RESPONSE TO THE RAMAKRISHNAN FINAL REPORT

John Harrison 11th May, 2008

In October 2007, I brought several problems with the draft report to the attention of the Ministry of the Environment. None of these problems were addressed in the final report[1]. Neither were they challenged. Dr Ramakrishnan's conclusions, then and now, concerning Dr. van den Berg's work[2] have no validity and should not be used in formulating revised new noise guidelines for Ontario. There are a few straws at which Dr. Ramakrishnan clutches but they in no way negate Dr. van den Berg's work or conclusions. This document is a response to Dr. Ramakrishnan's criticism of Dr. van den Berg's thesis and offers convincing evidence that masking noise is a myth. There will follow a further document which will argue that there is now a firm foundation for overhauling the Ontario noise guidelines for wind turbines to bring them into line with the recommendations of health authorities. This is an urgent matter with so many proposals for wind plants to be sited among the residents of rural Ontario.

Masking Noise

The over-riding fact that Dr. van den Berg introduced to world-wide attention is that masking noise is a myth. Despite what Dr. Ramakrishnan claims in his report, Dr. van den Berg did not start out with the hypothesis that there can be, particularly at night, a stable atmosphere that leads to high wind speeds at hub height and low wind speeds at ground level which would lead to large turbine noise and no masking noise at ground level. **That is, Dr. van den Berg did not postulate that masking noise is a myth and then set about trying to prove it.** I challenge Dr. Ramakrishnan or the Ministry of the Environment (MOE) to show that he did. What Dr. van den Berg did do was respond to claims that people living within a kilometre or so of a wind farm were experiencing annoyance from wind turbine noise when they had been assured that they would not be. This we now know is a common problem world-wide. Chapter 4 of the thesis is central to Dr. van den Berg's work that **led him to the hypothesis** that the cause of the complaints is that the wind speed at a turbine hub is significantly higher than that at ground level and that the masking noise, assumed by the wind industry and some regulating authorities, is absent or much reduced. As I pointed out in my earlier commentary, non-cooperation by the wind plant operator did not allow Dr. van den Berg to measure everything that he would have liked. Nevertheless he used great ingenuity in his investigation; as a fellow experimental scientist, I appreciate and admire what he did. I will review what Dr. van den Berg did to lead him to his hypothesis.

First, the sound emission (turbine noise) results for one of the turbines, shown in fig. IV.3 of the thesis[2], do seem credible and the octave band spectra at L_W =103 dBA agree well with Kerkers. Dr. van den Berg is using rotational speed of the blades (N) as a proxy for wind speed at the hub. What else was he to do? Kerkers does present L_W as a function of v_{10}. If we knew that Kerkers had made his or her measurements in a "stable atmosphere" (i.e. with m = 0.14), then we could relate N to the wind speed at the hub height. But, we don't. In any case, we see in fig IV.7 that N is an excellent proxy for wind speed. There is an excellent match between emission (turbine noise), as determined from blade rotation speed and measured immission (noise at a receptor) levels. If I use section 6.3.2 of Wagner et al[3], then, with a reflection term, I confirm the calculation for the difference of 58 dBA. That is, Dr. van den Berg is able to make convincing measurements of turbine noise and has turbine noise as a function of blade rotational speed.

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Turning to sound immission, I think that Dr. Ramakrishnan is being over-critical in expecting better than a 3 or 4 dBA difference between L_{10} and L_{90} as an indicator for the dominance of turbine noise. There is a difference between the constant noise of a fan, or two fans, that he used in his test and the variable noise of a turbine as the wind speed and wind direction change. There is strong evidence later in the chapter that sound immission levels were being measured.

