Report to the Director and Air and Noise Engineering Staff of EAAB Branch

Inadequacy of Present Ontario Turbine Noise Guidelines

John Harrison – August 27th, 2008

Intrusion

Typically, at night, the ambient (background) noise level in rural Ontario will be ~25 dBA. Therefore, the present Ontario wind turbine noise guidelines (TNG) allow an intrusion of ~15 dBA above ambient. I know of no research that can justify such a large intrusion. There are, however, at least two field studies that show significant distress at that level:

A survey of 223 people was conducted in Wisconsin 2 years after construction of a wind plant. The table shows the fraction of households that agreed that noise is a problem in their homes.

Distance from Turbine (m)	Noise Level (dBA)	Agree
800 - 1500	<35	32%
400 - 800	35 - 40	52%
250 - 400	>40	44%

NB: The noise levels are estimates, calculated from the distances.

In another study from Sweden, involving 350 responses, the following was found:

Noise (dBA)	Annoyed	Very Annoyed	Total
37.5 - 40	31%	20%	51%
>40	20%	36%	56%

The recommendations of authorities involved in the health and well-being of people living near wind turbines are summarized in the following table:

Reference	Limit
Harry (UK)	2.4 km
Frey & Hadden (UK)	2.0 km
UK Noise Association	1.6 km
French Acad. of Medicine	1.5 km
Nina Pierpont (USA)	2.4 km
World Health Org.	30 dBA
Int. Standards Org.	25 dBA
Sierra Club	Near Ambient

The limits recommended by the WHO and ISO are for the noise level inside a bedroom. Estimates for the sound level drop across the wall of a house vary from 7 to 15 dBA. I estimate that a setback of 1.5 km corresponds to a noise level of 30 dBA, or ~5 dBA above ambient.

To put the decibel (dBA) scale into perspective, an intrusion of 3 dBA is noticeable; an intrusion of 10 dBA is perceived as a doubling of the sound level.

Based upon the above evidence, the TNG should be reduced to 30 dBA from 40 dBA. At the very most, the level should be 35 dBA, in line with the limit used in Germany, Australia and Oregon.

Recommendation: Reduce the noise limit at a receptor to 30 dBA.

Amplitude Modulation

Anyone who has stood 500 metres from an operating turbine at a time when there is little near-by traffic knows that wind turbines emit a characteristic amplitude-modulated noise. The frequency of modulation is the blade passage frequency. It is thought to be the result of the interaction of the wake-turbulence, which generates the aerodynamic noise, and the tower. Figure V.4, reproduced from van den Berg's thesis, shows the noise at a residence neighbouring a wind farm on the Dutch/German border. The lower graph is an expansion of the upper compressed graph; both show the noise level as a function of time in seconds. Note the periodic variation with a frequency of about one per second, the blade passage frequency.

