

INTER-NOISE 2006

3-6 DECEMBER 2006
HONOLULU, HAWAII, USA

New Approach for the Development of Vehicle Target Sounds

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ABSTRACT

Today, vehicle interior noise is an essential evaluation criterion for drivers. The task of acoustic engineers used to consist of identifying and eliminating disturbing noise components of vehicle noise; in other words, of carrying out troubleshooting. However, this reactive procedure is not sufficient anymore to meet the customers' demands and to remain competitive. In fact, vehicle sound must be deliberately designed, which means that in order to create driving pleasure certain noise aspects have to be emphasized and others must be reduced. In this respect, the acoustic engineer's task is extended to design-engineering and to the exploration of preferred sounds which lead to the customers' contentment. Furthermore, sound simulation of new engines or even whole vehicle models at early stages of the development phase becomes more and more important. For example, different engine mounts are built virtually in and their effects on the interior sound can be examined without expensive iteration loops on the basis of physical prototypes.

This paper presents new opportunities with respect to procedures and tools for sound design and target sound development. Particularly, a new subject-centered method - Explorative Vehicle Evaluation (EVE) - for the determination of target sounds is introduced.

1 INTRODUCTION

The vehicle variety has continuously been increasing and the customers' expectations have been growing persistently at the same time. By means of intensified R&D activities automobile manufacturers try to meet the increasing requirements with respect to quality and comfort. Increasingly, emotional, affective criteria replace the previous objective, pragmatic demands. The satisfaction of the demands by the customers concerning comfort, driving pleasure, design appears imperative and "dry" functionality criteria take a back seat.

Drivers do not only drive their car to reach a certain destination, they experience the vehicle with their different senses. The car industry has been recognizing this shift of demands and has reacted by advertising their products with emotion-related slogans and motifs including new catchwords like passion, thrill, exciting, and desire.

The experience of the vehicle sound is increasingly an important factor, which significantly influences the driver's contentment. This aspect is covered by the NVH section of the car manufacturers. The NVH quality of vehicles has been a very vital task for acoustic engineers for more than 20 years. However, up to now they have not been developing target sounds, but have

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rather only been working on “symptoms”. Of course, the process of troubleshooting and the elimination of disturbing noise components is indispensable. However, does the avoidance of unwanted noise phenomena mean that the remaining sound is adequate and ideal for the respective vehicle?

2 THE TARGET SOUND

A customer-oriented, client-specific target sound regards the expectations of the target customers and will thus achieve acceptance.

In order to achieve this goal potential clients with their specific demands must be analyzed and integrated into the development process. Conventional marketing research tools collect respective information but the gained knowledge is often too non-specific for the development of a vehicle sound which is adapted exactly to the clients’ demands regarding specific sound characteristics, a well-balanced configuration of the engine orders, characteristic resonances, adequate turn signal noise, etc. Those specific data with respect to required noise characteristics must be determined with the help of listening tests considering vehicle class, image, interior and exterior design, target customers, performance of the vehicle and other aspects.

In order to be able to ascertain the mentioned necessary characteristics of the vehicle sound for a new vehicle, the application of driving simulators is important. With the help of such simulators new vehicles can be virtually experienced before the first prototypes, which are very cost-intensive, are actually built.

Altogether, the integration of target sound specifications into development processes leads to the improvement of product quality at early stages, and finally results in a significant enhancement of the product acceptance by customers. Furthermore, it leads to an increase of brand loyalty when the product is replaced. [1]

3 HOW TO GET THERE? – AN EXPLORATIVE EVALUATION METHOD

Listening tests with various test designs are carried out in order to collect data about subjective evaluations of predefined stimuli. For the reproducibility of the test results and analyses reasons tests are often completely standardized and are conducted in a “controlled” test surrounding. These test conditions should allow the provable statistical correlation between subjective ratings and objective parameters. However, the abstraction of the test situation, the stimulus representation taken out of the typical context, and the response limitation (pressing complex sensations into given scales) leads to biased results, which often cannot be generalized and confirmed in reality. Further aspects moderate the subject’s perception and evaluation of (noise) stimuli, for instance context, ambiance, interactivity, occurrence of several sensory inputs at the same time (combined stimuli), which should be considered as well.

