Project: A healthy society - towards the optimal management of wind turbine noise

D1.4 Masking of wind turbine noise by wind induced noise (M24)

Projekt: **Healthy society - towards optimal management of wind turbines' noise**

D1.4 Masking of wind turbine noise by wind induced noise (M24)

Executive summary

As is well known, wind turbine noise (WTN) is characterized by periodic fluctuations in the instantaneous value of the sound level over time, called amplitude modulation. Amplitude modulation certainly causes the effectiveness of wind turbine noise masking to decrease.

The research in this paper addressed the situation where the wind turbine is located in the vicinity of a common type of masker such as road traffic noise (RTN), due at least to the current locations of some wind farms. The study considered noise generated by turbulent airflow around the head and torso, which simulates the situation of potential masking of WT by wind noise (WN) to which an observer residing in the area of influence of a wind turbine is exposed.

The results showed that although the total WTN level is less than the road noise level, effective masking of wind turbine noise can occur when the WT noise level is less than the road noise level by a minimum of 11 dB. Wind noise resulting from airflow around the observer's head does not significantly alter the masking effect of WTN F(2) = 0.580, p=0.447. The insignificant masking effect of WTN by WN can be explained primarily based on regular fluctuations in WTN level (amplitude modulation), which is not observed in the case of changes in WN level.

Authors	Date of submission	Confidentiality level
Andrzej Wicher Maciej Buszkiewicz	31.III.2023	It can be made available on the project website: https://hetman-wind.ios.edu.pl

1. INTRODUCTION

In real environmental conditions, a sound source such as a wind turbine does not occur on its own; as a rule, there are other natural sound sources, such as tree noise, or artificial sources, which are moving vehicles, i.e. road noise, in the vicinity of a wind turbine. In many cases, wind turbines are located along roads, near expressways. In such situations, wind turbine noise is subject to a masking phenomenon, through road noise, or the sound of tree noise. The masking phenomenon occurs when the masking sound (masker-M) causes the sound signal (signal-S) to cease to be heard against the masker. A measure of masking is the increase in the threshold for hearing the signal in the presence of the masker.

They (Bolin et al., 2010) investigated the possibility of masking WT sounds by natural sounds. Three types of natural sounds were used the noise of a forest of deciduous trees, coniferous trees and the noise of sea waves. WT sound was recorded from a distance of 200m, or 400m. Turbine sounds were presented at 40 dBA. The measurements took place in an acoustically isolated room, and all sounds were presented through headphones. The masking thresholds for WT sounds, expressed by the SNR value (the ratio of the WT noise level to the noise level of natural sounds), ranged from -10 to -9 dB for a single turbine and

-11.4 to -8.3 dB for seventeen turbines. Considering 95% confidence intervals, SNR values reached as high as -13 dB. The results from this work showed that only when the sound level of the maskers in the form of tree noise or sea waves exceeded the WT sound level by several dB then WTN masking occurred.

Wind turbine noise (WTN) is characterized by periodic fluctuations in the instantaneous value of the sound level over time, called amplitude modulation for simplicity. Amplitude modulation certainly causes the masking effectiveness of wind turbine noise to be reduced.

The present study addressed the situation where the wind turbine is located in the vicinity of a common type of masker such as traffic, due at least to the current locations of some wind farms. In addition, noise generated by turbulent airflow around the head and torso was taken into account, which simulates the situation of potential masking of WT by wind noise (WN) to which an observer residing in the area of influence of a wind turbine is exposed.

2. EXPERIMENT

The purpose of the study was to determine the discrimination thresholds of WT annoyance against road noise depending on the relative distance between the source of the signal (WT) and the source of the masker (the road lane on which motor vehicles travel). Two experiments were performed, in the first experimental session the presented sounds were road noise and TW noise against road noise. In the second session, wind noise was added to all stimuli, which was the result of air flowing around the observer's head and torso at the same speed as the wind speed at the height of the wind turbine nacelle.

3. METHOD

3.1. RECORDINGS

3.1.1 Wind turbine noise

WTN recordings were gathered during measurement campaign on wind farm 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 Leq = 49.1 dBA. During recording session wind turbine rotation frequency was 0.8 Hz.

3.1.2 Road traffic 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 Leq = 60.5 dBA at 250 m and Leq = 56.9 dBA at 500 m.

3.1.3 Wind noise

Wind noise was recorded using a B&K artificial head and torso placed in an anechoic chamber, during the flow of a 4m/s airstream around the artificial head. The wind speed was equal to the wind speed at the observation point, during the operation of the WT, whose noise we evaluated in the experiment.

