WIND TURBINE NOISE

A Simple Statement of Facts – The Australian Experience
March 2016

Emission of Sound and Vibration

1. Wind turbine blades produce airborne pressure waves (correctly labelled sound pressure waves but often called noise). Noise is that portion of the sound which is audible. The loudness, or power, of the sound is measured in decibels (dB).

   Turbines with their long and complex blade shapes discharge a variety of sound waves with different frequencies. Frequency is a measure of the distance between successive peaks of the sound wave and is measured in a unit called Hertz (Hz).

2. The airborne pressure waves or sound from turbines presents as a mix of frequencies:
   - that with very long distances between peaks is infrasound, basically up to 20 Hz;
   - that where the frequency is between 20 plus Hz and 200 Hz is identified as low frequency sound; and
   - that above 200 Hz.

3. Sound at 100 Hz is audible at levels of around 27dB. The level of sound required for average audibility rises quite quickly (to 90dB plus) below frequencies of, say, 25 Hz. Since infrasound from turbines seldom, if ever, rises to such levels infrasound is not audible around wind projects.

4. ‘Sensation’ is relatively new term that successfully describes the body’s response to sound that cannot be heard, i.e., infrasound. Sensation is largely felt at infrasound frequencies and pressure levels around 40dB to 50db and is detected by the body and brain as pressure pulses or sensations, but via different mechanisms to the perception of audible noise. Sensations felt above, say, 45dB inside houses can cause severe impacts upon the human body.

   Specific additional pressure pulses are also created by each turbine blade passing the supporting pylon; an inherent consequence of the design of horizontal axis wind turbines. This pulsing is specific to wind turbine emissions and gives rise to the descriptor ‘pulsatile pressure waves’.

5. These pressure pulses increase with increasing blade length, as does the power generating capacity. People living near turbines have described the effect of these pulses on their homes as “like living inside a drum”. It is these pulses that, when plotted on a graph of power versus frequency in narrow (one twelfth of an octave)

bands, show the unique nature of wind turbine noise emissions known as the "wind turbine signature" quite separately from any environmental noise.

The rediscovery of the wind turbine signature, after Kelley et al identified it in the 1980s and the industry and their acoustic consultants "forgot" until Cooper re-identified it at Cape Bridgewater in 2014, means that the always varying background sound is irrelevant in setting sound limits for infrasound emanating from wind turbines (see *Noise Guidelines for Turbines* below)

6. The sound pressure waves lose power (and loudness) as they travel. This decline, known as attenuation, is said to be 6dB for a doubling of distance for audible sound and half that for infrasound. Recent measurements seem to show that infrasound attenuates much less than that as it can be distinguished up to 40km from source.

7. Larger turbines produce a greater percentage of their total sound emissions as low frequency noise and infrasound than do smaller turbines.[1] Therefore replacing a number of small turbines with a lesser number of larger turbines, whilst keeping the total power output of a wind project constant, will increase the total infrasound and low frequency noise (ILFN) emitted by a wind energy project and the distance travelled. This effect will be compounded by increased wake interference, unless the turbines have also been repositioned further apart in accordance with the spacing specifications for the larger turbines. Wake interference results in turbulent air flow into adjacent turbines, with a consequent loss of efficiency, and increased ILFN generation.

8. Turbines also transmit energy through the pylon to the foundations, generating ground-borne vibration. Little work has been done on this aspect but it is not uncommon for vibration being detected in building structures including houses at surprising distances from turbines. Some of the vibration so detected will be resonance inside the structure.

9. Recent measurements have indicated that turbines generate sound and vibration even when shut down,[2] presumably from the wind causing the flexing of large blades and the tower structure, and that these pressure waves (when turbines are shut down) can be detected at significant distances.

10. Wind turbine layouts are determined with the help of models that predict audible sound contours using data for turbines of a specific make and size. Planning permits are issued on the basis of this information. It is common for developers, before proceeding to construction, to seek to have the permit conditions varied to

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[1] http://waubrafoundation.org.au/resources/moller-pedersen-low-frequency-noise-from-large-wind-turbines/
[2] http://www.pacifichydro.com.au/english/our-communities/communities/cape-bridgewater-acoustic-study-report/?language=en

allow larger turbines.

As stated above, replacing the permitted turbines with larger turbines will significantly increase the persistence of the wake turbulence, and thereby the sound emitted by adjacent turbines whilst also increasing the proportion of ILFN emitted. This occurred at both the Waubra and Macarthur developments in Victoria and will occur when a lesser number of larger turbines are used to maintain the generating capacity of the development.

