT

$500 for a graduate student enrolled at a Canadian academic institution and conducting research related to the advancement of the practice of noise control. • $500 à un(e) étudiant(e) inscrit(e) au 2e ou 3e cycle dans une institution académique canadienne et menant un projet de recherche relié à l'avancement de la pratique du contrôle du bruit.

RAYMOND HÉTU UNDERGRADUATE PRIZE IN ACOUSTICS • PRIX ÉTUDIANT RAYMOND HÉTU EN ACOUSTIQUE

One book in acoustics of a maximum value of $100 and a one-year subscription to *Canadian Acoustics* for an undergraduate student enrolled at a Canadian academic institution and having completed, during the year of application, a project in any field of acoustics or vibration. • Un livre sur l'acoustique et un abonnement d'un an à la revue *Acoustique Canadienne* à un(e) étudiant(e) inscrit(e) dans un programme de 1er cycle dans une institution académique canadienne et qui a réalisé, durant l'année de la demande, un projet dans le domaine de l'acoustique ou des vibrations.

CANADA-WIDE SCIENCE FAIR AWARD • PRIX EXPO-SCIENCES PANCANADIENNE

$400 and a one-year subscription to *Canadian Acoustics* for the best project related to acoustics at the Fair by a high-school student • $400 et un abonnement d'un an à la revue *Acoustique Canadienne* pour le meilleur projet relié à l'acoustique à l'Expo-sciences par un(e) étudiant(e) du secondaire.

DIRECTORS' AWARDS • PRIX DES DIRECTEURS

One $500 award for the best refereed research, review or tutorial paper published in *Canadian Acoustics* by a student member and one $500 award for the best paper by an individual member • $500 pour le meilleur article de recherche, de recensement des travaux ou d'exposé didactique arbitré publié dans l'*Acoustique Canadienne* par un membre étudiant et $500 pour le meilleur article par un membre individuel.

STUDENT PRESENTATION AWARDS • PRIX POUR COMMUNICATIONS ÉTUDIANTES

Three $500 awards for the best student oral presentations at the Annual Symposium of The Canadian Acoustical Association. • Trois prix de $500 pour les meilleures communications orales étudiant(e)s au Symposium Annuel de l'Association Canadienne d'Acoustique.

STUDENT TRAVEL SUBSIDIES • SUBVENTIONS POUR FRAIS DE DÉPLACEMENT POUR ÉTUDIANTS

Travel subsidies are available to assist student members who are presenting a paper during the Annual Symposium of The Canadian Acoustical Association if they live at least 150 km from the conference venue. • Des subventions pour frais de déplacement sont disponibles pour aider les membres étudiants à venir présenter leurs travaux lors du Symposium Annuel de l'Association Canadienne d'Acoustique, s'ils demeurent à au moins 150 km du lieu du congrès.

UNDERWATER ACOUSTICS AND SIGNAL PROCESSING STUDENT TRAVEL SUBSIDIES • SUBVENTIONS POUR FRAIS DE DÉPLACEMENT POUR ÉTUDIANTS EN ACOUSTIQUE SOUS-MARINE ET TRAITEMENT DU SIGNAL

One $500 or two $250 awards to assist students traveling to national or international conferences to give oral or poster presentations on underwater acoustics and/or signal processing. • Une bourse de $500 ou deux de $250 pour aider les étudiant(e)s à se rendre à un congrès national ou international pour y présenter une communication orale ou une affiche dans le domaine de l'acoustique sous-marine ou du traitement du signal.

CAA Annual Conference in Halifax
Oct 11 – 13, 2006
www.caa-aca.ca/halifax-2006.html

Third Announcement
The 2006 annual conference of the Canadian Acoustical Association will be held in Halifax, 11-13 October 2006. There will be two and a half days of parallel sessions of papers on all areas of acoustics and auditory perception, as well as an interesting array of exhibits detailing acoustical products. Mark your calendars and plan now to participate!

