

Door Closing Sound Quality Methodology - Airborne and Structural Path Contributions

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ABSTRACT

The intent of this paper is to document comprehensive test-based approach to analyze the door-closing event and associated sound using structural and acoustic loads developed during the event. This study looks into the door-closing phenomenon from the structural interaction point of view between the door and the body of the vehicle. The study primarily focuses on distributing the door and body interaction as discrete multiple structural and acoustic phenomena. It also emphasizes on the structural and acoustic loads developed by the discretized interactions at the interfaces between the door and the body frame. These interfaces were treated to be the load paths from the door to the body. The equivalent structural and acoustic loads were calculated indirectly using the well-known Transfer Path Analysis (TPA) methodology for structural loads and the Acoustic Source Quantification (ASQ) methodology for acoustic loads. Considering the transient nature of the door-closing event, a time domain TPA methodology was also developed to study the loads being developed between the latch, the striker and the different interfaces of the door frame to the body structure. Similarly the equivalent acoustic loads were developed at the interfaces between the door frame and the body. Computed time domain and frequency domain loads were used to perform a partial contribution analysis from different paths and identify the contribution of the structural and acoustic loads and paths on the target response at the center of the operator's ear (COE) located the outside of the vehicle.

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INTRODUCTION

A typical vehicle door can be divided into several major subsystems. Each subsystem is also made of several other components. The door frame is usually composed of the outer and inner panels and the safety intrusion beam for side impact protection. Others include the arm rest, the trim panel, door mechanism, window system, hinges, power system, mirror system, door switches, speaker system and the function carrier module. All of these components have impact on the overall door NVH characteristics during the door closing event. The sound created by closing the door is a function of the physical characteristics of the door panel stiffness, mass distribution of the door, the design of weather strips, the local and global stiffness of the body including the A, B and hinge pillars, the upper rail, the dogleg and the C pillar and the rate of pressure built up inside the vehicle cavity. It also depends on the speed at which the slamming of the door occurs. Every one of these attributes requires a comprehensive investigation and analysis which are beyond the scope of this paper.

The door-closing event is a short duration transient phenomenon. Different segments of the door come in contact with the body as a function of time. [Figure 1](#) shows this time dependency.

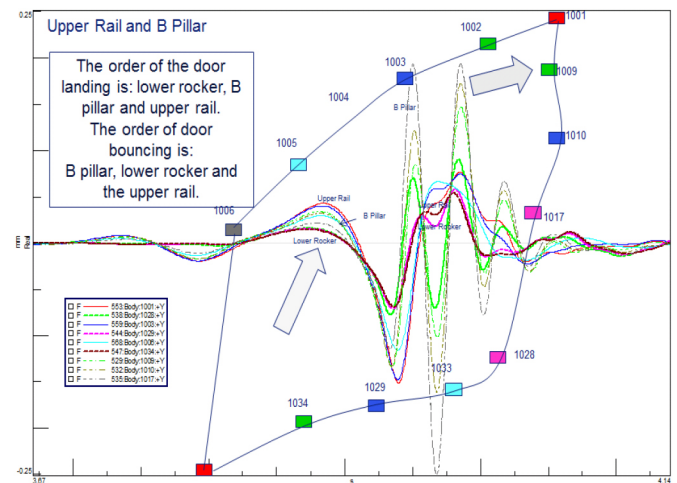


Figure 1. Landing Door as Function of the Door Slam Event

There are multiple short events which occur during the door-closing and each event generates mechanical impacts to cause transient noises. So the door-closing sound is actually a collection of the mechanical impact noises. See [Figure 2](#). Considering this fact, a time-based load identification approach was incorporated in conjunction with the frequency domain load calculations.

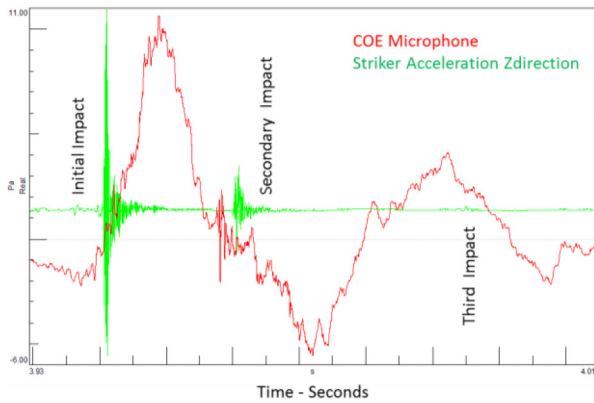


Figure 2. The Door-Closing Sound Collection of Mechanical Impact Noises

The filtering study of the door-closing event indicates the contribution of different events in specific frequency ranges. Figure 3 describes the acceleration response of the door-closing up to 30 Hz. As shown in this figure, the door impact generates a vehicle rocking up to 5 to 30 Hz. Figure 4 also demonstrates the body frame interaction (flexible modes of body, door, panels) up to 200Hz. Finally figure 5 shows the interaction of the door latch to the striker which occurs between 150 to 2000Hz. Figure 6 shows the collection of Figures 2, 3 4 and 5 describing the low frequency rocking, mid band frame flexural motion, and the striker and the latch mechanical engagement during the door closing event.

