

Body Induced Boom Noise Control by Hybrid Integrated Approach for a Passenger Car

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ABSTRACT

Vehicle incab booming perception, a low frequency response of the structure to the various excitations presents a challenging task for the NVH engineers. The excitation to the structure causing boom can either be power train induced, depending upon the number of cylinders or the road inputs, while transfer paths for the excitation is mainly through the power train mounts or the suspension attachments to the body. The body responds to those input excitations by virtue of the dynamic behavior mainly governed by its modal characteristics.

This paper explains in detail an integrated approach, of both experimental and numerical techniques devised to investigate the mechanism for boom noise generation. It is therefore important, to understand the modal behavior of the structure. The modal characteristics from the structural modal test enable to locate the natural frequencies and mode shapes of the body, which are likely to get excited due to the operating excitations. The critical transfer paths for the excitation through the structure have been identified with the help of transfer path analysis, while running mode analysis indicate the dynamic behavior of the structure due to the excitation. Similarly, the acoustic modal analysis describes the fundamental acoustic modal characteristics of the cabin cavity. The introduction of the experimental running mode inputs of the structure to the acoustic finite element model makes the hybrid analysis possible. The panel contribution analysis focuses on the components that have the significant contribution in the booming noise for in-phase as well as out of phase panels. The modifications revealed from the systematic study by hybrid approach, has led to substantial reduction in the booming noise both objectively and subjectively. This paper also describes the improvements suggested to reduce the boom noise.

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INTRODUCTION

Sound quality of a car cabin is one of the key criteria for customer comfort and is a major selling factor for present day cars. The increasing customer awareness also poses high demands on the right and pleasant sound quality perceptions [1]. With more powerful engines integrated to a lighter body, the refinement of the vehicle cabin for NVH has become a major challenge for automakers. A-segment and sub A-segment cars, the major volume makers in the car industry in developing nations are mainly designed upon cost constraints. To improve the fuel efficiency and reduce the cost, most vehicles have lighter body, posing major challenges for NVH engineers to design vehicles surpassing the customer's expectations. Boom noise is one of the key issues faced by many of the vehicle manufacturers. A boom is an objectionable low frequency auditory response in the vehicle

compartment, which can dominate the overall noise level occurring mostly due to structural excitations. The reduction in overall noise levels in the last few years has also resulted in highlighting the irritating sounds present in the spectrum.

Incab noise measured on the vehicle discussed in this paper shows a peak at 2200 to 2400 rpm range which is excited mainly by first engine order, 36 to 40 Hz. Subjective and objective data has indicated that, though the boom is present in all the gears, it is dominant and irritating in the higher gears. This can be attributed to the slow increment in the rpm at higher gears which leads to the effective transmission of energy to the radiating parts. A hybrid approach consisting of experimental and numerical methods was employed to quantify the source, transfer path and radiating surface for the booming perception inside the vehicle [1]. This systematic approach has not only helped in

understanding the root cause, but also in keeping the development cost low and reduce the overall process time. Different methods like BIW modal analysis, transfer path analysis, ranking of radiating panels etc. along with numerical analysis were employed for root cause analysis during the process. The sound synthesis has shown that a reduction by 7 to 8 dB(A) is required in the booming frequency for improving the boom noise perception.

Modifications like varying the suspension bush stiffness, secondary isolation, exhaust and cat-con design optimization etc. were tried out for improving the source and transfer path, while improvement in overall body stiffness, sections and radiating panels were also pursued for improved stiffness or better damping characteristics etc.

ROOT CAUSE ANALYSIS

Right from the design stage, design engineers pay much attention to improve the NVH performance of a car especially to the booming phenomenon. Though simulation tools are very effective in early design stages of the vehicle, it is difficult to fully represent the vibro-acoustic characteristics of the actual vehicle in a numerical model. This makes it very difficult to identify these problems perfectly in the design stage and starts creeping up at the later stages of the prototype evaluations [2]. Various methods are employed by the present day NVH engineers for the analysis of incab noise related to boom observed in the evaluation vehicle. The methods include structural modal analysis to understand the structural characteristics, acoustic modal analysis to understand the effect of cavity resonance, transfer path analysis to identify the critical transfer path of vibration, interior noise contribution analysis to understand the key airborne and structural sources for incab noise and panel contribution analysis to rank the panels as the major contributors for the booming perception [3]. Numerical validation of the data was also carried out to build an effective finite element model. Though the independent result of each method gives directive information for the problem; the information is not sufficient for complete understanding of the boom noise phenomenon. The insufficient information on the cause of booming noise may at times lead to some conclusions based on the engineering intuition. This may result in the misunderstanding of the phenomenon or the inefficient loop of trial-and-errors [4].