Special Sessions
We are planning many special sessions of contributed papers, as well as welcoming papers from all areas of acoustics. To date, the planned special sessions and organizers include those listed below. If you are interested in organizing a Special Session, please contact the Technical Chair.

Special Session	Organizer
Physical Acoustics/Ultrasound	Igor Mastikhin
Noise Control	Cameron Sherry
Speech Sciences	Scott Adams
Hearing Conservation	Alberto Behar
Architectural Acoustics	Dave Quirt
Underwater Acoustics	Sean Pecknold
Sensors, Probes, and Arrays	Brad Gover
High-frequency Acoustics/Communications	Anna Crawford
Music Cognition	Annabel Cohen
Bio-Acoustics	Marjo Laurinolli

Plenary Sessions
We are very excited to announce our two distinguished plenary speakers: Dennis Jones and Michael Kiefte.

Ethereal and reverberant, the song of the Hermit Thrush (*Catharus guttatus*) is one of the most beautiful in North America. Dennis will talk about a systematic analysis of many songs from birds in and around Halifax, Nova Scotia, that has revealed underlying complexities and subtleties that may allow individuals to be identified by sound alone.

Michael will provide an overview of recent advances in speech production and perception research at Dalhousie University from basic auditory processes in vowel perception to problems in dialectal variation in Nova Scotia.

Associated Events
The Canadian Standards Association (CSA) Committee Z 107 in Acoustics and Noise Control will hold a meeting Wednesday evening (11 Oct 2006). Contact Tim Kelsall (tkelsall@hatch.ca) for more information.

A reception and banquet will be held at the conference hotel on Thursday evening (12 Oct 2006). Tickets will be included in the registration of participants, please remember to pre-order extras for family and friends.

Venue and Accommodation
The conference will be held at the Citadel Halifax Hotel (www.citadelhalifax.com; 1-800-565-7162). Standard rooms are being offered for $145/night (+ taxes) based on single or double occupancy; additional adults will be an extra $15/night. Parking is available for an overnight charge of $9/day. Please stay at this hotel to support the CAA.

Travel
The Citadel Halifax Hotel is located in downtown Halifax, within walking distance to many restaurants and amenities. Taxis to/from the Halifax International Airport to/from Halifax are a flat fee of $53 one way and there is an Airport Bus Service that goes to/from local hotels (including Citadel Halifax) for $14 one way and $24 for a return ticket (Note: prices may vary by Oct 2006). October is a beautiful time to visit Nova Scotia, for more tourist information log onto www.novascotia.com.

Exhibits
The exhibit area is directly connected to the main session rooms and will be the central coffee break area. Please contact the Exhibit Coordinators for early information on the planned exhibit and sponsorship of various aspects of this meeting.

Student Participation
CAA strongly encourages and supports student participation in the annual conference. Student members who make presentations can apply for travel support and to win one of a number of student presentation awards. Please see the conference website for details.

Abstract and Summary Paper Submission
Wow – brand new this year, we will be offering an online abstract and summary paper submission service! All details will be posted on the conference website. Please contact the Website Manager with questions and comments. Deadlines are provided below.

Registration
Registration information will be available on the conference website. All participants must register for the conference. Early registration closes 15 Sept 2006; however, a registration desk will be open throughout the conference.

Conference Organizers		
Conference Chair	Nicole Collison	nicole.collison@drdc-rddc.gc.ca
Technical Chair	Francine Desharnais	francine.desharnais@drdc-rddc.gc.ca
Exhibit Coordinators	Joe Hood & Derek Burnett	jhood@akoostix.com & dburnett@akoostix.com
Website Manager	Dave Stredulinsky	dave.stredulinsky@drdc-rddc.gc.ca
Treasurer	Dave Chapman	dave.chapman@drdc-rddc.gc.ca
Logistics (Technical)	Jim Milne	jim.milne@drdc-rddc.gc.ca
(Registration)	Cheryl Munroe	cheryl.munroe@drdc-rddc.gc.ca

