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Same infrasound levels near wind turbines than in urban environment?

Panu Maijala
VTT, P.O.Box 1000, FI-02044 VTT, Finland, Panu.Maijala@vtt.fi

Sound from wind turbines has caused quarrels for decades. Since the sound levels at the audible frequencies have been reasonable small, the problem has been claimed to be at the very low end of the frequency range. Since last year, traceable calibrated infrasound microphones with preamplifiers down to 50 mHz have been commercially available. We used these infrasound microphones in a measurement campaign and compared the broadband sound from wind turbines, urban environment and wilderness, and found that the infrasound levels within the vicinity of wind turbines are on the same level or lower than in city centres. In addition to these interesting results, the problematics of the infrasound measurements are considered.

1 Introduction

Wind turbines produce broadband sound that include audible low frequencies (LF), usually referred to as a frequency range of 20 to 200 Hz, and also infrasound (IS), the frequencies below 20 Hz [1]. The defining frequency range for infrasound is not exact and is not generally audible at the sound levels typically occurring in the environment.

There are many prejudices and beliefs associated with the sound produced by wind turbines. Infrasound and its health effects is one of the issues raised [2]. There are many publications about IS measurements of wind turbines, some of which are also peer-reviewed [2–13]. However, none of the publications satisfies sufficient criteria for external validity so that they could be compared to each other. Jakobsen summarized the IS measurements published by 2005 and stated that none of the publications contained all the necessary background information, e.g. environmental conditions, types of wind turbines, signal analysis (length of integration), and background noise was missing from all the papers [14].

Typically, the lowest frequency of IS levels reported in peer-reviewed publications is one Hertz. Significantly fewer papers exist below that limit. One of these is a comprehensive study by the Japanese Ministry of the Environment, published in the NCEJ, where the results start from 0.8 Hz [15]. Increasing the measurement and analysis range to lower frequencies is a long and laborious process. We took this challenge and succeeded to go 4 octaves down to 0.05 Hz. The actual objective of our study was to find out the average IS levels for the emission of some wind power plants and to compare these measured levels to measured IS levels in a wild forest and an urban environment. Also, some immission levels were recorded.

2 Method

The criteria for selection of wind power production plants for measurements were: high power output, a significant number of complaints regarding wind power, topography, wind direction, proximity of residential areas, and accessibility of the power supply. Taking into consideration the selection criteria, two wind power production areas were selected: Märynummi (Salo) with three Gamesan G128 type 5 MW wind turbines and Jäneskeidas (Siikainen) with eight Vestas V126 type 3.3 MW wind turbines. Hervanta suburb of Tampere was chosen as the urban reference site and Hyytiälä forestry field station in Juupajoki was used for recording the sound of the nature.

The sound was captured in the vicinity of both wind power production areas for about two weeks at two distances. Emission levels of wind turbines were measured at about 200 meters from the nearest turbine and immission levels from 2 to 3 km from the nearest wind turbine.

Two types of acoustic sensors were used: microphones (G.R.A.S. 47AC) and microbarometers (Chaparral Physics Model 25). The manufacturer calibration values for the microphones covered the frequency range of 0.05 to 20 000 Hz and their sensitivity was monitored during the campaign with an infrasound calibrator (G.R.A.S. 42AE) in all the third octave bands between 0.05 and 250 Hz. One microbarometer and two microphones were used in each of the four locations: one microphone housed in a B&K 4198 outdoor unit at a height of 2 m and the other in a standard [16] measurement board (Microtech Gefell GFM 920.1) on ground, so that there was 2 m between the microphones and both of these were at the same distance from the nearest wind turbine. In addition, at each location, meteorological quantities were measured at two heights (2 and 10 m) using Davis Vantage Pro 2 Plus weather stations.

No standards exist for IS measurements, but the emission measurements were made according to standard IEC 61400-11 [16]. Due to limited two weeks' time window, we were not able to capture all the necessary wind speed classes. However, we succeeded to do a controlled measurement for one stop and operation cycle in Jäneskeidas: in cooperation with the wind power operator, all the 8 wind turbines were stopped on a windy day to provide comparative data in addition to the normal operation. The same was tried in Märynummi too, but a large power outage due to a spring storm prevented implementation.

