THE acoustic ecology INSTITUTE
. . . listen . . .

The Variability Factor in Wind Turbine Noise

source levels / sound quality / community response

Jim Cummings

cummings@acousticecology.org
AEInews.org **AcousticEcology.org**

The Variability Factor

Average sound levels
regulatory criteria

Peak sound levels
experienced within wide variability

Rated sound power levels
per idealized testing conditions: **basis for our sound models**

Real-world source levels
including directional shear, turbulence/load noise, and normal wear/aging:
variable source levels feeding into propagation variability

Sound quality variations
simple wind-off-blades **whoosh** . . . amplitude modulation **pulses** . . .
turbulence-induced **knocking**, **banging**, **thumping**, **"sneakers in drier"**

Small proportion of "bad" or peak conditions can feel like a chronic experience

Turbine Sound Variability
turbine source levels

Nearly all sound modeling use rated Sound Power Levels as starting point
Very little consideration of how reliable these ratings are over time in the field

Field measurements of dozens of turbines, "apparent sound power level," per IEC 61400-11, 8m/s wind

Standard deviations for turbines of <u>same size and make</u>:
1.6-3.5dB

90% confidence interval (per IEC 61400-14) requires 1.645x this:
2.6-5.75dB around the mean Sound Power Level

No investigation here of the causes of the variation in similar models:
Could be turbine wear or differences in load noise

Near-field propagation condition variability should be minimal, per use of IEC 61400-11

Møller and CS Pedersen (2011). Low-frequency noise from large wind turbines. J. Acoust. Soc. Am. 129 (6), June 2011, 3727-3744.

Turbine Sound Variability
turbine source levels

Variation in source level (2-5dB standard deviation)
results in a dramatically different distance requirements
(or, more likely in practice, higher received levels than models predict at any given distance)

And indeed, using **measured apparent sound power levels of 25 2.3-3.6MW turbines**, then modeling the distance required from either single or multiple turbines, to noise criteria:

Modeling a 4-turbine array, to meet Danish 44dB requirement:

Required setback ranged from 375m to 1241m
(6 of 23 were over 1km)

Also: large variability in low-frequency components
(measured using Danish dBALF, which is dBA weighting, but limited to 10-160Hz bands)

dBALF ranged from **34.5-41.8** when dBA was 44dB

CS Pedersen, Henrik Moller, Steffan Pedersen. Low-frequency noise from large wind turbines – additional data and assessment of new Danish regulations. 15th International Meeting on Low Frequency Noise and Vibration and its Control. Stratford upon Avon, UK. May 22-24, 2012

Turbine Sound Variability
averages and peaks

Projects can operate in compliance……
generally based on average sound levels

….yet generate widespread community complaints
triggered by peak sound levels

Most projects *do* meet regulatory average noise levels

Violations, when they occur, are usually small: 1-3dB

Noise models, using conservative assumptions about propagation, are generally working fairly well, at least for average sound levels

Peaks add a wild card…

Turbine Sound Variability
averages & peaks

David Hessler: Best Practices Guidelines, 2011
National Association of Regulatory Utility Commissioners

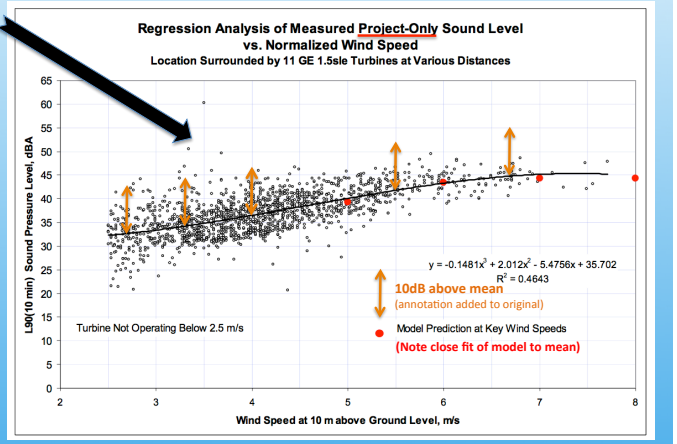
"Extensive field experience measuring operational projects indicates that **sound levels commonly fluctuate by roughly +/- 5 dBA** about the mean trend line and that short-lived (10 to 20 minute) spikes on the order of **15 to 20 dBA above the mean** are occasionally observed"

David Hessler (2011). Best Practices Guidelines for Assessing Sound Emissions From Proposed Wind Farms and Measuring the Performance of Completed Projects. Prepared for the Minnesota Public Utilities Commission, under the auspices of the National Association of Regulatory Utility Commissioners (NARUC). October 13, 2011.