In particular, the evaluation of vehicle noise depends on several features besides the noise itself. The evaluation of the sound quality, for instance, of the vehicle is based on the resulting vibro-acoustic exposure. In case those additional factors are neglected, tests will provide artificial, biased results. For example, several studies have revealed that vibrations considerably influence perceived sound quality. [2]

Inadequate vibrations which influence evaluations subliminally will lead to decreased sound quality assessments. Furthermore, context, ambiance and interactivity are also meaningful factors into which sound evaluations are usually embedded.

Because of the presented reasons, the development and application of new types of listening tests for the analysis of reality-relevant aspects seems imperative.

In connection with target sound development, the method EVE (Explorative Vehicle Evaluation) was developed and applied. Based on the open, but still laboratory-oriented method AISP (Exploration of Associative Imagination on Sound Perception) [3], which was applied in the EU-research project OBELICS, the new method is designed to be conducted in test surroundings which are close to reality and to operate with spontaneous associations, feelings and noise evaluations of the test persons.

The method takes into account the context in which evaluations of vehicle sounds are usually carried out, the interactivity, which occurs between the driver and the vehicle in common driving situations, the spontaneity of evaluations in real drive situations and the experiences of the test individuals. EVE considers the evaluation process. (figure 1).

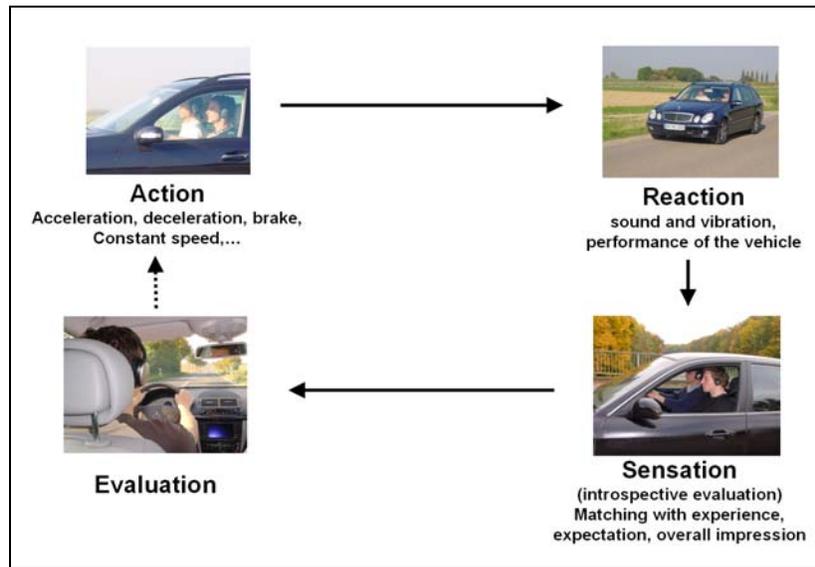


Figure 1: Process of evaluation in everyday life

The process of experiencing and evaluating vehicle sounds is transferred to a driving vehicle. Because of the authentic test situation which maintains the authenticity and genuineness of the situation, the test person can disengage from the test circumstances. Another advantage is that the test persons create their own stimuli, act on their own initiative to evaluate the perceived sounds and can explain their feelings and judgments in an open and free way as they are not compelled to give forced answers according to predefined quantities and scales.

Therefore, the evaluation of sound events takes place interactively and is modified by its significance in and for the ambient space. Furthermore, by means of the EVE method only perceptually-relevant noise events based on verbalized associations and sensations are identified and analyzed further in detail with respect to an ideal and preferred vehicle vibro-acoustic setting. A summary of essential EVE features is depicted in table 1.

