EFFECTS OF WIND TURBINE ACOUSTIC EMISSIONS

June 23, 2015

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Wind turbine effects

- Annoyance -- audible sound
- "Health" effects -- infrasound
- Sleep disruption -- both audible and infrasound

Wind turbine effects

- Annoyance -- audible sound
- "Health" effects -- infrasound
- Sleep disruption -- both audible and infrasound
- The Illinois Pollution Control Board (IPCB) is only responsive to the first bullet: annoyance
- So, the Health effects caused by infrasound are not addressed by the IPCB.

IPCB Does Not Adequately Protect Citizens From Wind Turbine Noise Annoyance

- A wind turbine is what is termed in ISO 1996-1 and ANSI S12.9 Part 4 an "impulsive source" but not a "highly impulsive source"
- The original IPCB rules had specific A-weighted limits for impulsive sources
- Sometime around 1990 or 2000, someone convinced the IPCB to make the definition of impulsive sound highly impulsive, which eliminates most impulsive sound from the regulation, leaving only gunfire, metal hammering and stamping, pile-driving, and similar highly impulsive sounds regulated, with essentially only a 5 dB penalty.

IPCB Does Not Adequately Protect Citizens From Wind Turbine Noise Annoyance (cont.)

- This action by the IPCB is incorrect in two ways: they mixed up the definitions, and failed to apply the recommended penalties to what was done
- ISO 1996-1 and ANSI S12.9 Part 4 both recommend 5 dB as the penalty for impulsive noise and 14 dB as the penalty for highly impulsive noise
- So wind turbine noise gets incorrectly classified as a continuous, non-tonal, non-impulsive industrial source with a nighttime limit of approximately 48-51 dB

IPCB Does Not Adequately Protect Citizens From Wind Turbine Noise Annoyance (cont.)

- All the Illinois rules regarding residential, commercial, and industrial land uses and the sound that can be emitted from one land use to another were written in about 1968, and did not contemplate wind farms.
- The following text will show the maximum acceptable sound level for wind farm noise at night.

Annoyance—audible sound

- Transportation noise is assessed using the Day-night Average Sound Level (DNL)
- Recommended level for traffic noise in urban/suburban areas is DNL = 55 dB (ANSI S12.9 Part 5, WHO, World Bank, FERC, others).
- Surface Transportation Board (STB) and Federal Railway Administration (FRA) essentially recommend DNL = 55 dB

Annoyance—audible sound

- Two modes of transportation, the two noisiest, recommend and use a *higher* criterion level:
  - The Federal Highway Administration's (FHWA) recommended level for road traffic noise is DNL = 65 dB; a 10-fold increase in power; a doubling of loudness over that recommended by neutral bodies.
  - The Federal Aviation Administration (FAA) also recommends DNL = 65 dB, but in this case, the source is known to be at least 5 dB more annoying than road - traffic-noise at the same DNL level. It represents a 30-fold increase in power; a tripling of loudness over that recommended by neutral bodies.

Annoyance—the role of weightings

- The so called A-weighting is used to assess most noise including transportation noise.
- The wind turbine industry has alleged that A-weighting should used to assess wind turbine noise.
- A-weighting cuts out much of the high and low frequencies
- Wind turbine noise contains “strong low-frequency content”

Annoyance—the role of weightings

- According to both ISO and ANSI S12.9 Part 4, A-weighting should not be used for wind-turbine noise, but the industry ***has not complied with these Standards.***
- Specifically, ISO 1996-1 contains the following:
  - For the assessment of sounds with strong low-frequency content, the rating procedures should be modified. The measurement location may be changed and the frequency weighting is affected since sounds with strong low-frequency content ***engender greater annoyance than is predicted by the A-weighted sound pressure level.***

Note: All references to ANSI are to S12.9 Part 4 except for the one reference to Part 5 on slide 7. All references to ISO are to 1996-1.

Annoyance—the criterion

- Because of its somewhat impulse-like character, an impulse noise adjustment that is added to other noise should be investigated for use with wind turbine noise
  - This impulse noise occurs at the rate that blades pass the tower
- An alternative metric to A-weighting is required
- These two factors together, sound character and the non-standard use of A-weighting, require a 5 to perhaps 15 dB adjustment.
- Note: in terms of listening, 3 dB is typically the smallest change people notice.