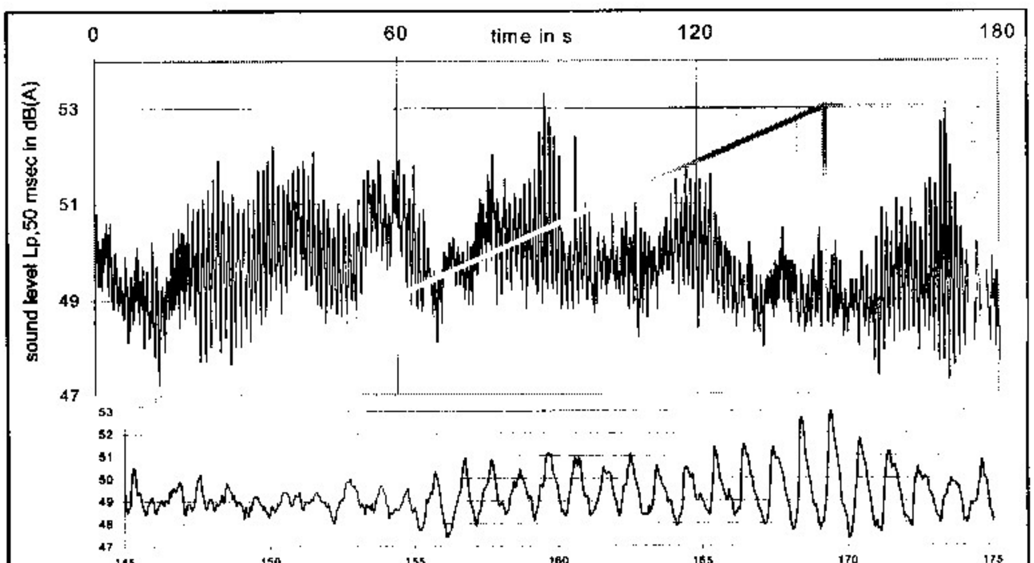


Figure V.4: fluctuations in broad band A-weighted sound immission level at façade of dwelling P; the lower panel is an expansion of the part within the grey rectangle

Four turbines dominated in creating the noise. These turbines passed in and out of synchronization causing the amplitude modulation, the size of the oscillatory

noise level, to rise and fall. The amplitude modulation of a single turbine is at least as large as the maximum seen in the graph; i.e. 5.5 dBA. It is obvious that L_{eq} (the noise level used in the TNG), which is a time average, smoothes out the amplitude modulation. However, the modulation is real and is perceived by the ear. It is this modulation that is responsible for much of the distress associated with turbine noise. Further measurements of amplitude modulation have been reported in the "Salford" report published by the British Wind Energy Authority. On page 38, the report quotes measurements of 3 to 5 dBA with measurements of 7 to 9 dBA in the frequency range 200 to 800 Hz. For one wind farm, the low frequency modulation was measured to be 12 to 15 dBA.
The TNG have a penalty of 5 dBA for this periodic variation of turbine noise (NPC-104) but the Approvals Branch of the Ministry of the Environment refuses to enforce the penalty. I cannot understand how, in the face of compelling evidence, this lack of enforcement can be justified.

Recommendation: Enforce NPC-104

Wind Speed Gradient

The evidence is now overwhelming that, at night in particular, the atmosphere is not "neutral". As an example, see the figure below, taken from a conference report; the authors are with the National Renewable Energy Laboratory, a US Department of Energy institution established to support renewable energy and its developers.

