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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 a 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 160dB¹ 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/m²) 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).

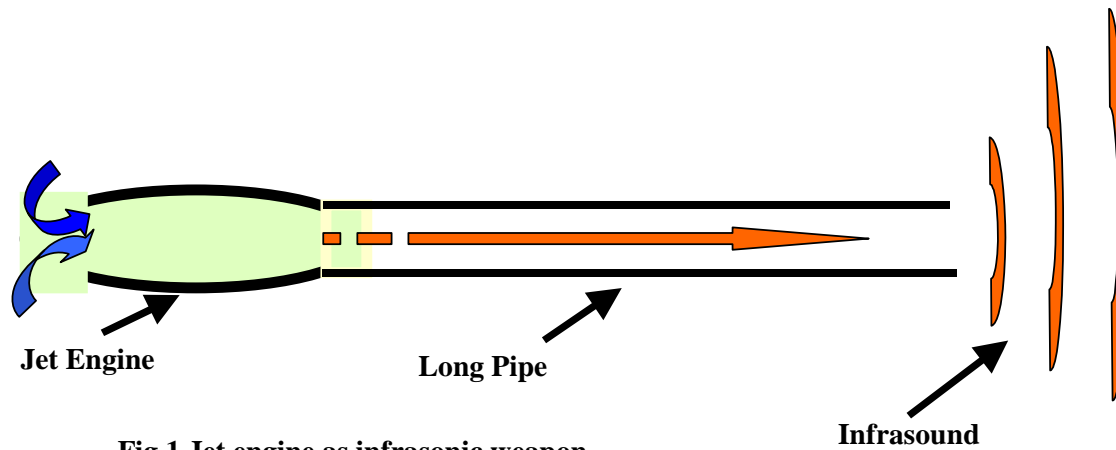
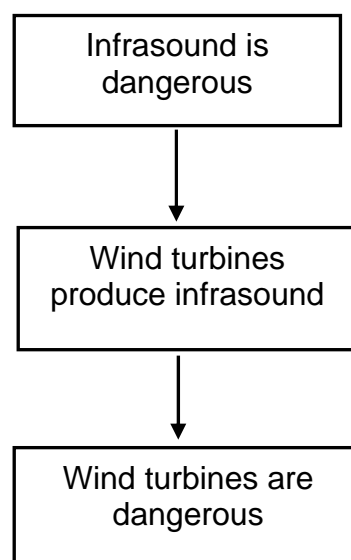


Fig 1 Jet engine as infrasonic weapon

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 objections 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.

