Rigghill Wind Farm – Infrasound and Low Frequency Noise

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The Effect of Pitch or Frequency on the Perception of Sound

1. The perception of sound in the human brain is caused by variation in pressure at the eardrum above and below the residual pressure due to the atmosphere. The rate of this variation gives the sound its apparent pitch with a slower variation causing a perception of a lower pitched sound and, correspondingly, a faster variation causing a higher pitched sound. This rate of variation is referred to as the frequency of the sound which is measured in pressure cycles per second or Hertz (Hz). The amount by which the sound is above a person's hearing threshold sets how loud the sound appears to them and is referred to as the sensation level, measured in decibels (dB).

2. The human ear is less sensitive to sounds at high and low frequencies than for sounds in the middle of the hearing range, meaning that the low and high frequency sounds have a lower sensation level for the same absolute noise exposure level. The ear is most sensitive to the frequencies corresponding to the weaker sounds of speech known as the 'fricatives' which occur at frequencies around 4,000 Hz.

3. If a sound at this frequency were presented to a normally hearing human ear, and then the frequency of the sound were gradually reduced whilst keeping the sound pressure level the same, the sound would not only reduce in apparent pitch but appear to reduce in volume. This reduction in volume is referred to as the 'frequency response' of the ear and occurs because the ear becomes progressively less sensitive to sound as the frequency decreases. This frequency response changes in the case of deafness, whether caused by noise at work, ageing or from other causes, with different causes having their own characteristic frequency response.

4. As a result of the decreasing frequency response of the ear at low and high frequencies, there comes a point at which the sound is no longer perceptible by the brain. In the example above, this point would depend on the level of the initial sound; what this means is that the ear needs a higher and higher level of sound for it to be perceptible as frequency increases or decreases.

5. The human ear is often said to be only responsive to sound between 20 Hz and 20,000 Hz, with sounds above and below these values being referred to as infrasound and ultrasound respectively. Because of the above, this is an over-simplification and, providing they are loud enough, such sounds can be perceived well into these ranges. It should be noted, however, that as the frequency moves significantly into the infrasound and ultrasound regions, the sound levels have to be very loud indeed to be perceived in any way by the hearing mechanism, which is the most sensitive receptor of such signals in the human body.

[1] It should be noted that neither author of this note had any input on the noise assessment chapter in the ES.

6. By way of illustration, a sound at 4 Hz has to be around 110 dB louder than a sound at 4000 Hz for it to be just perceptible – corresponding to an increase of 100,000,000,000 times in terms of sound energy.

7. It is also important to appreciate the tiny strength of these pressure fluctuations. Even a sound pressure level of 100 decibels (dB) has a fluctuating pressure level of 2 Pascals (Pa). Atmospheric pressure reduces with height and a decrease of 2 Pa in pressure is achieved at a person's head by raising its position by 20 cm. So, stepping up and down a single stair subjects the ear to a fluctuating pressure equivalent to 100dB. Doing this at a rate of, say, once per second would therefore generate infrasound at 100 dB.

8. There is often confusion as to the difference between sound at infrasonic and at 'low' frequencies. This can be explained by the above which shows that the distinction between the two is purely arbitrary. What happens is that the threshold of perception; the lowest level which can be heard, increases as the frequency of the sound increases. At 20 Hz, which is generally referred to as where infrasound becomes low frequency noise, the normal threshold of perception is 78 dB. The threshold then increases gradually such that at the top of what is commonly referred to as the low frequency range, at 200 Hz, although again this arbitrary, the threshold is 14 Hz. It can be seen that the low frequency range spans a large range of hearing thresholds.

Infrasound and Wind Turbines

9. Wind turbines produce sound (or noise – which can be defined as unwanted sound) at all frequencies but there has been particular concern over noise at the frequency at which the blades pass the tower, known as the 'blade passing frequency' which invariably lies in the infrasound region[2]. In older designs of turbines, where the blades rotate downwind of the tower, a significant level of noise was generated at such frequencies, resulting from the blades moving from being exposed to the incoming wind into a region of still air behind the tower, and then immediately back into the wind again as the turbine blades rotated around the hub. This design flaw, in acoustic terms, has been eliminated in all modern turbines of commercial scale which are designed with the blades rotating upwind of the tower so that they are always exposed to the full force of the wind.

