DOI: 10.61782/fa.2023.0487

METHOD FOR DETERMINING THE THRESHOLD OF WIND TURBINE NOISE MASKING BY HIGHWAY NOISE AS FUNCTION OF DISTANCE

Buszkiewicz Maciej[1*] **Wicher Andrzej**[1] **Pyffel Remigiusz**[1]
[1]Department of Acoustics, Faculty of Physics, Adam Mickiewicz University in Poznan, Poland

ABSTRACT[*]

Series of 4 experiments were conducted with use of 2-alternative forced choice (2AFC) method to determine the threshold of wind turbine noise perception amid masker. In each iteration two samples were presented. Masking noise (highway) was present in both samples, whereas wind turbine noise against the masker was present in only one.
Samples of wind turbine noise were prepared based on an actual recording at 150m from source. Using the transfer function based on the Nord2000 methodology, a set of samples reflecting the sounds of the wind turbine at distances 150 m – 2 150 m between observer and source point (with 10 m step) were created. Samples of masking noise were prepared for 4 distances of 250 m, 500 m, 1 000 m and 2 000 m between observer and source point. For each masking noise sample separate experiment was prepared. During experiments the subjects were asked to indicate the sample which was more annoying. No information about the sources were given. Authors adopted the hypothesis that samples containing wind turbine noise would be indicated as more annoying. Depending on the given answers, the wind turbine noise sample distance from subject was adjusted. Masking noise was presented each time at one of 4 fixed distances. Average of 5 last turn points was assumed as distance threshold for wind turbine noise masking. The results obtained from the study indicate that wind turbine noise is effectively masked by road traffic noise, especially when the turbine is located at distances of up to about 500 m relative to traffic noise sources. On the other hand, for the location of the wind turbine relative to the road traffic noise source at distances (above about 500 m), the effectiveness of masking by road noise decreases significantly

[*]***Corresponding author***: maciej.buszkiewicz@amu.edu.pl

Keywords: *wind turbine noise, annoyance, masking threshold*

1. INTRODUCTION

Wind power is considered a “green-energy” for being low- / zero-emission, renewable source of electricity. Thus the large-scale use of wind turbines is an opportunity to alleviate the climate crisis. Simultaneously wind turbines generate noise which many find annoying [1-3]. One of the main causes of annoyance in wind turbine noise (WTN) are so-called amplitude modulations [4, 5]. For masking this type of noise one should select a masker with similar time-pattern (presumably “AM-like” characteristics), similar spectrum, low-annoyance and available near wind farm sites. Although road traffic noise (RTN) is potentially good choice for WTN masker it’s effectiveness is not well determined [6]. Presented method aims for defining the potential of WTN masking by road traffic sounds with combination of WTN detection threshold. WTN detection is assessed by identifying sounds that are more annoying rather than directly asking for WTN indication, which can be successfully done even with very low SNR [7]. Moreover subjects are not being informed about the sound sources to reduce the influence of non-acoustical factors (e.g. prejudice towards wind turbine technology) on their responses. Detection by annoyance is more believed by the Authors as more “natural” way of perceiving environmental sounds.

2. MATERIALS AND METHODS

2.1 Sound recordings and measurements

2.1.1 Wind turbine noise

WTN recordings were gathered during measurement campaign on wind farm in Lodz Voivodeship in central Poland. Noise was measured from single 2.0 MW wind turbine with 90 m diameter rotor and nacelle located at height of 105 m. Receiver was located 150 m from wind turbine tower, on downwind side. Recordings were done using RODE NTSF1 ambisonics microphone at 1.5 m height with SQuadriga II recorder. Sound levels were measured with SVAN 979 Class 1 sound level meter. Weather conditions during recordings were stable with wind speed 4 m/s at 11 m (meteorological station) and 7 m/s at hub height. Terrain at wind farm location was flat, covered with compacted earth with occasional gravel and asphalt roads. WTN 5-minute equivalent sound pressure level of recorded signal was $L_{eq} = 49.1\ dBA$. During recording session wind turbine rotation frequency was 0.8 Hz. WTN 1/3 octave band spectrum is depicted in Figure 1.

