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INFLUENCE OF WIND NOISE ON A RECORD-BASED SIMULATION APPROACH OF VEHICLE DRIVING BY SCENARIOS

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Abstract

In order to investigate pedestrian safety, it is important to understand how they behave in different traffic scenarios. For reasons such as cost efficiency, consistent experimental conditions and increased safety, these investigations are transferred to virtual environments. Recent studies have used single-source recordings of vehicles to simulate vehicle pass-by scenes. A main concern at this point was the interfering noise caused by wind, which increased with vehicle speed. This study reviews previous literature and develops six different windscreen concepts. These concepts were tested and compared in anechoic conditions with a fan that could control wind speeds. Next, one concept was selected, and a transfer function and additional low-shelf filters for wind noise reduction were investigated. Vehicle pass-by scenes were simulated with and without pre-editing through filtering. These simulations were recorded with a dummy head in an anechoic chamber and compared to determine the influence of the improvements introduced in this paper on physical values.

Keywords: *virtual reality, wave field synthesis, electric vehicles, wind noise*

1. Introduction

Pedestrians must pay special attention to their surroundings when navigating through traffic situations. They must make important decisions about crossing streets and actively avoid objects. Due to the increased electrification of automotive development, emitted sounds have become more unconventional compared to combustion engine noise. As a result, acoustic cues are especially important for visually impaired people or when sight is blocked by parked cars. To develop Acoustic Vehicle Alerting System (AVAS) sounds and investigate pedestrian behavior in critical traffic scenarios, safety-relevant experiments are conducted in virtual environments. In recent studies, an objective-based simulation approach was used to simulate vehicle pass-by scenes to quantify reaction times, such as the Time To Collision point (TTC). [1–3] The influence of wind noise in close-up vehicle recordings was criticized. Other studies [4, 5] found that loudness affects pedestrian reaction times. When the vehicle simulation is louder, the vehicle is perceived as being closer.

This indicates that vehicle scenes must be simulated with the correct loudness. Otherwise, participants may have difficulty evaluating the correct distance. Since wind noise becomes more dominant at higher vehicle speeds, especially in the lower frequency ranges [6], this study focuses on this issue. In addition to testing different windshield concepts, this study also explores speed-dependent filtering of close-up recordings to further reduce wind noise rumble sounds. Ultimately, driving scenes with vehicles are simulated with and without pre-editing of the close-up recordings and compared to each other.

2. Windscreen selection

In a first step, different studies were analyzed to get an overview over existing wind screen literature. After that, different concepts are created and tested.

2.1 Existing windscreen studies

Recent studies have investigated how wind affects microphones. First, the position of the microphone affects the level of disturbing noise. [7] When the microphone is aligned with the wind direction and the wind hits the microphone membrane directly, the wind noise below 2000 Hz is about 10 dB quieter than when the microphone is rotated 90 degrees. Above this critical frequency, the opposite is visible. Therefore, the position generally influences the character of the

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disturbing noise. As other studies have generally shown, disturbing wind noise exists in a lower frequency range of about 20 Hz to 2 kHz [8–10], but is most dominant in the 20 to 200 Hz range. [6] In recent studies, foam wind screens [7] or furry wind screens [4] were used. There are also investigations, where a new concept with a thick foam layer is created for stronger wind environments. [10] Besides that, the present investigation also considers concepts with wind zeppelins, as showed on page 42 in figure 4. [8] They basically consist of a plastic basket with a thin foam layer inside. Based on this information, six windscreen concepts are tested in the next chapter.

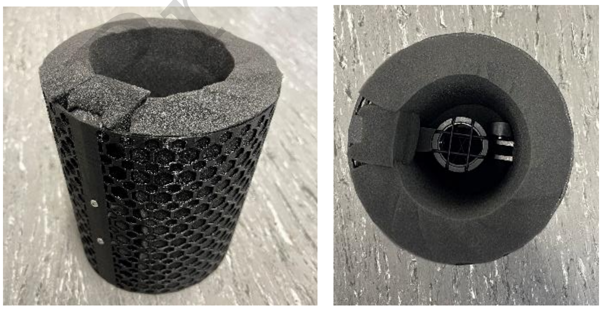
2.2 Preselection of different windscreen concepts

So, for this study, four commercial wind screens were tested against a self-made concept. (Table 1)

Table 1. Setup Identifiers and certain descriptions.

