A pragmatic view of a wind turbine noise standard

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ABSTRACT

New Zealand Standard 6808:2010 Acoustics – Wind farm noise is unique in that it acknowledges, up front under committee representation, that a representative of a university involved in its development does not support the Standard. Since that time a number of papers and presentations have decried this opposition to the Standard without giving the committee member the privilege of comment or reply. This paper is to put the record straight and explain why the Standard is not supported. Wind farms may well be a viable alternative energy source, but the effects of noise immissions on the health of people living within several kilometres of the wind farms is becoming a concern. The noise level from a wind farm may be quite low, but its characteristics compared to that of the normal background sound make it stand out as something quite different. Often the sound is heard more clearly indoors than outside due to its ability to excite room resonances, making it an irritant causing severe loss of sleep and extreme annoyance. New Zealand Standard 6808:2010 closely follows that used in Britain and parts of Europe, even though there are clear indications that the criteria to be met do not fully conform with World Health Organization recommendations, and the method used is likely mathematically, scientifically and ethically wrong. This Standard and similar standards across the world are clearly biased towards cost effective wind farm development, and it appears public health concerns are not being given enough attention.

INTRODUCTION

Most of us take too many things for granted. We assume that if something appears in a national or international standard it must be right, and if we have been taught to do something in a particular way, then that is the right way to do it. Rarely do we question, and then often only if we don't like what some person has said or suggested, and would like to retaliate. Even if we worry about something not being quite right, we often are reluctant to do anything about it for fear of ridicule - and let's face it, in our small world, some people are very good at ridiculing others, when they themselves have little to contribute but a client to satisfy.

This initially was intended as a discussion paper on the sound propagated from wind turbines and what seems to be accepted practice in national and international standards. We tend to forget that someone has to bear the cost of such standards, and that almost always this will be someone with a vested interest in the subject - someone or some organisation that can afford the cost and to whom the way the standard is written has a direct bearing on what they want it to achieve for them. Those that review the standard, in its public comment stage, often do not see the hidden implications - particularly if mathematics is involved in any way. Few people are willing to stand up with an opposing method for fear of public ridicule for daring to suggest that international experts may have it wrong. This author does not purport to be an expert in wind power generation and is neither for nor against the establishment of wind farms. He would just like to get to the truth of the matter, for sustainable management of the environment is not without human cost. In this world nothing is free. Everything has a cost, and some of the costs may be in diminished human health. Clearly these costs should be as low as humanly possible.

1 WIND TURBINES - THE IDEAL SOLUTION

In the developed world, sustainable management of the environment usually takes the form of trying to economize in the use of fossil fuel, and to find other ways of generating energy. Bio-fuel, hydropower plants and wind turbine generators are near the top in the minds of many governments. At first sight wind farms would seem to be an ideal solution to the power crisis. They stand there in the countryside quietly pumping energy into the electricity grid whenever the wind blows and logically should cause problems to no-one. The turbines need wind to turn so any sounds made will be rapidly dispersed and the sound of the wind itself will mask any sound from the turbines. But is this really true? Sounds can carry long distances downwind. Numerous ailments have been reported and blamed on the lower frequencies in the sound from wind farms [Pierpont 2009, Harry 2007, Frey and Hadden 2007], sounds which it would seem can easily penetrate a building, keeping awake those trying to sleep inside. At a few kilometres distance, people in the Manawatu district of New Zealand describe the noise as sounding like a heavy truck climbing an endless hill in the distance, or a train that never arrives, and it would appear there is nothing the local people can do to get relief. Whatever anyone may think, wind turbines do produce some noise, and there are claims of this noise at times causing extreme annoyance [Pedersen and Persson-Waye 2002] and possible adverse health effects.

Numerous large installations are on the drawing board in New Zealand and a number have already received resource consent to go ahead. How the local people - those within say a few kilometres of the installation - will benefit is never made clear, and any suggestion of adverse health effects is quickly quashed as being entirely without substance and scientific fact. There are indications, however, that something may be wrong and public health at risk of being compromised. A major, perhaps *the* major responsibility of local government is to protect the health and welfare of its residents and this should take priority over other things such as monetary gain. Regrettably from experience the health of the local people often takes a lower order of priority.

2 THE ASSUMPTIONS

The New Zealand Standard on the sound from wind turbines NZS 6808:2010 follows the same philosophy as the original 1998 Standard and as most other wind turbine standards in other parts of the world. It also uses the same method for noise measurement and assessment and the same noise limiting criteria. As some of the leading experts on wind turbine noise have produced these standards, one would assume they are right and promote the best way to protect the environment and public health. No-one seems to question this, so maybe we should.

Wind farm noise standards usually are based on the L_{A90} metric, and assume:

1 There will be a direct relationship between the wind speed at the hub of the wind turbine, and the background sound level at all places where people live in the locality.

2 That at night residents will be indoors and any windows that may be open for ventilation will provide a 10 dB to 15 dB attenuation of any sound from outside.

