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Wind Turbine Noise

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Environmental Noise: Aircraft and Wind Turbines

CONCERNS ABOUT INFRASOUND FROM WIND TURBINES

Geoff Leventhall
150 Craddocks Ave
Ashtead, Surrey KT21 1NL
United Kingdom

Infrasound

Infrasound has been defined as: "Acoustic oscillations whose frequency is below the low frequency limit of audible sound (about 16 Hz)." (IEC 1994)

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

The limit of 16 Hz, or more commonly considered as 20 Hz, arises from the lower frequency limit for which the standardized equal loudness hearing contours have been measured, not from the lower limit of hearing. From the subjective point of view, there is no logical reason for terminating a continuous process of hearing at an 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 logical reason for terminating at 100 Hz, and the range is sometimes extended to about 200Hz and down to 5Hz. However, objectors to wind turbine developments are now requesting that measurements are made down to below 1Hz.

"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."

Atmospheric infrasound

This is a well-established discipline, studying frequencies from about one cycle in 1000 seconds up to, say, 2Hz and higher (Bedard and George 2000). Atmospheric infrasounds are caused by weather variations, turbulence, meteorites, distant explosions, ocean waves interacting (microbaroms) or waves breaking on the shore, practically any occurrence which puts energy into the atmosphere over a relatively short period of time and any process with a low repetition rate. The attenuation with distance is small and propagation can be complex. Monitoring of atmospheric infrasound is an essential part of ensuring the success of the Nuclear Test Ban Treaty, since explosions in the air generate infrasound, and there are about 60 monitoring stations around the world.

Of course, it is important to realise that our evolution has been in the presence of naturally occurring atmospheric infrasound, which overlaps the lower end of wind turbine infrasound.

The Apollo Space Programme

Early work on low frequency noise and its subjective effects was stimulated by the Apollo space programme. It was known that large launch vehicles produce their maximum noise energy in the infrasound region. Furthermore, as the vehicle accelerates, the crew compartment is subjected to boundary layer turbulence noise for a few 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, Cole et al. 1965). It was concluded that subjects who were experienced in noise exposure, and who were wearing ear protection, could tolerate both broad¬band 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 high, long-term limits were set to prevent direct physiological damage. It was not suggested that the exposure is pleasant, or subjectively acceptable, for anybody except those whose occupation requires them to be exposed to the noise.

Work was also in progress in the UK (Yeowart, Bryan et al. 1969, Hood and Leventhall 1971) and France (Gavreau, Condat et al. 1966, Gavreau 1968) from the 1960s and in Japan and Scandinavia from the 1970s (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, Benton et al. 2003)

Origins of the Concerns

The early American work was published from the middle 1960s and did not attract public attention, 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 Apollo space programme. (Gavreau, Condat et al. 1966, Gavreau 1968). Infrasound at 7Hz from a defective industrial fan, which may have been operating at an unstable point on its characteristic, led to investigations of the problem and to the design of high intensity low frequency sound sources. The frequencies and levels reported in Gavreau (1968) were:

Frequency Hz	Reported level dB
2600	Not given
340	155dB
196	160dB
37	Not given
7	Not given

Gavreau made misleading statements, which led to confusion of harmful effects of very high levels at higher frequencies with the effects of infrasound.

For example from the 1968 paper on "Infrasound," which was published in a popular science journal: (Gavreau 1968):

> 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 lifelong invalid.

Of course, 2600Hz is not infrasound, but the misleading implication is that infrasound caused injury to Levavasseur.

Gavreau's progress

Gavreau energized 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 led to irritation of internal organs, so that Gavreau and his colleague felt unwell following a five minute exposure. 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 hemorrhage would have occurred.

196 Hz is not infrasound, but the unpleasant effects are described in a paper with the title "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 for low frequency operation.

Gavreau also 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.

And 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 whistle (340Hz, 155 decibels) had favorable 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. Much of the paper with the title "Infrasound" is not about infrasound. The work was picked up by the media and embellished further, including claims that 7Hz is fatal.

The misunderstanding between infrasound and low frequency noise continues. 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 objector 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 tumors, sudden infant deaths, 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*

Infrasound and low frequency noise are often associated in the public mind with the "hum." This is mystery noise of unknown origin, which is heard periodically by a few people, and causes them great distress, but is difficult to measure. The hum has been reviewed by Demming, who gives references to North American occurrences (Demming 2004). Demming has established a Yahoo Group Hum Forum, <http://tech.groups.yahoo.com/group/humforum/>, to help hum sufferers interact and support each other.

