Subjective verification of simulation of a vehicle pass-by

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The simulation of a moving vehicle can be a very powerful tool for investigating the perception of vehicle motion (velocity, acceleration, road traffic annoyance studies etc). Before applying a simulated vehicle in psychoacoustic noise annoyance studies, one should perform a subjective validation of this tool. The present paper presents the subjective validation of the simulation method created by the author. Real pass-by recordings were used to calculate the one-third octave power spectra of a vehicle. Based on these spectra, the simulated pass-bys were created. The simulation was validated in terms of the annoyance level and perception of velocity by comparing (in an psychoacoustic experiment) the original pass-bys with their simulated replicas. Two types of engines – Otto and Diesel - were tested, for velocities ranging from 30-110 km/h. For velocities above 50 km/h, the annoyance of simulated pass-bys is identical to the original signal. For lower velocities, simulated pass-bys result in slightly lower annoyance ratings. The solution to the problem would be a reconstruction of the tonal components from the exhaust system.

1 Introduction

In our everyday life, road-vehicles are one of the most important sources of annoyance. Investigating the annoyance caused by vehicle noise in many cases require a large number of recordings and psychoacoustic tests. The recordings are extremely time-consuming and difficult, since they require the control of many parameters, such as velocity, acceleration, distance, time and velocity distribution of vehicles in the traffic flow etc. Usually it is not possible to control all these parameters. Precise control of these parameters would give a great possibility to investigate many factors that influence the annoyance caused by a single vehicle and traffic flow. The solution to this problem would be the simulation of a single vehicle pass-by.

The method of simulating a road-vehicle pass-by was proposed by Kaczmarek [1]. The main purpose of this method was to create a car pass-by which would give identical annoyance ratings (objective and subjective) to a real car. Such a simulation could be widely used in psychoacoustic experiments which investigate the annoyance caused by a traffic flow. The influence of different parameters which characterize traffic flow (vehicle time distribution, velocity distribution, the number of a vehicles in a time unit, distance to the road etc.) on the perceived annoyance can be investigated with the proposed simulation method. For those purposes the simulations can be made with the source parameters taken from general vehicle noise prediction models, like Nord 2000 [2]or Harmonoise 2005 [3].

The present paper presents the results of subjective evaluation and verification of this simulation method. According to the main purpose of this method – the verification takes into account the physical parameters of a pass-by (L_{AE}, shape of a time pattern etc.), annoyance and additionally impression of velocity. In the psychoacoustics experiments real recordings of a car pass-bys will be compared with its simulated replicas. The input parameters for the simulation (distance, exact velocity, shape of a power spectrum) will be calculated separately from each recording.

2 Method

Two different cars were recorded; one with Otto engine, and one with Diesel engine. Recordings were made with a mono omni-directional microphone (G.R.A.S. 40AN) at 1.5 m over the ground, and 7.5 m from the center of a motion lane. The recordings were made for 5 different velocities: 30, 50, 70, 90 and 110 km/h. The actual velocity was controlled by a set of high-accuracy photo-detectors, and it's slightly different from the intended velocities mentioned above. The intended and exact velocities are presented in Table 1.

	v [km/h]				
intended	**30**	**50**	**70**	**90**	**110**
Diesel - exact	26	40	59	81	100
Otto - exact	27	45	65	84	106

Table 1. velocities of a car pass-bys

The exact input parameters (velocity, distance, sound power spectrum) were calculated individually for each pass-by. The present simulation also takes into account the ground effect and air absorption. Then individually simulated replicas were created for each real pass-by. The total set of 20 stimuli were used in the present study (10 real and 10 simulated – 5 different velocities and 2 types of engine). The length of stimuli was 6 seconds. The point of closest approach (calculated precisely from the photo-detector system) was always in the middle of the stimuli. The verification was divided into two parts – objective and subjective. In the objective part physical measures (1/3 octave spectra, level versus time, calculated loudness and sharpness) of real pass-bys and its simulated replicas were compared. In the subjective part – three psycho-acoustics experiments were conducted in which subjects judged the annoyance caused by real and simulated pass-bys using a numerical scale, and compared their annoyance and velocity impressions of real and simulated vehicles (in pairs).