Annoyance—the role of community norms

- There is a big difference between Capron IL, a quiet and rural area, and Manhattan Kansas, with there being a much bigger difference between Manhattan Kansas and Manhattan NY.
- This is known, and standards suggest up to 10 dB be subtracted from the criterion in quiet rural areas because of their lower tolerance for noise than in urban or suburban areas.

(ANSI/ASA S12.9 Part 4; ISO 1996 Part 1)

Annoyance—the criterion

- ***The quiet rural setting requires a 5 to 10-dB adjustment.***
- Of the 5 to 15 dB adjustment to be made because of A-weighting and impulsiveness, ***non-standard use of A-weighting alone requires at least a 5-dB adjustment.***
- So there should be a 10 to 25 dB adjustment to the criterion of DNL = 55 dB

Annoyance—the criterion

- DNL = 55 dB is the traffic noise criterion.
- Adjusting the 55 dB criterion by 10 to 25 dB indicates that the criterion should be adjusted down to DNL = 30 to 45 dB

Annoyance—the criterion

- The nature of DNL is that if the DNL is based on a sound level that is constant over the entire 24 hour day, that sound level is 6 dB lower than the DNL level that it calculates to.
- For example, a constant, 24 hour level of 39 dB calculates to a DNL = 45 dB. (ANSI, ISO)
- The results are that ***the nighttime level and, indeed, the 24 hour level at most should be ≤ 39 dB,*** and it is not unlikely that the correct limit is lower than 39 dB.
- A constant level range from 24-39 dB equates to a DNL range from 30-45 DNL.

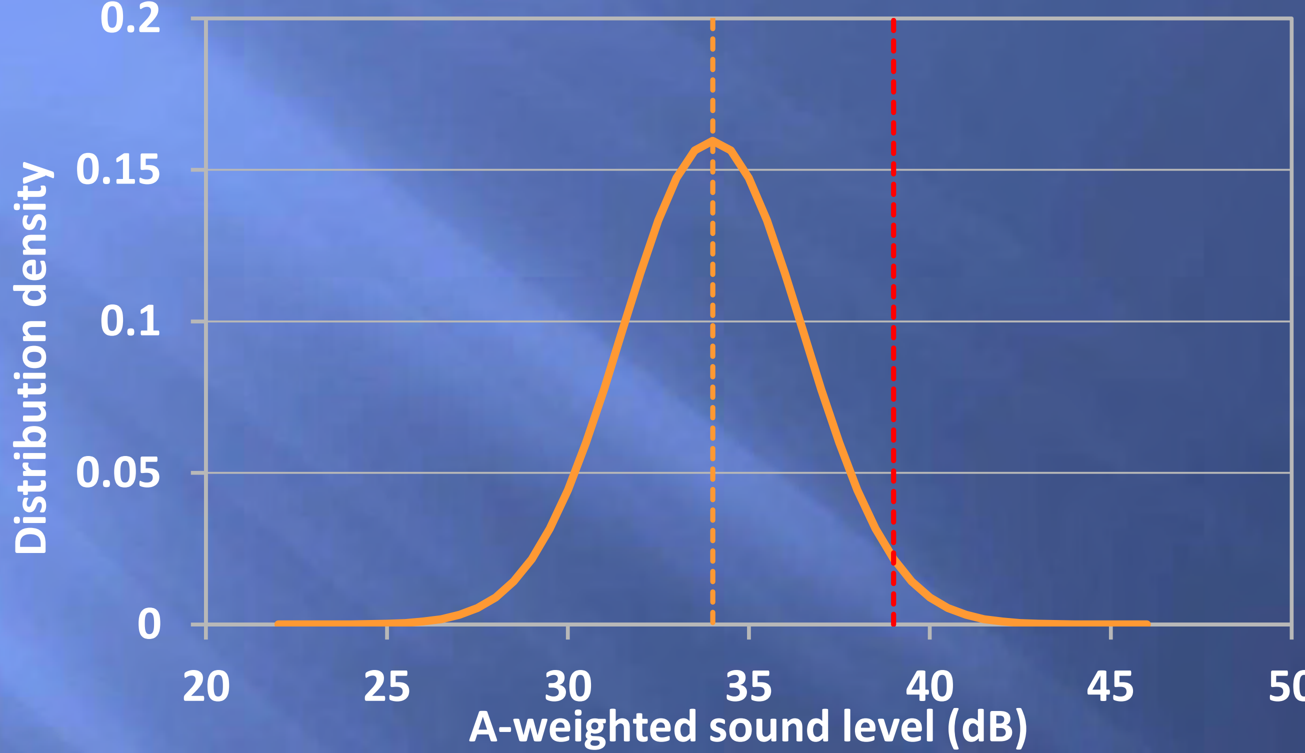
Uncertainty

- The travel of sound from a source to a receiving point constantly changes because of minor changes in the atmosphere between the source and the receiving point.
- The sound level one actually records at a receiving point takes the shape of a bell curve, and with a bell curve, half the data will be randomly above the design level and half the data will be randomly below.
- This random variation creates the uncertainty.

