Washington State Noise Standards and Wind Turbine Noise Analysis

TO: To Whom It May Concern

FROM: Mark Bastasch, P.E./CH2M HILL

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The purpose of this memorandum is to provide some background on how the State of Washington noise standards (WAC 173-60) have been applied to other projects and provide some information on the type of analysis that would be expected to demonstrate compliance with the WAC 173-60.

Regulatory Framework

WAC 173-60 provides the noise standards for Washington State, adopted by the Washington Department of Ecology. WAC 173-60 establishes maximum permissible environmental noise levels. These levels are based on the environmental designation for noise abatement (EDNA), which is defined as "an area or zone (environment) within which maximum permissible noise levels are established." There are three EDNA designations (WAC 173-60-030), which roughly correspond to residential, commercial/recreational, and industrial/agricultural uses:

- Class A: Lands where the principal use is people reside and sleep (such as residential)
- Class B: Lands requiring protection against noise interference with speech (such as commercial/recreational)
- Class C: Lands where the principal activities are of such a nature that higher noise levels are anticipated (such as industrial/agricultural)

Table 1 summarizes the maximum permissible levels applicable to noise received at residential lands (Class A EDNA) and at industrial/agricultural areas (Class C EDNA) from an industrial facility (Class C EDNA).

Table 1
State of Washington Noise Regulations (WAC 173-60-040)

Statistical Descriptor	Maximum Permissible Noise Levels (dBA) from a Class C EDNA Source		
	Class A EDNA Receiver		Class C EDNA Receiver
	Daytime (7 a.m. – 10 p.m.)	Nighttime (10 p.m. – 7 a.m.)	Any Time
L_{eq} (hourly average)	60	50	70
L_{25} (15 minutes per hour)	65	55	75

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	Class A EDNA Receiver		Class C EDNA Receiver
	Daytime (7 a.m. – 10 p.m.)	Nighttime (10 p.m. – 7 a.m.)	Any Time
$L_{16.7}$ (5 minutes per hour)	70	60	80
$L_{2.5}$ (1.5 minutes per hour)	75	65	85

While the WAC does not specifically address residences (a Class A use) located on agricultural lands (a Class C area), for agricultural parcels it is not unreasonable to assess the residential structure as a Class A receiver and the property line as a Class C receiver. This yields a 50 dBA limit at the residential structure and 70 dBA limit at the property line.

This interpretation has been accepted by the Washington State Energy Facility Site Evaluation Council (EFSEC) in several cases including Wild Horse Wind Project and the Kittitas Valley Wind Project. The Governors and EFSEC's approval of the Kittitas Valley Wind Power Project was upheld by the Washington State Supreme Court. This approach is also commonly taken by local jurisdictions when issuing conditional use or similar development permits authorizing wind power projects. Other interpretations are feasible and include that homes located on agricultural lands are not afforded the residential limits and the Class C EDNA limit is the only applicable criteria.

Operational Noise

The procedures for determining sound power levels from wind turbines are defined in International Electrotechnical Commission 61400 *Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques – Amendment 1* (IEC, 2006). This measurement technique outlines procedures to determine corrections for background noise, apparent sound power level, and wind speed dependence. The anticipated range in maximum sound power levels for an individual turbine varies but is typically between 104 to 110 dBA.

It is critical to understand the difference between a sound pressure level (or noise level) and a sound power level. A sound power level (commonly abbreviated as PWL or Lw) is analogous to the wattage of a light bulb; it is a measure of the acoustical energy emitted by the source and is, therefore, independent of distance. By way of example, a 60-watt light bulb emits 60 watts of power. It makes no difference to the wattage (power) where a person is viewing it from: the power is always 60 watts. A sound pressure level (commonly abbreviated as SPL or Lp) is analogous to the brightness or intensity of light experienced at a specific distance from a source. Again, by way of example, a 60-watt light bulb may have less brightness when view from a further distance away. Its power (60 watts) remains the same, but its intensity generally diminishes the further away one gets from it. Sound pressure is similarly attenuated by distance. Sound pressure is measured directly with a sound-level meter. Sound pressure levels always should be specified with a location or distance from the noise source.

Sound power level data are used in acoustic models to predict sound pressure levels. This is because sound power levels take into account the size of the acoustical source and account for the total acoustical energy emitted by the source. For example, the sound pressure level 15 feet from a small radio and a large orchestra may be the same, but the sound power level of the orchestra will be much larger because it emits sound over a much larger area. Similarly, a two-horsepower (hp) and 2,000-hp pumps can both achieve 85 dBA at three feet (a common specification), but the 2,000-hp pump will have a significantly larger sound power level, so the noise from the 2,000-hp pump will travel farther. A sound power level can be determined from a sound pressure level if the distance from and dimensions of the source are known. Sound power levels will always be greater than sound pressure levels, and sound power levels should never be compared to sound pressure levels. As noted above the sound power level of a wind turbine typically will vary between 104 and 110 dBA. This will result in a sound pressure level of about 65 dBA at 130 feet (similar in level to a normal conversation).

To ensure compliance under the maximum noise generating conditions at wind energy facilities, the turbine's maximum sound power levels is used as the basis for evaluating compliance with the WAC 173-60. When wind speeds are less, the sound level emitted from the project would be less. The model calculates the sound pressure level that would occur at each receptor from each turbine or substation after losses from distance, air absorption, blockages, etc., is considered. The sum of *all* these individual levels is the total project level at the modeling point. The modeling algorithms are typically based on the International Organization for Standardization 9613-2 *Acoustics – Sound Attenuation During Propagation Outdoors* (ISO, 1993). The model results are used to evaluate compliance with the applicable limits, (50 dBA at residential structure/70 dBA at the property line) and if exceedences are noted, set backs or layout are adjusted accordingly.

In some instances the final wind project layout will not be available until detailed engineering studies (e.g., geotechnical analysis) and turbine selection is completed. These tasks are typically accomplished as part of the final design efforts. It is, however, clearly feasible for a project to comply with the 70 dBA property line and 50 dBA residential limit at all receptors by adjusting turbine spacing. It is generally anticipated that 50 dBA would be achieved at a distance of approximately 1,500 feet from a string of turbines and that 70 dBA would be achieved within 50 feet of a turbine.

