For the attention of the World Health Organization Panel revising the European Noise Guidelines to include Industrial Wind Turbine Noise.

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1.0 RECOMMENDATIONS FOR AUDIBLE NOISE – AMPLITUDE MODULATION

1.1 Normal human hearing can discern a change of 3 dBA in noise level; thus Amplitude Modulation should be clearly defined using a methodology similar to Den Brook.
1.2 Noise testing for wind turbine noise levels should include the requirement for fast averaging at 125 or 200 millisecond bins.
1.3 Amplitude Modulation should be regulated as a unique compliance requirement separate from the average noise levels.
1.4 Recommended limits for wind turbine noise should include an upper limit of not more than 40 dBA for the peak amplitude modulation, in addition to the averaged noise.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

One of the WHO's stated goals is “shaping the research agenda and stimulating the generation, translation and dissemination of valuable knowledge.”
With that goal in mind, the following are my recommendations for additional research programs that the WHO could undertake, or encourage that they be placed on the research agenda of the nations that are investing in wind energy projects and technology.

2.0 RECOMMENDATIONS FOR INFRASOUND EMISSIONS FROM WIND TURBINES

Conduct, direct or encourage the design and implementation of:

2.1 A study similar to the Cape Bridgewater study to confirm the results.
2.2 A properly designed, longitudinal study, with an appropriate cohort, to monitor any long term health impacts from infrasound on nearby residents.

3.0 RECOMMENDATIONS FOR SEISMIC GROUND WAVES (SGV) FROM WIND TURBINES

Conduct, direct or encourage the design and implementation of:

3.1 A controlled pre and post construction seismic survey of the effect of the SGV from a modern turbine on shallow water wells at distances typical of setbacks from turbines, generally 500 meters to 2,000 meters.
3.2 A seismic survey on the effect of the operation of a modern wind turbine on shallow water wells at distances typical of setbacks from turbines.
3.3 Evaluate the effectiveness of vibration reduction technologies on SGV from operational turbines.

Below, please find my rationale for the above recommendations. The numbering aligns with the number of the recommendation listed above.

1.0 WIND TURBINE NOISE AND AMPLITUDE MODULATION

Noise guidelines developed for industrial wind turbines should include consideration of the unique characteristics of such noise.
One specific characteristic that I will comment on is Amplitude Modulation (AM).
In this context, Amplitude Modulation can be defined as a rhythmic rise and fall in the audible noise output of a wind turbine.

Figure 1 below appears in a presentation by Professor Helge Aagaard Madsen at the 6th International Conference on Wind Turbine Noise in Glasgow, April 2015. [1]