Looking at figure IV.5, I conclude that nothing can be deduced from panels A or C or, at least, I can deduce nothing. These are XY plots with three variables and time as a hidden variable. Panel B, I believe, is credible although I believe that the stability class is irrelevant. Stability class is just a label and adds nothing. Note that, for these results, on-site 10m wind speed measurements were made. Panel B is a graph of sound pressure level as a function of 10m wind speed as measured at a site 400m from the nearest turbine. There is considerable scatter because the turbine noise depends upon the 80m wind speed and, as we now know, the ratio of wind speeds at 80 and 10m varies with time. What we need to know from this panel is that, at night, the sound immission (sound at a receptor) is larger than predicted by the standard model, used by authorities and the wind industry, for the ground level wind speeds that were measured. Dr. van den Berg attributed this to a higher than expected wind speed at the hub. It is not a conclusion that resulted from the test of a hypothesis. **Instead, this is a hypothesis arrived at from the measurements of the immission levels and the ground level wind speed measurements!** He goes on to show that on average this wind speed can be modeled with an average value of m = 0.41 and with a maximum value of m = 0.57. m is a coefficient that he uses to describe the ratio of wind speeds at the turbine hub and ground level. **To summarize, Dr. van den Berg has shown that, at night, there can be significantly higher noise than expected, not masked by wind noise at ground level, and proposes, with a model, that it results from higher wind speed at the hub of the turbine than predicted by accepted atmosphere models.** Panel D is not really needed, but within the scatter, it does confirm the result deduced from panel B. However, it did make use of wind-speed measurements from a distance. By itself, panel D does not make a case.

Turning to figs. IV.8 and 9, there is convincing evidence that sound immission (sound at a receptor) was being measured correctly. The figures show sound pressure levels at three different sites with setbacks from the nearest turbine of

400, 750 and 1050m, and their differences. The sites are well separated and yet the noise levels rise and fall together. Furthermore, the differences are as expected. Again, using Wagner et al[3], my own estimate for the difference is close (~1 dBA higher). Even better confirmation of the quality of Dr. van den Berg's techniques is shown in fig. IV.10. He demonstrates, with some statistical uncertainty, the inverse square law of propagation out to beyond 2 km!

Is the Hypothesis True?

This is the question that MOE needs to be addressing. That is, are there times when the wind speed at the hub of a turbine is significantly larger than the wind speed at the ground? In that circumstance there will not be wind noise at the ground to partially off-set or mask the turbine noise which is governed by the wind speed at the turbine hub. All proponents of wind plants make wind speed measurements at different heights and they of course know the answer. They may or may not share that information with MOE but if they do, MOE keeps that information to itself. Therefore we must look where we can. The data that we have is often expressed in terms of a shear coefficient α (or m in Dr. van den Berg's thesis) defined by:

$$v_A/v_B = (h_A/h_B)^{\alpha}$$

where v_A and v_B are the wind speeds at heights h_A and h_B with h_A representing the turbine height and h_B =10 metres representing ground level. A neutral atmosphere, which is the basis for the Ontario noise guidelines, has $\alpha = 0.14$; this corresponds to a wind speed ratio $v_{turbine}/v_{ground} = 1.34$ for an 80 metre high turbine tower. Typically, the atmosphere will be stable with large α at night and unstable with low α in the turbulent atmosphere of a summer day. For the purposes of this report, I will instead present results in terms of the more accessible ratio of the wind speed at a height of 80m to that at 10m, the proxy for ground level. The first to address the question was Dr. van den Berg and the results are presented in chapter 6 of his thesis[2]. He used data that had been collected in 1987 at the Royal Netherlands Meteorological Institute research station at Cabauw. The annual average ratio was 1.4 at mid-day and 1.9 during the night hours. There was little seasonal variation in the night-time ratio, being just above 2 during the spring and summer and about 1.7 during the fall and winter. Figure VI.6 of the thesis shows that the ratio lies above 2.3 for about 15 to 20 % of the time; this percentage will be larger during the night hours. Dr. van den Berg also presented a survey of measurement from a variety of sources that were published up to 2005. These are summarized in the following table (rows 3 – 8). It is interesting and telling that Dr. Ramakrishnan selected from this list only those from New Zealand and Australia with their low values of the ratio of wind speeds at 80 and 10m! Of these two sites, the one in New Zealand was complex and hilly, and untypical of sites in Ontario. Since the time of Dr. van den Berg's thesis, other measurements have been presented and are included in the table. In addition we have some knowledge of ratios in Ontario from the Ministry of Natural Resources wind atlas and from measurements in the Kincardine area.