There has been some confusion regarding the presence of significant levels of low frequency noise from wind turbines. High levels of low frequency noise can be associated with simple cycle combustion turbines or natural gas compressor stations. However, the levels of low frequency noise emitted from wind turbines are significantly less than such other sources. The swishing noise associated with the rotation of turbine blades is often mistaken for low frequency noise. The frequency content of the swish is typically noted to be within the 500 to 1000 Hz range which is entirely within the audible range and appropriately characterized by the A-weighting, which is the standard because it characterizes the frequency sensitivity of the human ear. . [1]

[1] While several states do have regulations that specifically regulate low frequency noise (either in terms of specific frequency bands or using the overall dBC rating), the levels stated typically indicate that exceedences of 65 dBC *may* indicate there is a potential low frequency concern. Establishment of such levels is not an indicator that there *are* demonstrated effects. For example - Division 404, Regulation 1, Section 802 of the Colorado Code of Regulations (CCR) establishes allowable noise levels for oil and gas facilities. These limits are similar to those in WAC 173-60, including 50 dBA nighttime at residential uses. However, given that oil and gas facilities may generate significant levels of low frequency noise, 802 (d) states that " In situations where the complaint or Commission onsite inspection indicates that low frequency noise is a component of the

For wind turbines, it should be noted that the measurement of low frequency noise is complicated by the presence of wind and the resulting wind-induced noise (self-noise) through microphone windscreens. Recent wind tunnel testing of various windscreens[2,3] concludes that: "any casual measurement of sound using a standard windscreen in a windy field will yield ostensibly high levels of low frequency or infrasonic noise—whether a wind turbine is present or not. Such measurements, taken at face value, may be one of the reasons wind turbines are widely, but mistakenly, believed to be significant sources of low frequency noise." It is further documented that even when using more effective windscreens, the dBC levels from an operating turbine at 1,000 feet away and 3 miles away vary by only 1 dB (74 dBC at 1,000 feet and 73 dBC at 3 miles). This is a clear indication that the low frequency noise is the result of self-generated wind noise through the windscreen rather than the actual acoustic emissions of the wind turbine. In this instance, it is estimated that the actual acoustic emissions from the wind turbine at 1,000 feet result in a level of 48 dBC.

problem, the Commission shall obtain a sound level measurement twenty-five (25) feet from the exterior wall of the residence or occupied structure nearest to the noise source, using a noise meter calibrated to the dB(C) scale. If this reading exceeds 65 dB(C), the Commission shall require the operator to obtain a low frequency noise impact analysis by a qualified sound expert, including identification of any reasonable control measures available to mitigate such low frequency noise impact. Such study shall be provided to the Commission for consideration and possible action."

2 Hessler, G. F., Hessler, D. M., Brandstätt, P., Bay, K. 2008 "Experimental Study to Determine Wind-Induced Noise and Windscreen Attenuation Effects on Microphone Response for Environmental Wind Turbine and Other Applications," *Noise Control Engineering Journal*, J.56, July-August.

3 Hessler, D.M. 2009. "Wind Tunnel Testing of Microphone Windscreen Performance Applied to Field Measurements of Wind Turbines", *Proceedings of the Third International Meeting on Wind Turbine Noise, Aalborg Denmark*. 17-19 June.

ATTACHMENT 1
Fundamentals of Acoustics

Fundamentals of Acoustics

It is useful to understand how noise is defined and measured. Noise is defined as unwanted sound. Airborne sound is a rapid fluctuation of air pressure above and below atmospheric pressure. There are several ways to measure noise, depending on the source of the noise, the receiver, and the reason for the noise measurement. Table 1 summarizes the technical noise terms used in this memorandum.

TABLE 1
Definitions of Acoustical Terms

Term	Definitions
Ambient noise level	The composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location.
Decibel (dB)	A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the measured pressure to the reference pressure, which is 20 micropascals.
A-weighted sound pressure level (dBA)	The sound pressure level in decibels as measured on a sound level meter using the A-weighted filter network. The A-weighted filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise. All sound levels in this report are A-weighted.
Equivalent Sound Level (L_{eq})	The L_{eq} integrates fluctuating sound levels over a period of time to express them as a steady-state sound level. As an example, if two sounds are measured and one sound has twice the energy but lasts half as long, the two sounds would be characterized as having the same equivalent sound level. Equivalent Sound Level is considered to be related directly to the effects of sound on people since it expresses the equivalent magnitude of the sound as a function of frequency of occurrence and time.
Day–Night Level (L_{dn} or DNL)	The Day-Night level (L_{dn} or DNL) is a 24-hour average L_{eq} where 10 dBA is added to nighttime levels between 10 p.m. and 7 a.m. For a continuous source that emits the same noise level over a 24-hour period, the L_{dn} will be 6.4 dB greater than the L_{eq}.
Statistical noise level (L_n)	The noise level exceeded during n percent of the measurement period, where n is a number between 0 and 100 (for example, L_{50} is the level exceeded 50 percent of the time)

Table 2 shows the relative A-weighted noise levels of common sounds measured in the environment and in industry for various sound levels.

TABLE 2
Typical Sound Levels Measured in the Environment and Industry

Noise Source At a Given Distance	A-Weighted Sound Level in Decibels	Qualitative Description
Carrier Deck Jet Operation	140	
	130	Pain threshold
Jet takeoff (200 feet)	120	
Auto Horn (3 feet)	110	Maximum Vocal Effort
Jet takeoff (2000 feet) Shout (0.5 feet)	100	

TABLE 2
Typical Sound Levels Measured in the Environment and Industry

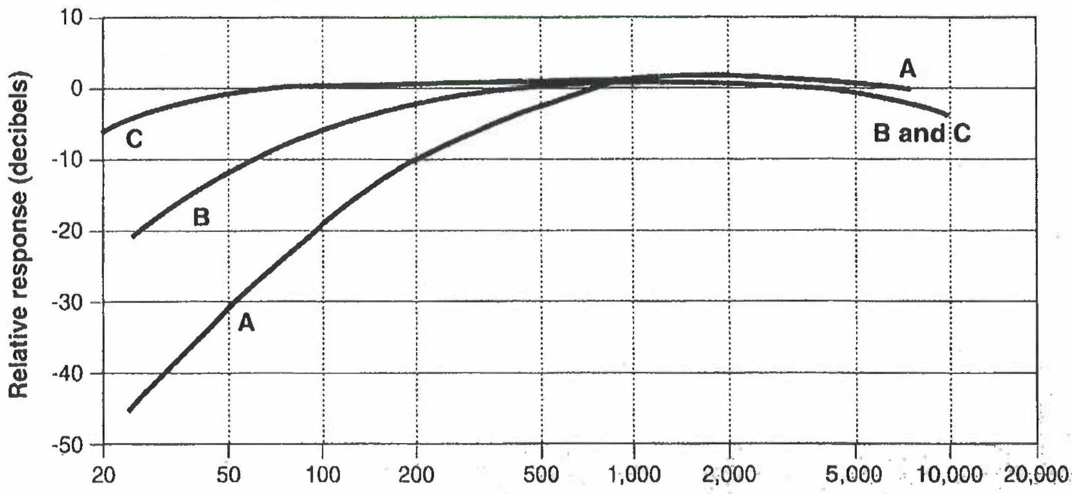
Noise Source At a Given Distance	A-Weighted Sound Level in Decibels	Qualitative Description
N.Y. Subway Station Heavy Truck (50 feet)	90	Very Annoying Hearing Damage (8-hr, continuous exposure)
Pneumatic drill (50 feet)	80	Annoying
Freight Train (50 feet) Freeway Traffic (50 feet)		
	70	Intrusive Telephone Use Difficult
Air Conditioning Unit (20 feet)	60	
Light auto traffic (50 feet)	50	Quiet
Living Room Bedroom	40	
Library Soft whisper (5 feet)	30	Very Quiet
Broadcasting Studio	20	Recording studio
	10	Just Audible