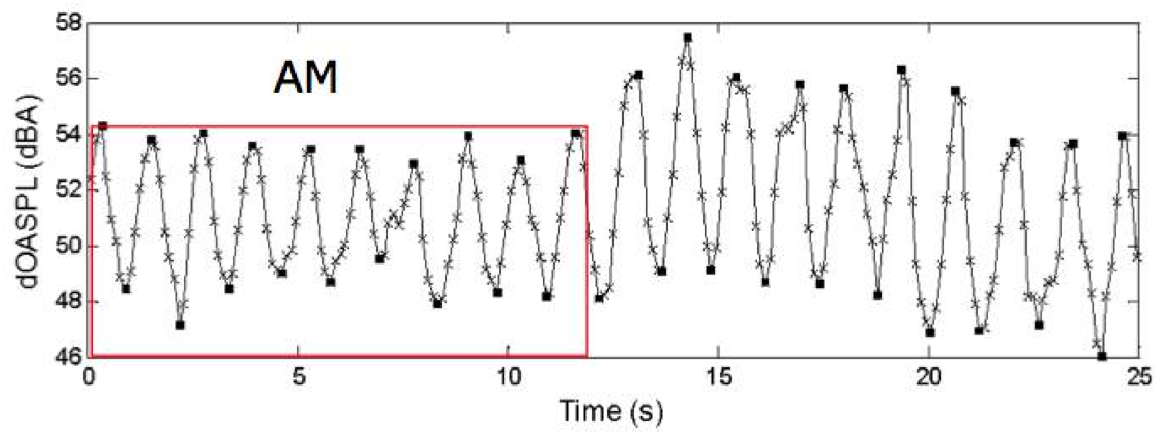

Figure 4: Time history of A-weighted overall sound level as a function of time (absolute levels not meaningful). The transition between normal swish and EAM occurs between 11 s and 13 s. The crosses indicate the instantaneous levels (averaged over 0.23 s), the squares indicate the maxima and minima.

Figure 1.

By using 200 millisecond bins, Professor Madsen has shown that there are two levels of AM, “Normal Amplitude Modulation (NOA)”, sometimes referred to as 'blade swish', with a modulation depth (peak to trough) up to 5 dBA, and “Other Amplitude Modulation. (OAM)”, with a greater modulation depth, up to 10 dBA or higher, and is often characterized as a 'booming' sound.

What has happened in recent years, and in various jurisdictions, is that Normal Amplitude Modulation has somehow been redefined as part of a wind turbine's normal operation, and is somehow no longer considered to be AM. OAM from turbines has been redefined as the only type of AM requiring consideration.

This position on AM is reflected in the document *Noise Guidelines for Wind Farms Interpretation for Applying MOE NPC Publications to Wind Power Generation Facilities* [2] from the province of Ontario, (Canada) Ministry of the Environment and Climate Change (MOECC). That document states:

> No special adjustments are necessary to address the variation in wind turbine sound level (swishing sound) due to the blade rotation, see Section 4. This temporal characteristic is not dissimilar to other sounds to which no adjustments are applied. It should be noted that the adjustments for special quality of sound described in Publication NPC-104, Reference [1], were not designed to apply to sounds exhibiting such temporal characteristic.

This position is not supported by observations from Ontario's own MOECC officers, and by acousticians commenting on this characteristic of wind turbines.

From an internal email obtained through a Freedom of Information request, dated April 9, 2012, from the MOECC's Senior Environmental Officer, Cameron Hall, to the MOECC District Manager, Guelph District Office, Ms. Jane Glassco, and to Supervisor Dave Bray, Guelph District Office, [3, appended] Mr. Hall states:

> It should be noted that the more recent 2008 NPC Guidelines Interpretation differs from the 2004 NPC Guidelines Interpretation by stating no adjustment should apply to the cyclic variation quality "swishing sound" of the noise contamination discharged from the WTGs. The 2008 NPC Guidelines Interpretation suggests the blade swish noise is temporal. **This conclusion is not supported by our field observations, or the findings in the Ministry 2007 Acoustic Consulting Report.** (my emphasis)

This comment appears in a 2007 Acoustic Consulting Report [4] that Mr. Hall refers to, prepared for Ontario's MOECC:

> **Due to the nature of the amplitude modulation phenomenon, the swishing or thumping exists all the time.** (my emphasis)

Brian Howe is President of HGC Engineering, the firm that prepared the Noise Assessment Report for a local wind project, the Suncor Cedar Point Wind Project in Ontario Canada. Suncor called him as a witness in the 2014/2015 appeal hearing before an Environmental Review Tribunal (ERT). The ERT qualified Mr. Howe as a mechanical engineer with expertise in acoustics, noise and vibration, and with special expertise in infrasound, low frequency noise and wind turbine noise.
In his witness statement, [5] and appended] Mr. Howe states at p.7:

> “Research has shown that the dominant audible characteristic is the amplitude modulation of broad-band sound (the “swoosh”).”

