Submission to the Senate Community Committee Affairs
'Inquiry into the social and economic impacts of rural wind farms'
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From Dr Geoff Leventhall

I have worked in the areas of infrasound and low frequency noise, and their effects on people, for over 40 years, as both an academic and a consultant. During my academic career I ran an active and highly regarded research group at London University and personally supervised 30 students to completion of their PhD degrees, a number of them in the areas of infrasound and low frequency noise. I was President of the UK Institute of Acoustics during the mid 1980s and, in recent years, have been a member of three committees considering the effects of noise on health. My short CV is attached.

Over the past 10 years unsubstantiated claims of harm from the noise of wind turbines have appeared in internet and print media publications. These claims have as their focus pathological effects of infrasound and low frequency noise from wind turbines, claiming direct effects on the body. The origin of these claims can be traced back to the late 1960s and early 1970s, when media hype, together with misleading presentations from a few scientists, who may have not been familiar with the workings of the media, led to misrepresentation in order to give exciting and scary news stories. A paper by Gavreau is one of the origins of the hype (Gavreau, 1968). A succession of "reinterpretations" over a period of five or six years led infrasound and low frequency noise to be described in popular science texts as a cause of death, whilst also possessing the ability to knock down buildings (Watson, 1974). The aura of mystery and danger still persists today, deep in the minds of many people, where it waits for a trigger to bring it to the surface. The most recent trigger has been wind turbines.

It is interesting to note that during the height of the media scare stories, work was in progress in the USA in connection with the Apollo space programme, including exposure of potential astronauts to very high levels of infrasound (130dB or more) in the infrasonic range around 10Hz (von Gierke and Nixon, 1976) (Mohr et al., 1965). This work did not attract media interest because it was well conducted and published responsibly. The work showed that there was very little effect during exposure and no post exposure effect. In comparison, wind turbine noise at 10Hz is about 60dB- 70dB, whilst the standard hearing threshold at this frequency is nearly 100dB. Comparing exposures at 70dB and 130dB, in order to receive the same noise "dose" at 70dB as the astronauts were given at 130dB, the exposure time at the lower level will need to be one million times longer than that at the higher level.

Despite claims going back over 40 years, no direct adverse effect of infrasound and low frequency noise has been demonstrated at the levels produced by wind turbines, but there is much supposition. Infrasound now occupies a special place in the communal psyche of various groups of people, who have willingly accepted the suggestion that there is something "creepy " or even "dangerous" about infrasound (Leventhall, 2006).[1] Some have made this acceptance because they enjoy being on the fringe of scary science, even though it is junk science whilst, on the internet, infrasound is often linked to the paranormal. Others have made this acceptance because it suits their opposition to wind turbines to do so. Nina Pierpont is one of these.

Pierpont, began her claims when, about six years ago, she came to local prominence as the leading campaigner against a proposal to erect wind turbines near to her home town of Malone, NY. Since that time, Pierpont has continued her publicity campaign and risen to further prominence in the national and international objector league. Some of the methods she used to achieve this position were questionable, particularly her misuse of other people's work, which led to one scientist publicly repudiating the manner in which she had misrepresented his findings (Todd, 2009). I believe Pierpont to be a campaigner first and scientist second.

My own study of Pierpont's writings has led me to the conclusion that she has a rather poor understanding of acoustics. Her main work has been the self- published, popular science

[1] This paper is attached

book “Wind turbine Syndrome”, in which she puts forward hypotheses on assumed effects of inaudible infrasound acting directly on both the vestibular system in the ear and related balance receptors in the body (Pierpont, 2009). However, a study of her hypotheses shows them to be weak and unfounded, as described in a critique which is attached.

A problem which arises from strong and persistent publicity of any kind, is the formation and manipulation of attitudes. In this case, attitudes to wind turbines and the fears and concerns which flow from the dissemination of negative feelings.

An earlier Australian study of Rural Wind Farms, concluded on page 121 (New South Wales. Parliament. Legislative Council, 2009 (December))

> 7.56 The Committee notes the concerns expressed by Inquiry participants regarding ‘Wind Turbine Syndrome’. The Committee further notes that research findings of ‘Wind Turbine Syndrome’ have not been published in a peer-reviewed journal.
>
> 7.57 The Committee is concerned that the significance of ‘Wind Turbine Syndrome’ is being unnecessarily exaggerated because Dr Pierpont is a medial doctor and has published a book on the issue, rather than any scientific merit of such a syndrome. As a result, a degree of fear is being instilled in communities that may host wind turbines. The Committee is concerned that, based on evidence received, this unwarranted fear may be causing greater health impacts than the presence of any actual ‘Wind Turbine Syndrome’.

Pierpont’s book, and the views expressed in it, made it necessary for others to consider the reliability of her claims of pathophysiological effects of infrasound from wind turbines and the following studies were made.

- Wind Turbine Sound and Health Effects. An Expert Panel Review prepared for the AWEA and CanWEA (Colby et al., 2009)
- The Potential Health Impact of Wind Turbines (Chief Medical Officer of Health Ontario, 2010 (May))
- Wind Turbines and Health (Australian_Government:_National_Health_and_ Medical_Research_Council, 2010 (July); New South Wales. Parliament. Legislative Council, 2009 (December))
- The Effects of Wind Turbine Sound on Health (Sims, 2010)

These four reports all concluded that there was no evidence of a direct pathophysiological effect from wind turbines, contrary to claims by Pierpont.

The difference in views between Pierpont and other objectors on the one hand and various experts on the other hand, has served to obscure and misdirect the wind turbine noise debate. It is very unlikely that anyone disputes that wind turbine noise, when it is audible, might annoy some people. The debate should not be about illness said to be caused by infrasound, but about how and why an audible noise, which is normally a rather low level of noise, might become a problem to some people. This aspect has been covered in the submission from Dick Bowdler.

There is genuine concern about infrasound, but only because people have been repeatedly *told* that it will harm them.

An insight into infrasound and the ear has recently been given by Salt and Hullar (Salt and Hullar, 2010). Salt showed that, in the guinea pig, the outer hair cells (OHC) in the inner ear respond to infrasound at levels below the threshold of audibility. This has been seized upon by objectors to wind turbines to support their views on harmful effects of inaudible infrasound. However, the conclusions of the paper by Salt and Hullar commence with the clear statement:

> 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 anyway.

It is interesting to note that, if the effect described by Salt did not occur, our hearing thresholds at infrasonic frequencies would be around 30dB lower than they are. We would then be hearing much of the naturally occurring infrasound which surrounds us, so affecting our communication and awareness of danger signals. It appears that the “Salt effect” is a desirable evolutionary development, and therefore unlikely to have an adverse consequence

Attitudes and sensitivity to noise are not fixed quantities. Recent work has shown that desensitization to a troublesome noise is possible through a course of Cognitive Behavioural Therapy. See **www.copingwithnoise.org** , which gives a link to an interim report on this work.