Average and night average ratios of the wind-speed at 80m to that at 10m.

Region	Source	Average	Night Average
Ontario Guidelines	MOE	1.35	1.35
Netherlands	vdB[2]	1.4	1.9
Spain (Plateau)	Perez[4]	1.25 – 4.3	
US Midwest	Smith[5]	1.2 – 1.5 (day)	1.7 – 2.5
Texas	Smith	1.1	<1.4
Berlin	Harders[6]	1.3	1.9
Australia 1 (Flat)	Botha[7]	1.5	1.8
Australia 2 (Flat)	Botha	1.5	1.7
N Z (Complex)	Botha	1.25	1.25
N Z (Complex)	Botha	1.25	1.25
Kincardine – 30-50m	OMB	1.85	2.55
Nr. Harrow, EC	MNR[8]	1.6	
N. of Leamington EC	MNR	1.85	
Nr. Cottam EC	MNR	2.1	
S. of Comber EC	MNR	2.1	
Sumner KS	NREL[9]	1.7	2.3
Washburn TX	NREL	1.4	1.7
Lamar CO	NREL	1.35	1.6
Crow Lake SD	NREL	1.55	1.8
Kingsbridge ON	WTN 2007	1.6	1.75 (summer 2.25)
Amaranth ON	WTN 2007	1.75	2.45 (summer 2.75)

OMB: Results presented to OMB hearing PL060986 (May 2007) by Dr. J.W.S. Young from Kincardine test tower results from April to Sept 2006

MNR: Ontario Ministry of Natural Resources wind atlas; EC: Essex County.

WTN2007: Presentation by W. Palmer to Wind Turbine Noise Conference (Sept 2007)

There is no question but that Dr. van den Berg was correct in his hypothesis. The night-time average ratio of wind speed at 80m to that at 10m is significantly larger than assumed by the wind industry and in particular by the Ministry of the Environment in the setting of its noise guidelines. Furthermore for a significant fraction of the night-time the ratio is going to be larger than the average.

The Need to Remove the Allowance for Masking

We start by looking at the results obtained and published by the National Renewal Energy Laboratory (NREL) in the USA for a variety of sites in the mid-west[9]. This laboratory was established by the DOE to support the wind industry in the USA. The average values of the ratio of the wind speeds at 80 and 10m, hereafter called R, varied from 1.35 to 1.7, with large diurnal variation. On average, average night-time values of R were 1.25x the annual average.

Looking now at the Ontario results, the average R = 1.85 ± 0.2; applying the same factor 1.25 as determined by NREL, the average Ontario night-time R = 2.3 ± 0.25. If the wind speed at 80m is 10 m/s, the assumed Ontario wind speed ratio $R_{Ont.}$ = 1.35 gives the wind speed at the ground equal to 7.5 m/s. The noise guideline for this wind speed is given as 44 dBA for a masking allowance of 4 dBA above the basic 40 dBA. However, with a more accurate night-time R = 2.3 ± 0.25, the wind speed at the ground is in the range 3.9 to 4.9 m/s. The noise guideline is now 40 dBA with no masking allowance. For another example, if the wind speed at 80m is 14 m/s, the Ontario wind speed ratio $R_{Ont.}$ = 1.35 gives the wind speed at the ground equal to 10.5 m/s with a noise guideline of 52 dBA or a masking allowance of 12 dBA. The more accurate wind speed at the ground is in the range 5.6 – 6.8 m/s where the noise guideline is in the range 40 – 42 dBA for a masking allowance of 1 ± 1 dBA. These and other examples are collected in the following table:

Wind Speed at 80m (m/s)	8	10	12	14	16
Ground Wind Speed (m/s) Ontario R = 1.35	6	7.5	9	10.5	12
Masking Noise (dBA) Ontario R = 1.35	0	4	9	12	15
Ground Wind Speed (m/s) Realistic Night-time R = 2.3	3.5	4.4	5.2	6.2 ± 0.6	7.2 ± 0.8
Masking Noise (dBA) Realistic Night-time R = 2.3	0	0	0	1 ± 1	3 ± 2

In summary, the noise generated by the turbines depends upon the wind speed at the hub height, in the range 80 – 100m. Any masking noise is generated by wind noise at ground level. The Ontario noise guideline badly over-estimates the wind-speed at ground level for any particular wind speed at the hub. The result is that the masking noise is actually negligible, in contradiction to the large values predicted by the Ontario noise guidelines. Obviously, Ontario needs to remove the allowance for masking noise from the noise guidelines.