DEFINING AMPLITUDE MODULATION

There is a need to define AM properly, and any definition must take into account the audibility of the rise and fall in a turbine's the noise output.
One example of an accurate AM definition is the Den Brook Condition. [6]
In order for a turbine noise to be deemed as exhibiting AM, one hour of external sound level data must contain at least:

- Six (6) separate one minute periods each with at least:

    - Five (5) events caused only by the wind turbines (not from any extraneous noise) that have a peak to trough of at least 3dB for each event.
- also, that minute must have an average LA_{eq} of not less than 28dB

DATA HANDLING FOR WIND TURBINE NOISE COMPLIANCE

In addition to the inaccurate and inappropriate definition of AM, the data handling and calculations used by the industry in various jurisdictions further hampers any effective evaluation of AM.

In Ontario, Canada, the compliance testing methodology for wind turbine noise, [7] developed by a member of the Canadian Wind Energy Association, is based on the calculated L_{eq} using the average noise level in 120 separate one minute bins. The 120 bins are then averaged logarithmically.

Expressing the average noise in one minute bins, and then using those results to calculate the average noise as a single dBA over 120 minutes for each integer wind speed, even if the calculation is logarithmic, is an oversimplification that effectively filters out any evidence of amplitude modulation, and will not describe the actual nature of the sound produced by wind turbines.
As an example, for a wind turbine operating at typical 10 to 15 rpm there will be 30 to 45 “blade swish” pulses in a one minute bin which will be averaged for that minute, and then further averaged with another 119 one minute bins. This will effectively hide any sign of AM.

One one can readily see from Figure 1, that this methodology can result in data showing turbines in compliance that are actually cycling out of compliance every 1.5 to 2 seconds depending on the turbine's rpm.

WIND TURBINE NOISE, ANNOYANCE AND HEALTH EFFECTS

If the AM peaks regularly approach and pass the 40 dBA level at nearby homes or schools, the impact on human health should not be underestimated.

In the WHO report Burden of disease from environmental noise, Quantification of healthy life years lost in Europe, [8] the authors state:

> In 2009, WHO published the Night noise guidelines for Europe (4). This publication presented new evidence of the health damage of nighttime noise exposure and recommend threshold values that, if breached at night, would threaten health. An annual average night exposure not exceeding 40 dB outdoors is recommended in the guidelines. (p. 99)

and

> It is estimated that DALYs (disability-adjusted life years) lost from environmental noise in the EU countries are 60 000 years for ischaemic heart disease, 45 000 years for cognitive impairment of children, 903 000 years for sleep disturbance, 21 000 years for tinnitus and 587 000 years for annoyance. Sleep disturbance and annoyance mostly related to road traffic noise comprise the main burdens of environmental noise in western Europe. (p. 101)

Mr. Howe also states at p. 8 in his witness statement (see [5] – the document is appended):

> "The largest and most comprehensive studies completed to date suggest that at noise impacts between 35 and 40 dBA, 6% will be very annoyed, while at noise impacts between 40 and 45 dBA, up to 20% of persons will be very annoyed."

BAVARIA, GERMANY, REGULATIONS

Bavaria instituted a penalty of 3 dBA for amplitude modulated noise in 2012. [9]

> "The decision of the Bavarian Higher Regional Court in Munich about the wind turbine in Kienberg points out that the Enercon E 82 turbine emits pulsed noise. Therefore to any actually measured sound level three decibels would have to be added."

The decision was challenged to a higher level of jurisdiction but the appeal was rejected.

> "The Federal Court of Justice has rejected the ENERCON case. The Federal Court of Justice is the highest Court for such cases in Germany, so Enercon has no possibility to go further in this case. The 3 dB addition for pulsed noise for the E82 is official."