In conclusion, my belief is that:

- There is no problem from infrasound from wind turbines.
- Low frequency noise may become audible outside residences at frequencies above about 40 to 50Hz.
- The main noise from wind turbines is the intermittent, audio frequency, swish sound.
- A low level of audible noise is not normally a problem, unless the listener is antagonistic to the source.
- Much of the effort of objector groups has been directed towards engendering antagonism to wind turbines

Once antagonisms been developed, even the slightest perception of a noise may lead to stress and, in its turn, long term stress may lead to somatic effects. However, this is not a function of the characteristics of the noise alone, but of the noise and listener in combination

Dr Geoff Leventhall 8 March 2011

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Short CV of Dr GEOFF LEVENTHALL

Geoff Leventhall is an experienced Acoustical Consultant, who works internationally on problems of noise and its control. He has had academic and research experience in addition to commercial consultancy work.

KEY QUALIFICATIONS

- BSc - Physics
- MSc - Acoustics
- PhD - Acoustics
- Fellow of the Institute of Physics
- Member of the Acoustical Society of America
- Honorary Fellow of the Institute of Acoustics
- Awarded Tyndall Medal (1978) and Stephens Medal (2001) of the Institute of Acoustics
- Institute of Noise Control Engineering (USA). 'Distinguished International Member'
- Affiliate of the Chartered Institution of Building Services Engineers (UK)
- Member of the American Society of Heating, Refrigeration and Air-conditioning Engineers
- Honorary Member UK Association of Noise Consultants

KEY EXPERIENCE

- Low Frequency Noise, Infrasound and Vibration
- Active Attenuation of Noise
- Wind Turbine Noise
- Noise and Acoustic Design in Buildings and HVAC
- Environmental Acoustics
- Noise and Vibration from Transportation
- Noise and Vibration Control
- Founding Editor of Journal of Low Frequency Noise and Vibration
- Organiser of two series of International Conferences:1) Low Frequency Noise 2) Wind Turbine Noise

COMMITTEE MEMBERSHIP

- Council of the Institute of Acoustics - President 1984-1986.
- National and International Committees dealing with noise and vibration.
- Director - International Institute of Noise Control Engineering 1986-89.
- DoE Noise Review Working Party (1990).
- DTp Mitchell Committee on Railway Noise (1990).
- DTp Committee framing Noise Insulation Regulations for new railways and Noise Calculation Technical Procedure (1992-96).
- Member of DoE/Defra 'Noise Forum' (1993>>>).
- Member of International Committee advising the Swedish Work Environment Fund on subjective aspects of noise research (1994).
- Member of International Committee advising the Swedish Research Council on Engineering Sciences on technical aspects of noise research (1995).
- Director INCE/Europe (1999 >>>)
- Member of Department of Health Committee considering the health effects of noise (2004-2009)
- Member of Health Protection Agency Committee considering health effects of ultrasound and infrasound (2005-2009)
- Member of Department of Trade and Industry Committee considering wind turbine noise (2006)
- Member of AWEA -.CanWEA Committee considering effects of noise on health (2009)
- Member of the UNECE GRB QRTV Working Group on quiet electric vehicles

PREVIOUS POSTS

- Professor and Head of the Institute of Environmental Engineering at London South Bank University.
- W S Atkins Group Consultants - Head of Acoustics and Technical Director.
- Chelsea College, University of London, Leaving (1982) as Reader in Acoustics and Head of Applied Acoustics Group. Personally supervised 30 PhD students to completion of theses on effects and control of noise.

- Currently acts as external examiner for higher degree theses in acoustics both in the UK and abroad.

Exhibit 18

Dr Geoff Leventhall MSc PhD FInstP HonFIOA
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Wind Turbine Syndrome – An appraisal

By Geoff Leventhall

This appraisal is based on a review of the material which has been on the web page www.windturbinesyndrome.com and on the digital version of paediatrician-ornithologist Dr Nina Pierpont's forthcoming self-published book "Wind Turbine Syndrome" (prepublication draft dated June 30, 2009).[1]

I am not a neurologist, and so my discussion will focus on the physics and acoustics addressed by Pierpont in her book. It will be shown that Pierpont's poor understanding of physics and acoustics has led her into errors which invalidate her discussions on neurological effects, at least in so far as the low levels of infrasound and low frequency noise from wind turbines are concerned.

1.0 Introduction. The book is easy to read and has nearly 150 references. On page 9 Pierpont states that her goal is "scientific precision." She interviewed a number of people who responded to a request she published online seeking individuals who claimed to be adversely affected by wind turbine noise, and lists the symptoms for ten families, giving data on 37 exposed persons. She groups the symptoms together as the Wind Turbine Syndrome of the title, and explains their origin through two hypotheses described by her as follows:

2.0 Hypothesis 1 - Book page 10.

> **"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. Several lines of**

[1] The page numbers given in this appraisal are from the prepublication draft. They will not be the same as those in the printed book. The Book is published by K Selected Books. Dr. Pierpont and her husband, Calvin Martin, are two of the four editors of K Selected Books.

> **evidence suggest that the amplitude (power or intensity) of low frequency noise and vibration needed to create these effects may be even lower than the auditory threshold at the same low frequencies. Restating this, it appears that even low frequency noise or vibration too weak to hear can still stimulate the human vestibular system opening the door for the symptoms I call Wind Turbine Syndrome. I am happy to report, there is now direct experimental evidence of such vestibular sensitivity in normal humans."**

3.0 Hypothesis 2 - Book page 42.

Note: VVVD is "visceral vibratory vestibular disturbance," which is a symptom Pierpont claims to have discovered, and claims is uniquely caused by wind turbines.

> **"With this background, I propose the following mechanism for VVVD. 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 vibrations or pressure fluctuations may also be occurring at different frequencies, without this particular resonance amplification.) 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."**

3.1 To summarise, Pierpont's thesis is that the low levels of infrasound and low frequency noise from wind turbines have a direct pathophysiological effect on the body, through the vestibular system (the system within the body that senses motion) and also by excitation of the airways and diaphragm to the viscera. Based on these hypotheses, Pierpont follows with a lengthy review of the neurology of vestibular disturbances and related matters. What she writes on neurology may or may not be good science, but appears irrelevant to noise produced by wind turbines, because her theory requires that wind turbine noise delivers orders of magnitude more energy to the listener than in reality, and because it posits impacts from low frequency sound that have never been observed from another source of similar level to the sound from wind turbines. We are then left only with the results of her telephone interviews, which will be referred to later.