3 That the natural background sound level plus 5 dB, or 40 dB whichever is greater, will be a satisfactory design level for the wind farm sound immission outside at any residence.

4 That the sound from a wind turbine can be considered as a point source at the hub of the turbine and using a standard method such as that promoted in ISO 9613-2:1996 the sound immission at any place people live can be predicted with reasonable accuracy.

Once the relationship between the background sound level is decided, the wind farm can then base all its operations on the wind speed at the hub of the nearest turbine to where the people live, and adjust the settings of the blades so that by prediction the wind farm will comply with the design sound immission at each residence. At a first glance, this would seem very straight forward and not open to question, but let us consider each facet in turn.

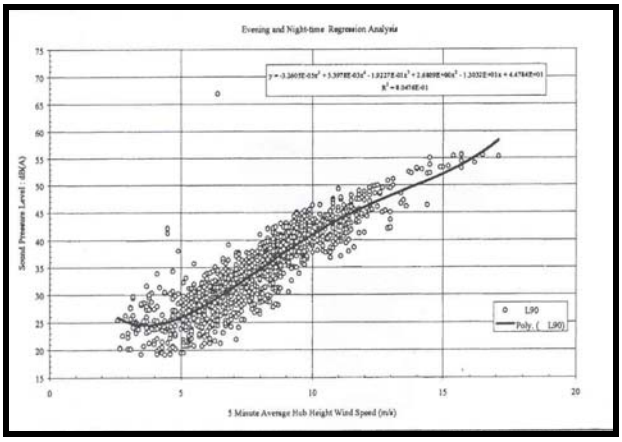
3 THE QUESTIONS

First, why L_{A90}? No other industrial standards use this metric, so why are wind farms different? The use of the L90 metric may have seemed a good idea to almost everyone at the time. The sound from a wind farm becomes the major component of the background sound, and the thinking no doubt was that if it were considered as background sound, one could use the L90 to eliminate transient sounds from general daily activities. One could then simply compare the measurement with one in similar wind conditions when the wind farm was not operational – and a noise monitoring system could do this without anyone being present i.e., unaccompanied monitoring. Unfortunately it introduces a confounding factor into the equation whereby, once the wind farm is in operation, it becomes almost impossible to prove any non-compliance with any rules set under the consent conditions.

Determining the relationship between wind speed and background sound level

The method involves taking background sound level measurements at residences likely to be affected by the noise from the wind farm and matching these with the wind speed at the height of the hub of the nearest wind turbine. More than fourteen hundred ten-minute measurements are required. This method is highly questionable, mathematically and scientifically. From experience we know the variation between the data pairs from the norm is far greater than would normally be accepted in scientific circles. Figure 1 shows a plot of such data pairs as would be produced for a wind farm resource consent [ETSU 1996]

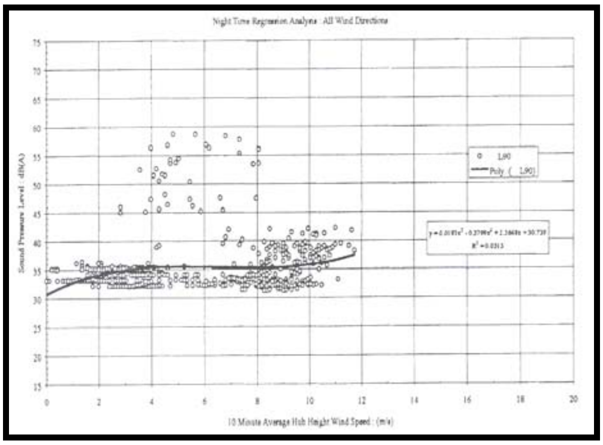
Figure 1 A plot of wind speed at hub position versus background sound level



The graph compares a 10 percentile level (L_{A90}) with a linear parameter and then takes a simple regression line on which to base the relationship between the background sound level at the recipient property and the wind speed at the hub of the turbine. Not only is there a wide scatter of data pairs – more than 15 dB on several occasions – but using a simple regression line to get a median value at various wind speeds for a statistic, rather than for a physical environmental parameter, artificially raises the value of the statistic and brings into doubt its mathematical validity.

Then the way the sounds are measured leaves much to be desired. Figure 2 below shows another data pair graph as would be used for a resource consent hearing. [ibid]

Figure 2 Another plot of wind speed at hub versus background sound level.

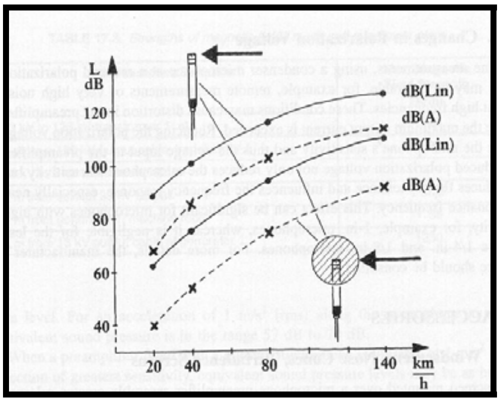


On this graph there is an even greater scatter – more than 20 dB on several occasions. The graph was produced to show how to use the data if there was present in the background a noise such as a running stream. On the other hand the graph is typical of that from instrumentation with an insufficiently low noise floor, and if such a data spread is found, there is the possibility that the instrumentation used in the unaccompanied monitoring has not truly measured the background sound level at all.