Adapted from Table E, "Assessing and Mitigating Noise Impacts", NY DEC, February 2001.

The most common metric is the overall A-weighted sound level measurement that has been adopted by regulatory bodies worldwide. The A-weighting network measures sound in a similar fashion to how a person perceives or hears sound, thus achieving a good correlation in terms of how to evaluate acceptable and unacceptable sound levels.

Figure 1

NOISE METRICS—FREQUENCY RESPONSE

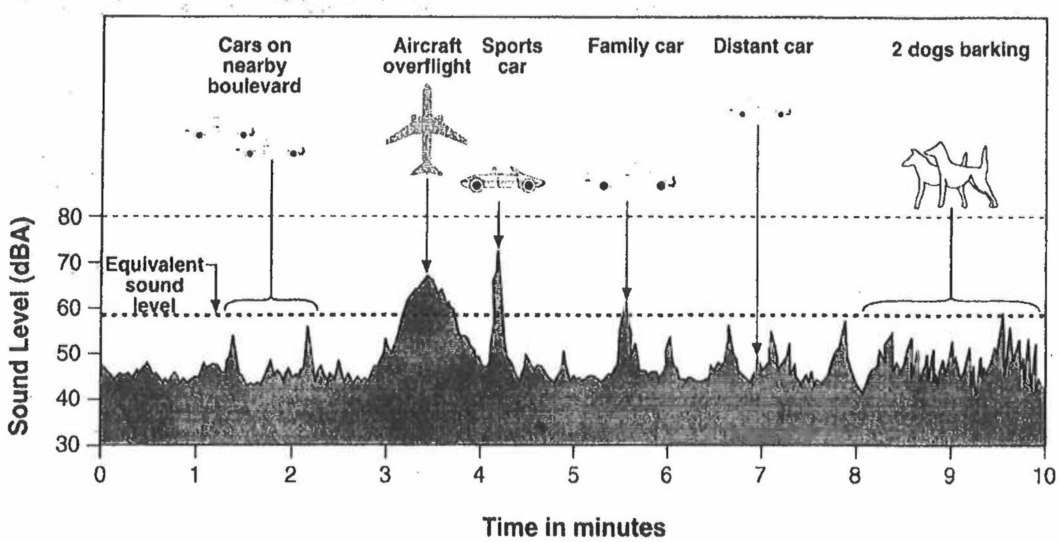


Source: A. Peterson and E. Gross, *Handbook of Noise Control*, West Concord: General Radio Company, 1967.

The measurement of sound is not a simple task. Consider typical sounds in a suburban neighborhood on a normal or "quiet" afternoon. If a short time in history of those sounds is plotted on a graph, it would look very much like Figure 2. In Figure 2, the background, or residential sound level in the absence of any identifiable noise sources, is approximately 45 dB. During roughly three-quarters of the time, the sound level is 50 dB or less. The highest sound level, caused by a nearby sports car, is approximately 70 dB, while an aircraft generates a maximum sound level of about 68 dB. The following provides a discussion of how variable community noise is measured.

Figure 2

NOISE METRICS—COMPARATIVE NOISE LEVELS



Source: *Protective Noise Levels, Condensed Version of EPA Levels Document*, United States Environmental Protection Agency, November 1978.

One obvious way of describing noise is to measure the maximum sound level (L_{max}) – in the case of Figure 2, the nearby sports car at 70 dBA. The maximum sound level measurement does not account for the duration of the sound. Studies have shown that human response to noise involves both the maximum level and its duration. For example, the aircraft in this case is not as loud as the sports car, but the aircraft sound lasts longer. For most people, the aircraft overflight would be more annoying than the sports car event. Thus, the maximum sound level alone is not sufficient to predict reaction to environmental noise.

A-weighted sound levels typically are measured or presented as equivalent sound pressure level (L_{eq}), which is defined as the average noise level, on an equal energy basis for a stated period of time, and is commonly used to measure steady-state sound or noise that is usually dominant. Statistical methods are used to capture the dynamics of a changing acoustical environment. Statistical measurements are typically denoted by L_{xx}, where xx represents the percentile of time the sound level is exceeded. The L_{90} is a measurement that represents the noise level that is exceeded during 90 percent of the measurement period. Similarly, the L_{10} represents the noise level exceeded for 10 percent of the measurement period.

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.

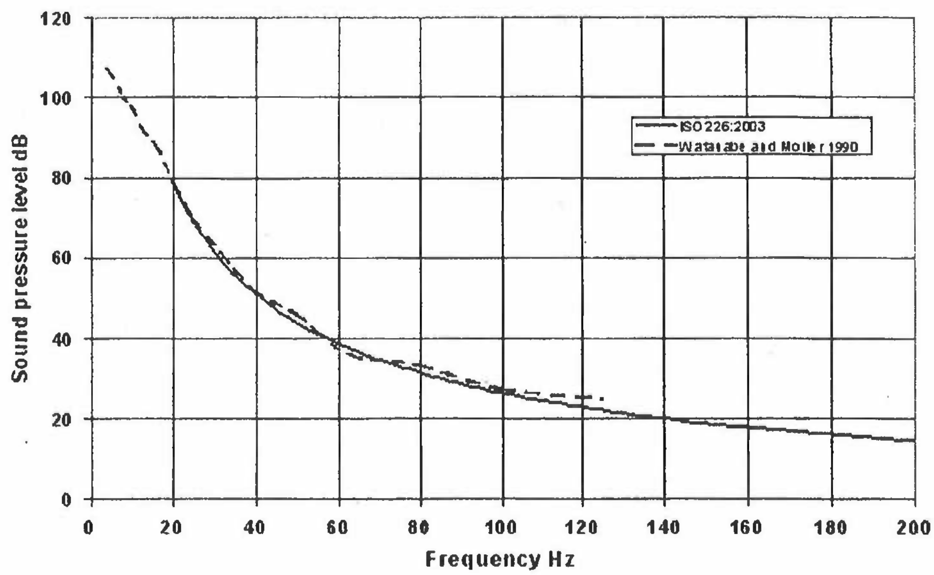

Figure 1. Infrasonic and low frequency threshold

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".