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 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

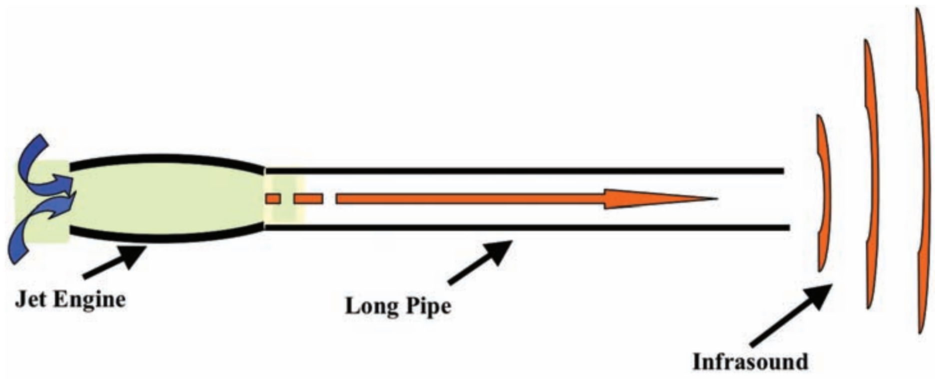

Fig 1. Jet engine as infrasonic weapon.

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.

The Internet

Currently, the internet is the favored medium for information on infrasound and wind turbines. A web page that features the subject is <www.windturbinesyndrome.com>. Main themes of this page are that wind turbine developers are greedy and heartless money-makers and that wind turbine infrasound causes a range of illnesses. The writers use colorful and forceful language. For example, as in <http://www.windturbinesyndrome.com/2013/why-wind-developers-are-sharks-mass/>. The writers are so focused on supposed dangers of infrasound, which they use as a scare tactic on residents near proposed wind farms, that they may be led astray by this. For example, the long range acoustic device (LRAD) is described as an infrasonic weapon, whereas it is actually based on an ultrasound carrier: <http://www.windturbinesyndrome.com/2011/the-misuse-of-infrasound-industry-military-and-now-the-cops/>. Any evidence on the production of even low level infrasound by wind turbines is hailed as a victory <http://www.windturbinesyndrome.com/2010/wind-turbines-produce-major-infrasound-period-no-question-about-it/>. Another view, not favored by the web page, is that wind turbines produce infrasound, but it is of negligible impact on humans (Leventhall 2006).

Public perceptions

We cannot blame the public for their anxiety about infrasound and low frequency noise when they have been exposed to statements like those described earlier. Public concern over infrasound was one of the stimuli for a growth in complaints about low frequency noise during the 1970s and 1980s 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 work at government research establishments. A current trigger is wind turbines.

Infrasound in the Cold War

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. However, during the cold war, the Conference of the Committee on Disarmament 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 resonance tube, shown in Fig. 1. The physics is at fault, because the rapid flow of the exhaust gas from the engine will prevent the development of resonance (Leventhall 1998). After taking advice, the Western powers con-

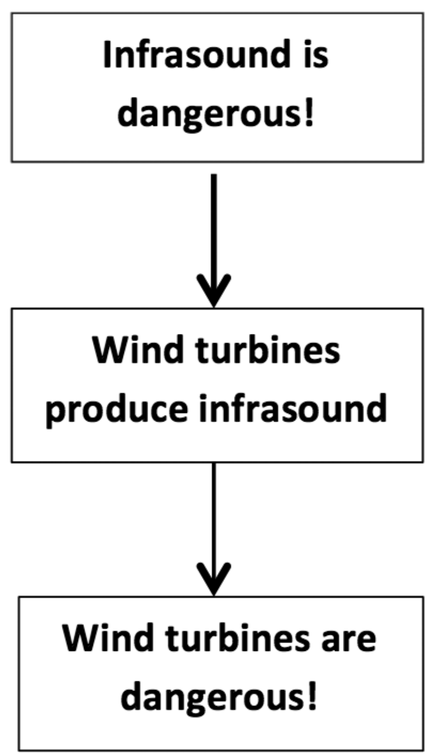

Fig. 2

cluded 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 to wind turbines, 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 connection shown in Fig. 2, which objectors to wind turbines are pleased to believe and which they make use of in planning applications. However, decibel for decibel, infrasound is less harmful than higher frequency noise.