Infrasound

1. Infrasound is common; but most natural infrasound is irregular and random, or is caused by a transient event. Some frequency bands below 20 Hz have been shown experimentally to cause a physiological stress response in humans at below audible levels.[3] Industrial machinery noises are often emitted day and night and with significant energy in the ILFN spectrum as is the case with wind project sound emissions.

2. Infrasonic pulsations travel much larger distances than audible noise and easily penetrate normal building materials, and once inside can resonate building elements (i.e., increase in impact), inside rooms.[4]

3. Infrasonic pulsations from a single 4 MW wind turbine were measured 10km from their source by NASA researcher William Willshire in 1985.[5] Recent data collected by acoustician Les Huson in Australia and the United Kingdom at onshore and offshore wind developments, has shown that attenuation of infrasound can be much less than the 3dB per doubling of distance quoted by Willshire in 1985.[6]

4. Some acoustic pressure pulsations are relatively harmless and indeed even pleasant to the body, including waves on a beach. Organ music at frequencies just below 20 Hz generates ‘feelings" in people that can be either pleasant or unpleasant, and have been designed to produce emotive effects.[7] Once it is understood that different frequencies can have very different effects on humans it is easy to understand the importance of accurate acoustic prediction and post start-up measurement across the full frequency spectrum.

5. Dr Neil Kelley and his colleagues from NASA demonstrated in the 1980’s that wind turbine generated energy pulses and noise in the infrasonic and low frequency bands, which then penetrated and resonated inside the residents’ living structures,

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[3] http://waubrafoundation.org.au/resources/numerical-simulation-infrasound-perception-with-reference-reported-laboratory-effects/

[4] http://waubrafoundation.org.au/resources/kelley-et-al-methodology-for-assessment-wind-turbine-noise-generation-1982/

[5] http://waubrafoundation.org.au/resources/nasa-long-range-down-wind-propagation-low-frequency-sound/

[6] http://waubrafoundation.org.au/resources/huson-wl-navitus-bay-wind-park-submission/

[7] http://www.hearingaidblog.com/2013/01/infrasonic-experiments/

directly caused the range of symptoms described as "annoyance" by acousticians and some researchers.[8] Annoyance is a non-quantitative word that implies mildness. A more accurate general descriptor would be mild, serious or intolerable "impacts".

6. Residents and their treating medical practitioners know these symptoms and sensations include repetitive sleep disturbance, feelings of intense anxiety, nausea, vertigo, headaches, and other distressing symptoms including body vibration. American Paediatrician, Dr Nina Pierpont, gave this constellation of symptoms the name "***wind turbine syndrome***" in 2009.[9]

Wake Interference and Turbulence

1. Historically it was accepted that wind turbines should be no less than 5 - 8 rotor diameters apart, depending on the direction and consistency of the prevailing wind with the higher separation being for turbines in line with the major wind direction. This was "accepted" industry practice, and as an example, was explicitly specified in the 2002 NSW SEDA handbook.[10] The purpose of this specification is to minimise turbulent air entering the blades of an adjacent turbine. As noted above, turbulent air is associated with increased sound levels and infrasonic pulsations.[11]

2. If a significant proportion of the wind blows at right angles (90^{o}) from the major direction used for turbine layout it follows that turbine spacing should be 7 or 8 rotor diameters in both directions. It should be noted that the 7 to 8 rotor diameter number is a compromise between ensuring smooth air inflow to all turbines (and hence less noise and vibration), and packing as many turbines as possible into the project area. Research conducted at Johns Hopkins University in 2012 showed that the best design for efficient energy extraction suggests wind turbines should be 15 rotor diameters apart.[12]

3. It is increasingly evident that some projects are not laid out in accordance with accepted specifications to reduce turbulence, which in turn significantly increases acoustic emissions including audible noise and infrasonic pressure pulses. The consequences of increased turbulent air entering upwind-bladed wind turbines (blades in front of pylon) resulting in increased generation of impulsive infrasonic pressure waves and low frequency noise were known to the industry in 1989.[13]