These 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-

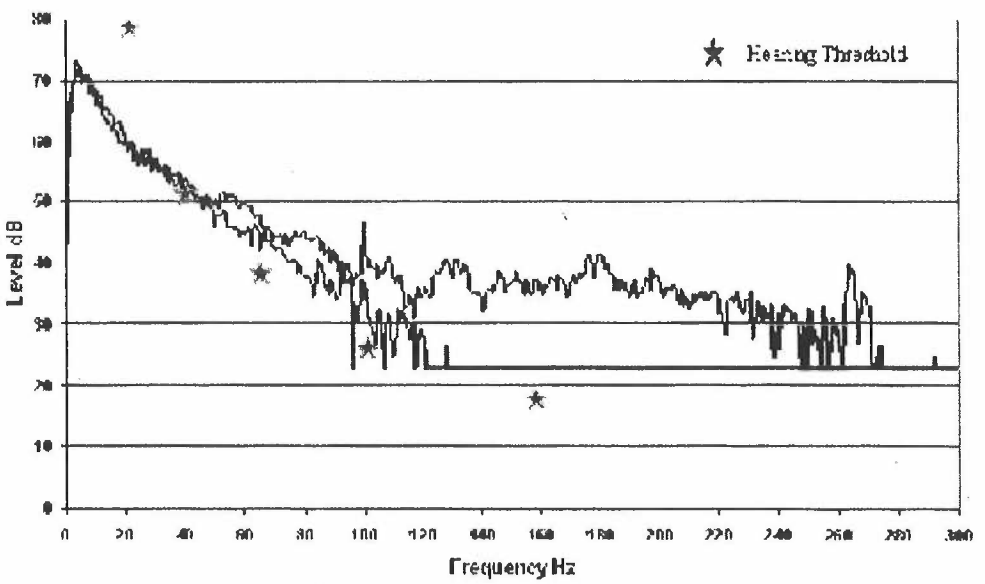

Figure 2. Spectrum of a modern upwind wind turbine - Upper trace Wind Turbine Noise. Lower trace Background noise.

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.

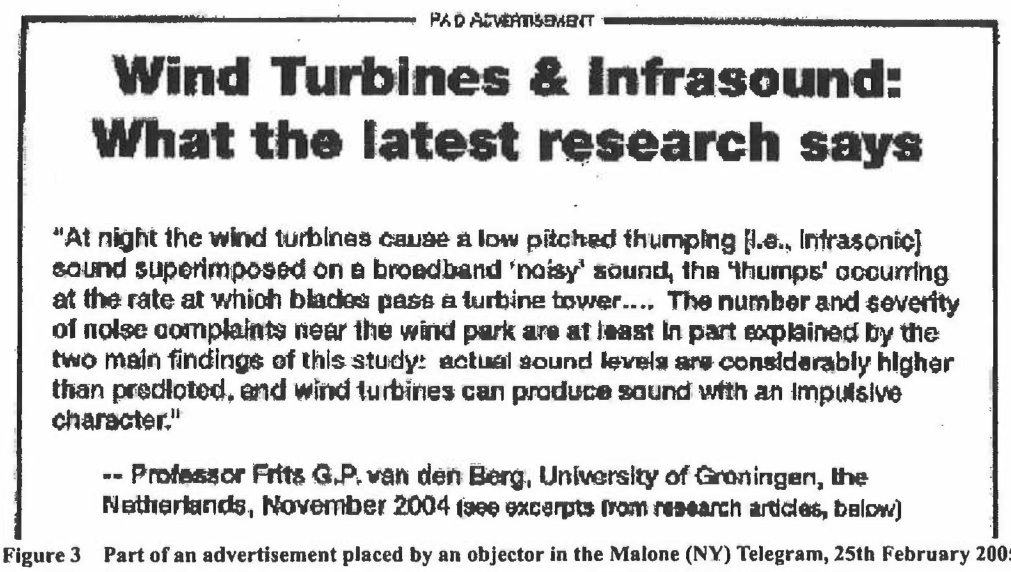

Figure 3 Part of an advertisement placed by an objector in the Malone (NY) Telegram, 25th February 2005.

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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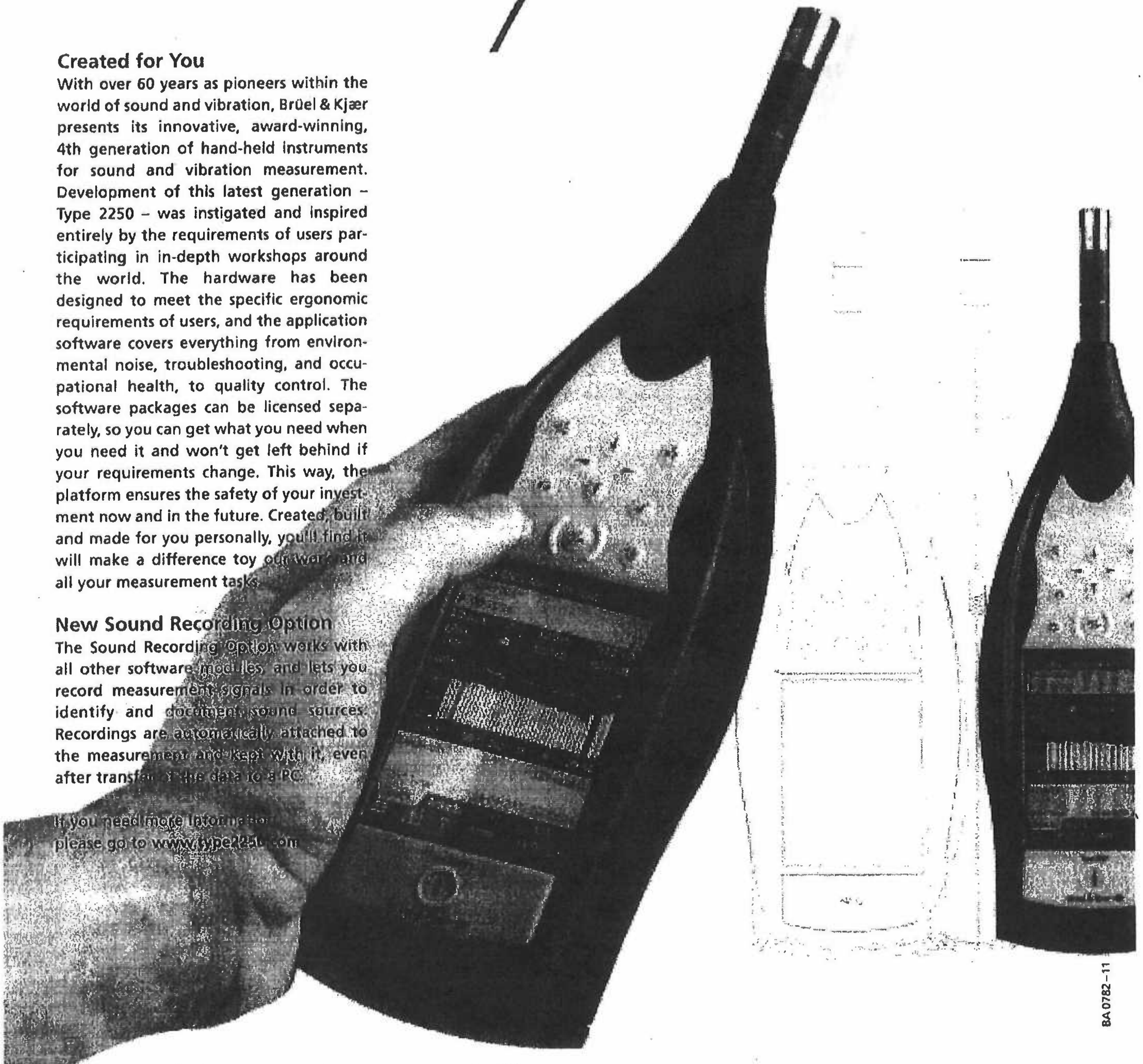