It will be noticed there is no scatter of results below about 31 dB, but tremendous scatter above 40 dB. Such a spread of data could suggest the noise floor of the instrumentation used was between 31 and 32 dB, so anything below about 28 dB was recorded as 31 dB, and anything between 28 and 32 dB recorded as 33 dB or over. The background sound level may have been well below 25 dB at times, even below 20 dB, but the instrumentation has recorded it as being a minimum of 31 dB. If this is so, it has artificially raised the value of the background sound level possibly by several dB. It may be noted that some of the equipment seen to be used by noise consultants in New Zealand for such purposes, has this limitation.

Another problem: Those using sound level meters have to be very careful that the wind at the microphone does not exceed 5 metres/second (18 km/hr) when measuring sounds between 40 dB and 50 dB, and not exceed 3 metres/second (11 km/hr) when measuring sounds between 30 dB and 40 dB, even with a good windshield in place. Figure 3 below shows the effect of a wind shield on a sound level meter [Brüel & Kjær 1996]. If the wind at the microphone is 5½ metres per second (20 km/hr), the sound level meter will register 40 dB without any other sound present even with a windshield in place.

Figure 3 Effect of windshield on microphone in wind



The wind farm noise standards place no limits to the wind speeds in which the measurements are to be taken. New Zealand does have a sound measurement standard [NZS 6801 2008] that does place limits on the meteorological conditions in which sound may be measured, but the wind farm Standard expressly precludes the use of this measurement standard. If the wind is over 5 metres per second, much of the measurement will be noise from the wind on the microphone and not the background level at all – even with a very good windshield in place. The background sound level is being artificially raised even more.

NZS 6808:2010, in common with most other wind turbine noise standards, gives no simple measurement method to show compliance (or non-compliance) once the wind farm is fully operational. The use of L_{A90} makes this very difficult. A windfarm is an industry and should be no different from any other industry in having to meet noise rules, and be monitored from time to time. There is no scientific reason why an enforcement officer could not take a series of simple short term measurements, say twenty or so five or ten minute time average level measurements ($L_{Aeq,5mins}$ or $L_{Aeq,10mins}$) when the sound from the wind farm dominates the environment, to prove compliance or not with any rules set for it. As the draft stands, once operational the wind farm can make almost any noise it likes without redress. All environmental standards should utilize a method of assessment that is within the resources of local territorial authorities. Wind farm sound is clearly heard downwind, certainly from experience at distances of some kilometres, and could easily be monitored as a time average level over a few minutes as long as an observer is present to judge that the sound being measured is that from wind turbines.

Sound attenuation by an open window

The Standard assumes that there will be a sound attenuation of 10 to 15 dB through the window opening before the sound reaches the sleeper (inside a bedroom). This is only correct on certain very limited occasions, such as possibly when the sleeper is situated at exactly the right position in a symmetrical and uniformly furnished room – a spatial average position – and then only if the total window opening is less than a very small amount of the wall area. Most rural people, and it is in the rural area where most wind farms are established, have their windows fully open on hot summer nights, and may sleep within a metre or so of the window, the opening of which may be up to 90% of the wall area and give no sound attenuation at all.

Table 1 gives the sound attenuation for an open window in a typical New Zealand house as a percentage of the wall area. This is based on a free-field sound level outside compared to the resulting spatial average sound level in a fully furnished room, which latter is assumed to give a reverberation time of 0.5 seconds.

Table 1 Sound attenuation through open window

Wall: 4 m x 2.7 m weatherboard, on 100 x 50 studs, 10 mm plasterboard, 75 mm batts in cavity

Octave band	Percentage of wall opening											
Centre Hz	3	5	7.5	10	20	30	40	50	60	70	80	90
	Attenuation in dB											
31.5	12	11	10	9	6	5	4	3	2	1	1	0
63	11	10	9	8	6	5	4	3	2	1	1	0
125	12	11	10	9	6	5	4	3	2	1	1	0
250	15	13	11	10	7	5	4	3	2	2	1	0
500	15	13	11	10	7	5	4	3	2	2	1	0
1000	15	13	11	10	7	5	4	3	2	2	1	0
2000	15	13	11	10	7	5	4	3	2	2	1	0
4000	15	13	11	10	7	5	4	3	2	2	1	0
8000	15	13	11	10	7	5	4	3	2	2	1	0

It is hard to see how a sound attenuation of 15 dB would be achieved even with a spatial average sound level inside - unless there was a very small opening (less than 3%) quite insufficient for proper ventilation.