Setup	Description
Setup 1	Small foam windscreen (diameter: 3 cm)
Setup 2	Big foam windscreen (diameter: 9 cm)
Setup 3	*Bubblebee* The Windkiller XS
Setup 4	*Rycote* Super-Softie 5cm 19/22
Setup 5	Self-made windscreen zeppelin
Setup 6	Self-made windscreen zeppelin with fur

Setups one to four are wind screens that are commercially sold. They are designed for microphones with larger diameters than the free-field calibrated microphones that will be used for close-up vehicle recordings in this study. [10] For this reason, individual adapters were 3D printed to ensure compatibility. Additionally, a new concept was developed. Therefore, a 15 cm diameter, 17 cm high cage was 3D printed. A shock mount that can hold a free-field calibrated measurement microphone was screwed into the middle of the cage. A 2.5 cm thick foam layer was integrated around it. (Figure 1)



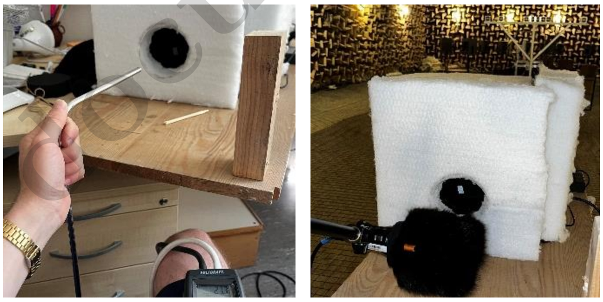
a) b)

Figure 1. 3D printed cage from the side (a) and from above (b).

The goal of this setup was to avoid the direct influence of vibrations from the car on the microphone and to reduce wind noise with a thick layer of acoustic foam. Additionally, synthetic fur was added to provide more wind protection. (Setup 6). Conventional wind screens, as described in Table 1, were tested and compared with this self-made setup regarding their performance. Setup one and two are conventional foam wind screens that are widely used. Setup four has a unique 3D foam structure, and setup three has a combined foam and fur structure.

2.3 Influence of wind on different wind screens

For the preliminary investigation, an AC Infinity Cloudline Pro T4 fan was placed on a wooden surface, and acoustic treatment (Caruso polyester nonwoven) was used to dampen the noise from the electrical motor and the fan itself. The fan could be controlled within certain steps. The wind speed was measured with a pitot tube and a differential pressure gauge (Voltcraft VPT-100) for each step. The pitot tube was placed 20 cm away from the fan's outlet, similar to the position of the free-field calibrated microphone capsule later on. (Figure 2)



a) b)

Figure 2. Placement of the pitot tube (a) and the microphone later on. (b)

In total, the fan was controlled with 5 different steps, where the wind speed was measured for each step. The values are written down in Table 2.

Table 2. Wind speeds of the fan, controlled by certain steps.

Fan step	Temperature [°C]	Wind speed [kph]
2	27.7	11.9
4	27.7	19.1
6	27.7	24.6
8	27.7	31.2
10	27.7	39.6

Based on this table, it can be concluded that a wide range of wind speeds is covered. The fan can simulate the effect of wind on a microphone at a test car traveling up to 40 kph. The fan experimental setup was placed inside the anechoic chamber at Dresden University of Technology. One by one, the windscreen setups were placed on a free-field calibrated microphone in front of the fan. The fan was operated with different steps, and a ten-second recording was made at each level. After being placed directly in front of the outlet, the microphone was also placed beside the fan so that it would not be influenced by the wind and could record the fan noise itself.

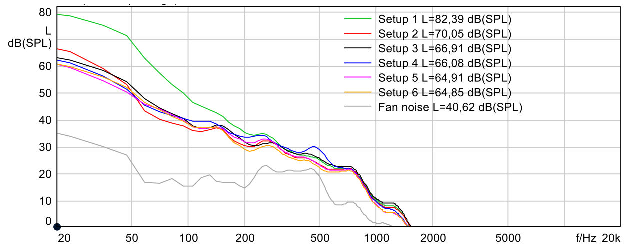


Figure 3. Influence of wind with a speed of 11.9 kph on the different windscreen setups.