Turbine Sound Variability
averages & peaks

The most variability,
largest peak/mean differences
and some absolute peaks
occur at low to moderate wind speeds

Note lots of scatter +/- 5dB to 10dB at low wind speeds, and nothing approaching 10dB over mean at high wind speeds



Turbine Sound Variability
averages & peaks

Bob Thorne reports similar high peaks and variability around averages

Peaks:

"Predicted values are given as a range, ±3 dB(A) at 1,000 meters for the most common prediction method with the predicted value being the 'middle' of the range. **The uncertainty increases with distance**"

*Affirming Hessler's observations, Thorne also stresses that "**peaks of up to 20dB over the predicted (average) levels can be expected at times**."*

Short-term Variability:
In 60 seconds the sound varies regularly by 10-20db (around the average)

Bob Thorne. The Problems with "Noise Numbers" for Wind Farm Noise Assessment. Bulletin of Science Technology and Society 2011 31: 262.

Turbine Sound Variability
averages & peaks

Thorne: Heightened Noise Zones Conceptual Model

Phase interactions between blades of multiple turbines: constructive/ destructive interference of sound wave trains

Propagation variations, including wind speed/direction, temperature pockets, and varying wake effects

"HNZ can be small in extent, even for low frequencies, and shift as rotation rates and propagation change… leading to turbine sounds 'appearing' and 'disappearing' in areas spaced only a few metres apart"

Figure 18: Noise from 2 turbines creating Heightened Noise Zones

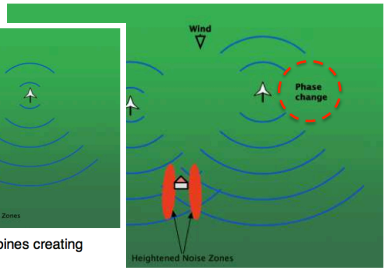


Figure 19: Noise from 2 turbines under slightly different conditions moving Heightened Noise Zones

Bob Thorne. Wind Farm Noise and Human Perception: A Review. Noise Measurement Services. April 2013.

Turbine Sound Variability
sound quality

Steady/Repetitive Sounds
Whoosh
Roar (distant jet)
Pulsing/Thumping

Irritating Sounds
Grinding
Whining

Irregular/Intrusive Sounds
Knocking
Banging
Like sneakers in a drier
Pressure waves felt in chest

"The first time they started them up, I didn't know what it was. I was like man, that's a weird noise."
2000 ft

"When it's really bad it takes on a repetitive, pulsating, thumping noise that can go on for hours or even days."
2500 ft

"**I think the worst is the foggy, raining nights when you get the banging, the thumping.** It brings you straight out of bed…We were told, 'you'll never know they're back there.."
1500 ft

Turbine Sound Variability
sound quality: varying, at times intrusive

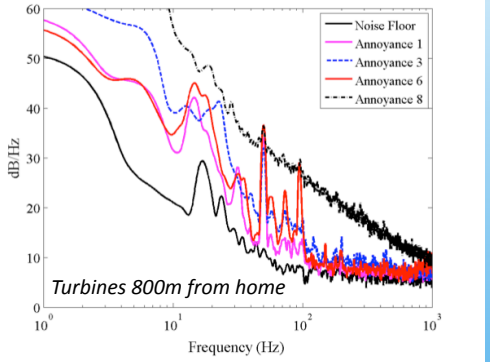


Figure 4. Power spectral density (unweighted) of the acoustic data for various resident-rated annoyance levels.

Nobbs, B., Doolan, C.J., Moreau, D.J. (2012) Characterization of noise in homes affected by wind turbine noise. Proceedings of Acoustics 2012, Freemantle. 21-23 November 2012.

More annoyance at sounds described as:
Pounding
Roaring
Thumping/rumbling

Less annoyance:
Hum
Murmur

Thumping or pounding may be associated with the broad peak between 10-30 Hz

Rumbling and roaring may be associated with the broadband energy to 1000 Hz as well as the spectral balance.

Acoustic energy below 10 Hz may be responsible for *thumping* noise

Turbine Sound Variability
load noise

inflow turbulence / turbine wakes / directional wind shear

Primary drivers for turbulence research:
Reducing blade loads (system wear/fatigue; facilitating longer blades)
Minimizing power losses

Many of the most troublesome aspects of turbine noise for neighbors may be associated with likely turbulence effects
"Knocking" "Banging" "Sneakers in drier"
Deep rumbling low frequency noise

These more intrusive sounds and harder-to-ignore sound qualities are key drivers of negative attitudes toward turbines
difficult to accept – perhaps making it harder to live with typical gentler turbine sounds

The relative lack of turbulence in open, flat ranch country may contribute to the lower incidence of noise issues
more consistent sound, less intrusive sound qualities

Turbulence research:
noise reduction as secondary benefit of innovation

Turbine wake research

Sandia SWiFT facility

Lubbock, TX

Being built to study turbine wake interactions; will include acoustic data

NREL wake research

60-70% decrease in power output behind first row of turbines (Churchfield, 2012)

NREL directional shear studies

looking beyond "the narrow definition of shear (change in wind speed with height) …**Directional shear can be 20-40 degrees or more…and can impart considerable stress on the turbine infrastructure**"

Jeffrey Freedman & Kathleen Moore (2012). Wind Shear and Why it Matters. North American Windpower, Volume 9, Number 5, June 2012, p.48-51.

