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WIND TURBINES AND INFRASOUND

SUBMITTED TO:
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November 29, 2006

EXECUTIVE SUMMARY

HGC Engineering was retained by the Canadian Wind Energy Association to address the issue of infrasound in relation to wind farms and its potential effects on residences. Infrasound is sound that occurs at a frequency below that generally considered detectable by human hearing. There are various ways to define the magnitude of infrasound, one of which is the G-weighting network, dBG, designated by ISO specifically to deal with infrasound. G-weighted sound levels of 85 dBG and lower are not sufficient to create human perception. Infrasonic levels created by wind turbines are often similar to the ambient levels prevalent in the natural environment due to wind, typically 85 dBG or lower, and there is no evidence of adverse health effects caused by this infrasound. Infrasound near modern wind turbines is generally not perceptible to humans, either through auditory or non-auditory mechanisms. There is often an audible 'swoosh' created by wind turbines, which is essentially broadband noise whose amplitude is modulated at a low frequency, but this should not be mistakenly confused with infrasound. All in all, based on Canadian and international studies, infrasound generated by wind turbines should not be considered a concern to the health of nearby residences.

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1. INTRODUCTION

Howe Gastmeier Chapnik Limited (HGC Engineering) was retained by the Canadian Wind Energy Association to address infrasound and determine if it is an issue of concern for the wind energy industry in Canada. Sound is generated by wind turbines and is routinely addressed when placing wind farms near residential land uses. As a subset of sound – broadly defined as any air-borne pressure fluctuation that can be sensed by humans – there is infrasound. Infrasound is defined as “a wave phenomenon of the same physical nature as sound but with frequencies below the range of human hearing”. Generally, hearing via the auditory nervous system is often considered to be limited at the low end to frequencies above 20 Hz. However, although infrasound may not be “heard” based on the normal meaning of the word, under certain circumstances it can be perceived by humans; there is some degree of auditory perception below frequencies of 20 Hz and there are non-auditory mechanisms such as the vestibular balance system and the resonant excitation of body cavities by which humans can sense infrasound.

Infrasound from wind turbines has been a contentious issue on occasion. The Toronto Star published an article[1] in November 2006 indicting that a family left their house alleging a health concern from inaudible sounds produced at the Pubnico Point Wind Farm in Nova Scotia. On the other hand, an article in the June 2006 issue of the Journal of the Canadian Acoustical Association[2] presented a technical study suggesting that infrasound was not an issue.

This paper is written to address issues related to infrasound, clarifying some misconceptions and focusing discussions in a meaningful direction. This paper raises, and attempts to answer, three pertinent questions:

1. At what levels does infrasound pose an issue with respect to health or annoyance for humans?
2. Do modern wind turbines produce infrasound, and if so at what level?
3. Are there acoustic phenomena and characteristics associated with wind turbines that could be mistaken for infrasound, and do they present a hazard?

2. CRITERIA FOR INFRASOUND

Infrasound, at a certain level, is prevalent everywhere in the natural environment: people are continually subjected to sound at infrasonic frequencies. Natural sources of infrasound include wind and breaking waves, and there are a wide range of man-made sources such as industrial processes, vehicles and HVAC systems in buildings.

The magnitude of sound, as well as infrasound, is customarily measured and reported in terms of decibels (dB) relative to a reference of 20 micropascal. Another important characteristic used to describe sound is the frequency at which the pressure oscillations occur, expressed in Hertz (Hz). There are a variety of weighting networks that are used to adjust sound levels as a function of frequency depending on the purpose. The A-weighting network is commonly used to adjust sound levels to approximate the sensitivity of human hearing making it is an inappropriate descriptor for infrasound. It is far better to use un-weighted (linear) decibel levels, and compare them to un-weighted criterion levels as a function of frequency, or to use the G-weighting network defined by ISO to specifically deal with infrasound, and compare G-weighted levels to criterion expressed in dBG. Microphones and instrumentation are readily available to measure infrasound and there are International Standards[3 4] that define these procedures.

In regard to environmental noise, most jurisdictions do not present specific assessment criteria for noise at infrasonic frequencies, as acoustic problems involving infrasound are not common.

Various papers and reports dealing with low frequency noise in general, and investigations of low frequency noise produced by wind turbines specifically, have been published in recent years. Hearing thresholds, below which infrasound is generally not discerned through auditory or non-auditory perception have been documented by various researchers including Berglund and Hassmen[5], and Watanabe and Møller[6]. These papers present spectral curves, with sound levels as a function of frequency, which indicate perception limits for pure tones. These perception limits vary from about 100 dB (linear) at 5 Hz down to 80 dB (linear) at 20 Hz.