The Wind Turbine Syndrome

This supposed syndrome is a collection of maladies, said to result from exposure to infrasound from wind turbines, including "… sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep."

In her self-published, popular science book, Nina Pierpont, who practices as a pediatrician, not an acoustics expert, gives two hypotheses on which the wind turbine syndrome is based.(Pierpont 2009)

1. Wind Turbine Syndrome, I propose, is mediated by the vestibular system — by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. These feed back neurologically onto a person's sense of position and motion in space, which is in turn connected in multiple ways to brain functions as disparate as spatial memory and anxiety …
2. Air pressure fluctuations in the range of 4-8 Hz, which may be harmonics of the turbine blade-passing frequency, may resonate (amplify) in the chest and be felt as vibrations or quivering of the diaphragm with its attached abdominal organ mass (liver). Slower air pressure fluctuations, which could be the blade-passing frequencies themselves or a lower harmonic (1-2 Hz), would be felt as pulsations as opposed to the faster vibrations or quivering … The pressure fluctuations in the chest could disturb visceral receptors, such as large vessel or pulmonary baroreceptors or mediastinal stretch receptors which function as visceral graviceptors.These aberrant signals from the visceral graviceptors, not concordant with signals from the other parts of the motion-detecting system, have the potential to activate the integrated neural networks that link motion detection with somatic and autonomic outflow, emotional fear responses, and aversive learning.

To summarize, Pierpont's claim is that the low levels of infrasound from wind turbines have a direct pathophysiological effect on the body, through the vestibular systems and also by excitation of the airways and diaphragm to the viscera. However, she has little understanding of acoustic magnitudes and changes at will between noise and vibration. The scientific backing for Hypothesis 1 is a paper on vestibular detection of vibration applied to the mastoid bone. In adopting this she has misrepresented the original paper (Todd, Rosengren et al. 2008) as being based on excitation by noise, when it was actually a bone conducted vibration detection investigation, comparing thresholds of vestibular and cochlear detection. Following a newspaper item which connected him with the wind turbine syndrome, Todd repudiated Pierpont's use of his work (Todd 2009). The backing for Hypothesis 2 is in body resonances resulting from whole body vibration. However, excitation by point vibration input at the seat or feet differs from that for long wavelength sound, which acts over the whole body, and different resonances are excited. Pierpont's hypotheses are scientifically invalid.

Some people are distressed by wind turbines, and noise is a factor in this. Those at the sharp end of environmental noise problems know how upsetting noise can become, especially if there is an antagonism towards the source. Symptoms which are given by Pierpont as comprising the Wind Turbine Syndrome are paralleled in the extreme distress from any environmental noise, which occurs with a small number of people, especially when coupled with psychological factors. However, Pierpont dismisses psychological effects with, "It is important to emphasize, these symptoms are not psychological (as if people are fabricating them), they are neurological." This contradicts much of what is known about responses to noise, especially low level noise. (Job 1988, Miedema and Vos 1999).

Pierpont has been the main proponent of dangers of infrasound from wind turbines and she, along with those who follow her, is responsible for much of the present public attitude. A fuller critique of Pierpont's work has been given previously (Leventhall 2009).

Support for an adverse effect from wind turbine infrasound has been given by Salt and Hullar, who showed that, at 5Hz, the outer hair cell (OHC) response threshold in guinea pigs is lower than the guinea pig hearing threshold, which depends on inner hair cell excitation. (Salt and Hullar 2010). This led to the definition of a rather broad brush OHC threshold, which gradually diverges from the hearing threshold below 1000Hz. Comparison of guinea pig and human hearing thresholds was used to define an equivalent OHC threshold for humans. The final destination in the brain of the excitations from the OHCs, which are not transmitted along the auditory nerve, is not known. Salt is cautious in his scientific papers and writes "The fact that some inner ear components (such as the OHC) may respond to infrasound at the frequencies and levels generated by wind turbines does not necessarily mean that they will be perceived or disturb function in any way." (Salt and Hullar 2010). However, Salt's web page falls squarely in the "infrasound is hazardous" school (<http://oto2.wustl.edu/cochlea/wind.html>).

