

**From:** MA.DR SWINBANKS

**To:** MPSCEDOCKETS;

**CC:** MA.DR SWINBANKS;

**Subject :** Re: Case No U-15899

**Date:** Wednesday, December 09, 2009 10:09:47 AM

**At tachments:** MAS Research Ltd Michigan Windmill Letter.doc

Dear Sir, **Case No U- 1 5 8 9 9**

I am enclosing a Word document relating to comments on Windmill Setbacks & Noise, which represents a letter that I have sent to you. I posted this letter in Port Hope yesterday, and hope that it arrives in Lansing before your Friday 5pm deadline. But I am also enclosing an electronic copy with this email. I hope this is satisfactory.

Sincerely,

M.A.Swinbanks

1

## MAS Research Ltd

### Mathematical & Scientific Research

Tel: 011-44-1-223-512250

Company Number 1586916 8 Pentlands Court

Incorporated 1981 Pentlands Close,

Cambridge CB4 1JN,

Executive Secretary, MPSC, United Kingdom

P.O.Box 30221, December 8th, 2009

Lansing,

Michigan 48909

Dear **Re: Case No U-15899**

I am a professional consultant engineer, and my company is based in the United Kingdom, but fourteen years ago I was asked to come to the US to lead an advanced research project for the Office of Naval Research. My American wife & I now live at 7087 Kinde Road, Port Hope, Michigan. During the course of my career, I became a consultant to many different companies and research organizations on a wide variety of problems related to unsteady dynamics, noise, vibration, shock and acoustics. I have worked personally with both Professor J.E.Ffowcs-Williams, and Dr H.G.Leventhall, two of the foremost UK acousticians. 20-30 years ago, I worked directly in collaboration with both on several low-frequency noise installations, thus gaining first-hand experience of the problems associated with low-frequency noise and infrasound. My actual time-on-site addressing low-frequency noise probably well exceeds either. [ 1], [2 ].

This letter addresses three separate issues relating to wind-turbines. First, an unresolved issue relating to low-frequency sound generation by wind-turbines. Second, further well-established characteristics of low-frequency noise. Third, the present status of permitted noise levels and setbacks.

#### **(1) Low-Frequency Sound Generation by Wind-Turbines**

The opinions of the two UK acousticians relating to wind-turbine noise differ. Professor Ffowcs-Williams has stated *"It is known that modern, very tall turbines, do cause problems, and many think the current guidelines fail adequately to protect the public."*

while Dr Geoff Leventhall has commented *"I can state quite categorically that*

*there is no significant infrasound from current designs of wind turbines.*

*• Infrasound is not a problem, • Low frequency noise may be audible under certain conditions, • The regular 'swish' is not low frequency noise."*

2

In practice, the transition from infrasound to low-frequency sound may be blurred. Based on my own experience, the consistent reports of physical discomfort resulting from wind-turbine noise reinforce my perception that low-frequency noise can indeed be a problem. The reported effects are entirely consistent with those that I have experienced at first hand, 20-30 years ago.

Low frequency noise can induce feelings of discomfort and nausea, not unlike seasickness. Like seasickness, the sensitivity of different individuals varies enormously, some being immediately sensitive, while others can barely detect anything. I have stood beside two people on a site where low-frequency noise was present. One person said "I can't really hear anything". The other said "I feel ill – I should like to leave". Both were reporting accurately; there can often be more than 12dB difference ( a factor of 4) in the sensitivity of individuals to low-frequency noise. Given that for very low frequencies, 12dB represents the difference between just audible, and uncomfortably loud, it is clear that very real problems are experienced by some individuals, while others remain largely unaffected.