Uncertainty (cont.)

- To ensure that nearly all of the data are below the criterion level, one subtracts a tolerance from the prediction. This tolerance is solely based on the parameters for the bell curve as fit to the data.
- To ensure that less than 5 percent of the data exceed the criterion, one needs to subtract 4-6 dB from the criterion of 39 dB.
  - The 4-6 dB comes from long-term measurements from colleagues and studies I have been involved with on windfarms in Oregon and Illinois. The standard deviations increase with increasing distance from the wind turbines. Hessler has collected A-weighted data in 3 directions at 1000ft and one direction at 2000ft. These data show standard deviations for the higher part of the data set as 1.5 dB at 1000ft and 2 dB at 2000ft, which clearly supports the selection of a standard deviation of 2.5 dB at 2500ft. These data are also consistent with other data collected in Illinois.

Bell Curve



This is frequently called a bell curve. It portrays what is called a "normal" distribution and it portrays how frequently different sound levels occur. The average level is 34 dB, marked by the orange line, and there are equal data on either side of the bell curve. The "near maximum" level, not to be exceeded, is marked by the red line. 95% of the area is beneath the orange curve and to the left of the red line; 5% are to the right of the red line.

Uncertainty (cont.)

- Subtracting 5 dB is my recommendation and, I believe, the minimum that can be recommended.
- By way of comparison, if one wanted to ensure that less than 1 percent of the data exceed the criterion, (in contrast to 5 percent), one needs to subtract 6-9 dB from the criterion of 39 dB.
- The percent of the data exceeding the criterion is directly related to the tolerance chosen. A smaller tolerance (e.g. 5 dB) protects 95 percent of the data. A larger tolerance (e.g. 7.5 dB) protects 99 percent.
- **So I recommend designing for 34 dB** and requiring that no more than 5 percent of the data exceed the 39 dB, nearly always by only 0-2 dB.

Annoyance—translating the criterion into distance

- The noise at any home or other site in the vicinity of a windfarm is the sum of the acoustic energies from each and every one of the wind turbines that reach that site. In the worst case, there can be perhaps four like turbines, each 1000 ft in a different direction from the residence.
- In this example, the sound level would be 6 dB higher than predicted for just one turbine. So basing the criterion on the distance between one turbine and a point in the community can under-predict the true sound level.

Annoyance—translating the criterion into distance (cont.)

- Conversely, because A-weighting eliminates most of the low-frequency energies, the decay with distance could be 6.5 dB per doubling of the distance rather than 6.
- Because 6 dB is the theoretical decay with distance term in simple situations and because it is cited in some industry-produced documents, we will use 6 dB.

Converting criterion (including tolerance) to distance

Wind Turbine Sound Propagation at the example of 102 dBA sound power at hub	
Distance (ft)	Noise Reduction (dBA)
1	102
2	96
4	90
8	84
16	78
32	72
64	66
128	60
256	54
512	48
1024	42
2048	36
4096	30

- The criterion, including tolerance, is 34 dBA.
- The table on the left gives dBA versus distance for a large wind turbine with an A-weighted power level of 102 dB.
- The distance that corresponds to 34 dBA is 2580ft; nearly half a mile.
- NOTE: These calculations are all for a hub power level of 102 dB. If the selected wind turbine had a different power, then all of these numbers go up or down by the difference between the power of the selected wind turbine and 102.

Wind turbine effects on sleep

- Effects of outdoor audible sound:
  - Almost no significant effects predicted at 39 dB or lower (WHO)
  - Sharp increase in adverse health effects predicted in the 40-55 dB range (WHO)
- Effects of non-audible low-frequency and infrasound:
  - Reported awakenings in agitated and/or scared states

Some of the reported effects of wind-turbine low-frequency and infrasonic emissions (Effects Reported)

- Pulsations
- Pressure on the ear
- Headache
- Fatigue
- Nausea
- Dizziness

Who will be affected? Where, when, and why?