The criteria

From the public health point of view also, there is a problem in using the background sound plus 5 dB as the design criteria. It is realised that for some years now planners have used this principle with some success and few if any people have questioned it. It is based on the results of social surveys and the average-maximum-level of noise (L_{A10}) one may impose on a community without the people taking concerted action, at central government level, out of sheer desperation. It does not relate to annoyance and any alleged ill health as a result.

For transient noise, such as from a new motorway or sports facility, an average-maximum-level of 10 dB above the background sound level is just about the maximum that can be imposed on a community, without incurring severe community action and court proceedings. The sound from a wind turbine varies up and down about 3 or 4 dB per second. Basing the design on the L_{A90} will of course miss sounds from the wind turbine that are not there 90% of the time. The average-maximum-level (L_{A10}) will be 3 or 4 dB higher and the time average level (L_{Aeq}) about 3 dB higher. So in many wind turbine noise standards across the world (including the New Zealand standard) the design criteria is set as the background sound level (L_{A90}) + 5 dB, or 40 dB, whichever is *greater* – again theoretically the maximum that can be imposed on a community, without there being very severe repercussions. At such levels there will be severe annoyance and possibly an adverse health effect, but most people will take no action realising that there is almost nothing they can do about it without it costing them quite a lot of money, which most of them could not afford. With the addition of another 3 dB (average-maximum-level 13 dB above the background sound level), people will no longer tolerate the situation and there will be severe community repercussions [Schultz 1982]. A design level based on the background sound does not limit annoyance, is not compatible with undisturbed sleep, and it does not protect public health.

Undisturbed sleep is extremely important. The more healthy a person is, the better they can resist illness and injury from any cause including noise. Heart disease, high blood pressure and mental or emotional illness are common complaints and need protection from other stressors such as noise [Williams 1970]. Everyone needs rest, relaxation and undisturbed sleep to maintain their health, and such is especially important for those with high blood pressure or trying to recover from illness. Chronic loss of sleep may impair performance and cause psychological distress. In fact, severe disturbances of sleep precede and accompany most acute psychiatric syndromes, and complaints of sleeplessness are among the most frequent symptoms presented to the general medical practitioner [ibid].

The World Health Organization has accumulated and précised the work of the leading experts in the world in order to produce recommendations for all countries to adopt to maintain and protect public health [Berglund et al 2000]. Of particular concern, for sound propagated at night, the level of *steady continuous noise* at any sleeping position should be no greater than a time average level of 30 dB (L_{Aeq}). As wind farm sound is steady continuous noise as defined in NZS 6801:2008 clause 8.2, the World Health Organization recommendation is a level not to be exceeded - it is not just a design average.

The reception of wind turbine sound, depends on wind direction of course, and may be present in an area for weeks on end. Often this coincides with warm calm nights, and on such nights the wind on the hill tops may still be more than sufficient to power the turbines even though it is calm on the valley floor. As already mentioned above, most rural people, and it is the rural area where most wind farms are established, have their windows fully open on hot summer nights. The sound they receive from a wind farm will have little or no attenuation at all from that outside.

The standard in assuming a 10 to 15 dB attenuation through an open window and using a design level of 40 dB (L_{A90}) at the property or an increase of 5 dB over the background sound level, whichever is *the greater*, is assuming that if the background sound is over 40 dB (giving more than 30 dB at the person sleeping or trying to sleep) then it is all right to increase the noise by 5 dB as no one will notice. This is contrary to the World Health Organization recommendation that 30 dB should not to be exceeded and is not sustainable management. Taking an analogy from an Environment Court judge, this is equivalent to hitting someone over the head with a hammer and saying it is all right to hit them 7 times as hard (5 dB) as they won't notice the difference. It is also greater than the noise allowed for even short term construction in the New Zealand Standard for Construction Noise (NZS 6803).

To this author's knowledge, the only scientific study of environmental noise at a national level in New Zealand, was undertaken by the New Zealand Government's Board of Health in 1973. In its report on Noise [Board of Health 1974] one can find the following table:

Table 2 Acceptable background noise levels

TABLE I—*Background Noise Levels Generally Considered Acceptable in New Zealand*

Zone	*7 a.m.-10 p.m.* dBA	*10 p.m.-7 a.m.* dBA
Z1—Rural and outer suburban areas with negligible transportation	35	25
Z2—Generally suburban areas with infrequent transportation	40	30
Z3—Generally suburban areas with medium density transport	45	35
Z4—Suburban areas with mixed commerce and industry or close to dense transportation	50	40
Z5—City or commercial areas or residential areas close to industry	55	45
Z6—Predominantly industrial areas	60	50

The report may well be 35 years old, but people's needs are unlikely to have changed and should be the same now as they were then.

The rural areas in New Zealand are generally extremely quiet most nights. In the author's area of Camborne, on numerous occasions at night the ambient sound has been measured at 20 dB - the noise floor of the sound level meter to hand. At such background sound levels, a sound even at only 35 dB outside a residence can be very noticeable, and if continuous and rhythmically modulating up and down three or four decibels, as it does for a wind farm, it can be extremely irritating and stressful – similar to the old Chinese water torture. Each impact in itself may be quite insignificant but when repeated continually for long periods of time - and from our own observations the causative weather patterns may hold for several weeks - it can drive people to desperation. In these areas in particular, any such sound from industry should at the boundary, not exceed 30 dB at the very most, and preferably not exceed 25 dB as the Board of Health recommended all those years ago.