4.0 The fundamental flaw in all of Dr. Pierpont's work is that she has a poor understanding of the fundamental physics of acoustics and vibration, which has hampered her work from the beginning, seriously limiting her ability to contribute in these areas. In common with many other lay people, she does not have an adequate understanding of acoustic levels, or of the pressures which lie behind decibels.[2]

5.0. Levels of infrasound and low frequency noise from wind turbines.

Pierpont (page 57) quotes van den Berg as giving wind turbine levels outside of a residence at a persistent complaint location as

1Hz	70 –100dB
10Hz	55 – 75dB
100Hz	50 –60dB

The levels at 1Hz are inaudible, and are within the range of naturally occurring infrasound (Bedard, 1998). We are exposed to infrasound in many of our activities. For example: when driving a car, especially with a window open; when jogging, where the change in level of the head produces infrasound at a frequency of a few hertz and level about 90dB. Even a child on a swing experiences infrasound at about 110db and 0.5Hz, depending on the length of the swing and change in height. If these levels of exposure are problematic, we should expect to see the effects in a wide swath of the exposed population.

Likewise, the levels at 10Hz are about 40 to 25 dB below the hearing threshold and will not be audible.

[2]For example, she tries, incorrectly, to manipulate decibels on page 46 of the book, whilst in the quotation on Hypothesis 1 above, an acoustician would not refer to "power or intensity" of a noise, but to pressure or intensity. There are other instances in the book and in her earlier work where she similarly misapplies acoustic concepts.

The levels at 100Hz are 20 – 30 dB above normal hearing threshold and will be audible externally. For comparison, 60 dB is sometimes identified as the sound level of a conversation at normal volume, at a distance of three feet.

Hayes (Hayes, 2006) carried out extensive measurements at three wind farms, where there had been complaints, finding similar, or lower, levels outside, and levels inside the house typically of

1Hz	around 70dB
10Hz	around 55dB
100Hz	around 30dB

The level of 30dB at 100Hz is a little above the average hearing threshold at this frequency.

6.0 Comments on Hypothesis 1-Vestibular Sensitivity to low-level, low-frequency sound.

Pierpont's statement that "several lines of evidence suggest" that low frequency sound at very low amplitude may cause physiological effects demands references, but none are given at that point. The only support which Pierpont gives is a paper by Todd and colleagues (Todd et al., 2008), which she claims as "direct experimental evidence of such vestibular sensitivity in normal humans." Her use of this paper is very puzzling, indeed alarming. The paper is entirely about sensing a vibration input to the mastoid area of the head, by both the normal hearing mechanism – the cochlea – and by the vestibular system. It does not deal with air conducted sound. Yet on her web page she wrote[3]

> **"In an article titled "Tuning and sensitivity of the human vestibular system to low-frequency vibration," three British scientists have demonstrated that the inner ear is "extremely sensitive" to extremely low levels of low frequency noise…**

[3] The following quotations were on the web page from early 2009 to mid August 2009, when they were removed after Dr. Neil Todd, primary author of the paper referred to by Pierpont, issued a statement to the effect that their work had been misinterpreted by Pierpont.

> **"This is precisely what Nina Pierpont has been talking about. This new research offers substantial support for her claim that *a perturbed vestibular apparatus* is one of the keys to explaining Wind Turbine Syndrome…"**

And then she quotes directly from the paper:

> **"The very low [noise] thresholds we found are remarkable as they suggest that humans possess a frog- or fish-like sensory mechanism which appears to exceed the cochlea for detection of substrate-borne low-frequency vibration and which until now has not been properly recognised…. A fundamental question is also raised as to the possible behavioral consequences … such a mechanism may have."**

However, the word "[noise]" is not in the original, but had been added by Pierpont, as a comment, in order to be able to use this work to support her own unsubstantiated ideas.[4] Take out "[noise]" and it is very clear that the paper describes an experiment on vibration transmission through the skull. And of course, wearers of bone conduction hearing aids receive vibration inputs to their vestibular systems, at levels well above the cochlear and vestibular thresholds, and are not known to exhibit vestibular disturbance.

This fundamental misunderstanding of the difference between air conducted sound and a direct vibrational input is a cause for concern. It is certainly not the "scientific precision" which she claims for herself. There are further references in the book to the Todd paper in which she incorrectly, and persistently, couples sound with the original references to vibration. Does Pierpont understand the difference between noise and vibration? Although she has a poor understanding of acoustic magnitudes and their significance, it is difficult to believe that, after five years of campaigning against wind turbines,[5] she has not yet grasped this difference. However, the manner in which she has used Todd's paper serves only to cast doubt on her scientific reliability.

7.0 Comments on Hypothesis 2 ("Body Resonance").

[4] Pierpont has made similar additions, in other connections, to quotations from original authors.
[5] She started as a NIMBY, when wind turbines were proposed near to her home town of Malone NY.

Exhibit 14

Her hypothesis of movements of the viscera due to sound in the range of 1-2Hz and 4-8Hz is supported by reference to publications on "body resonances." Again, she badly misunderstands the underlying physics. For example, on page 23 of the book we find

> **"All parts of the body (and indeed all objects) have specific resonance frequencies, meaning that particular frequencies or wavelengths of sound will be amplified in that body part. If the wavelength of a sound or its harmonic matches the dimensions of a room, it may set up standing waves in the room with places where the intersecting, reverberating sound waves reinforce each other. Resonance also occurs inside airfilled body cavities such as the lungs, trachea, pharynx, middle ear, mastoid, and gastrointestinal tract."**

That is correct as far as it goes - except that small body spaces do not resonate at the long wavelength (low frequency) acoustic excitation, which she states cause the adverse effects. Indications are that the resonant frequency for sound transmission through the system comprising the mouth, the lungs, and the external chest wall is much higher in reality—as high as 200Hz—a frequency far above the low frequency noise assumed by Dr. Pierpont (Royston T J et al., 2002).

Other references which Pierpont gives to support her thesis are mainly from the investigations for the 1960s – 1970s space program, when subjects were exposed to very high infrasonic levels of 120 – 130dB, levels far beyond those produced by wind turbines. These exposures, which had little effect on the subjects, are not relevant to the sound levels from wind turbines.

The references she gives on page 23 to support Hypothesis 2, all relate to mechanical excitation of the body. That is, vibration input to the feet or seat or whole-body mechanical oscillation, for example, like a massaging chair or vibrating platform. Mechanical excitation, either vertical or horizontal, does not excite the same set of resonances as are driven by low frequency sound, because sound has a uniform compressive effect, while mechanical excitation is a longitudinal force. These references do not support Hypothesis 2.

References to excitation of the body by sound are given on page 42, with two papers from Takahashi and colleagues, on forehead vibration in high sound levels (Takahashi et al., 2005)(Takahashi et al., 1999). These also do not support Hypothesis 2. If Pierpont had read the papers more carefully, she would have found that internal head vibration (background vibration) masked responses of the head to low frequency sound below 20Hz, even when using a high stimulus of 110dB. This is far in excess of wind turbine levels and leads us to the ultimate failure of Pierpont's second hypothesis.