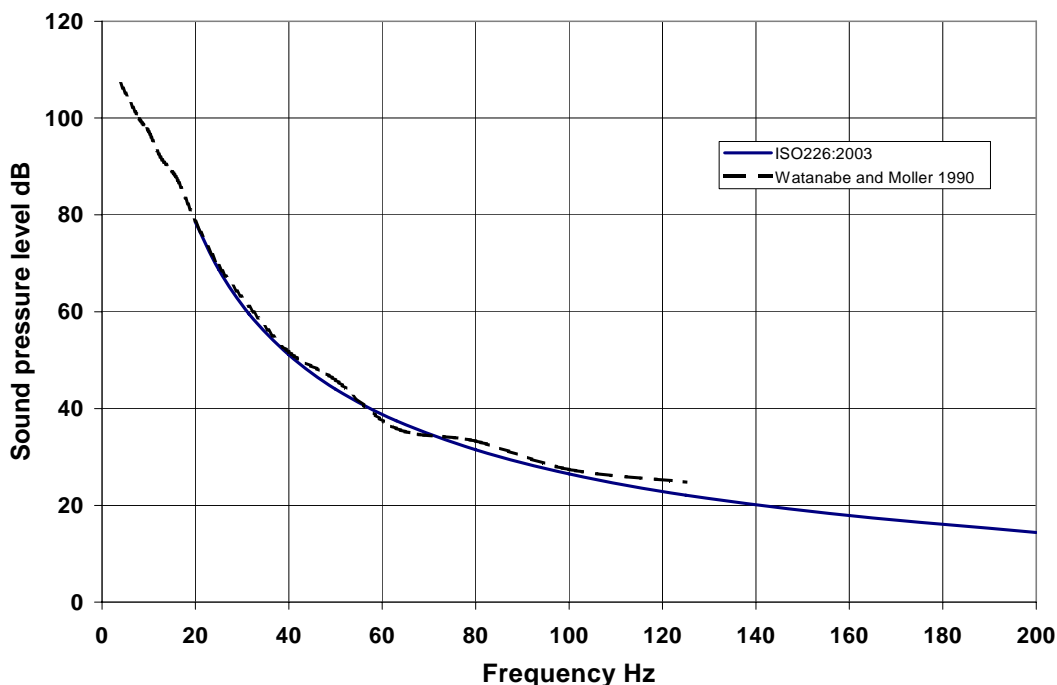


Fig 2. Low frequency threshold

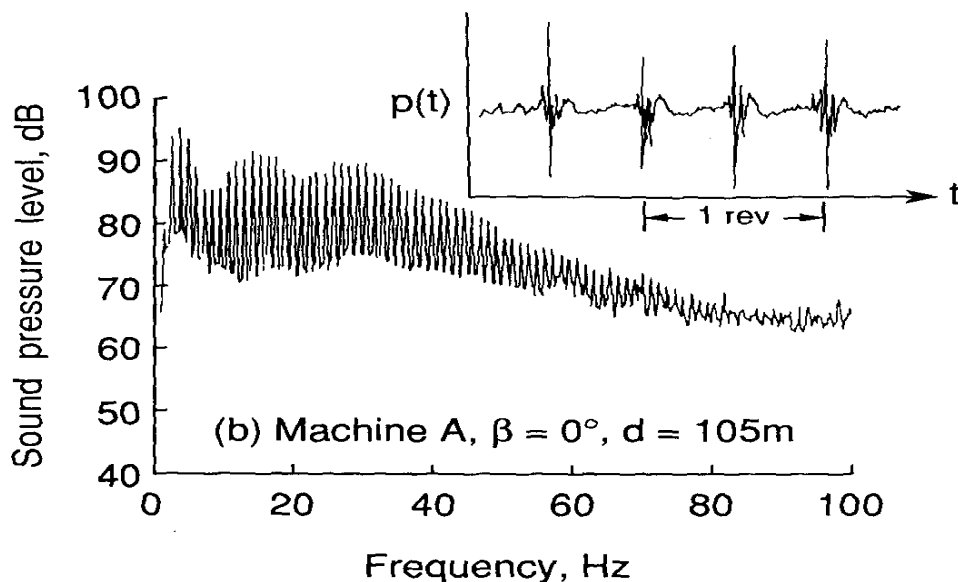
Part of the mythology is that infrasound can be felt but not heard. However, the ear is the most sensitive receptor in the body, as has been shown by threshold measurements on both normal hearing subjects and profoundly deaf subjects, which were carried out down to 8Hz (Yamada et al., 1983). If you can't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