Recordings done using Head and torso Simulator (B&K) with LAN-XI Data Acquisition System (PULSE, B&K) at controlled wind speeds: 3, 4, 5, 6, 8, 10, 12 m/s. The recordings were made in the anechoic chamber of the Institute of Heat Engineering in Lodz, Poland (Figure 1). Total level of the wind noise for 4 m/s was 42 dBA.

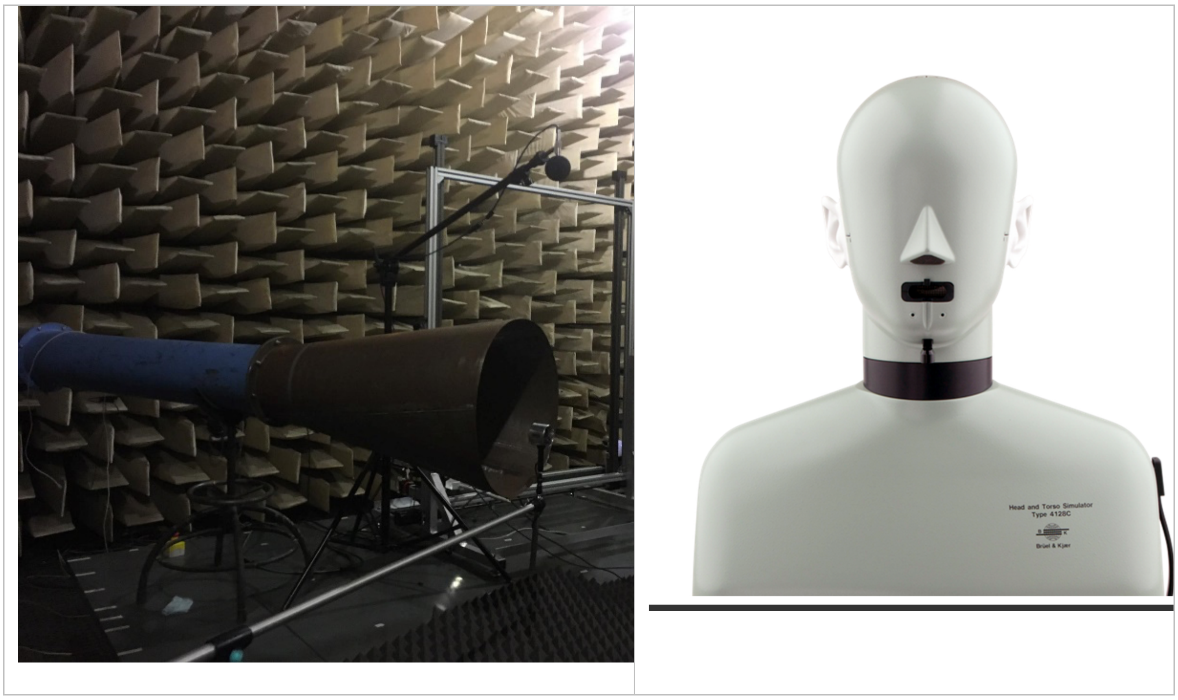

Figure 1. An anechoic chamber equipped with a special tube that serves as the inlet of a controlled velocity air stream with reference microphones. On the right is the artificial head and torso of B&K which was placed in the air stream of a given velocity.

Figure 2 shown 1/3 octave spectrum of wind noise.