The proposed inner and outer hair cell thresholds for humans are compared in Fig. 3. The outer hair cell threshold is 20dB at 100Hz, rising at 40dB/decade into lower frequencies, crossing 60dB at 10Hz and 100dB at 1Hz. The next section covers infrasound from wind turbines and it will be noted that much of this infrasound, especially at lower infrasound frequencies, is below the outer hair cell threshold, so that the relevance of the threshold to wind turbine infrasound is not clear. Many natural and man-made infrasonic sources exceed the threshold in the higher infrasonic region (Turnbull, Turner et al. 2012)

Infrasound from wind turbines

An early association of wind turbines and infrasound was the work of NASA in the 1980s. Investigations of the MOD-1 and similar downwind turbines revealed pressure pulses from interaction between the blades and the disturbed flow behind the tower. Downwind turbines were largely experimental models and were completely replaced by the three bladed upwind turbines, which make up the current operating fleet of utility scale turbines. Analysis of pulses from the MOD-1 and similar turbines, which typically have a repetition rate of 1Hz, leads to a harmonic series based on 1Hz and to the linking of infrasound with wind turbines (Shepherd and Hubbard 1991). However, this infrasound is of the type which might be produced by a single person hand clapping, or even a ticking clock! The problems from the MOD-1 turbine were not from the frequency, but from the peaks of the pressure pulses in the downwind turbine design, which caused vibration of loose building components and were also audible. Building response is the same over a wide range of pulse repetition rates, up to the point where the decay time of the this response merges with the repetition rate of the pulses.

There have been a number of measurements of infrasound from modern wind turbines (Hayes 2006, Hepburn 2006, Jung and Cheung 2008, O'Neal, Hellweg et al. 2011, Ambrose and Rand 2011 (December), Turnbull, Turner et al. 2012, Walker, Hessler et al. 2012, Evans 2013). Current measurements are often made to alleviate concerns of those objectors who believe that infrasound from wind turbines is harmful. Measurements show similar results. At typical nearest residential distances, the one-third octave level at 10Hz is around 60dB, with a negative spectrum slope of 3 to 6dB per octave. The levels decrease with distance and may merge into background infrasound. Evans showed that the averaged infrasound levels at residences 1.8km and 2.7km from the nearest turbine of a 140, 3MW turbine wind farm were similar when the turbines were on or off (Evans 2013). This confirms earlier work (Guldberg 2012, Howe, McCabe et al. 2012). Although the average infrasound level may not differ between wind turbines on and off, the characteristics of the sound may change when the turbines are operating. For example, the inaudible infrasound close to a wind turbine may have cyclic variations, whilst the inaudible background infrasound has random variations in level.

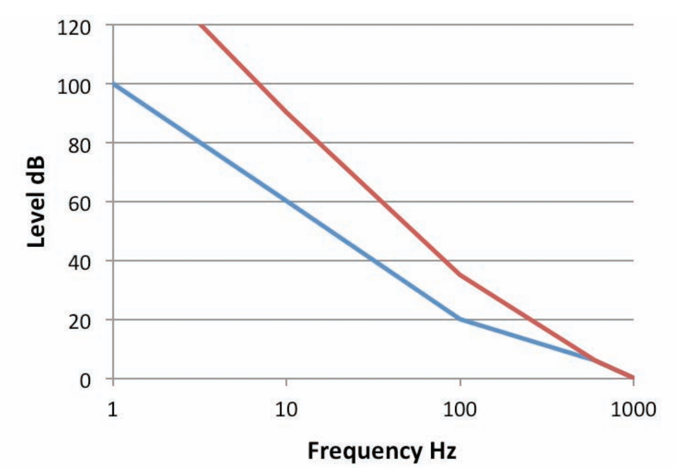

Fig. 3. Comparison of inner and outer hair cell thresholds. Above: Inner hair cell. Below: Outer hair cell.

There is no evidence that the low levels of infrasound from wind turbines, as shown by these measurements, are harmful to humans.

A narrow band analysis of noise from the Shirley wind farm at a residence 335m from the nearest turbine is in Fig. 4 (Walker, Hessler et al. 2012). The outdoors spectrum is 38-39dB at 10Hz, 0.05Hz band, leading to a one-third octave level of about 55dB. The slope of the outdoors spectrum is close to 20dB/decade (6dB/octave). The rise in the living room spectrum in the region of 20Hz is from building resonances, but is nearly 50dB below the hearing threshold at 20Hz. The residents had left their home, complaining of illness (nausea) caused by wind turbines, although all the levels in Fig. 4 are below the Salt OHC threshold of Fig. 3.