There have been numerous reports of low frequency noise penetrating closed windows and being heard more clearly indoors than outside [Kelly et al 1985, Wyle 1988, Hubbard and Shepherd 1984]. Sounds below 125 Hz can excite room resonances and be amplified, significantly disturbing sleep and hence compromising health. The oscillation (or "modulation") of the sound up and down 3 or 4 dB each second (as described below) adds to the irritation the sound gives to those trying to go to sleep.

The following table, Table 3, shows the natural room resonances in this writer's own bedroom.

Table 3 Primary room resonances for a 5.5m x 4.5m room, 2.4 ceiling height, 20°C.

Vibration mode Length	1	0	1	2	0	0	1	0	1	3	2	3	2
Vibration mode Width	0	1	1	0	0	2	0	1	1	0	2	1	1
Vibration mode Height	0	0	0	0	1	0	1	1	1	0	0	0	1
Resonant frequency Hz	31	38	49	63	72	76	78	81	87	94	99	101	103

All of these frequencies are present in wind turbine sound, so it would not be unreasonable to assume that a 5 to 10 dB amplification possible by this mechanism, and this, no doubt, is the reason for many people reporting severe sleep disturbance but then finding the noise apparently quieter outside. Thus the limit of low frequency sound, in the octave bands below 125 Hz, should be made not to exceed, say, 20 dB ($L_{Aeq,\ 10min}$) outside any residence. If, as is alleged, wind farms emit no significant low frequency sound, incorporating this rule in the wind turbine noise standard would place no imposition on the wind farms.

4 THE NOISE SOURCES

Assuming the background sound will mask the sound from a wind turbine again seems logical until one actually goes to an area downwind of a wind farm and experiences the sound. The sound from a wind farm is carried by the wind and as it has unique characteristics it penetrates the natural background sounds to make it clearly audible at fairly large distances. It has a totally different quality to the natural background or the sound of wind in trees, which latter has a quite different timbre and does not mask wind turbine sound. The noise generation from a wind farm is like no other noise source or set of noise sources.

Vortex shedding from trailing edge of blade

A major source is boundary layer air breaking away from the trailing edge of the blade. When the wind reaches a blade, part goes over and part goes under the blade which as an aerofoil is so designed that the air in the boundary layer has further to travel when going over the blade than under, creating a reduction in pressure. This of course produces the lift that turns the blade, but as the air is viscous the boundary layer flow is further impeded, some of the airflow being bonded with the blade (to travel around it as bound vortices producing drag on the blade) while that part of the airflow with momentum great enough to break away, forms trailing vortices and turbulence behind the blade, producing a set of sound sources [Schlichting 1979].

The power of each sound source depends on the strength of the turbulence, which in turn depends on the speed of airflow, the compressibility and viscosity of the air, the chord and surface texture (roughness) of the blade, the wind speed, and the velocity of the blade at that point, which in itself is dependent on the angular velocity of the blade and the distance from the hub. If the angular velocity of the blade can be governed so that the speed of all airflow across the blade is very small compared to the speed of sound, the air can be considered as incompressible and the sound sources reasonably low in intensity. The faster the blade is allowed to turn, the earlier the breakup in the bound vortices and the greater the interaction between the vortices shed by adjacent wind turbines. When observing the sound from a wind turbine at near distances, it appears that there is more turbulence and hence more noise generated on the downward movement of the blades, than in other positions. Some papers showing the use of a noise camera portray this. This, however, is an artifact due to the relatively close observer position on the ground. Other than the effect of the wind speed varying with height above the ground, the sound emissions by this mechanism should be the same whatever the position of the blade.

Vortices from blade tips

Another source is by air thrown from the blade tips interacting with the surrounding air, which is itself moving with the wind flow. This is the result of the boundary layer of air sliding down the blade as a result of centrifugal motion. As the air travels down the blade from hub to tip it gains speed and, governed by its elasticity and the point on the blade it first contacted, it will become less dense and travel out initially in the line of the blade but with a trajectory that changes according to the speed at which it separates from the tip of the blade, the tip speed of the blade, the wind vector and the temperature gradient. The temperature gradient is an unknown and never constant so cannot be taken into account, but the result of the other processes is a parabolic trajectory of the vortices in a rotating plane normal to the blade's plane of rotation and in the direction of the main airflow from the wind. The vortices travel downwind in the form of a helix, rotating about its axis with each vortex replacing the previous one in space at approximately 1 second intervals – sometimes more, sometimes less depending on the speed of rotation and number of blades. Figure 4 [from www.1] shows a analogy of this form of propagation as cavitation from a propeller in water.