Beating

As I wrote in my earlier commentary it was gratuitous of Dr. Ramakrishnan to suggest that Dr. van den Berg does not understand beating as defined in physics or engineering textbooks. Dr. van den Berg was referring to the amplitude modulation and its variation as a number of turbines pass in and out of synchronization. Dr. van den Berg has demonstrated a very deep level of understanding of theoretical physics in his thesis, including an excellent account of a possible source of the amplitude modulation. He is not going to be thrown by the difference between the coherent and incoherent addition of waves, which is taught in the first year of a physics degree program. Nowhere in the thesis does he refer to coherent addition of waves. There is mention of coherence of wind speed but that just means uniform wind speed over a number of turbines

What does occur is synchronization of the amplitude modulated sound. This will occur for variable speed turbines when the wind speed is close to constant over neighbouring turbines (i.e. a fairly stable atmosphere) and more generally for fixed speed turbines. I demonstrate the effect of synchronization for a simple example of three amplitude modulated noise sources, representing three turbines. The sources are incoherent in that the sound intensity adds, not the sound pressure. The loudness that results from the addition of sound from the three sound sources is given by:

$$L = 10\log(10^{L_1/10} + 10^{L_2/10} + 10^{L_3/10})$$

where the individual sound sources are labeled by the indices 1, 2 and 3. The level of sound for the three sources is different to reflect the reality of different distance from the point of reception to the turbines. However, in each case the amplitude modulation is 5 dBA. What will happen is that, as time goes by, the turbines will drift into and out of synchronization although for a large number of turbines, synchronization will occur infrequently if at all. When in synchronization, there will be the full 5 dBA of amplitude modulation; when out of synchronization the amplitude modulation will be smaller. See the attached figure. The three sound pressure levels of the three sound sources are shown in red with triangle markers. The resultant sound pressure level is shown in black with square markers. This is exactly what Dr. van den Berg observed. There are times of synchronization when the full 5 dBA amplitude modulation was measured and other times when the amplitude was reduced. The reduction of amplitude modulation will only occur if there are a number of turbines at a similar distance from the receptor. Proximity to a single turbine will expose a receptor to the full amplitude modulation. Note that if the addition had been coherent, then one adds pressures as follows:

$$L = 20\log(\frac{p_1 + p_2 + p_3}{p_0})$$

where p_1, p_2, and p_3, are the sound pressures at the receptor due to the three sources and p_0 is a reference pressure. The amplitude modulation does not change but the sound pressure levels are increased significantly. However, coherent addition does not occur and Dr. van den Berg did not in any way suggest that it did.

Noise Levels

Dr. Ramakrishnan demonstrates his bias with his comment on page 11 of his report. He notes: the data of figures IV.5 clearly shows that "the sound levels at Location A, 400m west of the wind farm is (*sic*) less than 40 dBA and the noise levels at location B, 1500m west of the wind farm, is less than 35 dBA for a substantial portion of the measurement period." The implication is that for a receptor 400m from a turbine, the sound pressure level is below that required by the Ontario noise guidelines for a substantial portion of the time. What Dr. Ramakrishnan fails to note is that his statement is true only for wind speeds at 10m that are less than 4 m/s and for turbines that are smaller than the modern turbines in use in Ontario. At 4 m/s, the noise level is larger that 40 dBA for the same amount of time as it is below 40 dBA. This can be expressed as the noise level is 40 ± 5 dBA at a wind speed of 4 m/s. From the comparison of emission and immission noise levels shown in figure IV.7, this means that the emission noise or turbine noise was 98 ± 5 dBA, corresponding to nominal wind speed $V_{10} = 7 \pm 3$ m/s. The discrepancy between the measured 4 m/s and the nominal wind speed is of course the whole point of the exercise: at night, the wind speed at the turbine is, for most of the time, far higher than predicted by the neutral atmosphere models used by the wind industry and regulating authorities.