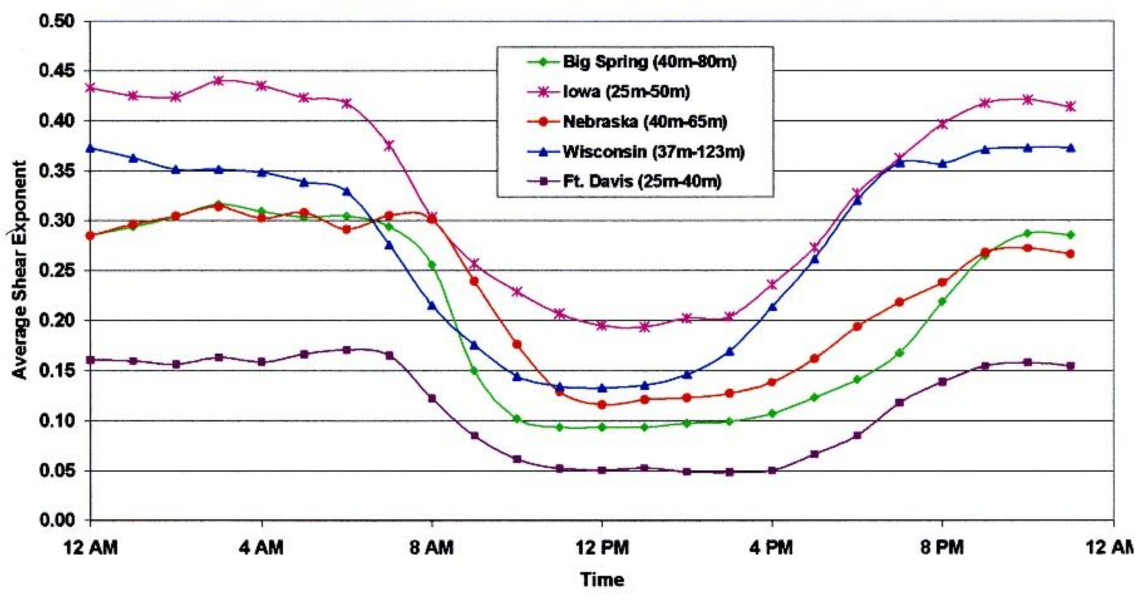


Figure 2. Comparison of Diurnal Wind Shear at TVP Projects

The figure shows the wind-speed gradient in terms of the parameter α, 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. The day-time values of α are clustered around 0.14, the accepted value for a neutral atmosphere. However, the night-time values are significantly larger. The Ontario TNG are predicated upon the "neutral atmosphere" with α = 0.14, which may be relevant for the day-time but certainly not for the night.

A more easily understood representation of the wind-speed gradient is the ratio of the wind speed at a height of 80 metres to that at 10 metres. 80 metres is a typical hub height and 10 metres is a proxy for the wind speed at a residence. The conversion is indicated in the following table:

Parameter α	0.14	0.2	0.3	0.4
Ratio v_{80}/v_{10}	1.35	1.5	1.85	2.3

The table below is taken from the paper that I presented at the World Wind Energy Conference held in June of this year. It contains all measurements of the wind-speed gradient that I know of. No inconvenient measurements have been omitted! The reference numbers refer to the bibliography of that paper; the bibliography also references all other facts included in this present report.

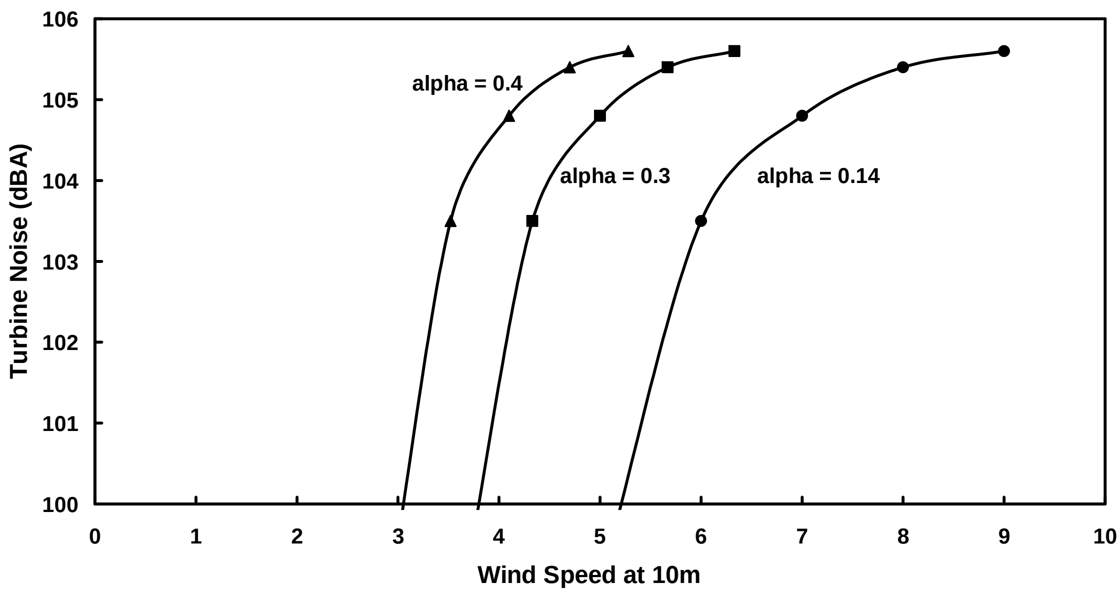
Average and night average ratios of the wind-speed at 80m to that at 10m.