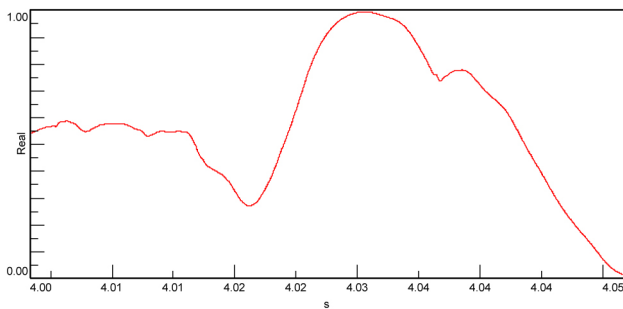


Figure 3. Accelerometer Located on Striker Z-Direction Filtered up to 30Hz

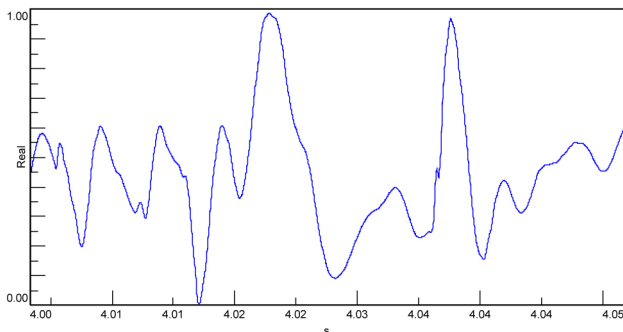


Figure 4. Accelerometer Located on Striker Z-Direction Filtered 30 to 200Hz

The corresponding sound pressure due to the door closing event Filtered up to 30Hz, 30 to 200Hz and the 150 to 2000Hz are provided in Figure 7.

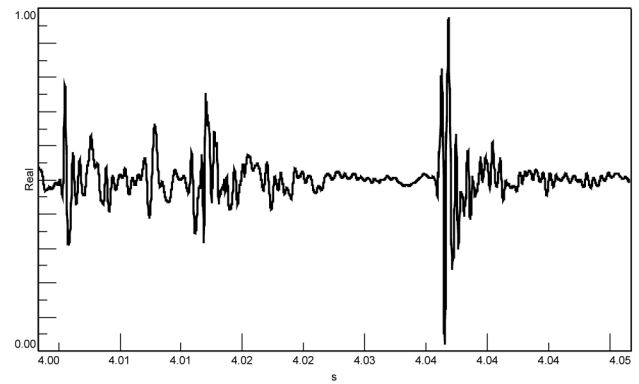


Figure 5. Accelerometer Located on Striker Z-Direction Filtered 150 to 2000Hz

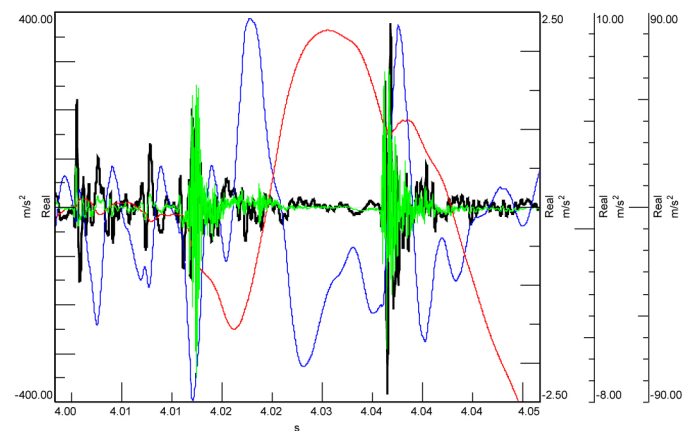


Figure 6. Striker & COE Low, Mid Band and High Frequency Events

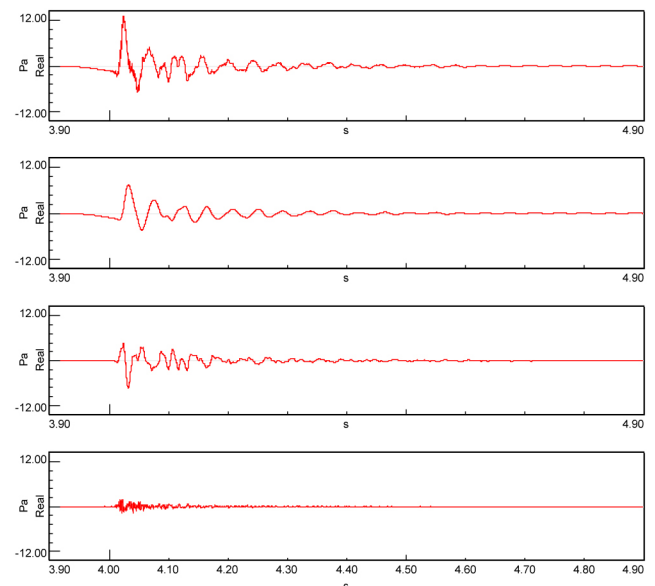


Figure 7. Filtered Sound Pressure COE - Door-Closing Low, Mid Band and High Frequency Events

It is important to study the door-closing event both in time and frequency domain. The time domain provides which event is important in door-closing while the frequency domain analysis shares some insights of the dynamic behavior of the door and the body side response during the door-closing event. The information obtained from the time and the frequency analysis can also link the door closing event to the door and the body design requirements.