One of the authors of the Shirley report suggested direct action of infrasound on the vestibular otoliths as a cause of illness, but the next section on infrasound and the ear shows that this is an unlikely explanation.

Infrasound and the ear

The pure tone hearing threshold has been measured in a chamber down to 4Hz (Watanabe and Møller 1990) and to lower frequencies using earphones (Yeowart and Evans 1974). The chamber data is shown in Fig. 5, where it is combined with the ISO standard threshold (ISO:226 2003). The Watanabe and Møller threshold at 4Hz is 107dB. At 12 Hz it is about 90dB. Yeowart and Evans give higher binaural thresholds: 112dB at 4Hz and 121dB at 2Hz.

The mechanism of hearing down into low frequencies is through normal excitation of the auditory cortex, as shown by fMRI investigations (Dommes, Bauknecht et al. 2009). Dommes, Bauknecht et al used functional Magnetic Resonance Imaging (fMRI) to investigate responses of the brain when exposed to infrasound both above and below the hearing threshold, at the following frequencies and levels:

Freq Hz	500	48	36	12	12	12
Level dB	105	100	70	120	110	90

Audible infrasound excited the auditory cortex, which is where hearing perception occurs. Inaudible infrasound did not show an excitation. This is to be expected if infrasound enters into the hearing system, and is transmitted to the brain in a similar manner to higher frequency sounds. Dommes, Bauknecht et al summarise the results of their work as:

> In our study, no other cortical regions owed a comparably extensive response to the high-level stimuli as did the auditory cortex, indicating that LFT [low frequency tones] were mainly perceived via acoustic pathways instead of representing a