Important Dates	
Abstract submission deadline	16 June 2006
Notice of abstract acceptance deadline	30 June 2006
Paper submission deadline	4 August 2006
Student travel subsidy submission deadline	4 August 2006
Early Registration Rate deadline	15 September 2006
CAA Annual Conference, Citadel Inn, Halifax	11-13 October 2006

Semaine canadienne d'acoustique 2006

11 – 13 octobre 2006

www.caa-aca.ca/halifax-2006.html

Troisième Appel

Le congrès annuel 2006 de l'Association Canadienne d'Acoustique se tiendra à Halifax, du 11 au 13 octobre 2006. Il y aura deux jours et demi de sessions parallèles de présentations dans tous les domaines reliés à l'acoustique et la perception auditive. De plus, plusieurs d'exposants présenteront leurs produits reliés au domaine acoustique. Marquez la date et prévoyiez participer dès maintenant!

Sessions Spéciales

Nous aurons plusieurs sessions plénières au programme, et nous invitons aussi les présentations dans tous les champs acoustiques. Les sessions plénières prévues jusqu'à maintenant sont dans la liste ci-dessous. Si vous êtes intéressé à organiser une session plénière, SVP contactez l'Organisatrice Scientifique.

Session Plénière	Organisateur
Acoustique physique / Ultrasons	Igor Mastikhin
Contrôle du bruit	Cameron Sherry
Sciences de la parole	Scott Adams
Préservation de l'audition	Alberto Behar
Acoustique architecturale	Dave Quirt
Acoustique sous-marine	Sean Pecknold
Senseurs, sondes et réseaux	Brad Gover
Acoustique à haute fréquence / communications	Anna Crawford
Cognition musicale	Annabel Cohen
Acoustique biologique	Marjo Laurinolli

Sessions Plénières

Nous sommes très heureux d'annoncer les noms de nos deux conférenciers pléniers distingués: Dennis Jones et Michael Kiefte.

Le chant majestueux et résonnant de la grive solitaire (*Catharus guttatus*) est un des plus beaux en Amérique du Nord. La présentation de Dennis parlera d'une analyse systématique de plusieurs chants d'oiseaux de la région d'Halifax, en Nouvelle-Écosse. Cette analyse révèle certaines complexités et subtilités dans les chants qui pourraient permettre l'identification d'individus par le son seulement.

Michael présentera un exposé général sur les avancements récents dans les recherches faites à l'Université de Dalhousie dans le domaine de la production et perception de la parole, des processus auditoires de base pour la perception des voyelles jusqu'aux problèmes sur les variations de dialectes en Nouvelle-Écosse.

Activités Associées

Le comité Z 107 pour l'Acoustique et le Contrôle du Bruit de l'Association Canadienne de Normalisation tiendra une réunion en soirée le mercredi, 11 octobre 2006. Contactez Tim Kelsall (tkelsall@hatch.ca) pour plus d'information.

Une réception et un banquet auront lieu à l'hôtel du congrès le jeudi soir (12 octobre 2006). Les billets sont inclus dans le prix de l'inscription, mais rappelez-vous de commander des billets supplémentaires pour les personnes qui vous accompagneront.

Lieu et Hébergement
Le congrès se tiendra à l'hôtel Citadel Halifax (www.citadelhalifax.com; 1-800-565-7162). L'hôtel offre ses chambres régulières, occupation simple ou double, au prix de 145$/nuit (+ taxes); 15$/nuit additionnel par adulte supplémentaire. Le stationnement est disponible à 9$ par jour.

Directions
L'hôtel Citadel Halifax est situé en plein cœur du centre-ville. Les compagnies de taxis offrent un tarif fixe pour le trajet entre l'aéroport international d'Halifax et le centre-ville (53$ pour un aller simple). Un service de navette est aussi offert entre plusieurs hôtels du centre-ville (incluant l'hôtel Citadel Halifax) et l'aéroport (14$ aller, 24$ aller-retour). Pour information sur la Nouvelle-Écosse, visitez le www.novascotia.com.