The signals of the acoustic sensors were continuously recorded as 24-bit linear PCM signals at a 48 kHz sampling rate. Equivalent sound pressure levels were calculated in 10 minute cycles over all third octave bands between 0.05 and 10 000 Hz using FFT filters described in IEC 61260 standard [17]. However, measurement uncertainty in the lowest band, 50 mHz, turned out to be greater than is reasonable to report, and was omitted from the graphs and overall levels. The presented values include the unweighted (L_Z), A-weighted (L_A), and G-weighted (L_G) [18, 19] levels. Simultaneous other noise sources were removed automatically if any of the third octave frequency band levels of the 10 minute period was 20 dB higher than the average level across the entire measurement range. There were only a few of these eliminated periods and all of these were listened through: typically, there was a tractor driving near the microphones. The number of included 10 minute periods for each measurement site is expressed by variable N in Table 1.

No ground correction (-6 dB) was applied.

A more detailed description of the measurement arrangements with topographic maps and coordinates can be found in the report number 28/2017 of the Finnish Ministry of Employment and the Economy [20].

3 Results

The equivalent sound pressure levels measured in the urban environment were about the same in magnitude with the emission levels measured in both wind power production areas, see Table 1. In Hervanta and Jäneskeidas, the same L_Z levels were recorded: 73 dB. It is also worth noting, that the measurement in Hervanta was carried out over a weekend, when there was much less traffic than on weekdays.

The IS levels measured in Hyytiälä were significantly lower than elsewhere.

Table 1: Comparison of equivalent (600 s) sound pressure levels [dB] between measurement points, valid 10 minute periods N and measurement periods

Measurement point	L_A	L_G	L_Z	N	Measurement period
Hervanta (urban)	49	62	73	587	20.04. — 24.04.2017
Hyytiälä (forest)	47	46	54	549	20.04. — 24.04.2017
Märynummi, emission	50	63	70	1807	05.04. — 18.04.2017
Märynummi, immission	41	51	65	1822	05.04. — 18.04.2017
Jäneskeidas, emission	49	64	73	1932	25.04. — 09.05.2017
Jäneskeidas, immission	41	51	63	2010	25.04. — 09.05.2017

3.1 Controlled emission measurement

A controlled emission measurement was carried out on Monday, 8 May 2017 in Jäneskeidas. The total measured sound pressure levels were practically caused by the IS. A strong turbulent wind caused considerable IS levels and it is difficult to distinguish between the background noise signal and emission signal, if only a Fast time-weighted signal is looked (see Figure 1). The maximum levels of linear Fast time-weighted signals for both the background noise (all the 8 wind turbines were stopped), and emission (wind turbines running at their nominal speed) were 107 dB.