This paper focuses on identifying both the structural and airborne transmission path of the energy developed during the door closing phenomenon. The goal is to understand the forces developed between the door and the body structure. The body structure includes the upper rail, A and B pillars, lower rocker and the hinge pillar where door is mounted. The airborne contribution of the door closing can also be represented by equivalent volume acceleration acoustic sources at the vicinity of the door and the body structure interfaces at the upper rail, the A and B pillars and the lower rocker.

EXPERIMENTAL ANALYSIS

The Transfer Path Analysis (TPA) is a method to calculate the forces developed between the door, weather strips, the vehicle body, the latch and the striker during the door-closing. During the door-closing event, the following data sets are required to compute the forces developed between the door and the body of the vehicle.

1. The operational response during the door closing event
2. The cross matrix of transfer functions between every assumed force path.

For structural forces, the transfer functions will be the (Acceleration/Force) and for the Acoustic Source Quantification (ASQ) it will be (Pressure/Volume Acceleration). Models also need transfer functions between the force path locations to target microphones. The mathematical model representations of the structural TPA as well as the acoustic source quantification are provided in Figures 8 & 9.

To build a TPA model of the door-closing event, the following measurements are required.

1. Impact hammer measurements on the door and the body for structural frequency response function (FRF).
2. Reciprocal noise transfer function using the low frequency volume velocity source between the structural path locations and the target microphone.
3. Acoustic-acoustic transfer functions between assumed acoustic source locations and all indicator microphones and target microphones using the mid frequency volume velocity source.
4. Operational measurements of the door-closing event.

As mentioned, the goal is to build TPA and ASQ models in time and frequency domain to better understand the dynamic behavior of the door closing phenomenon. These models provide the developed structural forces between the door and the body, the latch and the striker, and acoustic loads at the interface of door seal and the body

structure during the slamming event. A schematic of structural force and equivalent acoustic source representation developed during the door-closing event is described in Figures 10 and 11.

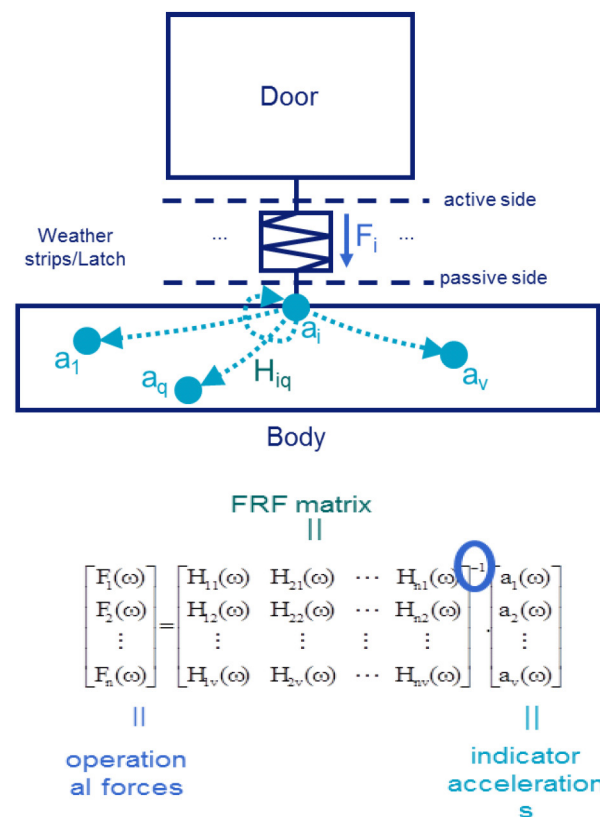


Figure 8. Mathematical Model of Structural TPA

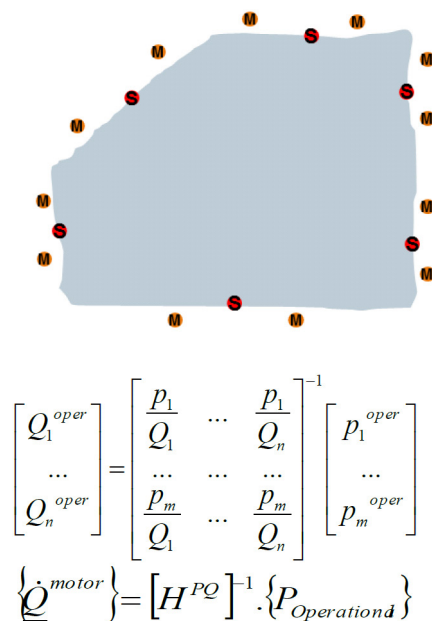


Figure 9. The acoustic source quantification (ASQ) Mathematical Model