Table 1: EVE-features and advantages

EVE Feature	Means	Advantage
Test in most authentic test surrounding	Sound Simulation System turns usual vehicle into a NVH driving simulator	Target sound development considering the impact of vehicle's specific ambiance on sound perception (with its appearance, haptics, ergonomics, etc)
Reflection of interactivity processes	Sound Simulation System simulates vehicle noise in dependence of the test person's actions	Evaluation of only self-stimulated stimuli
Test persons explain their evaluations with their own vocabulary	Qualitative analysis method allows the systematic analysis of comments and evaluations	Increased explanatory power of the test results because of the open test design (no restricting hypotheses and predefined scales)
Context-sensitivity	Test persons drive the test vehicle according to their accustomed manner in a most possible authentic situation	Test persons evaluate reliably familiar driving conditions which are close to reality
Examination of only perceptually-relevant noise phenomena	Test persons decide about time and number of given evaluations; no forced answers	Target-oriented acoustical analysis
External validity	Realistic test situation and the familiar form of verbalization leads to most reliable data	Specific test design allows generalization of test results (in case of adequate sample)
Deepening of relevant phenomena	Following semi-standardized interview allows detailed examination of evaluations	The process of communicative validity enhances the reliability of results

4 A MOBILE SOUND SIMULATION SYSTEM FOR TARGET SOUND DEVELOPMENT

A human being does not evaluate stimuli on the basis of a single dimension. In fact, it is rather a question of the interaction between the various levels of perception. In this field, developments in the area of „virtual reality“, adapted to special requirements of sound and vibration design, make a meaningful contribution.

The Sound Simulation System allows the examination of different sound stimuli. The evaluated sound events are recorded in an aurally-accurate way. By means of complex synthesis algorithms the sound simulation system permanently provides vehicle interior noise corresponding to the actual driving condition. The data base results from real measurements, in which the different noise contributions which result in the overall vehicle interior noise at the driver's seat are measured and calculated. Based on the measured data the sound simulation system can reproduce any vehicle sound in a given test vehicle.

The single contributions – engine sound dependent on speed, load and rpm, the tire and wind noise dependent on speed – is provided in real-time The vehicle sound which is adjusted to the monitored control parameters is played back via headphones. Moreover, besides the simulation of engine, wind and tire noise in general, a more detailed simulation is possible. The sound

simulation system in connection with the BTPA and BTPS technique (Binaural Transfer Path Analysis and Synthesis) allows the simulation of specific sound sources and transfer paths, which can be examined separately with respect to their contribution to noise evaluation. [5] Tests have shown that test persons often forget about the fact that they wear headphones because of the authentic driving situation with appropriate noise playback. Therefore, the comments and evaluations are expected as highly reliable and valid. The separation of the different “sound sources” allows a detailed consideration of certain contributions to the perceived sound quality.

The difference of a sound simulation system installed in a real vehicle compared to well-known laboratory sound design tools is that all sound perception effects are occurring within a very realistic context, a drivable “virtual” vehicle. [6]

The development from laboratory experiments to field experiments is illustrated in figure 2.



Figure 2: Different test scenarios; left: “laboratory”, stationary driving simulator, mobile driving simulator

Moreover, the advantage of a mobile sound simulation is that a perfect driving and dynamic model and an authentic vibrational setting are given by applying a real vehicle. However, these features are fixed and cannot be changed in order to study the influence of these parameters on the evaluations in detail. By contrast, a stationary sound simulation allows the control of the vibrational stimulus for instance, but the authenticity of the driving situation is reduced. With respect to the object of investigation the necessary test environment has to be selected. The determination of a vehicle’s target sound requires the most realistic test environment and thus, the application of the mobile version is imperative. [7]

5 EXPLORATIVE VEHICLE EVALUATION

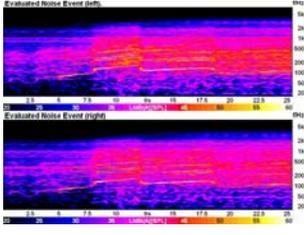
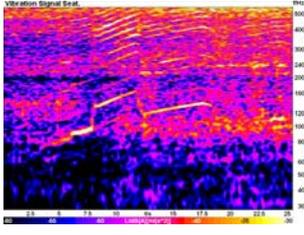
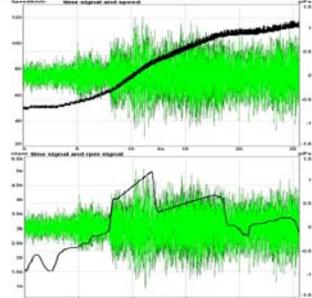
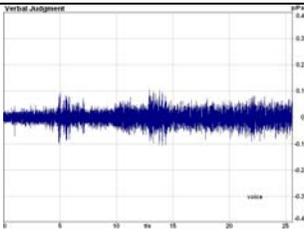
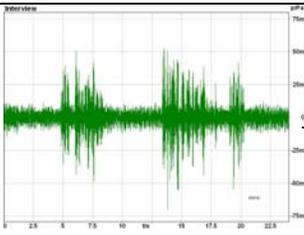
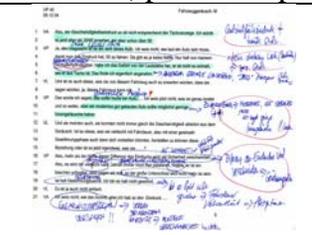
5.1 Short Description of the Test Design