An objectionable boom was observed in the operating range of the prototype vehicle during the design validation phase. Subjective evaluation had indicated that though the boom is present in all the gears it's mostly audible in the third and the fourth gears (vehicle has 4+1 gear configuration) which could be attributed to the slow increment in the engine rpm, which allow the excitation of radiating surfaces. Further, at higher gears the booming rpm falls in the vehicle operating range. The baseline measurement was done at driver and rear passenger inner ear level during full load wide open throttle test. [Figure 1](#) and [figure 2](#) shows the incab noise, measured at

driver and rear passenger inner ear respectively during a wide open throttle test, which clearly indicates that the boom is due to the first order engine excitation in 36 to 40 Hz range. To clear out the obvious paths and reasons, vibration measurements were done across the mounts but, no conclusive results were obtained. Further to understand the root cause of booming perception, the hybrid approach was employed; measurements and simulations were tailored systematically to classify the system level source and noise transfer paths, on a source-path-receiver basis, to identify and develop suitable countermeasures to bring the vehicle to an acceptable level of performance suiting the vehicle category.

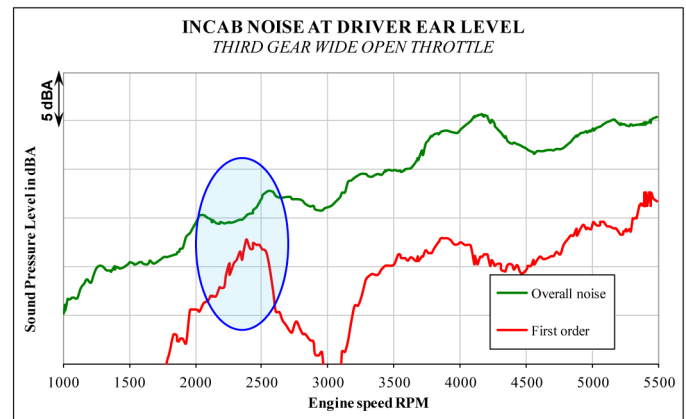


Figure 1. Incab noise at driver ear level

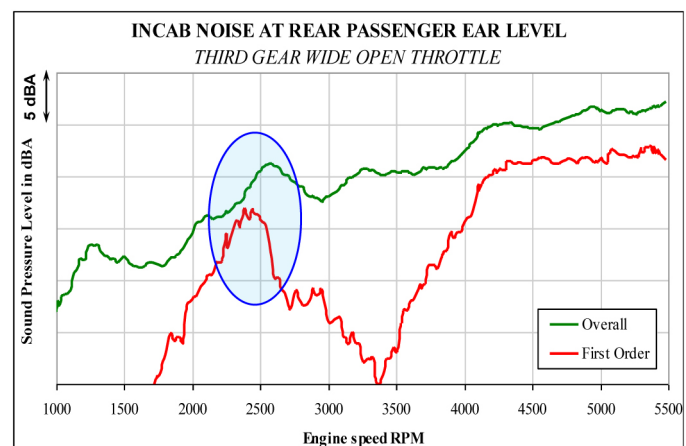


Figure 2. Incab noise at rear passenger ear level

Noise Source Identification at ENTIC

To understand the power train contribution for the boom perception inside the cabin, a power train was mounted on an engine dynamometer at ENTIC. The power train was mounted on the sub-frame similar to the way it is fitted to the vehicle with standard vehicle mounts. To ensure the right loading of the power train, ancillaries like alternator, drive assembly and air-conditioning unit were also assembled. Further the vehicle intake and exhaust systems itself were utilized during testing

(exhaust system in the vehicle under study is rigidly mounted on the power train, without de-coupler).