10. Measurements on upwind turbines[3], show noise at the blade passing frequency to be around 65 dB at around 500 metres, which can be set against a perception threshold of around 125 dB which is 60 dB higher, or 1 million times higher in energy terms. 70 dB of infrasound is described as equivalent to *'fluctuations in air movement that are less than the tiniest breeze through an open window. Perhaps just enough visibly to move a candle flame but probably not'.*

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[2] The blade passing frequency is calculated from the rate of rotation of the turbine hub in revolutions per second multiplied by the number of blades. For a 3-bladed turbine rotating at 20 revolutions per minute the blade passing frequency is 1 Hz

[3] Bowdler D, A Short History of the Dangers of Infrasound, Proceedings of the Institute of Acoustics Vol.40 Page 273-281, 2018

11. These results are usefully put in the context of infrasonic noise from a number of other sources in a German report for the Ministry for the Environment, Climate and Energy of the Federal State of Baden-Wuerttemberg in 2016[4]. This shows infrasound levels inside a moving car, with the window open, at 95 dB as compared to a range of wind turbine noise levels (at 300 metres) between 55 and 75 dB. Noise levels from various domestic appliances are shown to have similar levels of infrasonic noise to that from wind turbines, at similar distances, as is the level of infrasonic noise in an open field with a light wind blowing. Where wind turbine noise measurements were made, there was found to be little difference in infrasonic noise levels with or without the wind turbines operating.

12. A document produced for the World Health Organisation in 1995[5],[6] noted that '*there is no reliable evidence that infrasound below the hearing threshold produce physiological or psychological effects*' and although the latest WHO guidance on environmental noise[7] notes that wind turbines can generate infrasound it states that '*few studies relating exposure to such noise from wind turbines to health effects are available*'.

13. Very specific research carried out by Crichton et al[8] to investigate whether the expectation of experiencing effects from infrasound, at a similar level and frequency to typical levels from wind turbines, had any effect on their perception. This reports that *'results indicated the number of symptoms reported and the intensity of the symptom experienced during listening sessions were not affected by exposure to infrasound*' but that that they '*were influenced by expectancy group allocation*'; ie. by whether they expected to experience such effects or not.

Low Frequency Noise and Wind Turbines

14. No one would argue that wind turbines cannot be heard at the sound levels which are permitted at residential locations for planning purposes. This normally corresponds to a separation distance of between 500 and 1000 metres between such locations and the nearest turbines, depending on the size and layout of the site and the type of turbines installed. At these distances, the sound of wind turbines is not predominantly low frequency in nature but contains audible components both above and below the arbitrary value of 200 Hz which is generally used to delineate between 'normal' and low frequency sounds. Most environmental sounds of human origin, such as that from transportation and industry, fall into this same category. The LUBW study[3] shows the noise from wind turbines, traffic and even a general urban background, becoming perceptible at frequencies above about 30 Hz although, for noisy road traffic, it occurred at a lower level because the overall noise level was raised.

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[4] Low-frequency noise incl. infrasound from wind turbines and other sources, Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg, 2016

[5] Community Noise - Document Prepared for the World Health Organization, Eds. Bergland B. & Lindvall T., Archives of the Centre for Sensory Research Vol. 2(1) 1995

[6] The original document erroneously stated 2002 though the footnote correctly said 1995.

[7] Environmental Noise Guidelines for the European Region, World Health Organization, 2018

[8] Crjchton et al, Can Expectations Produce Symptoms from Infrasound Associated with Wind Turbines?, Health Psychology *33*(4), 360–364, 2014

15. The most important factor in the assessment of low frequency noise is the sensation level (see Paragraphs 1 and 2 (above)) of the noise as it varies with frequency. If the sensation level increases with increasing frequency then the sound will be perceived as not having a specifically low frequency characteristic. If, on the other hand, the sensation level increases with decreasing frequency then the sound will be perceived as having a specifically low frequency characteristic. This is highly unlikely to be the case for wind turbine noise at typical separation distances. Where it can occur, however, is if the turbines emit a very distinct low frequency tone or tones, characterised by a sharp rise and fall in sensation level in the low frequency region and which is normally regulated by planning condition. Alternatively, turbines may be perceived as creating increased low frequency noise if they are a significant distance away, under which circumstances noise levels at all frequencies are relatively low and typically well below permitted noise limits. Specific UK guidance on low frequency noise is provided within a report for the Government by Salford University in 2005 and updated in 2011[9].