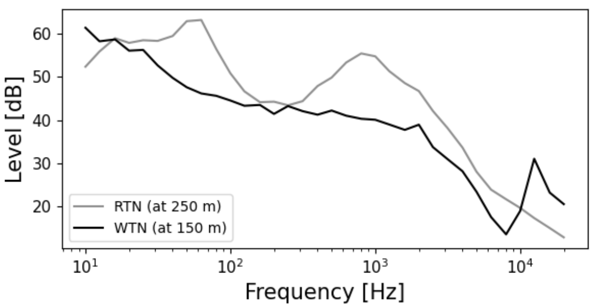

Figure 1. WTN and RTN 1/3 octave band spectra at different distances: 150 m and 250 m respectively.

2.1.2 Road traffic masking noise

RTN recordings were gathered by A2 highway close to Poznan (Poland) during rush-hours (15:00-17:00) on Friday. The traffic volume was 4 860 vehicles per hour with ratio of 82.3% light vehicles (passenger cars and small trucks) and 17.7% of heavy vehicles. No motorcycles were observed during recordings. Noise of steady vehicle flow was measured at 1.5 m height using the same recording setup as for WTN recordings (RODE NTSF1 ambisonics and Squadriga II recorder) within 3 distances perpendicular to highway axis: 25 m, 250 m and 500 m from the middle of external road lane. Sound levels were obtained by SVAN 979 Class 1 sound level meter. Weather conditions during recording session were alike to conditions for WTN recordings with the difference that no wind was present at RTN site (max wind speed <1 m/s). Measurement points were located along flat dirt road around which terrain was covered with packed earth. RTN 5-minute equivalent sound pressure levels were $L_{eq} = 60.5\ dBA$ at 250 m and $L_{eq} = 56.9\ dBA$ at 500 m. 1/3 octave band spectrum of RTN at 250 m is shown in Figure 1 with WTN spectrum at 150 m for depiction of dominant frequency bands distribution.

2.2 Preparation of sound samples

As the distance between the observation point (so-called “0 m point”) and the source changes, and so is the samples sound spectrum. This stem from a variety of mechanisms along propagation path, with two main being the absorption of sound energy in the air and the sound reflections from the ground surface.

The full-sphere ambisonics audio recordings were converted into dual-channel stereo wav files. Subsequently, for each measuring distance or noise source, 10 exemplary “source point samples” of 8-second length were selected: from WTN recordings captured at a distance of 150 m and from RTN recordings obtained at distances of 250 m and 500 m. In order to reflect the effect of distance alterations by means of spectral structure of sound, source samples were filtered with transfer functions.

Transfer functions were created using the Nord2000 [8] methodology. Main input data for the model were: height of sound source and receiver, horizontal distance between both points, weather parameters including wind speed, wind direction (downwind), air temperature, humidity, landform and terrain type along the propagation path.

Transfer functions calculated based on Nord2000 methodology resulted in 1/3 octave bands spectra of 20 Hz – 10 000 Hz center frequency range indicating attenuation on propagation path. Attenuation spectra resulting from transfer functions were treated as band-pass filters which source signals were processed with. By changing horizontal distance between source and receiver (while keeping the remaining parameters unchanged) Authors managed to calculate set of transfer functions suiting the needs of experiments.

For WTN samples 200 transfer functions, corresponding to distances 0 m to 2 000 m between source and observation point, with 10 m step, were calculated. Processing WTN source samples with transfer functions resulted in

generating samples for artificial source locations ranging from 150 m (original recording) to 2 150 m from the original location of wind turbine.
For additional RTN samples 2 transfer functions were calculated: for distance 500 m and 1 500 m between source and observation point. Thus RTN samples for experiments consisted of 4 distances: 250 m, 500 m, 1 000 m and 2 000 m. First two samples were original recordings, and two latter were created by filtering 500 m recording with mentioned transfer functions.
Filtering procedures, on the base of the Nord2000, were performed repeatedly for each of 10 source samples and each measuring distances of WTN and RTN. Table 1. presents detailed data considering sample preparation.

Table 1. Sample preparation details.