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First International Meeting on Wind Turbine Noise: Perspectives for Control Berlin 17th and 18th October 2005

How the "mythology" of infrasound and low frequency noise related to wind turbines might have developed

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Summary Objections based on infrasound and low frequency noise, often raised against wind farm developments, arise largely from a misunderstanding of these topics by the general public, for whom the problem has developed through media and related exaggerations. There was a period, about 30 years ago, when each time infrasound and low frequency noise were given publicity, more and more of the "facts" were lost in a cloud of increasing embellishment.

This paper traces some of the history of interest in infrasound and low frequency noise, showing how the misunderstandings have arisen, how they have been used in the past to cause confusion in international politics and are used currently by objectors to wind turbine developments.

Introduction Infrasound and low frequency noise are often raised in objections to the development of wind farms. It is necessary to understand how the concerns might have arisen, so that objectors can be shown that their anxieties are likely to be without foundation. In the UK there has been misrepresentation of the facts of infrasound and low frequency noise, both by objectors and also by some of the noise consultants who support the objectors. It is necessary to re-educate the public in order to remove the misconceptions which have developed.

In the definitions of infrasound and low frequency noise, infrasound is often considered as sound at frequencies below 20 Hz. However, from the subjective point of view, there is no reason for terminating a continuous process of hearing at this arbitrary frequency, so that from about 10Hz to 100Hz could be taken as the low frequency range. It may also be argued that there is no reason for terminating at 100 Hz, and the range is sometimes extended to about 200Hz. But we have to stop somewhere.

Atmospheric infrasound This is a well established discipline, studying frequencies from about one cycle in 1000 seconds up to, say, 2Hz. (Bedard and George, 2000) These infrasounds are caused by weather variations, meteorites, distant explosions, waves on the seashore, practically any occurrence which puts energy into the atmosphere over a relatively short period of time and any process with a low repetition rate, including pressure pulses from wind turbines. The attenuation with distance is very low. Monitoring of atmospheric infrasound is an essential part of ensuring the success of the Nuclear Test Ban Treaty.

Of course, it is important to realise that our evolution has been in the presence of naturally occurring atmospheric infrasound.

The American Space Programme Early work on low frequency noise and its subjective effects was stimulated by the American space programme. It was known that very large launch vehicles produce their maximum noise 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 levels of 140dB to 150dB in the range up to 100Hz (Mohr et al., 1965). It was concluded that subjects who were experienced in noise exposure, and who were wearing ear protection, could tolerate both broadband and discrete frequency noise in the range 1Hz 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 (von Gierke, 1973; von Gierke and Nixon, 1976). These limits were set to prevent direct physiological damage. It was not suggested that the exposure is pleasant, or even subjectively acceptable for anybody except those whose work requires them to be exposed to the noise.

Work was also in progress in the UK (Hood and Leventhall, 1971; Yeowart et al., 1969) and France (Gavreau, 1968; Gavreau et al., 1966) from the 1960's and in Japan and Scandinavia from the 1970's (Møller, 1980; Yamada, 1980). Japan and Scandinavia are now the main centres for work on infrasound and low frequency noise. A review of studies of low frequency noise has been given by Leventhall (Leventhall et al., 2003)

Origins of the Mythology The early American work was published in the middle 1960's and did not attract attention from the public, but a few years later *infrasound* entered upon its mythological phase, echoes of which still occur, currently in relation to wind turbines. The main name associated with the early phase is that of Gavreau from CNRS Marseille, whose work was in progress at the same time as that of the American space programme. (Gavreau, 1968; Gavreau et al., 1966). Infrasound from a defective industrial fan led to investigations of infrasonic problems and the design of high intensity low frequency sound sources. Gavreau made some misleading statements, which led to confusion of harmful effects of very high levels at higher frequencies with the effects of infrasound. (Note: According to the definition above, most of the sources developed by Gavreau and his colleagues were not infrasonic.) For example from the 1968 paper on "Infrasound", which was published in a "popular science" journal:

> *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 1kW.....This proved sufficient to make him a life-long invalid.*

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

Gavreau's progress Gavreau initially energised his sources in a laboratory, exposing himself and his co-workers to very high levels of noise at relatively high frequencies. For example at 196Hz from a pneumatic "whistle" and 37Hz from a larger whistle. Exposure to the 196Hz source at a level of 160dB [1] led to irritation of internal organs, so that Gavreau and his colleague felt ill for some time following a five minute exposure, which is not surprising. Again from the 1968 paper:

> *...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 severe irritation of the nerve endings. Presumably if the test had lasted longer than five minutes, internal haemorrhage would have occurred.*

196 Hz is not infrasound, but the unpleasant effects are described in a paper which is described as on "Infrasound". Internal haemorrhage is often quoted as an effect of exposure to any infrasound.