As previously analyzed in the literature review, it is clear that at low wind speeds, the wind influences the microphone capsule within a frequency range below 1000 Hz. (Figure 3). The small foam windscreen with a diameter of about 3 cm (Setup 1) minimizes wind noise the worst. Compared to the other windscreen setups, the wind-induced noise is about 15 dB louder in the lower frequency range. The other setups perform similarly and reduce low-frequency rumble to a similar level. More differences occur when the microphones are exposed to a wind speed of 39.6 kph. (Figure 4)

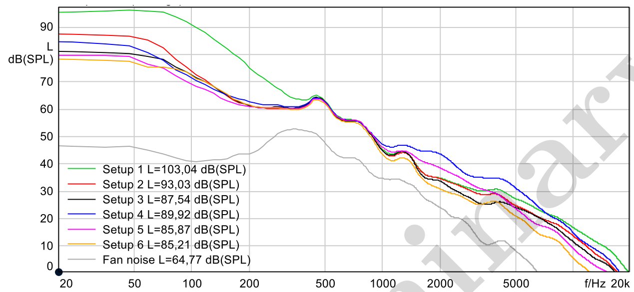


Figure 4. Influence of wind with a speed of 39.6 kph on the different windscreen setups.

Once again, the small foam windscreen performs the worst. In comparison, the homemade wind zeppelin with fur (Setup 6) most effectively reduces wind-induced noise, especially in the frequency range above 1000 Hz. Without the fur, however, the windscreen does not perform as well, and the wind noise in this higher frequency range is about eight decibels louder. The Rycote windscreen (Setup 4), which has only a foam structure, holds back wind influence the worst, especially in the 1000-5000 Hz frequency range. Below 50 Hz, the Rycote Windscreen's wind damping effect falls between that of the large foam windscreen and the other approaches. The aim of this study is to find a windscreen suitable for close-up recordings of cars. It must be flexible yet effective at reducing wind-induced rumble. Setup 3, with a combination of fur and a 3D foam structure, performs as well as the homemade wind protection, but dampens wind noise by about 3 dB less.

It is much more flexible than the wind zeppelin, making it the right choice for future recordings and experiments. (Figure 2b)

2.4 Transfer function

The windscreen affects the recording itself. Due to its fur and foam structure, the sound is slightly dampened at higher frequencies, as other studies have analyzed. [7] For this reason, an experiment was carried out in the anechoic chamber. A Genelec speaker (Genelec 8250A) was placed on a stand. First, a free-field calibrated microphone from Microtech Gefell (MV212 preamp, MKS221 capsule) was placed at a height of 27 cm between the tweeter and the low-frequency driver and 50 cm from the loudspeaker. Next, a sine sweep was played and recorded without a windscreen. Then, setup 3 was attached to the microphone, and the sinus sweep was played and recorded again. The difference could then be determined, and the transfer function was calculated. (Figure 5)

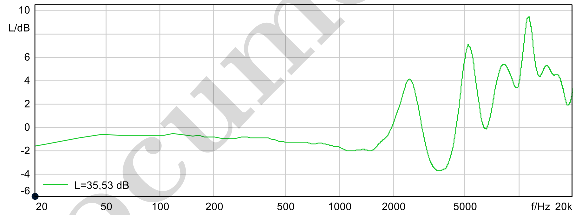


Figure 5. Transfer function for the Bubblebee wind screen.

The transfer function is needed for the following single source recordings.

2.5 Low shelf filter

To reduce the influence of the wind noise, low shelf filters are built inspired by the temporal progressions of the graph, that is visualized in Figure 7. In section 3.2 it is clarified, what was used as a basis for calculating the low shelf filters. For each speed, a low shelf filter is created, that reduces the low frequency rumble, caused by the wind on the microphones. (Figure 6)

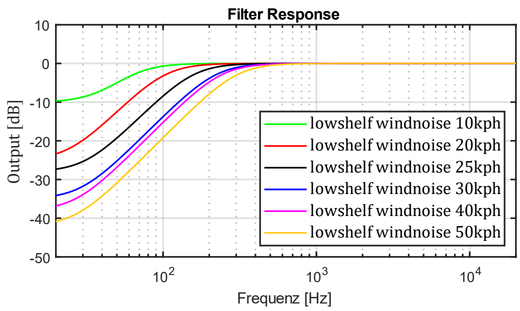


Figure 6. Low shelf filter for each speed, to reduce wind noise rumble additionally.