8.0 Internal body noise and vibration. The body is inherently a very noisy system at low frequencies. My own measurements on body vibration resulting from external low frequency noise showed that the inherent chest vibration was similar to that from excitation by an external sound level of 80dB at the chest resonant frequency, which was typically around 50Hz (Leventhall, 2006). Unlike the 200Hz resonance described above, this resonance was a structural resonance of the rib cage, and did not involve the lungs or other body cavities.

Internally generated body sounds may be detected by a microphone supported a few millimetres above the body surface, and indeed, the human diaphragm itself, which Pierpont depends on for transmission of wind turbine infrasound to the viscera, vibrates during its contraction, so radiating sound and vibration within the body. As stated in (Bellemare and Poirier, 2005)

> **"Like other skeletal muscles, the diaphragm vibrates laterally during the build-up of tension. These vibrations or sounds can be recorded with microphones or accelerometers positioned over the lower chest wall in the zone of apposition of the diaphragm with the rib cage."**

Pierpont's use of her stethoscope will have shown her that the body also contains a strong source of infrasound, working in the region 1Hz to 2Hz, which is one of the problem regions she suggests from wind turbines (Hypothesis 2). I am referring to the heart.

Any internal effect from the low levels of infrasound from wind turbines, say, 55-75dB at 10Hz, produce a much lower internal body vibration than that which already exists within the body, and will not be sensed by the body. It is interesting to note that a pressure of 74dB exerts equivalent pressure on the skin to that of a layer of water which is one hundredth of a millimetre thick (10^{-2}mm), lying over the skin. Skin thickness varies over the body, but is typically 1mm. (10^{-2}mm is similar to about five ten-thousandths of an inch.)

Again, Pierpont misunderstands the energy transmitted by sound to the body. Simple calculations shows that, if a system of the weight and area of the diaphragm and its attached liver are exposed to a level of 74dB for 50ms, which is one quarter cycle at 5Hz, the resulting displacement is only about five microns ($5x10^{-6}$m). Again, Pierpont's second hypothesis does not stand up to scrutiny.

The conclusion must be that, whatever Pierpont wishes to believe, infrasound and low frequency noise from wind turbines will not directly affect the body because the levels are too low and the body is full of low frequency masking sources. Both her hypotheses fail. The appropriate place for them is on the internet, along with other self published, alarmist infrasound material.

We are then left with the results of her case study interviews.

9. Case studies. Several years ago Pierpont put out a general call, repeated internationally on objector web pages, for anyone who thought that their health had been affected by wind turbines, to contact her for a telephone interview. She does not give details of the response. One of Pierpont's selection criteria was that a "before – during – after" exposure pattern was preferred, which meant that the interviewees will have moved away from the turbines. That is, they were the ones most severely affected and were a small selection from the people who might be bothered by wind turbine noise.

9.1 Results of interviews. Following the interviews, Pierpont defined the symptoms of the Wind Turbine Syndrome as:

> **"….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." (Book page 18)

I am happy to accept these symptoms, as they have been known to me for many years as the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise. The symptoms have been published before (Møller and Lydolf, 2002; Nagai et al., 1989).

9.2 Prior knowledge of these symptoms. Anybody who is fully experienced in environmental noise problems, particularly at "street level," will be familiar with the extreme responses to otherwise unobjectionable levels of sound which occur in a very small number of people. These responses occur for both higher frequency and low frequency noise. However, as environmental noise control criteria are A-weighted, they tend to under-rate potentially problematic low frequency environmental noise. This has led low frequency problems to be left to continue, whilst higher frequency problems are fixed more quickly. As a result, where genuine low frequency noise problems have occurred, their continuance leads to the development of undue stress in those affected. There is also a body of very stressful, unsolvable noise problems, described as "low frequency" by those affected, where detailed investigations cannot discover a specific noise source. These are sometimes called "Hum" problems and there is an Internet group devoted to them. The HUM FORUM. http://tech.groups.yahoo.com/group/humforum/

The paper by Nagai, referred to above, describes effects of rattles on residents in lightweight Japanese buildings. For example, rattling of windows, doors, etc. The rattles were caused by infrasound generated by traffic on an elevated highway. The infrasound, at about 80dB and 8Hz, was below perception level, but caused rattles, which disturbed residents. The rattle is at high frequencies, and produced the same symptoms as those found by Pierpont. Nagai had 909 subjects, whose complaints included:

> Irritating (62.4%), Headache (57.6 %), Heaviness in the head (52.8%), Pain in arms or legs (52.4%), Insomnia (47.6%), Confusion of thinking (42.6%) Vertigo (40.5%), Ringing in ears (29.6%), Palpitation (22.8%), Nausea or Vomiting (19.3%), Pressure on ears (17.9%), Hypertension (17.6%)

Nagai et al do speculate that long-term exposure to the noise might lead to increased sensitivity to the infrasonic element, but give no evidence for this effect at levels below the perception threshold.

The paper by Møller and Lydolf describes a survey conducted amongst 198 persons, who described themselves as low frequency noise sufferers. Some of these may have been stressed "Hum sufferers." The results on subjective effects were:

> Insomnia (67.5%), Lack of concentration (67%), Headaches (40.1%), Palpitation (41.1%), Dizziness (29.4%), Others (39.1%).

For a follow-up paper (Pedersen et al., 2008), 21 of the complainants from the Møller and Lydolf study were selected randomly for detailed investigations. This work concluded that seven of the complainants were annoyed by a physical sound in the 20 – 180Hz range. Six had low frequency tinnitus, perceived as between 40 and 100Hz. The remaining eight could not be classified. In no cases was infrasound a problem.

My own experience of helping those with noise problems, extending over about 40 years, has led me to the following list of symptoms (Leventhall, 2002)

> distraction; dizziness; eye strain; fatigue; feeling vibration; headache; insomnia; muscle spasms; nausea; nose bleeds; palpitations; pressure in the ears or head; skin burns; stress; tension etc.

9.3 Comparison of symptoms. The similarity of subjective effects found by Pierpont to those of Nagai at al, Møller and Lydolf and myself, demonstrates that what Pierpont describes is effects of annoyance by noise – a stress effect, not the direct physiological effect which she claims, as it has been shown above that these claims are without substance. What Pierpont describes are simply the well known effects of persistent, unwanted noise, and use of the words "Wind Turbine Syndrome" should be discontinued, in order to avoid confusion.

However, Pierpont has made one genuine contribution to the science of environmental noise, by showing that a proportion of those affected have underlying medical conditions, which act to increase their susceptibility. This is the only part of her book which merits further publication as original work.