Exposition
Le hall d'exposition sera joint aux salles de congrès et sera aussi l'endroit désigné pour la pause-café. Veuillez contacter les Responsables de l'Exposition pour plus d'information sur les exposants et commanditaires.

Participation Étudiante
L'ACA encourage et supporte la participation des étudiants au congrès annuel. Les membres étudiants qui présenteront au congrès pourront soumettre une demande de subvention pour leurs frais de déplacement et pourront se mériter l'un des prix offerts pour communications étudiantes. Pour plus de détails, visitez le site de l'ACA.

Soumission de résumés et articles
Wow – tout nouveau cette année, nous offrirons le service de soumission électronique des résumés et articles! Les détails seront sur le site internet du congrès. Si vous avez des questions ou commentaires sur le site internet, veuillez contacter l'éditeur du site.

Inscription
De l'information sur l'inscription sera disponible sur le site internet du congrès. La date limite pour se prévaloir du taux préférentiel d'inscription est le 15 septembre 2006. Un bureau d'inscription restera ouvert tout au long du congrès.

Les organisateurs		
Présidente du congrès	Nicole Collison	nicole.collison@drdc-rddc.gc.ca
Organisatrice scientifique	Francine Desharnais	francine.desharnais@drdc-rddc.gc.ca
Responsables de l'exposition	Joe Hood & Derek Burnett	jhood@ akoostix.com & dburnett@akoostix.com
Éditeur du site internet	Dave Stredulinsky	dave.stredulinsky@drdc-rddc.gc.ca
Trésorier	Dave Chapman	dave.chapman@drdc-rddc.gc.ca
Soutien logistique (Technique)	Jim Milne	jim.milne@drdc-rddc.gc.ca
(Inscriptions)	Cheryl Munroe	cheryl.munroe@drdc-rddc.gc.ca

Dates à retenir	
Date d'échéance pour la réception des résumés	16 juin 2006
Avis d'acceptation des résumés	30 juin 2006
Date d'échéance pour la réception des articles de 2 pages	4 août 2006
Échéance – demande de subvention pour frais de déplacement étudiants	4 août 2006
Date d'échéance pour le taux préférentiel	15 septembre 2006
Le congrès annuel, Citadel Inn, Halifax	11-13 octobre 2006

INSTRUCTIONS TO AUTHORS FOR THE PREPARATION OF MANUSCRIPTS

Submissions: The original manuscript and two copies should be sent to the Editor-in-Chief.

General Presentation: Papers should be submitted in camera-ready format. Paper size 8.5" x 11". If you have access to a word processor, copy as closely as possible the format of the articles in Canadian Acoustics 18(4) 1990. All text in Times-Roman 10 pt font, with single (12 pt) spacing. Main body of text in two columns separated by 0.25". One line space between paragraphs.

Margins: Top - title page: 1.25"; other pages, 0.75"; bottom, 1" minimum; sides, 0.75".

Title: Bold, 14 pt with 14 pt spacing, upper case, centered.

Authors/addresses: Names and full mailing addresses, 10 pt with single (12 pt) spacing, upper and lower case, centered. Names in bold text.

Abstracts: English and French versions. Headings, 12 pt bold, upper case, centered. Indent text 0.5" on both sides.

Headings: Headings to be in 12 pt bold, Times-Roman font. Number at the left margin and indent text 0.5". Main headings, numbered as 1, 2, 3, ... to be in upper case. Sub-headings numbered as 1.1, 1.2, 1.3, ... in upper and lower case. Sub-sub-headings not numbered, in upper and lower case, underlined.

Equations: Minimize. Place in text if short. Numbered.

Figures/Tables: Keep small. Insert in text at top or bottom of page. Name as "Figure 1, 2, ..." Caption in 9 pt with single (12 pt) spacing. Leave 0.5" between text.