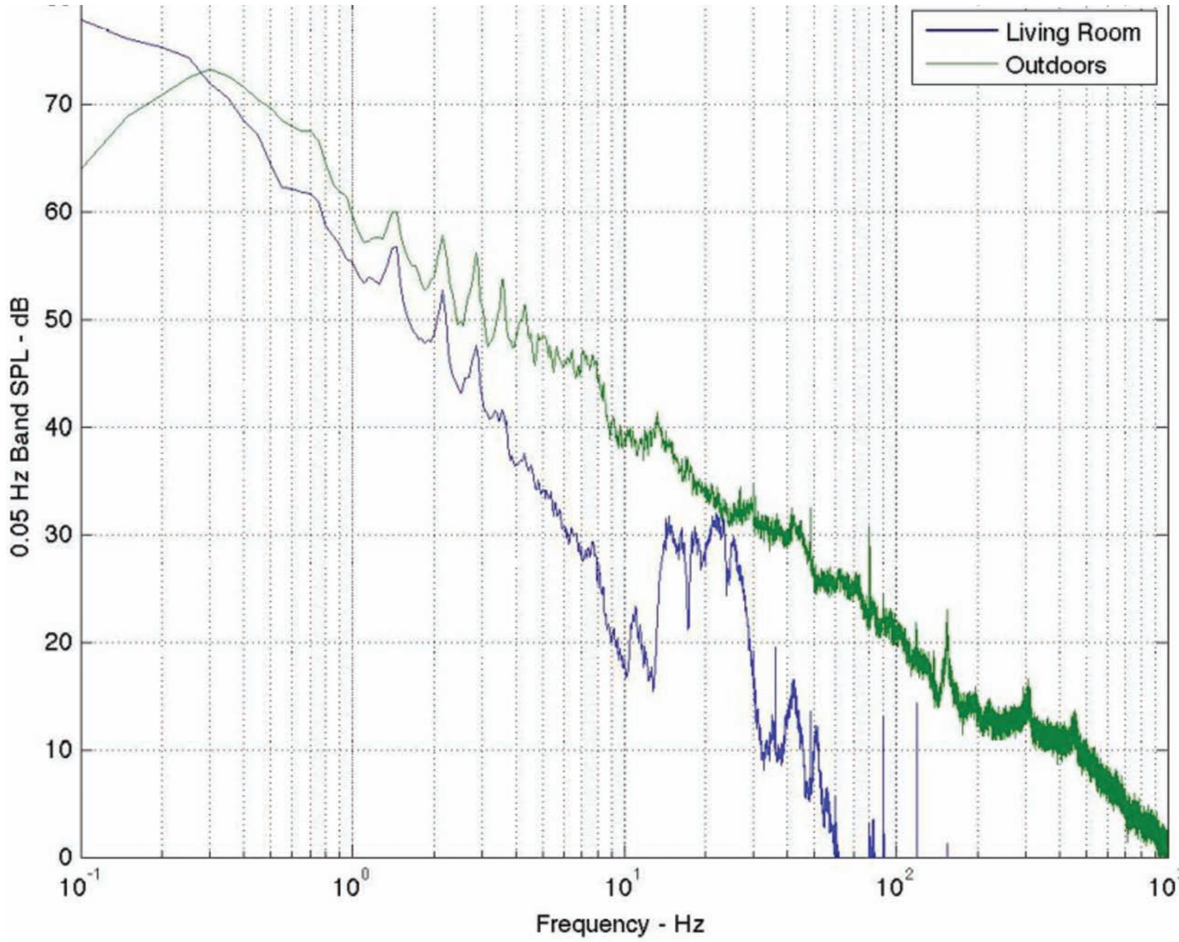

Fig. 4. Narrow band analysis (0.05Hz) of wind turbine noise.

somatosensory phenomenon.

In our study, cortical activation patterns appeared to be similar for all frequencies applied, suggesting that LFT are processed in a similar way as frequencies of our main hearing range (200 to 5000Hz).

We presented the 12Hz stimuli at three different levels. Tone bursts of 120 and 110 dB resulted in cortical activation. The 90dB stimulus did not induce a significant response of the auditory cortex in group analysis which, in agreement with the findings of Møller and Pedersen (2004), indicates that this SPL is below the estimated perception threshold for 12 Hz. (Møller and Pedersen 2004)

This shows that low frequency tones and infrasound are perceived through the normal auditory pathways, the same pathways as for higher frequencies.

Furthermore, sounds, including infrasound, which are below the hearing threshold, do not produce a response in the auditory cortex, as is also the case for sub-threshold higher frequencies. Whilst the lowest frequency used was 12Hz, the regular slope of the hearing threshold indicates that similar processes are likely to apply at lower frequencies. For example, Hensel et al showed that a biasing tone at 6Hz, 130dB was detected by the cochlea and that there was no abrupt change in response in the transition from infrasound to low frequency sound (Hensel, Scholz et al. 2007).

The ear is a bi-directional device

The ear operates in both forward and reverse directions. In normal, forward operation, sound waves excite the ear drum, which drives the ossicles to impart vibrations to the cochlear fluid (perilymph) via the oval window. (Fig. 6) These vibrations propagate up and down the cochlea to the pressure release of the round window, causing waves along the basilar membrane and exciting the inner hair cells, which send signals via the auditory nerve to the auditory cortex, where they are interpreted as sound The system is mechanical up to the oval window and largely hydrodynamic within the cochlea.

Reverse action of the ear was demonstrated through otoacoustic emissions (OAE) in which "ringing" of the cochlear amplifier, which is based in the outer hair cells, sends vibrations back through the oval window and ossicles to excite the ear drum. Vibrations of the ear drum can then be detected by a microphone in the ear canal (Kemp 2002).

The cochlear aqueduct and internally generated infrasound

The brain produces a fluid (cerebrospinal fluid) which bathes the brain and the spinal cord, providing protection, lubrication and an egress for metabolic wastes. The cerebrospinal fluid, which can be sampled by lumbar punctures, carries infrasonic pressure pulses resulting from heartbeat and breathing. A small duct, the cochlear aqueduct, connects

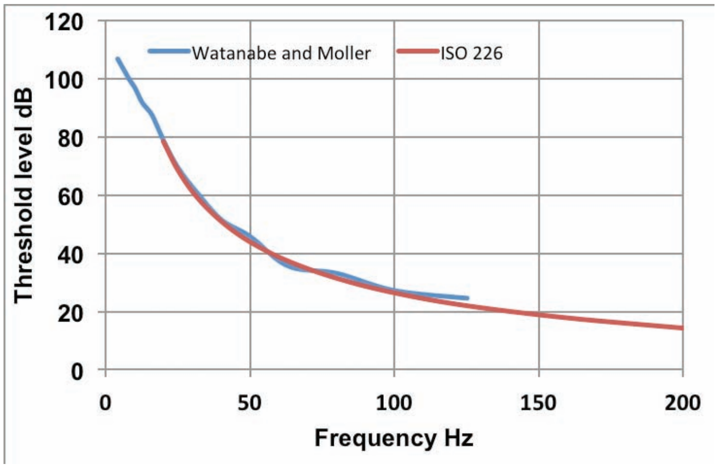

Fig. 5. Low frequency hearing thresholds.