10. Conclusions. Pierpont has failed to substantiate her hypotheses. These hypotheses lack credibility and do not appear to have any scientific basis. Pierpont has clearly misunderstood much of the acoustic material which she refers to.

The so called "wind turbine syndrome" cannot be distinguished from the stress effects from a persistent and unwanted sound. These are experienced by a small proportion of the population and have been well known for some time.

The final conclusion must be that Pierpont has misled both herself and her followers, but she can have the last word, as used by her in criticism of others:

> **Let me be emphatic.** ***You can't start with an implausible hypothesis or a flawed data set and get a result that means anything.*** **(Book page 170)**

26 August 2009

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Infrasound from Wind Turbines – Fact, Fiction or Deception

ABSTRACT

Infrasound is discussed in terms of what it actually is, how the media has dealt with it and what those with limited knowledge say about it. The perception of infrasound occurs at levels higher than the levels produced by wind turbines and there is now agreement amongst acousticians that infrasound from wind turbines is not a problem. Statements on infrasound from objectors are considered and it is shown how these may have caused avoidable distress to residents near wind turbines and also diverted attention from the main noise source, which is the repeating sound of the blades interacting with the tower. This is the noise which requires attention, both to reduce it and to develop optimum assessment methods

RÉSUMÉ

L'infrason est discuté en termes de ce qu'il est réellement, son traitement dans les médias et par ceux avec des connaissances limitée à son sujet. La perception de l'infrason est qu'il existe à des niveaux plus hauts que ceux produits par des éoliennes, mais il y a maintenant accord parmi les acousticiens que l'infrason des éoliennes n'est pas un problème. Des rapports sur l'infrason par des protestataires sont considérés et on montre comment ceux-ci ont pu causer de la détresse évitable aux résidants près des éoliennes et également divertir l'attention de la source principale de bruit: le son répétitif de l'interaction des lames avec la tour. C'est ce bruit qui exige de l'attention, pour le réduire et pour développer des méthodes optimales d'évaluation.

1. INFRASOUND

A definition of infrasound is: Acoustic oscillations whose frequency is below the low frequency limit of audible sound (about 16Hz). (IEC 1994)

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

The limit of 16Hz, or more commonly considered as 20Hz, arises from the lower frequency limit of the standardized equal loudness hearing contours measured in units of phons, which is a difficult measurement at low frequencies, not from the lower limit of hearing.

2. THE AUDIBILITY OF INFRASOUND

Hearing sensation does not suddenly cease at 20Hz when the frequency is reduced from 21Hz to 19Hz, but continues from 20Hz down to very low frequencies of several Hertz. It is not possible to define an inaudible infrasound range and an audible audio range as separate regions, unless the infrasound range is limited to naturally occurring infrasound of very low frequencies. The range from about 10Hz to 100Hz can be considered as the low frequency region, with possible extensions by an octave at each end of this range, giving 5Hz to 200Hz. There is a very fuzzy boundary between infrasound and low frequency noise, which often causes confusion.

Hearing thresholds in the infrasonic and low frequency region are shown in Fig 1. The solid line above 20Hz is the low frequency end of the ISO standard threshold (ISO:226 2003). The dashed curve, 4Hz to 125Hz, is from Watanabe and Møller (Watanabe and Møller 1990b). There is good correspondence between the two threshold measurements in the overlap region.

The slope of the hearing threshold reduces below about 15Hz from approximately 20dB/octave above 15 Hz to about 12dB/octave below. (Yeowart, Bryan et al. 1967). The common assumption that "infrasound" is inaudible is incorrect, arising from an unfortunate choice of descriptor. "Real" infrasound, at levels and frequencies below audibility are largely natural phenomena, although human activities, such as explosions, also produce infrasound. Microphone arrays for the detection of airborne infrasound are a component of the monitoring for the Nuclear Test Ban Treaty

The median hearing threshold is not a simple delineation between "Can hear - Can't hear", but the threshold is rather variable between individuals, depending on their genetics, prior noise exposure and age (ISO7029 2000). The standard deviation of threshold measurements is typically about 6dB.

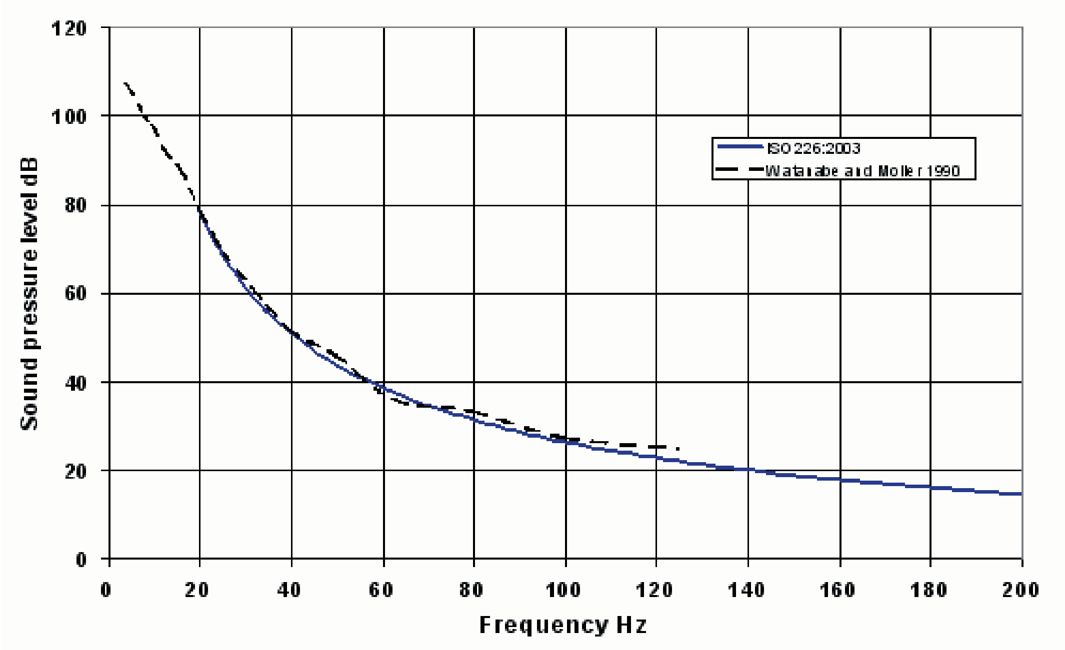

Figure 1. Infrasonic and low frequency threshold

Therefore, it is most unlikely that anyone will be able to hear sound at any frequency which is more than, say, 20dB below its median threshold.

The false concept that infrasound is inaudible, when coupled with the many common misconceptions about its subjective effects, has spawned concerns, particularly expressed in popular publications, which are best described as mythology, rather than fact.

A report reviewing low frequency noise (Leventhall, Benton et al. 2003) is available on the internet.