Criterion	WTN samples	RTN samples
Number of source point samples	10	10 + 10
Measuring distances [m]	150	250, 500
Number of transfer functions	200	2
Transfer function distances [m]	0 – 2 000 (10 m step)	500, 1 500
Distances between observation point and artificial source points [m]	150 – 2 150 (10 m step)	250, 500, 1 000, 2 000
Number artificial source points	2 000	40

2.3 Laboratory experiment

The experiment was divided into 4 separate sessions within which multiple trials were performed. Each session was dedicated to different masking signal (RTN) presented at different distance: 250 m, 500 m, 1000 m or 2000 m. During sessions masker distances were constant while WTN source point distance was changing according to subjects answers. The subject's task during each trial was to compare 2 listened samples and indicate which one was more annoying. The assumption was made that samples containing wind turbine signals present higher annoyance therefore their indication was treated as the correct response. Subjects were not informed about the sound sources contained in listened samples to nullify the influence of non-acoustical factors such as bias or aversion towards RTN or WTN. Subjects were instructed that selection is purely subjective and when unsure are asked to answer at random.

2.3.1 Experiment procedure

In study sessions two-alternative forced choice (2AFC) method with the 2 up/1 down adaptive procedure was used. Trials consisted of two 8-second samples containing: (1) wind turbine signal against masker and (2) solely masking signal. In each trial samples were presented at random order with 1 second of silence between sample presentation.
According to given responses procedure was adjusting the signal-to-masker ratio (SMR) which corresponded to the distance between the wind turbine and the observation point. If the subject indicated a sound sample containing the sound of a wind turbine (correct response), the SMR was reduced by presenting WTN further from observation point in next trial with current distance shift step (DSS). When response was incorrect procedure increased SMR by presenting WTN signal closer to the observation point with current DSS. DSS was decreasing every time procedure obtained a turning point (changing the trend of responses from correct to incorrect or vice versa). DSS were 150 m, 50 m and 20 m. When DSS dropped to 20 m it stopped decreasing. Session continued until obtaining 5 more turning points. Average value of last 5 turning points obtained for smallest DSS corresponded to the distance between the observer point and the WTN source point at which the subject was unable to assess the differences in the annoyance of the presented pair of sound samples. This value was considered as WTN amid RTN masker detection threshold. Experiment procedure were created and conducted with PsychoPy software [9].

2.3.2 Subjects

In experiment took part 17 subjects in age group 18 – 30 years. Every subject had it's hearing tested by pure-tone audiometry. All subjects had normal hearing. Subjects were instructed about task before each experiment. No information about origins of sound samples, neither WTN signal nor RTN masker, was given. Subjects were informed that at any time during experiments they can stop the procedure and between each experiment 5-minute breaks were conducted. Subjects were paid for participation in the study.

3. RESULTS AND DISCUSSION

Using the IBM SPSS v.28 software, an ANOVA analysis of variance was carried out on the obtained experimental results. The dependent variable was the minimum distance between the observer and the wind turbine determined by the subject, for which the differences in the annoyance sensations of the compared sounds (RTN and RTN+WTN) were just perceived. Referring to the research methodology used, it can be assumed that above the experimentally determined distance the wind turbine noise is completely masked by road traffic noise. The fixed factor was the distance between the traffic noise source and the wind turbine (RTN distance), while the subject factor was a random factor. The analyzes were performed at the significance level of p=0.05.

The results of the analysis of variance showed that RTN distance was a statistically significant factor $F(3, 47) = 12.499$, $p<0.001$. In addition, the subject factor also proved statistically significant $F(16, 47) = 2.150$, $p<0.001$.

Figure 1 shows the relationship between the mean Threshold distance of WTN annoyance, and RTN distance.

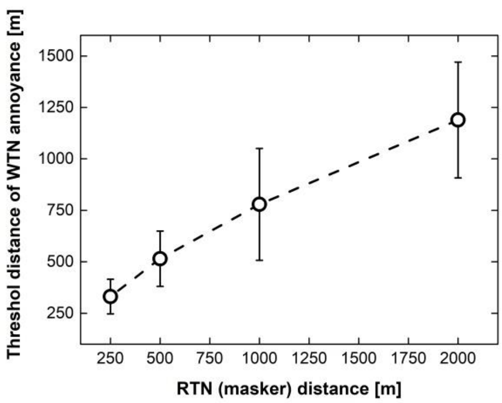

Figure 2. Relationship between mean Threshold distance of WTN annoyance, and RTN distance. Error bars indicate 95% confidence intervals.