3. Single Source Recording

3.1 Recording procedure

To test the windshields, a 51 kW Renault ZOE with all-season Kleber Quadraxer tires (195/55 R16) was used. Four free-field microphones from Microtech Gefell

(MV212 preamp, MKS221 capsule) were placed at the vehicle's main sound sources, which are characterized by tire and engine sounds (in this case, the AVAS sound). [11] The position was chosen according to the guideline DIN 11819-2 [12] and is described in more detail in previous literature. [2] The microphones were equipped with a Bubblebee windshield (setup 3) and a 3D-printed adapter. GPS data was also recorded to map the car's path for later simulation. The SQuadriga III from Head acoustics was used to handle all the measurement data. A street on an industrial site in Radebeul, Germany was chosen as a test track. It is decentralized, with little traffic, and thus perfect for the recordings. A factory, that operated a machine, stopped it for the recording period. Before every recording, passing vehicles were allowed to go by, so the recording procedure wasn't disturbed. In addition to the close-up microphones, two free-field microphones with wind screens (2 meters distant from the dummy head) and a dummy head (HSU III, Head acoustics) were placed on the street curb, whereas the microphone capsules were in a height of 1.60 m. (Figure 7)

Figure 7. Recording setup at the test track.

In front of the dummy head, a light sensor was also installed to measure the exact point at which the car crosses the listener's position. First, the car drove along the road with the close-up microphone setup. Then, after the microphones were detached, the car drove alongside the static dummy head setup. The car drove at 10, 20, 25, 30, 40, and 50 kph and was controlled using cruise control. 25 kph was also selected because the AVAS sound switches off at about 30 kph, and the last speed at which the AVAS sound is the loudest should also be included.

3.2 Signal analysis

First, some recordings were analyzed to determine the impact of wind on close-up microphones. Therefore, the recording of the right rear tire of the vehicle was cut into two-second intervals. Also, two seconds before the vehicle passes the point detected by the light sensor, the static recording of the left dummy head microphone is cut. Then, the difference in the FFT analysis of both recordings was calculated. (Figure 8) The FFT curve of the close-up vehicle microphone recording is subtracted from the FFT analysis of the static microphone recording. This is why, as the vehicle's speed increases, the difference decreases. The increasing wind speed causes a louder overall sound pressure level (SPL) at the close-up microphones and a higher SPL below a frequency of about 200 Hz compared to lower speeds.

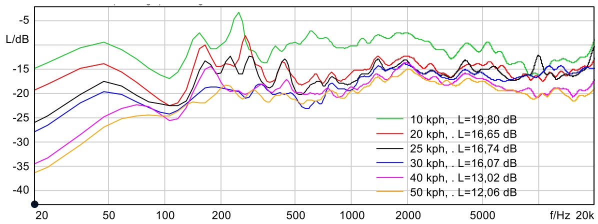


Figure 8. Difference of FFT analysis of the close-up and static microphone recording.

As was determined in the previous setup with a fan, wind noise is thus dominant in the lower frequency range.

4. Simulation of driving by scenes

4.1 Laboratory setup

The Wave Field Synthesis (WFS) laboratory at Dresden University of Technology was used for the vehicle pass-by simulations. [13] It was calibrated, as described in a previous study, to play back the vehicle pass-by scenes with the correct sound pressure levels (SPL). A MATLAB toolbox based on TASCAR [14] was used for the simulation. Using the wav files of the close-up microphone recordings and the csv files of the position data, vehicle pass-by scenes could be simulated with acoustic effects, such as air damping and distance-related delays. [2] On the day of the recording, a microphone array with ten free-field calibrated microphones was attached above the car. It was positioned 1.6 meters above the ground, in the far field of the main sound sources (i.e., the tire sounds). The microphone calibration values were chosen so that the SPL recorded by the close-up car tire and engine hood microphones would be the same as that recorded by the array microphones above because the latter showed a far-field reference.

4.2 Pre editing microphone recordings

All close-up recordings of the vehicle, such as the engine hood and tire recordings, were pre-filtered with speed-dependent low shelf filters (section 2.5) and the windshield transfer function. (section 2.4) These recordings were saved as new wav files.

4.3 Simulation approach with and without pre-edited recordings

At first, the recordings were put into the simulation unedited. In a next step, the pre filtered single source sounds were used. A dummy head was placed in the middle of the WFS laboratory, to record the simulations. In the following Figure 9, the mean values of the recordings from the average of the left and right dummy head ear recording are visualized.