RECENT STUDIES IN AMPLITUDE MODULATION

Ever since the advent of large scale wind turbines, a number of researchers have commented on the greater annoyance levels upon exposure to wind turbine noise. A very recent example is a report by Beat Schaffer published in the Journal of the Acoustical Society of America in 2016: Short-term annoyance reactions to stationary and time-varying wind turbine and road traffic noise: A laboratory study. [10]
The abstract appears below:

> Current literature suggests that wind turbine noise is more annoying than transportation noise. To date, however, it is not known which acoustic characteristics of wind turbines alone, i.e., without effect modifiers such as visibility, are associated with annoyance. The objective of this study was therefore to investigate and compare the short-term noise annoyance reactions to wind turbines and road traffic in controlled laboratory listening tests. A set of acoustic scenarios was created which, combined with the factorial design of the listening tests, allowed separating the individual associations of three acoustic characteristics with annoyance, namely, source type (wind turbine, road traffic), A-weighted sound pressure level, and amplitude modulation (without, periodic, random). Sixty participants rated their annoyance to the sounds. At the same A-weighted sound pressure level, wind turbine noise was found to be associated with higher annoyance than road traffic noise, particularly with amplitude modulation. The increased annoyance to amplitude modulation of wind turbines is not related to its periodicity, but seems to depend on the modulation frequency range. The study discloses a direct link of different acoustic characteristics to annoyance, yet the generalizability to long-term exposure in the field still needs to be verified.

NON-AUDIBLE EMISSIONS FROM WIND TURBINES

The announcement for this WHO initiative states that The Guidelines will include a review of evidence on the health effects of environmental noise to incorporate significant research carried out in the last years. This statement suggests to me that all evidence will be reviewed and that includes research on the full spectra of noise emissions from wind turbines including infrasound and seismic emissions.

2.0 INFRASOUND EMISSION FROM WIND TURBINES

There is a growing body of information that suggests infrasound has an adverse effect on human health. Perhaps the most rigorous to date is the Cape Bridgewater study in Australia by the highly respected acoustician Steven Cooper. [11] The following are excerpts from the executive summary of this study.

From page i:

> Despite the wind farm satisfying the acoustic criteria nominated on the permit [9] the operator of the wind farm (Pacific Hydro) is in receipt of noise complaints from residents in proximity to the wind farm.
>
> To address the issue of complaints from residents Pacific Hydro requested the conduct of an acoustic study at three residential properties to ascertain any identifiable noise impacts of the wind farm operations or certain wind conditions that could relate to the complaints that had been received. The study was to incorporate three houses that are located between 650 m to 1600 m from the nearest turbine.
>
> The acoustic investigation was not restricted to the general A-weighted level specified on the permit.
>
> Following consultation with residents, residents were asked to record (using severity rankings) perceived noise impacts, vibration impacts and other disturbances which, for the purposes of this study, have been labelled “sensation.” “Sensation” includes headache, pressure in the head, ears or chest, ringing in the ears, heart racing, or a sensation of heaviness.

From page ii:

> The study found that the diarized resident’s observations identified “sensation” as the major form of disturbance from the wind farm.

From page iv:

> By including narrowband analysis in the description of the acoustic environment, the study confirms that the infrasound obtained in a wind farm affected environment is different to that in a natural acoustic environment.
>
> From the resident’s subjective observations a wind turbine signature rating curve has been derived that indicates an unacceptable presence of sensation inside a dwelling (for those 6 residents) occurs at an level of 51 dB(WTS) – when assessed as rms values 400 lines for analysis range of 25 Hz. Utilising PSD values (400 line 25 Hz range) the unacceptable level for the 6 residents occurs at 61 dB(WTS).
>
> .... it is noted that the sample data is small and has persons already affected by the “noise”. The findings must be considered as preliminary and warrant further detailed studies of the scientific

rigour necessary for the purpose of confirming/verifying the suggestions for the use of the nominated dB(WTS) thresholds.

The issue of infrasound is an open question that warrants further study as recommended by Mr. Steven Cooper.

3.0 SEISMIC EMISSION FROM WIND TURBINES

Seismic ground waves from turbines have been studied in the context of their impact on seismic stations monitoring earthquakes, and in some cases, nuclear bomb testing. [12], [13].