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[8] http://waubrafoundation.org.au/resources/kelley-et-al-methodology-for-assessment-wind-turbine-noise-generation-1982/
[9] http://waubrafoundation.org.au/resources/dr-nina-pierpont-submission-australian-senate-inquiry/
[10] http://waubrafoundation.org.au/resources/nsw-wind-energy-handbook-2002/
[11] http://waubrafoundation.org.au/resources/shepherd-k-hubbard-h-noise-radiation-characteristics-westinghouse-wwg-0600-wind-turbine-generator/
[12] http://www.windturbinesyndrome.com/2011/wind-farm-operators-are-going-to-have-to-space-turbines-farther-apart-johns-hopkins-univ-researcher/
[13] http://waubrafoundation.org.au/resources/shepherd-k-hubbard-h-noise-radiation-characteristics-westinghouse-wwg-0600-wind-turbine-generator/

Recent projects with turbines positioned inappropriately too close together should not have been given final approval by the responsible authorities.

4. Yawing (side to side movement of the blades caused by minor wind direction changes) is also known to increase wake interference.

Transmission of Energy Pulses

1. Information on the different attenuative and penetrative properties of infrasound and audible sound are discussed above.

2. Topography, wind speed, wind direction, wind shear, and ambient temperature will also have an impact on sound emissions and how that sound travels.

Noise Guidelines for Turbines

1. Many acoustic consultants have known that wind turbines produce pulsatile ILFN as the blades pass the tower. It was common knowledge, in the 1980's, from research conducted by Dr Neil Kelley [14] and NASA researchers such as Harvey Hubbard[15] that the pulsatile infrasound generated by a single downwind bladed wind turbine, and other sources of ILFN such as military aircraft and gas fired turbines, penetrated buildings, amplified and resonated inside the building structures, and directly caused "annoyance" symptoms including repetitive sleep disturbance.[16]

2. Long term sleep disturbance and chronic stress symptoms (somewhat disingenuously described as "annoyance"), are well known to medical practitioners and clinical researchers to damage human health. Dr Kelley was quoted in 2013 as advising that the conclusions from his research in the 1980's were equally relevant to modern (upwind) turbine designs,[17] and this has been confirmed in the results of acoustic measurements on modern turbines commissioned by Pacific Hydro and conducted by acoustician Steven Cooper at the Cape Bridgewater (Victoria) development.[18]

3. The NZ and Australian Noise Standards for wind projects were written by the then, and apparently still, uninformed planning authorities. They were based on the UK ETSU 97, itself an uninformed document.[19, 20] There is little doubt that those

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[14] http://waubrafoundation.org.au/resources/kelley-et-al-methodology-for-assessment-wind-turbine-noise-generation-1982/
[15] http://waubrafoundation.org.au/resources/hubbard-h-1982-noise-induced-house-vibrations-human-perception/
[16] http://waubrafoundation.org.au/2013/explicit-warning-notice/
[17] http://waubrafoundation.org.au/resources/lloydg-newer-wind-turbines-could-be-just-as-harmful-as-prototypes/
[18] http://www.pacifichydro.com.au/english/our-communities/communities/cape-bridgewater-acoustic-study-report/?language=en
[19] http://waubrafoundation.org.au/resources/cox-unwin-sherwin-where-etsu-silent-wind-turbine-noise/
[20] http://waubrafoundation.org.au/resources/turnbull-c-turner-j-recent-developments-wind-farm-noise-australia/

drafting the guidelines were given too much help by the industry.

4. Despite information being available from the Kelley research in 1985 specifying recommended exposure levels of ILFN which should not be exceeded,[21] (approximately the same as those mentioned herein), the respective **Australian guidelines only specified limits for audible sound levels expressed as dBA outside homes; so there are no recommended limits or requirements to forecast, or to measure, ILFN levels or vibration inside homes neighbouring wind projects.**

5. Permitted sound levels across most Australian States for all industrial equipment are background noise levels plus 5dBA or 35dBA whichever is the **minimum**, whereas for wind turbines they are background plus 5dBA or 40dBA whichever is the **maximum.** There is no scientific evidence or reason for this difference. An increase of 5dBA represents an approximate doubling of the sound level. Most rural environments have a background noise level of 18dB to 25dB, approximately averaging 22dB at night. **Thus a permitted level of 40dbA represents a huge increase in audible sound.** Increases of 10 dB above background at night are long known by acoustic consultants to raise complaints, and increases of 15dB to 20 dB are associated with widespread complaints and legal action. Averaging measured levels of sound across too wide frequency bands also allows the hiding of sound pressure peaks to which the ear responds, understating the true extent of wind facility noise emission levels.

