Technical Note

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FINDING THE CHARACTER OF WIND TURBINE SOUND

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INTRODUCTION

Wind turbine sound has a unique nature that is variable over time and is highly dependent on wind speed and directions, as well as locale. Objective measurement of such sound is not easy yet can be achieved using suitable measurement methods. A tried and consistent methodology using sonograms is presented.

Considerable discussion has been raised over the last few years concerning the character of wind farm noise. Some standards refer to "special audible characteristics". Others standards and guidelines refer to amplitude modulation, tonality, impulsiveness and so on. Much of the debate has centered around the meaning of the various terms. A simple assessment can be made by spending a few hours actually listening to single and multiple turbines. The objective characterisation of turbines, individually and collectively, is complex. This article presents a tried and consistent methodology using sonograms.

AUDIBLE SOUND CHARACTER

The author has studied the sound fields and investigated the sound character and perception of turbines at different wind farms in different countries over different weather conditions. At each location the wind farm could be clearly heard at dwellings approximately 2000 metres from the nearest turbines. The sound of turbines can be heard upwind and downwind, as well at an angle to the turbines. The author has somewhat aged hearing and assumes that younger people with better hearing will be able to hear the turbines as well. The sound, with turbines operating, can be described as a steady rumble with a mixture of rumble – thumps. Some turbines had distinctive tonal character. Wind in the trees or vegetation did not mask the sound of the turbines.

Turbine sound character varies regularly both in "loudness" and "tonality". The general character of a long time period of an hour or so is of a steady rumble. This, however, depends considerably on wind speed and direction. The sound of turbines is also evident and sometimes more pronounced inside a dwelling, windows open. It is concluded that wind turbine sound at residences around 2000 metres or so is perceptible outside or inside a dwelling.

The question then becomes "Can the sound be analysed and assessed in a meaningful way?" This is an important question as sound character of the wind farm is clearly different within locales.

Figure 1 represents a time-slice for a survey (2009 and 2012) when the sound of the turbines was audible inside a bedroom. The observation from figure 1 is that the overall sound character shows substantial variation between the un-weighted minimum level, LZmin and the maximum levels LZmax in each third octave band. The variation is significant above 20 Hz because this is when the difference in sound levels becomes audible and potentially disturbing to sleep. The levels show the failure of A-weighted statistical levels in presenting the true sound character. Studies from Thorne (2007) and recently in 2012 indicate similar patterns for audible and inaudible sound.

These broad values tell little about the detailed character of the sound. To do this a more refined analysis method is required. The method often used to display sound character, modulation, tonality or tonal complexes is through sonograms[1]. These show the 'special audible characteristics' of sound at various frequencies over time. Amplitude and frequency modulation can be identified in the sonograms by distinctive regular patterning at 1 second (or longer or shorter) intervals. Tonality and tonal complexes can also be identified using sonograms. Generally the sonograms are not calibrated against measured sound level but present a comparison between peak and trough (maximum and minimum) levels in a short period of time. These show sound at various frequencies over time as shown in figure 2.

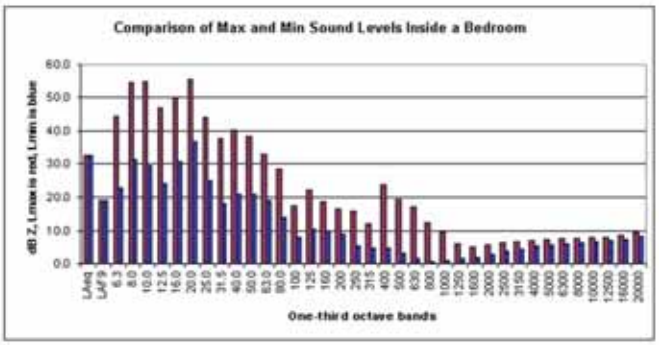

Figure 1. Indoor sound character for the initial survey (LZmax vs LZmin)

A sonogram can be thought of like a sheet of music or an old pianola roll; the left axis is frequency - musical pitch - while the bottom axis is time. The colour indicates the loudness in unweighted dB (SPL) with the colour bar at the right providing a key to the 'loudness' in decibels associated with each colour.

[1] Various methodologies are available to display sonograms or modulation. The methodology by Dr H. Bakker, Astute Engineering, is described.

The values (-30 to 20, for example) on the right-hand side of the sonogram are decibel levels. Loud notes appear yellow or while; soft notes would appear purple or black. In the following sonograms much of the colour scale has been made black so that peaks stand out better.

Generally the sonograms are not calibrated against measured sound level but present a comparison between peak and trough (maximum and minimum) levels in a short period of time. At the time of recording it is possible to include reference sound levels in order to assess the sonogram values against measured values.