Figure 4 Cavitation behind a propeller in water [www1]

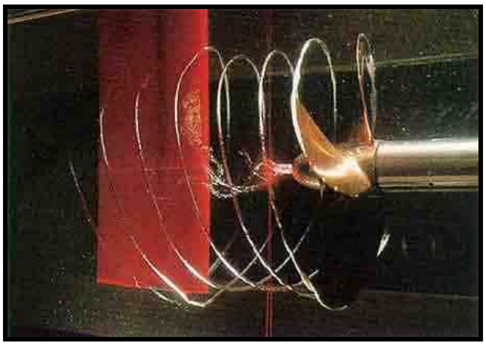


Figure 5, from the Rosi National Laboratory in Denmark, shows the development of the helix from an actual wind turbine using a smoke trace from the tip of one of the three blades. If two wind turbines are close enough in line, it may be possible for the vortices from the blade tips of one to interact with those thrown off by an adjacent one increasing the power of the new vortices and hence the aerodynamic noise produced [Shephard 2010].

Figure 5 A trace from one blade of a wind turbine

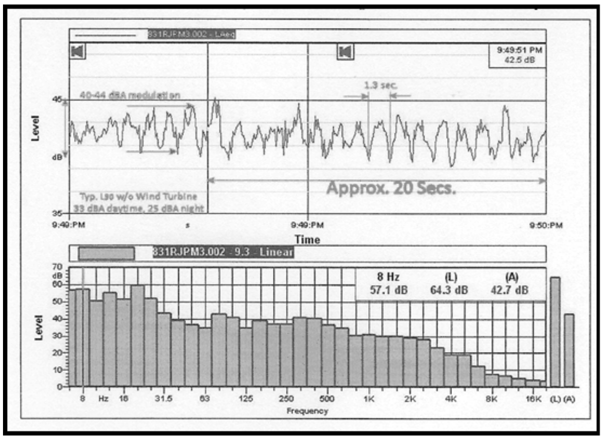
In the far field, this is the rumbling and modulation up and down 3 or 4 dB each second as the helical pressure waves reach the recipient, which is characteristic of the noise from a wind turbine making it stand out from all natural sounds – except that of running water or surf.

Figure 6 [Shephard 2010] of condensation produced by the vortices from wind turbines at Horns Rev in the North Sea, gives a clear indication of the interaction between the vorices from a multitude of wind turbines and the directionality of the propagation. These are the same vortices that generate and carry the sound on the wind. The sound does not propagate equally in all directions, as most standards assume, but is highly directional.

Figure 6 Condensation by wind turbines at Horns Rev

The characteristic sound modulation from a wind turbine is shown in Figure 7.

Figure 7 Wind Turbine Characteristic Modulation



This figure is taken from work done by Richard James in Wisconsin [James 2008] and shows in the top half of the figure, for a single wind turbine, the A-frequency weighted sound level rising and falling in synchronization with the rotation of the blades. The lower half gives a 1/3 octave band analysis of the sound at the point in time shown by the vertical line in the centre of the time history.

Blade stall

As the blades cover such a large area, it is possible for one blade to have insufficient wind to move it, while the other blades still have lift. This causes one blade to stall and produces an imbalance in the system and eccentric bending moments on the rotor shaft. When a blade partly stalls and starts up again, the imbalance is exacerbated and results in a thumping noise in the turbine itself. The sound has been described as a "woomping", by local residents in New Zealand at distances of between 1 and 1½ kilometres from the turbine. The directionality of this sound depends on the rotor housing and may propagate equally in an upwind as well as a downwind direction. The sound downwind however is encircled by the spinning helix of sound from the vortex shedding by the blades and carried along by the airflow. Clearly this imbalance would not be good for maintaining the efficiency of the turbine and designers try to eliminate this if at all possible.

Noise from associated equipment and other factors

Further sound is generated by the turbine mechanism itself and associated equipment, including the motion of the gearbox and rotor shaft. A new turbine is fairly quiet, but as it gets older the components wear, particularly the rotor shaft, bearings and gearbox, and the noise emission increases. An increase of 10 dB through wear and tear, or even more, should not be unexpected. The same also applies to the blades. As time goes on and they wear or become corroded or dirty, the boundary layer airflow becomes less smooth and produces more drag. The blade is then less efficient and produces less power in the turbine. Arguably there may be more turbulence and hence more noise generated.

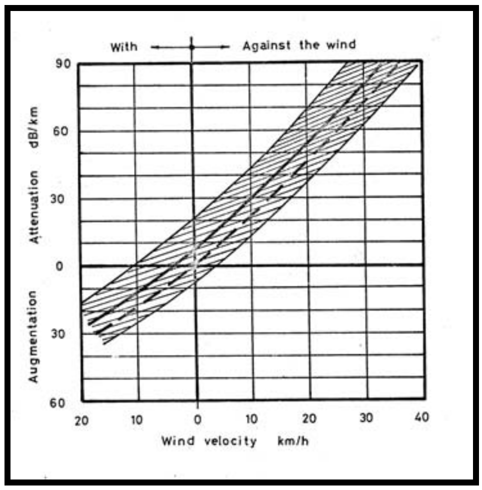
The result of all these noise sources is a pulsating wall of sound, not of any high intensity, but sufficient to carry many kilometres downwind and still have the power to excite room resonances and to disturb sleep. It would seem that certainly downwind the sound from a wind farm should be treated as from a line source with cylindrical spreading –this is not a new thought but one suggested back in the 1980s by scientists at NASA [Hubbard & Shepherd 1991].