High levels at very low frequencies: These may result in aural pain, which is not a hearing sensation, but arises from displacements of the middle ear system beyond its comfortable limits. Persons with both hearing ability and hearing loss, and with normal middle ears, exhibit aural pain at a similar stimulus level, which is at about 165dB at 2Hz, reducing to 145dB at 20Hz. Static pressure produces pain at 175 -180dB, whilst eardrum rupture occurs at 185 -190dB (von Gierke and Nixon 1976). A pressure of 5 x 104 Pa, which is about half atmospheric pressure, falls in the 185 -190dB range. A child on a swing experiences infrasound at a level of around 110dB and frequency 0.5Hz, depending on the suspended length and the change in height during the swing.

Natural infrasound: We are enveloped in naturally occurring infrasound, which is in the range from about 0.01 Hz to 2Hz and is at inaudible levels. The lower limit of one cycle in a hundred seconds separates infrasound, as a propagating wave, from all but the fastest fluctuations in barometric pressure. There are many natural sources of infrasound, including meteors, volcanic eruptions, ocean waves, wind and any effect which leads to slow oscillations of the air. Man made sources include explosions, large combustion processes, slow speed fans and machinery. Much natural infrasound is lower in frequency than 1 Hz and below the hearing threshold. (Bedard and George 2000). Our evolution has been in the presence of natural infrasound.

Alternative receptors: The question arises of whether there is a hierarchy of receptors, of which the ear is the most sensitive except at the lower frequencies, when other receptors may come into prominence. Several vibration and contact detectors reside in the skin, covering different frequency ranges (Johnson 2001). The Pacinian corpuscles are the most sensitive, with a threshold displacement of about 0.002mm in the region of 200Hz,. Their sensitivity into lower frequencies reduces at approximately 50dB per decade from the maximum sensitivity.

The threshold displacement of 0.002mm at 200Hz is similar to the particle displacement in air of a 200Hz sound wave of 94dB (1 Pa) pressure. Since the particle displacement in a sound wave of fixed pressure doubles as the frequency is halved (20dB per decade) inaudible sound waves will not excite these subcutaneous receptors.

There is no reliable evidence that infrasound at levels below its hearing threshold has an adverse effect on the body (Berglund and Lindvall 1995). A recent French study of wind turbine noise confirms that infrasound from wind turbines is not a problem. (Chouard 2006)

Body vibrations: It is known that high levels of low frequency noise excite body vibrations (Leventhall, Benton et al. 2003). The most prominent body response is a chest resonance vibration in the region of 50Hz to 80Hz, occurring at levels above about 80dB, which are audible in this frequency range. The low frequency perception thresholds of normal hearing and profoundly deaf subjects have also been investigated (Yamada, Ikuji et al. 1983), when it was shown that the profoundly deaf subjects perceived noise through their body only at levels which were in excess of normal thresholds. The threshold of sensation of the deaf subjects was 40-50dB above the hearing threshold of those with normal hearing up to a frequency of 63Hz and greater at higher frequencies. For example about 100dB greater at 1 kHz, at which level perception was by the subjects' residual hearing. Deaf subjects experienced chest vibration in the same frequency range as normal hearing subjects.

The much repeated statement that "infrasound can be felt but not heard" is not supported by these measurements. The erroneous thought processes which led to this confusion are possibly:

Infrasound causes body vibrations - (correct at very high levels)
But infrasound is inaudible - (not correct at very high levels)
Therefore infrasound can be felt but not heard - (not correct)

neglecting that the levels to produce body vibrations are well above the hearing threshold. But, as will be shown later, infrasound is not a problem for modern wind turbines.

The dimensions of noise: Noise is multidimensional. A one dimensional view of noise is the A - weighting, which considers only levels and neglects frequencies. Another one-dimensional view is to consider only frequencies and neglect levels. Developing the dimensions further, two dimensions include both frequency and level (the spectrum), three dimensions adds in the time variations of the noise, whilst higher dimensions include subjective response.

Many lay people take the one dimensional view of infrasound, which is based on frequency alone. They express concern at the presence of any infrasound, irrespective of its level. This is a significant failure of understanding.

Public Perceptions: The Public has been misled by the media about infrasound, resulting in needless fears and anxieties, which possibly arise from confusion of the work on subjective effects, which has been carried out at high, audible levels with the popular mindset that infrasound is inaudible. There have also been misunderstandings fostered in publications and popular science books, considered later.

Early work on low frequency noise and its subjective effects was stimulated by the American space program. Launch vehicles produce high noise levels with maximum energy in the low frequency region. Furthermore, as the vehicle accelerates, the crew compartment is subjected to boundary layer turbulence noise for about two minutes after lift-off. Experiments were carried out in low frequency noise chambers on short term subjective tolerance to bands of noise at very high levels of 140 to 150dB, in the frequency range up to 100Hz (Mohr, Cole et al. 1965). It was concluded that the subjects, who were experienced in noise exposure and who were wearing ear protection, could tolerate both broadband and discrete frequency noise in the range 1 Hz to 100Hz at sound pressure levels up to 150dB. Later work suggests that, for 24 hour exposure, levels of 120 -130dB are tolerable below 20Hz. These limits were set to prevent direct physiological damage, not for comfort. (Mohr, Cole et al. 1965; Westin 1975; von Gierke and Nixon 1976).

The American work did not attract media attention, but in the late 1960's two papers from France led to much publicity and speculative exaggerations. (Gavreau, Condat et al. 1966; Gavreau 1968). Although both papers carry "infrasound" in their titles, there is very little on frequencies below 20Hz (Leventhall 2005). Some rather casual and irresponsible experiments of the "try it and see" variety were carried out on exposure of the laboratory staff, primarily using high intensity pneumatic sources at frequencies mainly at the upper end of the low frequency range, or above. For example, 196Hz at 160dB sound level and 340Hz at 155dB sound level. A high intensity whistle at 2600Hz is also included in the "infrasound" papers.

Infrasounds are not difficult to study but they are potentially harmful. For example one of my colleagues, R Levavasseur, who designed a powerful emitter known as the 'Levavasseur whistle' is now a victim of his own inventiveness. One of his larger whistles emitting at 2600Hz had an acoustic power of 1 kW. . ... This proved sufficient to make him a lifelong invalid. (Gavreau 1968)

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

Referring to the exposure of 160dB at 196Hz:

...after the test we became aware of a painful 'resonance' within our bodies - everything inside us seemed to vibrate when we spoke or moved. What had happened was that this sound at 160 decibels........ acting directly on the body produced intense friction between internal organs, resulting in sever irritation of the nerve endings. Presumably if the test had lasted longer than five minutes, internal haemorrhage would have occurred. (Gavreau 1968)

96 Hz is not infrasound, but the unpleasant effects at 160dB are described in a paper which is said to be about "Infrasound". Internal haemorrhage is often quoted as an effect of exposure to infrasound. Exposure levels were not given for frequencies of 37Hz and 7Hz, although the 7Hz caused subjective disturbance and vibrations of the laboratory walls. Unfortunately, these papers by Gavreau were seized upon by the press and presented to claim that infrasound was dangerous . For example "The silent killer all around us", London Evening News, 25 May 1974. When work by other investigators detected moderate levels of infrasound in, for example, road vehicles, the press was delighted, leading to "The silent sound menaces drivers" - Daily Mirror, 19 October 1969.