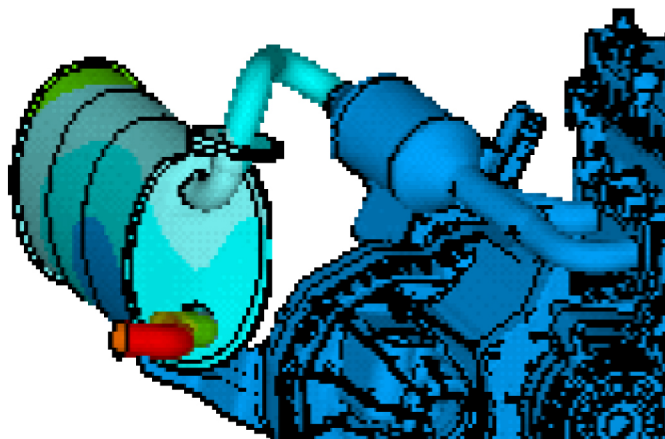


Figure 3. Exhaust system modes

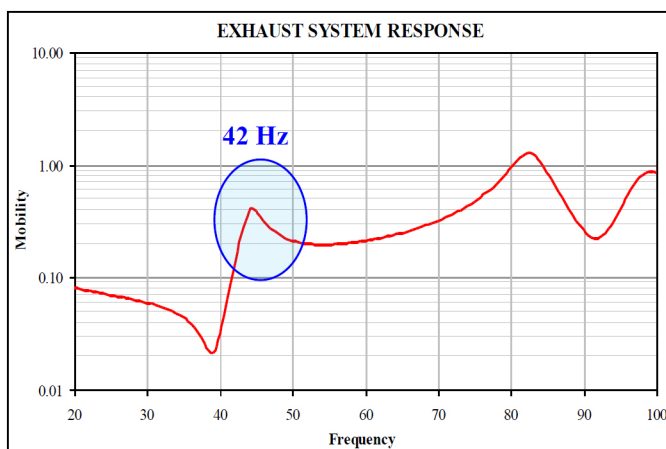


Figure 4. Exhaust system responses

Measurements were done at different build levels, planned to quantify the structure-borne noise for the booming perception. Noise and vibration measurements were done at various locations at different load and test conditions. Input point inertance was also measured at different locations on the power train and the ancillary components. The computed data was then compared with the vehicle level data to identify the potential cause of booming noise. The analysis indicated that the exhaust system has a significant mode at 41Hz which was likely to cause booms in the vehicle interior at 2400rpm (1EO excitation) and 1200rpm (2EO excitation). CAE simulation also indicated an exhaust system mode at the same frequency. To clarify the contribution of the exhaust system on the incab boom noise, mobility measurements were done at the exhaust bracket end, which correlated well in the incab booming frequencies. [Figure 3](#) shows the exhaust system mode at 42 Hz as obtained by simulation, while [Figure 4](#) shows the mobility data measured on the exhaust system in assembled condition. Further, comparison of different build

conditions had also indicated that the airborne or radiated noise from engine is not directly playing any role in the booming perception.

Structural Modal Analysis

Structural modal analysis was performed to determine the structural characteristics in the form of modal parameters, mostly resonant frequencies and associated mode shapes. The testing was done at BIW level, with the vehicle body hung in free-free condition. The excitation was given at a selected point after studying the reciprocity of the structure, with a sledge hammer. The vibration response of a number of key components were measured and analyzed. The modal parameters were estimated from the FRF's for every measuring point. Modal alignment was also done, detailing the modes of each component, and the system as a whole. The test data was then correlated with the simulation data.

The modal alignment indicated that the BIW has a global mode near the booming frequency of 38Hz. It was also observed that there is a substantial contribution to the mode from B-pillar, upper bulk head and the cross-car beam and the front roof along with the windscreen. A local mode of the roof was also observed at the front roof area of the vehicle at 40Hz. Since the correlation between modes identified in this modal analysis, and interior noise measurements, was only an indication of a source (only takes care of noise that are structure borne and not airborne), further evaluations were planned to confirm above identified sources are significant sources of incab noise problem. [Figure 5](#) shows the local mode of the front roof at 40 Hz.

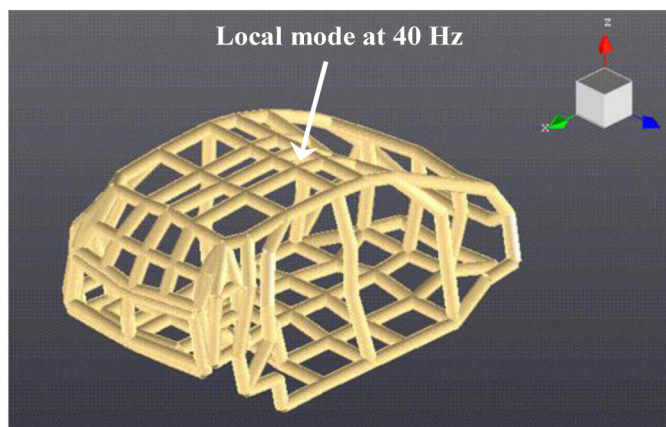


Figure 5. Local mode of the roof at 40 Hz

Modal analysis of cradle

The structural modal analysis of the cradle in free-free condition was also carried out to understand the dynamic behavior of the cradle and its effect in the booming frequency range. It has also helped to study the effect of some of the potential improvements possible at the cradle end that can be done to reduce the transfer of energy. [Figure 6](#) shows the sum response of the cradle while [Figure 7](#) shows the mode shape