Various reports and papers also suggest acceptable G-weighted sound levels, including a report from the University of Massachusetts[7] in 2006 that suggests threshold levels on the order of 100 dBG at 10 Hz. A report prepared for the British Government[8] in 2003 suggests that sound levels below 85 to 90 dBG are not sufficient to create human perception. Allowing for the statistical variation associated with the varying sensitivity of people would seem appropriate when defining the lower, conservative, bound for the criteria. The Environmental Protection Agency in Denmark[9] has developed criteria for infrasound in general (not just for wind turbines) of 85 dBG, explicitly allowing a 10 dB factor for people more sensitive than the norm.

In terms of health, at sufficiently high levels, infrasound can be dangerous and create serious health, visual and motor control problems. However, it is grossly inaccurate to conclude that infrasound, at any level, causes health risks. Infrasound poses a concern in regard to manned space flights, and studies prepared for NASA[10] suggest no significant effects from infrasound until the level exceeds 125 dB (linear). The University of Massachusetts study noted above concluded that there is “no reliable evidence that infrasound below the hearing threshold produced physiological or psychological effect”. Utilizing the perception criteria essentially provides conservative criteria for health effects.

In summary, making the worst case assumption that someone will be annoyed if they can perceive infrasound, an infrasonic sound level criterion in the range of 85 dBG is appropriate to ensure there are no adverse impacts.

3. INFRASOUND PRODUCED BY WIND TURBINES

In assessing whether or not wind turbines are capable of producing infrasound there is the practical difficulty of trying to separate the influence of the wind turbines from the influence of the wind. The turbines operate when there is wind, and that wind by itself creates infrasound.

A study completed by HGC Engineering for the Pubnico Point Wind Farm[11] was inconclusive in separating the infrasonic sound due to the wind turbines from the interference of wind and/or wave action in the Atlantic Ocean. The linear sound levels in the frequency range from 5 to 25 Hz were typically 60 dB, whether one was close to the Vestas V80 1.8 MW turbines or far from them. The overall G-weighted levels were 79 dBG at 60 m from a turbine, 81 dBG at 330 m, and 74 dBG at 700 m. Nonetheless, the study showed that, regardless of the source of the infrasound and the distance from the wind turbines, the infrasonic levels were below perception or annoyance criteria.

A noise study[12] for the Zagórze Wind Farm in Poland, consisting of fifteen Vestas V80 turbines, produced results comparable to the measurements conducted by HGC Engineering. Sound level measurements were conducted at various locations 100 m from a turbine and the maximum overall G-weighted level was determined to be 75 dBG.

HGC Engineering had a better opportunity to separate infrasonic sound levels due to a wind turbine from the ambient levels at a site in Ontario. Overall G-weighted sound levels were measured to be 80 dBG at 60 m, 67 dBG at 300 m, and 59 dBG at a distance greater than 3 km from a GE 1.5 MW turbine.

Another infrasound study[13] relevant to this paper was conducted for the Castle River Wind Farm in Alberta. The wind farm is comprised of fifty-nine 660 kW wind turbines and one 600 kW wind turbine. The results of that measurement program suggest that, under high wind conditions, the maximum infrasound level was 91 dBG at 50 m, versus an ambient level of 83 dBG, while at 1 km the maximum level was 84 dBG versus an ambient of 82 dBG. Under low wind conditions, the maximum infrasound level was 72 dBG at 50 m, versus an ambient level of 51 dBG, while at 1 km the maximum level was 69 dBG versus an ambient level of 62 dBG. The study concluded that infrasound is present near the turbines, but is not a significant concern.

As an aside, HGC Engineering has investigated and addressed situations where infrasound was problematic; a residential area near a 30 MW low speed diesel engine in the Caribbean, and a waste glass processing plant in Germany that made extensive use of vibrating screens and shakers. In both instances the levels were tonal (at a single frequency) and much higher than the perception criteria noted above, but interestingly enough the issue was not human response. Rather, windows and light fixtures whose natural frequencies matched the excitation frequency visibly shook.

Based on the above, it is reasonable to conclude that modern wind turbines in the power range prevalent at wind farms in Canada produce infrasound. Often the levels are sufficiently masked by ambient infrasonic levels due to other sources, but not always. In terms of infrasonic sound levels, overall levels on the order of 80 to 90 dBG would typically be expected close to the wind turbines, falling off with distance from the wind turbines.

At the closest distances at which residences are typically located near large wind turbines, approximately 300 m, the infrasonic levels are low enough to not be of concern. In any event, the discussion of whether or not infrasound poses a health risk at low levels is somewhat academic since, in the absence of wind turbines, comparable infrasonic levels are present in the natural environment.

In summary, there is no evidence to suggest that infrasound from wind turbines cause issues with respect to human perception or health. This is consistent with the studies already cited in this paper along with studies published in Britain[14], Australia[15], and New Zealand[16].