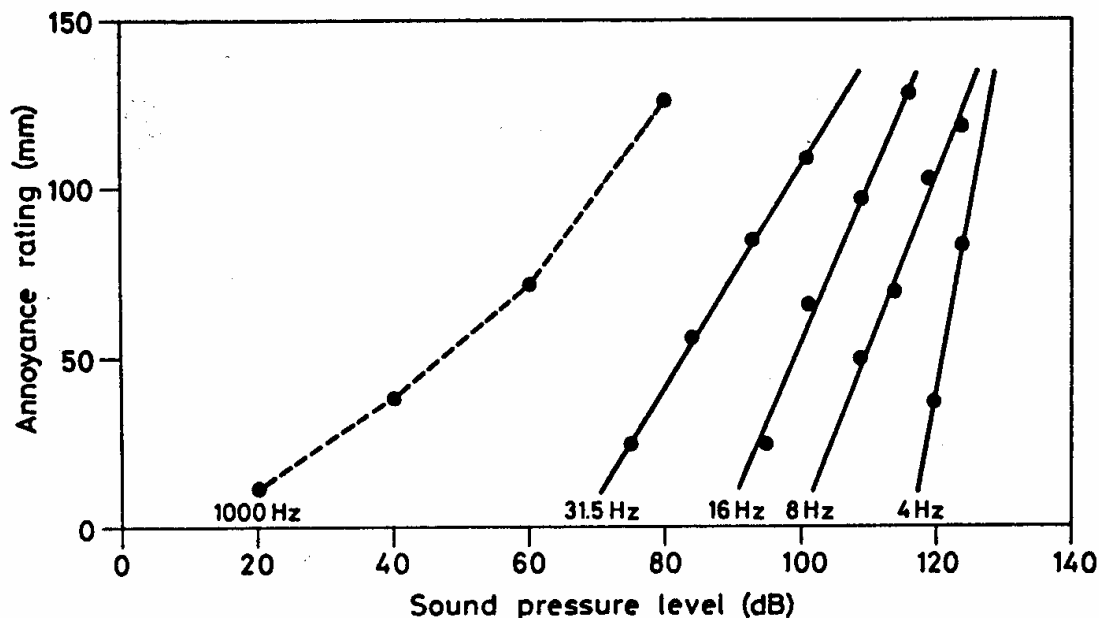
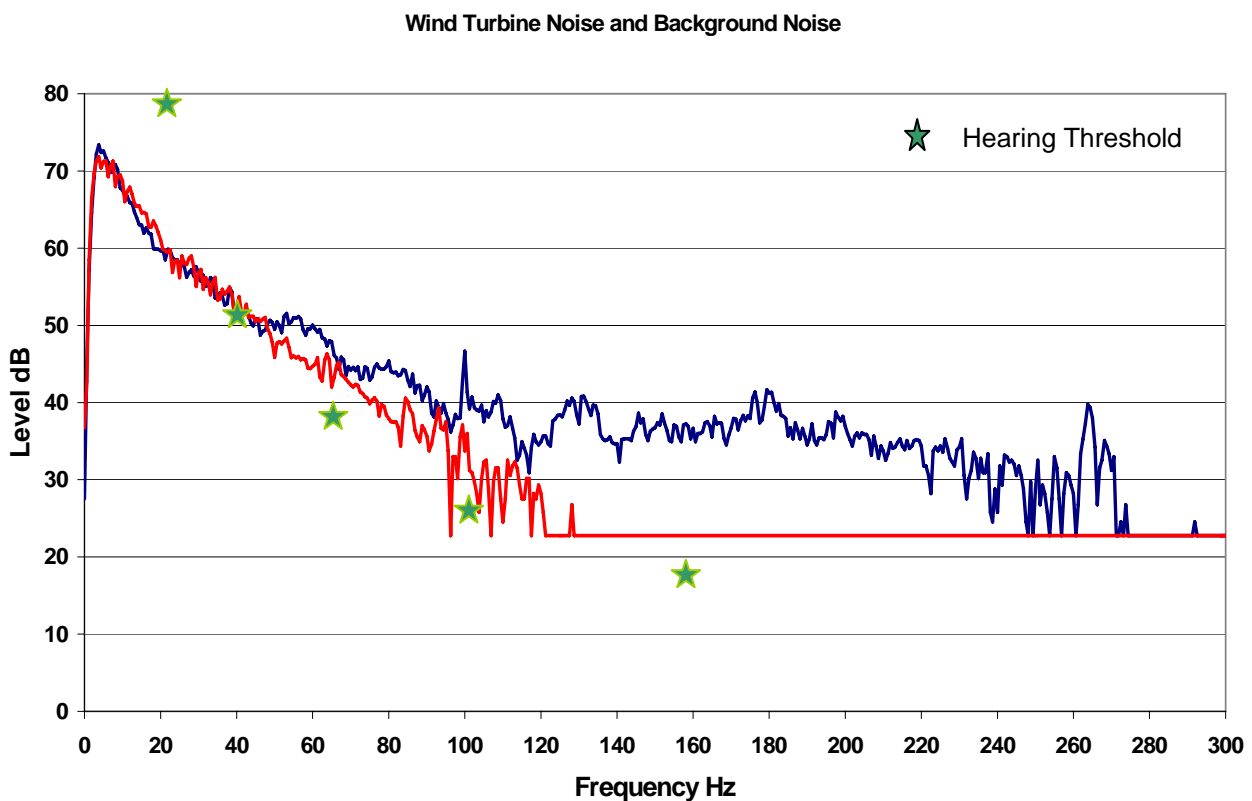


Fig 4 Growth of annoyance at low frequencies

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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