Consider now a modern fixed-speed turbine such as the Siemens 2.3 MW turbine planned for the Wolfe Island project in Ontario. At a wind speed of 4 m/s, with a nominal $V_{10} = 7 \pm 3$ m/s, the turbine noise is 105 dBA. The noise level at a receptor and turbine noise increase in step, as shown in figure IV.7. Therefore the noise level at 400m from the Siemens turbine will be 47 dBA, which is well above the Ontario noise guideline limit. As shown in the table, this noise level decreases with distance from the turbine. Again, this is for a Siemens 2.3MW turbine in a 4 m/s ground wind speed and at night. At a wind speed of 6 m/s, the noise levels will be 1 dBA higher.

Distance from Turbine (m)	400	600	800
Noise Level at Receptor (dBA)	47	42	37

Not even the present unsatisfactory and now irrational Ontario noise guidelines allow masking at ground level wind speeds of 4 and 6 m/s. Furthermore, these noise levels do not include the penalty for a periodic noise source as is the case with amplitude modulated turbine noise.

Summary

This response has demonstrated that Dr. Ramakrishnan's critique of Dr. van den Berg's thesis is without merit. Dr. Ramakrishnan misunderstood, whether on purpose or not I do not know, the aim of the thesis He writes that Dr. van den Berg had a hypothesis and put it to an experimental test. That is not true. Dr. van den Berg was faced with a problem, did some (very clever) experiments and drew a conclusion. That conclusion became his hypothesis which he tested himself through a study of wind speed records and by drawing on the work of others. Since that time, other wind speed measurements have been made and published. I have drawn together all of these measurements together in a table. I brought many of the more recent wind speed ratio measurements to the attention of Dr. Ramakrishnan in October but he chose to ignore then as he did with those quoted by Dr. van den Berg which did not suit his purpose. Overwhelmingly, the totality of the measurements show that at night the ratio of wind speed at 80m to that at 10m is significantly larger than the value of 1.35 used by regulating authorities in establishing noise guidelines for wind turbines. I conclude that a realistic night-time ratio is 2.3. This means that there can be loud turbine noise without any masking from the wind at ground level. I have demonstrated this with an analysis which is summarized in a table.

Dr. Ramakrishnan also confuses the issue of how the sound from two or more turbines combine, again whether deliberately or not I do not know. He accuses Dr. van den Berg of not understanding beating as described in textbooks. There is not one shred of evidence in the thesis that Dr. van den Berg suggests adding sound waves coherently. Instead, Dr. van den Berg measures the variability of the immission noise (noise at the receptor) on a short time scale and demonstrates that it results from several close by turbines moving into and out of synchronization. I have demonstrated this process by means of a diagram at the end of this response. For incoherent sounds, one adds sound intensity; for coherent sounds, one adds sound pressures. Within 500m of a wind plant, a small number of turbines will dominate the noise level and synchronization will occur some of the time; then, full amplitude modulation will be heard. At a distance of 2 km, say, many turbines will contribute and full synchronization will be unlikely.

Dr. Ramakrishnan tries to use data from figure IV.5 to show that anyway for much of the night the noise at night falls below the Ontario noise guidelines for a receptor site 400m from the nearest turbine. Even here he fails. His conclusion was based upon wind speeds below 4 m/s (14 km/hr) and for a smaller turbine than any proponent is planning to use in Ontario. I have shown, using the same data, that with a modern fixed speed turbine, such as the Siemens 2.3 MW turbine, the night-time noise at a receptor exceeds the Ontario noise guidelines out to 700m for wind speeds as low as 4 and 6 m/s (14 and 22 km/hr).