After passing the suitability test with respect to hearing ability and target customers specifics, the test person obtains detailed instructions for the test and is given time to familiarize with the test vehicle, to adjust steering wheel, seat position, mirrors, etc. This guarantees that the test person can drive the test vehicle without paying too much attention to the driving procedure itself. The test persons are requested to drive in their accustomed manner.

During the test drive the test person reports all present associations, feelings, emotions, impressions and ideas concerning the driving situation, the sound of the vehicle or the vehicle itself. Therefore, the evaluations are verbal reactions according to self-stimulated stimuli. The verbal evaluations, the respective noise and vibrations signals as well as specific pulse data (speed, rpm) are recorded and constitute the data pool for the analysis (table 2). A pre-trigger is applied which makes it possible to record the complete statements and accordingly the corresponding data about the driving situations which the comments refer to. Moreover, the instructor notes down assumed important observations as for example about certain events, gestures, emotions or behavior of the driver. This data can also be used for analysis.

For the purpose of verifying the articulated comments and collecting further significant data for the creation of the target sound, evaluations and corresponding noise events are played-back and discussed in a subsequent interview. The interview is conducted in the vehicle with the aim of supporting the test person's memory. The different remarks are presented and the instructor requests the test person to describe and explain his or her comments in detail. By means of this detailed inquiry the instructor can explore the emotional, social, psychological and contextual parameters of the sound evaluation process and can scrutinize the background of the embedded decision process of the acceptance or rejection of a certain sound in a specific driving situation. This part of the interview is known as communicative validity in qualitative research.

Table 2: Data base

<p>Acoustical Data</p>	 <p>Noise event (binaural)</p>	 <p>Vibration signals</p>	 <p>Pulse data (speed and rpm)</p>
<p>Evaluation Data</p>	 <p>Free verbal remarks with respect to noise event</p>	 <p>Interview</p>	 <p>Transcription and text analysis</p>

5.2 The Process of Target Sound Development

The analysis of the comments with a qualitative analysis technique (e.g. Grounded Theory) gives insights into the perception and evaluation of vehicle sounds. Detected phenomena are coded with general notations in the analysis stage of open coding. The purpose behind the analysis is to group similar events, sensations, reactions under a common heading or classification as well as to discover intersubjective evaluation patterns. However, the analyzing person does not interpret the material; instead he or she only enhances the level of abstraction to improve the generalization, accordingly, his or her task consists of conceptualization instead of description. [8]

Thus, the Grounded Theory is not only an exploratory tool for a quantitative study, but it rather permits the development of a theory and the identification of relevant moderators for perception. [9]

Based on the results, information concerning the character and features of a preferred vehicle sound are derived. On the basis of the first EVE-tests a vehicle sound is developed considering

the different remarks and comments, customer's preferences, the acoustical analyses and the generated theory. The theory provides information about general expectations, preferred overall character of the vehicle noise or certain acoustical properties, for instance, which will contribute positively to an accepted vehicle sound. The conclusions result in a modified vehicle sound, which is subsequently implemented in the mobile sound simulation system. This procedure is schematically depicted in figure 3.