Line Widths: Line widths in techincal drawings, figures and tables should be a minimum of 0.5 pt.

Photographs: Submit original glossy, black and white photograph.

Scans: Should be between 225 dpi and 300 dpi. Scan: Line art as bitmap tiffs; Black and white as grayscale tiffs and colour as CMYK tiffs;

References: Cite in text and list at end in any consistent format, 9 pt with single (12 pt) spacing.

Page numbers: In light pencil at the bottom of each page.
Reprints: Can be ordered at time of acceptance of paper.

DIRECTIVES A L'INTENTION DES AUTEURS PREPARATION DES MANUSCRITS

Soumissions: Le manuscrit original ainsi que deux copies doivent être soumis au rédacteur-en-chef.

Présentation générale: Le manuscript doit comprendre le collage. Dimensions des pages, 8.5" x 11". Si vous avez accès à un système de traitement de texte, dans la mesure du possible, suivre le format des articles dans l'Acoustique Canadienne 18(4) 1990. Tout le texte doit être en caractères Times-Roman, 10 pt et à simple (12 pt) interligne. Le texte principal doit être en deux colonnes séparées d'un espace de 0.25". Les paragraphes sont séparés d'un espace d'une ligne.

Marges: Dans le haut - page titre, 1.25"; autres pages, 0.75"; dans le bas, 1" minimum; latérales, 0.75".

Titre du manuscrit: 14 pt à 14 pt interligne, lettres majuscules, caractères gras. Centré.

Auteurs/adresses: Noms et adresses postales. Lettres majuscules et minuscules, 10 pt à simple (12 pt) interligne. Centré. Les noms doivent être en caractères gras.

Sommaire: En versions anglaise et française. Titre en 12 pt, lettres majuscules, caractères gras, centré. Paragraphe 0.5" en alinéa de la marge, des 2 cotés.

Titres des sections: Tous en caractères gras, 12 pt, Times-Roman. Premiers titres: numéroter 1, 2, 3, ..., en lettres majuscules; sous-titres: numéroter 1.1, 1.2, 1.3, ..., en lettres majuscules et minuscules; sous-sous-titres: ne pas numéroter, en lettres majuscules et minuscules et soulignés.

Equations: Les minimiser. Les insérer dans le texte si elles sont courtes. Les numéroter.

Figures/Tableaux: De petites tailles. Les insérer dans le texte dans le haut ou dans le bas de la page. Les nommer "Figure 1, 2, 3,..." Légende en 9 pt à simple (12 pt) interligne. Laisser un espace de 0.5" entre le texte.

Largeur Des Traits: La largeur des traits sur les schémas technique doivent être au minimum de 0.5 pt pour permettre une bonne reproduction.

Photographies: Soumettre la photographie originale sur papier glacé, noir et blanc.

Figures Scanées: Doivent être au minimum de 225 dpi et au maximum de 300 dpi. Les schémas doivent être scannés en bitmaps tif format. Les photos noir et blanc doivent être scannées en échelle de gris tifs et toutes les phoots couleurs doivent être scannées en CMYK tifs.

Références: Les citer dans le texte et en faire la liste à la fin du document, en format uniforme, 9 pt à simple (12 pt) interligne.

Pagination: Au crayon pâle, au bas de chaque page.
Tirés-à-part: Ils peuvent être commandés au moment de l'acceptation du manuscrit.

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

Application for Membership

CAA membership is open to all individuals who have an interest in acoustics. Annual dues total $60.00 for individual members and $20.00 for Student members. This includes a subscription to ***Canadian Acoustics***, the Association's journal, which is published 4 times/year. New membership applications received before August 31 will be applied to the current year and include that year's back issues of ***Canadian Acoustics***, if available. New membership applications received after August 31 will be applied to the next year.

