

Interior vehicle sound composition: Wind noise perception

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Introduction

Interior vehicle sound is composed of three major components: powertrain, road&tires, and Wind noise. The role of the balance of these three components was investigated first. The main focus was then set on wind noise perception. A typical characteristics of wind noise are temporal variations caused by the outdoor and driving conditions, which are perceived as signal fluctuations. Customer perception of these fluctuations was investigated by means of listening studies and a customer forum.

Interior Vehicle Sound Composition

Interior vehicle sound is dominated by three different contributions as shown in Fig. 1 :

- Road and tires: this component mainly contributes to the low frequency part and depends on the speed, the road surface, and the tire profile;
- Powertrain: the engine creates a component which strongly depends on the driving condition and especially the load. Usually it is low-frequency centred and contains tonal components defined by the engine orders;
- Wind: this component mainly contributes to the higher frequencies and depends on speed and outdoor conditions.

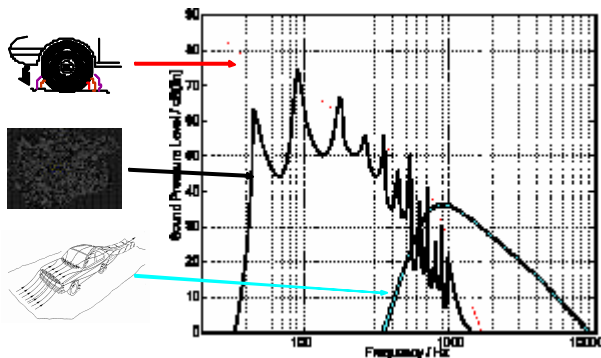


Fig. 1 Composition of interior vehicle sound

In order to compose an interior vehicle sound these three major components thus have to be „balanced“. Investigations including specialists and customers showed that a good sound is defined by the overall spectrum despite on what the actual source balance is.

In order to identify a target sound several investigations have been conducted:

- a customer questionnaire (see [1]);
- laboratory tests with customers and specialists;

- a field test with customers and specialists.

The results clearly show that sound quality is independent on the sound timbre: a good sound can be created with both, low and medium timbre. Actually customers form two groups, one clearly preferring low frequency sounds, the other preferring higher sounds. Attributes associated to the two sound characters are:

- low: power, strength, aggressiveness;
- higher: ease, elegance, lightness;

Especially for long distance drives the low frequency sound can change its positive impression into an annoying one, while the higher one is less obtrusive. But, in general a good higher sound is harder to create, since it can easily turn into a sharp impression and error states are much better audible.

In this context it has to be considered that the sound has to fit to other characteristics of the vehicle:

- the seating position;
- the visual overview;
- the handling etc..

As a consequence of these findings, wind noise is not undesired by definition and is not subject to be reduced as much as possible. On the contrary it can be used to balance the interior sound and to define a brand sound which is not low-frequency centred.

Wind noise

Wind noise offers the following characteristics:

- the basic character is that of a coloured high frequency noise (tonal components represent error states and should be avoided). The level and spectral range are defined by the vehicle form and the door and window sealing mainly;
- the strength is directly related to the resulting speed, it can thus be used as a speed indicator for the driver;
- outdoor wind characteristics (gust, e.g., trees locally changing the wind speed etc.) result in specific temporal fluctuations. The wind component thus establishes or maintains the contact to the exterior conditions.

The first two points can well be investigated in wind tunnels, where the vehicle is positioned in a stream of defined wind speed and direction of wind incidence. But, the latter point can not be investigated realistically there. On the other hand these tests can't be performed on the street. Here the drawback is that the outdoor conditions can not be controlled and

are not reproducible at all. A comparison of two different vehicles or vehicle status thus is difficult.

One major aim of the investigations presented here was to understand how customers perceive these fluctuations and how they are related to the interior vehicle sound quality.

In order to do so perceptual tests with both, customers and specialists, and a customer forum to verify the results have been conducted.