It is important to emphasize that there does not yet appear to be a full understanding of how to assess low-frequency wind-turbine noise. As recently as April 2008, A Danish researcher, T.H.Pedersen demonstrates clearly in [3] how different conventions for measuring the noise field of a turbine can lead to diametrically opposite conclusions. He summarizes by writing "The above mentioned issue has been discussed with a number of researchers (Henrik Moller, Aalborg University, Torsten Dau, Danish Technical University, Hugo Fastl and Geoff Leventhall) and solutions have been sought for without result." He goes on to describe a procedure involving weighting the spectra with the inverse hearing-threshold (HT-weighting) but while clarifying the problem, this does nothing to resolve the issue.

So it is difficult to understand how it can be argued emphatically that there is no problem, when it is clearly reported that significant ambiguity still remains in assessing these effects.

The present author has considered this aspect, and believes that the misunderstanding may lie in a failure to take into account correctly the impulsive nature of the turbine noise, as each blade passes the tower, and interaction takes place between the blade, the wake, and the tower. Although it is now widely recognized that this can give rise to low frequency modulation of higher frequency aerodynamic noise, resulting in a "swishing sound" (aerodynamic modulation), it remains the case that the low-frequency effects of the impulse are often incorrectly analyzed. This latter effect has been described as a distinct repetitive "thumping sound" audible at distances of 500 to 1000 meters (~ 1600 to 3300 ft.)

The feature of impulsive noise is that there is a large signal present for a short period of time. Consequently, the mean, or root-mean-square (rms) level of the signal may be very low, apparently well below the threshold of hearing, but the peak level is much higher and can be perceived. This ratio of peak-to- mean level is the Crest-Factor.

3

The present convention of combining frequency-weighted spectral or octave levels only measures the rms level – it does not take any account of the crest-factor.

The hearing threshold has been determined experimentally using individual sinusoidal sound waves. But sinusoidal waves have the lowest of all crest factors. C.S.Pedersen [4] has reported that band-limited 2Hz-20Hz, and 2Hz-40Hz white noise is audible 7-10dB below the threshold defined for sinusoidal signals. This observation is consistent

with the increased crest-factor of such noise. But low-frequency, repetitive impulsive sounds possessing a multiplicity of harmonic components, have an even more recognizable characteristic, and are likely to be audible at even lower levels. Preliminary calculations indicate that periodic 1Hz impulses may be audible even when the individual components of spectral lines lie 25dB below the threshold of hearing. So simply examining low-frequency spectra and observing that individual spectral lines lie well below the threshold of hearing does not begin to summarize this situation accurately. A further comment relates to this impulsive component of noise. If an observer stands near to the wind-turbine, the distance from him to different portions of the tower and blade varies significantly. Consequently, the time taken for sound to propagate to this observer differs for each portion of the blade segment. As a result, the arrival times of the impulsive effects are "smeared-out", and much less audible, despite the close-up distance. But for an observer positioned several hundred feet away, along the line of the axis of the turbine, the impulsive components all tend to arrive at the same time, giving a much enhanced effect.

## **(2) Additional Well-Established Effects of Low-Frequency Noise**

Two further effects relate directly to the annoyance of low-frequency noise. The hearing threshold of individuals does not remain fixed at a constant level, but rises or falls according to the background sound level. In addition, there is an acquired learning process, where a person can become much more sensitive to a specific low-frequency sound after repeated exposure. Unfortunately, the people most likely to become ultrasensitive to low-frequency wind-turbine sound are precisely those people who live closest to the unwanted source.

The variation of hearing threshold according to background noise has an important consequence. People are often invited to visit wind-turbine sites during daytime, when ambient levels are high, and they conclude that the turbine noise levels are not excessive. But under these circumstances, their own threshold of hearing is raised, so the extent to which the turbine noise protrudes above their threshold is minimal. But at night, in the quiet of an interior living room or bedroom, the ambient level is lower, their hearing threshold drops accordingly, and the wind-turbine noise can rapidly become intrusive or intolerable.

Indeed, subsequent attempts to shut out the sound, by closing doors and hiding under pillows and bedclothes, have exactly the opposite effect. The higher-frequency

4

background ambient levels are reduced still further, while the remaining component, the penetrating low-frequency turbine noise, can become even more dominant.