2.1 Objective verification

The stimuli were analyzed with help of a Head Acoustics Artemis Analyzer. The sound exposure level and average total loudness are presented in Table 2.

Table 2 also presents the differences between real and simulated stimuli. The example average 1/3 octave spectra and level versus time for the car with Otto and Diesel engine are presented in Figs. 1 and 2.

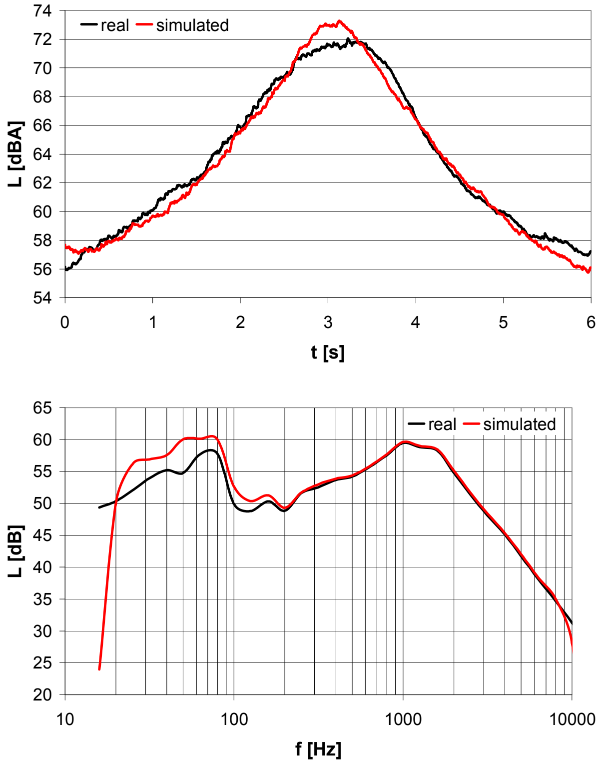

Figure 1. Level versus time (upper panel) and 1/3 octave spectrum (lower panel) of a car with Otto engine moving at 65 km/h.

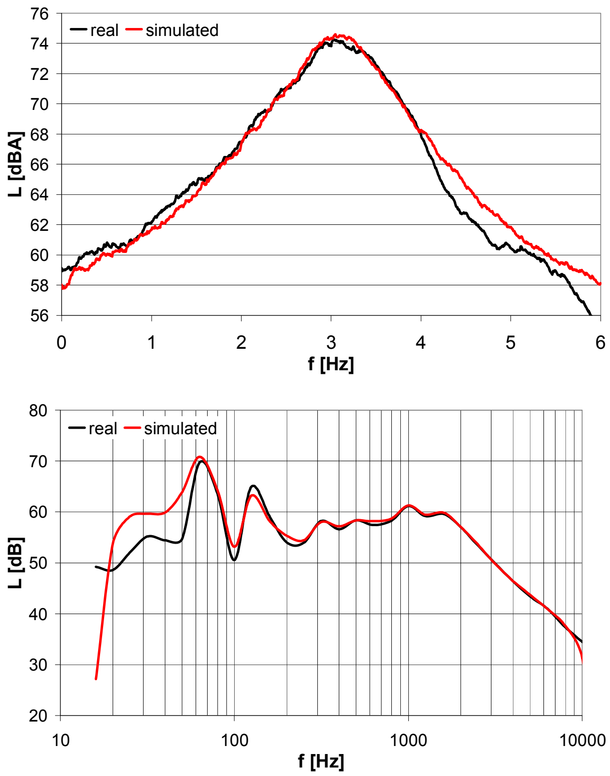

Figure 2. Level versus time (upper panel) and 1/3 octave spectrum (lower panel) of a car with a Diesel engine moving at 59 km/h.

