Door Operating Sound Improvement based on Jury Testing and System Analysis

Philipp Sellerbeck, Christian Nettelbeck

HEAD acoustics GmbH, 52134 Herzogenrath, Germany, Email: phillip.sellerbeck@head-acoustics.de

Introduction

Door opening and closure sounds are an important factor influencing the quality impression received from a vehicle. These sounds are often the first ones a customer hears when examining a car in a showroom or exhibition. Therefore car manufacturers attach increasing importance to door sound design. Even in the luxury car segment, large differences between door sounds are observed. But how should a good car door sound like? And, even more challenging, how to make its sound good? In this paper, methods and technologies are summarized that can help answer these questions.

Jury listening tests

Jury tests are a common method for sound evaluation, and a number of analysis methods exist for post-processing of the collected data. Usually, for several reasons, these tests are based on playback of pre-recorded sounds. However, a listener's rating of a sound is influenced by many factors. These can be either inherent in the recording (e.g. recording technique), the test environment (e.g. ambient noise, décor) or depend on the subjects themselves (e.g. personal attitude) [1]. Proper attention should be paid to adequate recording and playback of the sounds. For the described tests, binaural recording using artificial head and playback via headphones have been employed in order to achieve realistic perception. Additionally, door sounds recorded in an anechoic environment have been filtered using a room impulse response function of a typical vehicle showroom.

For door noise recording, parameters such as operating force and speed may influence the sound and have to be controlled during recording. Door closure sound is basically dependent on the closure speed (measured right before latch contact) whereas opening sound turns out to depend on peak force applied to the handle. Further studies using a number of persons opening and closing different car doors revealed that each door or car model shows typical ranges of opening force **(Figure 1)** and closure speed. Thus, when recording door sounds for a jury test, these typical parameters have to be maintained for each door individually.

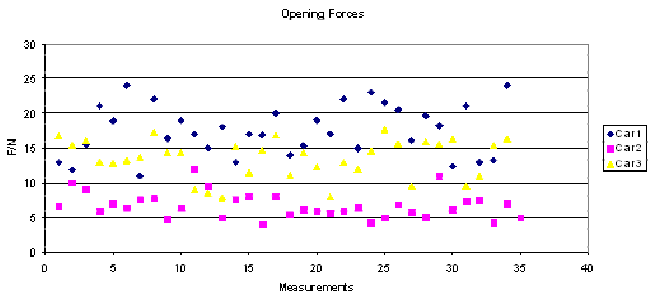

Figure 1: Opening force distribution of three different car doors

With door noise jury tests, two main objectives have been pursued:

- door sound benchmarking (e.g. comparison with competitors)
- deriving attributes for target sounds (characteristics used for sound design)

Benchmarking

In a jury listening test containing door opening and closure sounds of 9 cars, five attributes have been evaluated on a 1 to 7 scale **(Figure 2)**. As the almost concentric plots show, the attributes are strongly correlated. Thus an overall ranking of the sounds is possible.

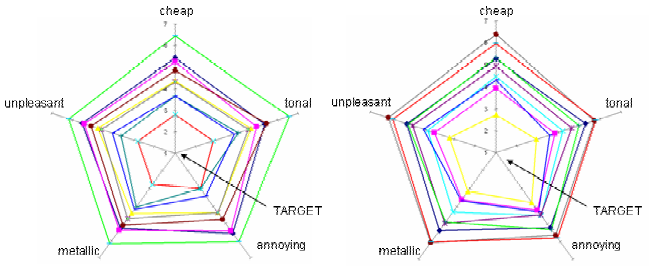

Figure 2: Jury test results of opening sounds (left) and closure sounds (right)

The center of the plots, indicating the positive end (best sound quality) of each attributes scale, can be referred to as an ideal target.

Target sound attributes

Based on an appropriate jury benchmark test, attributes of a so called target sound can be defined. As no ideal target sounds exist, the sounds rated best in the benchmark have been used as targets. The following attributes could be derived:

- predominantly low frequency content (below 200 Hz)
- decreasing level from low to high frequencies
- no prominent tonal components
- compact time structure (no multiple click)

Psychoacoustic Analysis

Due to the transient nature and complexity of door sounds, most standard measurements like level or loudness are not sufficient. Several acoustic and psychoacoustic analyses have been tested in order to measure the above characteristics and to detect annoying noise patterns. The ones that turned out to be most useful include the wavelet spectrogram, the specific loudness and the Relative Approach. A high correlation between the results of these analyses and the outcome of the jury tests could be observed.

Figure 3 shows an example of how unwanted noise patterns can be detected by specific loudness analysis.

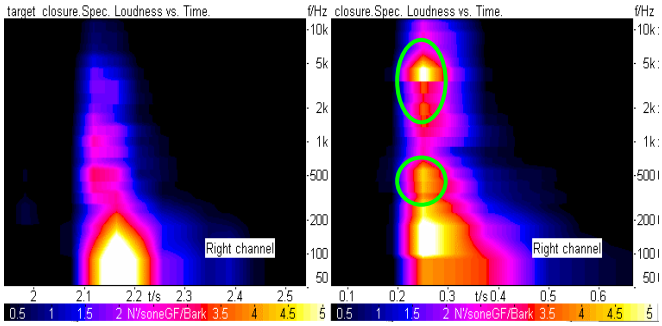

Figure 3: Specific loudness analysis of recorded door closure sounds, left: target from benchmark, right: competitor showing unwanted tonal and high-frequency noise patterns.