Several additional physical effects can cause the low-frequency sound levels of wind turbines to rise above conventional expectation. G.P. Van den Berg [5] has reported that variations in wind-gradient at night can cause wind levels at the turbine hub height to be considerably greater than wind speeds near ground level, thus giving rise to a more rapidly changing wind profile and underestimates of true wind speed. He reported increased sound levels of 15dB as a consequence.

In addition, the present author is familiar with reduced-temperature night-time conditions where low-frequency sound from a gas-turbine installation could be audible at distances of 1-mile (5280 ft), given appropriate atmospheric conditions, possibly associated with a temperature inversion. Calculation would have predicted that the gas-turbine noise should have been inaudible at approximately 400 yards (1200ft). By implication, the attenuation with distance was very much less than expected, apparently by an amount corresponding to over 12dB.

Finally, it should be noted that operation of several wind-turbines together, near synchronized, gives rise to additional modulation of sound intensity which itself can be very disturbing, and yields higher than predicted sound levels. Van den Berg has

reported this effect, and measured rising and falling intensities corresponding to the effects of the turbine noise sources moving into and out of phase.

Few, if any, of these directly relevant effects are taken into account in the present assessments of the low-frequency noise associated with wind-turbine farms. Yet they directly impact the quality of life for individuals and families living close to wind-farms.

### **(3) Setbacks & Noise Criteria for Wind-Turbines.**

It should be noted that UK criteria have been guided by a 1997 recommendation, *ETSUR-97* which has advocated night-time levels not exceeding 43dBA or 5dBA above background levels for external noise-levels at habitations. Specific setbacks are calculated according to the individual performance data and geometry of proposed wind turbine configurations, but in general, have tended to underestimate the actual sound levels that subsequently are manifest in practice.

These criteria have been consistently questioned for 12 years since 1997, and there have been repeated requests to revise the criteria in the light of actual experience. Professor J.E.Fowcs-Williams has stated

*"Van den Berg's paper adds weight to the criticisms frequently offered of UK regulations covering wind turbine noise, ETSU-R-97. The regulations are dated and in other ways inadequate. It is known that modern, very tall turbines, do cause problems, and many think the current guidelines fail adequately to protect the public..... It really is time for the DTI (Dept of*

5

*Trade & Industry) to clear the air on this one, and institute a comprehensive and fully transparent study, obtaining data from the United States and Europe, as well as the United Kingdom."*

Given that the UK night-time levels of 43dBA are now proving to be inadequate in practice, it is clear that proposed Michigan levels of 55dBA, corresponding to sound pressure levels 4 times higher, and 1000 ft setbacks would likely represent intolerable levels for many members of the community.

Moreover, the convention of using the A-weighted decibel scale has itself been questioned, since this specifically filters out and minimizes the effects of low-frequency noise. The flatter C-weighting scale has been suggested as a more appropriate alternative. This issue relates back to the author's earlier comments about the lack of rigour in defining the low-frequency impulsive effect.

In respect of actual measured levels for a wind farm, the paper by Van den Berg is very relevant. He measured sound levels adjacent to a wind farm consisting of seventeen 1.8MW wind-turbines. In particular, he derived a continuous record of dBA levels taken at 50 millisecond intervals, which showed modulating peak levels of 51-53dBA recorded on the terrace of a house 750m ( ~ 2500ft) from the wind farm. Projecting these levels back to 1000ft, would imply peak levels 8dB higher at 59-61dBA.