4. AUDIBLE CHARACTERISTICS OF WIND TURBINES

If the infrasound near wind farms is not perceptible, the question remains whether there are audible characteristics that could be perceived, albeit mistakenly, as infrasound. The noise produced by air interacting with the turbine blades tends to be broadband noise, but is amplitude modulated at the blade pass frequency (the number of blades times the revolution rate), resulting in a characteristic 'swoosh'. The spectrograph attached as Figure 1 illustrates the 'swoosh' measured near a typical Vestas V80 wind turbine generator. The various colours represent the A-weighted magnitude of the sound as function of time, along the horizontal axis, and frequency, along the vertical axis. The spectrograph shows an amplitude modulation frequency of about 0.8 Hz, and illustrates that the sound of the wind turbine generator was most noticeable in the 250 to 1000 Hz range. Figure 2 presents a similar spectrograph measured near a GE 1.5 MW wind turbine generator.

One could mistakenly conclude that a sound level being modulated at a frequency on the order of one Hertz must be infrasound since the modulation frequency is less than 20 Hz. However, in this case the sound pressure waves that one is hearing contain a wide range of frequencies (i.e. broadband) with a maximum on the order of 1000 Hz; it is only the overall level that rises and falls at a low frequency rate. The low frequency modulation of broadband audible sound does not equal the presence of infrasound.

Other interesting phenomena can occur when more than one wind turbine is near a point of reception. The frequency of modulation can change and vary, since any two wind turbines do not have to rotate at the same frequency or in phase. The amplitude of the modulation can also vary if the sound of the wind turbines begins beating together.

The amplitude modulation does not make the sound louder, but based on psychoacoustic research[17] the perceived or subjective loudness increases in relation to the level of the amplitude modulation and this effect is most noticeable for modulation frequencies centered near 4 Hz. Thus, the audible 'swoosh' can be expected to increase one's awareness of the noise from wind turbines, and can potentially increase one's annoyance.

The audible sound levels near wind turbines are, at worse, on par with sound levels experienced by the vast segment of the Canadian population that live near transportation sources and, in fact, the audible noise from a series of individual cars passing on a roadway can also display the same amplitude modulated characteristic. There is a wide body of research indicating that audible sound at this level poses no health concerns.

5. CONCLUSIONS

Infrasound is "a wave phenomenon of the same physical nature as sound but with frequencies below the range of human hearing", although it can be perceived to a certain extent if the levels are high enough. HGC Engineering has assessed the issue of infrasound in relation to wind turbines.

In terms of human exposure to infrasound, maintaining G-weighted sound levels in the range of 85 dBG or lower are appropriate to ensure that there are no adverse impacts. Wind turbines are capable of generating infrasound but often the levels of infrasound near the wind turbine generators are similar to the ambient infrasound levels prevalent in the natural environment due to wind, waves, and industrial and transportation sources.

Studies completed near Canadian wind farms, as well as international experience, suggest that the levels of infrasound near modern wind turbines, with rated powers common in large scale wind farms are in general not perceptible to humans, either through auditory or non-auditory mechanisms. Additionally, there is no evidence of adverse health effects due to infrasound from wind turbines.

The audible sound from wind turbines has a characteristic audible 'swoosh', which is essentially higher frequency broadband noise that is amplitude modulated at a low frequency. This low rate of modulation should not be mistakenly identified as infrasound even though it may increase the subjective loudness and potential annoyance.

All in all, while infrasound can be generated by wind turbines, it is concluded that infrasound is not of concern to the health of residences located nearby.