Wind fluctuation perception

In order to compare the effect of wind fluctuations for different vehicles a wind synthesis tool was developed. This tool allows to simulate fluctuations in a realistic but reproducible manner and is controlled by a set of parameters. The input signal is an interior vehicle recording, here we used real street recordings from a windless day. The resulting tool was verified by a group of NVH wind specialists.

Perceptual tests have been performed with the following specifications:

- Vehicle base sounds:
 - three different middle class vehicles
- Environmental conditions:
 - no, medium, strong wind
- Driving speeds:
 - 100, 130, 160 kph
- Attributes:
 - ranking
 - rating (9-point scale: -5 =“too less”, 0=“just right“, 5=“too much” fluctuations)
 - acceptance threshold
- Subjects:
 - 27 Ford employees (12 NVH, 15 non-experts)
 - 13 customers

The tests were implemented on a PC and performed in a sound-proofed chamber using calibrated headphone representation. The outdoor wind condition was illustrated by an animated video. The different parameters (vehicle, environmental condition, speed) were tested in separate runs in order to study reproducibility and context effects.

Fig. 2 shows the results for the comparison of the three different vehicles.

All curves derived (also for outdoor condition and driving speed) show this same principal behavior: on average subjects rate the condition without fluctuations as being with too less fluctuations. The rating “just right“ is given for slight but audible fluctuations.

A closer look to the data shows that subjects form two groups: one preferring no fluctuations, and the other preferring slight fluctuations. This grouping is independent from the experience of subjects (no specialists - non-specialists effect).

As expected the outdoor condition influences the rating: for strong exterior wind more fluctuations are tolerated than for no exterior wind. Also the vehicle base sound has an influ-

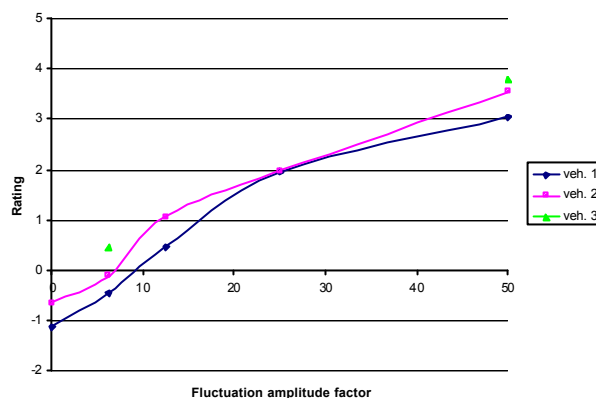


Fig. 2 Rating of fluctuation perception for three different vehicles. The fluctuation amplitude factor represents one major parameter of the wind synthesis tool and describes the strength of the fluctuations (0=no fluctuations, 50=strong fluctuations)

ence. A vehicle with a lower wind contribution to the interior sound also is less effected by fluctuations. The acceptance threshold was observed at a rating of 1.

The results found in the laboratory experiment were verified with the customer group in a customer forum. Here presentations, group discussions and small experiments are combined in an informal meeting. The customers have been selected from intensive customer questionnaire returns in order to cover different soziodemographic aspects. One test run was repeated here, and the results shows a high correlation of 0.98 to those of the Ford subject group. The ratings of customers and experts thus agree well.

Summary

Wind noise can be used to define a brand target interior vehicle sound. Its characteristics allow to create a light, comfortable and „easy“ sound which on one hand gives some contact to the exterior condition and on the other hand serves as a unobtrusive speed indicator.

Important in this context are wind fluctuations, which can not directly be evaluated and optimized in the wind tunnel. The investigations showed that:

- the outdoor condition influences the rating;
- the vehicle base sound influences the rating;
- subjects form two subject groups:
 - no fluctuations preferred
 - slight fluctuations preferred
- on average subjects prefer fluctuations compared to no fluctuations.

Literature

[1] Bodden, M.; Heinrichs, R.: Geräuschqualität im Kontext weiterer Fahrzeugattribute: Bewertung durch Kunden in Feld und Labor (in german). Proc. Daga 2003,