Van den Berg [5] described the situation as follows: *"However, on quiet nights the wind park can be heard at distances of up to several kilometers when the turbines rotate at high speed. On these nights, certainly at distances between 500 and 1000m ( ~ 1600 and 3300 ft) from the wind park, one can hear a low pitched thumping sound with a repetition rate of about once a second (coinciding with the frequency of blades passing a turbine mast), not unlike distant pile driving, superimposed on a constant broadband 'noisy' sound. A resident living at 1.5km (~ 4900 ft) from the wind park describes the sound as 'an endless train'."*

In conclusion, it is well-reported that the close proximity of wind-turbines to residences can cause very real annoyance and distress. Experience in practice has consistently shown that present guidelines for setbacks are proving to be inadequate. There is no fully agreed method of defining accurately the low-frequency noise effects, largely because these can vary markedly according to circumstance, wind gradients, atmospheric

conditions, and personal susceptibility. Consequently, it is important to be guided by lessons learned from experience.

Yours Sincerely,

Malcolm A. Swinbanks, M.A., PhD

References /(over)

6

#### References

[1] Swinbanks M.A. The Active Control of Low Frequency Sound in a Gas Turbine Compressor Installation, Inter-Noise '82, May 17-19, 1982

[2] Swinbanks, M. A. The Active Control of Noise and Vibration and some Applications in Industry. Proc. IMechE 198A, No. 13, pp. 281–288, 1984.

[3] Pedersen T.H. Low Frequency Noise from Large Wind Turbines  
A Procedure for Evaluation of the Audibility for low Frequency Sound, and a Literature Study. Delta Acoustics & Electronics. AV 1098/08 30 April 2008

Client: Danish Energy Authority

[4] Moller H & Pedersen C.S. Hearing at Low & Infrasonic Frequencies, Noise & Health, Volume 6, Issue 23, April-June 2004

[5] G.P. van den Berg Effects of the wind profile at night on wind turbine sound. Journal of Sound and Vibration, Volume 277, Issue 4-5, p. 955-970, 2004

## Biographical Sketch



Dr. Malcolm Swinbanks has worked for 23 years as an engineering consultant through his UK Company, MAS Research Ltd. (Mathematical & Scientific Research) and, more recently, as Chief Scientist to the U.S. Company Vibration & Sound Solutions Ltd. of Alexandria, Virginia. Encouraged to study applied mathematics, he gained 1st class honors at Trinity College, Cambridge, in 1970, before taking his Ph.D. under Professor Sir James Lighthill, one of the foremost applied mathematicians of the 20th century. He addressed theoretically the control of distributed parameter systems, focusing on fluid mechanics and wave propagation, and in 1972 filed his first patent on active control of sound propagation in ducts.

To broaden his skills in practical engineering, he worked as Marine Consultant Engineer for YARD Ltd (Yarrows Admiralty Research Department). Yarrows was a Scottish shipbuilder whose founder, Sir Alfred Yarrow, gave the first graphic demonstration of vibration cancellation in a torpedo boat, in 1892.

While he was addressing vibration isolation in naval ships, the National Research Development Corporation took up his patent, funding development of the first industrial active gas turbine exhaust silencer at Duxford, near Cambridge. Dr. Swinbanks returned to Cambridge University to lead this project successfully from 1979-1981, as Consultant to Topexpress Ltd.

He established MAS Research Ltd. to provide consultancy to the UK marine and aerospace industries. Rolls-Royce Aero Engines invited him to participate in their program for Active Control of Compressor Surge and Stall, resulting in the first successful demonstrations on a Viper jet engine in 1991. He worked for Douglas Aircraft and GEC Avionics on active silencing for propeller noise in aircraft cabins, and from 1990 collaborated with GEC Marconi Research on Project M, an offshore DARPA research program in active vibration control. In 1995, the U.S. Congress requested that this project transfer to the United States. Vibration & Sound Solutions Limited (VSSL) was formed to provide the focus, and the work was successfully transitioned, leading to a one-quarterscale demonstration of a large-scale machinery installation in 2000. Subsequently, the Office of Naval Research asked VSSL to investigate potential application to mitigating shock for occupants of high-speed vessels. Present R&D is focused on bringing active and passive techniques to fruition in this context.

Dr. Swinbanks is inventor of 15 patents, with three pending.