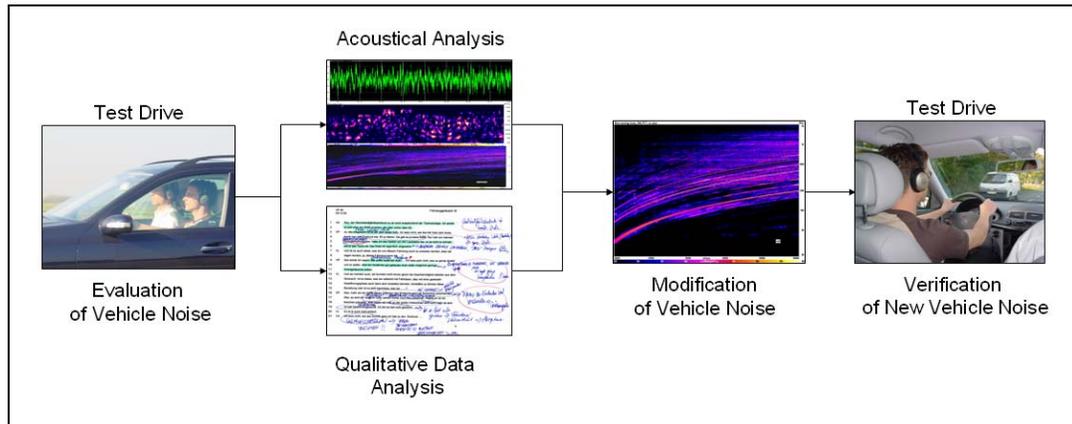


Figure 3: Important Steps of EVE

The new vehicle sound has to be evaluated again with the help of further EVE tests until the developed sound is verified and affirmed by the test persons. Only in case of complete affirmation of the new sound in further tests, the applicability of the developed vehicle sound with regard to the vehicle and the target group can be guaranteed. This implies that the created vehicle sound is not only unobjected, but rather leads to a high level of contentment and driving pleasure.

The iterative, circular process of developing the target sound allows the unerring determination of the vehicle's target sound and an almost unlimited fine tuning depending on the target specification. The number of iterative loops is not fixed and depends on the stepwise progress of the target sound development and the "exit condition".

The iterative process of target sound development is displayed in figure 4 and figure 5.