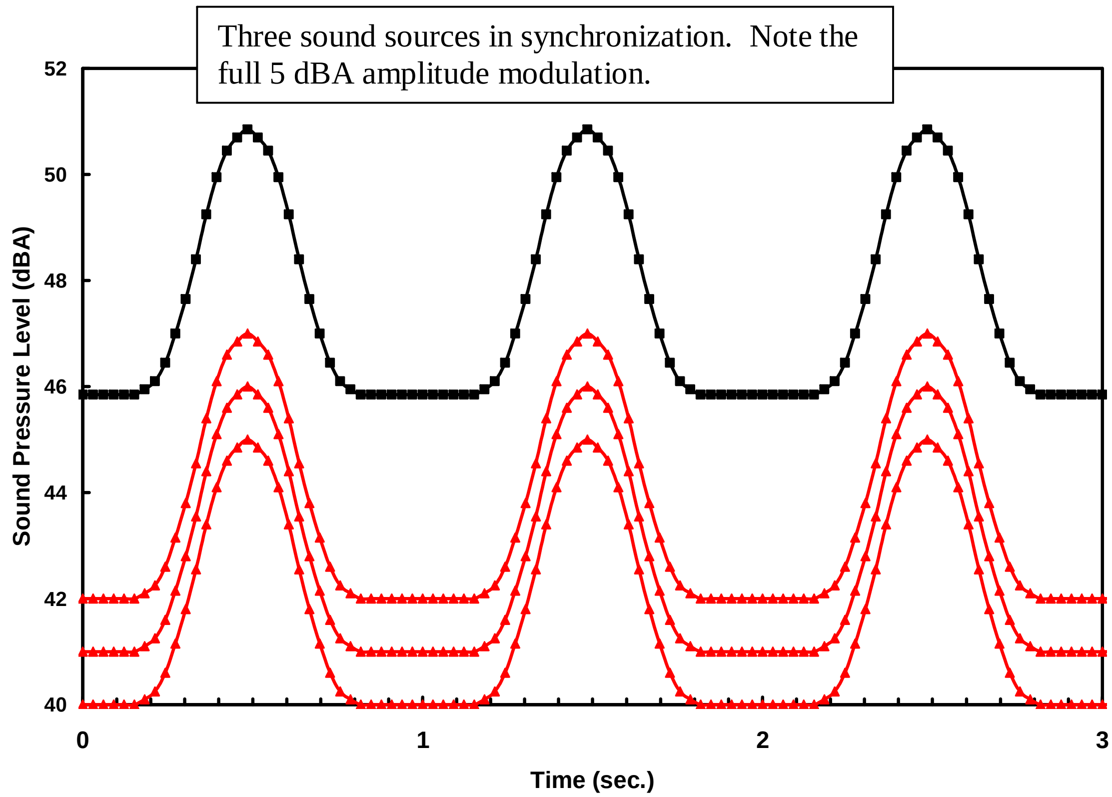
I do not see any way in which Ontario can cling to the myth of masking noise at the level set in the present Ontario noise guidelines. All of the science that is needed is complete. All of the measurements that are needed to support the science are in the literature and of course in the files of the wind industry. If MOE continues to bury its head in the sand on this issue, then it is doing a grave disservice to the rural population of Ontario which is having these turbines placed within 1.5 km of their homes. Furthermore, there have been so many issues in the past where warning signals were ignored with tragic results for everyone, companies, regulating authorities and of course, the victims: smoking and lung cancer, thalidomide, mercury in fish, asbestos mining, asbestos in houses and schools, tainted blood, unsafe cars and tires.