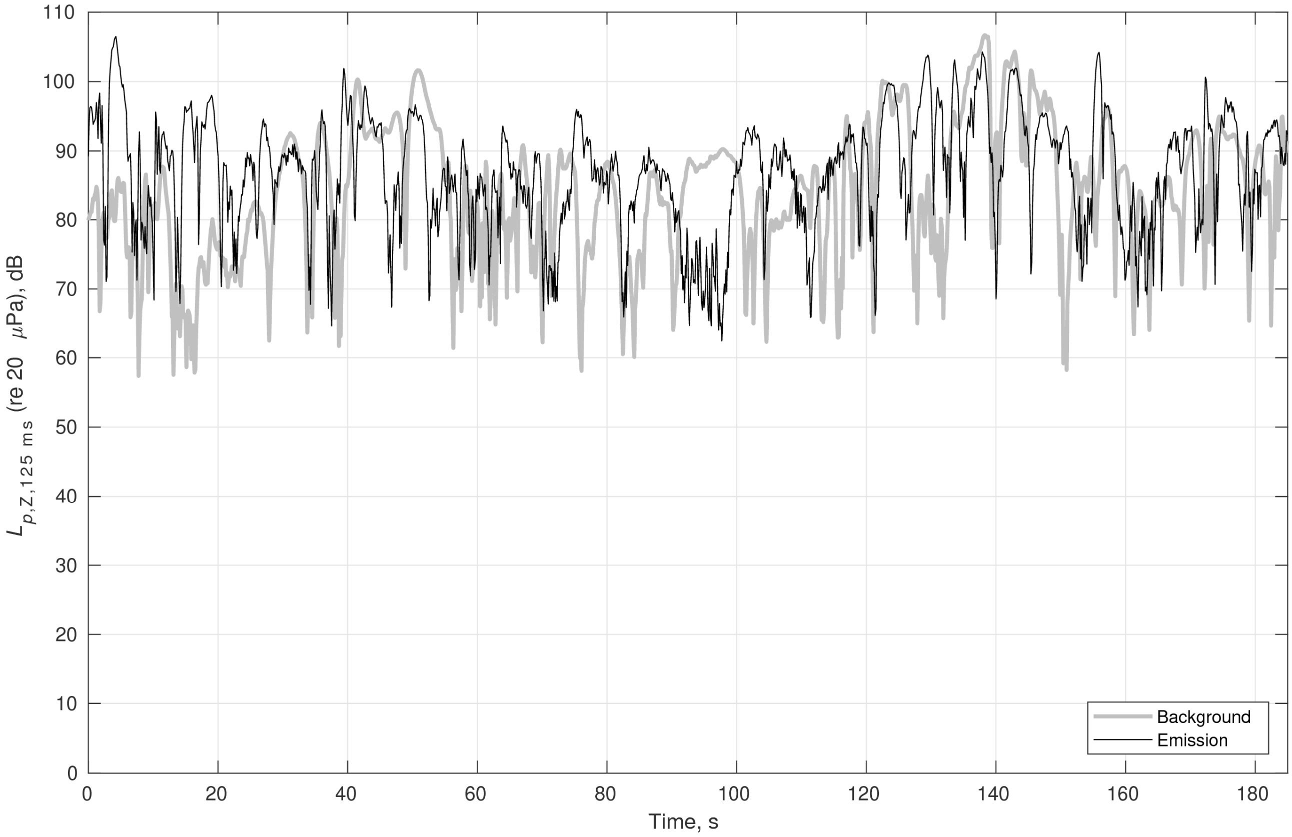

Figure 1: Variation of the measured background and emission noise.

The difference between the third octave bands in the LF range and in G weighted values (55 vs 69 dB) show clearly when all wind turbines were stopped (see Figure 2). However, the increase in the unweighted level is not so evident (from 87 dB to 90 dB).

Only the most important results were shown in this section, the more detailed results and the evaluation of uncertainties can be found in the report number 28/2017 of the Finnish Ministry of Employment and the Economy [20].

4 Discussion

Expanding the measurement range below the frequency of 1 Hz proved to be very challenging. The biggest challenges were related to calibration and analysis of measurement results. At the lowest frequencies, all events are very slow, so all operations, such as calibration, require significantly more time compared to the operations at higher frequencies. At low frequencies, the venting hole, a small hole in the preamplifier housing, has a significant effect on magnitude response and blocking this by e.g. dirt, changes the low frequency response. For this reason, we controlled all the third octave bands between 0.05 and 250 Hz during the measurement campaign. It took several hours to calibrate a single microphone. Also, the same repeatability for the low frequencies than is for the normal calibration procedure is hard to gain, e.g. a 100 000 seconds averaging at 0.1 Hz is equivalent to 10 seconds in 1 kHz! In addition, special attention must be paid to the coupling between the microphone and the calibrator: the pressure has time to leak out of the calibration chamber due to slow phenomenon.