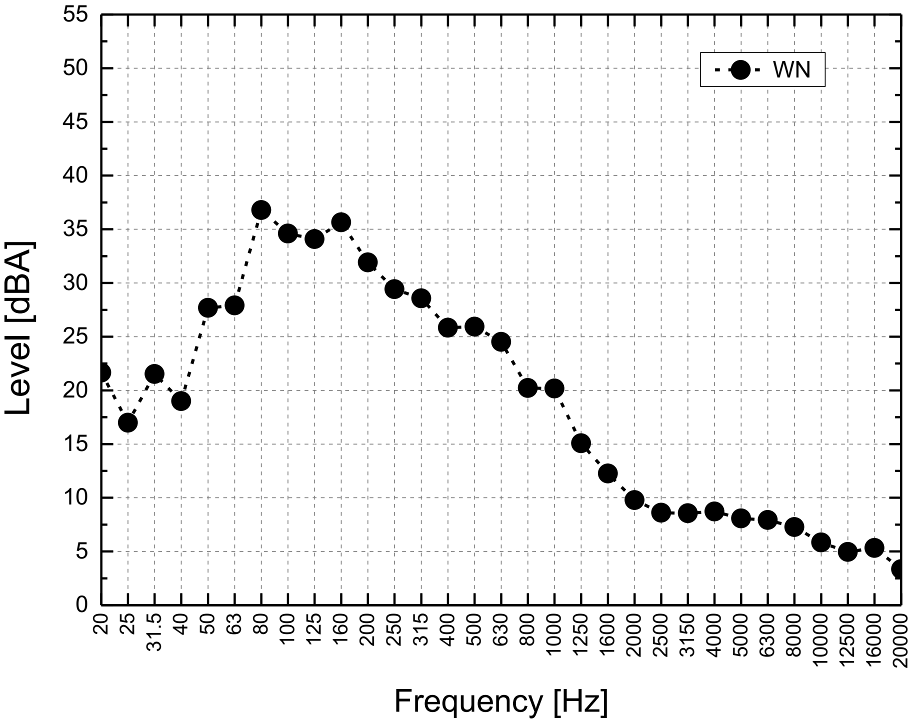

Figure 2. 1/3 octave band spectra of recorded wind noise (WN) for 4 m/s wind speed.

Flow surrounding the head and ears generates wind noise is: low frequency dominant, complex spectral characteristics and random amplitude envelope.

3.2. STIMULI

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 methodology (Plovsing, 2001). 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 RTN sample transfer function were calculated for distance 500 m between source and observation point. Thus RTN sample for experiments consisted of distance 500 m.

3.3. PROCEDURE

The experiment was divided into 2 parts (with and without wind noise). Each part was dedicated to masking signal (RTN) presented at distance 500 m. During sessions masker distance 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. The procedure in the second part of experiment was similar but all samples contained additional wind noise signal.

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.

3.3.1 Subjects

In experiment took part 20 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.

4. RESULTS

For each subject, the smallest observer-WT distance was determined for which traffic noise was as annoying as TW noise against traffic noise. The obtained results were then converted into values determining SNRs at annoyance discrimination thresholds.

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. The fixed factor was the absence/presence of wind noise. The analyzes were performed at the significance level of p=0.05.The results of the analysis of variance showed that wind noise was not a statistically significant factor F(2) = 0.580, p=0.447. Figure 3 shows mean SNR values at the annoyance threshold as a function of wind noise (absence/presence).

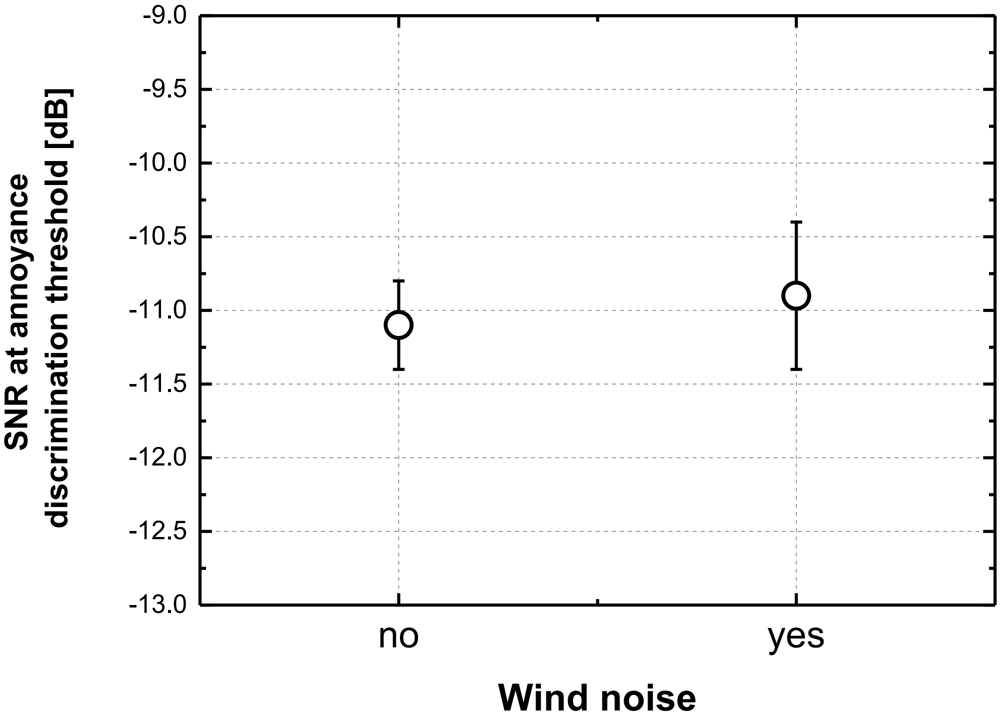

Figure 3. Mean SNR values at the annoyance discrimination threshold as a function of wind noise (absence/presence). Vertica bars show 95% confidence interval