The 37Hz whistle was run at a low level, but sufficient to cause the lightweight walls of the laboratory to vibrate. (Some of Gavreau's earlier work had been in the development of pneumatic high intensity ultrasonic sources, so that he merely had to scale up the size).

Gavreau generated 7Hz with a tube of length 24m, driven by either a loudspeaker or a motor- driven piston. He suggested that 7Hz was particularly "dangerous" because the frequency coincided with alpha rhythms of the brain. He also used a tube to generate 3.5Hz, but further details were not given.

However, from the 1968 paper:

> *The effects of low frequency sound and infrasound are noxious. However, we found one exception: the intense vibration of the nasal cavities produced by our*

[1] 160dB is about 2000Pa, or 1/50 of an atmosphere, which is in the non-linear region.

whistle (340Hz, 155 decibels) had favourable effects! In one case, a subject recovered a sense of smell which he had lost some years back and was able to breathe more easily.

Infrasound and the public By present standards, Gavreau's work was irresponsible, both in the manner in which it was carried out and in the manner in which it was described. Today, the experiments on people could lead to prosecution for negligence. Much of the paper with title of 'Infrasound' is not about infrasound. However, the work was picked up by the media and embellished further, including a statement that 7Hz was fatal. There was manipulation, sometimes willing manipulation, of scientists by the media, which was happy to describe all the sources developed by Gavreau as infrasound sources and to attribute all the adverse effects to infrasound, although they were actually due to high levels at frequencies above the infrasonic range.

The misunderstanding between infrasound and low frequency noise continues to the present day. A recent 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 études médicales indiquent que les éoliennes terrestres représentent un risque pour la santé des gens habitant à proximité, à cause de l'émission 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). A selection of some UK press headlines from the early years is:

The Silent Sound Menaces Drivers - Daily Mirror, 19th October 1969
Does Infrasound Make Drivers Drunk? - New Scientist,16th March 1972
Brain Tumours 'caused by noise' - The Times, 29th September 1973
Crowd Control by Light and Sound - The Guardian, 3rd October 1973
Danger in Unheard Car Sounds - The Observer, 21st April 1974
The Silent Killer All Around Us - Evening News, 25th May 1974
Noise is the Invisible Danger - Care on the Road (ROSPA) August 1974

Absurd statements were made in the book 'Supernature' by Lyall Watson, first published in 1973 as 'A Natural History of the Supernatural' and which has, unfortunately, had a number of reprints and large sales. This book includes an extreme instance of the incredible nonsense which has been published about infrasound. It states that the technician who gave the first trial blast of Gavreau's whistle "fell down dead on the spot". A post mortem showed that "all his internal organs had been mashed into an amorphous jelly by the vibrations". It continues that, in a controlled experiment, all the windows were broken within a half mile of the test site and further, 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".

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.

Perhaps the singer David Bowie had read "Supernature". On the 20th September 1977, the London Evening News published an interview with him, giving his views on life, including the following:

"He also expresses fears about America's new Neutron Bomb. 'It was developed along the lines of the French sound bomb which is capable of

destroying an area 25 miles around by low frequency vibration'. According to Bowie, plans for such a bomb are readily available in France and any minor power can get their hands on a copy. Low frequency sounds can be very dangerous. The 'sensurround' effect that accompanied the film 'Earthquake' was achieved by a noise level of nine cycles per second. Three cycles per second lower is stomach bleeding level. Any lower than that and you explode".

We cannot blame the public for their anxiety about infrasound and low frequency noise when they have been exposed to statements like these. Public concern over infrasound was one of the stimuli for a growth in complaints about low frequency noise during the 1970's and 1980's and has continuing effects. It appears that concerns over infrasound and low frequency noise have found a place deep in the national psyche of a number of countries and lie waiting for a trigger to bring them to the surface. Earlier triggers have been gas pipelines and government establishments. A current trigger is wind turbines.

Infrasonic weapons The media follow-up of Gavreau's work led to interest in infrasonic weapons, although these have not been produced, as it is not possible to generate directional infrasound of high enough level to be effective at a distance. For example, to produce 150dB (1000W/m^2) at 100m distance requires a point source power of about 60MW. At 20Hz, which has a wavelength of about 17m, an efficient directional reflector, which must have dimensions of several wavelengths, is not feasible. However, during the cold war, the Conference of the Committee on Disarmament (see: www.unog.ch) , which commenced its work in Geneva in about 1960, and is believed to be still sitting, was presented with a paper from the Hungarian Peoples' Republic (Anon, 1978) which discussed infrasonic weapons and concluded:

> *".....infrasound can become the basis of one of the dangerous types of new weapons of mass destruction.......*
> *All this leads to the unequivocal conclusion that the scope of the agreement on the prohibition of the development and manufacture of new types of weapons of mass destruction must also be extended to the military use of infrasound weapons of mass destruction......"*

An example of an infrasonic weapon was given as a jet engine attached to a long tube – reminiscent of Gavreau's 24m tube, as shown in Fig 1. Of course, the physics is at fault, because the rapid flow of the exhaust gas from the engine will prevent the development of resonance (Leventhall, 1998).

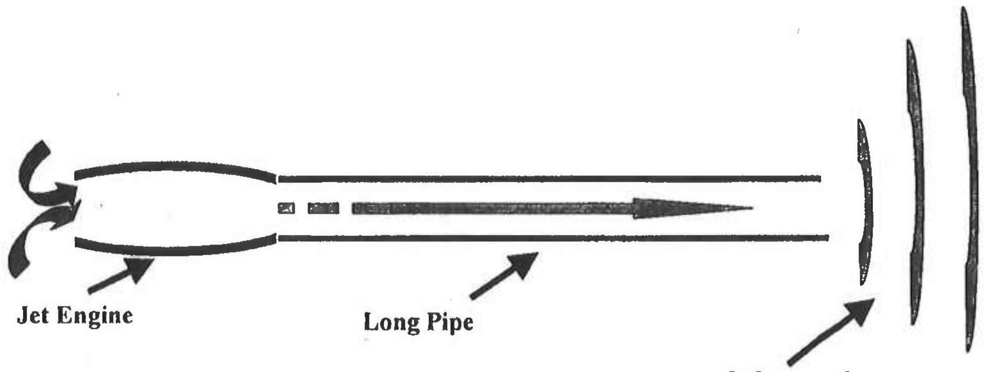
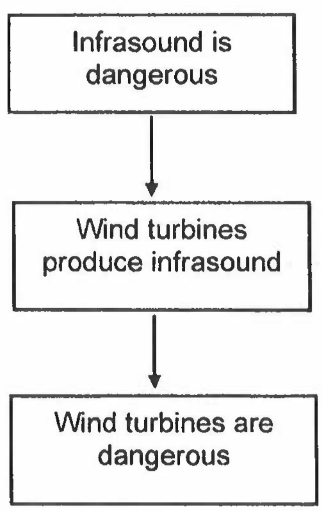


Fig 1 Jet engine as infrasonic weapon

However, after taking advice, the Western powers concluded that infrasonic weapons were a political distraction from the main points of the disarmament negotiations.