6. WHO (World Health Organisation) Night Noise Guidelines for Europe quoted the 1999 WHO Community Noise Guidelines "***If negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dBA indoors for continuous noise***".[22] Cities have a higher background noise than country areas. Denmark limits indoor noise from industrial sources, including wind turbines, to a maximum of 20 dBA at night [23]

   Thus, 25dbA inside houses could be an appropriate standard for **audible** noise without the complication of background sound.

The currently permitted outdoor noise level in NZ and some Australian states has been ameliorated somewhat by the addition of a deduction of 5dBA from the 40dBA limit to allow for especially quiet environments.

7. History has shown that these Australian guidelines were based on ETSU 97 from the UK, and were expressly designed to encourage development of the wind

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[21] http://waubrafoundation.org.au/resources/kelley-et-al-1985-acoustic-noise-associated-with-mod-1-wind-turbine/
[22] http://waubrafoundation.org.au/resources/who-night-noise-guidelines-for-europe/ see p 110 for background to 30dBA inside bedrooms – sourced from the 1999 WHO Community Noise document which can be accessed at http://waubrafoundation.org.au/resources/who-guidelines-for-community-noise-2/
[23] http://waubrafoundation.org.au/resources/sa-epa-resonate-infrasound-levels-near-windfarms-other-environments/ see page 9 for the Danish LFN criteria indoors overnight

industry, **not to protect the health of rural residents from wind turbine noise**. Predictably, because the Kelley criteria limiting exposure to impulsive ILFN were ignored,[24] these guidelines have turned out to be completely unsafe.

8. It is now suggested that a maximum noise level for ILFN inside homes of 45 dB is also appropriate.

9. **It is therefore necessary to predict and measure sound pressure levels across the full spectrum of frequencies in order to predict and control sound energy impacts on project neighbours**.

Compliance with Permitted Noise Conditions

There are several problems associated with validating compliance.

1. Compliance is generally carried out by an acoustician or acoustics consultancy, paid directly by the owner or operator of the project. It is not unusual for the developer to employ the same acoustician to predict the noise levels and to "verify" compliance.

2. Compliance is of importance to all parties with a financial interest in the development (so they may collect their subsidies), but it is absolutely critical to families that neighbour the projects.

3. There are many ways that data measurements can be rigged (faux compliance): measuring instruments placed under trees or too close to buildings; waiting for optimum weather and wind conditions; not measuring for long enough continuously; recording in octave bands that are too broad and other averaging techniques. Operators may also reduce sound emissions by reducing power output (with blade angle changes and slowed rotation) to reduce the sound during the monitoring period. Operators may also refuse to provide wind turbine facility operating data from test periods, claiming that it is 'commercial in confidence', thus making it impossible to verify actual operating conditions. A major acoustic firm and its wind industry specialist have been identified in the Senate for actions that are alleged to interfere with full and proper compliance.[25]

4. **It would therefore be both appropriate and necessary for all projects to have their compliance independently audited**.

5. **However sufferers will not escape disturbance to their sleep and damage to their health, even if a project is properly compliant with its permit conditions and sound guidelines, as findings of the acoustic survey commissioned by Pacific**

[24] http://waubrafoundation.org.au/2013/explicit-warning-notice/ see footnote number 10
[25] http://waubrafoundation.org.au/resources/madigan-sen-john-corruption-fraud-power-generation-industry/

Hydro, conducted by Steven Cooper, have recently demonstrated. [26]

6. A compliant project may still cause damage to neighbours for numerous reasons. First, **the standard only refers to dBA** and thereby omits reference to ILFN; and secondly, even with regard to audible noise, the standard **refers to a maximum of 40 dBA outdoors, whereas every other form of industrial or other noise in country and city is limited to 35 dBA maximum**. There is no technical basis for such an aberration, and it is clearly, (intended or not), discriminatory. Thirdly, **in quiet rural environments, even 35 dBA will be intrusive and loud, if the background level is below 25dBA, which is not uncommon**. The ear responds to the peaks of sound levels, not the averages. The wind turbine noise standards all refer only to averages, and exclude ILFN, and do not account for the human response, so cannot protect people from predictable serious harm to their health.

This document has been prepared in good faith from information available at the time of writing. The author does not warrant that the information is complete or that the conclusions are necessarily correct. What the author does represent however is that the science he has had access to has been interpreted and summarised with care, and without bias, to the best of his ability.

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[26] http://www.pacifichydro.com.au/english/our-communities/communities/cape-bridgewater-acoustic-study-report/?language=en