Transfer Path Analysis

In order to find the origins of unwanted noise patterns and to help improve existing door operating sounds, transfer path analysis and simulation can be applied. Existing methods turned out to be insufficient as they presume time-invariant systems. But during door opening or closure, noise transfer functions change rapidly due to seals compression, latch interaction and other mechanisms. Therefore, a new simulation procedure has been developed that makes use of a time-variant transfer path model.

All relevant noise transfer functions are measured at suitable locations, e.g. the latch and the striker, whereas structural vibration is considered as well as direct airborne radiation. Binaural recording technology is used throughout. In order to capture the variant system behaviour, these measurements have to be done at a number of door positions from fully opened to fully closed. Due to space requirements at the measurement locations, transfer functions are measured reciprocally using a binaural sound source [2].

In a second step sound pressure and vibration signals are recorded at the same locations as above. Closure speed and opening force are kept constant by a suitable set-up. These input signals are filtered by the corresponding binaural transfer functions. The results are then summed up to deliver a synthetic door operating noise. In order to achieve a realistic closure simulation, the binaurally recorded closure noise with removed latch (containing basically the seals slap and cavity boom) is added. A more detailed description of the method can be found in [3]. **Figure 4** shows an example of a simulated door opening sound compared to the original recording.

As all calculations are based on time data, all path results (or combinations of paths) can be listened to individually. Door sound components originating from the latch mechanism, striker impact, seals interaction and cavity boom can be auralized revealing the origins of unwanted noise patterns. Of course the signal analyses mentioned above can also be applied. **Figure 5** shows how two annoying noises patterns (high frequency click and tonal ring sound) can be assigned to different transfer paths.

By modifying the transfer path model it is possible to change the simulated sound and therefore predict the impact of physical modifications, e.g. additional damping, on the sound quality. Costly and time-consuming experiments can be avoided and mechanic changes are applied only after the simulation predicts positive effect, i.e. improvement of the door sound with respect to the target.

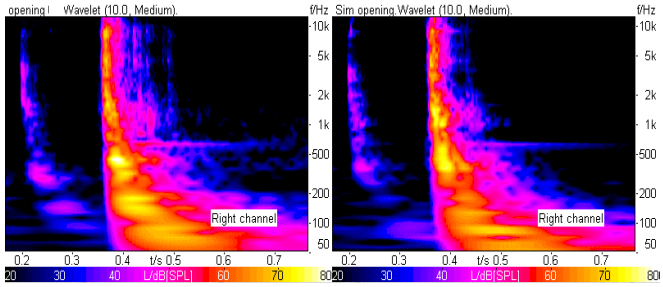

Figure 4: Wavelet spectrogram of recorded (left) and simulated (right) door opening sound

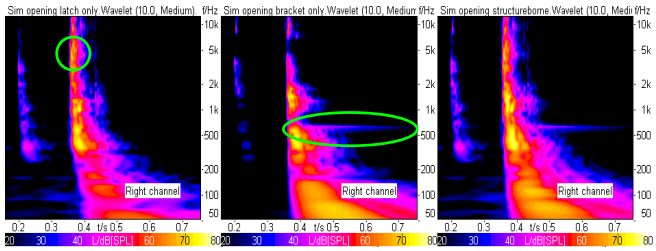

Figure 5: Simulated noise contributions from latch mechanism (left), striker impact (middle) compared to the total (right)

In the given example, additional damping of the latch mount and a different striker material have lead to a significant improvement of door opening and closure sound quality (**Figure 6**).

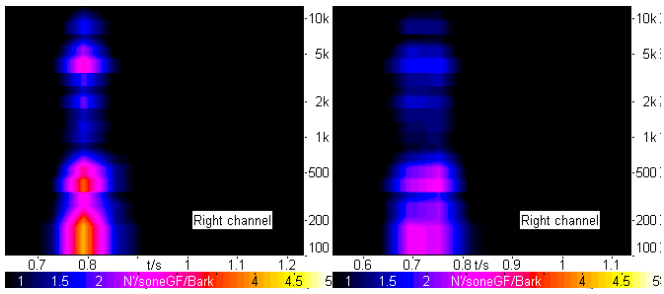

Figure 6: Specific loudness analysis of recorded door opening sound before (left) and after (right) modification

References

[1] N. Otto, S. Amman, C. Eaton, S- Lake: Guidelines for Jury Evaluations of Automotive Sounds. Sound and Vibration, 2001

[2] P. Sellerbeck, M. Klemenz, R. Sottek: Ein binauraler Schallsender zur reziproken Transferpfadanalyse. DAGA 2003

[3] P. Sellerbeck, R. Stanley, S. Young: Binaural Transfer Path Analysis and Simulation for Door Opening/Closure Sound Improvement. Submitted to Inter-Noise 2004