"Danger in unheard car sounds" The Observer, 21 April 1974.

The most deplorable example, in a book which claimed to have checked its sources, was in "Supernature" by Lyall Watson (Coronet 1973). In this it is claimed that the technician who gave one of Gavreau's high power infrasound sources its trial run "fell down dead on the spot" and that two infrasonic generators "focused on a point even five miles away produce a resonance that can knock a building down as effectively as a major earthquake".

These ficticious statements are, of course, totally incorrect but are clear contributors to some of the unfounded concerns which the public feels about infrasound. One can detect a transition from Gavreau and his colleague feeling ill after exposure to the high level of 196Hz to "fell down dead on the spot" and a further transition from laboratory walls vibrating to "can knock a building down", transitions which resulted from repeated media exaggerations over a period of five or six years.

The misunderstanding between infrasound and low frequency noise continues to the present day. A newspaper article on low frequency noise from wind turbines (Miller 24 January 2004) , opens with:

Onshore wind farms are a health hazard to people living near them because of the low-frequency noise that they emit, according to new medical studies. A French translation of this article for use by objectors' groups opens with:

De nouvelles etudes medicales indiquent que les eoliennes terrestres representent un risque pour la sante des gens habitant a proximite, a cause d'emission d'infrasons.

The translation of low frequency noise into infrasons continues through the article. This is not a trivial misrepresentation because, following on from Gavreau, infrasound has been connected with many misfortunes, being blamed for problems for which some other explanation had not yet been found e.g., brain tumours, cot deaths of babies, road accidents.

Infrasound, and its companion low frequency noise, now occupy a special position in the national psyche of a number of countries, where they lie in wait for an activating trigger to re-generate concerns of effects on health. Earlier triggers have been defence establishments and gas pipelines. A current trigger is wind turbines.

3 INFRASOUND AND LOW FREQUENCY NOISE FROM WIND TURBINES

Early designs of downwind turbines produced pressure pulses at about once per second, which were high enough to cause vibrations in lightweight buildings nearby. (Shepherd and Hubbard 1991). A series of pulses occurring at one per second analyses into a harmonic series in the infrasound region, which is the origin of the link between wind turbines and infrasound One could discuss whether the Fourier time-frequency duality is misleading on this point, since it was the effects of peaks of the pulses which caused the building vibration, not a continuous infrasonic wave. Similar vibration would have occurred with a faster stream of pulses, with the limiting condition that the pulse repetition rate was lower than the period of the vibration.

Modern up-wind turbines produce pulses which also analyse as infrasound, but at low levels, typically 50 to 70dB, well below the hearing threshold. Infrasound can be neglected in the assessment of the noise of modern wind turbines (Jakobsen 2004)

Fig 2 shows the infrasonic and low frequency noise at 65m from a 1.5MW wind turbine on a windy day. The fol-

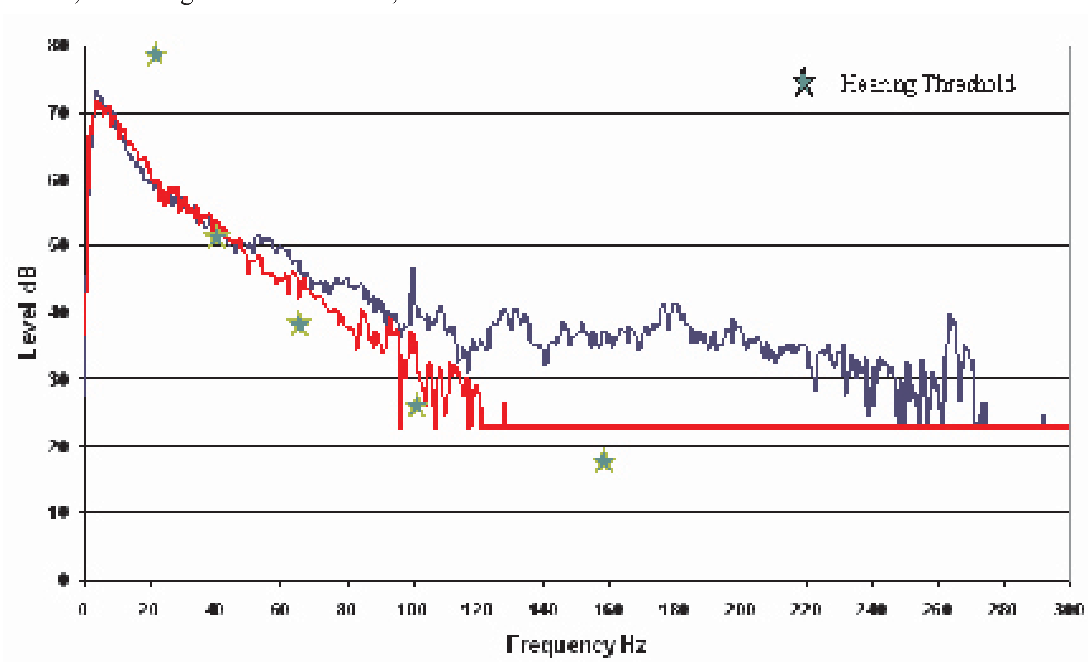

Figure 2. Spectrum of a modern upwind wind turbine - Upper trace Wind Turbine Noise. Lower trace Background noise.

lowing should be noted.

- The fall off below about 5Hz is an instrument effect. The background noise actually increases down to the frequencies of atmospheric pressure variations .
- Frequencies below 40Hz cannot be distinguished from background noise due to wind.
- The wind turbine noise and background noise separate above about 40Hz and both rise above the median hearing threshold.
- The measurements were taken at 65m. Levels are likely to be about 15dB lower at normal separation distances

On the occasions, such as unusually turbulent inflow conditions, when low frequency noise is produced by wind turbines, it may not be perceived as a noise, but rather as an unidentified adverse component in the environment, which disappears if the turbines stop, or if the inflow conditions change. This is because we are not accustomed to listening to low levels of broad band low frequency noise and, initially, do not always recognise it as a "noise", but more as a "disturbance" in the environment. An analogy is with air-conditioning rumble noise, which is noticed when it stops.