To produce sonograms it is necessary to record the sounds. In figure 2 the audio file which extends to 1 Hz identifies wind and wind farm sounds. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. Higher frequency content (800-5000 Hz) evident in the third octave band chart is not evident in the sonogram. Low frequency content is evident in both the sonogram and the third octave band chart.

Two sonograms shown; one is for audible frequencies (20 Hz to 1000 Hz), while the other is for low frequencies (0.8 Hz to 20 Hz), referred to as *infrasound*. The use of sonograms can show the presence of modulation. The rumble/ thump of wind turbine modulation has been demonstrated to exist in three, geographically separate wind farms.

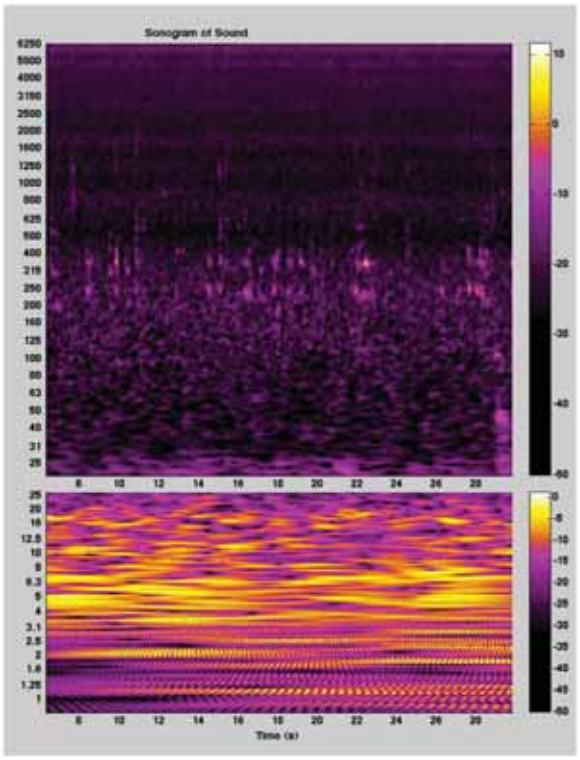

Figure 2. Wind farm sonogram inside a dwelling

SOUND PERCEPTION

If the character of the sound is foreign to the existing environment then it has less chance of being accepted. To an individual, the time of the day the sound is heard is important with unusual sounds in the early morning being less acceptable than if they are heard during the day. If a sound affects the personal space of a person while at home, inside or outside, that sound has a high degree of probability as being a disturbance. Additionally, if the sound has information content that the person does not want to hear that sound is perceived negatively. Personal perception therefore combines a variety of attributes that cannot be measured by instrumentation.

Clearly audible sound emissions from turbines will not occur all the time, of course, as turbines are often stopped and operate at different times and under different prevailing wind directions and wind speeds. The evidence, however, is that once a person has become sensitised to the activity of the turbines this sensitivity is not habituated.

The perception of audible character by individuals is 'active all the time'. This means that monitoring, measurement and assessment needs to be in real-time on a continuous '24/7' basis if identification and compliance with 'special audible characteristics' is required.

DEFINITIONS

Modulation (1)	'Amplitude modulation' is a spectral modification process that produces discrete upper and lower sidebands determined by the modulation frequency and the modulation depth m.
Modulation (2)	'Amplitude modulation depth' is a measure of the spectral energy spread of an amplitude modulated signal.
Modulation (3)	Modulation, by amplitude, is defined as a peak to trough variation that exceeds 3dB on a regular basis (3dB is taken as negligible, 6dB as unreasonable and 9dB taken as excessive); by frequency, modulation is defined as a variation that exceeds one semi-tone on a regular basis.
Special audible characteristics	Sound that has distinct features such as impulsiveness, modulation or tonality that makes the sound stand out from other sounds in the same soundscape
Tonal	Evoking pitch or tone sensation(s)
Tonality	A sound sensation having unambiguous pitch; other attributes include loudness or salience, timbre, and apparent duration *Cf. tone sensation*
Tonalness	The extent to which a sound evokes (pure or complex) pitch or audible tone sensations
Tone (1)	Sound which evokes a tone sensation; approximately or exactly periodic sound in the audible range of frequencies; sound whose various possible pitches belong mostly to a single chrom
Tone (2)	A sound sensation having pitch
Tone sensation	Auditory sensation having one, unambiguous pitch; other attributes include loudness or salience, timbre, and apparent duration

REFERENCES

[1] R. Thorne, *Assessing intrusive noise and low amplitude sound*, PhD Thesis, Massey University, New Zealand, 2007