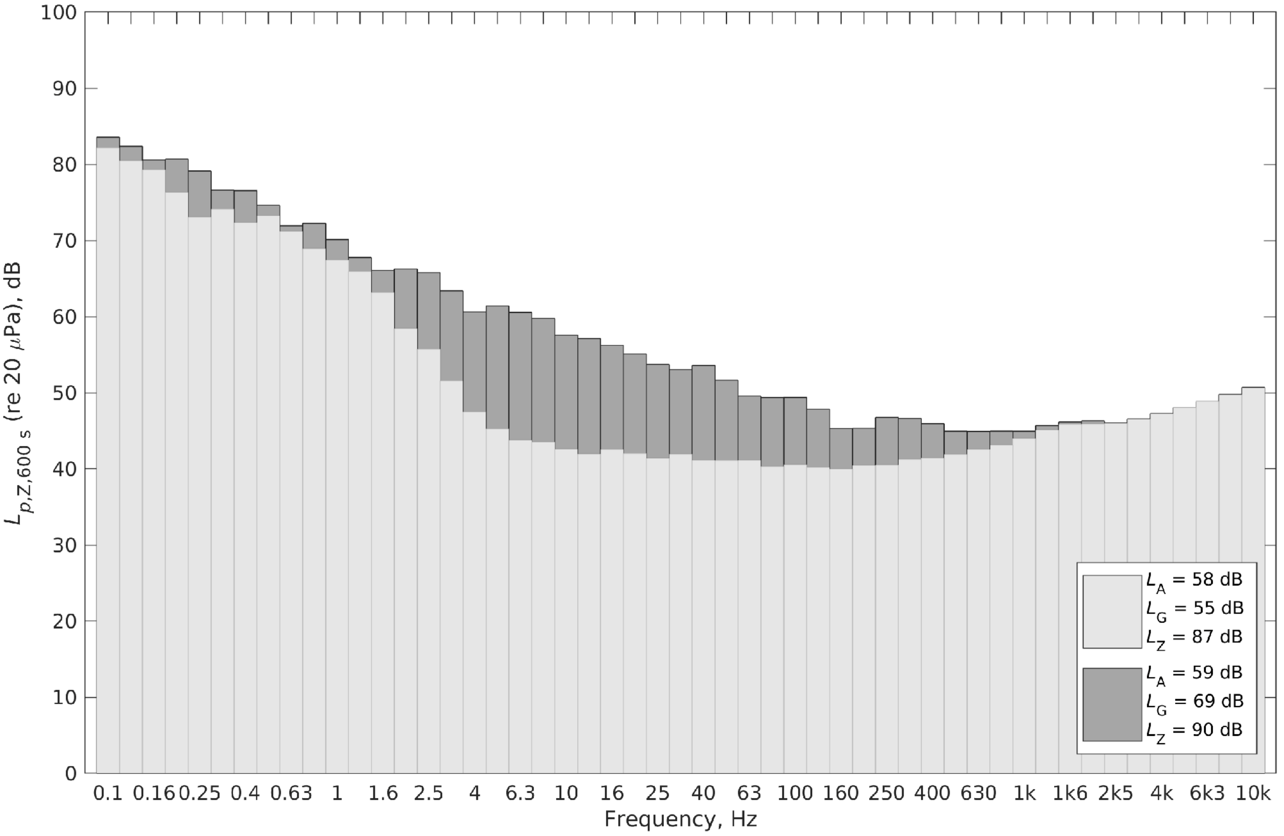

Figure 2: Equivalent sound pressure and the weighted total levels when the turbines were running normally (dark grey) and the background noise (all turbines stopped, light gray).

Expanding the measurement range also adds more requirements to the computational power of analysis. To reduce statistical uncertainty and to gain a frequency resolution narrow enough for the low frequencies, it is necessary to process long samples. In this project, processing the month's measurement results took over three years CPU time.

The main advantage of a microbarometer over a microphone comes from its filtering ability: the local pressure variation caused by wind is neglected by using hoses of up to thirty meters in length. The pressure variation measured by the microbarometer is a spatial mean of the area covered by the hoses. We tried to perform the sensitivity calibration of the microbarometer in a reverberation room and found that sensitivity of the sensor itself could be calibrated, but connecting the hoses to the device changed sensitivity in an uncontrolled manner, up to tens of decibels, making the device not suitable for traceable tracking of sound levels [18].

In environmental measurements (excluding emission measurements) the highest contribution to measurement uncertainty comes always from weather and changing environmental conditions. Some of these environmental factors such as absorption of air and acoustical properties of soil or other surfaces can be taken into account, either computationally or in the selection of the measurement site. Instead, the further away the measurement location is from the sound source, the effect caused by weather becomes more significant. In immission measurements, the effect of weather on measurement uncertainty is high. At a distance of 3 km from the source, the variation caused by weather and environmental conditions can be up to 80 dB, mostly explained by the changes in the atmospheric wind and temperature profiles, and especially at low frequencies, atmospheric stability. On windy days and nights, when the atmospheric stability is neutral (Pasquill Class 4), the sound pressure level at a distance of 3 km might be 20 dB over the geometric attenuation (Figure 3), the median being 30 dB below. At IS frequencies, the importance of environmental conditions is lower than at higher frequencies, because atmospheric and ground absorption is low and obstacles are small compared to wave length making their effect meaningless on IS propagation.