Region	Source	Average	Night Average
Neutral Atmosphere	α = 0.14	1.35	1.35
Netherlands (Cabauw)	Van den Berg[16]	1.4	1.9
Big Spring TX	NREL[17]	1.55	1.85
Algona IA	NREL[17]	2.0	2.45
Springview NE	NREL[17]	1.6	1.85
Glenmore WI	NREL[17]	1.8	2.1
Ft. Davis TX (1860m)	NREL[17]	1.25	1.4
Berlin	Harders[19]	1.3	1.9
Australia 1 (Flat)	Botha[20]	1.5	1.8
Australia 2 (Flat)	Botha[20]	1.5	1.7
N Z (Complex Terrain)	Botha[20]	1.25	1.25
N Z (Complex Terrain)	Botha[20]	1.25	1.25
Sumner KS	NREL[18]	1.7	2.3
Washburn TX	NREL[18]	1.4	1.7
Lamar CO	NREL[18]	1.35	1.6
Crow Lake SD	NREL[18]	1.55	1.8
Kincardine – 30-50m	OMB[21]	1.85	2.55
Kingsbridge ON	Palmer[22]	1.6	1.75 (summer 2.25)
Amaranth ON	Palmer[22]	1.75	2.45 (summer 2.75)
USA 10 Stations	Archer[23]		2.1 ± 0.3

The average ratio is 1.4 ± 0.2 and the night-time ratio is 1.9 ± 0.4, higher by 35%.

To see the significance, consider an application to south-western Ontario. Making use of the 3 highlighted results from Table 1 and numbers from the Ministry of Natural Resources wind atlas, a daily average ratio of 1.75 is predicted. The wind atlas gives only annual average wind speeds as a function of height above ground level. The higher averages for south-western Ontario are expected because of the presence of large bodies of water. With the same 35% enhancement, the night-time average ratio will be 2.3. Consider the case that the wind speed at 80m is 10 m/s. The assumed neutral atmosphere wind speed ratio of 1.35 gives the wind speed at the ground equal to 7.5 m/s. The Ontario noise limit for this wind speed is 44 dBA, which includes a masking allowance of 4 dBA above the basic 40 dBA. However, with a more accurate night-time ratio of 2.3, the wind speed at the ground is 4.5 m/s. For this ground-level wind speed, there is no masking noise. As another example, for a wind speed at the turbine hub of 14 m/s, the 12 dBA of masking noise is reduced to 1 dBA. Clearly, for night-time operation of wind-turbines, masking noise is a myth. Authorities in the Netherlands have now accepted this and no longer include masking noise in their noise limit.

A second approach is to follow the May 2008 Draft Interpretation for Applying MOE NPC Publications to Wind Power Generation Facilities, section 5.2.3. I have applied this interpretation guideline to a Siemens 2.3 MW turbine. The right-most curve is the published noise specification, presumably taken from neutral atmosphere measurements. The other curves are my calculations of the turbine noise for values of α equal to 0.3 and 0.4 corresponding to wind speed ratios of 1.9 and 2.3 respectively. For this turbine, for α equal to 0.3 or 0.4, the turbine has reached its maximum noise level at a 10 metre wind speed of 6 m/s. There is no masking noise for 10 metre wind speeds up to 6 m/s. The allowance for masking is therefore irrelevant!