There have been recent concerns raised in Ontario, Canada, that seismic ground waves from nearby wind turbines may have resulted in the contamination of rural wells with silt and fine particulates. [14]

At least one study that suggests that seismic ground waves emanating from turbines may be capable of coupling with foundations of residences, exciting the building's resonant frequencies and generating noise severe enough to result in sleep disturbance. [15]

Since wind turbine projects are almost always located in rural areas, further study on their seismic emissions and the potential impact on rural residences and well water quality is warranted.

Respectfully submitted,

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REFERENCES:

[1] H Aa Madsen, An overview of recent research on AM and OAM of wind turbine noise
WTN 2015 Glasgow April 20-23, 2015 Conference papers are available from INCE Europe.
https://www.windturbinenoise.eu/content/conferences/2-wind-turbine-noise-2015/buy-cd/

[2] Noise Guidelines for Wind Farms Interpretation for Applying MOE NPC Publications to Wind Power Generation Facilities
https://www.ontario.ca/page/noise-guidelines-wind-farms-interpretation-applying-moe-npc-publications-wind

[3] Cameron Hall, Senior Environmental Officer, Guelph District Office; Re: Comments - March 1,2010 draft document, "Renewable Energy Approvals Technical Bulletin Six Required Setbacks for Wind Turbines", April 9, 2010. Appended.

[4] Ramani Ramakrishnan, Ph. D., P. Eng. ACOUSTIC CONSULTING REPORT Prepared for the Ontario Ministry of the Environment WIND TURBINE FACILITIES NOISE ISSUES, Aiolos Report Number: 4071/2180/AR155Rev3, DECEMBER 2007
http://grandbend.northlandpower.ca/site/northland_power___grand_bend_wind_farm/assets/pdf/acoustic_consulting_moe_wind_turbine_facilities_noise_issues.pdf

[5] Brian Howe, President GHC Engineering Ltd., Witness statement, Cedar Point Environmental Review Tribunal. Appended.

[6] MAS Environmental, The Den Brook AM Condition,
http://www.masenv.co.uk/Den_Brook_AM_Condition

[7] Ontario Ministry of the Environment, Compliance Protocol for Wind Turbine Noise
Guideline for Acoustic Assessment and Measurement,
https://www.ontario.ca/document/compliance-protocol-wind-turbine-noise

[8] WHO European Centre for Environment and Health
Burden of disease from environmental noise, Quantification of healthy life years lost in Europe
http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf

[9] Media report at: http://www.windwahn.de/index.php/news/gerichte/enercon-e-82-pulsed-noise
Refers to: Higher Regional Court of Munich, Ref.no. 27 U 342/11 and 27 U 50/12
091 O 1693/10 LG Augsburg 021 O 1587/10 LG Augsburg

[10] Scaffer et al; Short-term annoyance reactions to stationary and time-varying wind turbine and road traffic noise: A laboratory study. Journal of the Acoustical Society of America, Volume 139, Issue 5, 2016.
http://scitation.aip.org/content/asa/journal/jasa/139/5/10.1121/1.4949566

[11] Steven Cooper; The Results of an Acoustic Testing Program – Cape Bridgewater Wind Farm Page i Energy Pacific (Vic) Pty Ltd
http://www.pacifichydro.com.au/english/our-communities/communities/cape-bridgewater-acoustic-study-report/

[12] Mark-Paul Buckingham, Eskdalemuir – Route to a solution
http://4f553fa71f6b11e5f9b0-e9e5be702ded16836c4ccca0ea3e9a9c.r68.cf3.rackcdn.com/uploads/events/presentations_new_file/onwin13_parallel_a.pdf

[13] W. N. Edwards, Analysis of measured wind turbine seismic noise generated from the Summerside Wind Farm, Prince Edward Island
http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=296443

[14] http://www.chathamdailynews.ca/2016/06/29/citizens-group-worried-vibrations-from-wind-farm-could-ruin-ground-water

[15] H.H.C. Bakker, School of Engineering and Advanced Technology, Massey University, Seismic Effect on Residents from 3 MW Wind Turbines, http://www.smart-technologies.co.nz/articles/seismic_effects_residents.html