Each measurement location had an acoustic antenna based on three acoustic sensors. The objective of this arrangement was to be able to calculate the direction of incident wave during the analysis phase. We did not have time to implement this calculation, but this or even a more massive antenna implementation [23] would have been required to reduce the uncertainty of immission measurements.

No results about traceable calibrated IS measurements from the frequency of 0.1 Hz upwards exist in peer-reviewed literature. By skipping the first 3 octaves and comparing the results of this study to other publications, a very good agreement can be found. For example, Turnbull et al. performed a similar campaign in Australia: two wind power production areas with 2 / 2.1 MW wind turbines and compared their results to measurements from urban and coastal regions. Their conclusions were similar to our survey: the IS levels of wind turbines were of the same magnitude as the references [3]. Also similar results were published by the Polish scientists; they reported measurements of 25 Vestas V80 2 MW turbines [8].

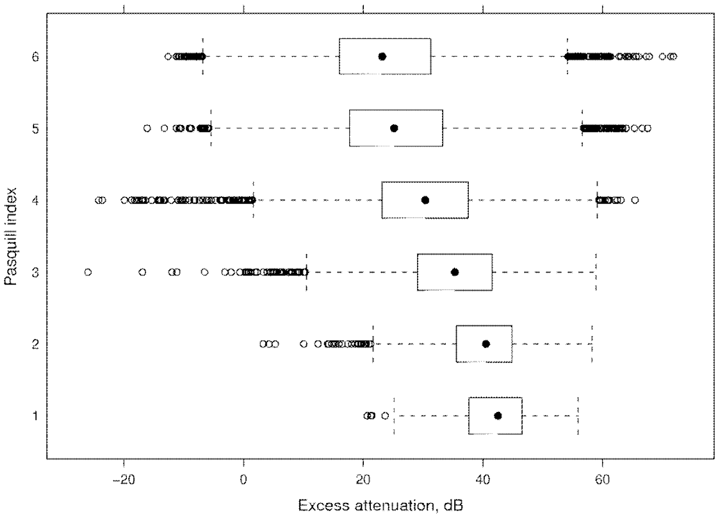

Figure 3: Excess attenuation (40 to 1600 Hz) based on measurements as a function of atmospheric stability at a distance of 3 km [22]. The results for the two middle quarters (50%) are limited by the box, the median is shown by the dot and the whiskers extend to distribution of 2.7σ.

5 Summary

We measured sound levels between 0.05 and 10 000 Hz for two wind power production plants, an urban area, and a natural wild forest. The sizes of the wind turbines were 3.3 and 5 MW. The A, G, and Z weighted sound levels were almost the same in magnitude for the wind turbines at a distance of 200 m and for the urban area, while in comparison to the forest only the A weighted levels were about the same, the G and Z weighted levels having about 20 dB lower values. The average immission levels at distances between 2 and 3 km were from 5 to 10 dB smaller than the emission levels.

Also, a controlled measurement was done. When all the wind turbines in the area were stopped, no change in Z weighted RMS values (125 ms sliding window) was shown. Running the turbines at their nominal speed increased the $L_{p,\mathrm{Z,eq}}$ by 3 dB and the levels in the LF range from 1 to 18 dB over the background noise level.

IS measurements, especially at the frequencies below 1 Hz, are significantly more challenging compared to the measurements at higher frequencies, because the sound pressure variation is closer to the pressure variation due to wind, the higher background noise levels, and a substantial increase in measurement uncertainty of instrumentation.

References

[1] Payam Ashtiani and Adelaide Denison. Spectral discrete probability density function of measured wind turbine noise in the far field. *Frontiers in public health*, 3, 2015. doi:10.3389/fpubh.2015.00052.

[2] Robert G. Berger, Payam Ashtiani, Christopher A. Ollson, Melissa Whitfield Aslund, Lind-say C. McCallum, Geoff Leventhall, and Loren D. Knopper. Health-based audible noise guidelines account for infrasound and low-frequency noise produced by wind turbines. *Frontiers in public health*, 3, 2015. doi: 10.3389/fpubh.2015.00031.

[3] Sung Soo Jung, Wan-Sup Cheung, Cheolung Cheong, and Su-Hyen Shin. Experimental identification of acoustic emission characteristics of large wind turbines with emphasis on infrasound and low-frequency noise. *Journal of the Korean Physical Society*, 53(4):1897–1905, 2008.