The results showed that although the total WTN level is less than the traffic noise level, effective masking of wind turbine noise can occur when the WT noise level is less than the traffic noise level by a minimum of 11 dB. Wind noise resulting from airflow around the observer's head does not significantly alter the masking effect of WTN F(2) = 0.580, p=0.447.

Figure 4 shows the 1/3 octave WTN and RTN noise spectra corresponding to the mean annoyance discrimination thresholds from Figure 1.

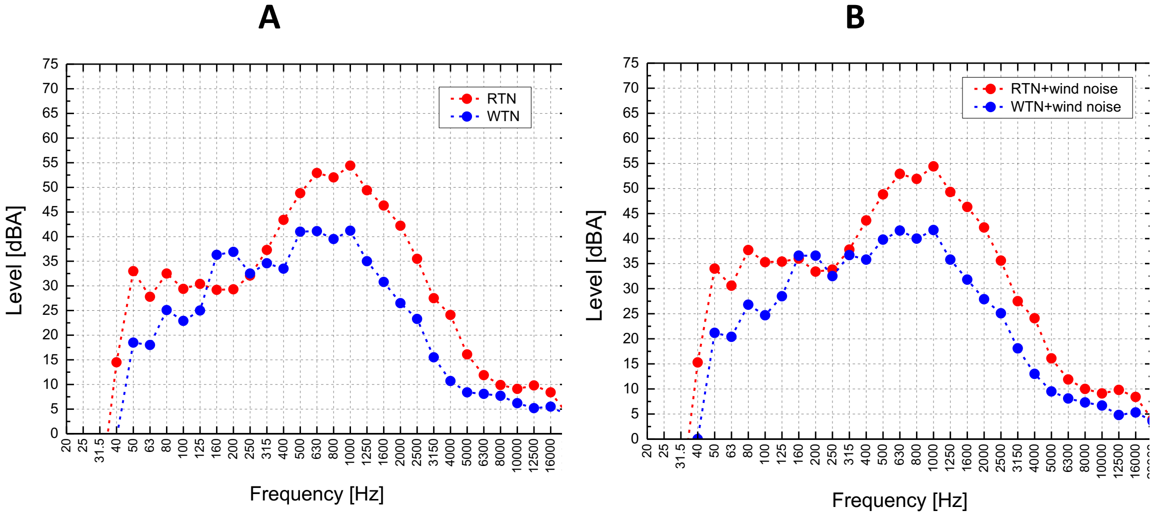

Figure 4. WTN and RTN 1/3 octave band spectra corresponding to the mean annoyance discrimination thresholds from Figure 3

The 1/3rd octave spectra in Figure 4 indicate that in almost the entire frequency band (except 200 Hz) at the annoyance discrimination threshold, RTN levels reach higher values than WTN. Moreover, the addition of wind noise (Figure 2A) only slightly affected the spectral structure of RTN and WTN, and most importantly did not affect the annoyance discrimination threshold of WTN. The results of this study once again demonstrate that the annoyance of WTN is determined by the amplitude modulation and not by the structure of the signal spectra (masking model based on the signal power spectrum), (Moore and Glasberg, 1987).

5. CONCLUSIONS

WTN is among the specific noise sources in terms of both spectral and temporal structure. The WTN spectrum is dominated by low-frequency components. While the low masking efficiency of WTN by RTN can be attempted to be explained by differences in energy maxima falling at higher frequencies for RTN than for WTN, the insignificant masking effect of WTN by WN observed in the present study can be explained primarily based on regular fluctuations in the level of WTN (amplitude modulation), which is not observed in the case of WN.

LITERATURE

Bolin, K., Nilsson, M.E., Khan, S. 2010. The Potential of Natural Sounds to Mask Wind Turbine Noise. Acta Acust United Ac 96, 131-137.

Moore, B.C., Glasberg, B.R. 1987. Formulae describing frequency selectivity as a function of frequency and level, and their use in calculating excitation patterns. Hearing research 28, 209-25.

Plovsing, P. 2001. Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 1: Propagation in an Atmosphere without Significant Refraction. Delta, 1-127.