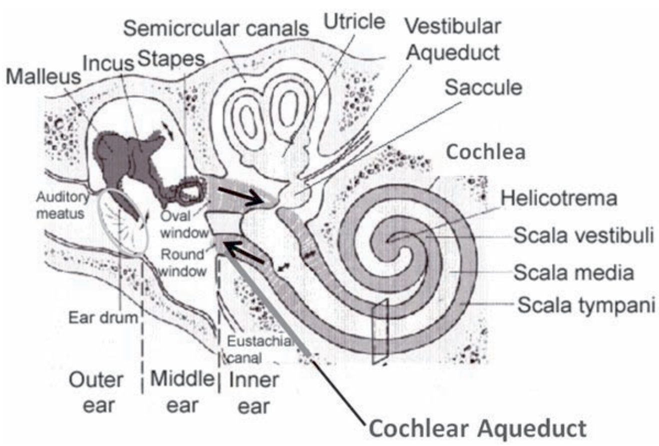

Fig. 6. Action of the ear. Adapted from (Maroonroge, Emanuel et al. 2009)

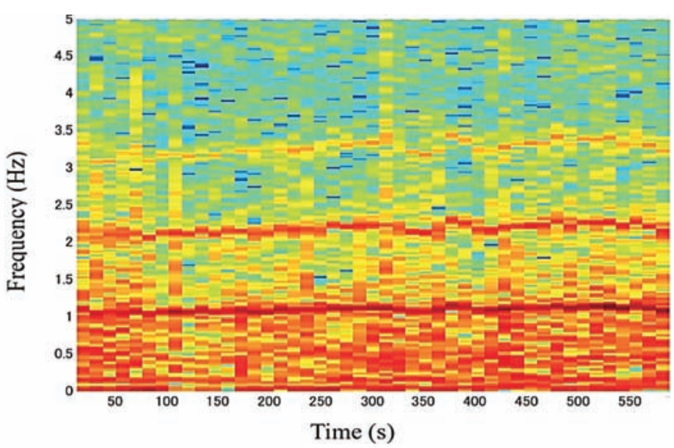

Fig. 7. Spectrum of infrasonic pressure in the occluded ear canal.

the cochlea to the cerebrospinal fluid, permitting bidirectional flow of fluid and allowing pressure equalisation of the cochlea, Fig. 6. The cochlear aqueduct offers a high resistance to high frequencies, but passes the low frequency pressure pulses from the cerebrospinal fluid into the fluid of the inner ear (Traboulsi and Avon 2007). This effect is strong enough to drive the ear in reverse so that infrasound pulses generated by heartbeat and breathing, which enter the cerebrospinal fluid and transmit to the inner ear via the cochlear aqueduct, may be detected with a microphone in the ear canal. The detection has similarities to detection of otoacoustic emissions and the cochlea is continuously exposed to infrasound from heartbeat and breathing at similar, and lower, frequencies to wind turbine rotational infrasound.

Traboulsi and Avon detected pressure peaks in the ear at 0.2Hz from breathing and at 1Hz from heartbeat.(Traboulsi and Avon 2007). Recent work has measured the transfer function between pulsations occurring in the carotid artery in the neck and the consequent pressure detected in the ear canal, when it was occluded by a microphone (Furihata and Yamashiti 2013). A 600 second analysis of the pressure detected in the ear canal is shown in Fig. 7, where the heart rate is close to 60bpm (1Hz) and two harmonics are shown . Below 1Hz there is infrasound from breathing and other body processes. The pressure in the small volume of the occluded ear canal was 95 -100dB, corresponding to an average ear drum displacement of nearly 0.1μm.