The sound sources are asymmetrical and may cover an area bigger than 3 football fields. (And a wind farm may have many wind turbines situated, often in line, and often less than 400 metres apart.)

All wind farm standards assume the sounds from a wind turbine can be represented by a point source at the location of the turbine hub, and rarely if ever is directionality taken into account. Nor is any account taken of the carrying of sound by the wind itself. If these factors are not taken into account, large under-prediction results.

The effect of sound convection by the wind itself (Figure 8) has been studied in the past [Hayhurst & Meister 1982] but, it is believed, has not been included in any prediction method. In a 10 km/hr wind, one should expect sound to be augmented by 10 to 20 dB. Unfortunately the vagaries of the wind flow introduce large uncertainties. Nevertheless, some acknowledgement of sound convection should be made when determining the uncertainties, and allowance made when designing windfarms to conform to public health requirements as recommended by the World Health Organization.

Figure 8 Sound convection on the wind [Stryenski 1961]



5 EXPERIENCE OF SOUND PROPAGATION

Computer prediction is obscure and notoriously inaccurate. Indeed it may be said that one can design the computer output to be whatever one wishes [Dickinson 1974]. There is no guarantee that any computer prediction of wind farm sound emission will be close to the value of that received. This also applies to the sound from aircraft and it is for this reason that the airport noise standard [NZS 6805:1992] and similar New Zealand Standards use an airnoise boundary, set by the territorial authorities, a boundary based on physical features in the area, within which all noise emission over a certain level must be contained. The control is by the measured noise levels and computer prediction is not involved.

Even if definitive methodology is given, one cannot rely on any computer predictions of noise as there is always human fallibility as well to consider. Inevitably, only evidence that suits the case will be presented, and from experience, manipulation of the evidence to prove a point is not uncommon.. The only transparent way to ensure that the defined methodology has been followed exactly, is to show (print out) all calculations and all assumptions, and with modern techniques a spreadsheet is the most practical way of doing this.

The predictions also should not be based on a long-term average. The World Health Organization recommendations are levels not to be exceeded – they are not design levels to try to achieve on average.

NASA studies [Hubbard and Shepherd 1991] show that at distances greater than about 750 metres from a wind turbine the sound propagation more closely follows that of cylindrical spreading i.e., a line source. In the Manawatu district of New Zealand, 50 dB was recorded at 2.5 km from the nearest turbine. This was the average of more than a dozen measurements of the 10 minute time average level ($L_{A,eq\ 10min}$) taken during night-time when the turbines were clearly predominant over all other sounds, and no other intrusive sounds were noticed.

In this situation, use of the prediction method given in the new Standard NZS6808:2010 (Table 4 below) gives a predicted sound level of 33 dB – which is an under-prediction of 17 dB.

Table 4 Prediction of level at 2500m by NZS 6808:2010

Using method in draft DZ 6808:2009 and 24 turbines

Octave band frequency	31.5	63	125	250	500	1000	2000	4000
Sound Power Level dB	119.8	116	109.2	105.5	102	100.7	95.4	90.8
At 2500 m distance, 15 degree C, 50% relative humidity, ground cover short grass								
Spherical spread + Dcr (= 3)	-76	-76	-76	-76	-76	-76	-76	-76
Air absorption viscous effects	0	0	0	0	0	-0.3	-1.3	-4.8
Oxygen and nitrogen relaxation	-0.3	-0.3	-1.3	-3	-5.5	-10.3	-25.8	-86
Ground absorption	-0.2	-0.7	-1.3	-3.7	-3.8	-4.3	-4.5	-7
Resulting band level	43.3	39	30.6	22.8	16.7	9.8	-12.2	-83
A-frequency weighting	-39.4	-26.2	-16.1	-8.6	-3.2	0	1.2	1
A-frequency weighted Level	3.9	12.8	14.5	14.2	13.5	9.8	-11	-82
Level from 24 turbines	17.7	26.6	28.3	28	27.3	23.6	2.8	-68.2
L_{Aeq} in dB	**33 dB**	i.e., prediction by draft standard is 17 dB below measured level						

It should be understood: The wind speed at the hub was not available and had to be estimated at 10 m/s.
so the base sound power levels may have been slightly lower, making the prediction even lower

It is interesting that Pedersen and Persson-Waye (2002) in their research found that wind turbine noise could be up to 18 dB more than predicted by this method. van den Berg (2003) also found up to 18 dB under-prediction by this method when compared to actual measurements at the Rhede wind farm in Germany.

If, on the other hand, one treats the wind farm sound emission as from a line source, i.e., with cylindrical spreading, one obtains a predicted noise level much closer to that measured.