As I have already recommended to MOE as part of the clarification process, section 5.2.3 must be rewritten to make it absolutely clear what a developer must do to account for the real wind speed gradient. My suggestion, presented in my response to the workshop, is as follows:

The wind speed profile on the site of the wind farm will have an effect on the manufacturer's wind turbine acoustic emission data and, consequently, on the sound levels at a Point of Reception. Therefore, the wind turbine generator acoustic emission levels should be consistent with the wind speed profile of the project area. To reflect this issue in the context of determining the "predictable worst case" noise impact, the following protocol shall be used:

From the measured wind-speed profile for the project area, the value of night-time α_{10}*, the value of α exceeded 10% of the night-time (11 pm to 6 am) is calculated. The manufacturer's wind turbine acoustic emission data is then to be adjusted to conform to this value of* α_{10}*. This adjusted acoustic emission data shall then be used in the noise impact assessment at each receptor. The manufacturer's acoustic emission data, before and after adjustment, must be tabulated in Table 3.*

The coefficient α is 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 present Ontario noise guidelines, has* $\alpha = 0.14$*.*

Recommendation: Drop the masking noise allowance or rewrite 5.2.3 as suggested above.

Turbulent Inflow Noise.

At present, noise generated by the inflow of turbulent air into the turbine (turbulent inflow) is not included in the Ontario TNG. Within the past 5 years there have been semi-empirical models of turbulent inflow aerodynamic noise and, from NREL, a comparison of actual turbine measurements with these models. The significance here is that turbulent inflow, when present, dominates the aerodynamic noise in the frequency range below 1 kHz, the frequency range where sound propagates with little absorption in the air.

Figure 16 from a 2004 National Renewable Energy Laboratory report, reproduced below, shows a comparison of calculations of various aerodynamic noise sources with measured noise for the National Wind Technology Centre research turbine. It is a 37m tower with a 42m upwind rotor diameter. The wind speed measurement tower is close by. The turbulence intensity, measured over a 1 minute time interval, was a high 46%. The wind speed was 5.7 m/s. The noise measurements were made 58m downwind. The figure is a plot of noise (sound pressure level) in 1/3 octave bands as a function of frequency. TBL is turbulent boundary layer, TE is trailing edge.

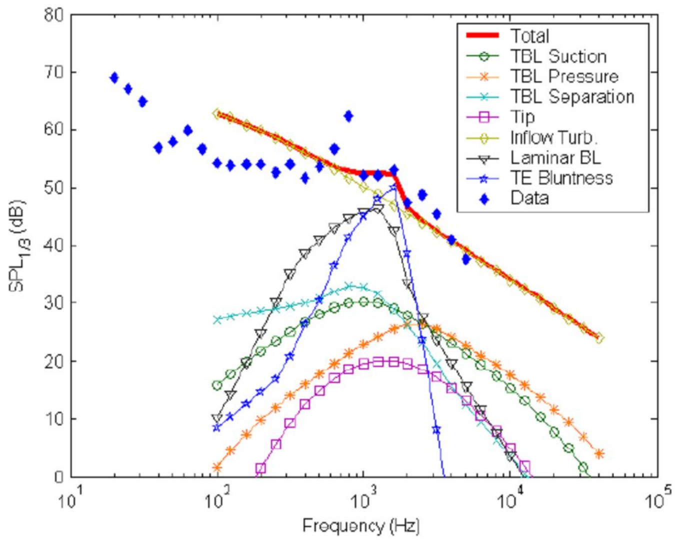


Figure 2: Calculation of aerodynamic contributions to turbine noise level.

Note that the character of the measured sound reflects that of turbulent inflow, although the calculation over-estimates the turbulent inflow noise. In particular, note the dramatic enhancement of the turbine noise in the frequency range10 to 1000 Hz when the air is turbulent. The authors realized that 1 minute is too long a time for determining the turbulence intensity and that good agreement would have resulted from a 30 sec interval. Turbulent inflow noise can now be estimated on the basis of turbulence intensity measurements, which require wind-speed measurements measured on a fast time scale with the average and standard deviation calculated for 30 second intervals. Before any wind plants are approved, turbulence intensity measurements need to be made and turbulent inflow noise estimated.

Recommendation: Require turbulence intensity measurements and inflow noise prediction.