The pressures produced in the inner ear fluid by external infrasound and internally generated infrasound, can be compared by ear drum displacements, allowing for forward gain and reverse losses. The reverse losses in the ear are greater than the forward gain, possibly 20-40dB greater (Hudde and Engel 1998, Puria 2003, Cheng , Harrington et al. 2011). By considering these, it was concluded that the levels of infrasound in the inner ear from internal body sources are greater than those from external infrasound from wind turbines (Leventhall 2013). The body, and vestibular systems, have developed to avoid disturbance from the high levels of infrasound which are produced internally from the heartbeat and other processes. In fact, the hearing mechanisms and the balance mechanisms, although in close proximity, have evolved to minimise interaction. (Carey and Amin 2006).

Assessment

Internally generated infrasound from heartbeat and breathing, which enters the inner ear via the cochlear aqueduct, is greater than that received externally from wind turbines at similar frequencies, perhaps by 20dB or more. Levels of infrasound received from wind turbines at typical residential distances are well below hearing threshold and also mainly below the outer hair cell threshold, proposed by Salt and Hullar as a possible onset level of adverse effects. There is no evidence that this wind turbine infrasound is harmful, whilst there is evidence from atmospheric infrasound that it is not. For example, microbaroms at around 0.2Hz may be of higher level than wind turbine infrasound at that frequency. Microbaroms have been measured at a power spectral density of 120dB at 0.2Hz (Shams, Zuckerwar et al. 2013).

Certainty is never 100%, especially when biological differences are involved, but all indications are that the Wind Turbine Syndrome is based on fallacious reasoning and that inaudible infrasound from wind turbines is not a problem for residents.

However, some people are convinced that they are harmed by infrasound from wind turbines, but this appears to be because they have been told, repeatedly, in publicity opposing wind turbines, that harm will occur. Frequent repetition of an incorrect fact does not make it correct although, as with advertising and propaganda, repetition brings converts. A collection from over 200 web pages and media stories, detailing supposed harmful effects from wind turbines has been made by Simon Chapman, Professor in Public Health at the University of Sydney, and can be viewed on:

<http://tobacco.health.usyd.edu.au/assets/pdfs/publications/DiseaseListIntro.pdf>

Deignan et al have analysed "fright factors" in Ontario newspapers related to wind turbines and concluded that the newspapers contained articles about wind turbines and health that may produce fear, concern and anxiety for readers.(Deignan, Harvey et al. 2013)

Similarly, Chapman considers that the Wind Turbine Syndrome is a "communicated disease", which is spread by concerns of noise rather than by pathological effects (Chapman 2012). Further, a recent study by Crichton et al has shown, in a laboratory setting, that if participants are concerned about the effects of infrasound upon them, they will display symptoms whenever they believe infrasound to be present, whether the infrasound is actually present or not. (Crichton, Dodd et al. 2013) This emphasises the importance of attitudes to a noise source in reactions to it. Objector groups to wind turbine developments have fostered negative attitudes - attitudes which can lead to distress through the nocebo effect (opposite of placebo). (Faase and Petrie 2013, Witthoft and Rubin 2013). The influence of complainant personality traits has been considered by Taylor et al. who have shown that those with negative traits are more likely to be disturbed and report non-specific symptoms.(Taylor, Eastwick et al. 2013)

Conclusion

The reason why some may be disturbed by the low levels of noise from wind turbines is clearly complex and requires a multidisciplinary approach. Whilst there are instances of genuine noise problems from wind turbines, the emphasis on infrasound and its supposed effects on health, distracts attention from solving these. Objectors to wind turbines, who promote wind turbine infrasound as a problem, are not helping those whom they wish to support.**AT**

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Geoff's career has been split almost equally between academic and consultancy work, including two moves between them. During his time as an academic at London University he personally supervised 30 PhD students to completion of their theses in acoustics.

In the past few years he has been invited to sit on three committees concerned with the effects of noise on health. Two of these were for the UK Government, the third was for the AWEA-CanWEA report.

He organises two international series of biennial conferences. Low Frequency Noise (the 15th was in Stratford upon Avon in 2012) and the International Meeting on Wind Turbine Noise (the 5th of which was in Denver in 2013).

Geoff has been practicing as an independent consultant for the past 20 years, working mainly on low frequency noise and infrasound, active control of noise and wind turbine noise.

He is a former President of the UK Institute of Acoustics, presently an Honorary Fellow, and has been awarded the Institute's Tyndall Medal and Stephens Medal for his work. He is also an Emeritus Member of the Acoustical Society of America and a Distinguished International Member of INCE-USA.