[4] Robert D. O'Neal, Robert D. Hellweg, and Richard M. Lampeter. Low frequency noise and infrasound from wind turbines. *Noise Control Engineering Journal*, 59(2):135–157, 2011.

[5] Chris Turnbull, Jason Turner, and Daniel Walsh. Measurement and level of infrasound from wind farms and other sources. *Acoustics Australia*, 40(1):45–50, 2012.

[6] Colin Tickell. Low frequency, infrasound and amplitude modulation noise from wind farms – some recent findings. *Acoustics Australia*, 40(1):64–66, 2012.

[7] T. Boczar, T. Malec, and D. Wotzka. Studies on Infrasound Noise Emitted by Wind Turbines of Large Power. *Acta Physica Polonica-Series A General Physics*, 122(5):850, 2012.

[8] R. Pierzga, T. Boczar, D. Wotzka, and D. Zmarzły. Studies on infrasound noise generated by operation of low-power wind turbine. *Acta Physica Polonica A*, 124:542–545, 2013.

[9] Paul Botha. Ground Vibration, Infrasound and Low Frequency Noise Measurements from a Modern Wind Turbine. *Acta Acustica united with Acustica*, 99(4):537–544, 2013.

[10] Ryszard Ingielewicz and Adam Zagubień. Infrasound Noise of Natural Sources in the Environment and Infrasound Noise of Wind Turbines. *Polish Journal of Environmental Studies*, 23(4):1323–1327, 2014.

[11] Matthew Stead, Jon Cooper, and Tom Evans. Comparison of Infrasound Measured at People's Ears when Walking to that Measured Near Wind Farms. *Acoustics Australia*, 42(3), 2014.

[12] John Vanderkooy and Richard Mann. Measuring Wind Turbine Coherent Infrasound. *Wind Turbine Noise*, pages 20–23, 2015.

[13] Branko Zajamšek, Kristy L. Hansen, Con J. Doolan, and Colin H. Hansen. Characterisation of wind farm infrasound and low-frequency noise. *Journal of Sound and Vibration*, 370:176–190, 2016. ISSN 0022-460X. doi: 10.1016/j.jsv.2016.02.001.

[14] Jørgen Jakobsen. Infrasound Emission from Wind Turbines. *Journal of low frequency noise, vibration and active control*, 24(3):145–155, 2005.

[15] Hideki Tachibana, Hiroo Yano, Akinori Fukushima, and Shinichi Sueoka. Nationwide field measurements of wind turbine noise in Japan. *Noise Control Engineering Journal*, 62(2):90–101, 2014.

[16] IEC. Standard IEC 61400-11:2012. Wind turbines — Part 11: Acoustic noise measurement techniques, November 2012.

[17] IEC. Standard IEC 61260-1:2014. Electroacoustics — Octave-band and fractional-octave-band filters — Part 1: Specifications, February 2014.

[18] IEC. Standard IEC 61672-1:2002. Electroacoustics — Sound Level Meters — Part 1:Specifications, May 2002.

[19] ISO. Standard ISO 7196:1995. Acoustics — Frequency-weighting characteristic for infrasound measurements, 1995.

[20] Timo Lanki, Anu Turunen, Panu Maijala, Marja Heinonen-Guzejev, Sami Kännälä, Tim Toivo, Tommi Toivonen, Jukka Ylikoski, and Tarja Yli-Tuomi. Tuulivoimaloiden tuottaman äänen vaikutukset terveyteen . Technical Report 28, Työ- ja elinkeinoministeriö, jun 2017.

[21] Kevin P. Shepherd and Harvey H. Hubbard. Physical Characteristics and Perception of Low Frequency Noise from Wind Turbines. *Noise Control Engineering Journal*, 36(1):5–15, 1991. ISSN 0736-2501. doi: 10.3397/1.2827777.

[22] Panu P. Maijala. *A Measurement-based Statistical Model to Evaluate Uncertainty in Long-range Noise Assessments*. Doctoral dissertation, Tampere University of Technology, P.O.Box 1000, FI-02044 VTT, Finland, December 2013.

[23] Rakesh C. Ramachandran, Ganesh Raman, and Robert P. Dougherty. Wind turbine noise measurement using a compact microphone array with advanced deconvolution algorithms. *Journal of Sound and Vibration*, 333(14):3058–3080, 2014. ISSN 0022-460X. doi: 10.1016/j.jsv.2014.02.034.