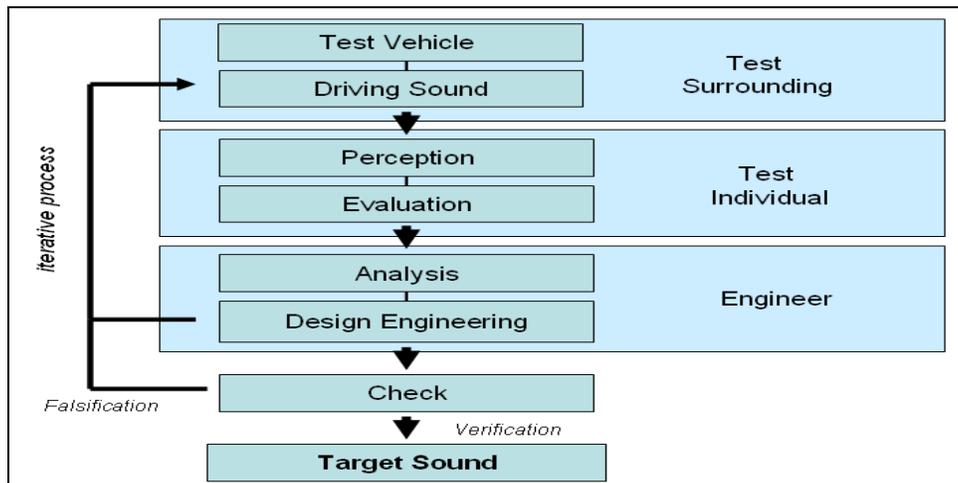


Figure 4: Levels of target sound development

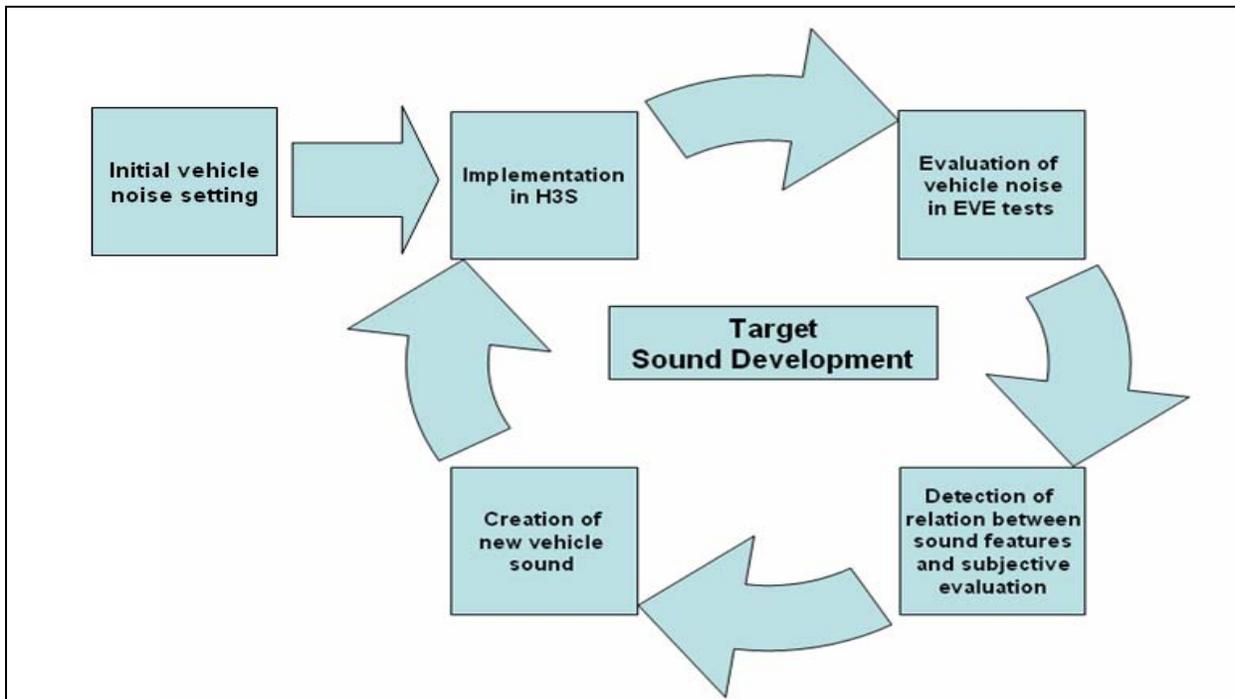


Figure 5: Process of target sound development

Furthermore, the presented mobile sound simulation system offers the opportunity of modifying the vehicles sound in real-time. With respect to the object of investigation an extension of the EVE-method is conceivable. The co-driver (investigator) can modify the vehicle sound (figure 6) online, while the test person is driving, in order to examine the influence of specific acoustical parameters on the evaluations. By means of different filter techniques (e.g. rpm-dependent filters) the investigator can change certain characteristics of the vehicle sound interactively in order to study the impact of these changes on the assessments and the perceived sound quality.

The modification of the vehicle’s soundscape during the test drive for an interactive sound design should not be carried out with naïve test persons because of the reduced authenticity of the situation which will have an influence on the evaluation behavior.



Figure 6: Investigator with simulation control unit

6 CONCLUSIONS

Sound and vibration must not be only considered as disturbing elements regarding the NVH-comfort; they can be used to develop an acoustical and vibrational environment which influences the customer's contentment positively. The creation of sounds which give the impression of high product quality helps manufacturers to stand out against their competitors and to meet the increasing demands of the customers. Sound quality considerations and target sound development require multi-dimensional approaches integrating new and interdisciplinary methods. The presented approach in connection with a sound simulation system installed in a drivable vehicle allows the determination of target sounds.

The advantages of EVE approach in connection with the mobile sound simulation system are

- Development of the most marketable products
- Fast implementation and efficient testing of new sounds with respect to the vehicle's target sound
- Target sound development based on the most convincing evaluation data
- Easy verification of new products with respect to the readiness for market, even for non-acoustic aspects.

The test design of EVE is flexible; the procedure of free evaluations of vehicle noise while the test person is driving can be extended to benchmarking tests and interactive sound design. The implication of such test design extensions have to be studied elaborately in order to avoid bias effects and artefacts caused by new test designs.

Furthermore, the sample has to be selected carefully with respect to the intended target group in order to guarantee the external validity and the possibility of generalizing the test results. EVE in connection with the presented mobile driving simulator reliably guarantees the determination of target sounds with high external validity because of the authentic test environment and test situation.

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