In relation to wind turbines, the concept that "infrasound is dangerous" has been absorbed into the minds of objectors, who take a one dimensional view of infrasound. That is, they consider only that it may be present from wind turbines and ignore the very low levels. So we have the relation:



Which objectors are pleased to believe and which they make use of in planning applications.

A recent example is from the leaflet from an objectors' group which stated: *"wind turbines still create noise pollution, notably 'infra sound' - inaudible frequencies which nevertheless cause stress-related illness ..."*

The wind farm developers referred this statement, and others, to the UK Advertising Standards Authority, which ruled that it was misleading.

What infrasound do we hear? The audibility of infrasound for subjects exposed in infrasonic chambers, has been measured reliably down to 4Hz, Fig 2, is based on work by Watanabe and Møller from 4Hz and on ISO 226 from 20Hz (ISO:226, 2003; Watanabe and Møller, 1990b). The median threshold at 4Hz is 107dB, at 10Hz is 97dB and at 20Hz is 79dB. The standard deviation of the threshold measurements is about 6dB, so that a very small number of people may have 12dB or more greater sensitivity than the median.

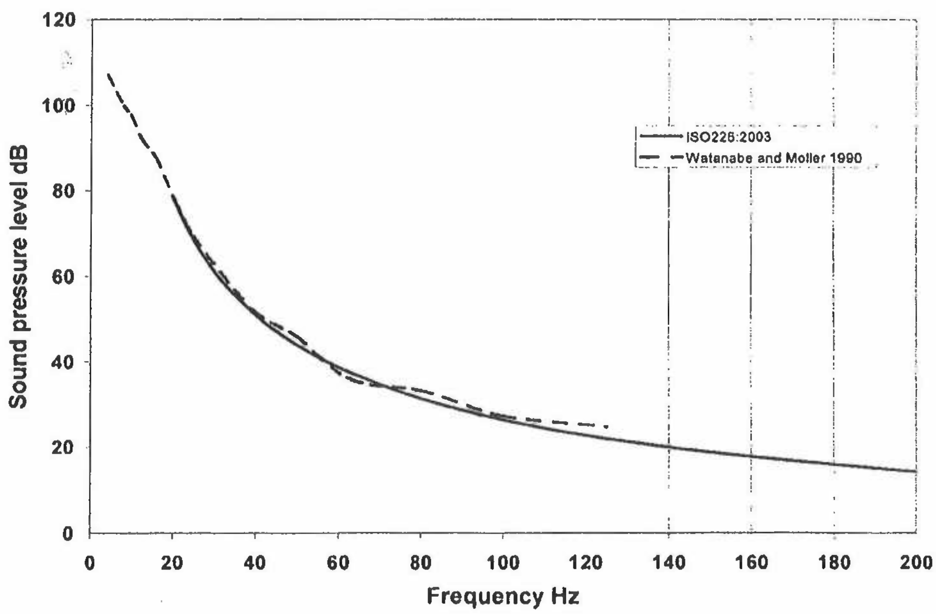


Fig 2. Low frequency threshold

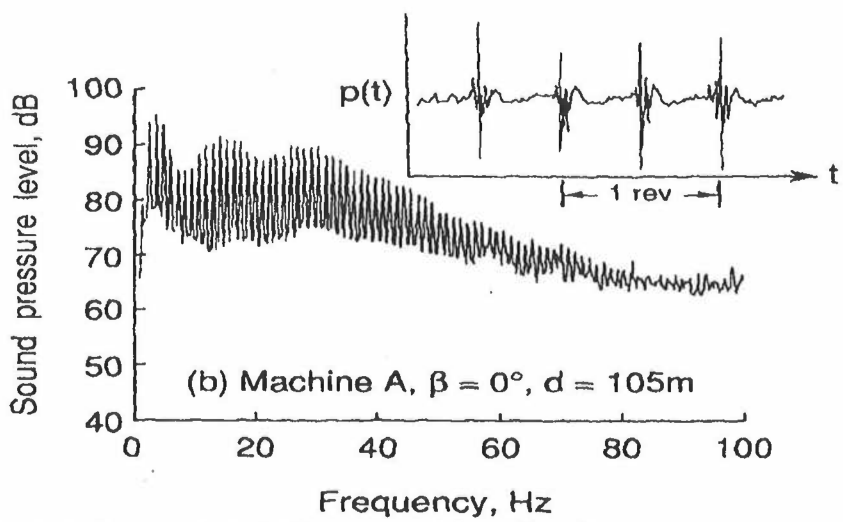
Part of the mythology is that infrasound can be felt but not heard. However, the ear is the most sensitive receptor in the body, as has been shown by threshold measurements on both normal hearing subjects and profoundly deaf subjects, which were carried out down to 8Hz (Yamada et al., 1983). If you can't hear it you can't feel it.

Gavreau (1968) used loud music to show that 7Hz infrasound could be masked by higher frequencies. Initially the sound was throbbing unpleasantly, but

> *'This musical experiment proved that this infrasound acted through the ears and not directly on the body. Furthermore, any kind of strong audible sound, by reducing the sensitivity of the ear, rendered this infrasound perfectly harmless'.*

Gavreau did not give the level of the 7Hz, but it is likely to have been at least 110 - 120dB.

Infrasound and wind turbines As is well known, earlier downwind turbines produced pulses at levels which caused vibration effects in light-weight buildings,



MOD-1 Downwind 1.5MW to 2MW 61m diameter rotor BPF ~ 1Hz

Fig 3 Infrasound from early downwind turbine

occurring twice a revolution from a two bladed turbine, as shown in Fig 3. (Shepherd and Hubbard, 1991)

Any slow train of pulses will analyse as infrasound. For example, pulses occurring once a second, as in Fig 3, will analyse as infrasound with a harmonic series at 1Hz intervals. But it was actually the peak pressure from the pulses which caused transient effects in the buildings, such as rattling of loose components, not the emission of a continuous infrasonic wave. These effects were heard as separate events.