- We do not know?
- Many windfarms have no observable problems
- However, in the case of wind farms with high numbers of complaints, it appears that something like 1/3 of the residents self-report being significantly affected, with a subset of these reporting to being severely affected
- We do not know the true number because those receiving money from the windfarm typically have in their contract a prohibition on speaking out or taking part in any action in opposition to the windfarm.

Who will be affected? Where, when, and why?

- Research could provide answers
- But almost always, industry has maintained research was not needed and gotten public authorities to agree.
- We now turn to the very recent results of a community research study where the windfarm cooperated by turning turbines on and off and supplying data on operations—I believe under court order.

The Cooper Study
(Cooper)

- Australia
- Subjects: 3 couples in 3 houses; 0.6 to 1.6 km (2,133 to 5,249 ft.)
- Power company provided operations data and turned turbines on and off; subjects did not know when
- Subject responses in sync with turbine power being generated, and major changes in power
- Subject responses were not in sync with the audible sound or vibration

The Cooper Study

- Demonstrates that there is a cause and effect relationship between turbine power output and subject response
- Power companies say it is a terrible study
- Followed all the rules set down by the power company itself
- If they think it is wrong ***they should want to replicate it*** with neutral experimenters at a similar site—e.g., Shirley WI (Shirley Study)

A brief history of wind industry allegations

- 7 major allegations, and potentially one revised allegation
- There are factual data to evaluate 6 of the 7

1. Alleges, A-weighting is appropriate: Wrong

- According to both ISO (International Organization for Standardization) and ANSI (American National Standards Institute) Standards, A-weighting should not be used for wind-turbine noise, but the industry ***has not complied with these Standards.***

2. Alleges, a wind turbine is quieter than a refrigerator: Wrong

- Follows from incorrect use of A-weighting
- A-weighted level from a wind farm may be lower than the level for a refrigerator but it is ***not quieter***
- This shows ***how wrong A-weighting is*** for assessing wind-turbine noise

3. Alleges, if you can't hear it, it can't hurt you: Wrong

- We don't see x-rays, but they ***can hurt us***
- We don't see infra-red, but it ***can hurt us***
- We don't hear ultrasound, but it ***can hurt us***

- We don't hear infrasound, but it ***can hurt us***

- The Cooper study shows that the wind industry's assertion is not correct

4. Alleges, it is 100% the nocebo effect; Australia, USA, Canada, etc.

- Claim non-auditory effects are 100% imagined in perhaps 25 countries around the world
- Claim people hear the sound and make themselves angry
- Due to the internet
- Those who are sensing effects:
  - Include infants, small children who can't read the internet (Shirley Wind study)
  - Include the deaf (Cooper study)

4. Alleges, it is 100% the nocebo effect; Australia, USA, Canada, etc.: Wrong

- Claim people **hear** the sound and make themselves angry
  - About **2/3 of the complainants** we met at Shirley **could not hear the turbines** inside their houses
  - The researchers could not reliably hear the turbines in 2 of the 3 tested homes
  - The **best subject** in the Cooper study is **deaf**
- Blaming the internet is also a fallacy
  - Same public responses to low-frequency industrial noise existed at least **40 years ago**—and there was **no internet** to blame

5. Alleges, no low-frequency noise or infrasound, it's all "modulation:" Wrong

- A wind turbine is a very big fan
- Just like ***all*** other ***fans***, a wind turbine ***radiates acoustic energy at its blade passage frequency***
- Borne out by measurements around the world

6. Alleges, no non-audible pathway and corresponding effect(s) exist: Wrong

- Cooper's study shows cause and effect for at least one non-visual, non-audible pathway by which wind turbine emissions affect the body and "signal" the brain.
- What you can't hear, can hurt you.

6. Alleges, no non-audible pathway and corresponding effect(s) exist: Wrong

- ISO 1996 Part 1: "Investigations have shown that the perception and the effects of sounds differ considerably at low frequencies as compared to mid or high frequencies. The main reasons for these differences are as follows:"
- Among other reasons, ISO 1996 Part 1 has:
  - "perception of sounds as *pulsations* and fluctuations;"
  - "complaints about *feelings of ear pressure*"

6. Alleges, no non-audible pathway and corresponding effect(s) exist: Wrong

- 1985 Toronto study exposed people to 8 Hz (Toronto Study)
  - 12 to 23 %, reacted
- 8 Hz that had lower levels and numbers of overtones elicited
  - Nausea, Dizziness
- 8 Hz that was rich in overtones elicited
  - Headache, Fatigue

6. Alleges, no non-audible pathway and corresponding effect(s) exist: Wrong

- The ISO standard shows that this allegation is Wrong.
- The 1985 Toronto study shows that this allegation is Wrong.
- The Cooper study shows that this allegation is Wrong.