Table 5 shows the prediction of wind farm sound at that same distance of 2,500 metres using a line source. At 49 dB, the predicted noise level is very close to the average recorded by the Class 1 instrumentation used for the measurements.

Table 5 Prediction of level at 2500m as by a line source

As I believe it should be predicted:
Using a line source with no directivity correction, corrected for spacing (400m), 24 turbines

Octave band frequency	31.5	63	125	250	500	1000	2000	4000
Sound Power Level dB	119.8	116	109.2	105.5	102	100.7	95.4	90.8
At 2500 m distance, 15 degree C, 50% relative humidity, ground cover short grass								
90m blade 310m space between	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4
Line source	-42	-42	-42	-42	-42	-42	-42	-42
Air absorption viscous effects	0	0	0	0	0	-0.3	-1.3	-4.8
Oxygen and nitrogen relaxation	-0.3	-0.3	-1.3	-3	-5.5	-10.3	-25.8	-86
Ground absorption	-0.2	-0.7	-1.3	-3.7	-3.8	-4.3	-4.5	-7
Resulting band level	71.9	67.6	59.2	51.4	45.3	38.4	16.4	-54.4
A-frequency weighting	-39.4	-26.2	-16.1	-8.6	-3.2	0	1.2	1
A-frequency weighted Level	32.5	41.4	43.1	42.8	42.1	38.4	17.6	-53.4
L_{Aeq} in dB	**49**	i.e., prediction using line source is within measurement tolerance.						

These recordings in the Manawatu may well have been in ideal sound propagation conditions – this author has not recorded quite so high levels of sound from wind turbines since that time - but the average of more than a hundred unaccompanied night-time measurements at a site 2.3 km from the nearest turbine, at times when local residents reported the turbines as "roaring", also came to just over 49 dB.

Initial findings from ongoing noise monitoring of ten-minute time average levels at 1500 metres and at 3000 metres being logged by local residents for times when the turbine noise is predominant, show noise levels well in excess of the levels predicted by the current methodology, and reinforce the premise that the sound from a wind turbine should not be considered as a point source, even though mathematically an infinitely long array of coherent sound sources will show an attenuation of 3 dB with a doubling of distance, seemingly justifying the use of ISO 9613 in this circumstance. Unfortunately, for a wind farm, it doesn't work in practice.

It is believed this clearly shows that, from experience, prediction of sound from a wind farm by the method used in New Zealand Standard NZS 6808 and that used extensively across the world, is wrong. The method used is that described in ISO 9613 even though the ISO standard clearly states it is not to be used for aircraft sound propagation, and is limited to distances under 1000m by the uncertainties. As the sound from aircraft is also produced by blades and turbines, why should the standard be applicable to wind farms if it is not to aircraft?

Perhaps most important: ISO 9613 suggests in section 4a) that the sources should have approximately the same strength and height above the local ground plane and b) that the same propagation conditions exist from the source to the point of reception. From the above description, one should be able to see that for a wind farm, the sound sources are well outside any of these conditions. Clearly ISO 9613 as it stands is not suitable for the prediction of sound from a wind farm.

So we left with a standard, albeit one that is very similar to other such standards across the world, that purports to be for the protection of public health and includes the input of some of the leading experts in wind turbine noise. Yet it would appear that not only does it utilize noise criteria that may contravene the World Health Organization recommendation, but it also employs a methodology that may overstate by several decibels the existing background sound levels on which it wants to base its operations.

Added to this, it under-predicts the sound the local residents will receive from the wind turbines, perhaps by an order of magnitude, and is so convoluted and time consuming as to be outside the capabilities and resources of the local territorial authorities who have the responsibility for managing the noise immission from such industrial operations.

6 CONCLUSION

Although the wind turbine noise standard appears to be taking into account the health and wellbeing of local residents, the concept on which it and most other wind turbine noise standards across the world are based, scientifically makes little or no sense, and public health may be compromised. On the other hand, by allowing wind farms to be sited relatively close to residential dwellings, it does allow the developer to use existing infrastructure and hence get the most out of the investment for the lowest possible outlay without causing the local community to take very serious legal action at central government level.

In New Zealand, and in many other parts of the world where population density is very low and large areas of land uninhabited, one must question the need for any wind turbine noise to intrude on local communities. Clearly wind farms are one answer to the energy crisis, although it is believed their efficiency leaves much to be desired and their working life is only about 20 years, 90% of which may be taken up in recouping the installation costs.

One easy solution for solving the noise problem and protecting public health, is a ruling that no wind farm sound emission shall exceed 30 dB ($L_{\text{Aeq,10mins}}$) at any residence, nor exceed 20 dB ($L_{\text{Aeq,10mins}}$) in total in the frequency bands 31.5 to 125 Hz. A very simple way of achieving this, and of eliminating the need for any further involvement by the territorial authority, would be to make a ruling that no wind farm shall be situated less than say 5 to 10 kilometres away from any residence unless the occupant agrees in writing for this condition to be waived.

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