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)

Low frequency noise

There is an easy transition from infrasound to low frequency noise and much of the publicity about infrasound applies equally to low frequency noise. Sometimes the terms are used interchangeably. However, audible low frequency noise does have annoying characteristics which are not shown in conventional environmental noise measures, such as the A-weighting. This has been recognised by the World Health Organisation, which makes a number of references to low frequency noise in its publication on Community Noise (Berglund et al., 2000) with statements such as:

It should be noted that low frequency noise, for example, from ventilation systems can disturb rest and sleep even at low sound levels

For noise with a large proportion of low frequency sounds a still lower guideline (than 30dBA) *is recommended*

When prominent low frequency components are present, noise measures based on A-weighting are inappropriate

Since A-weighting underestimates the sound pressure level of noise with low frequency components, a better assessment of health effects would be to use C-weighting

It should be noted that a large proportion of low frequency components in a noise may increase considerably the adverse effects on health

The evidence on low frequency noise is sufficiently strong to warrant immediate concern

An example of the difference between responses to low frequency noise/infrasound and other noises is in the growth of annoyance, illustrated in Fig. 4.

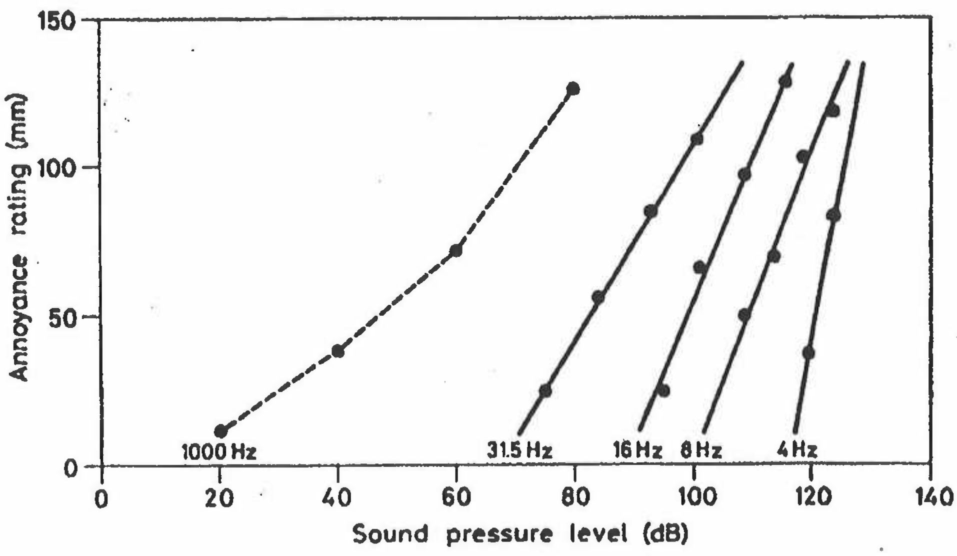


Fig 4 Growth of annoyance at low frequencies

Although low frequency tones require a higher level for the on-set of perception, their annoyance rating increases more rapidly with level. At 4Hz the range of annoyance is covered in a rise of about 10dB, compared with about 50dB at 1000Hz. Annoyance does not normally commence until the tone is 5 to 10dB above its threshold.

The concerns of the WHO on low frequency noise require us to look carefully at low frequency noise from wind turbines. In general, there is not a problem, although the mythology is that wind turbine noise has a substantial low frequency component.

This may be a misunderstanding of the "swish – swish - swish", at about once a second, which is typical of wind turbines. However, the swish is a modulation of a higher frequency, typically in the 500Hz to 1000Hz range, and does not contain low frequencies or infrasound. An analogy is with an amplitude modulated radio wave, which contains only the carrier and side bands, not the modulation frequency.

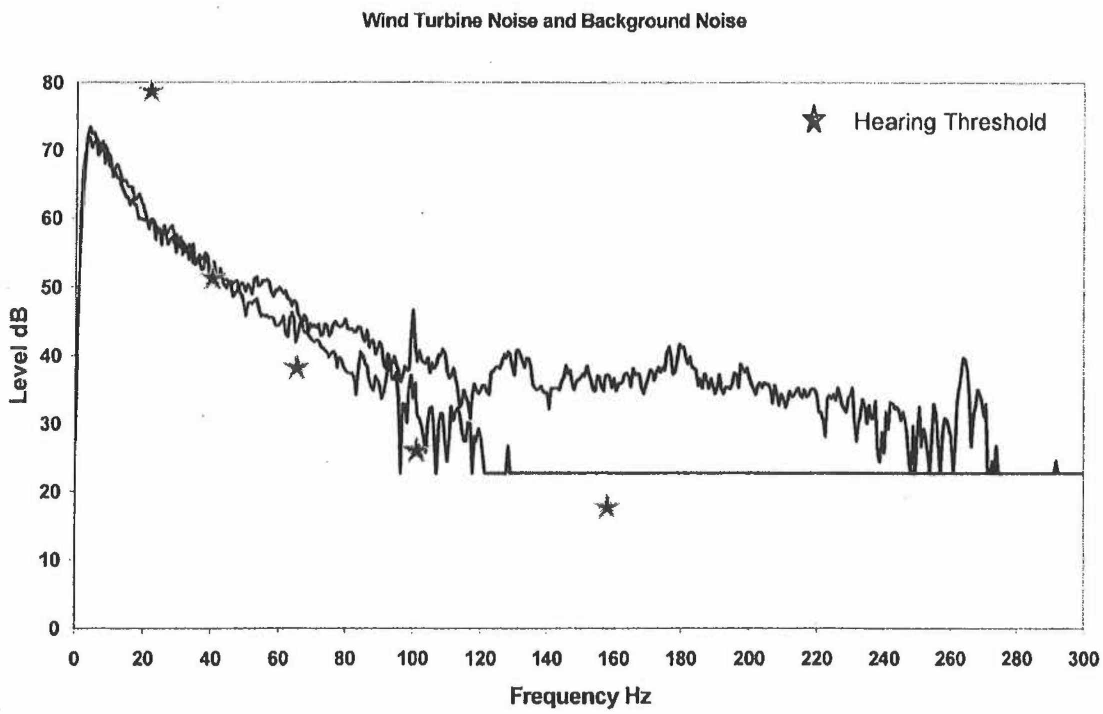


Fig 5 Wind turbine noise —— and background noise ——
65m distance. wind speed at hub ~ 15m/s

All wind turbines produce low frequencies, mainly mechanical noise, which has been reduced to low levels in modern turbines, but there are also circumstances in which turbines produce increased levels of low frequency noise. This is mainly when the inflow air to the turbine is very turbulent and there are interactions between the blade and the turbulence.

Fig 5 shows the infrasonic and low frequency noise at 65m from a 1.5MW wind turbine on a windy day. The following 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 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.

Conclusions. 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.

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