Subscriptions to *Canadian Acoustics* *or* Sustaining Subscriptions

Subscriptions to ***Canadian Acoustics*** are available to companies and institutions at the institutional subscription price of $60.00. Many companies and institutions prefer to be a Sustaining Subscriber, paying $250.00 per year, in order to assist CAA financially. A list of Sustaining Subscribers is published in each issue of ***Canadian Acoustics***. Subscriptions for the current calendar year are due by January 31. New subscriptions received before August 31 will be applied to the current year and include that year's back issues of ***Canadian Acoustics***, if available.

Please note that electronic forms can be downloaded from the CAA Website at **caa-aca.ca**

Address for subscription / membership correspondence:

Name / Organization ______________________________

Address ______________________________

City/Province ____________ Postal Code ________ Country ____________

Phone ____________ Fax ____________ E-mail ____________

Address for mailing Canadian Acoustics, if different from above:

Name / Organization ______________________________

Address ______________________________

City/Province ____________ Postal Code ________ Country ____________

Areas of Interest: (Please mark 3 maximum)

1. Architectural Acoustics
2. Engineering Acoustics / Noise Control
3. Physical Acoustics / Ultrasound
4. Musical Acoustics / Electro-acoustics
5. Psychological / Physiological Acoustic
6. Shock and Vibration
7. Hearing Sciences
8. Speech Sciences
9. Underwater Acoustics
10. Signal Processing / Numerical Methods
11. Other

For student membership, please also provide:

________ ________ ________ ________

(University) *(Faculty Member)* *(Signature of Faculty Member)* *(Date)*

I have enclosed the indicated payment for:
[ ] CAA Membership $ 60.00
[ ] CAA Student Membership $ 20.00
[ ] Institutional Subscription $ 60.00
[ ] Sustaining Subscriber $ 250.00
includes subscription (4 issues /year) to ***Canadian Acoustics.***

Payment by: [ ] Cheque
[ ] Money Order
[ ] VISA credit card *(Only VISA accepted)*

For payment by VISA credit card:

Card number ______________________________

Name of cardholder ______________________________

Expiry date ______________________________

____

(Signature) (Date)

Mail application and attached payment to:

D. Quirt, Secretary, Canadian Acoustical Association, PO Box 74068, Ottawa, Ontario, K1M 2H9, Canada

l'Association Canadienne d'Acoustique
The Canadian Acoustical Association

Formulaire d'adhésion

L'adhésion à l'ACA est ouverte à tous ceux qui s'intéressent à l'acoustique. La cotisation annuelle est de 60.00$ pour les membres individuels, et de 20.00$ pour les étudiants. Tous les membres reçoivent ***l'Acoustique Canadienne***, la revue de l'association. Les nouveaux abonnements reçus avant le 31 août s'appliquent à l'année courante et incluent les anciens numéros (non-épuisés) de ***l'Acoustique Canadienne*** de cette année. Les nouveaux abonnements reçus après le 31 août s'appliquent à l'année suivante.

Abonnement pour la revue *Acoustique Canadienne* et abonnement de soutien

Les abonnements pour la revue ***Acoustique Canadienne*** sont disponibles pour les compagnies et autres établissements au coût annuel de 60.00$. Des compagnies et établissements préfèrent souvent la cotisation de membre bienfaiteur, de 250.00$ par année, pour assister financièrement l'ACA. La liste des membres bienfaiteurs est publiée dans chaque issue de la revue ***Acoustique Canadienne***. Les nouveaux abonnements reçus avant le 31 août s'appliquent à l'année courante et incluent les anciens numéros (non-épuisés) de ***l'Acoustique Canadienne*** de cette année. Les nouveaux abonnements reçus après le 31 août s'appliquent à l'année suivante.