As part of the statistical analyses, a post hoc test, the Tukey test, was also performed. Tukey's test results showed that RTN significantly affects the average thresholds of distance of WTN annoyance. Increasing the RTN distance significantly increases the average values of the measured thresholds of WTN annoyance as the function of the distance.

It should be noted that as RTN distance increases, the value of the confidence interval increases. This means that for larger distances of the wind turbine from the traffic noise source, the comparison of annoyance between wind turbine noise and turbine vs. road noise becomes quite a difficult task.

This is primarily due to the decrease in noise levels with distance and the reduction in the frequency range of the spectra of the compared stimuli.

In summary, the results obtained from the study indicate that wind turbine noise is effectively masked by road traffic noise, especially when the turbine is located at distances of up to about 500 m relative to traffic noise sources. On the other hand, for the location of the wind turbine relative to the road traffic noise source at distances (above about 500 m), the effectiveness of masking by road noise decreases significantly. The research results presented in this paper refer to one of many stages of experimental study. Further stages of the research will take into account different sound samples of the maskers, i.e. recorded road noise from different times of the day and night. In addition, recordings of wind turbine noise with varying amplitude modulation rates will be included in future stages of the work.

4. CONCLUSIONS

Areas in close neighborhoods to roads with heavy traffic are exposed to high levels of noise and are most often excluded from residential development plans. The results of the present study showed that road noise is an effective masker for wind turbine noise, especially when the distance between the wind turbine and the road is no more than 500 m. The effectiveness of traffic noise masking decreases when the wind turbine is located at distances greater than 500 m from the road noise source.

5. ACKNOWLEDGMENTS

The research was carried out as part of the Polish-Norwegian project NOR/POLNOR/Hetman/0073/2019-00.

6. REFERENCES

[1] E. Pedersen and K. Persson Waye, “Perception and annoyance due to wind turbine noise—a dose–response relationship,” *J Acoust Soc Am*, vol. 116, no. 6, pp. 3460–3470, 2004.

[2] C. Hansen and K. Hansen, “Recent Advances in Wind Turbine Noise Research,” *Acoustics*, vol. 2, no. 1, pp. 171–206, Mar. 2020

[3] M. Pawlaczyk-Łuszczyńska, A. Dudarewicz, K. Zaborowski, M. Zamojska-Daniszewska, and M. Waszkowska, “Evaluation of annoyance from the wind turbine noise: A pilot study,” *Int J*

Occup Med Environ Health, vol. 27, no. 3, pp. 364–388, 2014,

[4] S. Lee, K. Kim, W. Choi, and S. Lee, "Annoyance caused by amplitude modulation of wind turbine noise," *Noise Control Eng J*, vol. 59, no. 1, pp. 38–46, Jan. 2011

[5] K. L. Hansen, P. Nguyen, G. Micic, B. Lechat, P. Catcheside, and B. Zajamšek, "Amplitude modulated wind farm noise relationship with annoyance: A year-long field study," *J Acoust Soc Am*, vol. 150, no. 2, pp. 1198–1208, Aug. 2021,

[6] E. Pedersen, F. van den Berg, R. Bakker, and J. Bouma, "Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound," *Energy Policy*, vol. 38, no. 5, pp. 2520–2527, May 2010.

[7] T. Van Renterghem, A. Bockstael, V. De Weirt, and D. Botteldooren, "Annoyance, detection and recognition of wind turbine noise," *Sci Total Environ*, vol. 456–457, pp. 333–345, Jul. 2013,

[8] B. Plovsing, "Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 1: Propagation in an Atmosphere without Significant Refraction," *Delta*, pp. 1–127, 2001.

[9] J. Peirce *et al.*, "PsychoPy2: Experiments in behavior made easy," *Behav Res Methods*, vol. 51, no. 1, pp. 195–203, Feb. 2019,