Reported effects of wind turbine low-frequency and infrasonic emissions

EFFECT	REFERENCE
Pulsations	ISO 1996-1
Pressure on the ear	ISO 1996-1
Headache	Toronto
Fatigue	Toronto
Nausea	Toronto
Dizziness	Toronto

7. “Expert” studies *find no references* to non-audible pathways: Wrong

- Several “expert” studies all find nothing
  - The “expert” studies do not find ISO 1996-1
  - The “expert” studies do not find the 1985 Toronto study

7 major allegations; all are shown to be wrong

- A-weighting is not OK to assess turbine noise
- Wind turbines are not quieter than a refrigerator
- What you can't hear, can hurt you
- It is not 100% nocebo
- Wind turbines emit infrasound
- A non-audible pathway by which wind turbine emissions affect the body does exist
- Research exists

What will industry say?

- They will bring in dozens of experts to say how wrong every fact is. They will find a reason why every Standard, every fact, and every study I quoted is flawed.
- They will tell you the levels used in the Toronto study were too high. This is true for wind turbines, but this was 1985 and the purpose was for higher level sources, not wind turbines.
  - But the "expert" studies should have found this study and reported on it. They did not.

Evaluating industry and supportive "expert" studies

- Studies by industry and /or government
- A Massachusetts study said every study in the world on human response to wind turbine noise that might help a community in any way was inadequate for one reason or another. One of their most cited reasons for deprecating a study was that the study was cross-sectional rather than longitudinal. It is not important, for now, what these terms mean.

(Massachusetts Study)

Evaluating industry and supportive expert studies

- Massachusetts EPA and Dept. of Public Health
- Panel of “Independent Experts”
- "The limited description of the selection process in this study is a limitation as well, as is the cross sectional nature of the study. Cross-sectional studies lack the ability to determine the temporality of cause and effect; in the case of these kinds of studies, we cannot know whether the annoyance level was present before the wind turbines were operational from a cross sectional study design. Furthermore, despite efforts to blind the respondent to the emphasis on wind turbines, it is not clear to what degree this was successful."

Evaluating industry and supportive expert studies

- There have been several hundred noise surveys around the world, mainly on transportation noise.
- I know of two (the Cooper study; Fidell, *circa* 1980) and doubt there were more than 3 or 4 that were longitudinal. The longitudinal method is almost always unfeasible in environmental noise studies, and certainly not feasible in the case of wind turbine noise studies; a community would need to have the survey under way before the survey had been announced to the community.
- Same for "hiding the purpose." How do you hide tank, artillery, and bomb noise in a survey around an army base; aircraft noise by an airport?

Evaluating industry and supportive expert studies

- Recent Health Canada study (Health Canada Study)
- I think it has focus problems but I will not go into those
- It has been lauded by the industry
- However, the quote that I gave a few slides ago fits this study perfectly:
  - "It is cross-sectional and you cannot tell how well they hid the purpose of the study."
- Nobody seems to mention this, not the CEO of AWEA, he lauded it.

The point is people need to evaluate what is being said

- Quieter than a refrigerator
- A-weighting is fine for assessment
- If you can't hear it . . .
- No low frequencies
- Of the thousands of people around the world having problems with wind turbines, 100 % are imagining it. It is all nocebo.
- No known pathways or effects except for hearing
- No known research supporting other pathways or effects

Conclusions

- With Cooper, the preponderance of the evidence is that infra-sound causes adverse effects in some people
- Industry provides no proof that the wind turbine acoustic emissions are not causing adverse effects. Their proof is "expert" studies that find that "no literature exists." And all of these expert studies failed to find the pertinent international standard and at least 2 other pertinent documents.

Recommendations

- For audible noise, public officials should require that the the maximum A-weighted sound level at any residence be < 39 dBA
- For very low-frequency sound and infra-sound, public officials should require industry to prove that their new designs will not create adverse effects on people, notably, on sleep or those of the type listed on earlier charts. This proof from industry must be provided before any new windfarms are approved.