Pour obtenir des formulaires electroniques, visitez le site Web: **caa-aca.ca**

Pour correspondence administative et financière:

Nom / Organisation ____________________

Adresse ____________________

Ville/Province ____________ Code postal ________ Pays ____________

Téléphone ____________ Téléc. ____________ Courriel ____________

Adresse postale pour la revue Acoustique Canadienne

Nom / Organisation ____________________

Adresse ____________________

Ville/Province ____________ Code postal ________ Pays ____________

Cocher vos champs d'intérêt: (maximum 3)

1. Acoustique architecturale
2. Génie acoustique / Contrôle du bruit
3. Acoustique physique / Ultrasons
4. Acoustique musicale / Electro-acoustique
5. Physio / Psycho-acoustique
6. Chocs et vibrations
7. Audition
8. Parole
9. Acoustique sous-marine
10. Traitement des signaux /Méthodes numériques
11. Autre

Prière de remplir pour les étudiants et étudiantes:

____________ ____________ ____________ ____________

(Université) (Nom d'un membre du corps professoral) (Signature du membre du corps professoral) (Date)

Cocher la case appropriée:

[ ] Membre individuel $ 60.00
[ ] Membre étudiant(e) $ 20.00
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(comprend l'abonnement à ***L'acoustique Canadienne)***

Méthode de paiement:

[ ] Chèque au nom de l'Association Canadienne d'Acoustique
[ ] Mandat postal
[ ] VISA *(Seulement VISA)*

Pour carte VISA: Carte n° ____________

Nom ____________

Date d'expiration ____________

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(Signature) (Date)

Prière d'attacher votre paiement au formulaire d'adhésion. Envoyer à :

Secrétaire exécutif, Association Canadienne d'Acoustique, Casier Postal 74068, Ottawa, K1M 2H9, Canada

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

SUSTAINING SUBSCRIBERS / ABONNES DE SOUTIEN

The Canadian Acoustical Association gratefully acknowledges the financial assistance of the Sustaining Subscribers listed below. Annual donations (of $250.00 or more) enable the journal to be distributed to all at a reasonable cost. Sustaining Subscribers receive the journal free of charge. Please address donation (made payable to the Canadian Acoustical Association) to the Secretary of the Association.

L'Association Canadienne d'Acoustique tient à témoigner sa reconnaissance à l'égard de ses Abonnés de Soutien en publiant ci-dessous leur nom et leur adresse. En amortissant les coûts de publication et de distribution, les dons annuels (de $250.00 et plus) rendent le journal accessible à tous nos membres. Les Abonnés de Soutien reçoivent le journal gratuitement. Pour devenir un Abonné de Soutien, faites parvenir vos dons (chèque ou mandat-poste fait au nom de l'Association Canadienne d'Acoustique) au secrétaire de l'Association.

ACI Acoustical Consultants Inc.
Mr. Steven Bilawchuk - (780) 414-6373
stevenb@aciacoustical.com - Edmonton, AB

Acoustik GE Inc.
M. Gilles Elhadad - (514) 487 7159
ge@acoustikge.com - Cote St Luc, QC

Dalimar Instruments Inc.
Mr. Daniel Larose - (514) 424-0033
daniel@dalimar.ca - Vaudreuil-Dorion, QC

Eckel Industries of Canada Ltd.
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eckel@eckel.ca - Morrisburg, ON

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info@hgcengineering.com - Mississauga, ON

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jcoulter@on.aibn.com - Toronto, ON

JASCO Research Ltd.
Mr. Scott Carr - (902) 491-4489
scott@jasco.com - Halifax, NS

Novel Dynamics Test Inc.
Mr. Andy Metelka - (519) 853-4495
metelka@aztec-net.com - Acton, ON

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mehmooda@silex.com - Mississauga, ON

Solutions Acoustiques Inc.
Sylvain Larivière - (514) 793-3767,
sylvainlariviere@solutionsacoustiques.com - Laval, QC

State of the Art Acoustik Inc.
Dr. C. Fortier - (613) 745-2003
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Dr. Al Lightstone - (905) 764-5223
solutions@valcoustics.com - Richmond Hill, ON

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Dejan Zivkovic, M.Sc. - (613) 839-3053-x258
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