As can be seen from Table 2, the real and simulated vehicles have very similar sound exposure level and loudness. In most cases the level difference do not exceed 1 dB. Slightly higher differences were found for low velocities. This can be explained by the method of simulation. The preset method is based on 1/3 octave spectrum, which introduces some inaccuracy in the lowest frequency bands. This phenomenon can be observed also in Figs. 1 and 2. The tonal components from the exhaust system were simulated by the 1/3 octave noise bands. This phenomenon only has a significant impact for lowest velocities, for which the engine (with its tonal sources) is the dominant sound source. This method works fine for the higher velocities, where the dominant source is the interaction between the road surface and the tire, which has a wide-band spectrum.

DIESEL					
v [km/h]	26	40	59	81	100
LAE [dBA]					
real	67.4	73.2	75.9	78.3	80.7
simulated	69.1	73.8	76.1	78.6	81.2
ΔL	**1.7**	**0.6**	**0.2**	**0.3**	**0.5**
LE [dB]					
real	81.3	82.2	81.7	81.7	83.4
simulated	82.2	84.1	82.7	83.1	84.5
ΔL	**0.9**	**1.9**	**1**	**1.4**	**1.1**
N [sone]					
real	13.2	17.8	19	20.5	23.3
simulated	14.3	18.8	19.4	20.6	23.5
N1/N2 [%]	**8.3**	**5.6**	**2.1**	**0.5**	**0.9**
OTTO					
v [km/h]	27	45	65	84	106
LAE [dBA]					
real	67.2	70.3	74.2	76.6	79.0
simulated	66.1	71.6	74.4	76.9	79.1
ΔL	**-1.1**	**1.3**	**0.2**	**0.3**	**0.1**
LE [dB]					
real	74.9	74.8	76.5	78.5	81.6
simulated	74.0	76.2	77.8	79.0	82.0
ΔL	**-0.9**	**1.4**	**1.3**	**0.5**	**0.4**
N [sone]					
real	11.9	13.3	16	17.8	20.9
simulated	11.1	14.3	15.9	17.6	20.4
N1/N2 [%]	**-6.7**	**7.5**	**-0.6**	**-1.1**	**-2.4**

Table 2. Results of objective analyses

2.2 Subjective verification

The subjective verification consists of three psychoacoustical experiments. In all the experiments the stimuli were presented via Sennheiser HD 600 headphones. In the first experiment subjects rated the annoyance caused by each pass-by using an 11 point (0-10) scale recommended by ICBEN [4,5]. The question was: "*What number from zero to ten best shows how much you are bothered, disturbed, or annoyed by the noise? If you are not at all annoyed choose zero, if you are extremely annoyed* *choose ten, if you are somewhere in between, choose a number between zero and ten."*

Each of the 20 stimuli was presented in random order 30 times. In the second and third experiment pair comparison was used in order to find whether the simulated and real stimuli evoke the same annoyance, and the same impression of velocity. The atimuli were presented in pairs. Each pair consisted of a real stimulus and its simulated replica. Each pair was presented 30 times, with a random order of stimuli within a pair. The subjects were asked to chose which of the two stimuli within a presented pair was more annoying (Experiment 2) or which one moved faster (Experiment 3). In an ideal situation, if subjects perceive the simulated and real stimuli as exactly equally annoying / equally fast, they should obtain the score of 50%. If one assumes that more than 75 % of responses choosing one stimulus as a more annoying/faster means that subjects can really distinguish between the annoyance/velocity of real and simulated stimuli, then the results in the range of 25-75% can be interpreted as there being no difference between simulated and real moving vehicles.

2.3 Participants

Nineteen participants took part in each experiment. Each participant took part in all the experiments. The participants were between 19 and 25 years old. All participants qualified as having normal hearing (normal hearing was defined as the audiometric threshold of 20 dB HL, or better, for the frequency range from 250 to 8000 Hz, according to the ANSI standard [6]) and were paid for their participation.

3 Results

The result of Experiment 1 is the average annoyance ratings for 2 types of sources (simulated and real, with two types of engines (Otto and Diesel) and for 5 velocities). The results are presented in Fig. 3. The results are plotted with the 95% confidence intervals.