What Objectors Say Objectors have eagerly grasped the media hype on infrasound and low frequency noise and used it to engender concerns about wind turbine developments. In this they have, possibly, done a disservice to the communities they were established to help, through raising false concerns and diverting attention from more important aspects of the development. Two examples are as follows.

In the UK there is an Advertising Standards Authority(ASA), to which deceptive adverts can be referred for assessment. An objectors' group (Ochils Environmental Protection Group) issued a leaflet "FACTS ABOUT WIND POWER". containing a number of assertions including:

. "... wind turbines still create noise pollution, notably 'infra sound' - inaudible frequencies which nevertheless cause stress-related illness ..."

In their Judgment (April 02, 2004), the ASA concluded that the objectors had not produced evidence to substantiate their claim.

In the USA, a high profile objector (Nina Pierpont of Malone NY) placed an advertisement in a local paper, consisting entirely of selected quotations from a previously published technical paper by van den Berg (Van den Berg 2004). However the comment "[i.e. infrasonic]", as shown in Fig 3, was added in the first line of the first quotation in a manner which might mislead naive readers into believing that it was part of the original.

The van den Berg paper was based on A-weighted measurements and had no connection with infrasound. So, not only is the advertisement displaying the advertiser's self deception, but this has also been propagated to others who have read it. To mistakenly connect the noise to infrasound, which has unpleasant associations is, however, a way to gather support . (When a person has adopted a particular mindset, new information is processed to support that mindset. We all do this.)

It takes little technical knowledge to be aware that a modulated high frequency wave does not contain the modulation components. For example, an amplitude modulated radio wave contains the carrier wave and sidebands, which are close in frequency to the carrier. The fluctuations of wind turbine noise (swish – swish) are a very low frequency modulation of the aerodynamic noise, which is typically in the region of 500 - 1000Hz. The modulation occurs from a change in radiation characteristics as the blade passes the tower, but the modulating frequencies do not have an independent and separate existence.

The comment, [i.e. infrasonic], added into Fig 3 gives incorrect information. Claims of infrasound are irrelevant and possibly harmful, should they lead to unnecessary fears.

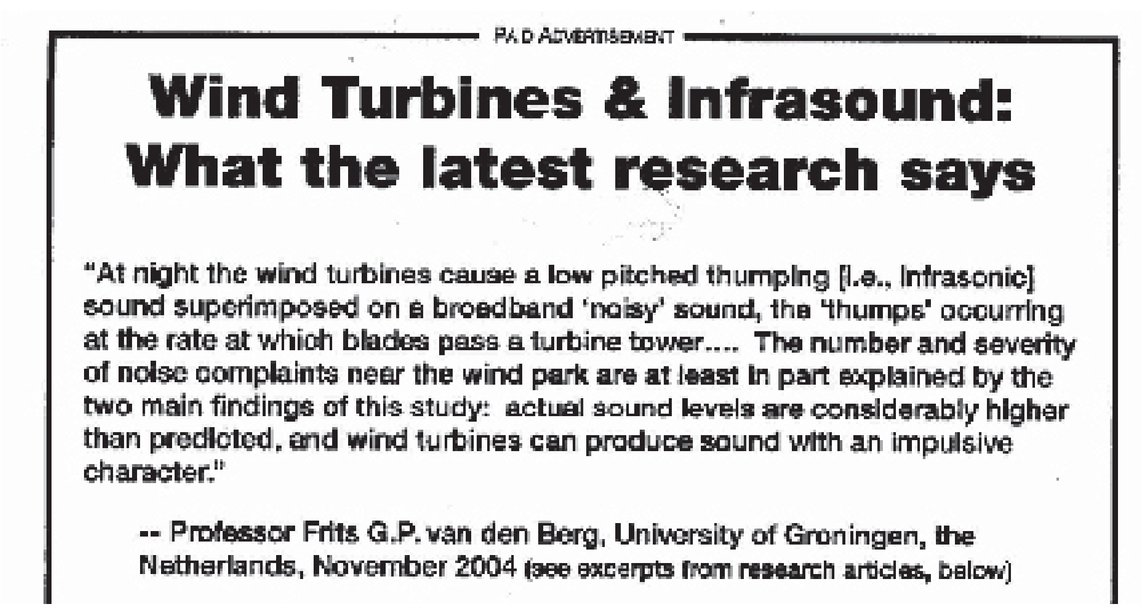

Figure 3 Part of an advertisement placed by an objector in the Malone (NY) Telegram, 25th February 2005.

It has been shown that fear of a noise source, for example that aircraft might crash, increases the extra annoyance of a person with a high fear of a crash by up to 19dB DNL equivalent, compared with a person who has no fear (Miedema and Vos 1999).

Fear of a source is not the same as fear of the noise itself, but it is understandable that those who fear the effects of a noise upon their health will be less tolerant of the noise than those who do not fear it. We can only speculate upon the harm which objectors might have done by, for example, taking a one dimensional view of infrasound and publicising the subjective effects of high levels of both infrasound and low frequency noise in a manner which implies that the effects may also be caused by the low levels produced by wind turbines.

4 WIND TURBINE NOISE

It has been shown above that there is insignificant infrasound from wind turbines and that there is normally little low frequency noise. Turbulent air inflow conditions cause enhanced levels of low frequency noise, which may be disturbing, but the overriding noise from wind turbines is the fluctuating audible swish, mistakenly referred to as "infrasound" or "low frequency noise". Objectors uninformed and mistaken use of these terms (as in Fig 3), which have acquired a number of anxiety-producing connotations, has led to unnecessary fears and to unnecessary costs, such as for re-measuring what was already known, in order to assuage complaints.

Attention should be focused on the audio frequency fluctuating swish, which some people may well find to be very disturbing and stressful, depending on its level. The usual equivalent level measurements and analyses are incomplete, as these measurements are taken over a time period which is much longer than the fluctuation period and information on the fluctuations is lost. A time varying sound is more annoying than a steady sound of the same average level and this is accounted for by reducing the permitted level of wind turbine noise. However, more work is required to ensure that the optimum levels have been set.

5 CONCLUSIONS

- Infrasound from wind turbines is below the audible threshold and of no consequence.
- Low frequency noise is normally not a problem, except under conditions of unusually turbulent inflow air.
- The problem noise from wind turbines is the fluctuating swish. This may be mistakenly referred to as infrasound by those with a limited knowledge of acoustics, but it is entirely in the normal audio range and is typically 500Hz to 1000Hz. It is difficult to have a useful discourse with objectors whilst they continue to use acoustical terms incorrectly. This is unfortunate, as there are wind turbine installations which may have noise problems.
- It is the swish noise on which attention should be focused, in order to reduce it and to obtain a proper estimate of its effects. It will then be the responsibility of legislators to fix the criterion levels, However, although the needs of sensitive persons may influence decisions, limits are not normally set to satisfy the most sensitive.

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