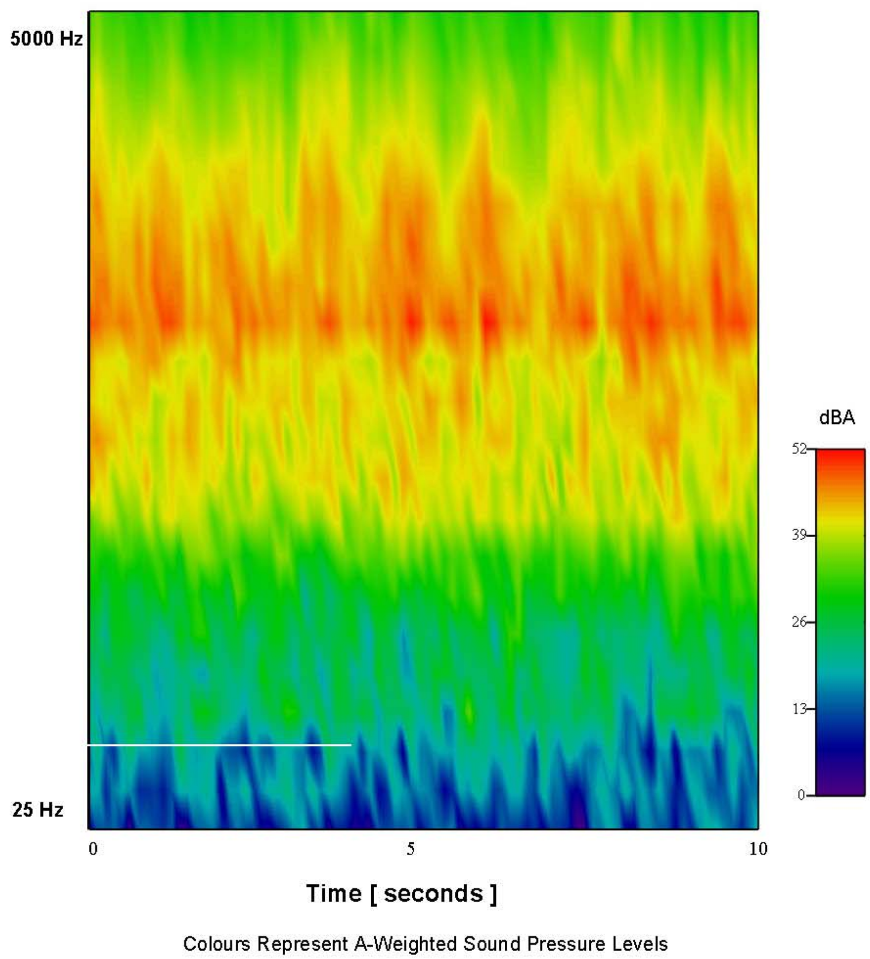

Figure 1: Spectrogram of Sound Pressure Levels Measured near a Vestas 1.8 MW Wind Turbine Generator.

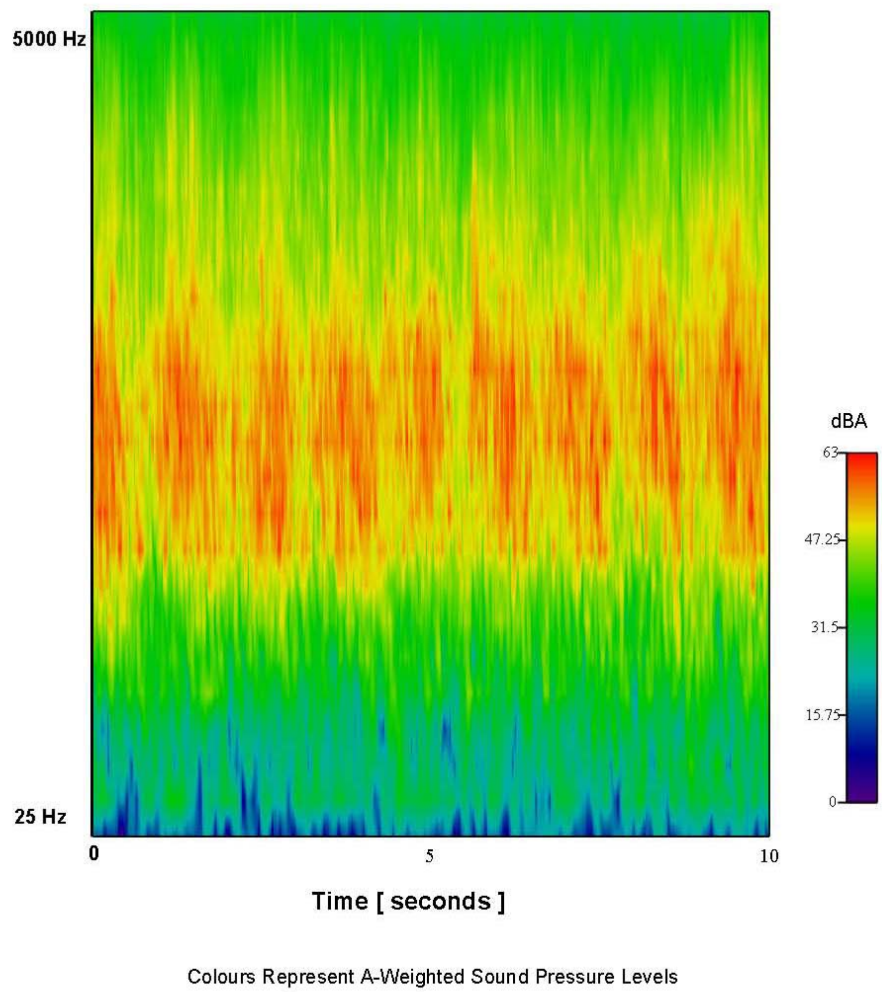

Figure 2: Spectrogram of Sound Pressure Levels Measured near a GE 1.5 MW Wind Turbine Generator.

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