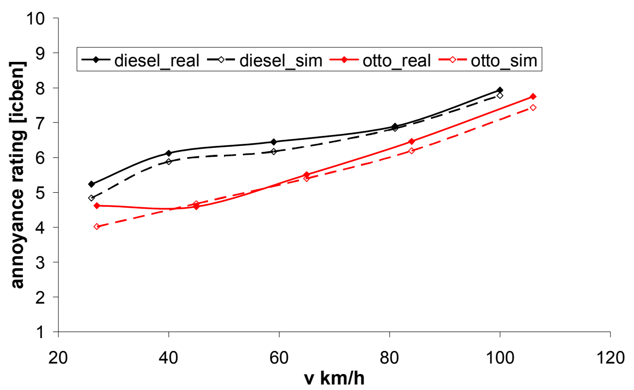

Figure 3. Annoyance ratings of real and simulated pass-bys

As can be seen from the Fig. 3, there is significant difference in annoyance between Otto and Diesel engines. The significant differences between simulated and real recordings exist only for the lowest velocity. The simulated pass-bys are judged as less annoying than the real ones for this velocity. This result is consistent with the objective analyses presented in Table 2. The reason for this phenomenon was also explained in the objective analysis section.

The results of Experiment 2 are presented in Fig. 4. The results describe the percentage of responses in which simulated pass-bys were perceived as more annoying. All the results fall in the 25-75% interval. This means that there is no difference in annoyance between real and simulated pass-bys. However for the lowest velocity the results reach almost 25% - which is also consistent with the results of Experiment 1.

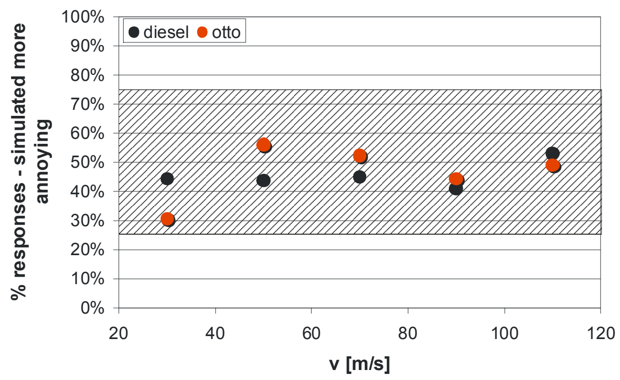

Figure 4. Comparison of annoyance caused by real and simulated pass-bys

The results of Experiment 3 is presented in Fig. 5. The results describe the percentage of responses in which simulated pass-bys were perceived as faster than real pass-bys.

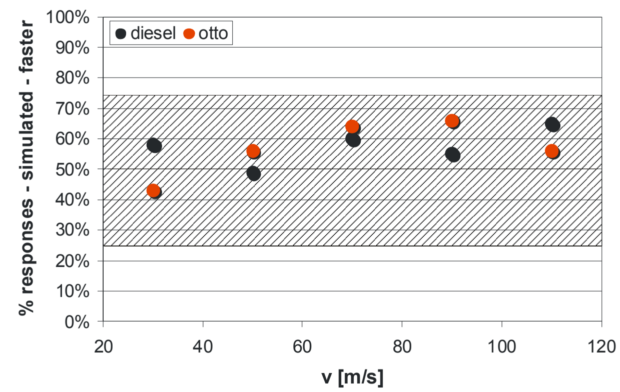

Figure 5. Comparison of velocity impression of real and simulated pass-bys

All the results fall in the 25-75% interval. This means that there is no difference in impression of velocity between real and simulated pass-bys.

5 Conclusion

The simulation method proposed by the author has been positively verified, overall. The present experiments proved that the simulated single pass-bys of a passenger car evoke the same annoyance and give the same impression of speed as their real counterparts. This means that the method is useful for psychoacoustic studies on road-vehicle noise annoyance. However, the method needs to be improved for accurate simulation of low velocities (below 40 km/h). The tonal components from the traction and particularly the exhaust are now implemented and tested. Implementing tonal components will also help with the appropriate simulation of heavy vehicles, where the low frequency tonal components are of highest importance. Further verification is planned, which will verify the method also with different traffic flow noise scenarios.

References

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