Turbine Sound Variability
source level, propagation, load noise

OK: it's clear that there's a lot of variability, both between turbines and around any given turbine or wind farm over time

Periods of peak sound or peak audibility will be the most troublesome for neighbors

✧Peaks above the regulatory threshold or project mean
(caused by increased load noise or enhanced propagation)

✧Times of easy audibility of moderate noise in low ambient conditions

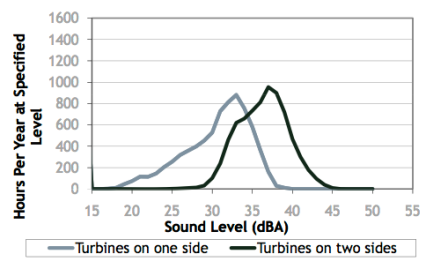
✧Periods of more intrusive sound qualities

Can we adjust operations at these times?

The key question:

How often do received sound levels, audibility, or sound qualities reach especially troublesome levels?

Turbine Sound Variability
how common are peaks?



Kenneth Kalisky. Wind Turbine Noise Regulation: Perspectives in New England. NEWEEP Webinar #2, July 2010.

Kalisky used manufacturer sound power levels per wind speed

Atmospheric stability factors (vertical wind shear and temperature profile, atmospheric turbulence) used only to model propagation—no effect presumed on source levels

Ken Kalisky

Calculating annualized sound levels for a wind farm

(ASA/NOISE-CON 2010)

(NEWEEP 2010)

Meteorological records used to calculate received sound levels for a year, on an hourly basis

Sound levels are within 5dB of their peak just **12% of the hours** that the turbines are operating

Sounds pretty reassuring…

Turbine Sound Variability
how common are peaks?

Yet: if we ***very conservatively*** **equate percent time operating with capacity factor** (say, 33%), we would find peak noise levels occurring for just **4%** of the hours of the year

Doing the math, 4% of hours in the year is:
58 days with peak sound for 6 hours
or 116 days (a third of the days in the year) with peak sound for 3 hours

Louder times are **more likely to cluster seasonally**, when high winds or shear conditions or turbulence are more common, making peak conditions **more frequent** in some seasons.

For neighbors, 4% of the time may plausibly feel like a chronic experience of peak sound conditions

And bear in mind:

- This is an extremely conservative, likely significant under-estimate of total hours operating
- Many of the omitted hours will be at less than full power, where some of the most variable sound levels occur

Turbine Sound Variability
how common are peaks?

Doing the math, 4% of hours in the year is:
58 days with peak sound for 6 hours
or 116 days (a third of the days in the year) with peak sound for 3 hours

This is simply peak dBA sound levels per standard modeling

- Not accounting for variable sound quality
- Not accounting for variable source levels or dBA_{lf} content (i.e., based on rated sound power level)
- Very little research into how load noise affects source level (or how common load noise is in particular regions)

We don't have real-world numbers for proportion of time neighbors consider turbine sounds to be at their worst
This mental exercise could be made concrete by new field research

If the proportion of problematic times is small, operational adjustments could greatly minimize negative reactions among neighbors

Community noise tolerance variability
place identity / noise sensitivity

Community noise tolerance variability
place identity / noise sensitivity

Community noise tolerance variability
place identity / noise sensitivity

In towns *with* issues, how many people are *actually* upset?

Broad community acceptance is not the whole story
Commonly find 70-85% wind approval in town or county as a whole

How do those *who routinely hear* the new source of community noise react?
Within a half mile or so, 20% or more of residents can be upset *about the noise*

This is the seedbed for the backlash we're now dealing with

Even the Gold Standard of community annoyance surveys shows this dichotomy:

Pedersen et al: 3 studies, 1700 people
(Scandinavia 2000-2007; **annoyance = 4 or 5**, on 5 point scale)
8-9% noise annoyance among all those surveyed (out to 1 or 1.5mi.)
But: 22% of those who can hear turbines
In rural areas: 25-45% of those who hear 40dB or more

Community noise tolerance variability
place identity / noise sensitivity

Many wind farms *don't* spur widespread complaints

Why are complaints much more rare in working farm and ranch country?
Texas, Iowa, Wyoming, Nebraska

Residents more used to machinery noise? Or less noise-sensitive?
Lower population density, no critical mass of problems

Turbine sound level and sound quality more consistent?
Wind steadier and less turbulent?

Is the variability more of a trigger than the absolute noise level?

THE acoustic ecology INSTITUTE
. . . listen . . .

AEI Wind Farm Noise Resources
AcousticEcology.org/wind

WTN 2013 paper, 17pp
much more detailed discussion of these and related variability issues

Three comprehensive annual reports on wind farm noise science and policy

NEWEEP presentation on community responses

Jim Cummings
cummings@acousticecology.org

Cummings: Wind Turbine Noise 2013, Denver, CO August 29, 2013