Noise, Health and Wind Turbines

16. Noise only has what could be termed direct health effects where it is of such high level that it causes hearing loss. Such high noise levels are not permitted to occur at residential locations by planning and other regulation. Noise at lower levels can, however, cause health effects indirectly through stress and/or sleep disturbance. Stress in itself can cause sleep disturbance and noise can cause stress even if it is only just audible although it is generally accepted that higher noise levels cause higher levels of stress, all other things being equal.

17. Wind turbines have been cited by some as causing effects on health such as sleep deprivation, severe chromic stress and dysfunction of the vestibular system. In her book, *Wind Turbine Syndrome*, Nina Pierpont, a pediatrician in the USA, goes further than this and suggests that noise from wind turbines can cause symptoms which '*include 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 pulsing or quivering that arise while awake or asleep*'. These assertions were based on case studies of 10 families living in proximity to wind turbines who also had health problems (38 people in total). It is suggested by Pierpont that the collection of symptoms '*resembles syndromes caused by vestibular dysfunction*' which she attributes to infrasound. She notes that '*statistically significant risk factors for symptoms during exposure include pre-existing migraine disorder, motion sensitivity, or inner-ear damage (pre-existing tinnitus, hearing loss, or industrial noise exposure)*' meaning that those problems existed prior to any wind turbine noise exposure. No results of any acoustic measurements at the homes of any of the subjects of the case studies were included in the book so the extent to which any of these subjects were exposed to levels of sound at any frequency is unknown.

[9] DEFRA Contract Report NANR45, Proposed criteria for the assessment of low frequency noise disturbance, University of Salford, 2011

18. Similar claims have been made by others including a Portugese research team headed by Mariana Alves-Pereira who has coined the term Vibro-Acoustic Disease to describe physiological damage caused by high levels of industrial noise and who has made claims that the same symptoms can be caused by wind turbine noise without any consideration of the actual levels of noise generated. Alves-Pereira has been known to graphically demonstrate her interpretation of the impact of infrasound on the body by punching herself in the arm or hand[10] to show the physical effect. However, as we have already described the effect on the body is less than lightly blowing on it and bears no resemblance to her self-inflicted assault.

19. The two examples above are symptomatic of the way the alleged effects of wind turbine noise on 'health' have been cited, and the lack of reliable evidence as noted by the WHO and referred to in Paragraph 10 (above). The most important issue in any study of cause and effect is to evaluate both the possible cause, as well as the effects, in detail. In the case of wind turbine noise this would require quantification of noise level right across the frequency range from the blade passing frequency and upwards into the normal audible range with particular attention given to audible sounds, which are known to cause stress and sleep disturbance, rather than those which are orders of magnitude (see Paragraph 8 (above)) below it. In particular, no research alleging health effects from significantly sub-perception wind turbine infrasound appears to have investigated the reasons why infrasound exposure from other sources (see Paragraph 9 (above)) does not cause similar claims of ill-health. Suggestions that wind turbine infrasound causes ill-health fail to explain what the causal link might be either through the hearing or vestibular mechanism and generally confuse the effects of substantial levels of infrasound and/or whole body vibration with the tiny changes of air pressure corresponding to the levels of infrasound generated by turbines (and many general environmental sources.

Conclusions

20. The above presents only a summary of infrasound, low frequency noise and the claimed effects on health of noise from wind turbines. It is apparent from consideration of the evidence, however, that audible wind turbine noise has the capacity for causing annoyance which may in turn cause stress and sleep-disturbance even at low levels. The reason for this is not related to infrasound which occurs at orders of magnitude below perception threshold and which is at a similar level to many other sounds in the environment which people are exposed to on a regular basis without any attributable effects on their health. In this respect, wind turbines are no different to other sources of unwanted noise except in respect of some non-acoustic factors which may affect the subjective response to such noise.

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[10] For example at a presentation in Glasgow http://www.windsofjustice.org.uk/2017/09/wind-turbine-noise-seminar-review-and-up-date/ and in Slovenia https://www.youtube.com/watch?v=ZXCZ3OyklrE at 1m 10s.