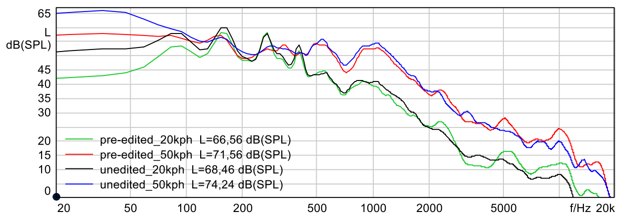


Figure 9. Average amplitudes of the left and right dummy head recording of the pass-by simulations in the WFS laboratory.

The vehicle pass-by scene was cut into one second before and one second after the pass-by point. The FFT analysis was calculated exactly for this interval. As can be seen in Figure 9, the pass-by scenes with the pre-edited source sounds show less SPL in the lower frequency range under about 100 Hz. Also, the higher frequency range is pushed a bit, especially at 5000 Hz and 10000 Hz, what is caused by the transfer function of the wind screen.

5. Conclusions

This study tested different windscreen setups. One windscreen performed well in reducing wind noise while remaining flexible and lightweight. It was used for single-sourced recordings made on a Renault Zoe electric vehicle. Vehicle pass-by scenes were simulated once with and once without pre-editing the source sounds. The comparison showed that, with pre-editing, the scenes had less low-frequency content and thus less wind noise. In future studies, it will be necessary to determine whether pre-editing the signals also influences the perception of pass-by scenes.

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References

[1] J. Krautwurm und M. E. Altinsoy, Hg., *Assessing Pedestrian Behavior in Traffic: A Pilot Study on Real-World Time to Collision Estimations*, 2025.

[2] J. Krautwurm und M. E. Altinsoy, Hg., *Comparing Time To Collision estimations: Experiments in a Wave Field Synthesis Laboratory and the Real World Environment*, 2025.

[3] F. Beyer, S. Fischer, L. Steinbach und M. E. Altinsoy, Hg., *Comparison of Recorded and Synthesized Stimuli of Traffic Scenarios in an Auditory Virtual Reality Environment Using Wave Field Synthesis*, 2023.

[4] D. Oberfeld, M. Wessels und D. Büttner, "Overestimated time-to-collision for quiet vehicles: Evidence from a study using a novel audiovisual virtual-reality system for traffic scenarios," *Accident; analysis and prevention*, Early Access. doi: 10.1016/j.aap.2022.106778.

[5] Behrang Keshavarz, Jennifer L. Campos, Patricia R. DeLucia und Daniel Oberfeld, "Estimating the relative weights of visual and auditory tau versus heuristic-based cues for time-to-contact judgments in realistic, familiar scenes by older and younger adults," 2017.

[6] C. Zühlsdorf, *Informationen rund um das Thema: "Windschutz bei Mikrofonen"*

[7] P. Rasmussen, "Windscreens-Practical Guidlines for Acoustic Measurements in Situations with Wind Flow," 2016.

[8] J. Wuttke, *Mikrofonaufsätze*. Karlsruhe: Schalltechnik Dr.-Ing. Schoeps GmbH, 2000.

[9] P. Költzsch, "Zur Windgeräuschdämpfung von Windschirmen," 1971.

[10] Z. Jones *et al.*, "Examining wind noise reduction effects of windscreens and microphone elevation in outdoor acoustical measurements," in *179th Meeting of the Acoustical Society of America*, Acoustics Virtually Everywhere, 2021, S. 45007, doi: 10.1121/2.0001413.

[11] R. O. Rasmussen, R. J. Bernhard, U. Sandberg und E. P. Mun, "The Little Book of Quieter Pavements," The Transtec Group Inc., Springfield, 2007.

[12] *Akustik – Messung des Einflusses von Straßenoberflächen auf Verkehrsgeräusche – Teil 2: Nahfeldmessverfahren (ISO 11819-2:2017); Deutsche Fassung EN ISO 11819-2:2017*, Deutsches Institut für Normierung, Berlin, 2017.

[13] M. E. Altinsoy, U. Jekosch, S. Merchel und J. Landgraf, Hg., *Progress in Auditory Perception Research Laboratories - Multimodal Measurement Laboratory of Dresden University of Technology*, 2010.

[14] G. Grimm, J. Luberadzka und V. Hohmann, "A Toolbox for Rendering Virtual Acoustic Environments in the Context of Audiology," *Acta Acustica united with Acustica*, Jg. 105, Nr. 3, S. 566–578, 2019, doi: 10.3813/AAA.919337.