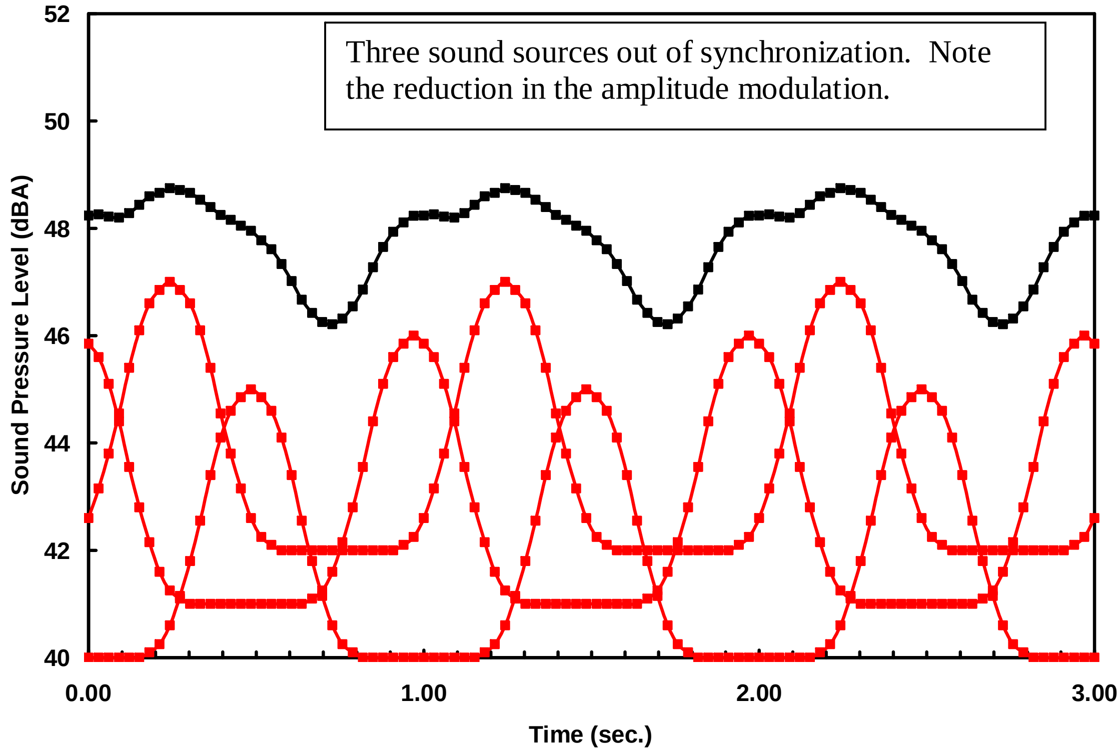
Not mentioned at this stage is the negligence of MOE in not enforcing the penalty of 5 dBA for periodic noise sources (NPC-104), the increase of turbine noise when the blades move through turbulent air and the coherent reflection of sound from the ground for low frequency sound.

As a courtesy, I will be sending copies of this response to Dr. Ramakrishnan and to Dr. van den Berg. I will also circulate copies to the members of the focus group that met on October.

References:

1. R. Ramakrishnan, Wind Turbine Facilities Noise Issues, Aiolos Report Number 407/1/2080/AR155Rev3 (2007) .
2. G.P. van den Berg, The Sound of High Winds, Thesis.
3. S Wagner, R Bareiss and G Guidati, Wind Turbine Noise (Springer 1996).
4. I.A. Perez, M.A .Garcia, M.L. Sanchez, and B. De Torre, Solar Energy 78, 809-821, (2005).
5. K. Smith, G. Randall, D. Malcolm, N. Kelly, and D. Smith, National Renewable Energy Laboratory, NREL/CP-500-32492 (2002).
6. H. Harders and H.J. Albrecht, Proceedings of Wind Turbine Noise, Berlin (2005).
7. P. Botha, Proceedings of Wind Turbine Noise, Berlin (2005).
8. see for instance: Jones Consulting Group Report, Essex County (2007).
9. M Schwartz and D Elliott, Wind Shear Characteristics at Central Plains Tall Towers, AWEA Wind Power Conference (2006).


Three sound sources in synchronization. Note the full 5 dBA amplitude modulation.
Sound Pressure Level (dBA)
52
50
48
46
44
42
40
0
1
2
3
Time (sec.)


Three sound sources out of synchronization. Note the reduction in the amplitude modulation.
Sound Pressure Level (dBA)
52
50
48
46
44
42
40
0.00
1.00
2.00
3.00
Time (sec.)